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BULLETIN 111

PETROGRAPHY OF UPPER PERMIAN ROCKS IN SOUTH-CENTRAL KANSAS

By

ADA SWINEFORD

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PETROGRAPHY OF UPPER PERMIAN ROCKS IN SOUTH-CENTRAL KANSAS

By

ADA SWINEFORD

ABSTRACT

Blanket-type deposits of post-Wolfcampian Permian age exposed in south-central Kansas constitute a northern part of the mid-continent Permian basin. They are restudied petrologically with reference to their composition, texture, structure, stratigraphy, and genesis.

The sediments are predominantly red in color, and consist of very fine-grained nonfossiliferous feldspathic sandstones and siltstones, silty shales and shales, and extensive thin evaporites. The detrital minerals of the sandstones and siltstones are primarily of igneous origin and are poorly rounded. The feldspars consist predominantly of orthoclase, with minor sodic plagioclase and microcline; they display various stages of weathering. The most common clay minerals are illite and chlorite, with montmorillonite in the upper part of the section.

The rocks are assigned to Krynine's tectonic arkose series but are far from their source areas and are intra-cratonal rather than postgeosynclinal in origin. These important differences are reflected chiefly in the clay mineralogy, average particle size, and shape and extent of the deposits.

The red color is due essentially to hematite stain on the mineral grains. The redbeds are classed with the primary detrital redbeds of Krynine, and the iron oxide is thought to have been transported as coatings on the detrital minerals and in colloidal solution from distant highlands, chiefly in Colorado and Oklahoma, having granitic terrane and humid tropical climate. The site of deposition is considered to have been a shallow restricted marine basin with deficient rainfall.

Present commercial use of the deposits is restricted essentially to the evaporites in the section: salt and gypsum. Some of the rocks formerly were used for building stone, common brick, and paint pigment. Some of the shale is potentially useful for ceramic aggregate and brown slip glaze.

INTRODUCTION

PURPOSE OF STUDY

The Permian redbeds of Kansas range in character from fine-grained shales and siltstones to fine sandstones, and the associated rocks include gray and green shales, siltstones, and sandstones, plus numerous dolomites and beds of salt, gypsum, and anhydrite. Except for the fine particle size of the clastic sediments, the Kansas redbeds are possibly typical of many of the Permian

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deposits in central United States and elsewhere, and therefore are judged to be worthy of detailed study.

The Permian redbeds of Kansas are the northern end of a broad area of redbeds which reaches nearly to the Pecos River in west Texas and covers half of Oklahoma (Moore, 1920). The Kansas redbeds are among the least well known outcropping rocks of the State. Their correlation with the thicker Permian section to the south and west has been discussed and argued at great length, but no petrographic description of the Kansas rocks is known. The purpose of the present study is to describe these deposits and, if possible, to discuss their origin and significance.

Inasmuch as this is not a stratigraphic study, no attempt has been made here to evaluate published correlations of Kansas deposits with the Permian rocks of Oklahoma, west Texas, or Colorado. It is hoped that the data on the Kansas redbeds accumulated here will be of some use to stratigraphers in future correlations, provided petrographic data from other regions become available.

The present economic value of the upper Permian section is almost entirely restricted to the extensive evaporite deposits. Study of the composition and texture of the redbeds themselves may indirectly disclose potential uses for them and lead to their economic development.

Scope of Study and Acknowledgments

The Permian redbeds of Kansas are included within the Leonardian and Guadalupian? Series, according to the current classification of the State Geological Survey (Moore and others, (1951). The lowermost Leonardian formation is primarily gray shale and salt, but it is included within the study because it seems to represent a lithologic transition from the older marine deposits to the redbeds proper.

The field work for this report was begun in the summer of 1948 and completed in the spring and summer of 1951. The laboratory work was started in the Mineralogy Division of the Pennsylvania State College in the autumn of 1948 and was completed in the petrography laboratory of the State Geological Survey of Kansas during 1949-1953. The study was done under the supervision of Professor Paul D. Krynine. I am also indebted to

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Professors J. C. Griffiths and Thomas F. Bates for criticism and advice, particularly on particle-size analyses and clay mineralogy.

Geography, Topography, Drainage, and Climate

The surface exposures of the Leonardian and Guadalupian? Series of Kansas occur chiefly in the south-central and central parts of the State. They are found in 22 counties and extend for about 185 miles east-west along the southern border of the State. The lowermost formation, the Wellington, extends in a nearly north-south direction all the way across the State from Oklahoma to Nebraska, a distance of approximately 200 miles. As the present report refers only incidentally to the Wellington formation, the area discussed is restricted to the southern part of the State (Fig. 1).

The region is traversed by U. S. Highways 160, 283, 183, 54, 281, 50S, 50N, 81, and 77, and numerous state, county, township, and section roads, particularly in the eastern part. It is served by the Atchison, Topeka, and Santa Fe Railroad; the main line of the Chicago, Rock Island, and Pacific Railroad; and the Missouri Pacific Railroad.

The entire area lies within the Great Plains physiographic province. The eastern part, comprising the older formations, is in the Wellington area and Great Bend region as defined by Frye and Leonard (1952, p. 202). The western part, which includes the Cedar Hills sandstone and younger Permian deposits, lies within the Red Hills subdivision. The Red Hills are described by Fenneman (1931, pp. 28-29) as a deeply eroded belt 10 to 20 miles wide—a ragged and picturesque escarpment 300 to 400 feet high. He notes (p. 29):

> The upland level is held locally by beds of gypsum which, while very soluble in a humid climate or by circulating ground waters, make a resistant cover in a dry climate. The white gypsum, underlain by bright-red sands and shales, gives gorgeous coloring to the escarpment, already picturesque on account of its terraced canyons, jutting headlands, branching divides, and outlying buttes.

The Red Hills as mapped by Adams (1903), Schoewe (1949), and Frye and Leonard (1952) include not only the escarpment but all the exposures of redbeds from Harper and Kingman Counties on the east to the top of the Permian section in south-

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eastern Meade County. Parts of the area of greatest relief are shown in Plate 1.

West of the Blaine escarpment the topography is broadly rolling (Pl. 1C) and is marked locally by minor scarps of resistant beds, such as the Day Creek dolomite. In some areas, notably in southern Barber County, multiple-generation pediments are well developed. These are noted and described by Frye and Leonard (1952, p. 205).

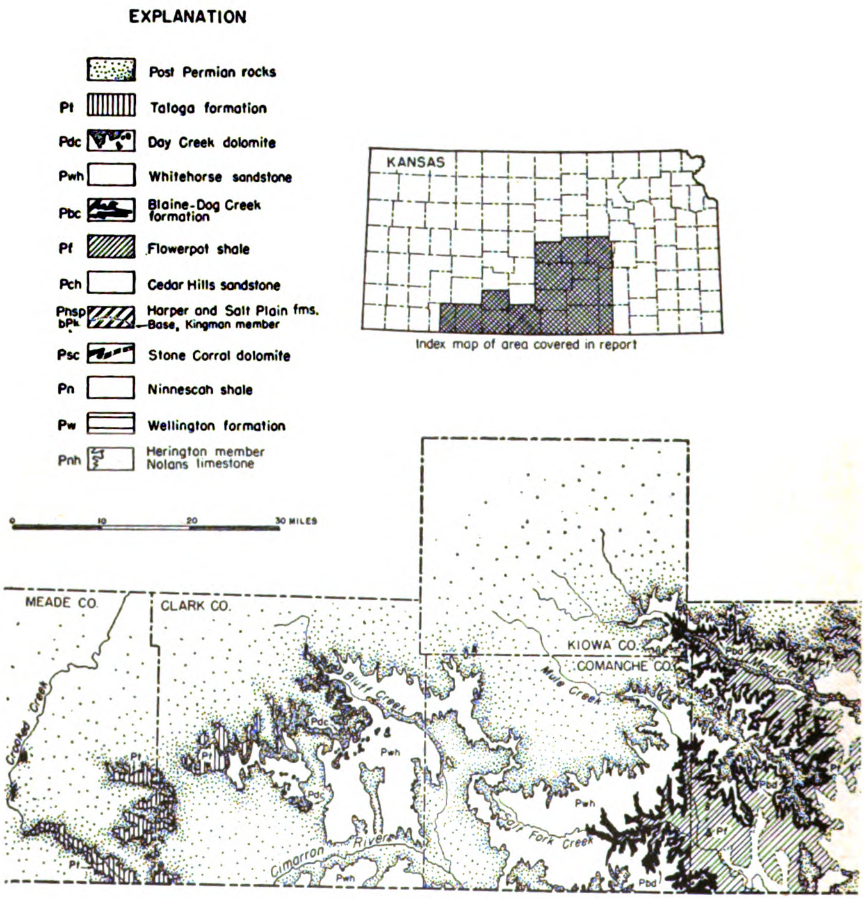

FIG. 1.—Areal geology of post-Wolfcampian Permian rocks of south-cen-

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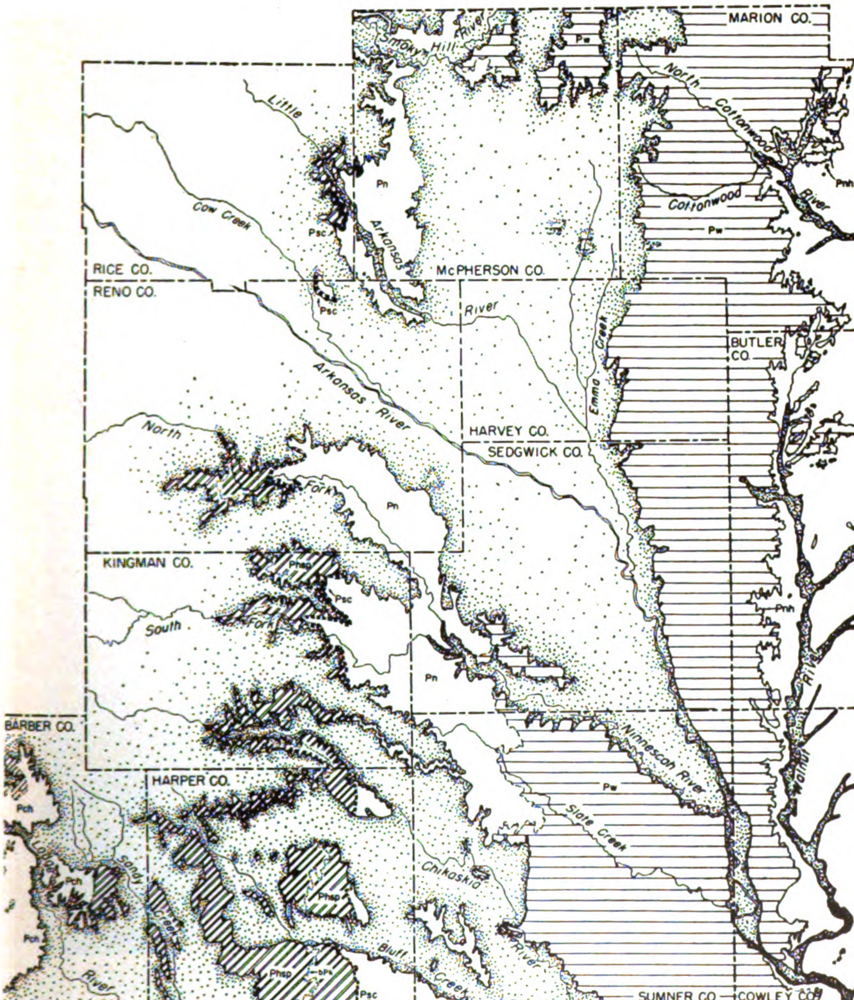
The area immediately east of the Red Hills in the Wellington area subdivision is underlain by rather weak siltstones, silty shales, and shales, and consequently is a plain of low relief, with very few good exposures except in local areas, although it consists predominantly of pediments (Frye and Leonard, 1952, p. 206). In general the only natural exposures are in



tral Kansas. Adapted in part from Moore and Landes (1937), Norton (1939), Frye (1942), Williams and Lohman (1949), and Fent (1950).

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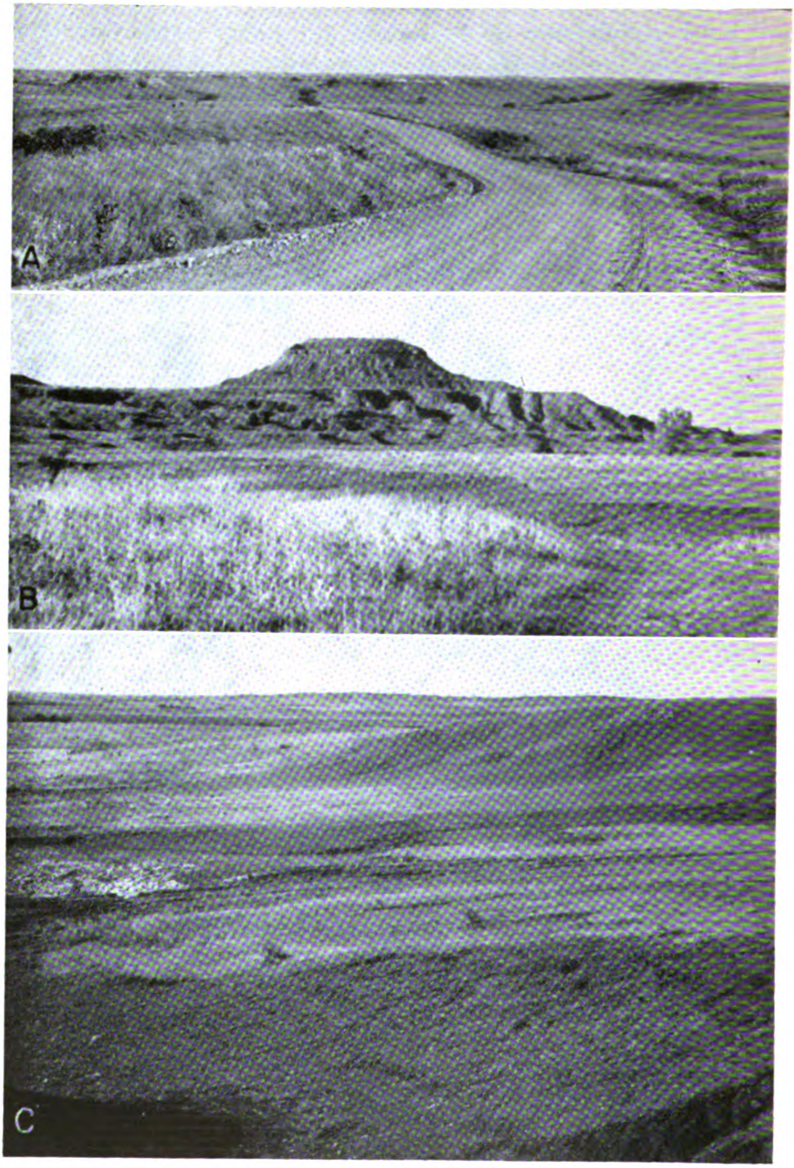

PLATE 1. Topography of areas underlain by Flowerpot shale, Blaine gypsum, and Taloga formation. **A**, Gypsum-capped Flowerpot shale 2½ miles south of Sun City, Barber County. **B**, Flowerpot Mound, sec. 26, T. 32 S., R. 13 W., Barber County. **C**, Rolling topography in Taloga formation, sec. 14, T. 32 S., R. 23 W., Clark County.

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low valley-side scarps, stream banks, and in some bluffs. Thin resistant beds form prominent benches in some areas (Pl. 2A).

The northern part of the lower redbeds lies within the Great Bend region, where in general, Permian sediments are overlain by Pleistocene alluvial deposits and dune sand.

Solution of Permian evaporites has produced typical physiographic features in the western part of the Red Hills. Big Basin (Pl. 2B) in Clark County is one of the largest solution features in the area. It is described by Schoewe (1949, p. 305) as "a subcircular undrained depression about 100 feet deep and a mile in diameter."

Direct evidence of solution is marked in the area of the Blaine gypsum. Gypsum caves are present in Comanche and Barber Counties, and natural bridges have also developed. Natural Bridge of Barber County is a well-known landmark. This bridge is about 35 feet wide and 55 feet across, and the span is about 12 feet above the level of the stream which passes under it (Schoewe, 1949, p. 303). A long, tunnel-like cave parallels the stream at this locality. A detail of the solution features in the gypsum is shown in Plate 2C. These are very similar in appearance to vadose solution features in some limestone caverns and in a gypsum cave described by Bretz (1952). Large gypsum caverns and several natural bridges occur across the state line in Oklahoma where the gypsum is thicker. The upper surface of the gypsum in some areas tends to expand during weathering and to produce small, low domes which later are broken through. These have been described as sink holes, but are not comparable with the sinks of karst regions. Bretz (1952, p. 282) attributes them to hydration of an anhydrite fraction still in the gypsum rock.

Drainage is toward the southeast. Cimarron River, Crooked Creek, and Bluff Creek drain the western part of the area (Meade, Clark, and Comanche Counties). The Red Hills subdivision is drained by Salt Fork and its tributaries, chiefly Medicine Lodge River and Sandy Creek. In the area included in the Osage section the main streams are Bluff Creek, Chikaskia River, Ninnescah River, and Arkansas River. Cimarron River, Salt Fork, and Ninnescah River empty directly into the Arkansas, the first two in Oklahoma and the third in Sumner County, Kansas. Crooked Creek, Medicine Lodge River, and Chikaskia River

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are major tributaries to Salt Fork south of the Kansas line in Oklahoma.

The climate of the area is subhumid to semiarid, with slight to moderate precipitation, abundant sunshine, moderately high average wind velocity, and rapid evaporation. Summers are hot, and winters are moderate with occasional short severe cold periods. The mean annual precipitation ranges from 20 to 33 inches and increases from west to east. Deviations from the mean are frequent and extreme. The average annual temperature is about 56°F.

Previous Work Done on the Region

According to Marcy (1854) geologists and explorers have noted the redbeds of the southwest since the days of Marcou. Marcy himself studied the Oklahoma and Texas redbeds but did not explore those of Kansas.

The early publications referring to the redbeds of Kansas are summarized by Prosser (1897, pp. 76-83). Most of them do not include descriptions of the deposits, but simply concern themselves with correlation. Mudge's (1878) early geological map of Kansas represents the greater part of the Permian redbed area as of upper Carboniferous age, although Mudge states that west of Harper the region was little examined by himself or others. In 1883 St. John correlated the redbeds with the Cretaceous Dakota formation. This correlation was accepted by Cragin in 1885 and 1886, and the extent of the deposits was described briefly by him.

In 1887 St. John referred the redbeds provisionally to the Triassic on the basis of their stratigraphic relations and lithologic similarity to "the Triassic Red-Beds which are so well developed along the eastern foot of the Rocky Mountains a few hundred miles to the west. . . ." This assignation was followed by several later writers (Hay, 1889; Cragin, 1889; McGee, 1894).

Hay (1890) was the first to describe the redbeds in any detail. He judged them to be Jurassic-Triassic in age, but did not break them down into formations. Instead he referred to them as upper red rock, gypsum series, and lower red rock. He described lithified layers of arenaceous ferruginous limestone alternating with beds of red clay and shale; he also noted ripple marks, rain-drop impressions, and the absence of fossils, and concluded that the sediments were deposited in littoral environments. Three years

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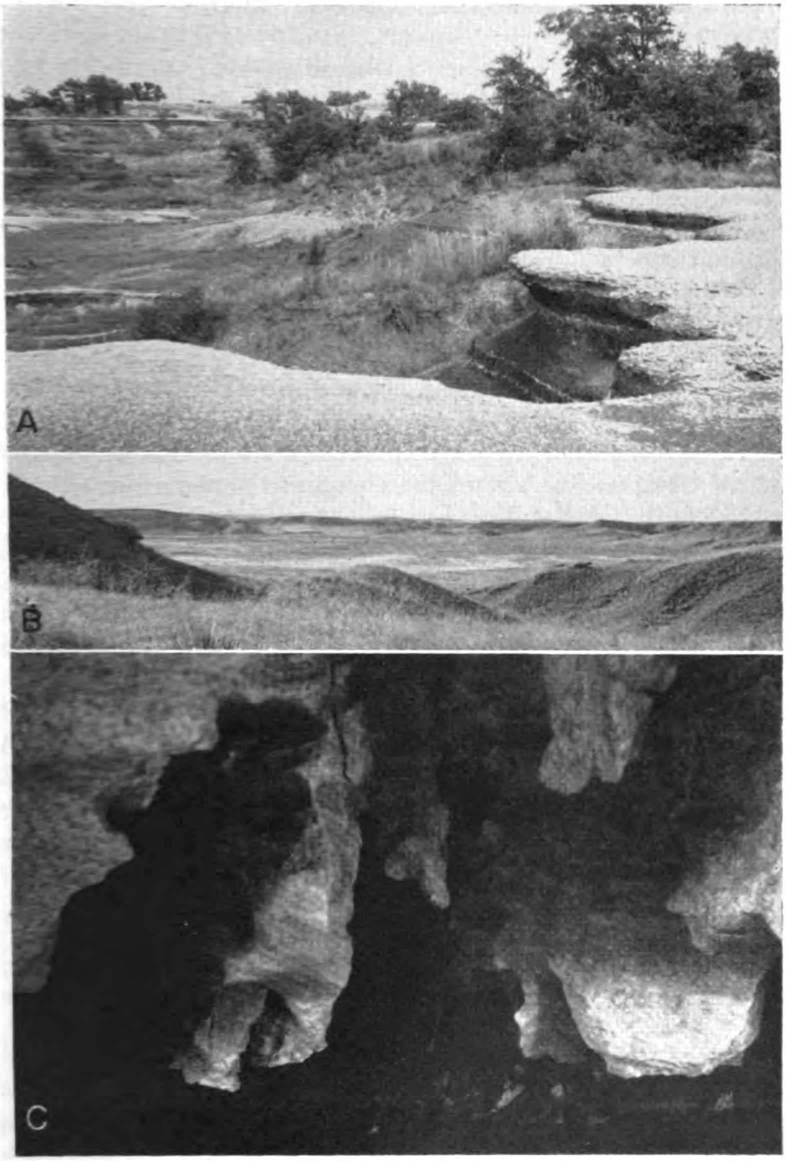

PLATE 2. A, Thin resistant calcareous silty shales in lower part of Ninnescah formation; NE¼ sec. 14, T. 35 S., R. 3 W., Sumner County. **B,** Big Basin, western Clark County. **C,** Solution features in gypsum at Natural Bridge, Barber County.

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later he (Hay, 1893) assigned an upper Permian age to the redbeds, on the basis of the discovery of some vertebrate fossils in northern Texas.

The first detailed stratigraphic work of a modern nature on the Kansas redbeds was that of Cragin (1896). He referred the redbeds to the Permian System and introduced 10 formation names, most of which are in current use. He also noted the general lack of stratigraphic continuity of the various beds. His classification was modified in a later paper (Cragin, 1897).

Prosser (1897, p. 82) preferred to group the redbeds into only three formations, because of the great similarity of their lithologic characters.

Some of the more recent work on the redbeds of the region has been summarized by Norton (1939, p. 1754). Gould (1901) described some vertebrate and invertebrate fossils from the redbeds of Oklahoma and noted the absence of fossils in the Kansas equivalents. Most of the subsequent reports (Gould, 1901a; Moore, 1920; Aurin, Officer, and Gould, 1926; Gould and Willis, 1927; Evans, 1931; Wilmarth, 1931; Roth, 1932; Anderson, 1933) were concerned chiefly with changes in classification of the Kansas redbeds and their correlation with Permian rocks to the south and west. Inasmuch as the present study is not concerned with problems of correlation, the literature on that subject will not be reviewed in detail. The latest published stratigraphic studies of the outcropping Kansas Permian redbeds known to me are those of Norton (1939), although several petroleum geologists have worked in the area, and a few subsurface correlation charts have been added to the literature.

Methods of Investigation

FIELD WORK

Field work included the location of outcrops, measurement of about 60 stratigraphic sections, study of gross lithology, and collection of approximately 300 samples. In collecting samples, an attempt was made to obtain a suite of samples representative of the deposits, but thin marker beds and rocks of unusual lithology were also collected. The importance of the latter is not great quantitatively, but they represent extremes or end-members which may help in interpretation of the geologic history.

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Color designations were made in the field (and also in the laboratory) with the aid of Munsell color charts (Munsell Color Co., 1942). The National Research Council rock color charts were found to be inadequate for differentiating among the various reds and reddish browns, so the standard soil color charts (Pendleton and Nickerson, 1950) were used more extensively. Descriptive names to correspond to the numerical designations were taken from the rock color charts wherever possible; otherwise names from the soil charts were used.

LABORATORY INVESTIGATION

Fifty-one thin sections were studied. Mechanical analyses of all the clastics from which thin sections had been cut were made. Mineral analyses of "light" and "heavy" separates from some of the coarser clastics were made, and the mineral composition of some of the finer-grained rocks was studied by x-ray diffraction. Diffraction was also employed in semiquantitative determination of calcite-dolomite ratios in the carbonate rocks and in cements, and it proved helpful in the rough estimation of quartz-feldspar ratios in fine siltstones.

The minus 1-micron fractions from 12 samples were studied in the electron microscope, and electron micrographs were made by Mr. C. C. McMurtry, Department of Oncology, University of Kansas School of Medicine.

Chemical analyses of 10 selected representative samples were made in the chemistry laboratory of the State Geological Survey of Kansas.

Light Microscopy

Thin sections.—Seventeen of the 51 thin sections were from representative shales and siltstones. Slices were also cut from 24 sandstones and 10 evaporite specimens which were considered to be representative of the various lithologic types throughout the stratigraphic section.

Study of mineral grains.—"Heavy" and "light" minerals were obtained from the sand-size fractions by bromoform separation. Heavy and light minerals were sampled by an Otto microsplit and mounted in Canada balsam for microscopic study. Light grains were also mounted in a 2:1 glycerine-water mixture for study of grain shape and surface textures.

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The heavy and light mineral slides were studied by making counts of 200 grains per slide. Roundness determinations on the quartz and feldspar grains of 14 samples were made by visual comparison with Krumbein's (1941) roundness chart. The roundness of grains from a few samples was determined from photomicrographs by actual measurement according to Wadell's (1935) method.

Mechanical Analyses

Particle-size analyses were made by a combination of sieving and pipette methods. Pretreatment of the sample depended upon the degree of cementation or induration, and varied from sample to sample. This variation affected the particle size as determined by the pipette method, and detailed comparisons of these different samples is therefore not entirely justified.

Sandstones and siltstones cemented with carbonate, and shales containing carbonate particles of silt size or larger, were broken up and leached with warm dilute (0.1 *N*) hydrochloric acid. Other samples were crushed carefully to pass a 500-micron screen (or coarser screen, if thin section showed coarser sand grains). Those samples which required acid treatment were washed with distilled water and acetone before dispersion. Approximately 35-gram samples were agitated for 24 hours in distilled water containing a few drops of ammonium hydroxide. They were then transferred to liter graduates, and enough water (with NH_4OH) was added to make 1 liter of suspension. Analyses were carried out by pipetting at intervals of one phi unit, from 62 microns to 1 micron. Sand sizes were analyzed by shaking the sand 10 minutes in a Ro-Tap sieve shaker after decanting most of the silt and clay and drying the remainder.

Electron Microscopy

Particles from the minus 1-micron fraction were used for the electron micrographs. The particles were deposited on a Parlodion film from a dilute water suspension, and shadow-cast with chromium from an angle of approximately 17°, producing shadows 5 times as long as the height of the particles. Electron micrographs were made in an RCA EMU-2B microscope at magnifications of 6,000 to 8,000 diameters. The microscope was operated by C. C. McMurtry.

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X-ray Diffraction

Diffraction patterns of most of the samples studied by x-ray were made with a GE XRD-3 spectrogoniometer. Debye-Sherrer powder-camera patterns were made from samples too small for optimum work with the spectrogoniometer.

CuKα radiation having a kvp of 50 kv at 15 ma was used for most of the spectrogoniometer and camera patterns. Where the background produced by some iron-bearing specimens was somewhat objectionable, cobalt Kα radiation was used.

Samples were crushed to pass a 62-micron screen and were packed into a specimen holder having a rectangular depression approximately 44 mm long, 13 mm wide, and slightly more than 1 mm deep. The powder was packed into the holder with the edge of a spatula, and the surface was made level by pressing down with a glass microscope slide above rough paper.

Clay mineral and chlorite analysis was made according to some of the procedures described by Brindley (1951). The methods were as follows.

1. A pattern was made from the original untreated sample.

2. A pattern was made from a glycerated sample to check for montmorillonite. Just enough glycerine was added to the powdered sample to wet it, and the paste was packed into the specimen holder with a spatula. The surface was made level and flush with the sample holder by pressing it down with wax paper under a glass microscope slide.

3. If the first patterns indicated the presence of calcite or dolomite, the carbonates were removed by treatment with cold dilute (0.05 *N*) hydrochloric acid. A test for vermiculite was made by boiling the sample for 5 minutes in concentrated ammonium chloride solution. If the 14 A reflection in the subsequent pattern was not affected, it was considered to represent a chlorite basal reflection rather than vermiculite. A check for kaolinite was made by destroying the 7 A chlorite reflection with hot HC1. A few oriented specimens were prepared.

Relative proportions of calcite and dolomite and quartz and feldspar were estimated roughly by comparison of relative intensities of characteristic reflections with those from standard mixtures.

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No quantitative x-ray analysis of sandstones for quartz-feldspar ratios was attempted, because its impracticability is stressed by Phillippe and White (1951). They point out that grinding affects the various minerals differentially. Silt sizes of a few sands were studied.

The presence or absence of other mineral constituents, such as barite and gypsum, was noted.

STRATIGRAPHY

The exposures of Permian rocks in Kansas range in age from lower Wolfcampian to upper Leonardian and possibly Guadalupian. The Wolfcampian rocks, which have a total outcrop thickness of about 785 feet, are predominantly thin, persistent, evenly bedded limestones and shales, most of which were deposited under normal marine conditions (Elias, 1937). At least two of the limestone formations and several other beds are dolomitic, and several of them contain abundant chert. The thickest limestone formation, the Barneston, is about 80 to 90 feet thick. The interbedded shale units are green, gray, and red in color, and some of them contain marine fossils.

The lithologic difference between Wolfcampian and Leonardian rocks is pronounced. Computation of the number of feet of the various lithologies, based on Moore and others (1951) indicates that Wolfcampian rocks include 290 feet of limestones, 375 feet of gray shales, 95 feet of red shales, 25 feet of sandstones, 1 foot of coal, and less than 1 foot of gypsum. The post-Wolfcampian rocks, on the other hand, are predominantly red and reddish-brown siltstones, shales, and sandstones, with significant quantities of evaporites.

The major redbeds of the Permian System in Kansas are thus post-Wolfcampian in age (Leonardian Series and younger (?)). According to the classification of the State Geological Survey of Kansas (Moore and others, 1951, pp. 37-38), the topmost 290 feet of Permian rocks is within the Guadalupian Series. A graphic column of Kansas rocks published later (Moore and others, 1952) indicates an indefinite upper boundary for the Leonardian Series, and no series designation for the deposits formerly referred to the Guadalupian. In this report the 1951 classification will be used, simply in order to provide a label for the younger deposits.

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The problem of correlation of nonfossiliferous red clastics in Kansas with a type marine section in west Texas seems almost insurmountable, and it is not the concern of this study.

Above a few hundred feet of lithologically transitional gray, green, and red shales, thin discontinuous limestones and dolomites, gypsum, anhydrite, and thick salt in the basal part of the Leonardian section, the redbeds proper were deposited. Exposures are in general irregularly bedded, demonstrating pronounced facies changes (especially obvious in the subsurface); they consist predominantly of silty shales, feldspathic siltstones, and very fine-grained feldspathic sandstones and a few thin dolomite beds and one extensive gypsum formation (and in the subsurface anyhdrite and salt). The transitional beds have a total thickness of about 700 feet, and the overlying redbed formations at their outcrops have a combined thickness of about 1,500 feet. They thicken toward the southwest in the subsurface.

The redbed section (exclusive of the lower transitional part) is thought to consist of about 87 percent red rocks. The evaporites are not red, and a few thin beds of sandstone, siltstone, and silty shale are light buff to grayish green, but the predominant color is brownish red in the lower part (and in the red shales) and brilliant orange red in the upper sandstones and siltstones. Many of the exposures of units which actually are not red are commonly obscured by a red wash so that in general appearance the outcrops are remarkably uniform in color.

Mud cracks, ripple marks, salt casts, and a few rain prints are present at several horizons in the Leonardian and Guadalupian? rocks. Fossils are extremely scarce, and are limited to a few insects, problematical worm borings, pelecypods and brachiopods, and *Cyzicus* (Moore, Lalicker, and Fischer, 1952, p. 545), a brine shrimp, in the lowermost part of the section. Vertebrates of a type unknown to me have also been reported from the lower Leonardian rocks (Norton, 1939) but no reptilian tracks are known in Kansas.

The absence of fossils and the seeming lithologic similarity of the various redbeds in the section have made their subdivision into formations and members somewhat arbitrary. Many formational and member boundaries are marked only by a "bleached" zone or an evaporite unit, although formational units are more or less characterized by finer or coarser particle size, blocky or

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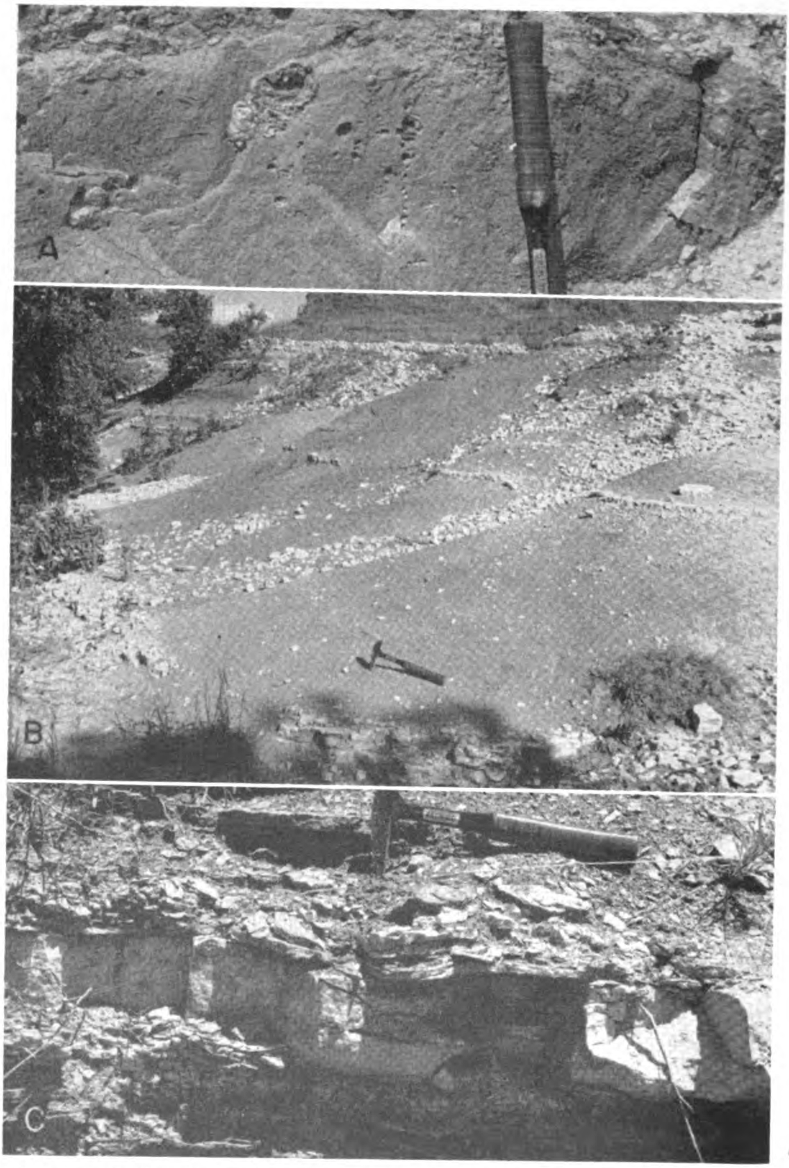

PLATE 3. **A,** Geodes in Herington limestone, NE¼ sec. 10, T. 27 S., R. 3 E., Butler County. **B,** Milan dolomite at type locality; SE¼ sec. 30, T. 32 S., R. 3 W., Sumner County. **C,** Bed 1, Ninnescah shale; Cen. W. line sec. 9, T. 28 S., R. 3 W., Sedgwick County.

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flaky appearance, slight differences in color, or some other common lithologic feature.

The classification of formations in the Leonardian and Guadalupian? Series used by the State Geological Survey of Kansas is shown in Table 1. This table also includes the average thickness and a brief lithologic description of each formation adapted in part from Moore and others (1951, pp. 37-41). A generalized rock column is shown in Figures 2 through 5.

A brief description of the uppermost limestone member of the Wolfcampian Series is included here as a basis for comparison with the younger rocks. The Herington member of the Nolans limestone in southern Kansas is primarily a soft to dense, light yellowish-tan dolomite. It is characterized by siliceous and calcareous geodes and cauliflowerlike concretions of rusy chalcedony. Mollusks are abundant in some localities. The member ranges in thickness from 7 to 30 feet. A geodal part of the Herington in a quarry face is shown in Plate 3A.

Leonardian Series

The lower Leonardian rocks in Kansas include most of the transition from the normal marine interstratified fossiliferous limestones and shales of the lower Permian (Wolfcampian) to the typical redbeds of the upper part of the Permian section. The topmost formation of Wolfcampian age, the Herington limestone, differs chiefly from most of the underlying limestones in its dolomitic character, but is not otherwise unusual.

The advent of Wellington deposition in Kansas represents a marked change in conditions. Instead of marine limestones and shales, a thick sequence of fine clastics and evaporites was laid down. Succeeding formations in the Permian sequence are characterized by evaporites and chiefly red clastics, somewhat coarser than those of the Wellington. In general, the younger rocks are the coarsest and the most feldspathic, although nowhere in the surface outcrops of Permian rocks in Kansas is the average particle size coarser than that of fine sand.

SUMNER GROUP

The Sumner group, according to Moore and others (1951, p. 40) consists of about 1,000 feet (at the outcrop) of gray, red, and

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TABLE 1.—*Generalized section of the outcropping Leonardian and Guadalupian? formations of south-central Kansas*

Series	Group	Formation	Member	Thickness, feet	Character
?	No group assignation	Taloga fm.		45+	Shale, silty shale, siltstone, very fine sandstone, feldspathic, chiefly red, in thin beds. Lower 25 ft. silty shale. Bottom few feet greenish gray. In Meade and Clark Counties.
		Day Creek dolomite		2	Dolomite, dense, massive; gray, buff, and lavender. Clark County.
		Whitehorse sandstone			Sandstone, siltstone, feldspathic; shale, orange-red and (shale) brownish-red; and a few thin dolomites and limestones. Cross-bedding present, especially in lower part. Concretionary friable calcareous "sand balls" common. Meade, Clark, Kiowa, Comanche, and Barber Counties.
			(Upper shale)	38	Upper shale member consists of clay shale, siltstone, and thin fine-grained sandstone, red, locally with dolomite zone at base and gray-green silty shale in upper part.
			(Even-bedded)	100	Even-bedded member: alternating red very fine sandstones and clayey siltstones, moderately thin-bedded, with occasional reddish-brown silty shales.
			Relay Creek? dolomite and sandstone	22	Relay Creek dolomite and sandstone member consists of two thin beds (locally) of dolomitic limestone each less than 1 ft. thick separated by white and red locally cross-bedded fine feldspathic sandstone.
			Marlow	110	Marlow member is predominantly red sandstone, feldspathic, generally soft, massive; locally clayey, silty, cross-bedded.
		Dog Creek shale		14 to 53	Silty shale, brownish-red; siltstone, very fine sandstone, red. Also thin (<1 ft.) dolomites, dolomitic siltstones, and gypsum. Kiowa, Comanche, Barber Counties.
LEONARDIAN	Nippewalla	Blaine fm.			Gypsum beds, massive, locally with thin dolomites at base, separated by red shales. Kiowa, Comanche, and Barber Counties.
			Haskew gypsum (red shale)	<1 to 5	Gypsum, massive; present only locally; underlain by 5 ft. of red shale.
			Shimer gypsum	14 to 24	Gypsum, massive, overlying ½ to 1½ feet of dolomite.
			(red shale)	4 to 9	Shale, red.
			Nescatunga gypsum	2 to 8	Gypsum, massive.
			(red shale)	<9	Shale, red, with selenite crystals.
			Medicine Lodge gypsum	20 (av.) to 30	Gypsum, massive, with anhydrite layer near middle; overlying ½ to 1 foot dolomite, oölitic. Forms rim rock at top of Flowerpot shale.
		Flowerpot shale		170 to 190	Shale, silty, brownish-red, with occasional thin gypsiferous and dolomitic sandstones, grayish-green; and thin grayish-green silty shales. Formation is characterized by numerous intersecting veins of satin spar and selenite crystals. Essentially restricted to Barber County.

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TABLE 1.—*Generalized section of the outcropping Leonardian and Guadalupian? formations of south-central Kansas*

Series	Group	Formation	Member	Thickness, feet	Character
LEONARDIAN	Nippewalla	**Cedar Hills sandstone**		180	Alternating thin (2 to 15 ft.) beds of very fine massive sandstone, red, friable; and clayey siltstones and silty shales, red. Sandstone, white, about 1 to 2 ft., with gypsum "snow balls" at top of formation. White sandstone, grading upward into red, at base. Barber County.
		Salt Plain fm.		265?	Silty shale, red (some with small spherical green spots), flaky; siltstone, and some sandstone. Two silty sand beds near top, locally cross-bedded. Underlies nearly featureless plain in Harper, Barber, and Kingman Counties.
		Harper sandstone			Shaly siltstone, reddish-brown, and numerous thin sandy siltstones and a few very fine sandstones, reddish-brown with small spherical gray-green spots. Harper, Kingman, Reno, and Rice Counties.
			Kingman sandstone	80	Shaly siltstone and very fine sandstone, reddish-brown. Silty sandstone white, 3 ft. thick, marks base.
	Nippewalla		Chikaskia	100 to 160	Flaky siltstone, sandy siltstone, and silty shale, mostly red, but some greenish-gray. Some sandy dolomite lenses in upper part.
LEONARDIAN	Sumner	**Stone Corral dolomite**		6 (max.)	Dolomite, light-buff to yellowish-gray (locally with red streaks), cellular (from loss of anhydrite or gypsum) and containing calcite-filled vugs. Ripple marks characteristic. Dolomite pinches out toward the south, where the formation consists chiefly of shale with scattered dolomite rhombs. Rice and Reno Counties.
		Ninnescah shale		300 (av.) to 450 (max.)	Predominantly silty shale, mostly dolomitic or calcareous, mostly brownish-red, blocky, with gray-green spots. Contains several beds of dolomitic and calcareous siltstone, and associated gray-green, silty shale. *Cyzicus* present in lower part. The Runnymede sandy siltstone, 7 to 8 ft. thick and containing copper carbonate, forms the top of the formation. Harper, Sumner, Kingman, Sedgwick, Reno, Rice, and McPherson Counties.
		Wellington fm.		Ca 700 (including salt in subsurface)	At outcrop chiefly shale and silty shale, in part calcareous, mostly gray and green with some red especially in lower part. Contains lenticular beds of gypsum and soft fine-grained silty limestone and dolomite beds, some of which are named. The thin Milan dolomite at the top contains green copper carbonate. Formation contains *Cyzicus*. Sumner, Cowley, Sedgwick, Butler, Reno, Harvey, McPherson, and Marion Counties.
WOLF-CAMPIAN	Chase	**Nolans limestone**	Herington limestone	7 to 30	Dolomite, yellowish-tan, soft to dense, geodal; locally containing mollusks.

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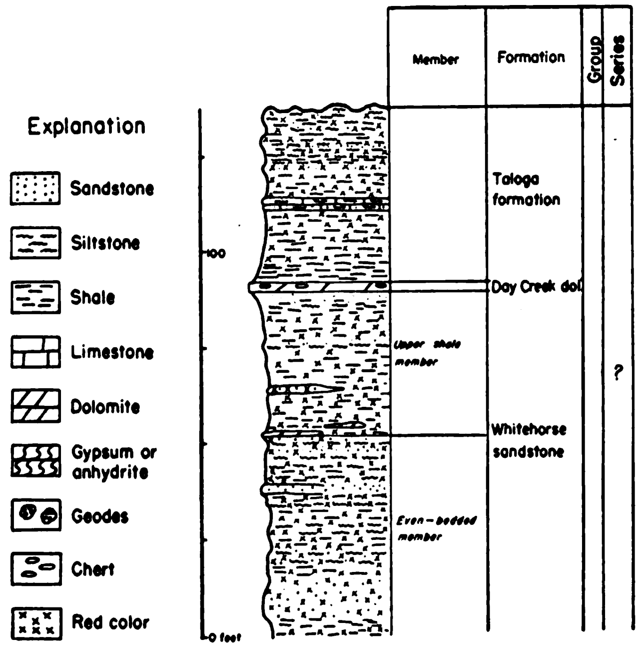

FIG. 2.—Generalized stratigraphic section, outcropping Permian rocks of post-Wolfcampian age in Kansas. Adapted in part from Moore and others (1951, 1952).

green shale, thin siltstones,* and deposits of dolomite, limestone, gypsum, and anhydrite. Thick beds of salt occur in the subsurface. The group includes the Wellington formation, Ninnescah shale, and Stone Corral dolomite.

Wellington Formation

Rocks of the Wellington formation are poorly exposed in a broad north-south-trending strip which extends entirely across the State of Kansas from Sumner and Cowley Counties at the Oklahoma line to Washington and Marshall Counties at the northern boundary. The formation was originally named and described by Cragin (1885, 1896) for exposures at the City of Wellington in Sumner County, Kansas. As now defined by the Kansas Geo-

* In the stratigraphic sections which follow, the siltstones and sandstones are not labeled "feldspathic," even though all samples examined in the laboratory are found to contain from 10 to 30 percent feldspar. The reason for this is that the estimation of feldspar in field studies of these very fine-grained, deeply stained rocks is not feasible. To name only the paler, relatively coarse sandstones feldspathic would introduce a false connotation.

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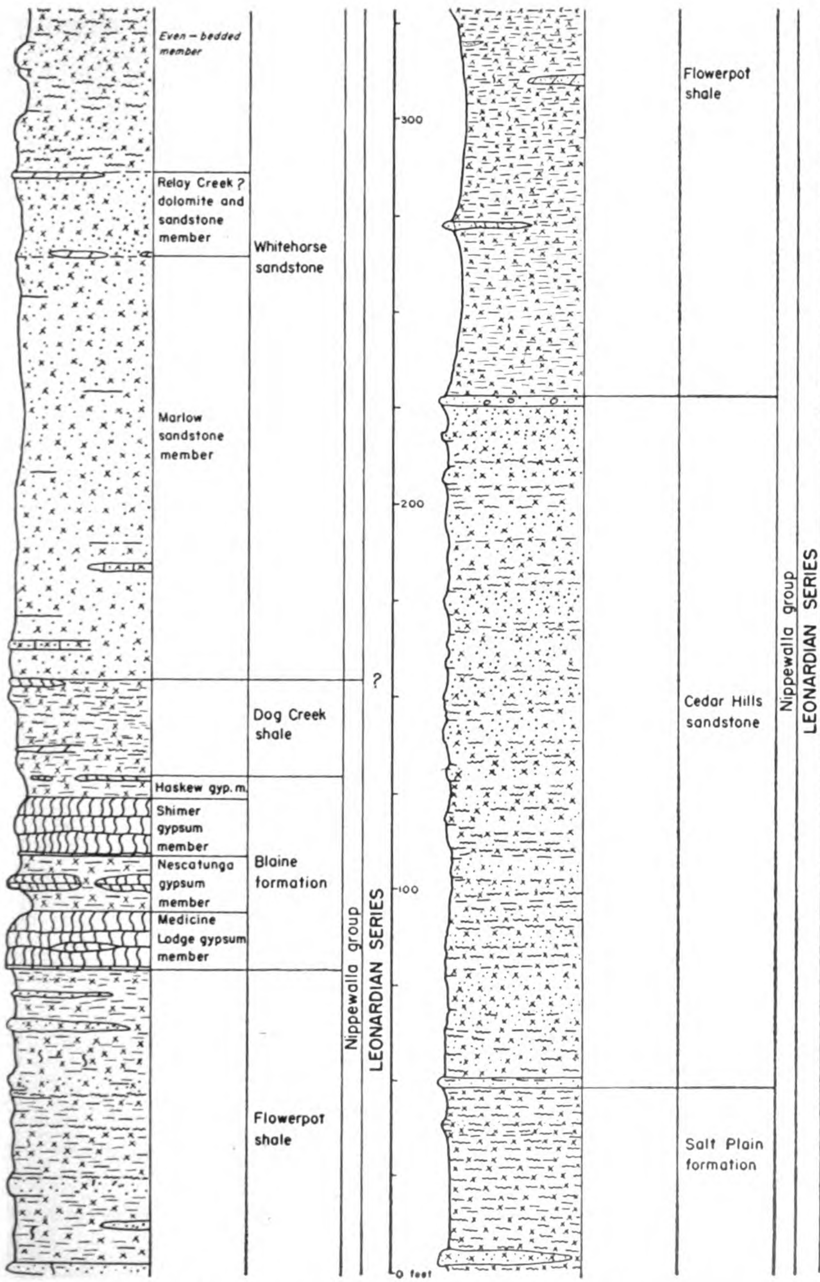

Fig. 3.—Generalized stratigraphic section, outcropping Permian rocks of post-Wolfcampian age in Kansas. Adapted in part from Moore and others (1951, 1952). See Figure 2 for explanation.

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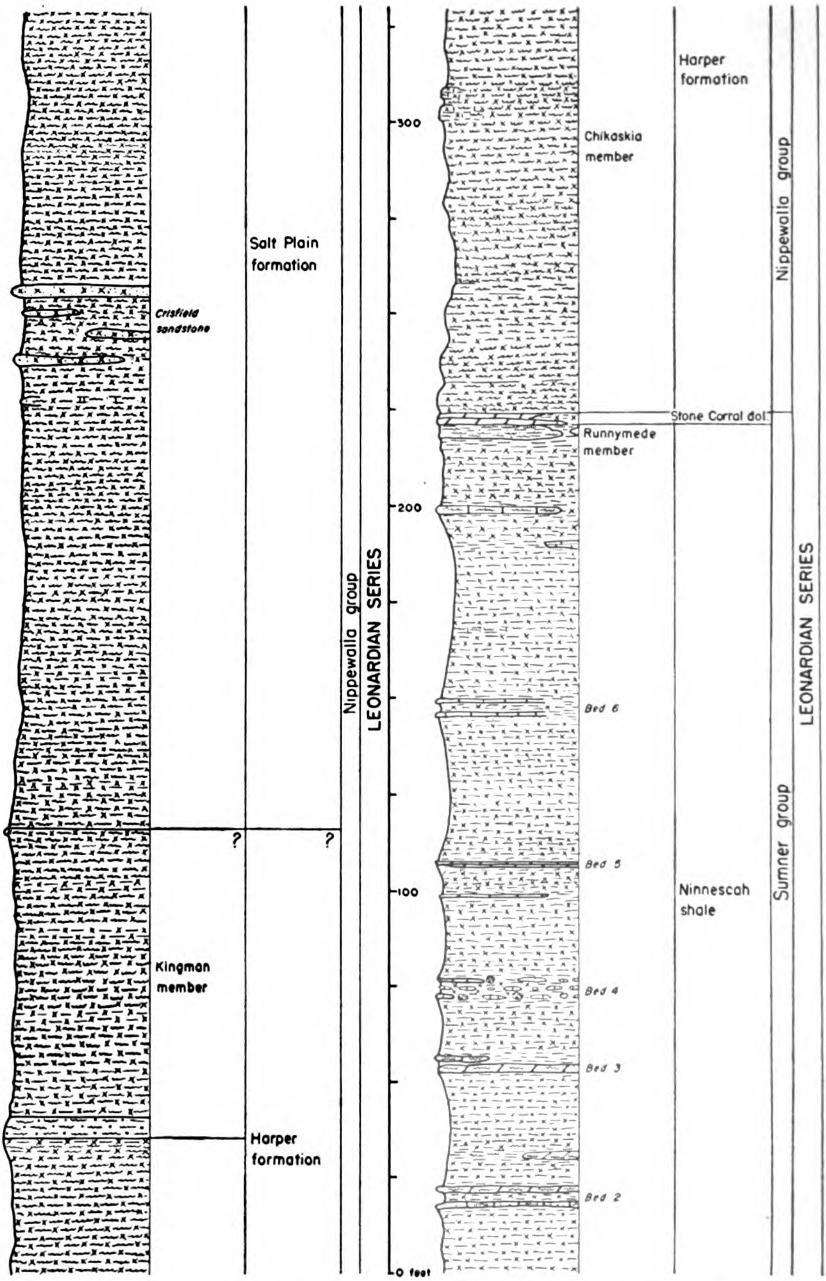

FIG. 4.—Generalized stratigraphic section, outcropping Permian rocks of post-Wolfcampian age in Kansas. Adapted in part from Moore and others (1951, 1952). See Figure 2 for explanation.

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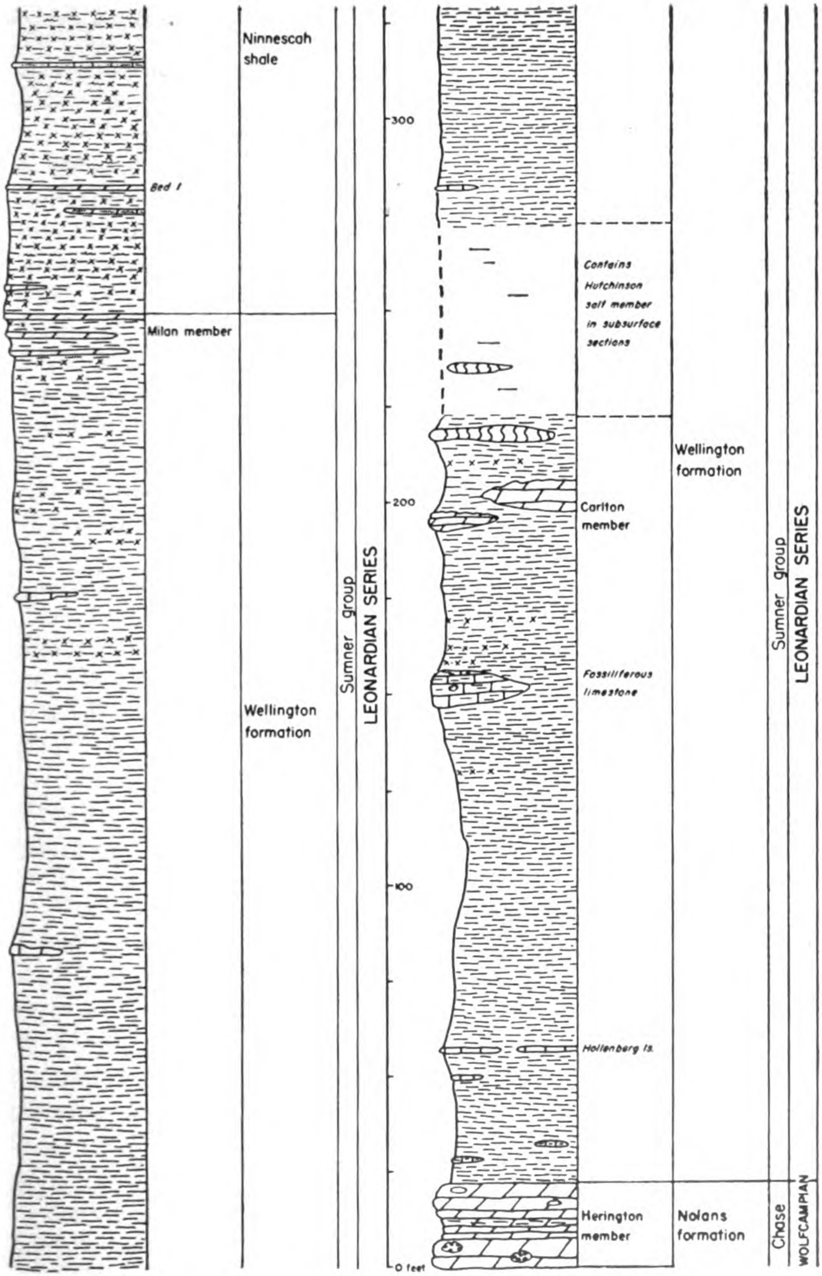

Fig. 5.—Generalized stratigraphic section, outcropping Permian rocks of post-Wolfcampian age in Kansas. Adapted in part from Moore and others (1951, 1952). See Figure 2 for explanation.

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logical Survey, it includes all beds above the Herington limestone (topmost Wolfcampian) and below the Ninnescah shale (base of the "redbeds" proper).

The surface exposures of the Wellington consist primarily of gray to greenish-gray somewhat silty shales having subconchoidal fracture. There are some beds of brownish-red, maroon, and purple shales, particularly in the upper part of the formation, and many of the shale units are somewhat calcareous. Numerous thin lenticular silty limestones (less than 15 feet thick) and dolomites occur throughout the section, and a few discontinuous beds of gypsum are also exposed. The thick section of salt, which is exploited in the subsurface, is of course destroyed in surface exposures, but a brief description of the salt seen in the Carey mine at Hutchinson is included in this report. Solution of this salt and gypsum at or near the surface has produced rather steeply dipping small-scale structures at many localities.

The basal beds of the Wellington formation are fairly well exposed in a stream bank in the SE¼ NE¼ sec. 21, T. 34 S., R. 3 E., Cowley County, a short distance southeast of Geuda Springs. This exposure, although poor, was considered by Bass (1929) as one of the best in Cowley County, and consists primarily of gray-green clay shales, in part calcareous. The rocks exposed are as follows.

Lower part of Wellington formation, exposed in stream bank in the SE¼ NE¼ sec. 21, T. 34 S., R. 3 E., Cowley County

	Thickness, feet
PERMIAN—Leonardian	
Wellington formation	
11. Limestone, hard, vesicular, light yellowish-brown to gray, weathered, badly slumped. Hollenberg?	5 +
10. Shale, yellowish gray-green, seemingly structureless	6.9
9. Marl, thin-bedded, light-gray; contains calcite veins	1.5
8. Shale, calcareous, medium light-gray	1.7
7. Marl and horizontal calcite streaks	0.9
6. Shale, calcareous, medium light-gray	6.0
5. Calcite veins (horizontal) in shale	0.1
4. Shale, calcareous, medium light-gray (Munsell N6); has subconchoidal fracture; contains a few thin dark-maroon beds	2.8
3. Marl, light-gray	0.6
2. Covered	10.3
1. Shale, medium light-gray, partly covered	15.0
PERMIAN—Wolfcampian	
Nolans limestone—Herington limestone member (in stream bed)	
Total	50.8

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The limestone exposed at the top of this section may be a correlative of a bed that was later named the Hollenberg limestone by Condra and Upp (1931, pp. 63-66) from exposures along Little Blue River 3½ miles southeast of Hollenberg, Washington County, Kansas. This bed is dolomitic and is seemingly one of the very few wide-spread thin limestone units in the Wellington formation.

A few local limestones lithologically similar to the Hollenberg are found slightly higher in the section. One of these, Ver Wiebe's (1937) Udall limestone lentil, is exposed in the road ditch along the S. line SW¼ SW¼ sec. 21, T. 30 S., R. 3 E., where it consists of 1.5 feet of gray to brown, very dense, hard, coarsely vesicular limestone and coarsely crystalline calcite in the usual section of gray-green shale. Like the Hollenberg, it probably once contained anhydrite crystals.

A higher lenticular limestone of Herington aspect (although chiefly calcareous rather than dolomitic) is exposed in an abandoned quarry in the NW¼ sec. 36, T. 31 S., R. 2 E., Sumner County, on a high bluff overlooking Arkansas River. This is the bed noted by Norton (1939, p. 1757) and said by him to be about 125 feet above the Herington limestone. More than 10 feet of impure somewhat clayey cream-colored limestone is exposed in this quarry. The upper part weathers to slabby, soft material, but some of it is hard and massive where fresh. The upper part is geodal, as is the Herington. The middle third is very fossiliferous, with numerous large brachiopods (*Derbyia*) and occasional cup corals and gastropods.

The upper part of the lower Wellington shales is exposed in a stream bank in the NW¼ sec. 29, T. 18 S., R. 2 E., Marion County. The beds here are stratigraphically a few feet below the horizon of the Carlton limestone. The section here contains, from top to bottom, about 10 feet of gray and brownish-gray shales with intercalated thin calcareous layers and thin-bedded siltstones showing minute "cut-and-fill" micro-bedding. Below this is 0.6 foot of light-gray calcareous shale and then 0.8 foot brownish-gray silty shale. At the base is 3+ feet of light-gray dense impure limestone. Many joints in the upper shales and limestones are filled with pink to orange crystalline material composed of dolomite and celestite.

The Carlton dolomitic limestone member, which is reported to occur a short distance below the Hutchinson salt (Moore and

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others, 1951, p. 41) consists of about 60 feet (Ver Wiebe, 1937, p. 5) of gray-green (and some maroon) shales containing numerous discontinuous lenses of white earthy limestones. A Carlton dolomite lens is well exposed in a quarry in the NE¼ sec. 30, T. 19 S., R. 2 E., Marion County. The bed has a minimum exposed thickness of 5 feet, and consists primarily of cream-colored thin-bedded (<0.5 foot), dense earthy dolomite. Its upper surface is bulging or undulatory, and mud cracks (some at intervals of 10 inches) are common. One bed having a thickness of about 3 inches is composed of large oölites up to 0.5 mm in diameter and flat angular fragments of dense dolomite as large as one-half inch thick and 4 inches long.

Another Carlton area which also shows some of the adjacent shales is along the N. and W. lines NW¼ sec. 32, T. 34 S., R. 1 E. The section there follows.

Part of Wellington formation, including Carlton member, along N. and W. lines NW¼ sec. 32, T. 34 S., R. 1 E., Sumner County

	Thickness, feet
PERMIAN—Leonardian	
Wellington formation	
15. Limestone, slabby, cream-colored	0.1
14. Clay shale, brownish-gray	4.3
13. Clay shale, greenish-gray	3.1
12. Limestone, argillaceous, pale-gray	0.1
11. Clay shale, smooth, weak-red and green	0.7
10. Limestone, slabby, cream-colored	0.3
9. Clay shale, gray	2.8
8. Shale, smooth, slickensided, noncalcareous, weak-red (Munsell 2.5YR4/2); weathers into very small splinters	3.5
7. Clay shale, dark-gray; weathers slightly bluish	7.0
6. Limestone, slabby, cream-colored	0.2
5. Clay shale, gray and weak-red	0.8
4. Limestone, slabby, cream-colored; contains small (<2 inch diameter) mud cracks	0.5
3. Covered, probably gray shale	3.0
2. Limestone, slabby, argillaceous, light-gray; interbedded with thin (<0.4 foot) calcareous shales. Main benchformer	5.5
1. Clay shale, dark-gray	1+
Total	32.9

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In the early summer of 1951, beds a short distance above the horizon of the Carlton member were exposed in an old pit in the W. line NW¼ sec. 33, T. 19 S., R. 1 E., Marion County. The abandoned pit exposed a small domelike or noselike structure. The section was not measurable, but consisted of green and dark-gray noncalcareous blocky clay shales, some brownish-red shale, and thin beds (<0.5 foot) of light-gray calcareous shale or argillaceous limestone. Some of the gray shale immediately below a calcareous layer breaks along the bedding planes and shows small depressions in the upper side, with corresponding bumps on the lower side. The depressions range from very minute to 3 mm in diameter and are shallower than wide. They have almost no raised rims, but are presumably rain-drop impressions or gas pits. There are approximately 20 to the square inch. Mud cracks are well developed in some of the light-gray calcareous material. Their depth is not great, and they are about 2 inches apart. The fill is 1 to 4 mm wide and consists of darker, not very calcareous brownish-gray material. By October 1951 this exposure had been destroyed.

The middle part of the Wellington formation is chiefly comprised by the Hutchinson salt member, and is very poorly exposed at the surface. A small section in the Hutchinson salt may be seen in the workings of the Carey salt mine at Hutchinson. There the working face shows a rather regular alternation of clear, white, coarsely crystalline halite, in beds several inches thick, with thin laminae of gray silty shale, gypsum, and anhydrite. Wallace Lee (oral communication) has indicated that these thin crinkly shaly interbeds with selenite or anhydrite crystals are diagnostic of salt zones in rotary cuttings.

Beds of middle Wellington gypsum are exposed in the vicinity of Wichita in Sedgwick County. There is some indication that the Hutchinson salt grades into gypsum toward the south and east (Bass, 1929, p. 101), that the original margin of the salt basin passed through Sumner County (Bass, 1926, p. 94), and that the vicinity of Wichita was not far from the margin. A remnant of a thin bed of gypsum is exposed in a stream bank in the NE¼ NE¼ sec. 3, T. 27 S., R. 1 E., Sedgwick County. The gypsum cropping out here is less than 4 feet thick, is partly removed by solution, and is associated with red and gray shales.

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Thinly laminated green and gray shales and calcareous shales of the middle Wellington formation crop out in a stream bank on the N. line NW¼ NW¼ sec. 15, T. 24 S., R. 1 E., Harvey County. This is one of the lowermost sections in which *Cyzicus* (formerly *Estheria*), or brine-shrimp, is found. This fossil continues well up into the Ninnescah shale.

Another easily accessible minor exposure of middle Wellington shales occurs in the road ditch along U. S. Highway 160, at the Cen. N. line, sec. 16, T. 32 S., R. 1 E., Sumner County. About 30 feet of rocks here is poorly exposed. They are essentially gray-green soft clay shales containing at least three very thin slightly more resistant beds which are lighter in color and calcareous and which occur at intervals of about 10 feet. One of these includes a layer pock-marked with minute rectangular depressions having random orientation. These depressions, which may be salt casts, occur with a density of about 20 per square cm, and average about 1.5 mm in diameter. The uppermost resistant bed exposed at this locality is 0.1 foot of grayish-brown, calcareous, oölitic intraformational conglomerate having small rounded limestone and limonite fragments (<3 mm) and flat angular clay galls as large as 1 cm in long diameter.

A small exposure of clay shale somewhat above the middle of the Wellington formation occurs in a road ditch in the NE cor. sec. 28, T. 32 S., R. 1 W., Sumner County, and shows some of the color variation which is rather common in the upper part of the formation. The section follows.

Wellington formation, exposed in road ditch in the NE cor. sec. 28, T. 32 S., R. 1 W., Sumner County

	Thickness, feet
PERMIAN—Leonardian	
Wellington formation	
7. Limestone, thin-bedded, slabby, argillaceous, white (10YR8/1)	1.1
6. Clay shale, blocky, calcareous, medium-gray (N5/0) to greenish-gray (5GY6/1); weathers to orchid, gray, gray-green, and blue-green	4.7
5. Clay shale, blocky, greenish-gray	0.3
4. Clay shale, blocky, very slightly calcareous, pale-red (10R6/2); gradational color change at top and bottom	0.8
3. Clay shale, blocky, grayish-green	1.2
2. Clay shale, calcareous, light grayish-green (bench former)	0.4
1. Clay shale, blocky, grayish-green	3.2
Total	11.7

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Multicolored shales are even more notable in a section somewhat higher in the formation, exposed near a stream in the NE¼ SE¼ sec. 17, T. 33 S., R. 2 W., Sumner County.

Wellington formation, exposed near a stream in the NE¼ SE¼ sec. 17, T. 33 S., R. 2 W., Sumner County

	Thickness, feet
Soil	
PERMIAN—Leonardian	
Wellington formation	
17. Shale, red and green, poorly exposed	0.9
16. Shale, silty, blocky, noncalcareous, reddish-brown (Munsell 2.5YR5/4)	1.0
15. Marl, vuggy, white (10YR8/1) with red to nearly black hematite stains and brown limonite stain; contains scattered coarsely crystalline calcite and a pink fibrous very finely crystalline mineral (celestite?)	0.2
14. Clay shale, blocky, slightly calcareous, grayish-red (5R4/1)	1.3
13. Clay shale, greenish-gray	0.1
12. Clay shale, calcareous, white (10YR8/1)	0.8
11. Clay shale, noncalcareous, greenish-gray (5GY6/1)	0.4
10. Clay shale, soft, noncalcareous, reddish-brown; yellow at top and bottom; curved slickensided surfaces	2.8
9. Clay shale, blocky, calcareous, greenish-gray (5GY6/1) with discontinuous red streaks	0.6
8. Clay shale, green and brown with red streak at top	3.5
7. Clay shale, noncalcareous, reddish-brown (5YR4/3) mottled green; brownish at top	3.3
grades downward into	
6. Clay shale, noncalcareous, dark greenish-gray (5GY5/1)	1.7
5. Clay shale, light brownish-gray (2.5Y6/2) with red and greenish-gray mottling; some mottling in concentric bands	2.0
4. Clay shale, blocky, reddish-brown (2.5YR4/4); calcareous in pin-point spots; some slickensided surfaces	3.8
3. Clay shale, blocky, noncalcareous, dark greenish-gray (5GY4/1) to greenish-gray (5GY6/1); weathers to yellowish-green	0.4
2. Limestone, blocky, argillaceous, or very calcareous shale; gray (various shades); faintly laminated with discontinuous wavy laminae; contains tiny faults	0.5
1. Clay shale, greenish-gray	1+
Total	24.3

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Many of these colors may be recent features caused by differential weathering stages of the ferrous iron.

The uppermost part of the Wellington section is characterized by numerous thin beds of earthy argillaceous limestone and dolomite. Some of these are exposed in the Cen. W. side sec. 9, T. 28 S., R. 3 W., Sedgwick County. At this locality are two limestones, each about 0.5 foot thick, separated by about 7 feet of gray calcareous shale containing 2 feet of maroon shale in the middle.

The top of the Wellington formation, at which the principal change in color from gray to red takes place in southern Kansas, is marked by the Milan limestone member. According to Norton (1939, p. 1758), this member includes three thin limestones (one or more of which may be missing) in the topmost 8 feet of the Wellington formation. The three limestones, which are dolomitic and baritic in at least some localities, are less than a foot thick, and characteristically contain malachite in small spots, said to be weathered from chalcopyrite. The section in the type locality, SE¼ SE¼ sec. 30, T. 32 S., R. 3 W., 2 miles south of Milan, Sumner County (Pl. 3B), is given below.

Section at type locality of Milan limestone, SE¼ SE¼ sec. 30, T. 32 S., R. 3 W., Sumner County

	Thickness, feet
PERMIAN—Leonardian	
Ninnescah shale	
12. Clay shale, blocky, noncalcareous, dark reddish-brown (2.5YR3/4)	0.5+
11. Limestone, dolomitic, argillaceous, light-gray	0.7
10. Clay shale, calcareous, blocky, light greenish-gray	0.4
9. Clay shale, blocky, dark reddish-brown	3.3
8. Clay shale, blocky, maroon	1.4
7. Clay shale, dark-gray and dark-maroon	1.6
6. Limestone, very argillaceous, gray	0.3
5. Clay shale, blocky, dark-maroon	1.1
4. Clay shale, blocky, dark-green and some maroon	0.7
Wellington formation—Milan limestone member	
3. Limestone, dolomitic, white or yellowish-gray (5Y8/1); contains malachite, pink celestite, and barite	0.9
2. Clay shale, grayish-green	0.4
1. Covered to stream	10
Total	21.3

The Milan limestone and the color change from gray and maroon in the Wellington formation to brownish-red in the Nin-

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nescah shale are well exposed in the Cen. S. side sec. 9, T. 28 S., R. 3 W., Sedgwick County. At this locality there is a marked color contrast between the purplish red below and reddish brown above.

Ninnescah Shale

Exposures of the Ninnescah shale in Kansas extend from the Kansas-Oklahoma line to northern McPherson County and southeastern Ellsworth County where they are covered by Cretaceous rocks. The outcrop belt is about 110 miles long in a north-south direction and is approximately 22 miles wide at its broadest point near Oklahoma. Like the Wellington, the Ninnescah forms a low, rather featureless plain with only local areas of outcrops. The formation has an average outcrop thickness of 300 feet (Moore and others, 1951, p. 40); it thickens to about 450 feet toward the Oklahoma line, and thins to 50 feet in the subsurface near the Nebraska line. It consists primarily of brownish-red, calcareous and dolomitic, blocky, silty clay shales, commonly with scattered greenish-gray spots; plus occasional thin silty dolomites or dolomitic siltstones and rarely silty limestones or calcareous siltstones. Norton (1939) has noted seven principal scarp-forming beds in the Ninnescah which according to him can be traced for some distance along their strike. The Ninnescah is capped by the Runnymede member, a grayish-green, copper-bearing, sandy siltstone about 8 feet thick.

The formation was named by Norton (1939, p. 1767) from its exposures on both forks of Ninnescah River in south-central Reno County and north-central Kingman County. It includes all beds from the top of the Milan limestone to the top of the Runnymede member or the base of the Stone Corral dolomite.

The seven principal scarp-forming beds described by Norton are summarized below.

Bed 1 is dove-gray, dense, platy limestone, normally less than 1 foot thick; it breaks into small rectangular blocks stained with copper carbonate and is mud-cracked, pocked, pitted, and locally oölitic. This bed lies between green shales each half a foot thick, and 5 feet above a calcareous bed; in some places it is red, in some places contains salt casts, and commonly is veined with coarsely crystalline calcium carbonate 30 to 35 feet above the base of the

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Ninnescah. This bed contains *Cyzicus,* and maintains its limestone character for 40 miles, extending into Oklahoma.

Bed 2 is gray calcareous sandstone (siltstone?) in a ripple-marked double bed with 2 feet of red shale between the sandstone units. Thickness is 1 to 5 feet. Traceable for 60 miles, it increases in thickness and becomes cross-bedded near the Oklahoma line. Bed 2, which contains many *Cyzicus* shell impressions, lies about 100 feet above the base of the Ninnescah. Slightly more than 35 feet below Bed 2 is a thin, calcareous, fissile, ripple-marked sandstone (siltstone?) forming a low bench. Immediately above this bench, near Caldwell, Norton found some bone fragments and two teeth, but did not describe the type of animal they represented.

Bed 3 is sandy (silty?) limestone, 1 to 2 feet thick, and 10 to 40 feet above Bed 2. Bed 3 becomes double to the north, the two sandstones (siltstones) being separated by thin red shale. The upper surface of the bed is ripple-marked and pocked as with worm borings. The bed becomes sandier toward the Oklahoma line, as do the underlying shales.

Bed 4 consists of three thin dense gray limestones separated by largely green (but some red) shales, totaling 5 feet in thickness, and 15 to 20 feet above Bed 3. According to Norton (1939, p. 1771) Bed 4 can be traced for 25 miles or more and is characterized by rosette-shaped calcareous concretions on weathered surfaces. The deposits between beds 3 and 4 consist of red and gray shales with a thin geodal middle limestone.

Bed 5 is sandy limestone which is gray, thin-bedded, rather fissile, 1 foot thick (locally several feet thick), and about 30 feet above Bed 4. The upper surface is ripple-marked and mud-cracked, and *Cyzicus* and salt casts are present. A calcareous concretionary shale layer 6 inches thick occurs 1 foot above, and a black geodal dolomitic limestone 8 feet below; exposed near Castleton in Reno County.

Bed 6 comprises two limestones separated by 1 to 3 feet of red and gray shale, about 40 feet above Bed 5, and underlain by a thin bed of brick-red sandstone. The limestones contain salt casts, and the topmost part is locally shaly and ripple-marked. Bed 6 is a scarp former and is exposed near Castleton. Toward the south the limestones grade into thick green calcareous shales separated

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by thin red shale. Between Beds 5 and 6 are red shales containing many thin green calcareous shale bands with calcareous nodules.

Bed 7 is a calcareous sandstone, gray, 1 to 2 feet thick in central Kingman County, 60 feet above Bed 6. *Cyzicus* is common, and is not found stratigraphically higher than this in Kansas. Toward the Oklahoma line, Bed 7 becomes cross-bedded, and there is also more gray-green calcareous shale in the underlying beds toward the south. Above Bed 7 are red and gray shales, the top part becoming sandy toward the north and containing more limestone toward the south.

The topmost bed of the Ninnescah shale is known as the Runnymede member. It consists of about 8 feet of greenish-gray clayey sandy siltstone. The member was named by Norton (1939, pp. 1773-1774) from the town of Runnymede in northeastern Harper County.

Beds in the lowermost part of the Ninnescah shale are well exposed at the type locality of the Milan limestone in sec. 30, T. 32 S., R. 3 W., Sumner County, and there show transitional features between the Milan and Norton's Bed 1 (see measured section and Pl. 3B). Bed 1 is exposed near the Cen. S. line sec. 30 at the top of a small pit in typical brownish-red clay shale. Less than 1 foot of gray-green clay shale underlies the limestone, which is a light-gray, dense, earthy, and pitted dolomitic rock having a thickness of about 8 inches.

Bed 1 is better exposed in a road cut in the Cen. W. line sec. 9, T. 28 S., R. 3 W., Sedgwick County. The limestone here is 0.9 foot thick and contains a pink mineral (celestite?). It lies between two 6-inch beds of gray-green clay shale. The adjacent shales contain many thin veins of calcite having columnar structure. The exposure is shown in Plate 3C.

One hundred feet of Ninnescah shale, including the strata between Beds 1 and 3, is exposed on both sides of U. S. Highway 81 south of Caldwell in secs. 12, 13, and 14, T. 35 S., R. 3 W., Sumner County. At this locality many lateral variations take place within a few hundred yards, and few beds can be traced with certainty from one hillside to the next without showing some differences in lithology.

One section measured south of Caldwell follows. The section starts near Bluff Creek on the east side of the railroad bridge,

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sec. 12, and continues to the top of the hill in sec. 13, T. 35 S., R. 3 W.

Ninnescah shale near Bluff Creek in secs. 12 and 13, T. 35 S., R. 3 W., Sumner County

	Thickness, feet
PERMIAN—Leonardian	
Ninnescah shale	
42. Dolomite, silty, or dolomitic sandy siltstone; dense, light-gray to brown to pale-red (2.5YR6/2); contains *Cyzicus*. Norton's Bed 2? To the west one-fourth mile this is a reddish-brown (5YR5/4) cross-bedded dolomitic sandy siltstone; scale of cross-bedding ca. 1 cm	5.0
41. Covered	1.1
40. Limestone, silty, or dolomitic siltstone; slabby, gray	0.7
39. Clay shale, blocky, red-brown; contains thin gray resistant silty shale beds	15.0
38. Siltstone, calcareous, white (10YR8/1); mud-cracked, ripple-marked	1.2
37. Clay shale, blocky, greenish-gray	1.0
36. Clay shale, blocky, reddish-brown with green spots	2.0
35. Siltstone, resistant, light-gray	0.2
34. Clay shale, blocky, reddish-brown with green spots, especially near top	5.8
33. Limestone, silty, light-gray; slightly geodal	1.3
32. Clay shale, gray	0.4
31. Clay shale, blocky, reddish-brown; contains two thin light-gray resistant silty shale beds	12.0
30. Dolomite, silty, light-brown (5YR6/4); cross-bedded (1 cm thick); vertical "worm borings" 1 mm diameter, lined with calcite	0.7
29. Clay shale, gray-green (irregular base)	0.8
28. Clay shale, blocky, reddish-brown	8.1
27. Siltstone, fine-grained, noncalcareous, white (10YR8/2); contains scattered dwarf *Cyzicus* and holes which may be minute gas pits	0.3
26. Clay shale, blocky, reddish-brown	3.0
25. Siltstone, argillaceous, blocky, resistant, pale-red; 0.3 foot white streak in center (30 yards away, another white streak present in lower part)	1.3
24. Clay shale, blocky, reddish-brown	4.1
23. Siltstone, argillaceous, resistant, calcareous, white	0.1
22. Clay shale, blocky, reddish-brown	0.9
21. Geodes, calcareous, white; bench-forming; a thin vesicular bed with trace of associated greenish-gray shale	0.1
20. Clay shale, blocky, reddish-brown	5.3

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19. Shale, dolomitic, calcareous, slabby, light greenish-gray (5GY7/1); bench-forming; grades downward to red shale; contains thin beds (<1 cm) of dolomitic siltstone	0.8
18. Clay shale, blocky, brownish-red with green-gray streaks at top and bottom	1.0
17. Shales, interbedded thin red and gray; mostly red at base	0.8
16. Clay shale, light grayish-green	0.1
15. Clay shale, red and greenish-gray mottled; upper surface slightly wavy with 1.0 cm "chicken scratches"	4.0
14. Clay shale, blocky, brownish-red	6.3
13. Clay shale, crumbly, gray-green	0.1
12. Shale, silty, hard, calcareous, light greenish-gray (5GY7/1); bench-forming; mud cracks one-half to 1 cm diameter; contains trace copper carbonate and some coarsely crystalline calcite (Norton's Bed 1?)	0.4
11. Clay, very slightly calcareous, soft, crumbling, light olive-gray (5Y6/2)	0.4
10. Clay shale, silty, crumbly, somewhat calcareous, reddish-brown (2.5YR4/4) with widely scattered small greenish-gray spots (<3 mm diameter)	2.2
9. Shale, silty, calcareous, pale-red (10R6/2) (gray to pink-streaked); conchoidal fracture; forms bench	0.8
8. Clay shale, blocky, reddish-brown	0.9
7. Clay shale, greenish-gray	0.1
6. Clay shale, crumbly, reddish-brown	0.1
5. Clay shale, blocky, reddish-brown (2.5YR4/4); contains scattered greenish-gray spots and curved black slickensides having metallic luster; in part a very calcareous microbreccia or intraformational conglomerate	3.0
4. Shale, silty, hard, calcareous, gray-green; forms bench	0.1
3. Clay shale, crumbly, reddish-brown	5.2
2. Clay shale, slightly silty, hard, very calcareous, grayish yellow-green grading to red at base and top	0.3
1. Clay shale, blocky, reddish-brown (2.5YR5/4); contains a few greenish-gray horizontal streaks 1 to 30 mm in diameter	8+
Total	105.0

Some features of the Caldwell exposures are shown in Plate 4. Plate 4A shows the spotted blocky brownish-red shale with calcite veins which is typical of the entire Ninnescah section. Plate 4B is a detail of the "bleached" area below a dolomite. Plate 4C shows three orders of mud cracks in a pale red argillaceous siltstone in the middle part of the section.

Bed 2 as described by Norton is exposed in a hillside and road ditch along the N. line NE¼ sec. 4, T. 27 S., R. 4 W., Sedgwick

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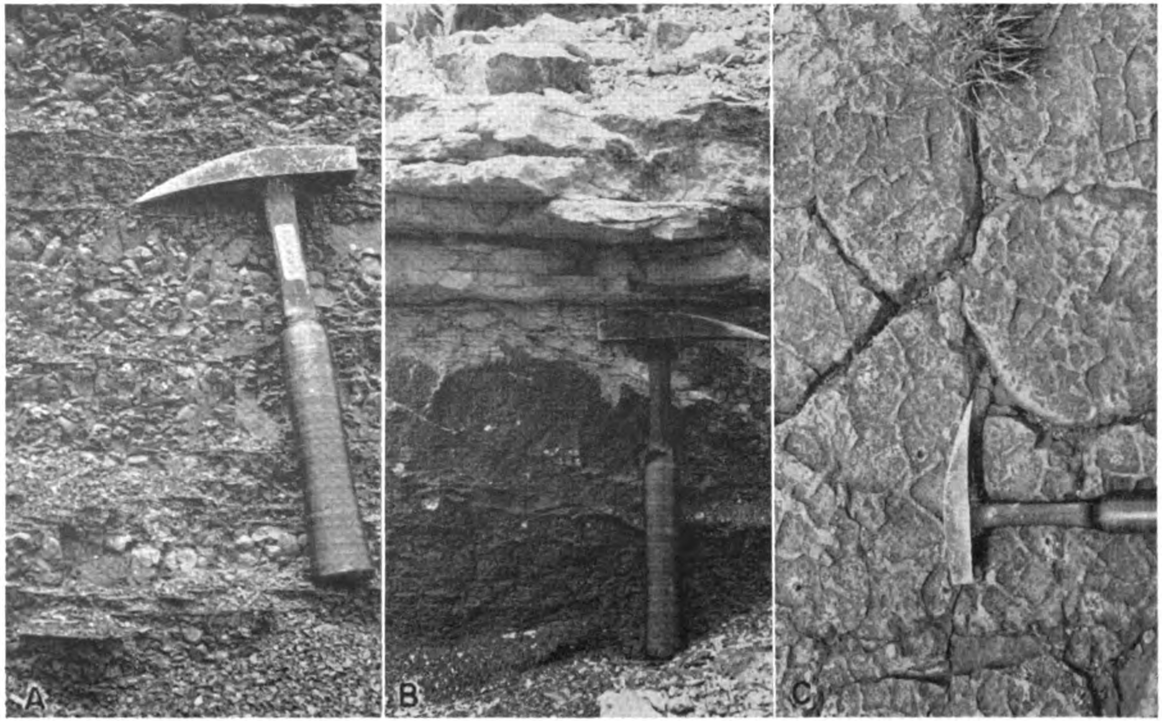

PLATE 4. Exposures in Ninnescah shale; sec. 14, T. 35 S., R. 3 W., Sumner County. **A**, Brownish-red blocky silty shale with calcite veins typical of Ninnescah formation. **B**, Detail of bleached area below a silty dolomite. **C**, Three orders of mud cracks in pale-red argillaceous siltstone.

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County. The upper bed is a light greenish-gray (5GY8/1) dolomitic siltstone 1.3 feet thick which has a ripple-marked upper surface. The ripples are essentially symmetrical in cross section, with an average amplitude of about 1 mm, wave length of 100 to 150 mm, and a N 150° W strike. The lower part of this bed contains horizontal calcite veins. The middle reddish-brown (2.5YR4/5) calcareous silty shale is 3 feet thick and has scattered greenish-gray spots up to 3 mm diameter. The lower bed is yellowish-gray (5Y8/1) poorly sorted unconsolidated clastic limestone with calcite crystals (2 mm diameter) in the lower part. The calcite fragments are sand size, and the superficial appearance is that of a fine-grained quartz sandstone.

Norton's Bed 3, a silty dolomite, is exposed in the northwest bank of Sand Creek in the NW¼ sec. 27, T. 29 S., R. 4 W., Sedgwick County. The section at this locality is given below.

Ninnescah shale exposed in northwest bank of Sand Creek in the NW¼ sec. 27, T. 29 S., R. 4 W., Sedgwick County

	Thickness, feet
PERMIAN—Leonardian	
Ninnescah shale	
3. Dolomite, silty, light greenish-gray (5GY8/1); contains vertical (3 mm diameter) worm borings in upper part	1.2
grades into	
2. Clay shale, gray-green	0.8
1. Clay shale, blocky, reddish-brown; contains calcite veins and a few zones with spherical green spots	15+
Total	17.0

A similar silty dolomitic limestone, possibly also Bed 3, has been quarried in the NE¼ sec. 14, T. 34 S., R. 4 W., Sumner County. The rock is a light-gray silty dolomite, 1.5 feet thick, with ripple marks, mud cracks, and green shale partings. It overlies several feet of normal reddish-brown blocky clay shale.

Worm borings are not everywhere present in Bed 3, nor are they restricted to this bed. Borings were noted in an unnumbered silty dolomite at a lower horizon (between Beds 1 and 2) in the hills south of Caldwell.

The three layers of Bed 4 may be seen clearly in road ditches along the N. line sec. 5, T. 26 S., R. 4 W., and the S. line sec. 32, T. 25 S., R. 4 W., Reno County (Pl. 5A). The section at this locality follows.

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Ninnescah shale exposed in road ditches along the N. line sec. 5, T. 26 S., R. 4 W. and the S. line sec. 32, T. 25 S., R. 4 W., Reno County

	Thickness, feet
PERMIAN—Leonardian	
Ninnescah shale	
9. Limestone, pale-green; variable thickness, about	0.2
8. Clay shale, silty, very slightly calcareous, light greenish-gray (5GY8/1)	0.6
7. Clay shale, blocky, brownish-red	2.5
6. Calcite rosettes (geodes) and surrounding green shale	0.4
5. Clay shale, blocky, brownish-red	1.5
4. Calcite band or vein	<0.1
3. Clay shale, blocky, brownish-red	2.5
2. Calcite rosettes (geodes), small (<10 cm diameter), and surrounding light greenish-gray calcareous shale	0.4
1. Clay shale, blocky, gray-green	0.6+
Total	8.8

The geodes consist of coarsely crystalline calcite, and the inside is coated with a bright-yellow material which turns buff-colored on exposure to air. Microchemical analysis indicates only $CaCO_3$ in this material (R. T. Runnels, personal communication).

At the Cen. W. line sec. 31, T. 25 S., R. 4 W., the bottom "limestone," although thin, is not geodal, and the interval between the two lower beds is thinner. A section measured at this locality follows.

Bed 4, Ninnescah shale, exposed along road at the Cen. W. line sec. 31, T. 25 S., R. 4 W., Reno County

	Thickness, feet
PERMIAN—Leonardian	
Ninnescah shale	
6. Limestone, dull, white; contains groups of coarse calcite crystals; surface knobby; more resistant parts weather into relief	0.2
5. Clay shale, blocky, gray-green	0.4
4. Clay shale, blocky, brownish-red	2.7
3. Limestone, argillaceous, geodal, light-gray; consists of masses of coarse calcite crystals, in part stained red, with a few scattered fragments of greenish-gray shale	0.3
2. Clay shale, fine-grained, blocky, brownish-red	1.9
1. Limestone, dolomitic, light greenish-gray; closely jointed, as in mud cracks	0.2
Total	5.7

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Norton's Beds 5 and 6 seemingly are no longer well exposed in the vicinity of Castleton, from which locality he originally described them. The area is rather flat, and very little shale is visible. A poor exposure of gray geodal dolomite less than 1 foot thick occurs in a road ditch along Kansas Highway 17 in the NW¼ sec. 36, T. 25 S., R. 6 W. A light-gray thin hard silty limestone overlies red and green blocky clay shales in the SW¼ sec. 27, T. 25 S., R. 6 W. About 0.8 foot of gray crumbly limestone, weathering white, occurs in the SW¼ sec. 21, T. 25 S., R. 6 W. A dense hard gray limestone is poorly exposed in the SW¼ sec. 13, T. 25 S., R. 6 W.

At Norton's locality for Bed 7 (SE¼ NE¼ sec. 2, T. 28 S., R. 6 W., Kingman County) is a poorly exposed 1-foot bed of white calcareous siltstone overlying brownish-red blocky clay shale. One-half mile to the south is a slightly thinner calcareous siltstone which contains calcite crystals, scarce ripple marks, and mud cracks.

Beds in the upper part of the Ninnescah are exposed in the NW¼ sec. 30 and the SW¼ sec. 19, T. 34 S., R. 5 W., Harper County. At this locality near the Oklahoma line, as pointed out by Norton (1939, p. 1772), the section includes more greenish-gray clay shales. The section follows.

Upper Ninnescah shale in the NW¼ sec. 30 and the SW¼ sec. 19, T. 34 S., R. 5 W., Harper County

	Thickness, feet
PERMIAN—Leonardian	
Ninnescah shale	
8. Siltstone, calcareous, gray; forms bench; contains thin finely drusy calcite veins	0.6
7. Clay shale, silty, blocky, brownish-red; contains 0.2-foot red resistant clay shale in middle	1.4
6. Siltstone, massive, calcareous, gray	2.9
5. Clay shale, silty, blocky, reddish-brown	1.1
4. Clay shales, silty, alternating thin gray and red-streaked	0.8
3. Siltstone, massive, light-gray	3.5
2. Clay shale, blocky, grayish-green	0.5
1. Clay shale, hard, blocky, brownish-red	1+
Total	11.8

The upper 30 feet of the Ninnescah shale is excellently exposed in bluffs in the SE¼ NW¼ sec. 8, T. 28 S., R. 6 W., King-

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man County. The top of the bluffs is underlain by an orange-red friable calcareous siltstone containing many coarse calcite geodes. This lithology is similar to that of the basal Chikaskia. Underlying it is 5 feet of gray-green siltstone: the Runnymede facies. Below the siltstone is 28 feet of brownish-red blocky clay shale with numerous diagonal calcite veins, bands of thin gray siltstone, and a few layers of gray-green clay shale and calcite geodes.

The Runnymede member was examined at Norton's type area in the NE¼ SE¼ sec. 10, T. 31 S., R. 6 W., Harper County (Pl. 5B). According to Norton (1939, p. 1773) the beds are in a gradational facies at this locality, the Runnymede facies extending up into the Chikaskia member of the Harper formation. The section is as follows.

Chikaskia-Ninnescah contact and transitional beds at type locality of Chikaskia member, in the NE¼ SE¼ sec. 10, T. 31 S., R. 6 W., Harper County

	Thickness, feet
PERMIAN—Leonardian	
Harper formation—Chikaskia member	
14. Siltstone and silty shale, thin-bedded, brownish-red	3+
13. Dolomite, silty, hard, mud-cracked, greenish-gray (5GY7/1) stained red; contains columnar calcite veins and thin angular fragments of green shale	0.1
12. Siltstone, argillaceous, sandy, reddish-brown, and interbedded reddish-brown blocky clay shale	4.0
11. Clay, silty, reddish-brown; contains argillaceous siltstone interbeds and hard calcareous concretions 1 to 3 inches in diameter; also coarsely crystalline calcite in veins associated with greenish-gray shale	4.9
10. Clay shale, soft, blocky, reddish-brown (2.5YR4/5)	1.7
Transitional beds?	
9. Clay shale, calcareous, greenish-gray; contains dolomite rhombs (<1 mm diameter) in vugs and clusters	0.2
8. Clay shale, silty, soft, blocky, slightly calcareous, reddish-brown (2.5YR4/5); contains greenish-gray dolomite rhomb streak near base	3.8
7. Siltstone, dolomitic, massive, hard, red (2.5YR4/6); contains slot-shaped holes (<1/8 inch) which possibly are salt casts, and minute (<0.5 mm) dolomite rhombs disseminated and in veins	1.1
6. Clay shale, minutely blocky, brownish-red	3.1
Ninnescah shale?	
5. Siltstone, dolomitic, thin-bedded, Runnymede-type, greenish-gray (5GY6/1); in part with minute wavy	

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streaks of dark-gray calcareous silty shale (thinner than 0.5 mm) and small areas of green copper carbonate	0.8
4. Clay shale, silty, blocky, gray	0.5
grades into	
3. Siltstone, argillaceous, calcareous, blocky, reddish-brown (5YR5/4)	3.5
2. Siltstone, calcareous, blocky, light greenish-gray (5GY7/1)	2.4
grades into	
1. Clay shale, silty, blocky, reddish-brown	3.2
Total	32.3

As the Stone Corral dolomite is absent in Harper County, the beds of dolomite rhombs and shale presumably take its place. The greenish-gray Runnymede siltstone is abnormally thin here. According to Norton, it is commonly 8 feet thick. Four feet is exposed at the top of the Ninnescah in sec. 8, T. 28 S., R. 6 W., Kingman County.

Stone Corral Dolomite

The Stone Corral dolomite was named by Norton (1939, p. 1775) from exposures in and near sec. 11, T. 20 S., R. 6 W., Rice County. Chiefly anhydrite in the subsurface, it is a key marker bed. In the outcrop area it loses its dolomitic character south of northern Reno County, and the horizon of the Stone Corral cannot be traced with certainty in the clay shales.

A small abandoned quarry (Pl. 6A) in the type area, NW cor. sec. 11, T. 20 S., R. 6 W., exposes the entire 6-foot thickness of the Stone Corral. The dolomite is dense to cellular, and grayish buff in color. It contains many vugs partly or completely filled with coarsely crystalline calcite or gypsum. The basal one-third is in part oölitic, with individual oölites up to one-half mm in diameter. Large oölites (1 mm diameter) also occur 2 feet below the top. The top 2 inches, also locally oölitic, is in part pink. The material of the oölites is more soluble, under ordinary conditions of weathering, than that of the matrix.

The top 3 feet of the Stone Corral is quarried for road material in the SE¼ SE¼ sec. 15, T. 20 S., R. 6 W. The rock is similar to that of the type locality, except that oölites are less abundant and the upper surface is locally ripple-marked. The weathered areas show well-defined beds with thicknesses up to 1 foot, and

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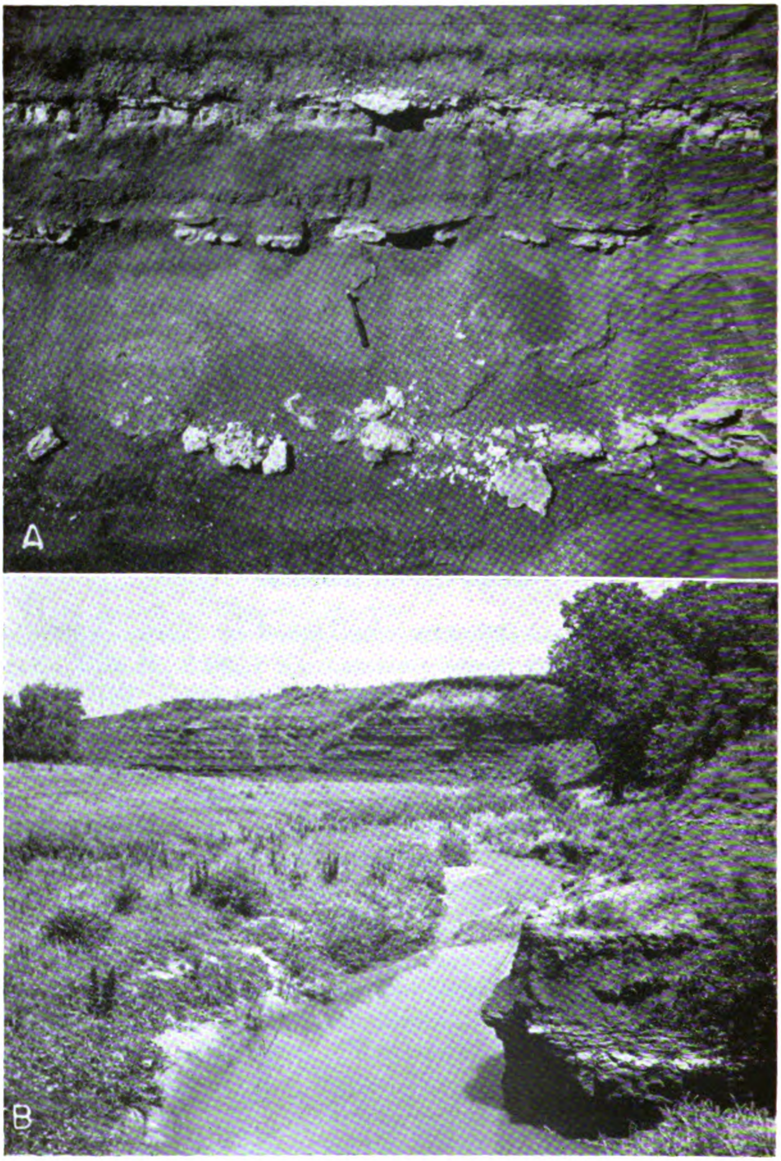

Plate 5. A, Geodal facies of Ninnescah Bed 4; SE¼ sec. 32, T. 25 S., R. 4 W., Reno County. **B,** Runnymede siltstone (foreground) and Chikaskia siltstone (background) at type locality; SE¼ SE¼ sec. 10, T. 31 S., R. 6 W., Harper County.

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some surfaces are speckled with a dark material (possibly manganese dioxide).

The grayish-green silty shales underlying the Stone Corral in the type area are exposed in a road cut along the N. line sec. 22, T. 20 S., R. 6 W. According to Norton (1939, p. 1779), the underlying shales to the south in Reno County are maroon.

In northeastern Reno County, 13 miles south of the type locality, the Stone Corral is 4 feet thick where it crops out in the S. line SE¼ sec. 9 and the W. line NW¼ NW¼ sec. 15, T. 22 S., R. 6 W. The rock here is grayish-buff in color and has a coarse sugary texture. It is porous but does not contain large vugs except on weathered surfaces. It weathers into thin beds (Pl. 6B) and includes a 2-inch brownish-red shale break about 0.8 foot below the top of the dolomite. The dolomite also contains short discontinuous red and gray shaly streaks abut 2 to 4 mm thick and clay galls 4 or 5 mm in long diameter.

In northern Kingman County the Stone Corral is exposed along the W. line NE¼ sec. 22, T. 25 S., R. 7 W. The dolomite here has the same coarse sugary texture but is only 0.4 foot thick. It overlies 0.3 foot grayish-green shale, which is above at least 6 feet of brownish-red blocky clay shale with diagonal calcite veins. Farther south in Harper County the Stone Corral is represented only by scattered dolomite rhombs in silty shale.

NIPPEWALLA GROUP

The Nippewalla group is described by Moore and others (1951, p. 38) as consisting mostly of redbeds that form a plain. The sediments of this group are primarily siltstones and very fine-grained sandstones, with minor quantities of silty shale and gypsum. The formations included in the Nippewalla are the Harper siltstone, Salt Plain formation, Cedar Hills sandstone, Flowerpot shale, Blaine formation, and Dog Creek shale.

Harper Formation

The Harper sandstones were named by Cragin (1896, pp. 18-19) from exposures in Harper County and particularly because of the low ledges of sandstones which were quarried near the City of Harper. Norton (1939, p. 1782) removed the Ninnescah and Stone Corral formations from Cragin's Harper sandstones

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and restricted the unit to the beds above the Stone Corral dolomite and below the flaky silty shales of the Salt Plain formation.

The Harper consists of 180 to 220 feet of brownish-red, spotted argillaceous siltstones and silty shales plus a few thin silty sandstones. It has been subdivided by Norton (1939, p. 1782) into the Chikaskia member, below, and the Kingman member, above.

Chikaskia member.—The type locality of the Chikaskia member (named from Chikaskia River) is in sec. 10, T. 31 S., R. 6 W., Harper County, where the basal beds overlie the type Runnymede siltstone (Pl. 5B). The member consists primarily of brownish-red sandy siltstone to silty shale and ranges in thickness from 100 feet at the northernmost exposures in Kingman County to 160 feet near the Oklahoma line.

According to Norton (1939, pp. 1782-1783) the Chikaskia has three general divisions; from base to top:

> 1. At the base, is a highly variable sand and shale section, the soft red sandstones containing grotesque concretions and salt casts, the more resistant red sandstones, several feet thick, weathering at the ordinary exposure to an exfoliated, bulgy or pot-bellied appearance, each of these ledges being capped by gray, fissile, fine-grained, ripple-marked and in places cross-bedded sandstone, the lower contact of which is very irregular so that the thickness varies abruptly from 1 or 2 feet to twice that thickness but everywhere levels off at the top. 2. Next is a series of bench-forming, well cemented, even-bedded, hard, red sandstones, weathering to a rough jagged surface, whose beds are locally quarried for dimension stone. These beds, together with those above, far better than those underlying, represent the rock character ordinarily associated with the name "Harper sandstones." 3. The uppermost third of the Chikaskia is more variable in thickness than the beds above or below, and there is also considerable variation in the composition of the strata. There are numerous white sandstones of fair strength which serve to break up the redbed section but the most distinguishing characteristic of this part of the member, outside of its contact with the next higher member of the Harper, is the sugary-dolomite lentils and concretions in the red shales, characteristically polka-dotted with small green spots.

The basal Chikaskia at the type locality is described in the section on the Runnymede sandstone. In the absence of Stone Corral dolomite, definite placing of the base of the Harper formation is not feasible. Another section similar to that at Runnymede is poorly exposed in sec. 2, T. 28 S., R. 6 W., Kingman County, where massive red siltstones 1 to 2 feet thick are interbedded with soft red silty shales. The sandy siltstone overlying the Run-

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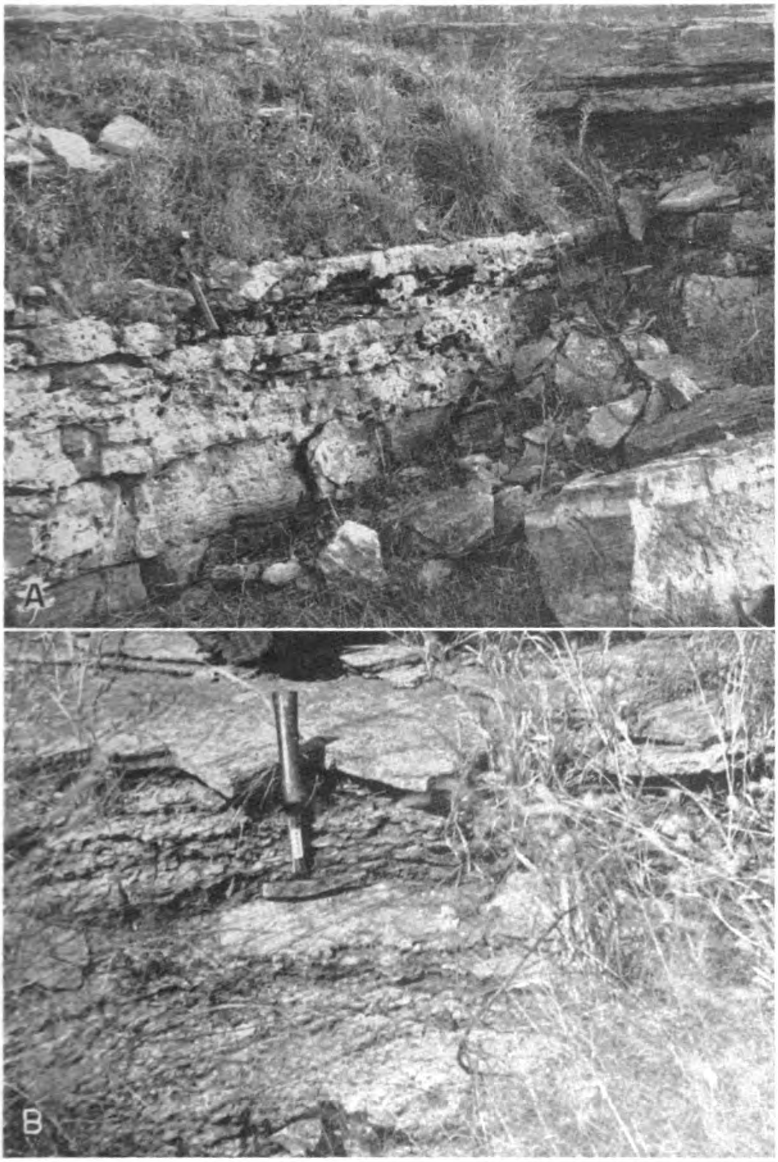

Plate 6. Stone Corral dolomite. **A,** Exposure in old quarry face at type locality; NW cor. sec. 11, T. 20 S., R. 6 W., Rice County. **B,** Thin-bedded granular facies; S. line SE¼ sec. 9, T. 22 S., R. 6 W., Reno County. Hammer head on red shale break.

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nymede in the SE¼ NW¼ sec. 8, T. 28 S., R. 6 W., Kingman County is orange-red, friable, and contains many coarse calcite geodes.

The lower Chikaskia is well exposed in the SW¼ SW¼ sec. 5, T. 28 S., R. 6 W., Kingman County, in a road ditch along the west line and also along the south line. At this locality are large crystal casts of red siltstone and calcite having the shape of curved rhombs (presumably dolomite rhombs, Pl. 7A). The section follows.

Lower part of Chikaskia member, Harper formation, exposed in road ditches in the SW¼ SW¼ sec. 5, T. 28 S., R. 6 W., Kingman County

	Thickness, feet
PERMIAN—Leonardian	
Harper formation—Chikaskia member	
13. Siltstone, argillaceous, calcareous, thinly laminated, red (2.5YR5/6); upper one-third contains bands of columnar calcite and gray siltier laminae	7.5
12. Siltstone, slabby, red with scattered tiny green spots	6.7
11. Shale, silty, red; contains thin calcite seams	0.8
10. Siltstone, slabby, red	4.8
9. Siltstone, very calcareous, friable, slabby, red (2.5YR4/6); contains sand-size calcite crystals and red silt-filled casts, curved rhomb-shaped (up to 80 mm diameter)	1.0
8. Siltstone, knobby, red	3.6
7. Siltstone, calcareous, white mottled reddish-yellow (5YR6/6)	0.9
grades into	
6. Siltstone, knobby, red	2.6
5. Siltstone, very calcareous, drusy, geodal, white (5Y8/2) in part mottled red	0.6
4. Clay shale, silty, brownish-red coarsely mottled with gray; middle third uniformly red, slabby; poorly exposed	5.2
3. Siltstone, argillaceous, hard, light-gray	0.7
2. Clay, silty, brownish-red coarsely mottled with gray	4.1
1. Shale, silty, and shaly siltstone; gray-green	1+
Total	39.5

Siltstones of the upper Chikaskia member are poorly exposed in road ditches in the NE¼ NE¼ sec. 27 and NW¼ NW¼ sec. 28, T. 25 S., R. 8 W., Reno County. At this locality the deposits consist of alternating 0.8 to 1.0-foot beds of brownish-red fine-grained argillaceous siltstone and coarse-grained sandy silt-

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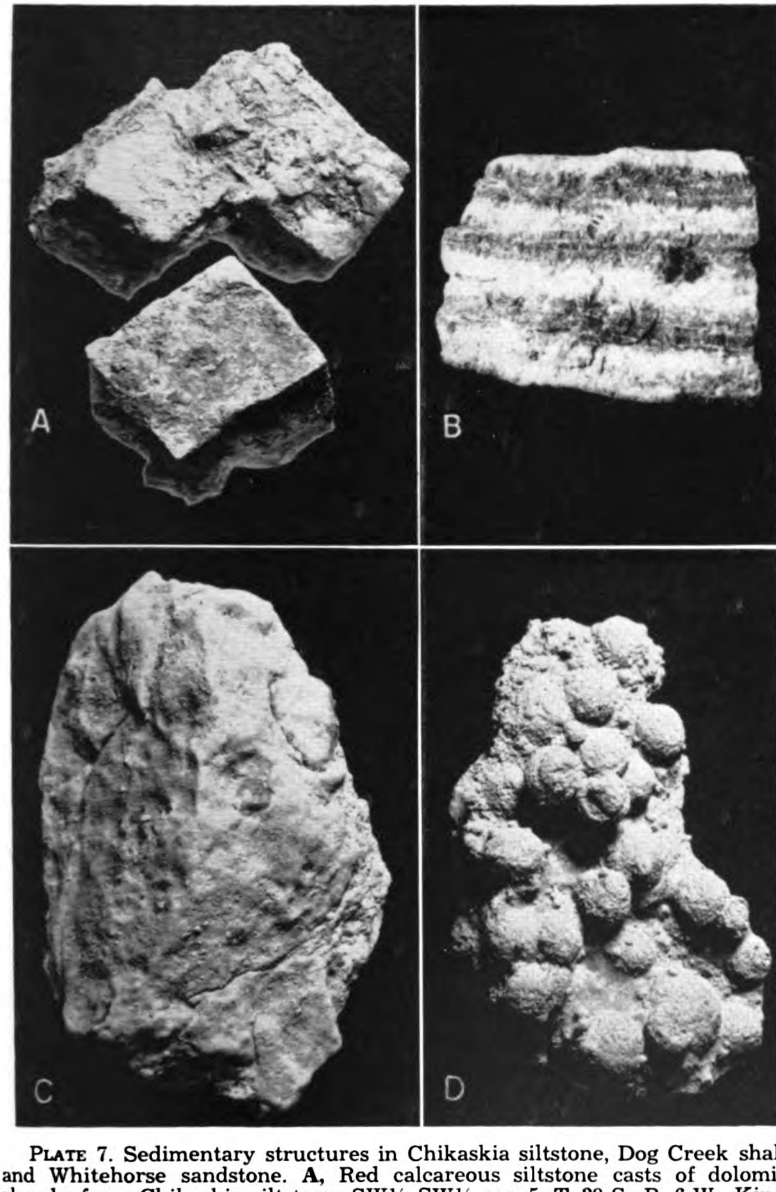

PLATE 7. Sedimentary structures in Chikaskia siltstone, Dog Creek shale, and Whitehorse sandstone. **A,** Red calcareous siltstone casts of dolomite rhombs from Chikaskia siltstone; SW¼ SW¼ sec. 5, T. 28 S., R. 6 W., Kingman County. ×0.5. **B,** Red- and white-banded gypsum from top of Dog Creek shale; SW¼ sec. 28, T. 34 S., R. 17 W., Comanche County. ×0.4. **C,** Gypsiferous feldspathic sandstone containing large gypsum crystals; upper Dog Creek shale, sec. 28, T. 34 S., R. 17 W., Comanche County. ×0.6.**D,** Detail of sand balls, Whitehorse sandstone; SE¼ sec. 4, T. 33 S, R. 19 W., Comanche County. ×0.7.

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stone. One bed consists of interlaminated light-gray and some red siltstone.

The top of the Chikaskia is well exposed at the type locality of the Kingman member on U. S. Highway 54, three-fourths mile east of Kingman (Pl. 8A). The following section (in the SE¼ NE¼ sec. 33, T. 27 S., R. 7 W.) starts at road level.

Upper part of Chikaskia member and the lower part of Kingman member, Harper formation, at Kingman type locality in the SE¼ NE¼ sec. 33, T. 27 S., R. 7 W., Kingman County

	Thickness, feet
PERMIAN—Leonardian	
Harper formation	
Kingman member	
11. Siltstones, thin, alternating hard and soft, very calcareous, slightly argillaceous, red (2.5YR5/6), green-spotted	5.0
10. Siltstone, friable, red	0.8
9. Siltstone, argillaceous, moderately soft, red (2.5YR5/6)	2.8
8. Siltstone, dolomitic, massive, resistant, red	1.5
7. Clay shale, very silty, soft, red	0.8
6. Siltstone, dolomitic, calcareous, massive, light greenish-gray (5GY7/1); contains discontinuous thin shale partings. Grades to pale-red in upper part, which has a few calcite-lined vugs. Somewhat micaceous	3.6
Chikaskia member	
5. Shale, silty, calcareous (or dolomitic), blocky, reddish-brown (2.5YR4/4) with widely scattered small green spots	2.7
4. Siltstone, friable, white	0.3
3. Siltstone, friable, pale-red; contains numerous flat calcareous concretions, some with one-fourth inch calcite crystals (geodes)	0.8
2. Shale, silty, calcareous, massive, slightly resistant, reddish-brown (5YR5/4) and some argillaceous siltstone with small green spots; pronounced conchoidal fracture; scattered calcareous concretions	3.2
1. Siltstone, massive, friable, red (2.5YR4/6) with scattered green spots; common calcareous siltstone concretions, 2 to 8 inches diameter, flat, oval, consisting of coarse calcite crystals (up to 0.8 mm diameter) scattered thickly in red siltstone	2.6
Total	24.1

Kingman member.——The Kingman member is composed of approximately 80 feet of brownish-red, thin, slabby siltstones with occasional beds of brownish-red silty shale and light-gray to white siltstones and sandy siltstones. The base of the member is

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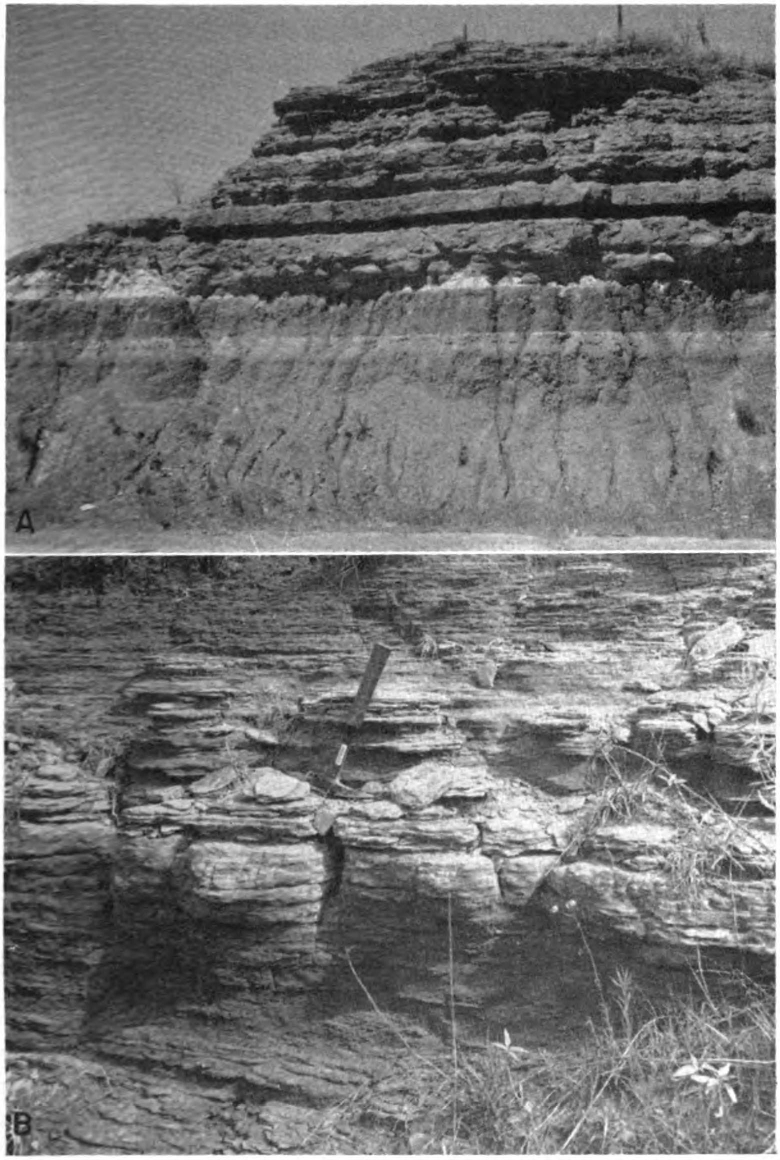

PLATE 8. Siltstones of the Harper formation. **A**, Chikaskia-Kingman contact at type locality of Kingman member; NE¼ sec. 33, T. 27 S., R. 7 W., Kingman County. **B**, Red siltstone in Kingman member; N. line NE¼ sec. 25, T. 32 S., R. 7 W., Harper County.

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marked by a prominent white sandy siltstone about 3 feet thick. The top of the member is not clearly defined, but is placed arbitrarily at a bed of reddish-brown (maroon) shale (Norton, 1939, p. 1785). Much of the Kingman member is lithologically nearly identical with the overlying Salt Plain formation although the Kingman is slightly more resistant to erosion and the silt is in general somewhat coarser. The member was named by Norton (1939, p. 1785) from exposures in and around Kingman, and throughout Kingman County north and south of that city.

The basal Kingman section at the type locality east of Kingman (SE¼ NE¼ sec. 33, T. 27 S., R. 7 W.) (Pl. 8A) is given above.

The lower Kingman is poorly exposed in a long shallow road ditch in the Cen. N½ sec. 14, T. 35 S., R. 7 W., Harper County, Kansas, about 1 mile north of Manchester, Oklahoma. The basal "white" bed is similar to that of the type locality, and is said (Norton, 1939, p. 1784) to continue far into Oklahoma. The section of the basal Kingman at this locality follows.

Lower part of Kingman member, Harper formation, exposed in road ditch in the Cen. N½ sec. 14, T. 35 S., R. 7 W., Harper County

	Thickness, feet
PERMIAN—Leonardian	
Harper formation	
Kingman member	
4. Siltstone, very calcareous, micaceous, red (3YR5/6) with small green spots	2.2
3. Shale, silty, calcareous, micaceous, reddish-brown (2.5YR4/4)	0.7
2. Siltstone, argillaceous, slabby, reddish-brown with small green spots	3.0
1. Siltstone, sandy, argillaceous, calcareous, light greenish-gray (5G8/1) (base)	3.1
Chikaskia member	
Total	9.0

The section higher is about 45 feet of poorly exposed green-spotted, red, slabby siltstones with a few light greenish-gray siltstones and reddish-brown shales. The upper and lower boundaries of most of the light-gray siltstones are gradational in color to the more predominant red and reddish-brown.

Siltstones in the middle Kingman are poorly exposed along the E. line NE¼ sec. 4, T. 26 S., R. 8 W., Reno County, about 5 miles south of Arlington. By digging into the roadside ditch one can see

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seemingly uniform slabby, micaceous, slightly calcareous, reddish-brown siltstone, with some slabs only slightly harder than others. The Munsell designation for the color of this rock is approximately 2.5YR5/6 (reddish-brown). The bedding surfaces are not plane but slightly undulatory, and the mica (and chlorite?) concentrated thereon is about half white and half green.

Better exposures of this typical Kingman siltstone occur in road ditches in the NE¼ sec. 25, T. 32 S., R. 7 W., Harper County. Plate 8B shows the slabby character of the soft, easily eroded, micaceous red siltstone. The more massive beds consist of slightly coarser siltstone, and some of them weather into peculiar polygonal masses resembling giant worn mud cracks. Obscure ripple marks are also present at this locality.

Salt Plain Formation

The Salt Plain formation was named by Cragin (1896, p. 22) from the Great Salt Plain of Cimarron River in northern Oklahoma. The salt plains of the Cimarron are located in northern Woodward County, Oklahoma (Gould, 1901a, p. 182) and the deposits there must be stratigraphically higher than the Salt Plain formation in Kansas. That Cragin did not refer to the Salt Plain of the Salt Fork in northern Woods County as the type locality is definitely shown by his statement (1896, p. 23) that the salt springs of that area are only "provisionally referred to the Salt Plain measures." Therefore, "Salt Plain" is a misnomer, and the formation has no type locality. The Salt Plain includes the reddish-brown flaky siltstones, thin sandy siltstones, and very fine-grained sandstones between the top of the Harper formation and the base of the Cedar Hills sandstone, and comprises a total thickness of about 265 feet (Moore and others, 1951, p. 39). In Kansas the formation crops out in central and western Harper County, eastern Barber County, and southern Kingman County. Because of the soft, friable character of the siltstones and solution of salt, exposures are few and poor; most of the area of outcrop is a plain of low relief. The lithologic similarity of the Salt Plain formation to the underlying Kingman member of the Harper formation and the absence of any unconformity or distinctive marker bed at the contact make this boundary an artificial and unmappable one which should be revised or eliminated by stratigraphers.

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Fifty feet of typical middle Salt Plain deposits is well exposed in the S½ sec. 3, T. 32 S., R. 9 W., Harper County, in the drainage of Cottonwood Creek. The section follows.

Middle part of Salt Plain formation in the S½ sec. 3, T. 32 S., R. 9 W., Harper County

	Thickness, feet
PERMIAN—Leonardian	
Salt Plain formation	
16. Sandstone, very fine-grained, silty, calcareous, massive, resistant, knobby, brownish-red with unevenly distributed small greenish-gray spots; contains vugs (<1 cm diameter) lined with calcite crystals	4.0
15. Siltstones, sandy, thin (<one-half inch), and soft micaceous silty shales (average thickness 0.5 foot); brownish-red (Pl. 9A)	10.8
14. Siltstone, slightly argillaceous, calcareous, resistant, knobby, micaceous, red (2.5YR4/6); forms bench	0.3
13. Clay, silty, soft, brownish-red	2.8
12. Sandstone, silty, knobby, brownish-red (green-spotted)	1.1
11. Clay shale, micaceous, reddish-brown	0.4
10. Siltstone, calcareous, slabby, micaceous, white- (5Y8/1) and red-mottled	1.0
9. Shale, silty, calcareous, blocky to flaky, reddish-brown	1.5
8. Clay shale, silty, brownish-red	0.2
7. Shale, silty, calcareous, blocky to flaky, reddish-brown (2.5YR4/5)	4.8
6. Siltstone, calcareous, ripple-marked, gray to brownish-red; current ripples, wave-length 1-3/8 inches; current direction from N 45° E	2.5
5. Shale, calcareous, thin-bedded, flaky, micaceous, yellowish-red (5YR4/6); contains a few thin (<one-half inch) interbeds of siltstone; trace of gypsum coating on some surfaces	5.3
4. Siltstone and silty shale, calcareous, slabby, micaceous, light-brown (2.5YR5/6)	0.7
3. Clay shale, very silty, calcareous, blocky, reddish-brown (5YR5/4)	2.2
2. Covered	10.0
1. Siltstone, coarse, soft, slabby, calcareous, micaceous, yellowish-red (5YR5/6) with greenish-gray spots; well-sorted	2.3+
Total	49.9

True sandstone is extremely rare in the Salt Plain, and it is possible that the top sandstone bed at this locality may be at approximately the same horizon as the "Gerlane" sandstone, which

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is said (Norton, 1939, p. 1787) to be 42 feet below the base of the Cedar Hills sandstone.

Another area in which true sandstones can be seen in the Salt Plain formation comprises the NW¼ sec. 17 and the SE¼ sec. 18, T. 33 S., R. 9 W., Harper County. This locality is near the settlement of Crisfield and the deposits are probably Norton's (1939, p. 1788) "Crisfield" sandstone. The sandstone is said to be 29 feet thick and 115 feet below the base of the Cedar Hills sandstone. However, about 20 feet of redbeds are exposed here, and not more than 6 feet of them is true sandstone; the remainder is siltstones and sandy siltstones. The sandstone is lithologically similar to that in the drainage of Cottonwood Creek; it is slightly coarser grained, some grains being as large as 0.15 mm. The section also includes gypsum "snowballs" (not in place) and common white gypsiferous coatings on part of the rocks.

The top of the Salt Plain and its contact with the Cedar Hills sandstone are exposed 2 miles north of Sharon in the NW¼ NW¼ sec. 9, T. 32 S., R. 10 W., Barber County. The section here is given below.

Upper part of the Salt Plain formation and the lower part of the Cedar Hills sandstone in the NW¼ NW¼ sec. 9, T. 32 S., R. 10 W., Barber County

	Thickness, feet
PERMIAN—Leonardian	
Cedar Hills sandstone	
19. Siltstone, argillaceous, slightly calcareous, thin-bedded, red (2.5YR5/6)	3.0
18. Sandstone, very fine-grained, very calcareous, red (2.5YR5/6) (white spots up to 3 mm diameter)	8.1
17. Sandstone, very fine-grained, argillaceous, red	3.9
16. Sandstone, fine-grained, friable, white	0.2
15. Sandstone, very fine-grained, silty, very calcareous, somewhat resistant, red (white spots)	3.0
14. Sandstone, very fine-grained, silty, slightly calcareous, red (white spots)	0.8
13. Siltstone, argillaceous, hard, slightly calcareous or dolomitic, red (white spots)	1.2
12. Covered, probably red and white soft silty sandstone	1.4
11. Siltstone, coarse-grained, sandy, massive, red (white spots)	6.6
10. Sandstone, very fine-grained, silty, calcareous, red (white spots up to 0.6 mm diameter); argillaceous in upper part; red oblate spheroidal calcareous sandstone concretions (some hollow with calcite crystals) in lower part (average 2 inches in diameter). Some darker red micro-galls of shale	3.0

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9. Sandstone, fine-grained, friable, calcareous, thinly laminated, white grading upward to light-pink (5YR7/6); with small-scale cross-bedding (Pl. 9B)	0.8
8. Sandstone, fine-grained, massive, essentially unconsolidated, slightly calcareous, well-sorted, white (2.5Y8/2) spotted red (Pl. 9B); sharp contact with locally bleached Salt Plain below	1.2
Salt Plain formation	
7. Siltstone, argillaceous, calcareous, micaceous, reddish-brown (5YR4/4) (green spotted)	5.0
6. Covered	9.8
5. Siltstone, sandy, fairly resistant, slabby, calcareous, yelowish-red (5YR5/6) (large green-gray spots); bimodal size distribution, some rounded sand grains >0.3 mm diameter. Also large calcite crystals	0.8
4. Covered, probably red, green-spotted calcareous argillaceous siltstone	9.0
3. Siltstone, calcareous, thin-bedded, slabby, micaceous, reddish-brown (2.5YR5/4) and white (5Y8/1) banded; white is coarser grained, more calcareous, than reddish-brown	2.1
2. Shale, silty, slabby, micaceous, calcareous, reddish-brown (5YR5/4)	1.0
1. Shale, silty, calcareous, micaceous, yellowish-red (5YR5/6) with greenish-gray spots	7.4
Total	68.3

The sandy siltstone 15 feet below the top of the Salt Plain formation at this locality is the lowermost bed known to me in which scattered large rounded sand grains occur. These grains are much more common in the younger rocks.

Cedar Hills Sandstone

The Cedar Hills sandstone comprises about 180 feet of redbeds between the Salt Plain formation and the Flowerpot shale. The formation, which crops out in Barber County, was named by Cragin (1896, p. 24) from the Cedar Hills a few miles northwest of Hazelton in T. 33 S., Rs. 10 and 11 W. It consists of brownish-red, massive, very fine-grained sandstones and sandy siltstones separated by beds of argillaceous siltstone and silty shale. The base and top are marked by beds of white fine-grained sandstone. The top sandstone contains many white to pink "snowballs" of granular gypsum.

The individual beds of the Cedar Hills sandstone seem to be traceable for long distances. Detailed stratigraphic study might make correlations within the formation possible.

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The section of the basal Cedar Hills in the NW¼ NW¼ sec. 9, T. 32 S., R. 10 W., Barber County, is given above.

Most of the Cedar Hills section is exposed in the canyons of the type locality northwest of Hazelton. The most prominent features of the deposits exposed here are two massive friable silty sandstones, 10 to 20 feet thick, separated by even less resistant sandy siltstones and argillaceous siltstones. Box canyons have developed in the thick sandstones, and waterfalls in ephemeral streams have eroded large potholes.

A small section in the lower Cedar Hills sandstone in a road cut in the SW¼ sec. 28, T. 31 S., R. 11 W., Barber County, is typical of the formation almost throughout.

Lower part of Cedar Hills sandstone in road cut in the SW¼ sec. 28, T. 31 S., R. 11 W., Barber County

	Thickness, feet
PERMIAN—Leonardian	
Cedar Hills sandstone	
5. Sandstone, very fine-grained, resistant, calcareous, red (2.5YR5/6) (white spots)	0.5
4. Sandstone, very fine-grained, silty, soft, friable, slightly calcareous, red (white spots)	3.5
3. Sandstone, very fine-grained, resistant, calcareous, red (white spots)	0.4
2. Sandstone, very fine-grained, silty, soft, friable, slightly calcareous, red (white spots)	0.8
1. Shale, silty, somewhat blocky, hard, slightly calcareous, red (2.5YR4/6)	2.1
Total	7.3

The top 30 feet of Cedar Hills sandstone is exposed in the NW¼ NE¼ sec. 20, T. 32 S., R. 12 W., Barber County (see section below).

Upper part of Cedar Hills sandstone exposed in the NW¼ NE¼ sec. 20, T. 32 S., R. 12 W., Barber County

	Thickness, feet
PERMIAN—Leonardian	
Cedar Hills sandstone	
6. Sandstone, very fine-grained, silty, calcareous, friable, white (5Y8/1); contains white to pink granular gypsum "snowball" concretions in top part, average 6 inches diameter. Bottom contact gradational	1.1

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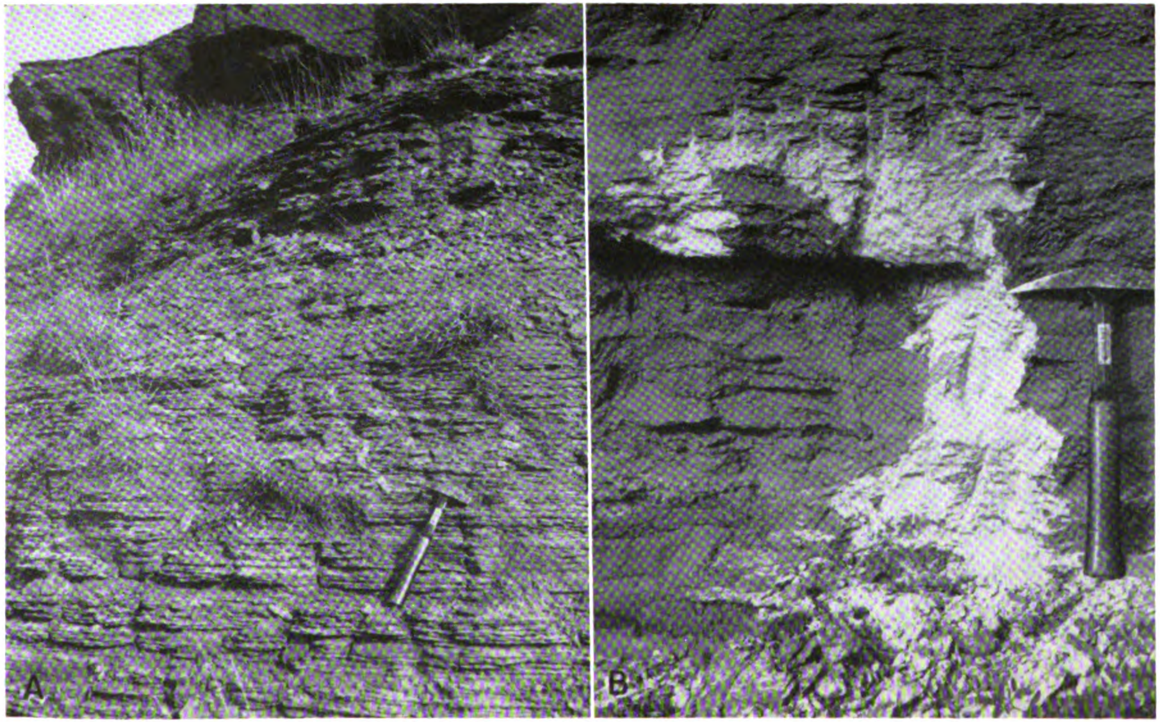

PLATE 9. **A,** Brownish-red micaceous siltstone and calcareous sandstone, Salt Plain formation; SE¼ sec. 3, T. 32 S., R. 9 W., Harper County. **B,** Basal bed of white sandstone, Cedar Hills formation; NW¼ sec. 9, T. 32 S., R. 10 W., Barber County.

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5. Sandstone, fine-grained, calcareous, fairly resistant, red (white spots); forms base of top ledge	0.9
4. Siltstone, coarse, sandy, very friable, calcareous, red (white spots)	4.4
3. Sandstone, very fine-grained, silty, very friable, slightly calcareous, red; contains scattered gypsum nodules	5.3
2. Sandstone, very fine-grained, very friable, calcareous, red (white spots)	4.7
1. Sandstones; silty, and sandy siltstones; very fine-grained, thin (0.6 foot or thinner), interbedded, red (white spots). Siltstones contain white flat gypsum nodules up to 4 cm in long diameter; some of the sandstones are hard, cemented with coarsely crystalline dolomite (and gypsum)	10.0
Total	26.4

The top few feet of the Cedar Hills sandstone is slightly different as exposed in a canyon in sec. 19, T. 32 S., R. 12 W., Barber County. In this canyon is 25 feet of almost entirely unconsolidated red silty very fine-grained sandstone with many criss-cross gypsum veins, overlain by 12 feet of more resistant red massive calcareous very fine-grained silty sandstone. Landslides are common, and most of the section below is covered.

Parts of the formation which have been rapidly eroded or undercut and form steep cliffs do not show much detail in the bedding. The appearance of such exposures is characteristically massive, although weathering would reveal alternating finer and coarser beds.

In general, silty shales are more common in the lower part of the Cedar Hills than in the upper part. Micaceous silty shales are interbedded with sandy siltstones and silty sandstones near the base of the formation in the NE¼ sec. 30, T. 34 S., R. 11 W., Barber County. The shales here break with sharp, right-angled fractures and are the usual uniform red color with light-gray spots. The mica flakes are primarily white rather than green.

Large areas of white sandstone several inches in diameter are common in the middle part of the formation in sec. 7, T. 32 S., R. 11 W., Barber County.

Gypsum "snowballs" are not restricted to the top of the formation. A snowball horizon in the lower part crops out locally in a road cut on U. S. Highway 160 in the NW¼ SW¼ sec. 8, T. 32 S., R. 12 W., Barber County. This bed is about 0.2 foot thick and

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occurs in a 0.6-foot red argillaceous siltstone zone. Some of the gypsum concretions are 3 inches or more in long diameter.

Flowerpot Shale

The Flowerpot shale consists of about 180 feet of reddish-brown gypsiferous shale and silty shale with a few thin beds of sandstone and siltstone. Eroded slopes are characteristically covered with many-hued fragments of selenite and satin spar (Pl. 10B). It overlies the white, "snowball"-bearing top sandstone of the Cedar Hills sandstone and underlies the Blaine gypsum. Outcrops in Kansas are restricted to Barber County and the eastern part of Comanche County. The formation was named by Cragin (1896, p. 24) from Flower-pot Mound, a prominent butte in sec. 26, T. 32 S., R. 13 W., Barber County (Pl. 1B).

One of the most accessible and best-exposed Flowerpot sections is a U. S. Highway 160 road cut in the SE¼ SE¼ sec. 1, T. 32 S., R. 14 W., Barber County. The section, which is in the upper half of the formation, starts at road level; it ends 15 feet below the base of the Blaine gypsum (Pl. 10A).

Flowerpot shale exposed along U. S. Highway 160 in the SE¼ SE¼ sec. 1, T. 32 S., R. 14 W., Barber County

	Thickness, feet
PERMIAN—Leonardian	
Flowerpot shale	
10. Sandstone, very fine-grained, silty, friable, gypsiferous, pink (7.5YR7/4); forms slight ledge	4.0
9. Shale, slightly silty, gypsiferous, thin-bedded, reddish-brown	15.4
8. Sandstones, gypsiferous, thin (<0.5 foot), pink, interbedded with reddish-brown silty shales	4.5
7. Siltstone, sandy, dolomitic, gypsiferous, white (2.5Y8/0) to pink	0.4
6. Shale, gypsiferous, weak-red (2.5YR5/2) mottled gray (7.5YR6/0)	7.3
5. Siltstone, sandy, light reddish-brown (5YR6/4), and intergrown gypsum (selenite and satin spar)	0.9
4. Clay shale, blocky, reddish-brown (2.5YR4/4); contains numerous gypsum veins	13.5
3. Siltstone, argillaceous, sandy, light greenish-gray (5G7/1); contains a few thin streaks of clay shale and clear colorless gypsum veins. Very slightly calcareous	0.3

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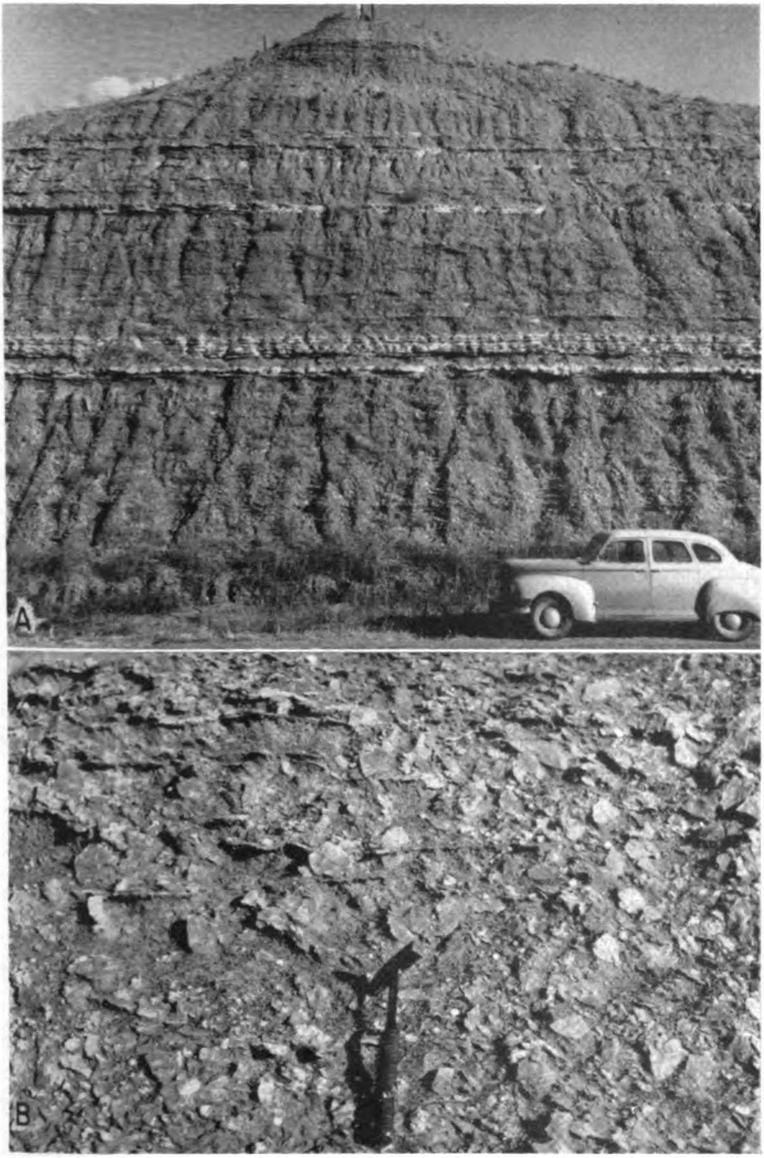

PLATE 10. Flowerpot shale, Barber County. **A**, Road cut in upper part of Flowerpot formation; SW¼ sec. 1, T. 32 S., R. 14 W. **B**, Selenite in shale; sec. 25, T. 32 S., R. 13 W.

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2. Sandstone, very fine, and sandy siltstone; white (5YR8/1) mottled reddish-brown; cemented with gypsum. Coarser grained at top	5.0
1. Clay shale, silty, blocky to splintery, reddish-brown (2.5YR4/4); contains numerous gypsum veins	15+
Total	66.3+

Although the Flowerpot consists primarily of reddish-brown gypsiferous clay, several sandy or silty zones make prominent benches. One of these benches, about 40 feet above the base of the formation, is well developed southwest of Medicine Lodge in sec. 20, T. 32 S., R. 12 W. It consists of about 1 foot of light reddish-brown gypsiferous very fine sandstone, mottled greenish-gray. Other prominent sandstone benches within 40 feet of the top of the formation crop out in canyons in sec. 19, T. 32 S., R. 12 W., Barber County. Some of the gypsiferous sandstones in the Flowerpot (e.g., a 1-foot bed 75 feet below the Blaine in the SW¼ sec. 5, T. 32 S., R. 13 W., Barber County) are cemented with coarsely crystalline gypsum and contain numerous large crystals of clear gypsum without included sand grains.

The topmost few feet of the Flowerpot is well exposed in a road cut in the SE¼ sec. 11, T. 31 S., R. 15 W., south of Sun City, Barber County. Although immediately below the Blaine formation, this section is notable for its small quantity of secondary gypsum.

Upper part of Flowerpot shale exposed in road cut in the SE¼ sec. 11, T. 31 S., R. 15 W., Barber County

	Thickness, feet
PERMIAN—Leonardian	
Blaine formation	
10. Gypsum, massive, white	1+
9. Dolomite, hard, dense, gray	0.2
Flowerpot shale	
8. Clay shale, hard, noncalcareous, greenish-gray	0.3
7. Clay shale, silty, reddish-brown (5YR5/4); calcareous in small pin-point areas	0.7
6. Clay shale, greenish-gray	0.2
5. Clay shale, noncalcareous, reddish-brown	1.5
4. Clay shale, greenish-gray	0.3
3. Clay shale, reddish-brown	0.4
2. Covered	2.6

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1. Sandstone, very fine-grained, poorly sorted, light-gray (mottled reddish-brown); cemented with coarsely crystalline gypsum	2+
Total	9.2+

Blaine Formation

The Blaine formation consists of about 50 feet of massive gypsum, thin dolomite, and brownish-red shale. The formation, which is divided by Norton (1939) into four members, crops out in Barber, Comanche, and Kiowa Counties. It was named by Gould (1902) from Blaine County, Oklahoma, and the type locality is in Salt Creek Canyon in northern Blaine County. It is one of the most extensive and easily traced formations of the Permian redbeds, reaching from Kansas across western Oklahoma and into the Texas Panhandle and central northern Texas.

The topmost member of the formation, the Haskew gypsum, was named by Evans (1931) from exposures near an old store in sec. 2, T. 25 N., R. 19 W., Woodward County, Oklahoma. The member consists of 1 foot or less of gypsum underlain by about 5 feet of brownish-red shale. The gypsum has been removed by solution in many places, particularly north of the Kansas-Oklahoma line, and it was not in evidence at any of the localities seen by me.

The Shimer gypsum member underlies the Haskew. This member was named by Cragin (1896, p. 27) from exposures in Shimer Township, Comanche County, Kansas, and consists of a 13- to 23-foot bed of massive gypsum overlying 0.5 to 1.5 feet of dolomite. Much of the gypsum has been removed by solution.

Underlying the Shimer is the Nescatunga gypsum member, named by Norton (1939, p. 1794) from exposures along the lower reaches of Nescatunga Creek in southeastern Comanche County. The member includes 8 feet or less of red shale overlying 2 to 8 feet of gypsum, and 8 feet or less of red shale underlying the gypsum. The Nescatunga and Shimer gypsum beds pinch out in Comanche County and are not present as far east as Barber County.

The lowermost member of the Blaine formation is the Medicine Lodge gypsum member, named by Cragin (1896) for Medicine Lodge River and the City of Medicine Lodge in Barber

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County. This is, in Kansas, the thickest bed of gypsum, attaining a maximum thickness of 30 feet or more. The member also includes a foot of dolomite at the base of the gypsum and grades into it. Included within the gypsum (about 10 feet above the base) are resistant lentils of massive anhydrite 10 to 12 inches in thickness.

The stratigraphy of the Medicine Lodge member in the Sun City area has been carefully summarized by McGregor (1948), and it is not discussed further here. An exposure of the Medicine Lodge gypsum and anhydrite is illustrated in Plate 11B.

The Nescatunga and lower Shimer members are fairly well exposed in a stream bank in the NE¼ sec. 32, T. 34 S., R. 16 W., Comanche County, along Red Ford Creek (Pl. 11A). At this locality the upper 3 feet of the Medicine Lodge gypsum is exposed just above stream level, and the interval below the Nescatunga gypsum consists of 8 feet of soft brownish-red shale with scattered crystals of impure gypsum. The gypsum of the Nescatunga member is partly dissolved and slumped, but it has a maximum thickness of 4.5 feet at this locality. Above the gypsum is 8 feet of crumbly brownish-red silty shale with occasional thin (less than 0.3 foot) streaks of brownish-red and greenish-gray mottled silty shale.

At least 15 feet of Shimer gypsum is exposed at this locality. At the base is 1.3 feet of dolomite, much of which is oölitic, the oölites consisting predominantly of dolomite and the matrix (cement) of gypsum. The upper part of the dolomite is gradational into the massive gypsum and contains many stringers or veins of clear, colorless selenite or satin spar. Part of the dolomite shows small-scale cross bedding (Pl. 12B).

The oölitic dolomite is interpreted to have been produced by agitation of shallow-water sediments by wave action in calcium-magnesium carbonate- and sulfate-saturated water. A recently published paper (Illing, 1954) describes such a locus of sedimentation in the Bahamas. Oölites in the Blaine gypsum are seemingly wide spread, for they are reported from well cuttings at several localities. An algal origin is also possible. Moore (personal communication, July 1954) notes that algal growth is favored by hypersaline conditions (for example, Great Salt Lake and Pennsylvanian and Permian regressive parts of cycles) in which dolomite may be formed.

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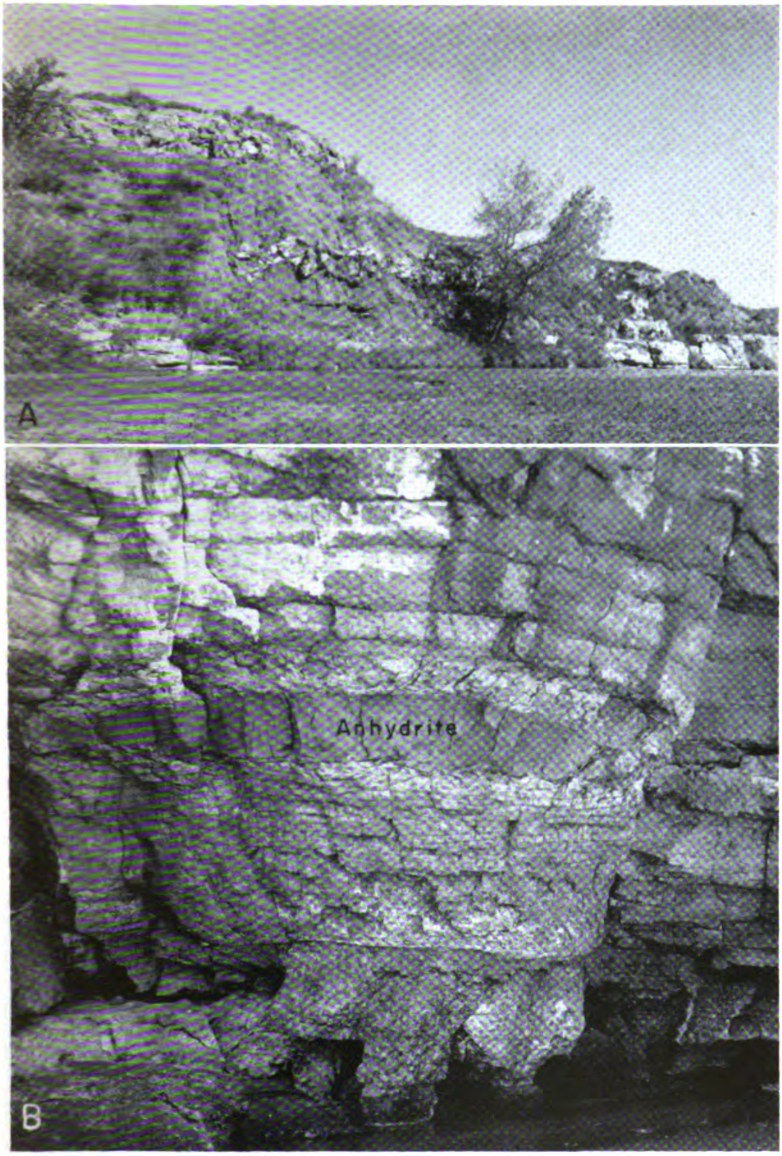

Plate 11. Blaine formation. **A**, Upper Medicine Lodge (at stream level), Nescatunga, and lower Shimer gypsum members; sec. 32, T. 34 S., R. 16 W., Comanche County. **B**, Medicine Lodge gypsum member at Natural Bridge, Barber County. Note anhydrite lentil.

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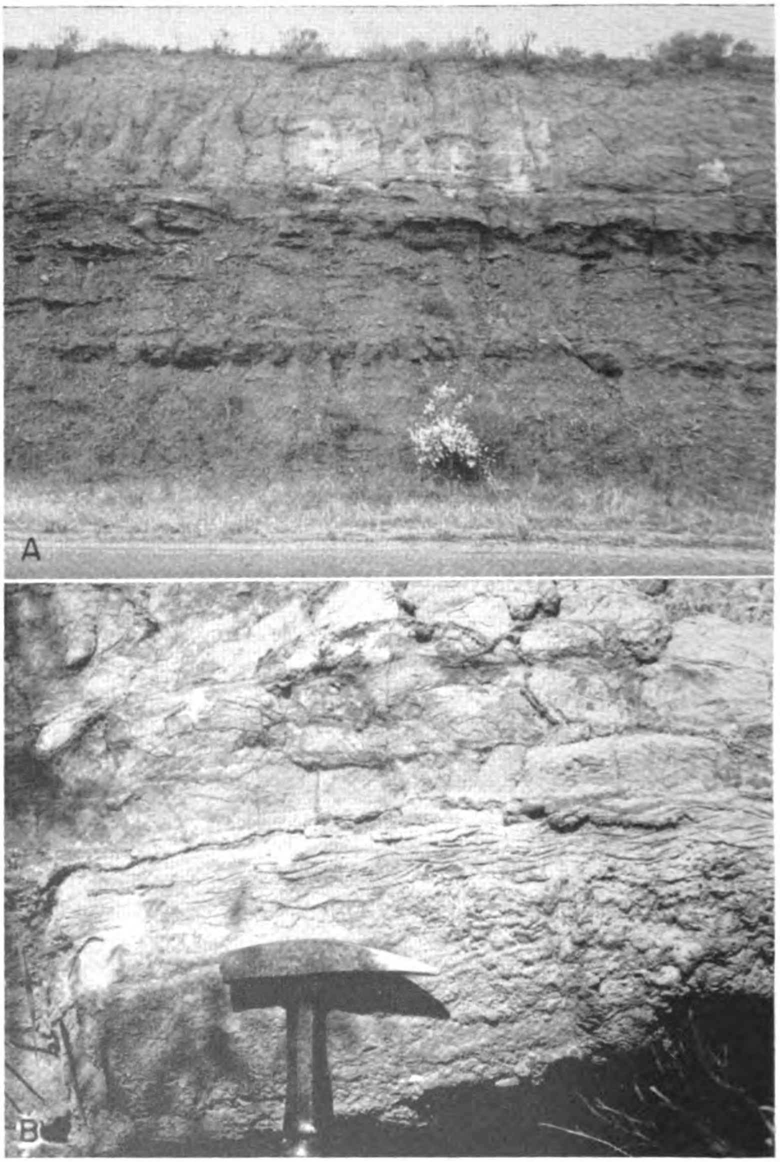

PLATE 12. **A**, Upper Dog Creek shale and basal Whitehorse sandstone at type locality of Dog Creek shale, Barber County. **B**, Cross-bedded gypsiferous oölitic dolomite at base of Shimer gypsum; sec. 32, T. 34 S., R. 16 W., Comanche County.

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Dog Creek Shale

The Dog Creek shale is commonly grouped with the Blaine formation, for it includes all the deposits between the uppermost gypsum of the Blaine and the base of the Whitehorse sandstone. Where the three upper gypsums are missing, the Dog Creek includes the shales overlying the Medicine Lodge member. Thus the thickness is variable and is reported to range from 14 to 53 feet. The formation consists of thin beds of dark-red silty shale, brownish-red and greenish-gray siltstone, and very fine-grained sandstone, dolomite, dolomitic and gypsiferous sandstone, and gypsum. It was named by Cragin (1896, p. 40) from exposures on Dog Creek south of Lake City, Barber County (probably S. line sec. 4, T. 32 S., R. 14 W.) (Pl. 12A).

Although the Dog Creek has been classified tentatively as the topmost formation of the Leonardian Series, there is no indisputable evidence in Kansas of an unconformity separating it from the overlying Whitehorse sandstone.

The Dog Creek shale at the type locality overlies the Medicine Lodge gypsum member of the Blaine formation and is approximately 75 percent shale or silty shale. The section is given below.

Dog Creek shale near type locality in the S½ sec. 4, T. 32 S., R. 14 W., Barber County

	Thickness, feet
PERMIAN—Guadalupian?	
Whitehorse sandstone	
30. Sandstone, very fine-grained, friable, cross-bedded, red with large irregular white spots; contains a few thin (5 cm) calcareous sandstone lentils	15+
29. Sandstone, hard, calcareous, red; contains sand balls as much as 2.5 mm diameter	3.5
28. Siltstone, dolomitic and calcareous, white to red; lenticular	0.2±
27. Clay shale, silty, dolomitic, blocky, brownish-red	1.8
26. Siltstone, dolomitic, white (5Y8/1) with discontinuous red streaks; microscope shows large chlorite flakes	0.3
25. Clay shale, silty, brownish-red	1.3
24. Siltstone, argillaceous, calcareous, thin-bedded, red mottled light-gray; an 11-mm layer near base contains salt casts up to 9 mm in diameter on lower side	1.0
23. Clay shale, silty, blocky, dark-red	1.4
22. Siltstone, hard, calcareous, light-red with white and brownish-red spots (<2 mm diameter)	3.5

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21. Siltstone, slabby, white; contains thin greenish-gray silty shale seams	1.0
20. Clay shale, massive, reddish-brown	4.1
19. Siltstone, greenish-gray mottled light-brown	0.4
18. Clay shale, blocky, reddish-brown (2.5YR5/4)	6.5
17. Limestone, vesicular, hard, sugary, white to red; contains many specks of black to dark-brown organic matter	0.2
16. Clay shale, blocky, brownish-red	2.4
15. Siltstone, massive, white mottled light-brown	2.2
14. Partly covered; chiefly brownish-red blocky silty clay shale with a few thin gray streaks	7.8
13. Siltstone, slightly argillaceous, slabby, white	0.2
12. Clay shale, blocky, brownish-red	0.8
11. Siltstone, dolomitic, hard, uneven, light-gray	0.1
10. Clay shale, silty, blocky, brownish-red	1.9
9. Siltstone, calcareous, white with minute spots (<1 mm) stained brown to black by organic matter	0.2
8. Clay shale, blocky, dark-red	0.6
7. Siltstone, very calcareous, white (10YR8/1) with minute spots (<1 mm); stained dark-brown by organic matter	0.8
6. Clay shale, blocky, brownish-red slightly mottled light-red	0.9
5. Clay shale, greenish-gray; surfaces uneven	0.3
4. Clay shale, blocky, dark-red	2.4
3. Clay shale, greenish-gray mottled	0.2
2. Clay shale, silty, blocky, dark-red	0.8
1. Covered	5.3
Blaine formation—Medicine Lodge gypsum member	
Total	67.1

Forty-one feet of Dog Creek shale is exposed above the Medicine Lodge gypsum in the NW¼ sec. 13, T. 30 S., R. 16 W., southeastern Kiowa County, where a section has been measured by Latta (1948, p. 120). This exposure is less than 15 miles from the type area, but individual beds in the two sections seemingly cannot be correlated. The argillaceous calcareous silty sandstone of Latta's bed 8 is a coarser grained clastic than any in the Dog Creek of the type locality, but on the other hand siltstone beds are more common in the shales of the type area.

The lower few feet of the Dog Creek is exposed in an abandoned gypsum quarry in sec. 19, T. 30 S., R. 15 W., northwestern Barber County, about 9 miles from the type area.

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Lower Dog Creek shale in abandoned gypsum quarry in sec. 19, T. 30 S., R. 15 W., Barber County

	Thickness, feet
PERMIAN—Leonardian	
Dog Creek shale	
6. Sandstone, fine-grained, friable, calcareous, red (2.5YR5/6) with small white spots; bleached white at top	3.5
5. Sandstone, silty, very fine-grained, friable, red with small white spots	1.2
4. Clay shale, silty, brownish-red	4.0
3. Dolomite, calcareous, argillaceous, highly vesicular, sugary, light greenish-gray (5G8/1) with brownish-red stain; in thin beds	1.8
2. Clay shale, silty, brownish-red; contains thin resistant dolomitic siltstones, bleached zones, and thin (<3 inches) porous dolomite beds	8.0
1. Covered	5.2
Blaine formation—Medicine Lodge gypsum member	(4+)
Total Dog Creek	23.7

Near the Oklahoma line larger quantities of sandstone occur in the upper part of the Dog Creek shale, and red- and white-banded gypsum locally marks the top of the formation. This gypsum and the underlying sandstones are exposed in a road ditch along the S. line sec. 28, T. 34 S., R. 17 W., Comanche County. The gypsum is 1.8 feet thick and is coarsely crystalline. It consists of alternating red and white bands of uniform thickness (about 0.8 to 1.3 cm) with the white bands perhaps slightly thicker than the red (Pl. 7B). The crystals of red gypsum are somewhat coarser than those of the white gypsum, and the red layers are multiple. Underlying the gypsum is at least a foot of light reddish-brown (5YR6/4) very fine-grained, luster-mottled gypsiferous sandstone with large (0.3 mm diameter) crystals of gypsum. Below the red sandstone is about 1 foot of light greenish-gray (5GY8/1) poorly sorted gypsiferous sandstone containing pink gypsum crystals as large as 22 mm in long diameter (Pl. 7C). The sandstone is predominantly fine-grained, but it also contains greenish-gray clay galls and scattered large well-rounded quartz grains 1 mm in diameter or smaller. Some of the large grains are somewhat concentrated in streaks and pockets of 3 or 4 square cm in area. This may be the "conglomeratic sandstone" of Norton (1939, p. 1800).

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Guadalupian? Series

FORMATIONS NOT ASSIGNED TO A GROUP

Whitehorse Sandstone

The Whitehorse sandstone consists of about 270 feet of red friable sandstone, siltstone, and shale, and minor quantities of white to buff sandstone and dolomite. Calcareous "sand balls" are common. Exposures are in Barber, Kiowa, Comanche, and Clark Counties. The formation overlies the Dog Creek shale with seeming conformity in Kansas, and underlies the Day Creek dolomite.

The Whitehorse was named by Gould (1905, p. 55) from exposures in the vicinity of Whitehorse Springs, Woods County, Oklahoma. This name replaced the preoccupied term "Red Bluff sandstone" of Cragin (1896).

In Kansas the formation is subdivided into four members (Norton, 1939, p. 1803), which are, from bottom to top, the Marlow sandstone member, the Relay Creek (?) dolomite and sandstone member, an unnamed even-bedded member, and an unnamed upper shale member.

The Marlow sandstone member was named by Sawyer (1924) for exposures at Marlow, Stephens County, Oklahoma. It has since been redefined to include beds between the Dog Creek shale and Relay Creek (?) member. In Kansas the Marlow is about 110 feet thick and consists predominantly of red, friable, massive, very fine-grained sandstone which is cross-bedded locally and contains numerous sand balls and large irregular areas of white to buff sandstone.

The Relay Creek (?) dolomite and sandstone member is supposedly a correlative of the Relay Creek dolomite of northwestern Oklahoma, named by Evans (1931) from exposures north and south of Relay Creek in T. 15 N., R. 12 W., Blaine County. The member in Kansas consists of two beds of dolomite, each less than 1 foot thick, separated by about 21 feet of white and red fine-grained sandstone. At many localities only one of the dolomite beds is present, and in the northern exposures, neither can be identified.

Norton's even-bedded member consists of about 100 feet of well-bedded, red, fine-grained sandstones and siltstones with occasional reddish-brown (maroon) shales. Sand balls are present,

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and some of the sandstones are cross-bedded. The upper shale member, which comprises the topmost 38 feet of the Whitehorse sandstone, consists of reddish-brown (maroon) clay shale with a few beds of silty shale, siltstone, and very fine-grained sandstone. Thin drusy dolomite beds occur in the basal part, and the top consists of greenish-gray argillaceous sandstone. The member is overlain by the Day Creek dolomite.

The soft, unconsolidated Marlow sandstone member is not generally well exposed. The basal 12 feet crops out at the type locality of the Dog Creek shale in sec. 9, T. 32 S., R. 14 W., Barber County (Pl. 12B). At this locality the basal Marlow consists of light-red (2.5YR6/6), friable, cross-bedded, noncalcareous, fairly well-sorted, fine-grained, slightly argillaceous sandstone. The particle size distribution in much of the sandstone is seemingly bimodal; well-rounded highly spherical quartz grains having an average diameter of about 0.5 mm (observed maximum 0.8 mm) are sparsely scattered throughout very fine-grained, otherwise well-sorted sand. Irregularly distributed through the light-red sandstone are large areas or splotches of white (10YR8/2) sandstone with longest diameter as much as 1.5 to 2 feet and greatest elongation in the vertical direction. There are also some lentils, about 2 inches thick and as much as 18 inches long, of pink (5YR7/4) very calcareous (more than 50 percent acid-soluble) well-sorted fine-grained sandstone or sandy limestone. Some calcareous lenses consist of masses of small sand balls, described in detail by Norton (1939, p. 1808).

Almost entirely unconsolidated lower Marlow sandstone is exposed in a road cut in the S. line sec. 26, T. 34 S., R. 17 W., Comanche County. Thick massive rather poorly sorted red (2.5YR5/7) fine-grained sandstone alternates with thin, soft, silty micaceous red sandstone in a section about 18 feet thick. The sand grains are nearly free from clay, are rather well rounded for their small size, and have an orange, polished appearance. The sandstone is obscurely cross-bedded.

In Kansas the Relay Creek (?) dolomite and sandstone member is well developed only near the Oklahoma line, although sections exposing both the upper and lower dolomites are rare. In the NW¼ sec. 18, T. 33 S., R. 16 W., and in the SE¼ sec. 12, T. 33 S., R. 17 W., Comanche County, the upper dolomite and underlying sandstones are exposed in a shallow draw (Pl. 13A).

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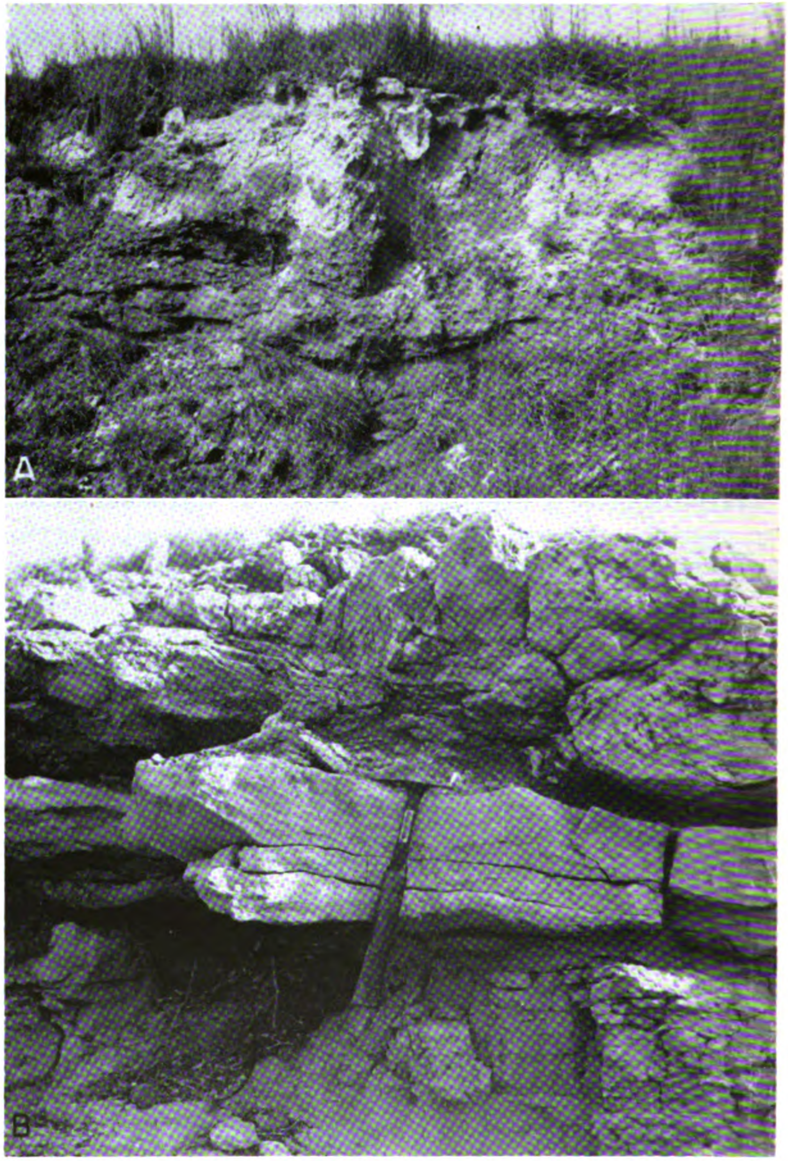

Plate 13. A, Thin dolomite and white sandstone at top of Relay Creek? member, Whitehorse formation; sec. 12, T. 33 S., R. 17 W., Comanche County. **B,** Day Creek dolomite and underlying cross-bedded sand; SW¼ sec. 3, T. 33 S., R. 24 W., Clark County.

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Relay Creek(?) dolomite and sandstone member, Whitehorse sandstone, exposed in the NW¼ sec. 18, T. 33 S., R. 16 W., and the SE¼ sec. 12, T. 33 S., R. 17 W., Comanche County

	Thickness, feet
PERMIAN—Guadalupian?	
Whitehorse sandstone—Relay Creek(?) member	
7. Limestone, dolomitic, dense, gray (N6/0) to white to moderate orange-pink (5YR8/4); contains numerous areas of more coarsely crystalline calcite. Pink specimens contain brownish-red clay galls. Locally ripple-marked at top	0.2-0.3
6. Sandstone, fine-grained, well-sorted, cross-bedded, very calcareous, white. Light-red (2.5YR6/6) 50 feet to south. Scattered flat calcite-sand concretions (1-2 cm diameter) at top	0.5
5. Sandstone, fine-grained, well-sorted, cross-bedded, nearly unconsolidated, white (some red); grades downward into red sandstone	3.4
4. Siltstone, calcareous, white to buff; one thin (<1 cm) bed contains salt casts up to 3 mm diameter	0.2
3. Siltstone, argillaceous, dolomitic, light-gray mottled red	2.7
2. Sandstone, fine-grained, fairly well-sorted, calcareous, red (2.5YR5/6)	3.1
1. Siltstone, slightly argillaceous, thick-bedded, noncalcareous, red (2.5YR5/6)	5+
Total	15.1

To my knowledge the dolomite is not present north of T. 33 S. White sandstones in the mid-Whitehorse farther north have been attributed to the Relay Creek (?) horizon, but their positive correlation is not clear. One such sandstone is along a road cut in the S. line SE¼ sec. 4, T. 33 S., R. 19 W., Comanche County, where the section is as follows.

Whitehorse sandstone exposed in a road cut on the S. line SE¼ sec. 4, T. 33 S., R. 19 W., Comanche County

	Thickness, feet
PERMIAN—Guadalupian?	
Whitehorse sandstone	
6. Siltstone, slightly slabby, pale-yellow; contains many resistant calcareous veins trending in various directions	4+
5. Siltstone, massive, bulging, pale-yellow (5Y8/3)	5.0
4. Siltstone, coarse, noncalcareous, red (2.5YR5/6)	3.1
3. Siltstone, pale-yellow; irregular base and top	0.6±0.3
2. Siltstone, sandy, red; contains thin layers of small hard calcareous siltstone concretions. Color gradational at base	1.8

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1. Sandstone, fine-grained, friable, pale-yellow (5Y8/4); contains scattered large rounded grains in some areas; coarser at bottom; contains innumerable pockets and streaks of sand balls (not in horizontal beds) (Pl. 7D)	6+
Total	20.5

The sand balls in the above section are best developed at the surface of the sandstone. They are somewhat friable, and some of them are hollow. The calcite cement is fine grained rather than a large, optically continuous crystal. The origin of these sand balls is obviously quite different from that of the sand balls studied by Norton (1939), and they are not a depositional feature.

Another possible correlative of the Relay Creek (?) member consists of 1.4 feet of white medium-grained sandstone (with sand balls) below red argillaceous siltstone in the SE¼ sec. 7, T. 32 S., R. 21 W., Clark County.

Cragin's (1896, p. 43) type locality for the Red Bluff sandstones (Whitehorse) is on Bluff Creek west of Protection. Exposures in this area are in the lower part of Norton's even-bedded member of the Whitehorse formation. In the SW¼ SE¼ sec. 33, T. 32 S., R. 20 W., Comanche County, within a few feet of the stream, 25 feet of this member is exposed. The section is very similar to that illustrated by Hay (1890, p. 39).

Whitehorse sandstone exposed along Bluff Creek in the SW¼ SE¼ sec. 33, T. 32 S., R. 20 W., Comanche County

	Thickness, feet
PERMIAN—Guadalupian?	
Whitehorse sandstone—Even-bedded member	
13. Soil	
12. Siltstone, argillaceous, red	1.9
11. Sandstone, very fine-grained, silty, somewhat resistant, red	0.7
10. Siltstone, argillaceous, red	2.4
9. Sandstone, very fine-grained, silty, somewhat resistant, red with poorly defined darker red streaks	0.6
8. Siltstone, slightly argillaceous, seemingly massive, somewhat calcareous, red (2.5YR5/7)	2.4
7. Sandstone, very fine-grained, massive, red (2.5YR5/8); bulging appearance at crop; softer and coarser at top	2.0
6. Siltstone, argillaceous, red; indistinctly thin-bedded	4.0
5. Sandstone, very fine-grained, massive, resistant, red	1.9
4. Siltstone, red	2.3
3. Sandstone, very fine-grained, red; moderately soft with angularly fluted weathered surface	4.6

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2. Siltstone, sandy, greenish-gray; top and base irregular	0.1
1. Shale, silty, dark-red	2.5
Total	25.4

Series of alternating very fine-grained sandstones and siltstones, nearly all of which are red, are rather common in certain parts of the redbed section. They may perhaps be formed by migration of channels across a flood plain, as illustrated by Krynine (1949, p. 63).

The topmost 49 feet of the even-bedded member is exposed along Kiger Creek just north of U. S. Highway 160, in the SE¼ SW¼ sec. 3, T. 33 S., R. 24 W., Clark County.

Even-bedded member, Whitehorse sandstone, exposed along Kiger Creek in the SE¼ SW¼ sec. 3, T. 33 S., R. 24 W., Clark County

	Thickness, feet
PERMIAN—Guadalupian?	
Whitehorse sandstone—Even-bedded member	
15. Siltstone and very fine-grained sandstone; massive resistant, red; in indistinct beds	4.0
14. Siltstone, argillaceous, red	4.6
13. Sandstone, very fine-grained, resistant, red	2.1
12. Clay shale, silty, red	0.6
11. Siltstone, resistant, red with small greenish-gray spots	2.8
10. Clay shale, silty, slightly dolomitic, red (2.5YR5/6) with two thin green streaks; contains a few rounded fine sand grains and small flakes of white mica	3.0
9. Siltstone, resistant, red	3.5
8. Clay shale, silty, red	3.0
7. Siltstone, sandy, massive, resistant, red	4.4
6. Clay shale, silty, red; 0.2-foot "bleached" zone in middle	2.0
5. Sandstone, fine-grained, massive, resistant, red; some siltstone in lower part	7.8
4. Clay shale, silty, red with 0.1 foot greenish-gray streak near center	1.9
3. Sandstone, very fine-grained, silty, massive, friable, red (2.5YR5/7); contains uniformly scattered minute (0.1 to 0.3 mm) specks of a white flaky mineral, grown around some sand grains	6.4
2. Clay shale, silty, greenish-gray	0.2
1. Clay shale, silty, red (2.5YR4/6); contains a few greenish-gray (5GY7/1) irregular siltier areas	3+
Total	49.3

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In the NW¼ sec. 29, T. 32 S., R. 21 W., Clark County, are exposures of a shalier part of the even-bedded member. The section in that locality is in the upper half of the member.

Even-bedded member, Whitehorse sandstone, exposed in the NW¼ sec. 29, T. 32 S., R. 21 W., Clark County

	Thickness, feet
8. Soil	
PERMIAN—Guadalupian?	
Whitehorse sandstone—Even-bedded member	
7. Sandstone, very fine-grained, red (bleached white with red remnants in middle); massive, becoming thin-bedded at top; contains 5-mm sand balls	3.9
grades into	
6. Clay shale, slightly flaky, dark-red	3.0
5. Clay shale, silty, red (with irregular light greenish-gray areas); upper part sandy and contains sand balls	0.3
4. Clay shale and silty clay shale, red (2.5YR4/6); irregular fracture and curved slickensided surfaces, some with black film	9.0
3. Sandstone, silty, massive, white (5Y8/1) with scattered irregular-shaped red areas in lower part	3.4
grades into	
2. Clay shale, silty, red with some greenish-gray spots	5.6
1. Clay shale, slightly silty, red (2.5YR4/6); irregular fracture and curved slickensided surfaces, some with black film; scattered minute (<0.5 mm) dolomite crystals; breadcrust outcrop-surface suggesting presence of montmorillonite	0.4+
Total	25.6

Another exposure in the upper part of the even-bedded member is in a road cut along the E. line SE¼ sec. 26, T. 33 S., R. 23 W., Clark County.

Even-bedded member, Whitehorse sandstone, exposed in road cut along E. line SE¼ sec. 26, T. 33 S., R. 23 W., Clark County

	Thickness, feet
9. Soil (colluvium)	
PERMIAN—Guadalupian?	
Whitehorse sandstone—Even-bedded member	
8. Sandstone, very fine-grained, red; contains nearly vertical thin veins of calcite with small sand balls up to 2 mm diameter; bulging outcrop surface	4+
7. Claystone, silty, very calcareous, reddish-yellow (5YR6/6); mud cracks at top, up to 3 mm deep and 12 mm diameter; curvature concave up	2.5

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6. Sandstone, fine-grained, massive, friable, bulging, red; contains diagonal white joints (former calcite veins?)	5.4
5. Sandstone, very fine-grained, glistening (calcareous), red	2.7
4. Siltstone, calcareous, red (lens)	0.05
3. Siltstone, argillaceous, red	2.0
2. Sandstone, very fine-grained, massive, bulging, red; contains diagonal calcite-sand ball veins	5.3
1. Siltstone, massive, red	3+
Total	25+

The sand balls in this locality are dense, and the calcite is coarsely crystalline. However, their occurrence in diagonal veins does not suggest primary deposition.

Another type of sand ball in the even-bedded member may be found in a 6-foot bed of red and white very fine-grained sandstone overlying red argillaceous siltstone in a small box canyon in the SW¼ sec. 4, T. 33 S., R. 24 W., Clark County, near U. S. Highway 160. The sand balls here are calcareous and football-shaped, and are uniformly smaller than 7 mm in diameter. They are dense enough to weather out from the softer sandstone. Many of them display smaller knobs on their surfaces. Some of them are intergrown with their long axes normal to each other. These are obviously not worn to that shape.

The upper shale member is described by Norton seemingly principally from the exposures in some prominent buttes about 10 miles north of Freedom, Oklahoma, about 6 miles south of the Kansas line. Norton (1939, p. 1806) describes this section as including, from base to top, a two- or three-member dolomitic horizon (the dolomites each about one-half foot thick) in maroon clay shale containing interlocking calcite crystals; brick-red sandy clays; a calcareous sandy lentil; a thin hard red sandstone; more soft red sandstones; a thin maroon shale; and 4 to 7 feet of gray-green sandy shale.

The basal dolomites were not recognized by me in the Kansas exposures of this member; the base of the unit in Kansas is not clearly defined. All thick clay shale beds within 40 feet of the base of the Day Creek dolomite and not associated with sand-ball-bearing sandstones are assumed to be within the upper shale member.

The basal dolomitic horizon in the exposures 10 miles north of Freedom has a total thickness of about 6 feet. The dolomite

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(and the more abundant calcite, as shown by x-ray diffraction) are coarsely saccharoidal in texture and contain numerous clay galls of greenish-gray (5GY6/1) montmorillonitic clay up to 1 cm in diameter. Removal of the clay by weathering gives the dolomite-calcite a cellular character. The soft red sandstone 6 to 20 feet above the dolomite is very fine-grained and highly calcareous, but the associated white sandstones are essentially noncalcareous and more argillaceous. Norton's thin maroon shale must be classed here as a red (2.5YR5/6) slightly calcareous very argillaceous siltstone; the clay fraction seemingly is montmorillonitic. The topmost bed, the gray-green sandy shale, is similar to that in some Kansas exposures. The upper part (1 foot) is a pale yellow (2.5Y8/4) argillaceous, silty, very fine-grained sandstone with scattered specks of a white flaky mineral.

The top bed of the upper shale member (3 feet) at the Kiger Creek locality (SE¼ SW¼ sec. 3, T. 33 S., R. 24 W., Clark County) is almost entirely a white (2.5Y8/2) friable dolomitic very fine-grained sandstone, grading downward into red very fine-grained sandstone. It is marked by scattered sand-size (60 to 100 microns) flakes of a chlorite mineral.

More than 60 feet of the Whitehorse formation, including all the upper shale member and part of the even-bedded member, is exposed along a stream in the NE¼ sec. 27, T. 31 S., R. 22 W., Clark County.

Upper part of Whitehorse sandstone exposed along a stream in the NE¼ sec. 27, T. 31 S., R. 22 W., Clark County

	Thickness, feet
PERMIAN—Guadalupian?	
Day Creek dolomite	2+
Whitehorse sandstone	
15. Sandstone, argillaceous, very fine-grained, white; red in lower part	3.0
14. Clay shale, silty, red	1.9
13. Siltstone, sandy, red	1.1
12. Clay shale, silty, red	1.5
11. Siltstone, resistant, massive, red	2.2
10. Clay shale, silty, red	4.7
9. Siltstone, shaly, fairly resistant, red	9.0
8. Clay shale, highly calcareous, hard, reddish-brown (5YR5/4); silty in upper part	11.5
7. Siltstone, argillaceous, greenish-gray; some irregular red areas (base of upper shale member?)	1.2

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6. Clay shale, silty, and argillaceous siltstone; red; partly covered	10.8
5. Siltstone, resistant, massive, red	0.9
4. Shale, silty, red with greenish-gray irregular spots	3.7
3. Shale, silty, soft, red; contains a few thin (0.3 foot) red siltstone beds	5.0
2. Siltstone, argillaceous, red	3.2
1. Sandstone, very fine-grained, red; bulging outcrop surface	1+
Total	62.7

The base of the upper shale member is arbitrarily placed at the top of the 10.8-foot red silty clay shale.

The topmost beds of the upper shale member are exposed in the Cen. sec. 14, T. 32 S., R. 23 W., Clark County, where the greenish-gray clay shale is well developed. At this locality 1 foot of greenish-gray shale underlies and grades into the fine-grained yellowish-gray sandstone beneath the Day Creek dolomite.

Day Creek Dolomite

Exposures of the Day Creek dolomite in Kansas are restricted to Clark County north of Cimarron River. In Oklahoma, however, a dolomite formation correlated with the Day Creek of Kansas crops out for about 60 miles in a southeast-trending belt in Harper and Woodward Counties (Norton, 1939, pp. 1760-1761). The formation was named by Cragin (1896, p. 44) from exposures at the head of Day Creek in Clark County, Kansas, a few miles east of Ashland.

The Day Creek in Kansas consists of a single bed of pale-gray to pink dense fine-grained dolomite ranging in thickness from 2 to 3 feet. At some localities the formation contains chert nodules and disseminated chert. The origin of the chert is reported to be post-Permian and is related to the Cenozoic deposits (Norton, 1939, p. 1811). Weathered surfaces of the dolomite are characterized by intricately wavy ridges (Pl. 14A), and this character has led to its tentative correlation with the "crinkly limestones" of northeastern Colorado, the Forelle limestone of Wyoming, and the Minnekahta limestone of the Black Hills (Norton, 1939, p. 1812).

The dolomite in the type area (sec. 33, T. 32 S., R. 22 W.) is approximately 2 feet thick. Outcrops are poor and the rock is found chiefly as rubble on slopes. The wavy structure is well

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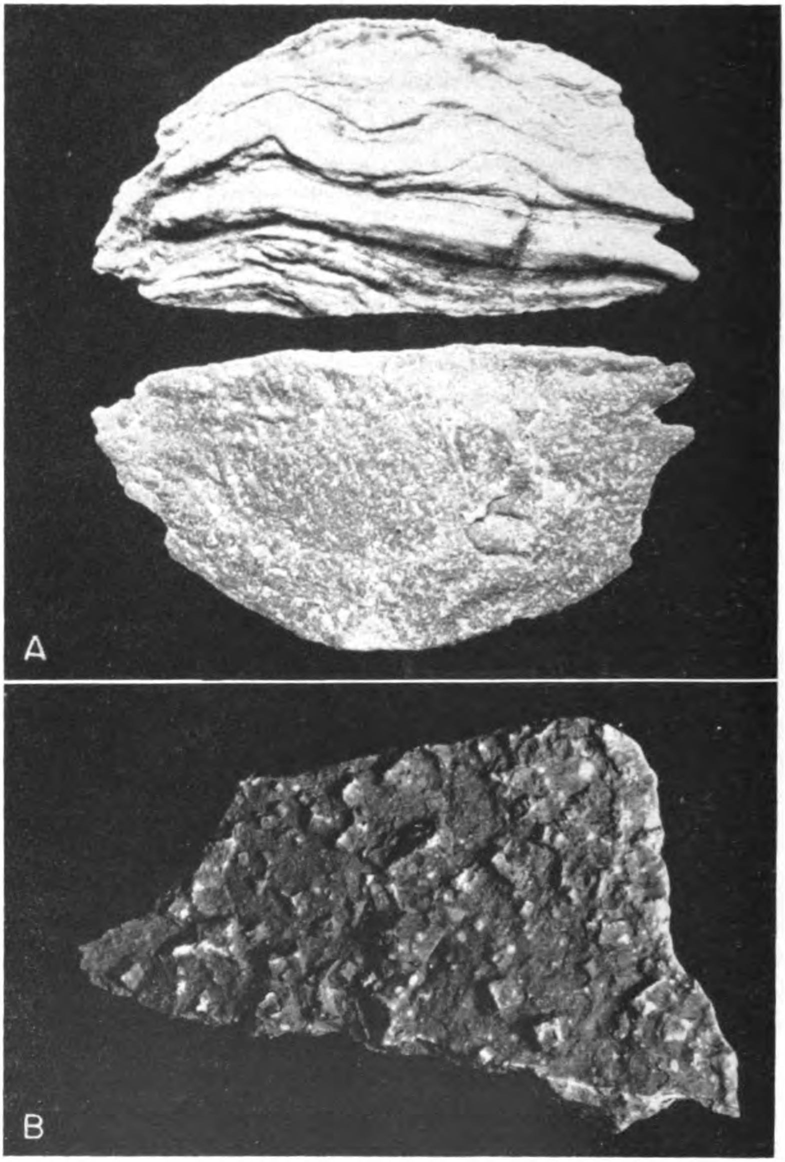

PLATE 14. **A,** Weathered and fresh surfaces of chip of Day Creek dolomite; sec. 33, T. 32 S., R. 22 W., Clark County. ×0.8. **B,** Casts of halite crystals in argillaceous siltstone from type Dog Creek shale. ×0.9.

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developed on the float blocks, and small chert nodules (generally less than 2 mm diameter) and stringers are common; they are particularly obvious in parts of the dolomite which are weathered. Calcite-lined vugs and nodules of red very calcareous siltstone are also present. This rock is of complex origin and deserves detailed study. Up to 30 percent of the dolomite in the type area is acid-insoluble and consists in part of globular drusy chert. Future petrographic study may indicate whether or not any of this chert is primary in origin.

Better exposures of the Day Creek dolomite may be seen at the Kiger Creek locality in the SW¼ SW¼ sec. 3, T. 33 S., R. 24 W., Clark County (Pl. 13B). The dolomite here is 2.2 feet thick. The upper 1.1 foot is cherty and extremely vuggy; the middle 0.6 foot is light-gray and dense, but in places slightly geodal. The lower 0.5 foot is similar to the middle, but also has yellow and purple streaks. This part is gradational downward into hard, well-cemented, dolomitic, well-sorted very fine-grained sandstone.

The Day Creek dolomite is well exposed along the section road on the E. line sec. 19, T. 31 S., R. 22 W., Clark County. The total thickness at this locality is 2.3 feet; the upper two-thirds is white, and the remainder is faintly pink and purple and sandy. The upper surface of some of the dolomite in this general area has a siliceous crust, even where it underlies the basal greenish-gray montmorillonitic shales of the lower Taloga formation. This suggests that perhaps the Cenozoic deposits were not the only source of the silica. If the lower Taloga shale is bentonitic, silica may have been leached from volcanic ash and deposited at the top of the Day Creek dolomite.

In the Cen. sec. 14, T. 32 S., R. 23 W., the Day Creek dolomite is approximately 2.1 feet thick. The color is predominantly white.

The Day Creek 10 miles north of Freedom, Oklahoma, is 3 feet thick, light-gray to white, rather coarsely crystalline to very fine-grained, and highly calcareous.

Taloga Formation

The Taloga formation includes all Kansas Permian deposits which are stratigraphically higher than the Day Creek dolomite. The outcrop area is restricted to western Clark County and southeastern Meade County, and according to Moore and others (1951)

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its maximum thickness is about 45 feet. The formation consists primarily of montmorillonitic shale, silty shale, siltstones, and some very fine-grained sandstones. The color is predominantly red, except for the lowermost few feet, which is greenish-gray clay shale. The units, except for the lower clay shales, are rather thin beds, generally thinner than 3 feet.

The lower Taloga is well exposed near the Cen.sec. 14, T. 32 S., R. 23 W., Clark County.

Lower part of Taloga formation, exposed near the Cen. sec. 14, T. 32 S., R. 23 W., Clark County

	Thickness, feet
PERMIAN—Guadalupian?	
Taloga formation	
4. Clay shale, somewhat silty, hard, dolomitic, thin-bedded, reddish-brown (2.5YR4/4); breaks into small irregular fragments; contains a few thin (<1 cm) white coarsely crystalline calcite layers which have red streaks	4+
3. Siltstone, resistant, red (mottled white); coarsely crystalline dolomitic and calcite cement; parts contain small (<5 mm diameter) brownish-red clay galls	3.1
2. Clay shale, silty, or argillaceous siltstone; red (2.5YR4/8); hackly fracture	14.8
1. Clay shale, montmorillonitic, grayish yellow-green (5GY7/2); looks bentonitic; breadcrust surface	3.1
Day Creek dolomite	
Total	25.0

The lower part of the Taloga formation is poorly exposed in the SE¼ SW¼ sec. 19, T. 31 S., R. 22 W., Clark County. The lowermost grayish yellow-green clay, here only 2 feet thick, has a peculiar granular appearance caused by an abundance of minute dolomite rhombs (less than 0.5 mm diameter). The overlying red silty clay shale is nearly 20 feet thick but includes a few thin mottled red and white silty argillaceous very fine-grained dolomites and a white dolomitic siltstone. One of these beds contains red clay galls similar to those in the preceding section. It also contains grayish-green clay galls having minute dolomite rhombs.

Beds higher within the Taloga, but at an unknown distance above the base, are exposed in a few stream valleys in south-

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eastern Meade County. In the SE¼ sec. 3, T. 24 S., R. 26 W., is a small exposure immediately above the bed of a tributary to Fivemile Creek.

Taloga formation exposed in stream bank in the SE¼ sec. 3, T. 24 S., R. 26 W., Meade County

	Thickness, feet
PERMIAN—Guadalupian?	
Taloga formation	
9. Siltstone, argillaceous, soft, red; mostly covered	6.2
8. Siltstone, sandy, argillaceous, soft (but ledge-forming), massive, red (2.5YR5/8); contains scattered large rounded sand grains; micaceous (unoriented flakes)	1.3
7. Siltstone, very soft, slightly slabby, argillaceous, red (2.5YR5/8)	0.7
6. Siltstone, very argillaceous, resistant, red (2.5YR5/8)	2.6
5. Clay shale, silty, red (2.5YR4/6)	1.8
4. Sandstone, silty, hard, light-red (2.5YR6/6) and some light-gray; calcite and dolomite cement; contains scattered large rounded sand grains	0.1
3. Clay shale, silty, red (2.5YR4/6); somewhat micaceous; montmorillonitic	2.0
2. Siltstone, sandy, micaceous, indistinctly thin-bedded, red (2.5YR5/8); contains white flaky mineral in clumps around silt grains	3.2
1. Sandstone, very fine-grained, silty, rather resistant, slabby, red (2.5YR5/8); contains mica as in overlying bed	1+
Total	18.9

Summary of Subsurface Stratigraphy

The following review of Leonardian and Guadalupian? subsurface stratigraphy in Kansas and adjacent areas is based on published descriptions and cross sections by Norton (1939), Maher (1946, 1947, 1948), Edson (1947, 1947a), Collins (1947), Lee (1949, 1953), and Maher and Collins (1952). The published information is based almost entirely on examination of rotary cuttings, because the redbeds are not cored. The deposits are characteristically irregular and lenticular, with facies changes common in relatively short distances, so that the placing of formation and group boundaries depends to a large degree upon the interpretation of the individual geologist.

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WELLINGTON FORMATION

The Wellington formation, which is said (Moore and others, 1951) to be about 700 feet thick at its outcrop, seemingly attains its greatest thickness (in Kansas) in southern Barber County, where Lee (1949) reports 980 feet of Wellington in his No. 2 well. The formation thins toward the northwest, and is only about 200 feet thick in western Wallace County near the Colorado line.

Norton (1939, p. 1758) and Lee (1949) describe the subsurface Wellington as including an upper gray shale member, a middle salt member, and a lower anhydrite member, with a few thin dolomite beds in the lower part. The thickest salt is penetrated in wells in Kingman, Barber, Ford, and Gray Counties; it is interstratified with gypsum or anhydrite. In some wells the salt member is 400 to 500 feet thick. The base of the salt grades downward into dolomite (Lee, 1953, p. 7). The thick evaporites wedge out toward the north and west, although thin salt beds are reported higher in the Wellington in the southwestern part of the State (Edson, 1947). Near the Colorado line evaporites are represented only by thin beds of dolomite and anhydrite, and most of the shale is maroon rather than gray. Fine-grained red sandstone is reported (Maher, 1947, 1948) in the Wellington of eastern Colorado and western Kansas.

Normal lower Wellington rocks grade into "granite wash" in the western part of the Oklahoma panhandle and the northwest corner of the Texas panhandle, acording to the cross section by Edson (1947a). Granite wash is described by Ward (1952) as a term used to designate deposits of granite conglomerate, arkose, and a conglomeration of decomposed and disintegrated acidic and basic igneous rock.

The top of the Wellington is difficult to identify in well cuttings, because the color change from gray to red is neither abrupt nor complete (Collins, 1947, p. 3). According to Maher (1948) an important unconformity at the top of the Wellington is indicated in Kansas and Nebraska, although this feature is difficult to identify in well cuttings and is not apparent in surface exposures. The Milan limestone does not seem to be prominent in subsurface samples. Wellington shale grades to red in Oklahoma.

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NINNESCAH SHALE

The Ninnescah is predominantly a silty shale throughout Kansas. Its thickness at the outcrops averages about 300 feet, but its maximum outcrop thickness is reported to be about 450 feet (Moore and others, 1951, p. 40). In the subsurface the formation thins northward; near the Nebraska line it is only 50 feet thick.

Near the area of outcrop the subsurface Ninnescah is predominantly red or maroon shale with a very few (two to four) discontinuous dolomite beds in the lower part (Lee, 1949). Toward the west and north the lithology becomes more diverse. Edson (1947) portrays salt beds in the upper part of the formation in Ford, Hodgeman, and Finney Counties, and several beds of dolomite and anhydrite throughout. Maher (1946) describes the Ninnescah of west-central Kansas as consisting chiefly of red and brown shale and thin beds of sandstone, dolomite, and fibrous gypsum. He also notes that the formation becomes sandier west of the Kansas-Colorado line. It also is sandier in the Oklahoma panhandle (Cimarron County) and there also includes thin salt beds (Edson, 1947a).

Maher (1947) depicts anhydrite, dolomite, salt, thick maroon shales, and thin sandstones in the Ninnescah of southwestern Kansas (Scott, Kearny, and Hamilton Counties). He does not discuss the significance of the facies changes from anhydrite in these counties to fibrous gypsum a few miles to the north.

Westward gradation to fine-grained red sandstone is well shown in Collins' (1947) cross section through Trego, Gove, Logan, and Wallace Counties in northwestern Kansas.

The top of the Ninnescah shale is marked by a few feet of fine-grained Runnymede sandstone which immediately underlies the Stone Corral dolomite-anhydrite. Norton (1939, p. 1774) reports that the Runnymede has been identified in well cuttings from central and northwest Kansas in Pratt, Stafford, Ellis, Rooks, Osborne, Russell, and Ellsworth Counties. Some more recent workers, however, do not stress its value as a horizon marker. Lee (1949) reports no sandstone at the top of the Ninnescah, even though the wells he studied (in Barber and Kingman Counties) are fairly near the outcrop area. Maher (1946) shows thin red shaly sandstone at the top of the Ninnescah in wells in Ness, Lane, and Scott Counties, but not in wells directly to the

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west (except in southeastern Colorado, where the Ninnescah in general is sandier). Sand is not consistently present at the top of the Ninnescah in the tier of counties from Wallace to Trego (Collins, 1947).

STONE CORRAL DOLOMITE

The base of the Stone Corral dolomite is regarded generally to be conformable on the underlying Ninnescah shale (Maher, 1946, 1947; Collins, 1947; Lee, 1949).

The Stone Corral, although a porous dolomite at the outcrop, is primarily anhydrite in the subsurface, where it commonly is known as the Cimarron anhydrite in Kansas. This formation, which disappears south of Reno County at the outcrop, is not reported in the near-by subsurface in Kingman, Harper, and eastern Barber Counties (Lee, 1949). To the west, however, the Stone Corral is a good marker bed and consists chiefly of white to buff crystalline anhydrite with associated thin beds of maroon shale, grayish-yellow dolomite, pink finely crystalline limestone, and salt (Maher, 1946, 1947). It attains a maximum thickness of 100 feet in Scott County (Norton, 1939, p. 1781). It thins to the northwest, and is not readily identified in eastern Colorado.

A possible minor unconformity at the top of the Stone Corral is reported (Maher, 1946, 1947, 1948; Collins, 1947).

NIPPEWALLA GROUP

The Nippewalla group includes the Harper sandstone, Salt Plain formation, Cedar Hills sandstone, Flowerpot shale, and Blaine-Dog Creek formations. The Harper, Salt Plain, and Cedar Hills formations are so similar in well cuttings that they are not commonly differentiated. For this reason the following paragraph describes the general characteristics of the three formations as a unit.

The Harper formation in the subsurface of eastern Barber and Kingman Counties is described by Lee (1949, p. 2) as "entirely similar" to the Ninnescah shale. Farther west, however, the Harper, Salt Plain, and Cedar Hills are represented by thick red sandy shales and fine silty sand containing lenses of salt, anhydrite, and dolomite (Maher, 1946, 1947). Maher (1946, 1947)

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reports the presence of salt in the Salt Plain (?) in Kearny and Scott Counties. He also mentions orange polished round sand grains in the Cedar Hills sandstone, but does not consider them unique, because similar sandstones are present in other parts of the Permian System in eastern Colorado (Maher, 1947, p. 4).

The Harper, Salt Plain, and Cedar Hills formations, which have an average thickness of 665 feet at their outcrop (Moore and others, 1951, p. 39), are thickest in the subsurface in the southwestern part of Kansas (Hugoton embayment), where in western Stevens County they total 690 feet (Edson, 1947a). That this is in the direction of the center of a local depositional basin is suggested by the presence of much salt in the section in Dallam County, extreme northwest corner of Texas (Edson, 1947a). The section thins and becomes sandier toward the northwest in Colorado (Maher, 1947).

The Flowerpot shale, 170 to 190 feet thick at the outcrop in Barber County, is fairly easily identified in well cuttings except in the westernmost part of the State. It is described (Maher, 1946, 1947) as a soft gypsiferous maroon shale. Its greatest thickness in Kansas is seemingly in the area of the outcrop. There is no obvious unconformity at the top of the Flowerpot in Kansas.

BLAINE FORMATION AND DOG CREEK SHALE

The Blaine formation at its outcrop in south-central Kansas near the Oklahoma line consists of four or fewer named gypsum members (Medicine Lodge, Nescatunga, Shimer, and Haskew) separated by dolomite and red shale, and is overlain by the maroon silty shales, dolomites, and dolomitic siltstones of the Dog Creek formation. The total thickness of the two formations at their surface exposures is about 64 to 103 feet. In the subsurface these formations cannot everywhere be differentiated, but they thicken tremendously toward the west. The greatest thickness is in the area of northwestern Kearny County, where about 235 feet of red shale and anhydrite were penetrated by a drill hole. In general, the Blaine-Dog Creek of the subsurface consists chiefly of red shale in the upper part and pink to white crystalline anhydrite in the lower part. The anhydrite is interbedded locally with red or maroon shale, and in places the upper red shale is missing. Collins (1947, pp. 2-3) reports that the lower half of the Blaine in a well in Gove County consists of red oölicastic anhydritic dolo-

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mite. According to Maher (1946, 1947) there is some salt in the lower part of the Blaine in Hamilton, Kearny, and Scott Counties.

The evaporites thin markedly in Colorado, and in some places to the north and west they are also more dolomitic. Lee (1953) reports that the Blaine-Dog Creek is dominantly dolomite near the margin of the basin in Rush and Edwards Counties. Maher (1947, p. 3) writes that the Blaine probably is equivalent to part of the lower Lykins formation of the Purgatoire River Valley.

According to Maher (1946, p. 3) the presence of an unconformity at the top of the Dog Creek cannot be proved or disproved by his investigations.

WHITEHORSE SANDSTONE

At its surface exposures in Kansas the Whitehorse sandstone is about 270 feet thick and consists predominantly of very fine grained red sandstones and siltstones with a few beds of shale and occasional dolomites. In the subsurface it also includes thin stringers of dolomite and anhydrite (Maher, 1946). In Kansas it attains its maximum thickness in Kearny County, where it is more than 300 feet thick (Maher, 1947). It thickens even more in eastern Colorado, and then thins toward the west (Maher and Collins, 1952).

DAY CREEK DOLOMITE

The Day Creek dolomite, a uniform thin bed at its surface exposures, shows much variation in the subsurface. In some wells it is entirely anhydrite; in some it consists of two brown or pink dolomite beds separated by red shale or anhydrite; in some it is represented by thin-bedded anhydrite and red shale (Maher, 1947, p. 3). It attains its greatest thickness (120 feet) in northeastern Morton County (Maher and Collins, 1952, sheet 3), where it is predominantly anhydrite.

TALOGA FORMATION

The upper limit of the Taloga formation is at the erosional unconformity at the top of the Permian System, and its former thickness is not known. In the subsurface it consists of red sandy shale, fine red silty sandstone, and thin beds of anhydrite and dolomite (Maher, 1947). It is thickest in northeastern Morton County, where Maher (1947) reports a thickness of about 225

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feet. The area of its greatest original thickness of course is not known.

In general, nearly all the lower Permian (and Pennsylvanian) rocks grade into arkose toward the Front Range, and thin toward the Sierra Grande uplift. Part of the Kansas Permian (Wolfcampian) is an equivalent of the Fountain arkose (Maher, 1953) which is described by Krynine (1949) as a true tectonic arkose. However, in post-Wolfcampian time when the Front Range was low and the post-Fountain deposits became quartzose, feldspathic material was being contributed to the Kansas part of the Permian basin.

MINERALOGY

Major Constituents

QUARTZ

The quartz grains of sand and coarse silt size show a wide range in roundness from extremely angular (particularly in the finer sizes) to very well rounded. Most of the grains are subangular, except for the scattered large grains in the upper part of the section, which are almost invariably very well rounded. The degree of rounding, as will be shown in the section on petrography, seemingly is not entirely a function of differences in particle size.

The surfaces of some grains are polished and have an orange color. Some grains are slightly etched and are partly replaced by carbonates or clay minerals. Some of the large well-rounded grains have frosted surfaces. Much of the frosted appearance seems to be produced by small quartz overgrowths.

Nearly all the quartz grains throughout the section are of silt size or very fine-grained sand size (less than 125 microns in diameter). The larger rounded grains are approximately 0.2 to 1.0 mm in diameter and are most abundant in the upper part of the section (Whitehorse, Taloga formations), although they are found as low as the upper Salt Plain formation. Degree of sorting is variable. In general the quartz (and feldspar) grains themselves are rather well sorted but they are commonly associated with clay minerals. The sorting of quartz in those samples which contain the large rounded grains is seemingly bimodal.

Relatively straight extinction in most of the grains indicates that they are nearly strain-free, but from 5 to 35 percent show

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undulose extinction. Nearly all the large rounded quartz grains show strain shadows. Flamboyant extinction typical of some vein quartz is extremely rare.

Many types of inclusions are observed, indicating several modes of origin. Bubble planes form the most common type, but several varieties of idiomorphic and allotriomorphic crystalline inclusions also are observed. Apatite is particularly common, and the following minerals were also identified: rutile, biotite, hornblende, tourmaline, and chlorite. A very few grains contain carbonaceous inclusions. Large fluid inclusions are also somewhat rare. In summary, most grains have the internal characteristics of igneous (plutonic) quartz (Krynine, 1946).

Small quartz overgrowths are fairly common in some specimens, although in no case are they pronounced or well developed. A few grains exhibit worn overgrowths.

FELDSPARS

The feldspar grains are angular to rounded, and in general are only slightly better rounded than the quartz. There are almost no large very well-rounded feldspars corresponding to the large very well-rounded quartz grains in the upper part of the section; only two such grains were observed (Pl. 15A).

Most of the feldspar is orthoclase. Very few grains of sodic plagioclase and even fewer of microcline were observed; this may be in part a function of the very fine particle size of the grains, so that small grains might not include the twinning boundaries. Chemical and petrographic evidence, however, suggests that the paucity of plagioclase feldspar may be attributed to penecontemporaneous alteration and reorganization of the grains shortly after deposition.

Much of the feldspar is fresh, but many degrees of weathering are observed in any one sample; some are partly replaced by chlorite. Replacement by carbonates is not common. Large overgrowths are rare but in some thin sections incipient overgrowths may be observed on most of the orthoclase grains. "Worn" feldspar overgrowths (Pl. 15B) are rare in most parts of the section. It is possible that even those which seem to be worn are actually xenomorphic sedimentary overgrowths (Krynine, personal communication, April 4, 1954).

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DOLOMITE AND CALCITE

Carbonates are present in most of the specimens which were examined in thin section, and are abundant in many of them. Formations or beds consisting predominantly of carbonate rocks are thin but relatively persistent; dolomite is the most common mineral in these beds. Dolomite rhombs are common in many of the clays and shales (particularly the greenish-gray shales). Calcite is a common cementing material in many siltstones and sandstones, and also occurs as veins in some of the silty shales and sandstones. Calcite of chemical clastic origin is present in some sandstones.

GYPSUM AND ANHYDRITE

Gypsum occurs in beds ranging in thickness from a featheredge to 30 feet (in the Blaine gypsum), as the cementing material in certain sandstones, and as individual selenite crystals and satin spar veins in clay shale (particularly in the Flowerpot shale). Gypsum also occurs as vug fillings and as replacement of oölites or parts of oölites in certain dolomite beds. Anhydrite is common in the subsurface, particularly in the Blaine and Stone Corral formations. Thin discontinuous lenses of anhydrite also crop out in the middle part of the Medicine Lodge gypsum. The relationship between gypsum and anhydrite in the Medicine Lodge gypsum has been studied by McGregor (1948) and is reviewed in the present report in the section on petrography.

HALITE

Halite occurs interbedded with gray shale in the Wellington formation in central Kansas (in the subsurface), and it is also found in large quantities stratigraphically higher (Stone Corral, Blaine formations) farther west. Evidence of salt at various horizons throughout the Permian redbeds is found in the form of small casts of cubic crystals. Most are well under 1 cm in diameter (Pl. 14B).

LAYER LATTICE SILICATES

The clay minerals, coarser micas, and chlorite are all grouped together here although they seemingly have divergent origins.

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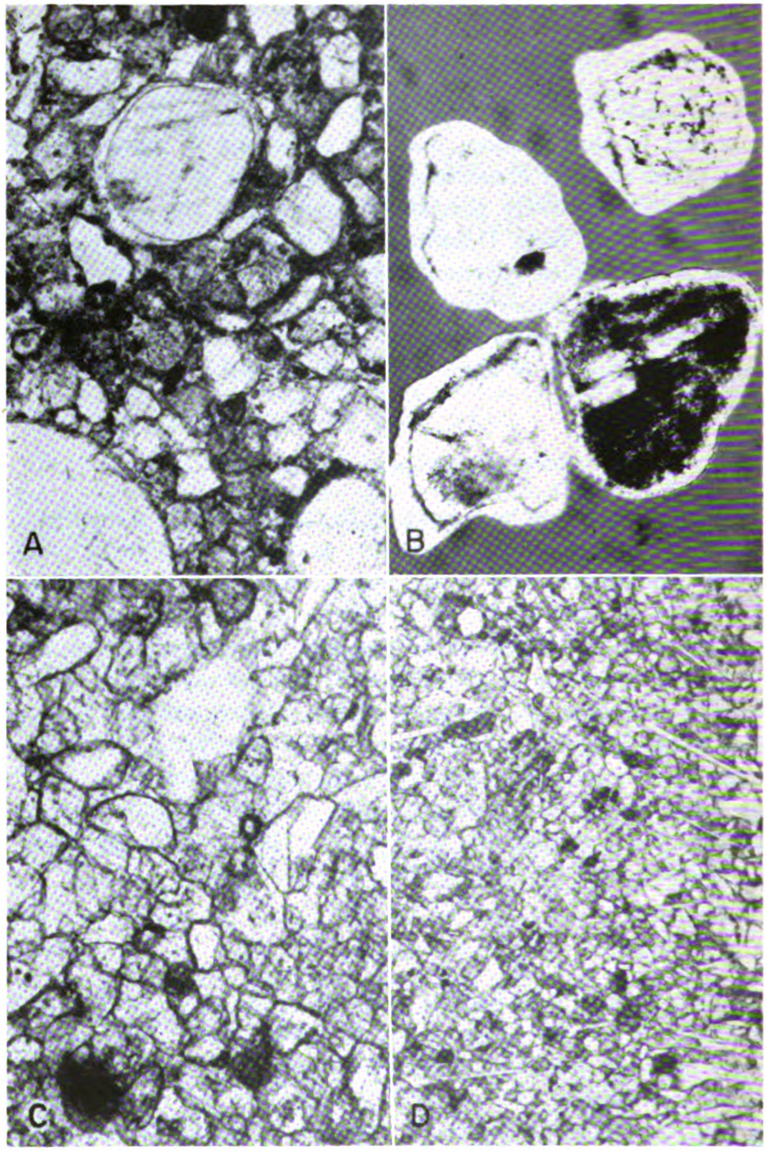

PLATE 15. Photomicrographs, Whitehorse sandstone. **A,** Overgrowth on large orthoclase grain, lower Marlow member; sec. 4, T. 32 S., R. 14 W., Barber County. ×76. **B,** Feldspar grains with worn overgrowths, mounted in glycerine and water; Relay Creek? member, NW¼ sec. 18, T. 33 S., R. 16 W., Comanche County. ×100. **C,** Friable sandy clastic limestone from Marlow member; SW¼ sec. 4, T. 32 S., R. 14 W., Barber County. ×76. **D,** Red micaceous feldspathic siltstone, upper shale member; 10 miles north of Freedom, Oklahoma. ×76.

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In general the coarser grained flakes are of detrital origin, but this is not invariably true.

Coarse detrital micas (i.e., of very fine sand size) are abundant in some siltstones and sandstones, particularly in the lower part of the section. These are predominantly muscovite, but biotite also occurs. Some of the biotite is partly altered to chlorite. Most of the coarse micas are well rounded. Chlorite flakes of coarse silt size are present in many samples; they may be only in part detrital. Chlorite is also an important constituent of nearly all the clays. Illite is the predominant clay mineral in nearly all samples from which diffraction patterns were obtained. Some beds in the upper part of the section contain montmorillonite, and some beds contain small quantities of kaolinite (Pls. 16, 17). Detailed descriptions of these clay minerals and a discussion of their relationship to the other constituents of the rocks is deferred to the section on petrography.

Small green grains of glauconite are observed rarely in certain white sandstones (e.g., Relay Creek member, Whitehorse sandstone), dolomites, and nonred siltstones. The origin of this mineral is not clear, but its associations may be significant genetically.

HEMATITE

Hematite occurs as a stain on sand and silt grains, and as the principal coloring matter in the red clay shales. Although large quantities of pure hematite do not occur, the mineral is responsible for the red coloration in all the redbeds under consideration. The only evidences of hematite other than stain are occasional small areas of bright-red opaque material around a few sand and silt grains observed in thin section, and problematical particles from the Kingman siltstone observed in the electron microscope. The less than 1-micron fraction of some samples from the Kingman contains extremely thin (as determined by chromium shadows) flaky particles with density so great that they are nearly opaque to the electron beam. The bright-red-stained sandstones and siltstones contain generally less than 3 percent Fe_2O_3, and the red shales contain less than 6 percent.

The mineral is identified as hematite rather than one of the hydrated iron oxides because diffraction patterns of less than 2-micron fractions of some of the brightest red shales and silt-

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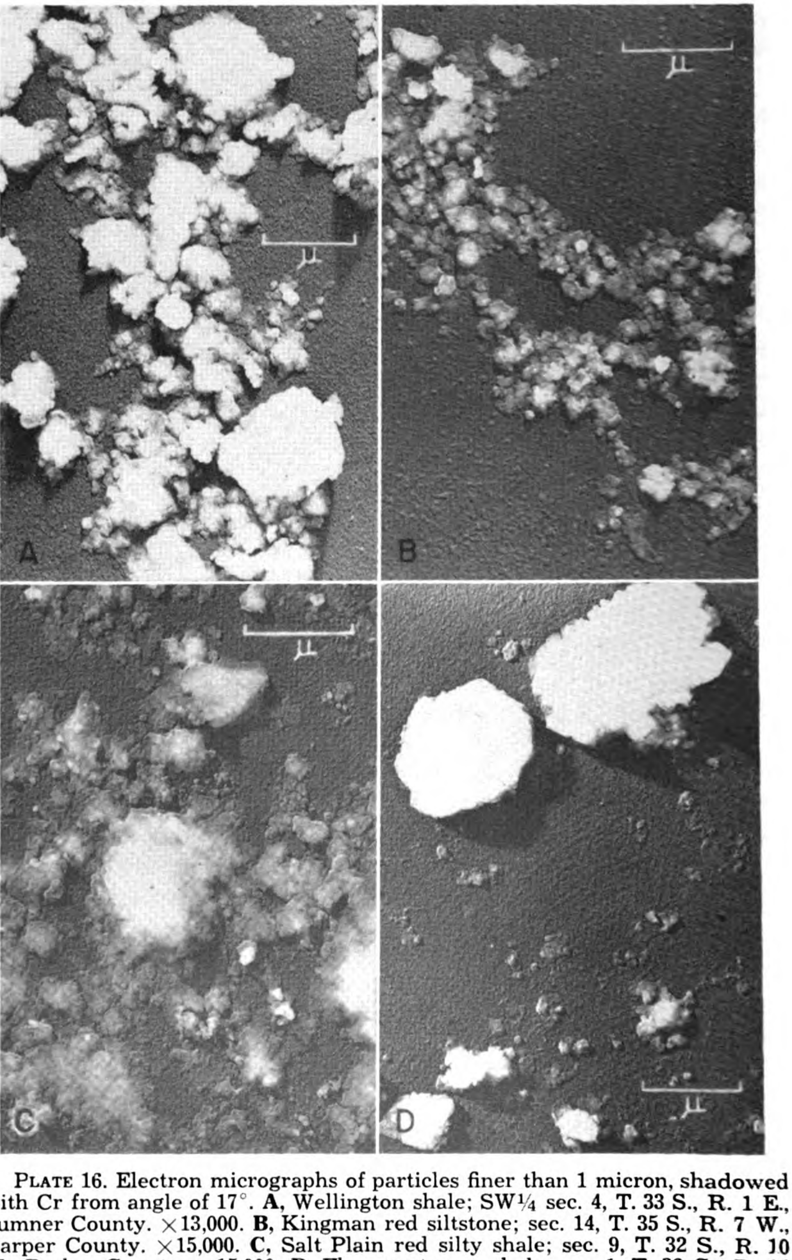

PLATE 16. Electron micrographs of particles finer than 1 micron, shadowed with Cr from angle of 17°. **A,** Wellington shale; SW¼ sec. 4, T. 33 S., R. 1 E., Sumner County. ×13,000. **B,** Kingman red siltstone; sec. 14, T. 35 S., R. 7 W., Harper County. ×15,000. **C,** Salt Plain red silty shale; sec. 9, T. 32 S., R. 10 W., Barber County. ×15,000. **D,** Flowerpot gray shale; sec. 1, T. 32 S., R. 14 W., Barber County. ×13,000. Note aggregates suggestive of kaolin mineral.

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stones show weak reflections at 3.67, 2.69, 2.51, 2.20, and 1.45 A, rather than reflections for goethite or lepidocrocite.

AGGREGATES AND ROCK FRAGMENTS

The scarcity of rock fragments is attributable in part to the fine grain of most of the sediments. A few small fragments of granite were observed in the coarser sandstones in the upper part of the section. Rare phyllite and fine-grained schist occur in sandstones in several formations. Chert is generally rare, but forms a rather large proportion of the large rounded grains in the upper formations. The most common aggregates are colorless, almost clear grains, some of the crystalline units of which show low birefringence similar to that of chert, and which are tentatively attributed to the alteration of sodic plagioclase feldspars under alkaline conditions.

Accessory Heavy Minerals

NONOPAQUE MINERALS

Apatite.—Small rounded grains of apatite are observed in some sandstone specimens. The acid treatment necessary to remove iron oxide destroyed most of the apatite.

Chlorite.—Relatively large flakes of chlorite (up to very fine sand size) occur in many of the argillaceous siltstones. Most of these flakes are judged to be detrital, and many are probably altered biotite. A few flakes show aggregate polarization. Much chlorite, particularly in the finer sizes, may not be detrital.

Epidote.—This mineral is observed rarely. It occurs as small pale-yellow subrounded grains with characteristic "compass-needle" interference figure.

Garnet.—Garnet is present in all the heavy mineral concentrates examined. Most of it is colorless, but some grains are pink and a few are pale yellow. The grains are characteristically pitted, although some are smooth, and others have roughly fractured surfaces. A few grains have deep embayments and are an irregular shape. Inclusions are rare.

Rutile.—Rutile is a rare mineral in the heavy mineral concentrates studied. Where observed, it consists of small subrounded to subangular elongate or equant grains having a brownish-red or amber-yellow color.

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Sillimanite.—A few elongate colorless grains of sillimanite are observed in some concentrates. They are extremely rare.

Staurolite.—Staurolite is one of the more common minerals and is present in nearly all the concentrates, particularly in the fractions coarser than 62 microns. It is invariably deeply etched and has delicate saw-toothed edges which seemingly could not have survived transportation. No broken sawteeth are observed. A few of the grains contain dark carbonaceous inclusions.

Titanite.—Small rounded dusky grains having high relief and high birefringence occur sparingly in a few samples. They are provisionally identified as titanite. Some of them are partly coated with white opaque material ("leucoxene"?).

Tourmaline.—Many varieties of tourmaline are present in the heavy mineral concentrates from the sandstones. Some grains are worn and a few are very well rounded, others are prismatic, and still others have irregular angular shapes. Most of the grains are brown, with few inclusions, and are rounded to subrounded. Also fairly common are well-worn brown prismatic grains, with few inclusions. Another common type is subrounded to rounded green tourmaline with few inclusions.

The following types are also present: black, rounded to subrounded; golden to reddish-brown, rounded to subrounded and worn prismatic; brown with acicular (rutile?) inclusions, rounded to subrounded; brown with many inclusions, subrounded to rounded and prismatic (some nearly idiomorphic); green with many inclusions, rounded to subrounded; blue, subrounded to rounded and subangular (indicolite); and varicolored, brown-green, and brown-pink.

Some of the grains are olive green, and the boundary line between brown and green tourmaline is indistinct. Most of the tourmaline is of granitic origin (Krynine, 1946a). Some obviously is reworked from older sediments. No overgrowths are observed. The mineral is most common in the coarser sandstones.

Zircon.—Zircon is common in the finer fractions. It occurs principally as subangular to well-rounded, colorless worn prismatic grains, but some grains are worn only slightly. A few grains are pale yellow and a few are zoned. Large black irregular inclusions and slender rodlike crystalline inclusions are present in some grains. Zoning is more common, or more obvious, in angular grains than in round ones.

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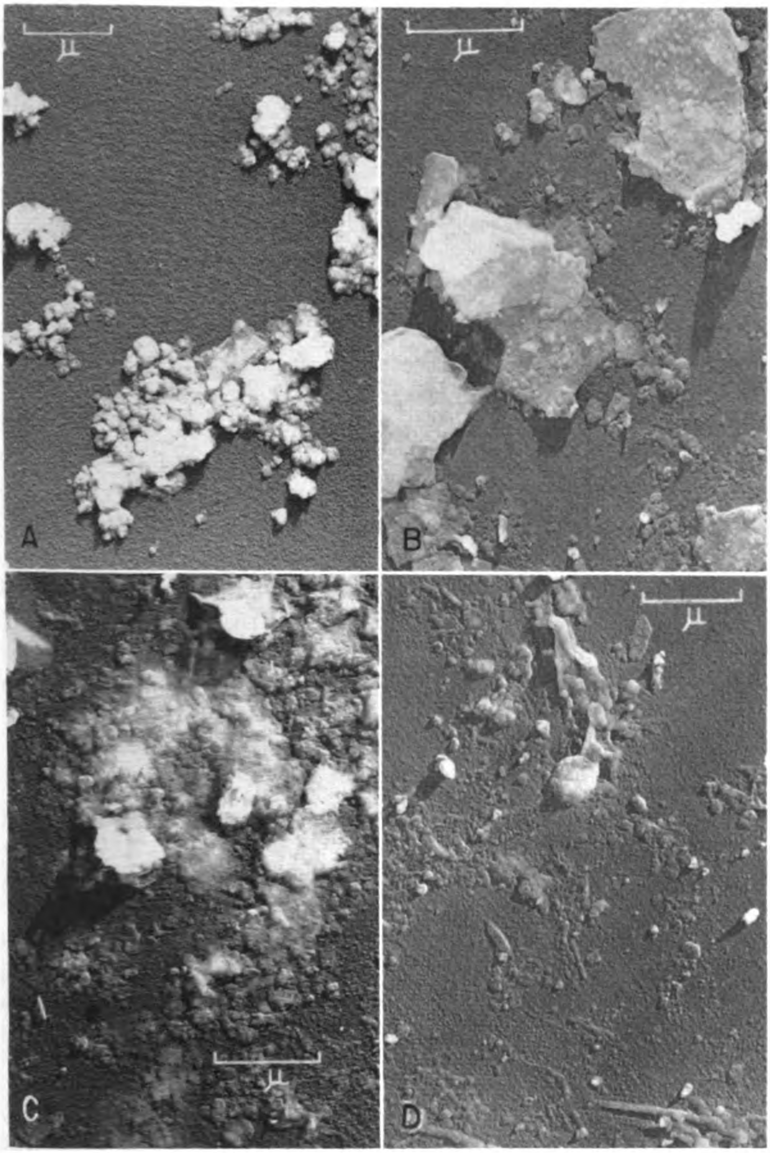

PLATE 17. Electron micrographs of particles finer than 1 micron, shadowed with Cr from angle of 17°. **A,** Red Ninnescah shale; sec. 33, T. 26 S., R. 4 W., Reno County. ×13,000. **B,** Cedar Hills red sandy siltstone; sec. 9, T. 32 S., R. 10 W., Barber County. ×15,000. **C,** Marlow white sandstone; sec. 4, T. 32 S., R. 14 W., Barber County. ×14,500. **D,** Taloga silty shale; sec. 3, T. 34 S., R. 26 W., Meade County. ×15,000.

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OPAQUE MINERALS

Hematite.—Hematite, the mineral responsible for the red coloration of the sediments, occurs as stain in clay coatings around sand and silt grains, and as staining material in the red clays. The mineral is identified as hematite because some of the brighter red clays give the prominent hematite reflections in diffraction patterns. The mineral is so common that it is described in greater detail in the section on major constituents.

Ilmenite, "leucoxene," and magnetite.—Well-rounded grains of ilmenite are common in the finer fractions of the heavy concentrates. Magnetite is also present, but rare. White opaque, well-rounded "leucoxene" grains are nearly as common as, or more common than, ilmenite in many samples. Some ilmenite grains are partly white. Some white opaque grains are quite angular and "fluffy" or porous in appearance and probably have not been formed by the alteration of well-rounded ilmenite grains. In studying the leucoxene content in several Permian sandstones of Oklahoma, Coil (1933) noted that this mineral is the most common of all the accessories, sometimes constituting more than 2.5 percent of the sample. Coil found leucoxene to be five times as common as ilmenite, and attributed its formation to the alteration of ilmenite by carbonate waters.

AUTHIGENIC MINERALS (OTHER THAN LAYER-LATTICE SILICATES)

ANHYDRITE

Other than in the anhydrite-gypsum formation (Blaine), this mineral occurs as small crystals in the Hutchinson salt and in some shales, particularly those associated with salt. Much of the gypum may have been anhydrite at one time.

BARITE

Barite is not common, but occasional clear, irregularly shaped grains are found in some sandstones and shales. It is an important constituent of the Milan member of the Wellington formation, where it fills vugs in the dolomite. Norton (1939) reports barite nodules in the Whitehorse sandstone. It is also present in salt.

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CALCITE AND DOLOMITE

Calcite is the cementing material in some sandstones and siltstones, and commonly forms veins in many of the red shales and sandstones. The calcite veins in the red shales occur at a low angle to the bedding and the calcite has a columnar structure. The peculiar structure has led some workers to describe the veins as aragonite. Their diffraction pattern, however, is that of calcite. Most of these veins are only a few millimeters thick. Calcite also occurs as disseminated particles in clay shales.

Dolomite, other than that in the bedded dolomite units, occurs as the cementing material in some sandstones and siltstones, and as rhombohedral crystals in some of the clays and clay shales, particularly in some of those which are greenish gray (Pl. 18A). Curved rhombohedral calcite-cemented red siltstone casts in red siltstone at one horizon attest to the former presence of large dolomite crystals at that place (Pl. 7A).

CHALCOPYRITE AND MALACHITE

Scattered small spots (less than 3 mm diameter) of bright-green copper carbonate are observed at various horizons in the lower part of the redbeds, particularly in thin silty limestones. They are identified by x-ray diffraction as malachite. According to Norton (1939, p. 1757), chalcopyrite is the original copper mineral in the unweathered rock. I was unable to find any copper mineral other than malachite.

GYPSUM

Other than in the massive beds, gypsum occurs as cement and veins in a few sandstones (Pl. 18B), and as selenite crystals and satin spar veins in the Flowerpot shale and clay of the Blaine formation. It forms large subround sand-free crystals in a few sandstones in the upper part of the redbeds (Pl. 7C).

HALITE, POLYHALITE, AND GLAUBERITE

The only evidences of soluble salts in the surface exposures are occasional zones of halite casts in some of the silty shales. These occur at various horizons throughout the section. Minor quantities of finely crystalline polyhalite and glauberite have been identified from the Hutchinson salt in the Carey mine at Hutchinson, Kansas (Swineford and Runnels, 1953).

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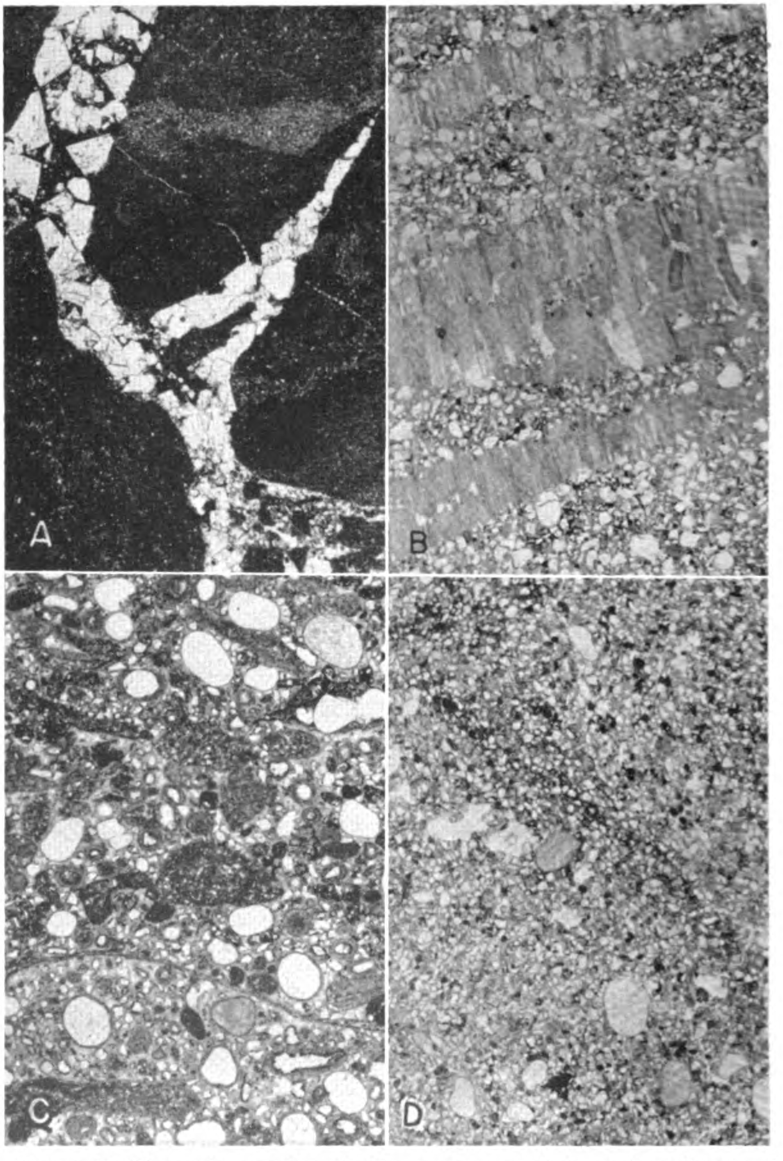

PLATE 18. Photomicrographs of thin sections of shale and sandstone. **A,** Dolomite rhombs in shrinkage cracks of greenish-gray dolomitic shale, horizon of Stone Corral dolomite; SE¼ SE¼ sec. 10, T. 31 S., R. 6 W., Harper County. ×8.5. **B,** Gypsum vein in gypsum-cemented feldspathic sandstone of upper Flowerpot shale; sec. 11, T. 31 S., R. 15 W., Barber County. ×8.5. **C,** Calcite-cemented Verden sandstone; 1.6 miles east of Tegarden, Oklahoma. ×8.5. **D,** Light-red, noncalcareous, very fine-grained feldspathic sandstone, lower Marlow member, Whitehorse sandstone; sec. 4, T. 32 S., R. 14 W., Barber County. ×8.5.

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PYRITE

Pyrite is extremely rare, but is observed at one or two localities. It occurs as irregularly-shaped particles filling interstices between sand grains, and is associated only with deposits which are not red.

PETROGRAPHY

General Character of the Rocks

The Leonardian and Guadalupian? sediments in south-central Kansas are but a small fraction of the deposits of that age in the northern part of the Permian basin. They overlie relatively undisturbed, predominantly normal marine shales and limestones of Wolfcampian age and consist in general of thin-bedded units which display some lateral change in texture (and therefore in overall composition). In general, the lithologic units may be described as blanket deposits, because their lateral extent is at least 1,000 times as great as their thickness (Krynine, 1948, p. 146).

In the Kansas outcropping rocks the lateral variation is not particularly evident except in certain formations, but subsurface data must be taken into account when the regional picture is evaluated.

The source rocks which supplied the outcropping Kansas sediments are several hundred miles from the site of their deposition, but presumably consisted predominantly of acid igneous rocks, older sediments, and minor metamorphic rocks, in decreasing order of abundance. Transport over long distances at low energy levels produced sediments of fine grain and rather uniform mineralogy, so far as clastic particles are concerned. Tracing of the lithologic units in the subsurface shows coarsening to the west and points to the Front Range region and possibly to the Sierra Grande uplift area as source regions (Maher, 1953), and also areas west of the Front Range (Kay, 1951). These positive areas are approximately 150 to 400 miles or more from the area of outcropping red Permian rocks in Kansas. Other local sources are minor uplifts to the south in Oklahoma and Texas.

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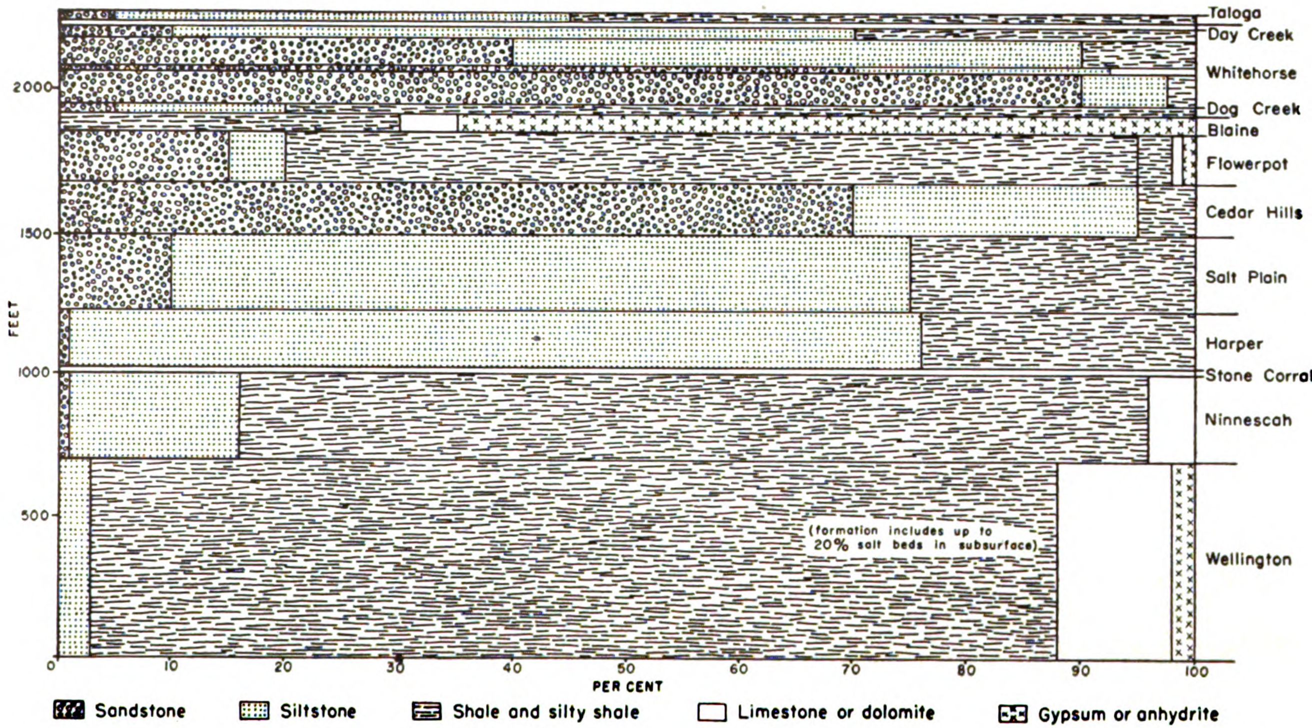

FIG. 6—Generalized lithology of outcropping post-Wolfcampian Permian rocks of Kansas, arranged by formation.

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DISTRIBUTION OF ROCK TYPES

The sediments of the Kansas Permian redbeds consist predominantly of feldspathic siltstones, shales and silty shales, and very fine-grained feldspathic sandstones, with numerous thin beds of dolomite, gypsum, anhydrite, halite, and some limestone. In general, the finer grained clastics are in the lower part of the section, and the fine-grained sandstones in the middle and upper part. The average particle size is also fine (that is, there are fewer sandstones) in the uppermost beds. In geographic distribution the grain size is coarser toward the west and southwest (and also south, in the Whitehorse). Areas of evaporite deposition shift upward stratigraphically toward the west.

The generalized lithology of the outcropping rocks is summarized in Table 2 and presented graphically in Figures 6 and 7.

TABLE 2.—*Generalized lithology of the outcropping Leonardian and Guadalupian? sediments in Kansas* (Values in percent of total thickness of formation)

Formation	Sandstone	Siltstone	Shale (silty shale)	Carbonates (limestone-dolomite)	Gypsum-anhydrite	Red	White, gray, green, mauve
Taloga	<5	40	55	....	....	95	5
Day Creek	....	....	....	100	....	<1	100
Whitehorse[1]	60	20	20	<1	....	90	10
Dog Creek	5	15	75	<5	<1	85	15
Blaine	....	....	30	<5	65	25	75
Flowerpot	15	5	80	<1	<1	90	10
Cedar Hills	70	25	<5	....	....	98	2
Salt Plain	<10	65	25	....	....	>95	<5
Harper	< 1	75	25	....	....	90	10
Stone Corral	....	....	20	80	....	20	80
Ninnescah	< 1	15	80	<5	....	80	20
Wellington	....	3	85	10	2	15	85
Total (weighted)	15	25	50	<5	<5	65	35[2]

[1] Coarser clastics predominate in lower two-fifths of formation. Marlow contains 90 percent sandstone, Relay Creek? 70 percent sandstone, even-bedded member 40 percent sandstone, and upper shale member 10 percent sandstone.

[2] Exclusive of Wellington formation, the sediments are about 87 percent red.

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CHARACTER OF END MEMBERS

As stressed by Krynine (1948, p. 137), sedimentary rocks may be regarded as mixtures of three textural elements: grains, matrix, and cement.

The end members of the Kansas Permian redbeds are (1) feldspathic sands and silts; (2) clayey matrix which is at least in part authigenic and chiefly red; (3) carbonates and sulfates (predominantly dolomite and gypsum); and (4) salt.

The grains in the redbeds are characteristically of silt or very fine sand size with the following average mineral composition.

	Percent, grains
Quartz	75 to 80
Feldspar	
Orthoclase	15
Microcline	5
Plagioclase	1
Micas and detrital chlorites	<2

The matrix is generally illite clay with significant quantities of chlorite, fine-grained quartz and feldspar, and hematite stain. A few sandstones contain a silt matrix. The clay in some specimens is predominantly montmorillonite, but this is not typical except in the upper part of the section. Some matrix contains no hematite. The typical clayey matrix has approximately the following mineral composition.

	Percent
Illite and sericite	50
Chlorite	15
Kaolinite and montmorillonite	<10
Hematite	5
Quartz and feldspar	>20

The characteristic cement is dolomite or calcite, or both; some gypsum cement also occurs.

The type of mixture of these three textural elements (and the depositional environment) depends upon degree of activity in the source areas, or, more probably, degree of warping between the source and the site of deposition, character of water from which the sediments were deposited, depending on such factors as effectiveness of barrier to open sea, and degree of rainfall, and possibly diagenesis. The controlling genetic factor seems to be

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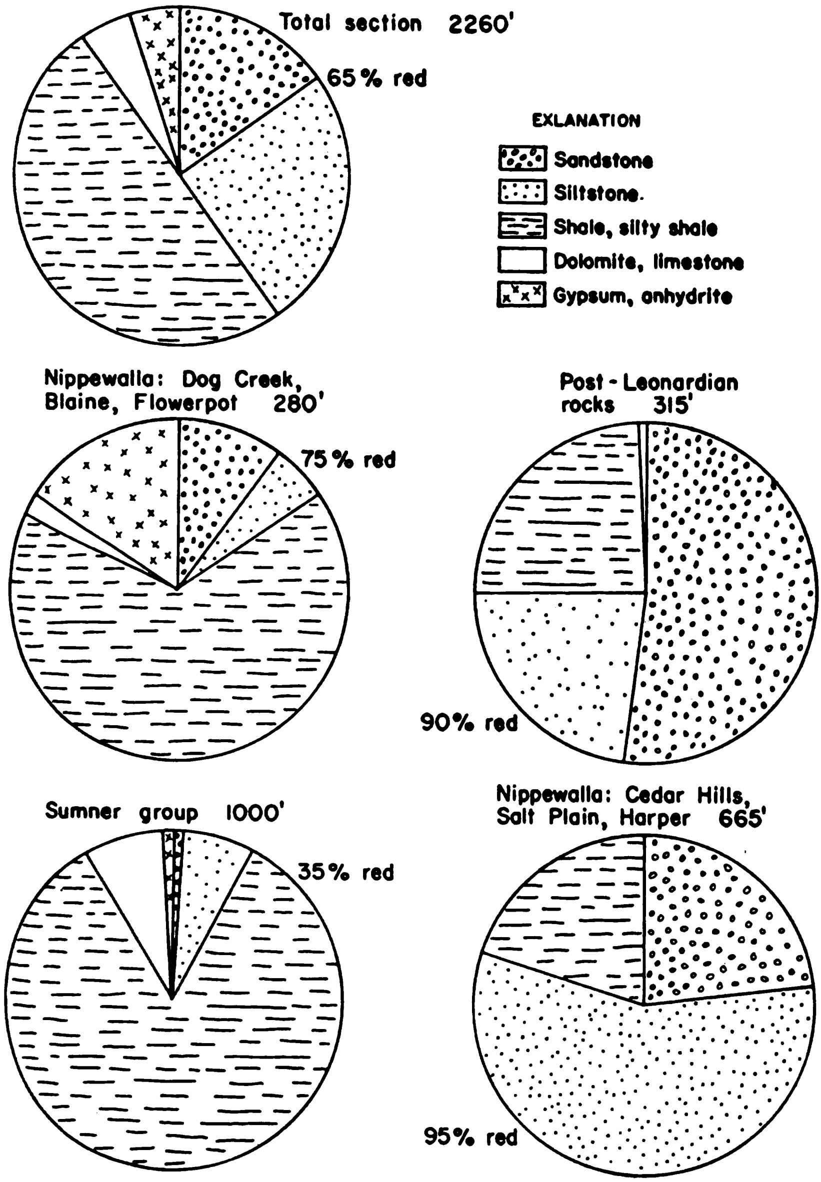

FIG. 7.—Stratigraphic distribution of lithologic types and of redbeds.

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gentle warping in broad shallow basins, plus possible uplift in the source areas.

The principal lithologic types (exclusive of salt) are red and greenish-gray (commonly dolomitic or calcareous) silty shales; red and greenish-gray to white (commonly dolomitic or calcareous) siltstones; red and white very fine-grained feldspathic sandstones; dolomites and limestones; and gypsum and anhydrite.

The overall composition of some typical samples is shown on a trilinear diagram in Figure 8. As shown by the diagram, the siltstones are characteristically calcareous (or dolomitic) and heterogeneous in character. The sandstones are rather well sorted and range from very calcareous (or dolomitic or gypsiferous) to entirely uncemented. The shales are mostly silty, and some have

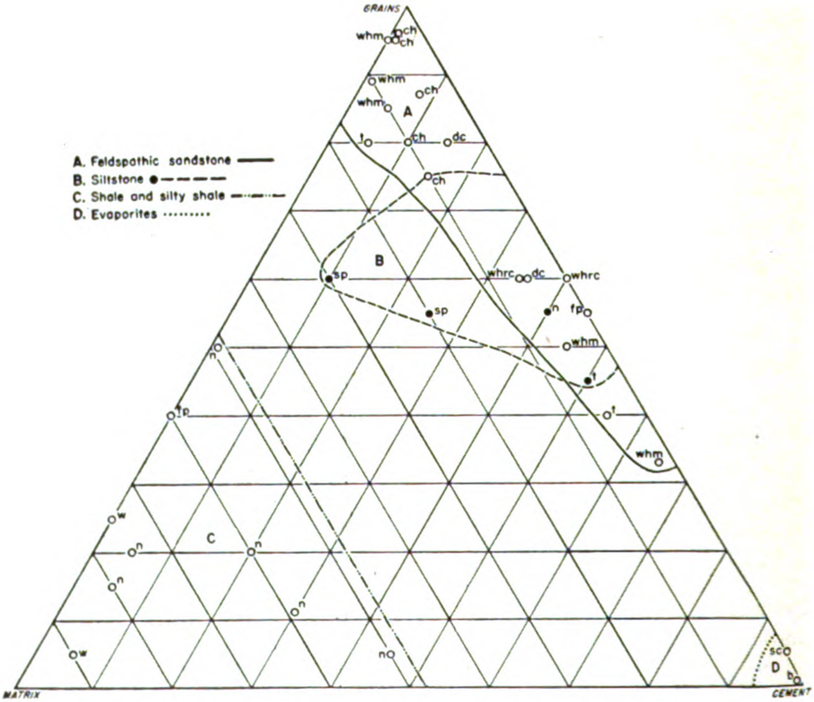

Fig. 8.—Over-all composition of some typical sandstones, siltstones, shales, and evaporites from the post-Wolfcampian Permian deposits of Kansas. (**t**, Taloga; **whrc**, Relay Creek; **whm**, Marlow; **dc**, Dog Creek; **b**, Blaine; **fp**, Flowerpot; **ch**, Cedar Hills; **sp**, Salt Plain; **sc**, Stone Corral; **n**, Ninnescah; **w**, Wellington.)

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appreciable quantities of carbonates (or sulfates). The evaporites are remarkably free of detrital clastic material.

SUMMARY OF TEXTURE

Particle Size and Sorting

Definition of terms.—The clastic deposits of the Leonardian and Guadalupian Series in Kansas include fine-grained sandstones, siltstones, and clay shales. Some of the geologists who have described these rocks in the literature have not used "siltstone" as a descriptive term. This practice has led to a certain degree of confusion concerning the actual texture of these Permian deposits.

In the present report the following terms are used.

Sandstone: A rock consisting of at least 50 percent of grains between 1,000 microns and 62.5 microns (0 to 4ø) in diameter. Most of the sandstones under consideration are fine grained (250 to 125 microns) or very fine grained (125 to 62.5 microns, or 3 to 4ø).

Siltstone: A rock consisting of at least 50 percent of grains between 62.5 microns and 3.9 microns (4 to 8ø) in diameter, or gritty but finer than sand size.

Shale or clay shale: A rock consisting of at least 50 percent of grains finer than 3.9 microns (8ø), or nongritty.

The adjectives silty, argillaceous, sandy, indicate at least 20 percent of the modifying component.

Grain-size distribution.—In general, the rocks in the section are very fine grained. No sandstone sample examined by me has a median grain size coarser than 3ø (125 microns). No individual detrital grains (other than fragments in intraformational conglomerates) larger than 1,500 microns were observed.

The outcropping rocks include about 15 percent very fine sandstones, 25 percent siltstones, and 50 percent silty shales and shales. The data from mechanical analysis of 41 samples are shown in Table 3. Representative cumulative size-frequency curves are shown in Figures 9 and 10.

Sorting.—The degree of sorting, expressed as phi percentile deviation (PDø) ranges from 0.4 to 3.6. In general the sands are well sorted and the shales poorly sorted. This correspondence

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TABLE 3.—*Mechanical analyses of Leonardian and Guadalupian rocks, arranged in stratigraphic sequence from youngest to oldest formation*

No.	Formation	Location	Size distribution (percent by weight) in phi units																		Mdφ	PDφ
			2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.5	5	6	7	8	9	10	11	11+		
1149	Taloga	3-34-26W Meade Co.	1.3	0.3	0.0	0.0	0.0	1.4	5.0	12.1	22.9	23.8	11.7	8.8	3.7	2.4	1.2	0.8	0.9	3.7	4.12	1.56
1155	Taloga	3-34-26W Meade Co.		tr	tr	0.0	0.0	0.0	0.4	3.2	6.8	20.5	22.9	20.3	8.4	4.9	3.6	1.8	1.5	5.5	4.91	2.32
1163	Taloga	3-34-26W Meade Co.	1.4	0.1	0.2	0.5	0.9	2.1	3.8	13.5	21.4	22.5	7.8	7.2	4.6	4.3	2.3	1.1	1.3	5.0	4.10	2.19
1151	Taloga	14-32-23W Clark Co.						0.2	3.3	8.6	21.3	35.4	11.8	7.3	3.4	2.5	1.6	0.5	0.9	3.2	4.18	1.46
1117	Whitehorse upper shale m.	14-28N-18W Woods Co., Okla.					0.0	0.1	0.1	0.1	0.7	21.8	29.2	26.5	8.0	3.7	1.9	1.7	1.3	4.9	4.96	1.84
1160	Whitehorse even-bedded m.	14-28N-18W Woods Co., Okla.				0.1	0.7	12.5	33.4	23.2	10.4	3.5	2.3	4.3	3.0	1.3	0.3	0.2	0.5	4.4	3.53	1.36
1166	Whitehorse Relay Creek	18-33-16W Comanche Co.		0.7	0.2	0.8	5.0	14.1	19.9	18.9	12.1	8.5	4.9	4.2	2.8	2.0	1.5	1.2	0.8	2.3	3.62	1.59
1145	Whitehorse Relay Creek	18-33-16W Comanche Co.		0.8	2.8	10.4	19.1	33.9	15.0	8.6	3.3	1.7	0.9	0.8	0.5	0.3	0.0	0.3	0.2	1.5	3.10	0.53
1134	Whitehorse Relay Creek	18-33-16W Comanche Co.	0.3	0.1	0.5	6.2	27.1	39.4	8.5	4.0	4.4	1.6	1.4	1.4	0.8	0.5	0.5	0.3	0.6	2.6	3.06	0.60
1135	Whitehorse	18-33-16W Comanche Co.	0.1	0.2	0.3	4.4	19.6	41.9	13.5	9.7	2.6	1.2	0.8	1.1	1.0	0.6	0.3	0.4	0.1	2.2	3.12	0.46
1148	Whitehorse upper Marlow	33-32-22W Clark Co.				0.0	0.0	0.2	3.7	14.5	22.2	35.5	8.4	5.7	3.7	2.4	1.2	0.5	0.3	1.8	4.09	1.16
1108	Whitehorse Marlow	22-33-19W Comanche Co.		0.0	0.0	0.2	1.1	6.0	9.8	18.9	12.7	23.7	9.9	8.2	2.9	2.0	0.8	0.9	0.3	2.5	4.02	1.32
1104	Whitehorse Verden	20-27N-16W Woods Co., Okla.	15.2	0.5	1.7	5.9	10.1	13.5	8.8	9.4	4.5	6.3	4.5	7.1	3.8	2.7	1.4	0.7	0.5	3.4	3.33	2.40
1133	Whitehorse lower 10′ Marlow	4-32-14W Barber Co.		0.2	0.2	1.2	9.9	25.6	20.0	20.3	10.1	2.7	1.5	2.3	1.5	1.3	0.6	0.4	0.6	1.7	3.42	0.75
1150	Whitehorse lower 10′ Marlow	4-32-14W Barber Co.		0.0	0.1	4.3	16.2	29.2	16.5	12.5	7.3	2.9	2.1	2.8	1.6	0.8	0.5	0.2	0.5	2.5	3.26	0.95
1165	Whitehorse lower 10′ Marlow	4-32-14W Barber Co.		2.4	0.4	2.7	8.6	18.5	19.0	19.0	10.4	7.9	1.8	2.7	1.8	1.0	0.6	0.6	0.6	1.8	3.47	0.90
1158	Dog Creek (top)	4-32-14W Barber Co.								0.2	0.3	5.8	12.4	29.8	18.0	12.2	7.6	3.9	3.7	5.8	6.07	2.62
1161	Dog Creek (upper)	4-32-14W Barber Co.						0.1	0.1	0.5	3.8	23.5	33.8	21.7	6.0	2.3	2.3	1.3	1.3	3.3	4.82	1.52
1164	Dog Creek (middle)	13-30-16W Kiowa Co.				0.0	1.0	4.5	6.5	15.5	22.7	26.0	9.4	3.8	2.0	1.5	1.5	1.0	0.7	3.9	3.99	1.39

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1122	Flowerpot (upper)	11-31-15W Barber Co.	5.9	9.6	16.6	13.0	12.9	8.9	10.8	8.4	4.5	2.2	2.7	1.2	0.9	0.5	0.3	0.0	1.5	3.10	1.03
1138	Flowerpot	1-32-14W Barber Co.						0.1	0.5	1.9	21.7	18.9	20.7	12.4	8.4	5.0	3.8	3.0	3.3	5.24	2.45
1144	Cedar Hills (middle)	8-32-11W Barber Co.		0.0	0.2	0.6	4.3	15.2	35.1	21.1	14.3	4.3	1.5	0.5	0.5	0.2	0.1	0.2	1.9	3.70	0.56
1128	Cedar Hills	9-32-10W Barber Co.		0.1	0.2	0.1	0.2	0.4	1.6	5.2	36.5	30.1	14.5	3.3	1.6	1.1	0.9	0.9	3.3	4.60	1.09
1146	Cedar Hills (lower)	9-32-10W Barber Co.					0.2	0.7	3.1	6.1	34.3	29.0	13.6	3.0	1.3	1.0	0.7	1.3	5.6	4.58	1.51
1162	Cedar Hills (lower)	9-32-10W Barber Co.				0.0	0.2	0.4	1.5	4.0	20.1	26.4	22.4	7.3	3.7	2.2	1.9	1.7	8.3	4.94	2.91
1147	Cedar Hills (basal)	9-32-10W Barber Co.	0.1	0.1	0.6	3.7	14.5	34.3	33.0	9.4	1.7	0.5	0.3	0.2	0.3	0.2	0.0	0.2	0.9	3.47	0.52
1140	Salt Plain	3-32-9W Harper Co.			tr	tr	tr	0.1	0.3	0.6	17.4	37.4	28.3	7.5	3.3	1.4	1.3	0.8	1.7	4.91	1.21
1156	Salt Plain	3-32-9W Harper Co.				tr	tr	tr	0.0	0.7	4.9	19.8	41.3	17.9	7.6	3.5	1.7	0.7	1.9	5.71	1.52
1137	Salt Plain	3-32-9W Harper Co.						0.1	0.4	2.7	51.9	35.3	6.6	0.9	0.4	0.2	0.1	1.3	lost	4.43	0.43
1139	Runnymede	10-31-6W Harper Co.						tr	tr	0.1	8.3	34.8	40.8	7.1	2.9	1.8	1.1	2.0	lost	5.20	1.16
1159	Ninnescah (near top)	10-31-6W Harper Co.							tr	tr	4.4	29.0	43.8	9.0	4.2	2.6	1.7	1.3	3.8	5.31	1.64
1154	Ninnescah (near Bed 4)	5-26-4W Reno Co.									0.1	14.9	22.7	19.1	13.7	8.1	6.0	4.8	10.7	6.62	3.21
1303	Ninnescah (Bed 4)	5-26-4W Reno Co.								tr	0.7	15.7	36.5	17.8	9.8	5.7	4.4	3.6	5.7	5.89	2.54
1160	Ninnescah (near Bed 3)	33-26-4W Reno Co.									0.1	8.5	25.0	19.2	12.7	9.0	6.5	4.6	14.5	6.87	3.49
1143	Ninnescah	33-26-4W Reno Co.									0.2	13.1	25.1	20.8	15.0	8.4	7.4	4.1	6.0	6.55	2.56
1152	Ninnescah (below Bed 3)	23-29-4W Sedgwick Co.							tr	tr	5.8	20.1	34.9	14.3	6.8	4.6	3.7	3.4	6.3	5.67	2.62
1141	Ninnescah	5-27-4W Sedgwick Co.						tr	tr	tr	1.5	11.5	23.6	26.7	16.3	9.0	4.8	3.1	3.4	6.50	2.19
1142	Wellington (upper)	23-29-4W Sedgwick Co.									0.3	28.9	26.1	11.9	6.7	4.7	4.0	4.0	13.5	5.74	3.59
1153	Wellington (upper)	23-29-4W Sedgwick Co.									0.1	10.1	27.7	22.9	10.9	6.9	5.3	5.6	10.4	6.50	3.11
1157	Wellington	4-33-1E Sumner Co.									0.3	1.5	8.7	19.2	13.8	13.8	9.3	9.6	24.0	8.45	±3.14
1263	Wellington	17-33-2W Sumner Co.									0.7	1.7	12.7	19.2	19.2	12.4	11.7	5.8	16.5	7.80	±3.3

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between size and sorting in sediments is noted by Krynine (1950, p. 80) and Griffiths (1951).

PDø is plotted against Mdø in Figure 11, and the correlation is evident. The correlation coefficient, *r*, for 40 pairs is .840. According to Fisher's (1948, p. 209) table this value is statistically

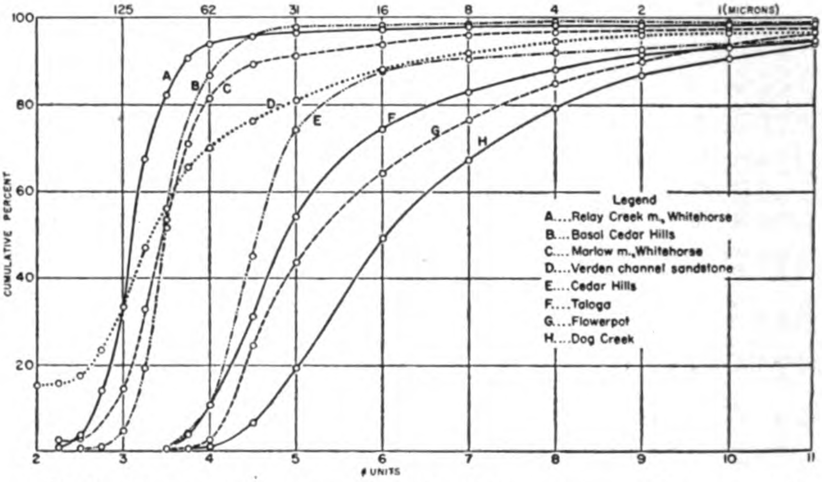

Fig. 9.—Representative cumulative size-frequency curves for some post-Wolfcampian sandstones and siltstones.

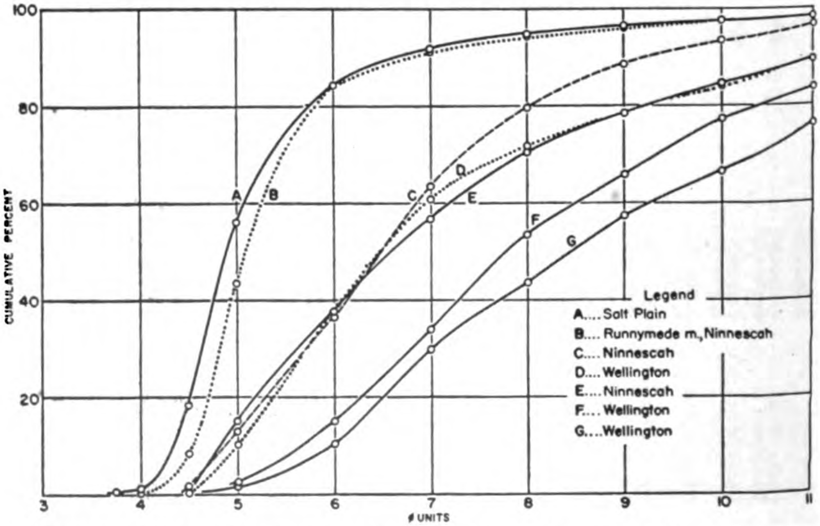

Fig. 10.—Representative cumulative size-frequency curves for some post-Wolfcampian siltstones and shales.

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significant ($P<0.001$). Griffiths (personal communication, April 21, 1954) points out that $r^2=70.56$ percent, or 70 percent of variation in size is common to sorting, and 30 percent is not.

The relationship between the two variables was computed by the method of least squares, and the line of best fit is superimposed on the chart (Fig. 11). The spread as measured by the standard error of estimate is also indicated. The data can thus be compared directly with those of Griffiths for his Caribbean sediments.

The equation for the line of best fit is $PD\phi = 0.5769\ Md\phi - 1.0344$. The standard error of estimate, Sy, is 0.51.

Griffiths (1951) indicates that the position of a sample with respect to the band of "average trend" in the coarser grained sediments may have geological significance. It should be noted that the siltstones of the Salt Plain formation are better sorted than the average, whereas those of the Taloga are more poorly sorted. A sample from the Verden "channel" sandstone of the lower Whitehorse of Oklahoma is also plotted, although this point was not used in the other computations. It is interesting to note that the "channel" sandstone sample differs markedly from the

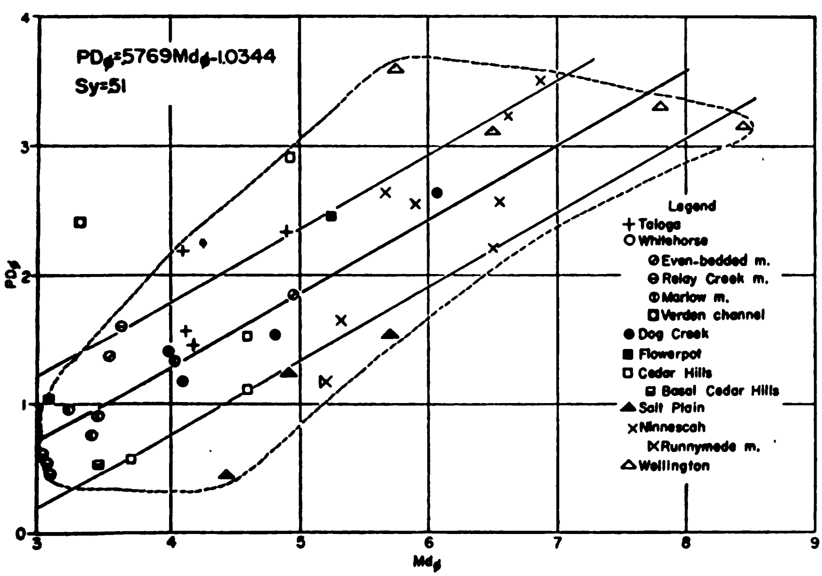

FIG. 11.—Graph showing relation between particle size and degree of sorting in some post-Wolfcampian Permian sediments.

normal facies in the size-sorting relationship. This may indicate more rapid "dumping" of sediments in the Verden member, and less reworking of the material. The data suggest that the Salt Plain sediments were subjected to long reworking in comparison with the other samples. This is also the case for the Runnymede siltstone (Mdϕ = 5.20; PDϕ = 1.16) which apparently has broad lateral extent, and for a sample (Mdϕ = 3.70; PDϕ = 0.56) from the "Peace Treaty" bed in the Cedar Hills sandstone which according to Norton (1939, p. 1789) can be correlated "over considerable distances."

It is of interest to note that the value of Sy is lower than most of those of Griffiths (1951) for single formations. This may indicate rather uniform conditions of transport and deposition over a long period of time.

Particle Shape (Sphericity and Roundness)

Most of the sand and silt grains are subangular to subrounded; this is in large part, but not entirely, a function of the fine average particle size. The apparent roundness is also modified in some samples by incipient overgrowths and in other samples by etching or replacement by carbonate.

The roundness of the 105 to 88-micron fraction was measured on six samples according to the method of Wadell (1935). Fifty quartz grains from each sample were measured. The mean roundness of the 105 to 88-micron fraction ranges from 0.395 in a sample from the Marlow to 0.506 in one from the Relay Creek member, Whitehorse formation.

Roundness was measured for 8 size grades in a sample from the Verden sandstone of Oklahoma and the results are included

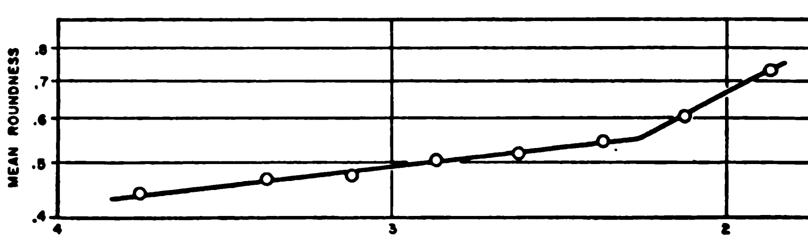

FIG. 12.—Graph showing relation between log size and log roundness in sample from Verden sandstone.

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in Table 4. The Verden was chosen because of its wide range in grain size in the sand sizes. Figure 12 shows the diameter in phi units plotted against log mean roundness; except for the larger sizes the points fall on a straight line. This straight-line function is the usual relationship between size and roundness, according to Pettijohn (1949, pp. 404-405). The deviation of the larger grains suggests that they have a different abrasional history. Their petrographic character (strain shadows, abundant chert, no feldspars) also shows that their history differs from that of the smaller grains. The well-rounded character of the large grains in the Verden sandstone is shown in Plate 18C.

In general the feldspar grains (particularly the weathered ones) are slightly better rounded than the quartz, although some feldspars still retain a prismatic shape and are scarcely rounded at all. A few of the zircon and tourmaline grains are very well rounded. Micas are very well rounded at some horizons, particularly in the Salt Plain formation.

No quantitative measurements of sphericity were made. In general the sphericity of the quartz grains seems to be rather low in the finer sizes; that of the large well-rounded grains is high.

Surface Textures

Surface textures are varied. A few grains are frosted, but the type of frosting is not everywhere clear. Some is due to minute incipient overgrowths. Some grains, particularly in the upper

TABLE 4.—*Wadell roundness values for quartz grains from six Permian sandstones*

No.	Formation	Diameter. microns	Mean roundness
1135	Relay Creek? dolomite member, Whitehorse	105- 88	.506
1108	Marlow member, Whitehorse	105- 88	.395
1104	Verden sandstone member, Whitehorse	310-250	.734
	do	250-210	.606
	do	210-177	.549
	do	177-149	.521
	do	149-125	.507
	do	125-105	.475
	do	105- 88	.469
	do	88- 62	.445
1164	Dog Creek	105- 88	.478
1122	Flowerpot	105- 88	.477
1147	Basal Cedar Hills	105- 88	.503

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part of the section, have a bright polished appearance; many of these grains are light orange in color. Surface textures of some of the heavy minerals are discussed in the section on mineralogy.

SUMMARY OF COMPOSITION

Mineral Composition

Major constituents.—Detrital minerals in the typical sandstone consist of approximately 80 percent quartz, 20 percent feldspar (at least three-fourths of which is without multiple lamellar twinning), and less than 2 percent mica (predominantly muscovite, but some chlorite and traces of biotite). The typical siltstone contains a somewhat larger proportion of mica; in some argillaceous siltstones the mica content may reach more than 5 percent, but such a large proportion is not common. Most of the sandstones contain less than 5 percent of clay minerals (many are nearly free from clay), and the normal siltstones contain 10 to 30 percent. The clay minerals as such are not regarded as 100 percent detrital constituents.

The typical clay shale is silty, with approximately 20 percent quartz, 4 percent feldspar, and 3 percent micas in the silt fraction. The clay fraction (as shown by x-ray diffration data) also contains quartz, feldspar, and micas, with a somewhat lower proportion of feldspar. It also contains a few percent of hematite which is responsible for the common red color. Most of the clay shales also contain dolomite or calcite or both.

The major constituents of the clay fraction are (besides quartz, feldspar, and hematite) illite, chlorite, montmorillonite, and kaolinite. Of these minerals the typical clay shale contains essentially cnly illite and chlorite, in the proportion of about 4:1. Some noncalcareous clays contain small quantities of kaolinite, and some clays near the top of the section are chiefly montmorillonite.

The predominant chemical minerals among the major constituents include dolomite, calcite, anhydrite, gypsum, and halite. Each of these occurs in thin essentially monomineralic beds or lenses. Calcite, dolomite, anhydrite, and gypsum are also common cementing materials in sandstones and siltstones, in some sandstones constituting about 50 percent of the rock. Calcite, dolomite, and gypsum occur as veins in some sandstones and silty shales, and as disseminated particles and crystals in many shales.

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Sandstones in some zones are characterized by the presence of small unworn overgrowths on some of the quartz and orthoclase grains. One of the dolomite units—the Day Creek—commonly contains nodules and stringers of secondary chert. The time of origin of this chert is not clear; it has been postulated to be Tertiary or younger in age (Norton, 1939, p. 1811) but the presence of greenish-gray Permian montmorillonite clay immediately above it suggests that the silica may have been leached from the overlying bed. A primary origin is of course possible.

Accessory minerals.—Accessory heavy minerals are neither abundant nor varied in the upper Permian sandstones. The quantity is everywhere less than 1 percent (not including the micas) and commonly less than 0.4 percent of the total sample. A sample from the base of the Cedar Hills formation was found to contain 0.38 percent heavy minerals, most of which were finer than sand size (less than 62 microns). A sample from the Relay Creek member of the Whitehorse sandstone contains only 0.15 percent heavy minerals, most of which are in the very fine sand sizes.

Except for the micas, there are no obvious stratigraphic variations in mineral suites. The only variations observed by me can be attributed to differences in particle size of the deposit, and perhaps to selective destruction of certain minerals, notably staurolite, after deposition.

The opaque minerals (ilmenite, "leucoxene," magnetite) make up from 40 to 65 percent of the heavy residues (micas excluded). The nonopaque minerals apatite, epidote, garnet, rutile, staurolite, titanite, tourmaline, and zircon form the remainder. Tourmaline, garnet, and staurolite are particularly abundant in the coarser fractions, whereas zircon and the opaque minerals predominate in the finer.

The nonopaque heavy minerals seem to be essentially unaltered, but all the staurolite is corroded. Much of the garnet is pitted; these pits may be vacuoles exposed on surface planes by fracturing (Krynine, personal communication dated April 4, 1954). Many staurolite grains are so delicately etched that they seem to have been corroded after deposition. However, it is conceivable that such grains could have survived transport in a suspension load.

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Authigenic nonopaque heavy minerals ($G>2.87$) are not common. A few irregularly shaped grains of barite are noted in a few samples from the Whitehorse sandstone.

Chemical Composition

Chemical analyses of 19 samples from the Leonardian and Guadalupian? Series, two Wolfcampian carbonate rocks, and one upper Pennsylvanian shale are shown in Table 5. Ten of the analyses (1802, 1801, 1794, 1138, 1128, 1146, 1147, 1156, 1137, 1139) were made specifically for this study in the chemical laboratories of the State Geological Survey of Kansas, under the supervision of Russell T. Runnels. The remaining analyses are taken from published reports and from data on file at the State Geological Survey of Kansas. Some of the samples have been studied in thin section or by x-ray diffraction, or both, so that somewhat detailed interpretation of the chemical data is possible.

Fairbairn and others (1951) have shown that there is great variation betwen analyses made in different laboratories. Comparison of the analyses with Clarke's (1921) "average" sandstone and "average" shale may therefore not be of great significance, but in general the greatest differences are in the percentages of MgO and Fe_2O_3. Analyses of 29 Pennsylvanian shales (Plummer and Hladik, 1951, p. 20), incidentally, are very similar to Clarke's average shale. The nine Permian shales, however, are marked by their extremely high content of MgO (ranging from 6.05 to 19.54 percent, as opposed to 2.45 in the "average" shale and 1.98 ± 0.09 percent in the 29 analyses of Pennsylvanian shales). In comparing the mean values for the Pennsylvanian and Permian analyses (all of which were made in the same laboratory), the value of Student's t is 10.883 for 36 degrees of freedom. For 36 degrees of freedom, t must be not less than 3.59 to be significant at the 0.1 percent level. Thus the obtained difference of 9.94 is statistically significant well beyond the 0.1 percent level of confidence. The magnesium is of course found chiefly in the large quantities of chlorite, and also in dolomite, in most of the Permian shales.

A somewhat unexpected character of the Permian sediments is their rather low percentage of Fe_2O_3, despite their common bright-red coloration. The iron oxide content of the Permian sediments analyzed (exclusive of the evaporites and rare white sand-

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stones) ranges from 0.79 percent, in a light-red sandstone, to 5.87 percent in a sample of red Ninnescah shale; whereas the average iron oxide content of the 29 Kansas Pennsylvanian shales (most of which are gray) is 6.56 percent, and of Clarke's 78 shales is 6.49 percent.

Student's *t* test for comparison of mean Fe_2O_3 content (4.63 percent) of 6 Permian red shales with the 29 Pennsylvanian shales indicates that *t* is 3.429 for 33 degrees of freedom. For 33 degrees of freedom, *t* must be not less than 2.7 at the 1 percent level. Thus we may take it with that degree of assurance that the populations are different.

Data for comparison of Fe_2O_3 content of Permian red shales with Permian green or gray shales are limited. The *t* test on six red shales and three green or gray shales (mean $Fe_2O_3 = 4.33$ percent) indicates that *t* is 0.424 for 7 degrees of freedom. For 7 degrees of freedom *t* must be not less than 1.90 to be significant at the 10 percent level. Accordingly, there is no evidence here that the populations are different.

The lower values for Fe_2O_3 in the Permian shales seemingly cannot be attributed to dilution with free SiO_2. Clarke's average sandstone contains 1.38 percent Fe_2O_3, which is somewhat less than the average iron oxide content of 1.84 percent in seven Permian sandstones and siltstones.

The content of P_2O_5 in the Leonardian and Guadalupian? rocks is also low (average P_2O_5 in 9 shale samples is 0.13 percent as opposed to 0.17 percent in Clarke's average shale and 0.19 percent in 29 Pennsylvanian shales). Only two samples exceed Clarke's average; they are both gray shales from the Wellington formation ($P_2O_5 = 0.18$ percent). The paucity of P_2O_5 may perhaps be attributed to adverse living conditions in Kansas during most of Leonardian and Guadalupian? time, for according to Rankama and Sahama (1950, p. 588) phosphorus has distinctly biophile character.

The Na_2O: K_2O ratios in the Permian sediments are also of interest (Table 6). According to Rankama and Sahama (1950, p. 432) the Na_2O: K_2O ratio in argillaceous sediments has an average value of 0.36, and that in igneous rocks is 1.09. The average Na_2O: K_2O ratio in 28 Kansas Pennsylvanian shales is 0.31; that in the 9 Permian shales analyzed is 0.24.

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Table 5.—*Chemical analyses of selected Permian sediments and a Pennsylvanian shale, arranged in stratigraphic sequence from youngest to oldest rocks*

No.	Formation	Description	SiO_2	Al_2O_3	Fe_2O_3[2]	TiO_2[3]	CaO	MgO	P_2O_5	SO_3	S	K_2O	Na_2O	Ig. loss	Total
		Leonardian and Guadalupian													
1802	Taloga	Red silty shale	60.86	10.42[1]	3.35	0.97	0.81	12.88	0.12	nil	0.02	3.57	0.24	6.52[4]	99.74
1801	Basal Taloga	Green shale	50.50	12.74[1]	3.84	0.94	0.77	19.54	0.06	0.17	0.05	2.13	0.20	9.28[4]	100.17
	Day Creek	Dolomite (Jewett and Schoewe, 1942, p. 111)	1.64	1.28	1.98		31.54	18.02						46.34	100.80
1794	Whitehorse upper shale	Red dolomite—shale	27.71	7.28[1]	3.30	0.42	16.38	14.04	0.09	nil	0.10	1.61	0.66	27.94[4]	99.43
1779	Whitehorse	Dark-red shale	52.08	12.16[1]	4.42	1.01	1.34	18.14	0.13	nil	N.D.	2.41	0.43	7.34[4]	99.46
1816	Whitehorse (Marlow)	Light-red cross-bedded sandstone	85.74	6.84[1]	0.79	0.38	0.49	1.11	0.01	nil	N.D.	2.19	1.16	1.12[4]	99.83
	Medicine Lodge	Gypsum (Grimsley and Bailey, 1899, p. 147)	0.19	0.10[5]			32.53	0.16		45.73				21.27[6]	99.98
1138	Flowerpot	Red silty shale	61.47	14.10[1]	5.76	0.64	0.62	6.95	0.14	0.35	0.06	2.96	1.38	5.48[4]	99.85
1128	Cedar Hills	Red sandy siltstone	73.02	7.15[1]	2.01	1.04	4.85	2.54	0.09	nil	trace	1.70	1.38	5.76[4]	99.54
1146	Cedar Hills	Red sandy siltstone	75.98	7.92[1]	2.02	0.45	3.16	2.20	0.07	nil	nil	1.87	1.54	4.28[4]	99.49
1147	Basal Cedar Hills	White sandstone	83.29	8.19[1]	0.68	0.62	0.72	0.89	0.05	nil	nil	1.75	1.90	1.51[4]	99.60
1156	Salt Plain	Red argillaceous siltstone	65.02	11.03[1]	3.93	1.03	4.40	3.28	0.12	nil	0.03	2.57	1.42	6.87[4]	99.67
1137	Salt Plain	Red sandy siltstone	77.54	7.69[1]	1.77	0.79	2.61	1.77	0.09	nil	nil	1.66	1.70	3.67[4]	99.29
	Stone Corral	Dolomite. Av. of 5 analyses (Jewett and Schoewe, 1942, p. 111)	3.00	2.98	0.55		34.41	14.74						42.48	98.16
1139	Runnymede	Gray dolomitic siltstone	63.35	8.63[1]	1.70	1.05	6.46	4.95	0.11	trace	0.03	1.62	1.30	10.56[4]	100.33[7]
	Ninnescah	Red blocky shale (Lab. no. 48275)	52.89	15.83[1]	5.87	1.39	3.97	6.39	0.14	trace	N.D.	3.23	0.72	9.11[4]	99.54
	Ninnescah	Red blocky shale (49438-42). Av. of 5	56.17	14.02[1]	5.10	1.04	4.52	6.05	0.15		N.D.	2.95	0.69	8.48[4]	99.17
	Wellington	Gray shale (49414)	44.33	13.68	5.05	1.10	7.86	9.66	0.18	trace	N.D.	2.51	0.67	14.09[4]	99.13
	Wellington	Gray (and yellow) shale (49417)	34.84	9.92	4.09	0.94	11.90	13.64	0.18	trace	N.D.	1.68	0.36	21.56[4]	99.11

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					Wolfcampian									
Herington	Dolomite (5124, partial analysis)	6.21	1.30[3]	0.79		30.52	18.04	0.04		0.07			43.40[6]	100.30
Fort Riley	Limestone (5128, partial analysis)	7.45	1.94[5]	0.84		47.41	2.08	0.05		0.37			38.84[6]	98.61
					Pennsylvanian (Wabaunsee group)									
Langdon	Gray shale (Plummer and Hladik, 1951, p. 20)	55.74	21.00	7.49	1.02	0.70	2.57	0.17	nil		3.77	1.54	5.97	99.97
					"Average" Sediments (Clarke, 1924)									
	Av. of 78 shales (Clarke, 1924, p. 631)	58.38	15.47	6.49	0.65	3.12	2.45	0.17	0.65		3.25	1.31	8.47[9]	
	Av. of 253 sandstones (Clarke, 1924, p. 547)	78.66	4.78	1.38	0.25	5.52	1.17	0.08	0.07		1.32	0.45	6.68[9]	

[1] Contains MnO_2.
[2] Total iron expressed as Fe_2O_3.
[3] Contains ZrO_2 and V_2O_5.
[4] 140°C. to 1000°C.
[5] Contains MnO_2 and TiO_2.
[6] Water at 200°C., plus carbon dioxide (calc.).
[7] Includes 0.6 percent CuO (determined spectrographically).
[8] 105°C. to 1000°C.
[9] Reported as H_2O, CO_2, C.

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Seven Permian sandstones and siltstones, on the other hand, have an average ratio of 0.80. This seems to indicate a high proportion of sodic plagioclase feldspar in the sands although large quantities of this mineral are not observed in thin section. Some sodium doubtless occurs in the orthoclase grains, and it is possible that a large proportion of the mineral aggregate grains so common in many of the sandstones are plagioclase feldspars which have been altered and recrystallized without loss of sodium ion (under conditions of high pH).

Medium-Grained Clastics

FINE-GRAINED SANDSTONES

The medium-grained clastics of the Kansas Permian redbeds consist entirely of very fine-grained sandstones and form approx-

TABLE 6.—*Sodium-potassium ratios in some Permian sediments*

No.	Formation and lithology	$Na_2O:K_2O$
	Shales	
1802	Taloga red silty shale	0.07
1801	Basal Taloga green shale	0.09
1794	Whitehorse red dolomite-shale	0.41
1779	Whitehorse dark-red shale	0.18
1138	Flowerpot red shale	0.47
48275	Ninnescah red shale	0.22
49438-42	Ninnescah red shale (average of 5)	0.23
49414	Wellington gray shale	0.27
49417	Wellington gray and yellow shale	0.21
	Average of above	0.24
	Average of 28 Kansas Pennsylvanian shales (Plummer and Hladik, 1951, p. 20)	0.31
	Average argillaceous sediment (Rankama and Sahama, 1950, p. 432)	0.36
	Sandstones and Siltstones	
1816	Lower Whitehorse light-red sandstone	0.53
1128	Cedar Hills red sandy siltstone	0.81
1146	Cedar Hills red sandy siltstone	0.82
1147	Basal Cedar Hills white sandstone	1.09
1156	Salt Plain red argillaceous siltstone	0.55
1137	Salt Plain red sandy siltstone	1.02
1139	Runnymede gray siltstone	0.80
	Average of above	0.80
	Average sandstone (Clarke, 1924, p. 547)	0.40
	[Average igneous rock (Rankama and Sahama, 1950, p. 432)]	1.09

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imately 15 percent of the Leonardian-Guadalupian? section. The sandstones are all feldspathic; most of them are stained red by red iron oxide-stained clay minerals or by hematite. Some are highly calcareous, dolomitic, or gypsiferous; other contain no carbonates or sulfate. Degree of size-sorting ranges from very good to moderate; roundness and sphericity of the grains are variable, but the mean values are neither extremely high nor low.

Detailed descriptions of selected specimens will serve to illustrate the various types, their color, texture, composition, and structure.

Light-Red Noncalcareous Sandstone

Light-red (2.5YR6/6), noncalcareous very fine-grained feldspathic sandstone from the lower part of the Marlow member of the Whitehorse sandstone is judged to be typical of the "orange-red" essentially noncalcareous sandstones of the Marlow, and was collected from 10 feet above the base of the Whitehorse, in sec. 4, T. 32 S., R. 13 W., Barber County (Pl. 18D).

Mechanical analysis shows that the sample has a median diameter of 3.47 phi (about 92 microns), and a phi percentile deviation of 0.90. Thus it is a very fine-grained well-sorted sandstone with a relationship between size and sorting which is about average for the Kansas Permian sediments under consideration. In thin section a very few large grains having an average diameter of about 600 microns and a maximum of about 800 microns are scattered throughout the finer sand. Grains of silt size are rare, and clay coats the sand grains.

The sphericity of the small grains is variable. These grains are angular to subrounded; most are subrounded. The large grains are very well rounded and have fairly high sphericity (about 0.85 projection sphericity according to the chart of Rittenhouse, 1943).

The matrix consists of reddish-brown argillaceous material, much of it with high birefringence, most of which is found by x-ray diffraction to consist of illite and chlorite. The clay coats the sand grains, commonly showing orientation of the flakes normal to the surfaces of the grains. It also fills some small interstices. The clay constitutes less than 10 percent of the rock.

Chemical cement is absent, except for occasional shreds of fibrous gypsum. The bonding effect is due almost entirely to clay.

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Quartz overgrowths are absent except for a few well-worn ones on occasional large grains. Most of the small grains have normal extinction, but all the large ones show moderate strain shadows. Inclusions in the small grains are of various types. Nonoriented crystalline inclusions (particularly rutile and apatite) are common. Bubble planes are also common, some vacuoles are present, and a few grains contain chlorite inclusions. The quartz is judged to be at least 60 percent of igneous (plutonic) origin and less than 40 percent metamorphic, based on the criteria of Krynine (1946). The large grains have been subjected to some pressure metamorphism.

All degrees of alteration are shown in the feldspars, which range from clear and colorless to nearly opaque from fine-grained alteration products. A few feldspars are saussuritized. Some have red clay along the cleavage planes. The feldspars are composed of about 75 percent orthoclase, 15 percent plagioclase (almost entirely oligoclase-albite), and less than 10 percent microcline. A few large unworn overgrowths occur on orthoclase grains, and many of them have small overgrowths which are scarcely visible in thin section. One of the two large orthoclase grains (neither of which shows normal straight extinction) has a well-developed unworn overgrowth which is not in optical continuity with the grain (Pl. 15A).

Chert occurs as a few small grains only, and includes particles having various crystallite sizes. This occurrence is not typical, for the chert is commonly more prevalent in the larger grains.

Chlorite of sand size occurs as rounded flakes with aggregate polarization. Some grains are slightly brownish-green.

A few fairly well-rounded black opaque grains are noted. These are identified as ilmenite because some of them have a white alteration product. Other white opaque grains are small with irregular "fluffy" shapes, and seemingly were not produced by alteration of ilmenite. Red opaque grains have the same general appearance as the white.

Garnet is the most common of the nonopaque accessory minerals; it occurs as small, colorless, angular to subrounded grains. Most of the tourmaline observed is of igneous varieties (Krynine, 1946a): chiefly rounded and subrounded brown grains with fluid and acicular crystalline inclusions. Zircon occurs as small subrounded grains. One flake of biotite is noted, and one rounded

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yellow-brown dusky grain having high relief and high birefringence is tentatively identified as titanite.

Heavy mineral separates also include staurolite in the coarser fractions, and prismatic tourmaline (metamorphic?), pink and yellow rounded zircons, and foxy-red rutile in the finer.

In thin section the structure of the sandstone is seemingly massive, with random distribution of the large rounded grains. In some outcrops of the Marlow, however, cross-bedding is faintly evident, and in occasional specimens the large rounded sand grains are concentrated in micro-lentils.

White Noncalcareous Sandstone

There is no clear relationship between carbonate content and color of the sediment. Very pale red sandstones commonly contain more carbonate cement than those which are bright red. White sandstones, however, do not necessarily contain carbonates, although many of them are associated stratigraphically with limestone or dolomite beds.

The following description is of white, friable, cross-bedded, essentially noncalcareous very fine-grained sandstone from one foot below a thin dolomite bed in the Relay Creek? member of the Whitehorse formation (NW¼ sec. 18, T. 33 S., R. 16 W., Comanche County).

Mechanical analysis shows that it is one of the coarsest grained sandstones in the entire section, having a phi median diameter of 3.10 (about 117 microns). The degree of sorting ($PD\phi = 0.53$) is slightly better than average for a sandstone of its grain size, but good sorting seems to be typical of Relay Creek? white sandstones.

A thin section made from this sandstone shows that the sorting is much better than that of the Marlow sandstone previously described. The largest grain observed has a maximum diameter (in the plane of the section) of about 0.4 mm, and the extremely large well-rounded grains are absent. A similarly well-sorted Relay Creek sandstone, but with calcite cement, is shown in Plate 19A. Some samples from the Relay Creek member, however, contain the large rounded grains. Sphericity and roundness of the quartz and feldspar grains range from moderately low to high. Most quartz grains are fairly well rounded and have moderately

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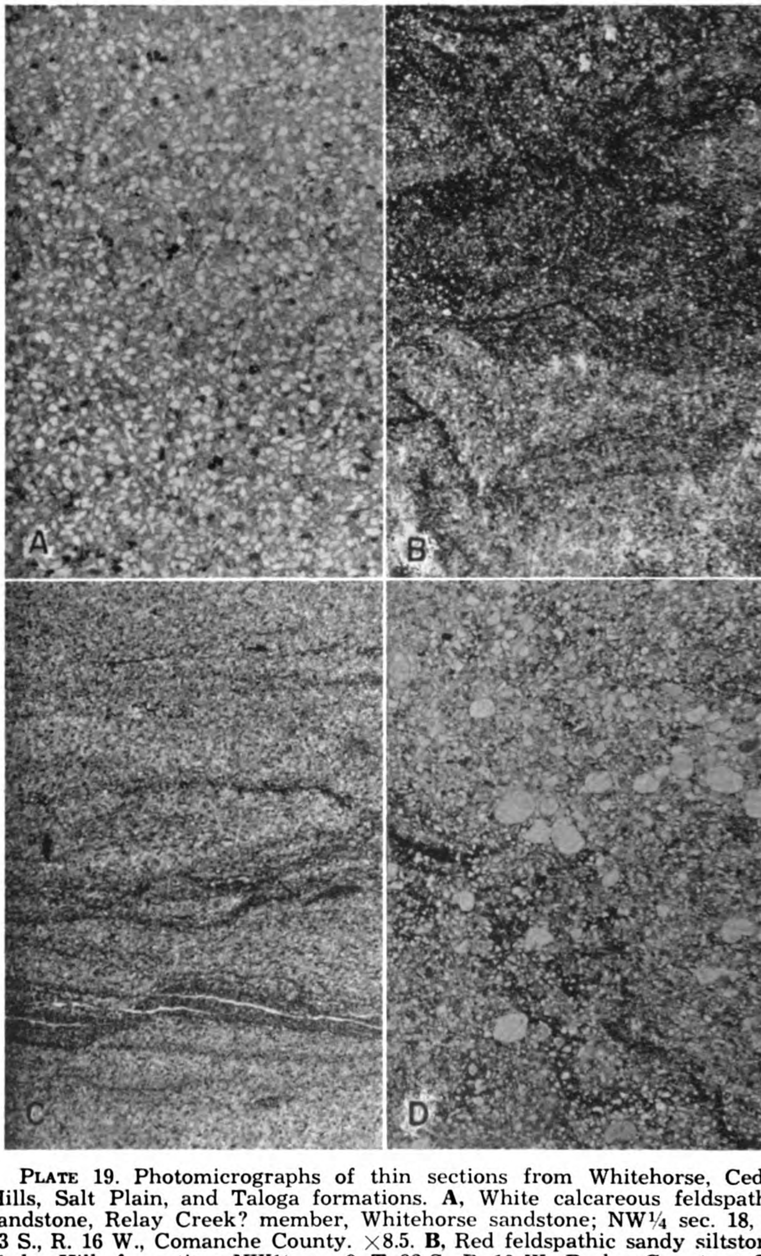

Plate 19. Photomicrographs of thin sections from Whitehorse, Cedar Hills, Salt Plain, and Taloga formations. **A,** White calcareous feldspathic sandstone, Relay Creek? member, Whitehorse sandstone; NW¼ sec. 18, T. 33 S., R. 16 W., Comanche County. ×8.5. **B,** Red feldspathic sandy siltstone, Cedar Hills formation; NW¼ sec. 9, T. 32 S., R. 10 W., Barber County. ×8.5. **C,** Gray and red calcareous feldspathic siltstone, Salt Plain formation; sec. 3, T. 32 S., R. 9 W., Harper County. ×8.5. **D,** Gray and red feldspathic sandy siltstone, Taloga formation; sec. 3, T. 34 S., R. 26 W., Meade County ×8.5.

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high sphericity. The higher-than-average roundness (and sphericity) may be attributed to the relatively large size of the grains.

The rock consists of about 96 percent grains, 2 percent matrix, and less than 2 percent cement. The matrix is made up of pale-green clay (illite, chlorite) coating the grains and partly penetrating some grain surfaces. Not all grains are coated with clay; some show definite orientation of the flakes normal to the surface of the grain.

Chemical cement is absent except for a few isolated areas of gypsum cement and a spot of coarsely crystalline calcite cement. One irregularly shaped particle of striated pyrite is observed, and there is also a small area of shrinkage-cracked glauconite associated with brown organic matter. The pyrite and glauconite are not typical of the sandstones in the section, but are thought to have genetic significance in connection with the absence of red coloration.

The sandstone is very friable, and evidently is held together only by the small quantity of clay.

The mineral composition of the grains observed in thin section is about as follows: Quartz, >65 percent; feldspars, <25 percent; chert, <5 percent; rock fragments, 1 percent; white opaques, 1 percent; and zircon, garnet, tourmaline, apatite, chlorite, staurolite, titanite, trace.

The quartz grains contain several types of inclusions, of which small vacuoles, bubble planes, and microlites are the most common. Seventy-five percent of the quartz is judged to have an igneous origin. Several rounded quartz overgrowths are observed. A few grains have red opaque iron oxide coatings, but most of the remainder are coated with green clay.

The feldspars consist of about 85 percent orthoclase, <10 percent plagioclase (chiefly sodic), and less than 5 percent microcline. A large proportion of the feldspar grains are clouded with alteration products; a few are saussuritized. Most of the grains are subrounded to rounded. Rounded feldspar (orthoclase on orthoclase) overgrowths are even more common than rounded quartz overgrowths, although they may be xenomorphic rather than worn. They are illustrated in Plate 15B. Two zoned plagioclases are noted.

Chert is more common than in most thin sections studied. Most of the chert grains are well rounded, and several varieties

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are present; some contains chlorite and sericite. One subrounded rock fragment consists of a subrounded slightly altered orthoclase grain surrounded on three sides (in the plane of the section) by a substance which seems to be chert, although it may possibly be glassy aphanitic groundmass of a volcanic rock.

Rock fragments include several grains of metaquartzite, one elongate mica-schist, one or more orthoquartzites, one quartz-sericite fragment, one granitic fragment (quartz, orthoclase, sodic plagioclase). The greater-than-average abundance of rock fragments is attributed to the relatively coarse particle size of the sandstone.

The white opaque grains are nearly all fairly well rounded with smooth surfaces. They seem to have formed by alteration of black opaque (ilmenite) grains which have the same general appearance. Their color ranges from nearly white to pale brown. Zircon and garnet are the most common of the nonopaque accessory minerals. The zircon grains are subrounded; the garnet is chiefly subrounded to rounded except where it is somewhat pitted. Tourmaline is chiefly of the subrounded brown igneous variety. Some blue pegmatitic tourmaline is noted in the heavy-mineral separates. Small prismatic grains of this mineral are rare, probably because of selective transport.

Apatite occurs as small rounded grains. One rounded flake of chlorite is observed. Staurolite is relatively scarce and those grains present are strongly etched. Its scarcity may possibly be due to post-depositional removal.

The structure of the sandstone in thin section seems to be massive, although cross-bedding is observed in the field. In summary, the following deductions are made: the quartz and perhaps the orthoclase overgrowths grew in a previous deposit, and became well rounded before their final deposition. The red clay coating so prevalent in most of the section was probably reduced by organic matter in waters which were less alkaline than usual. The presence of organic matter and perhaps temporary approach to more normal marine conditions are suggested by the brown semi-opaque material, pyrite, and glauconite. The time of introduction of the gypsum and calcite is not known, but it may have been later.

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Red Calcareous Sandstone

For comparison with the foregoing uncemented white sandstone, a brief description of a red, cemented rock is included. This sandstone is also from the Relay Creek member of the Whitehorse formation, and was collected from the same outcrop in sec. 18, T. 33 S., R. 16 W., Comanche County. The sample was taken from a 3-foot bed of red silty sandstone 7 feet below the thin dolomitic limestone layer. This rock is atypical in that it is poorly sorted for its grain size, and in that it has three different cementing materials as well as considerable red clay matrix.

Mechanical analysis gives the value of 3.62 for the phi median diameter (about 82 microns). The phi percentile deviation is 1.59. The thin section shows a few scattered larger quartz grains having an average diameter of 0.4 mm and a maximum observed diameter of 0.7 mm. These grains, however, are so few that their presence is not discernible in the mechanical analysis.

The smaller grains are sharply angular (particularly some feldspar) to subrounded. Some are etched ragged by calcium carbonate. The large grains are very well rounded. The sphericity is low to high in the small grains, and only moderately high in the large ones.

The thin section consists of about 60 percent grains, 35 percent cement, and 5 percent matrix.

The matrix is irregularly distributed and seems to occur as long stringers. In some areas it is a plexus of reddish birefringent material containing randomly oriented muscovite, biotite, chlorite, and small dolomite rhombs. Nearly all the grains are coated with red clay; some grains are particularly heavily coated with red iron oxide and clay, and were probably transported in that condition.

The chemical cement fills about 70 percent of the remaining pore space. It consists chiefly of large areas of calcite up to 2 mm in diameter, the individual crystalline units being larger than the sand grains which they enclose. In the more argillaceous parts of the slide very fine-sand-size dolomite rhombs are common. These rhombs, many of which have hollow centers, do not penetrate any of the sand grains and may be chemical-clastic in origin. Some must be at least in part post-depositional, however, because their crystal form is interrupted by sand grains. Approximately

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25 percent of the cement is gypsum, which is commonly associated with the carbonate but occurs in smaller areas. The average size of the individual gypsum crystals is only slightly larger than the average grain size of the sandstone. The sequence in cementation is not clear, except that the carbonate and sulfate cements seem to be post-iron-oxide, for no iron oxide coating cement is observed adjacent to a pore.

The mineralogy is similar to that in the thin section previously described, with the following exceptions. Muscovite and biotite make up almost 1 percent of the grains. They occur as relatively large flakes, some of which are strongly bent between the quartz and feldspar grains. Although black opaques (chiefly ilmenite) are fairly common, white opaque grains of corresponding size and shape are extremely rare.

No structure is visible in the thin section. The rock is massive and texturally nearly homogeneous except for the scattered large grains.

A thin section of Cedar Hills sandy siltstone which shows a similar distribution of red clay and carbonates is shown in Plate 19B.

One other fairly common type of fine-grained sandstone is a mixed detrital chemical clastic material. An example of this is collected from the lower part of the Marlow member of the Whitehorse formation in the SW¼ sec. 4, T. 32 S., R. 14 W., Barber County, Kansas. The rock is a salmon-colored highly calcareous very fine-grained feldspathic sandstone. The phi median diameter is shown by mechanical analysis to be 3.42 (95 microns), and the phi percentile deviation is 0.75. The sorting is about typical for that particle size.

Although the rock consists of about 65 percent calcite (in which the quartz and feldspar grains float), it is very friable and the calcite behaves as discrete sand grains rather than as cement (Pl. 15C). Examination of the sediment in the field leads to its classification as a feldspathic calcite-quartz sandstone. However, it is actually a sandy clastic limestone.

The calcite grains are angular to well rounded, chiefly subangular to subrounded. They show a greater range in grade size than do the quartz or feldspar grains. The grain boundaries are distinct, and some of them are obviously coated with thin films of clay or oxides; this is probably responsible for the friability of

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the rock. Each grain is a crystallographic unit. In a few areas the space between the calcite grains is filled with calcite which has different optical orientation, but in general the grains seem to fit against each other as if they were in a somewhat plastic or gelatinous condition when deposited; or else the iron oxides and clay materials were expelled as crystallization proceeded from individual centers simultaneously. The nearly uniform particle size distribution in the very fine sand size, however, seems to favor the first explanation. Much of the calcite contains minute inclusions of a green flaky mineral which may be chlorite, and some contains common fluid inclusions.

Clay matrix is essentially restricted to coatings on grains, particularly on detrital grains. The coating ranges from red opaque iron oxide to red clay to buff-colored clay.

The grains are thought to have been deposited with the clay already coating them. Calcite was deposited rapidly as gel along with the grains, from water which also contained ferric iron, magnesium ion, and some silica in solution (colloidal or ionic). Chlorite is considered to have crystallized shortly after deposition. Evidence of reworking of carbonate grains is shown in several thin sections.

Fine-Grained Clastics

SILTSTONES

Many of the siltstones in the section are very coarse grained; a large proportion of them are just at the sand-silt boundary (average diameter is about 4.5ϕ), and these have many of the characteristics of the very fine-grained sandstones described in the foregoing section.

White and Red Calcareous and Dolomitic Argillaceous Siltstones

The following paragraphs describe one of the finer grained siltstones which are common in the Salt Plain formation. It is not typical of the section as a whole, because it is too well sorted for its size; however, it seems to be typical of the Salt Plain except for its color.

The sample was collected from the middle part of the Salt Plain formation in the bluffs northwest of Attica, Harper County (S½ sec. 3, T. 32 S., R. 9 W.). The bed from which the sample

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was collected is 1.0 foot thick and consists of gray and red mottled slabby calcareous siltstone. Mechanical analysis of a 30-gram sample shows the phi median diameter to be 4.91 (about 40 microns), and the phi percentile deviation to be 1.21. The size and sorting are similar to those of Peoria loess in Kansas (Swineford and Frye, 1951). Some quartz grains in thin section are as large as 60 microns, and some mica flakes are of course much larger.

The thin section consists of about 55 percent grains (quartz, micas, feldspars), 20 percent matrix (chiefly micas and green clay), and 25 percent cement. Elongate and flaky grains show good preferred orientation locally, but the trend varies throughout the slide. The sorting within any one micro-layer seems to be very good.

The quartz grains are angular to subrounded (predominantly angular) and their average sphericity is rather low. The low roundness and sphericity are doubtless correlated with the fine particle size. The flakes of muscovite are markedly well rounded. One slightly worn hexagonal biotite flake was observed.

The matrix, which is not evenly distributed throughout the slide, consists of green micaceous clay (illite and chlorite) and shreds of mica, many of which are bent. There are a few areas of bright-red highly birefringent clay material showing rough optical orientation. Very thin, green, birefringent clay coats most of the grains.

The chemical cement consists of silt-sized blobs of calcite and rarer dolomite rhombs distributed throughout the thin section but particularly abundant in the coarser grained laminae. About one-fifth of the carbonate cement may be dolomite. Some of the cement encloses small spots of black opaque material, and some small areas of brownish-black opaque matter surround a few grains; this seems to be organic material. The bonding effect is probably due primarily to calcite because the rock splits along the micaceous shaly laminae.

The grains in the thin section consist of approximately 70 percent quartz, 15 percent feldspar, 8 percent muscovite, 3 percent biotite, 2 percent chlorite, 1 percent white opaques, and traces of red and black opaques, tourmaline, chert, and possibly metaquartzite.

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The quartz grains seem to be at least 60 percent of igneous varieties, but they are so small that their determination is difficult. Nearly all are very angular, and most have greenish-yellow clay coatings. The feldspars are predominantly orthoclase, most of which is very fresh and angular. A few slightly altered plagioclase grains were observed.

Muscovite, biotite, and chlorite occur as large to small flakes. Many are bent around the other grains. Most of the biotite is green, but its high birefringence distinguishes it from the chlorite. Some of the chlorite has aggregate polarization; some flakes are yellowish green.

The white opaque grains are angular to subrounded. Some may be leucoxene. The black opaque grains are small and are more angular than the white particles. The red opaques are similar to the white ones in general appearance.

One tiny green prismatic tourmaline grain with irregular black inclusions is observed. One grain of chert is noted, and one grain is identified as either metaquartzite or coarse chert.

Structurally, the rock is thinly laminated, with thickness of laminae generally less than 3 mm and commonly about 0.3 mm. Clay and fine mica flakes are somewhat segregated into laminae. Cut-and-fill features are present on a microscopic scale, and the laminae are curved (Pl. 19C).

Finer grained siltstones of the Salt Plain are similar to the above, except that preferred orientation of the micas is less pronounced, and the sorting is less perfect.

A red dolomitic feldspathic siltstone from the upper shale member of the Whitehorse formation is also somewhat similar to the siltstones of the Salt Plain, except for its structure (Pl. 15D). The rock is banded, mottled, and sworled, almost as if stirred with a spoon, and the flow structures resemble those in viscous material. Consequently the rock is not slabby. A micro-bedding feature of another red siltstone is shown in Plate 20A. Here the micas are concentrated in the shale lentils.

Sandy Siltstone

Another type of siltstone which is particularly common in the upper part of the section (especially in the Taloga formation) is a "micro-puddingstone" containing scattered large round sand

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grains. The following description is based on study of a thin section from a 0.2-foot bed of gray and red, fairly hard, calcareous massive sandy siltstone of the Taloga formation in the SE¼ sec. 3, T. 34 S., R. 26 W., Meade County (Pl. 19D). The rock, which is exposed in a stream bank, is a common type of sandy siltstone, except for the large quantity of carbonate cement.

Mechanical analysis indicates that the phi median particle size is 4.10 (about 59 microns)—just within the coarse silt range. The phi percentile deviation is 2.19; the rock is therefore much more poorly sorted than average for its grain-size. Poor sorting is not uncommon, however, in samples from the Taloga formation. Examination of the thin section suggests that the size distribution curve is trimodal, with rather large sand grains, coarse silt grains, and mica-like clay. The average diameter of the large grains in thin section is about 80 microns; that of the silt grains is about 40 microns.

The rock consists of about 50 percent grains, 45 percent cement, and 5 percent matrix. The silt grains are very angular to subrounded (especially weathered feldspar). Their sphericity is fairly low to high; most is moderately high. The "large" sand grains are all well rounded (except where replaced with carbonate) and have moderately high sphericity.

The matrix consists of red micaceous "clay" in localized blobs and stringers. The crystallite size is unusually coarse and the micaceous character of the material is obvious. The individual flakes seem to have random orientation. The clay also occurs as red coating on silt and sand grains.

About 90 percent of the cement is calcite, which occurs as intergrown allotriomorphic crystals slightly larger than the average clastic grain size. Dolomite (about 4 percent of the cement) consists of scattered rhombs of coarse silt size. Six percent of the cement is gypsum, also in allotriomorphic crystalline units of approximately coarse silt size to very fine sand size. The gypsum is associated particularly with the red micaceous clay. Gypsum seemingly replaces a few detrital grains. One orthoclase grain is nearly all replaced by gypsum and is surrounded by calcite; calcite replaces part of the gypsum.

The bonding effect is due chiefly to calcite. Much of the gypsum is bent, suggesting that it may have been formed first and later deformed by the growing calcite crystals.

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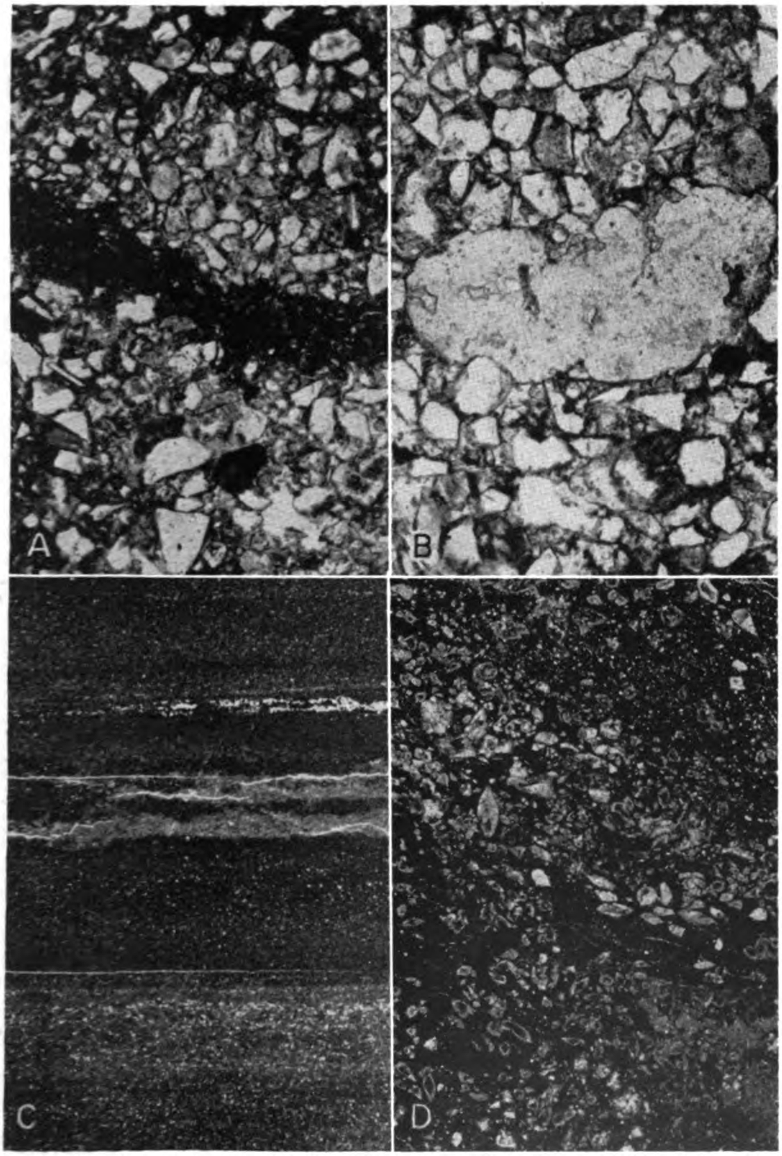

Plate 20. Photomicrographs of thin sections from Taloga, Wellington, and Dog Creek formations. **A,** Red shale lentil in red feldspathic sandy siltstone, Taloga formation; sec. 3, T. 34 S., R. 26 W., Meade County. ×76. **B,** Large chert grain partly replaced by calcite; Taloga formation, sec. 3, T. 34 S., R. 26 W., Meade County. ×76. **C,** Gray clay shale from Wellington formation; SW¼ sec. 4, T. 33 S., R. 1 E., Sumner County. ×8.5. **D,** Red silty shale with large dolomite rhombs; Dog Creek shale, sec. 4, T. 32 S., R. 14 W., Barber County. ×8.5.

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This is one of the most feldspathic rocks examined. The grains consist of about 70 percent quartz; more than 25 percent feldspars; 2 percent chert; 1 percent muscovite; somewhat less than 1 percent chlorite, biotite, ilmenite; and traces of rock fragments, zircon, rutile, and red and white opaque grains. The large grains are 95 percent quartz and 5 percent chert.

Most of the quartz (more than 60 percent) of silt size is characterized by straight extinction, bubble chains, acicular and other igneous-type inclusions. A few grains of vein quartz are observed. All the grains are coated with red clay (except where shattered or replaced by calcite or gypsum). One or two silt grains have been separated and pushed apart by coarsely crystalline calcite. One silt grain with a white opaque clay coating has a worn quartz overgrowth; in general, quartz overgrowths on the silt grains are rare.

Among the large rounded quartz grains, at least 80 percent show pronounced strain shadows; some have many criss-crossing bubble chains. At least two large quartz grains have worn quartz overgrowths, which are separated from the original grains by red clay coatings.

The feldspars are about 70 percent orthoclase, 20 percent plagioclase (chiefly oligoclase), and 10 percent microcline. The grains show various degrees of alteration, and several are partly replaced by calcite or gypsum.

Chert is found in both the sand and silt sizes, and at least four varieties are observed. About 5 percent of the large grains are chert; a large proportion of them are partly replaced by calcite. The calcite has attacked chert more readily than it has quartz (Pl. 20B).

Muscovite occurs as sparsely scattered flakes throughout, but much fine muscovite is concentrated in the clayey laminae (see also Pl. 20A). Chlorite is found as flakes with unit extinction, as green to brownish-green aggregate grains, and as replacement of some orthoclase. Biotite occurs as greenish-brown pleochroic flakes; a few are bent.

Ilmenite is by far the most common opaque mineral. It occurs as subrounded to subangular grains without white spots. The red and white opaque grains are seen on close examination to be, as a rule, heavy coatings on nonopaque grains.

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A few metaquartzite fragments are present, particularly in the large sizes where they constitute almost 3 percent of the large rounded grains. One green foliated metamorphic rock fragment is noted (small suite).

A few small subangular to subrounded grains of zircon are noted, as well as dusky golden-brown grains of rutile.

In thin section the structure is indicated by very irregular or wavy bedding on a small scale, shown by differences in grain size.

CLAY SHALE AND SILTY CLAY SHALE

The shales and silty shales show much variation from one thin section to the next, so that one or two descriptions are not adequate to show their character. Descriptions of a single red and a single gray shale are here followed by brief comments on thin sections of other specimens.

Red Shale

The first shale thin section described is from typical blocky reddish-brown Ninnescah shale collected in a stream bank along the Cen. S. line sec. 33, T. 26 S., R. 4 W., Reno County. The shale at this locality shows pronounced conchoidal fracture and contains scattered spherical greenish-gray spots with average diameters of about 9 mm, but only a small part of one spot is included in the thin section. In stratigraphic position this shale is close to Norton's Bed 3, or about 170 feet below the top of the formation.

Mechanical analysis indicates that the phi median diameter is 6.87 (about 8.5 microns). Strictly speaking, this is within the silt range, but the rock is classified as clay shale because it is not gritty and because it contains more clay minerals than other constituents. The largest quartz grain observed in thin section is nearly 60 microns in long diameter; most of the silt grains, however, are much smaller (average 20 microns, or less). The phi percentile deviation determined by mechanical analysis is 3.49. This is not so good as the expected degree of sorting, and it is not typical of mechanical analyses from other Ninnescah samples.

The rock consists of about 15 percent grains, 80 percent matrix, and 5 percent cement (or carbonates). The noncarbonate grains are all allotriomorphic, and are predominantly angular to

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subangular. Their sphericity is moderately low, and they show no preferred orientation.

The matrix is red clay; the slide shows several rounded elongate areas with aggregate extinction in one direction. These do not seem to be mud balls or areas of intraformational conglomerate, but are judged to be postdepositional "growth units" of the clay minerals. Two spherulitic areas are noted. The matrix contains numerous tiny flakes of white mica ("sericite"?), and small areas (up to 0.1 mm in diameter) which are not stained red with iron oxide. Aside from the color, there is no obvious difference between the greenish-gray spots and the red portion.

The chemical "cement," or carbonate fraction, consists of scattered rhombohedra of dolomite, all of silt size, many of which have growth zones or rhombohedral centers of red clay. The dolomite perhaps should not be referred to as cement, because its bonding effect is probably negligible.

The clay (or colloid) and silt grains were doubtless deposited together from water rich in Ca and Mg ions. The dolomite probably grew during deposition, and it may be partly responsible for the blockiness and conchoidal fracture of the rock. The iron oxide in the gray areas may have been reduced by minute quantities of organic matter deposited with the clay and silt.

The composition of the grains is difficult to determine because of their small size and extremely thick clay coating. Study of cleavage, alteration, and refractive indices of grains at thin edges of the section suggests that quartz probably constitutes about 75 percent of the grains; feldspars, 10 percent; and mica, 15 percent. The mica consists chiefly of small shreds of sericite-like material and perhaps should be considered part of the matrix.

Only about 15 percent of the quartz shows undulatory extinction, and most of this mineral is probably igneous in origin. Inclusions are difficult to determine because of the thick section and prevalence of red clay.

The feldspar seems to be chiefly orthoclase; almost no twinned plagioclase or microcline is observed. No chert is noted. The very small grain size may account for the absence of some of these features.

The matrix consists of about 97 percent red clay and 3 percent greenish-gray clay. X-ray diffraction data show that the clay minerals are predominantly illite and chlorite (Table 7). An elec-

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tron micrograph of particles from the fraction finer than 1 micron is shown in Plate 17.

The rock has a massive structure; some areas are coarser grained than others, but there is no clear bedding or lamination. Some very fine-grained bright red-brown lenses without silt or dolomite seem to be flattened clay galls. The rock, and similar blocky clay shales, may perhaps best be called reddish-brown dolomitic silty claystone.

Greenish-Gray Shale

A greenish-gray, blocky to splintery, silty clay shale, described in the following paragraphs, was collected from a road cut and stream bank exposing beds in the upper part of the Wellington formation 6 miles south of Mayfield, NE¼ SE¼ sec. 17, T. 33 S.,

TABLE 7.—*X-ray diffraction data for some shales and silty shales*

Wellington, gray, —1 micron, oriented		Ninnescah, red, —2 microns, oriented		Upper Whitehorse, red, glycerated		Taloga, basal, green, glycerated		Mineral
d(A)	I	d(A)	I	d(A)	I	d(A)	I	
				18	ss	18	ss	Mont.
14.5[1]	w	14.7[1]	mw	14.1	w	14.2	mw	Chlorite
10.2b[2]	s	10.2[2]	s	10.0	m	10.0	m	Illite
				9.3	w			?
				9.04	mw	9.1	mw	Mont.
7.19b	m	7.19	mw	7.07	w	7.1	mw	Chlorite (+kaol. ?)
5.02b	ms	5.02	wm	4.98	w	4.98	w	Illite
		4.8	w	4.71	w	4.69	ww	Chlorite
				4.56	w	4.57	w	
		4.53	w	4.53	w	4.53	w	
				4.47b	m	4.48	mw	Illite
				4.25b	w	4.25	w	Quartz?
				4.13	w			
						3.60	w	Mont.
3.56	m	3.56	mw	3.54	w	3.53	w	Chlorite (+kaol. ?)
				3.48	w			
3.34b	s	3.35	s	3.33	m	3.35	s	Illite, Mont., Quartz
		3.26	ww	3.25	w	3.24	mw	Feldspar
		2.90	s					Dolomite

[1] Does not shift after treatment with glycerol.
[2] Slight asymmetry, lost on glycerated sample, suggests small quantity of mixed-layer mineral or degraded illite.

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R. 2 W., Sumner County. The sediments at this locality consist of thin beds (2 inches to almost 4 feet thick) of variously colored splintery, blocky clay shales. The greenish-gray bed from which the sample for the thin section was collected is 1.7 feet thick and grades upward into brownish-red, green-mottled clay shale. The greenish-gray shale has a general appearance which is typical of most of the Wellington shales.

Mechanical analysis shows the average particle size of the material to be 7.80 phi (about 4 microns). The phi percentile deviation, 3.3, indicates that the relation between size and sorting is about average.

Comparatively few grains of silt size are observed in thin section; only 4 quartz grains with maximum projection diameter greater than 15 microns were noted. Some mica of that size is present. The rock consists of about 75 percent matrix (clay minerals) and 25 percent grains (mica, chlorite, and very small quartz and feldspar grains). No chemical cement is observed.

Parallel alignment of mica and clay is pronounced; this may be related to the absence of chemical cement. The largest silt grains are subangular to angular and somewhat elongate.

X-ray diffraction data indicate that the rock contains detectable quantities of illite, montmorillonite or expanding mixed-layer mineral, chlorite, and quartz, and a suggestion of feldspar. Chlorite is less common than in most of the shales and siltstones. Illite is by far the predominant clay mineral, but the character of the reflections in the diffractometer patterns suggests that it is much more poorly crystallized than are illites in most Pennsylvanian shales of Kansas.

In structure, the rock shows parallel bedding chiefly by the orientation effect, but it appears to be practically massive because of the uniform particle-size distribution throughout the slide.

Carbonates and Sulfates in Shales

Most of the silty shales and shales, both red and gray, contain significant quantities of carbonates or sulfates, or both. Dolomite and calcite are the most common. One greenish-gray (streaked with red) clay shale contains about 5 percent barite and gypsum. The barite occurs as scattered grains of coarse silt size; the gypsum is in slightly smaller units. Orientation of the clay minerals is less perfect than that in the noncalcareous, nonsulfate rock

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previously described. A clay shale (from the Wellington formation) which contains minute grains of anhydrite (or gypsum) and calcite is shown in Plate 20C.

A greenish-gray silty clay shale (claystone) from the Ninnescah formation contains at least 35 percent carbonate minerals (chiefly dolomite) as disseminated grains. No preferred orientation of the clay minerals is observed.

A very pale greenish-gray silty clay shale (claystone) from the approximate horizon of Ninnescah bed 4, contains not only calcite, dolomite, and barite, but also a trace of green copper carbonate. One area of malachite (?) in a thin section of this material consists of two bright-green grains with green highly birefringent streamers curving out from them. They may have developed from postdepositional alteration of an opaque copper mineral.

Large dolomite rhombs (up to 0.3 mm in diameter) characterize a sample of red silty shale from the Dog Creek formation (Pl. 20D). The silt and clay are somewhat segregated into separate areas, and there are some short streaks of seemingly nearly pure, opaque hematite. The structure is that of an intraformational conglomerate. The dolomite crystals may have been deposited with the clay and shortly after the silt; the whole was later reworked into an intraformational conglomerate.

A mottled red and greenish-gray dolomitic clay shale from the lower Ninnescah (near Bed 2) contains almost 50 percent dolomite. The dolomite rhombs occur as a complex irregular network throughout the clay, much of which shows good aggregate polarization. The network structure may have been formed following shrinkage of the mud. Irregular particles of black opaque material (apparently organic matter) are associated with the clay and also occur as inclusions in some of the larger dolomite rhombs. The presence of organic matter may account for the greenish-gray color of part of the clay, because it seems to have been bleached after deposition. Organic matter is much more common in the green clay than in the red.

A purple shale from the Wellington formation also seemingly owes its color to partial reduction of Fe^{3+} by organic matter. The organic matter occurs as fine-silt-size particles disseminated throughout the thin section, which also contains much carbonate. Chlorite is no more prevalent than in the common brownish-red dolomitic shales of the Ninnescah.

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Mineral Composition of Wellington Shale Sample from Drill Core

A small shale sample from the Morton Salt Company hole No. 4, in sec. 35, T. 23 S., R. 6 W., Reno County, southwest of Hutchinson was analyzed qualitatively by x-ray diffraction for mineral composition. Shales from the Wellington were the only subsurface samples available for comparison with surface material. The specimen was taken from a layer of gray shale interbedded with halite.

The raw sample (—250 mesh) produced reflections for anhydrite and for layer lattice minerals having basal spacings of 14.2, 10.1, and (faint) 7.14 A; and a very small quantity of quartz. Treatment with glycerol did not cause any measurable displacement of the 10 A or 14.2 A lines. A sample boiled in ammonium chloride did not destroy the 14.2 A reflection but produced a faint suggestion of an increase and shift in the 10 A peak. Treatment with warm dilute hydrochloric acid (Brindley and Robinson, 1951, p. 188) removed the anhydrite, and also eliminated the reflections at 14.2. 7.1, 4.84, 2.11, 2.00, and 1.70 A. As a result, the following layer lattice minerals are judged to be present, in order of decreasing quantity: illite, chlorite, and probably a small percentage of muscovite. Halite is not observed.

Evaporites

dolomites

Formal names of some of the carbonate stratigraphic units are somewhat misleading; thus, those samples of the Milan limestone examined for the present study are mixtures of dolomite and barite, and samples from the Relay Creek dolomite are shown (by x-ray diffraction) to contain at least 50 percent calcite. The basal dolomite from the Medicine Lodge gypsum contains a large proportion of gypsum, and the Carlton limestone of the Wellington formation seems to be dolomite. A few of the dolomites and so-called dolomites are here described in detail.

The first thin section described here is from the Stone Corral dolomite in the NE¼ NE¼ sec. 22, T. 20 S., R. 6 W., Rice County. The dolomite is porous and contains many vugs (about 0.4 to 5 mm in diameter), most of which are filled with clear, coarsely crystalline calcite. Some of the vugs are connected by calcite-

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filled veins. The main mass of the rock consists of minute rhombs of dolomite having an average diameter of about 10 microns and a maximum diameter of about 20 microns; the sizing is therefore very good.

In composition, the rock consists of about 90 percent dolomite, less than 4 percent quartz and feldspar, and less than 5 percent calcite, most of which occurs as vug fillings. No clay is observed in thin section or detected in x-ray diffraction patterns. Some brown opaque specks of organic matter are present, particularly around the edges of some vugs and as irregular subparallel bands from a fraction of a millimeter to 1 mm thick.

The quartz and feldspar occur as subrounded to very angular grains having an average diameter of about 30 microns and ranging up to 70 microns. Some of the grains have been partly replaced by carbonate. Much of the quartz shows undulatory extinction; perhaps 40 percent of it is of metamorphic origin. The quartz and feldspar are scattered throughout the slide, but seem to be more concentrated in the areas of organic matter (perhaps in part because they are not replaced by carbonate there).

Traces of detrital muscovite, green tourmaline (one grain), and white and black opaque minerals were observed.

The structure is massive and uniform except for branching irregular veins containing calcite and dolomite rhombs, and lenses of organic matter.

The thin dolomite bed at the base of the Medicine Lodge gypsum grades upward from carbonate into massive gypsum. Much of this bed is characteristically oölitic. The description which follows is based on examination of a thin section of oölitic dolomite-gypsum from a road cut south of Sun City in sec. 11, T. 31 S., R. 15 W., Barber County (Pl. 21A).

The texture is chemical-clastic. In general, the fabric pattern is one of odd-shaped oölites (mostly fine-grained dolomite) in a matrix of coarsely crystalline gypsum with dolomite rhombs. Gypsum clearly replaces some of the oölites. The rock is heterogeneous, but the sorting is good with respect to any one constituent. The average size of the oölites is 0.2 mm; the largest is 0.75 mm. Dolomite rhombs range in size from 0.01 mm to 0.08 mm. Some of the gypsum crystals are coarser than 1.5 mm.

Most of the oölites are elongate; some are crescent-shaped. Concentric structure is not well developed. A very few contain

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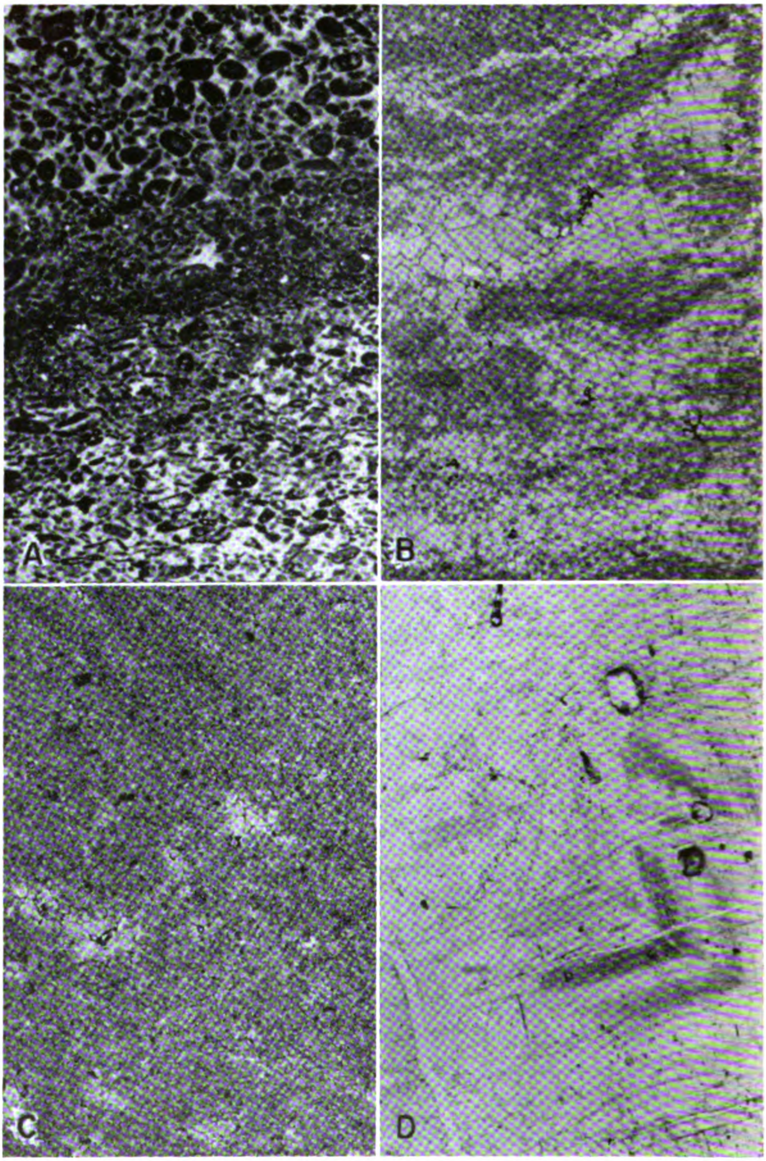

PLATE 21. Photomicrographs of dolomite and halite. **A,** Oölitic dolomite-gypsum from base of Medicine Lodge member, Blaine formation; SE¼ sec. 11, T. 31 S., R. 15 W., Barber County. ×8.5. **B,** Upper dolomite, Relay Creek? member, Whitehorse sandstone; sec. 18, T. 33 S., R. 16 W., Comanche County. ×8.5. **C,** Day Creek dolomite; sec. 33, T. 32 S., R. 22 W., Clark County. ×8.5. **D,** Halite from Carey Salt Mine, Hutchinson, Kansas. ×8.5.

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small quartz grains as nuclei but most do not; and most of the few scattered quartz grains are not within the oölites at all. There is no visible clay matrix. The cement consists of coarsely crystalline gypsum in some areas, minute dolomite rhombs in others, and mixtures of the two (dolomite rhombs in gypsum) elsewhere. The bonding effect is due chiefly to gypsum.

Seemingly the oölites are the oldest, but gypsum accompanied their deposition and replaced parts of the oölites. Some of the dolomite rhombs are probably post-gypsum, because they are found inside occasional oölites where there has been replacement by gypsum.

In composition, gypsum constitutes about 50 percent of the thin section, and most of the remainder is dolomite. There is less than 1 percent of quartz, and a trace of a grass-green mineral having aggregate polarization (tentatively identified as glauconite).

The small dolomite grains which make up the oölites are not idiomorphic. X-ray diffraction patterns, however, show no indication of calcite. The dolomite rhombs which occur in the matrix are more or less allotriomorphic against the oölites. The quartz grains have nearly all been strongly etched and are partly replaced by gypsum.

Bedding is suggested by differences in character of the cement and in shapes of the oölites. The crescent-shaped oölites are difficult to explain; they may possibly be fragments of older oölites which have been broken up, worn, and redeposited.

The Milan "limestone" is similar to the Medicine Lodge basal dolomite in that it is a mixture of carbonate and sulfate. The following description is based on study of a thin section from the type locality in Sumner County and on x-ray diffraction data on samples from several localities.

The rock is very fine-grained, earthy, porous material which has the general appearance of an argillaceous limestone. Diffraction data indicate that its composition is about 70 percent dolomite, 20 percent barite, 5 to 10 percent illite, less than 3 percent quartz, and a trace of malachite (segregated in green spots).

Texturally, the rock consists of a fine mosaic of dolomite and scattered barite crystals, with scattered small vugs and a faintly spotty appearance. The dolomite and barite particles are about the same size—i.e., 5 to 10 microns in diameter. A few larger

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crystals (principally barite) partly fill some vugs. Some of the vug fillings are a bright-green fine-grained (some fibrous) copper carbonate mineral which has been identified by x-ray diffraction as malachite. Some of the malachite is associated with or surrounded by a pink mineral which is probably celestite. Norton (1939) found chalcopyrite in the Milan member, but none was visible in the thin section examined by me.

The rock is massive except for the vugs and a vague mottling.

Samples of dolomite from the Relay Creek? member of the Whitehorse formation are shown by x-ray diffraction to contain at least as much calcite as dolomite; there are no reflections from quartz, feldspar, or clay minerals.

A thin section was made from material from a 3-inch bed of Relay Creek? dolomite from sec. 18, T. 33 S., R. 16 W., Comanche County, Kansas. The thin section (Pl. 21B) shows irregular bands of coarse crystals set in a finer matrix. The rock is essentially all carbonate, but the grains are poorly sorted with respect to size, which ranges from coarse silt size to 0.4 mm. The calcite grains, which are the largest, are irregular, straight-sided polyhedra in the plane of the thin section. Most of the dolomite grains are imperfect rhombs. The bonding effect is due to interlocking of crystals. The peculiar moth-eaten appearances of some of the dolomite suggests that it has been replaced by calcite, but this order of succession is not proved. Some of the dolomite appears as skeleton crystals inside calcite. Some dolomite crystals contain dark-brown to black, unidentified inclusions (organic matter?). Some dolomite crystals intersect boundaries between calcite crystals. The dolomite seems to be concentrated in bands in some parts of the slide.

The thin section shows a complex, irregular, wavy structure consisiting of alternating fine and coarse bands, some of which are as thick as 2 mm.

A thin section of pale pink, chert-free Day Creek dolomite was made from rock collected in sec. 33, T. 32 S., R. 22 W., Clark County, Kansas. The section consists of a mass of fine-grained dolomite rhombs with small, coarser grained areas (Pl. 21C). The average grain size is about 80 microns, and the range is from less than 40 microns to 350 microns. The dolomite particles are nearly all idiomorphic or hypidiomorphic; they show no preferred orientation. Some rhombs have black opaque inclusions (organic

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matter) at their centers. The bonding of the rock is due to intergrowth of dolomite crystals.

The pink color is attributed to a trace of ferric oxide, or iron oxide-stained clay, which fills a few interstices between dolomite rhombs and also coats some rhombs. Irregular elongate areas of coarser dolomite give the rock a mottled appearance. Nothing seen in the thin section corresponds to the wavy-ridged effect observed in weathered exposures.

The Carlton "limestone" of the Wellington formation was not studied in thin section, but x-ray diffraction data from several samples from Marion County indicate that it is composed principally of dolomite, with minor quantities of quartz and feldspars, and a faint suggestion of chlorite and illite. Calcite is not present in quantities detectable by x-ray diffraction.

Megascopically the Carlton is soft, earthy, porous, fine-grained, pale cream-colored rock; some zones are distinctly oölitic.

GYPSUM

A thin section from a sample from the Medicine Lodge gypsum (NE¼ NW¼ sec. 8, T. 32 S., R. 14 W., Barber County) is herein described. Megascopically the rock consists of white, coarsely "sugary" gypsum (crystals up to 1 mm diameter) with very pale-gray angular mottled areas. The thin section shows that the rock is homogeneous in composition but that the size sorting of the gypsum crystals is poor; the crystals range in size from less than 60 microns to more than 1,000 microns with an average diameter of about 200 microns. In shape, most of the crystals are prismatic with ragged ends. The bonding effect is due to intergrowth of gypsum crystals.

The only constituents other than gypsum seen in thin section are one idiomorphic crystal of barite, 50 microns in long diameter and containing carbonaceous inclusions, and one allotriomorphic area of unit-crystalline calcite about 80 microns in diameter.

The Medicine Lodge gypsum contains lenses of anhydrite (up to 2 feet thick) about 10 feet above the base of the member. According to McGregor (1948), both the gypsum and anhydrite were original precipitates, with only partial subsequent hydration of anhydrite to gypsum. McGregor reports gradation of anhydrite to gypsum, fracture fillings of gypsum in the anhydrite,

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absence of anhydrite in the upper and lower part of the gypsum, and no evidence of distortion resulting from hypothetical hydration of anhydrite.

HALITE

One thin section of salt was examined. The specimen was collected from the Carey Salt Mine at Hutchinson, Kansas. The thin section consists essentially of large allotriomorphic halite crystals, more than 2 mm in diameter, with a few very small mineral and fluid inclusions (Pl. 21D). The impurities are chiefly calcite, anhydrite, and shale.

Growth zones in the halite are marked by negative cubic crystals containing liquid or gas or both. Other fluid inclusions are elongate and are lined up en echelon. Minute grains of allotriomorphic calcite also occur along the growth zones.

Idiomorphic crystals of anhydrite range from fine silt size to larger than 500 microns in long diameter. They occur as microlites and inclusions in the salt, commonly in clusters associated with clay or along growth zones. Anhydrite constitutes less than 1 percent of the thin section.

Very fine-grained gray clay with high birefringence (probably illite) occurs as thin short sinuous streaks which seem to follow boundaries between some of the salt crystals.

A sample of mine-run salt from the Carey mine was found to have a water-insoluble residue of about 1.5 percent.

STRUCTURE

At their outcrop in Kansas, the post-Wolfcampian Permian rocks are nearly flat-lying, with regional dips of 10 to 15 feet per mile to the southwest. In the subsurface, the deposits thicken toward western Kansas, and are upturned at the Front Range and Wet Mountains in Colorado. Kay (1951, p. 24, pl. 9) refers to the areas in Colorado east and west of the Front Range, where the Permian and Pennsylvanian sediments are fairly thick, as zeugogeosynclines which grade into an autogeosyncline toward the Kansas line. Kay (1951, p. 107) defines a zeugogeosyncline as an intracratonal elliptical basin or trough which contains sediment from eroded complementing highlands within the craton. Autogeosynclines are similar, but without associated highlands.

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The following description of the structural history of the Permian rocks in Kansas is condensed from Lee (1953). In Pennsylvanian and early Permian (Wolfcampian) time, thick deposits were laid down in the Ouachita basin, and the rocks in Kansas thicken toward the southeast. The Central Kansas uplift was also active during that time. By Leonardian time, however, there was no further change in the Central Kansas uplift, and the region tilted toward the Hugoton embayment of the Anadarko basin. The salt beds were deposited as a result of gentle downwarping, somewhat to the east of the Hugoton embayment.

Before Cretaceous time the Permian redbeds were all tilted up toward the northeast and eroded, producing a low angular unconformity at the Permian-Cretaceous contact.

Small pronounced dips are common in present exposures of the Leonardian and Guadalupian? rocks. Most of these local structures are attributed to collapse caused by solution of underlying evaporites.

CLIMATE, SEDIMENTATION, AND PALEOGEOGRAPHY

General Classification

The presence in the detrital fraction of the sandstones and siltstones of 10 to more than 30 percent feldspars (chiefly potassium feldspar and minor sodic plagioclase) indicates that these rocks are primarily related to Krynine's (1943) arkose series. If the mineral compositions of the detrital fraction of the sandstones and nonargillaceous siltstones are plotted on the sedimentary series diagram of Krynine (1948, p. 137), they all fall within the arkose field and the orthoquartzite field (Fig. 13). (Many of the clayey siltstones fall in the low-rank graywacke field. A probable reason for this will be described later.)

Even those sandstones which are within the arkose area cannot be called arkoses. Krynine (1940, p. 50) has defined an arkose as a "highly feldspathic (30 per cent of feldspar or more) sediment derived from a granite and having the appearance of a granite." They are more properly called feldspathic sandstones, which Krynine describes as sandstones moderately rich in feldspar and not similar to granite in appearance.

In general, the post-Wolfcampian Permian deposits of Kansas are genetically more closely related to the arkose series than to

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any other series. The task remains to pigeonhole these rocks more exactly within the tectonic scheme. Krynine (1943) subdivides arkoses into tectonic arkoses, typified by the Triassic redbeds of Connecticut, and residual arkoses, which are commonly weathered and have not moved far from their source. Normal tectonic arkoses, which are of necessity thick and associated with post-geosynclinal pronounced uplift and usually block faulting, are not to be expected on relatively stable continental platforms such as the Kansas area.

The Kansas deposits are obviously not residual on feldspathic igneous rock. On the other hand they are said (Maher, 1953) to be correlated stratigraphically with quartzose sediments in Colorado which overlie true tectonic arkoses (Krynine, 1943). It is here proposed to refer to these Kansas blanket deposits as *ab*-arkosic in nature in the sense that they are "away from" tectonic arkose geographically, mineralogically, and texturally, but yet have their origin in the tectonic arkose framework. Such deposits are not necessarily post-tectonic, but they tend to be late tectonic.

The trend, then, from normal tectonic arkose to *ab*-arkose is in the direction of Krynine's first-cycle secondary orthoquartzite, as suggested in Figure 13.

Genetic Significance and Interpretation of Deposits

COLOR

A large proportion of the red shales, siltstones, and sandstones in the section all have the same reddish yellow-red hue (Munsell notation 2.5YR) and differ from each other only in value and chroma. The color of the average post-Wellington red Permian shale has a value of 4 and chroma of 4. The common red siltstones have a value of 5 and chroma of 6. The normal red sandstones have a value of 6 and chroma of 6. Although these colors seem rather brown in the color chart, the impression of redness is enhanced by a foreground of green grass and background of blue sky.

The value, which indicates degree of lightness, seems to be a function of the proportion of quartz and feldspar present in the sediment and not entirely coated. Thus sandstones show the highest value number. The causes for variations in the chroma notation (strength, or departure from neutral) are harder to in-

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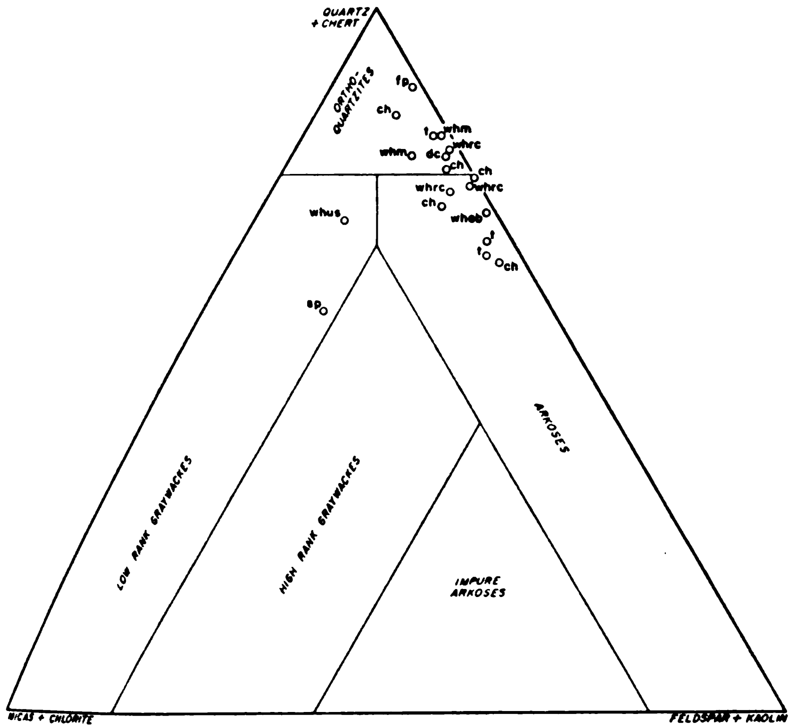

FIG. 13.—Mineral composition of detrital fraction of some Leonardian and Guadalupian? sandstones and siltstones. (**t**, Taloga; **whus**, upper shale member, Whitehorse; **wheb**, even-bedded member, Whitehorse; **whrc**, Relay Creek; **whm**, Marlow; **dc**, Dog Creek; **fp**, Flowerpot; **ch**, Cedar Hills; **sp**, Salt Plain.) Triangular diagram from Krynine (1948, p. 137).

terpret. Possibly the presence of large quantities of a neutral-colored clay mineral (illite) in the shales produces a chroma of 4 in the shales as opposed to 6 in the siltstones and sandstones. This is not probable, however, because the clay flakes are normally completely coated with opaque iron oxide.

The 2.5YR hue (reddish yellow-red) is attributed primarily, but not entirely, to the presence of hematite. The color of typical hematite streak (or fine powder) is about 7.5R3/4 or yellowish-red (Munsell Color Co., 1942). The pure hematite hue has less yellow in it than does that of the redbeds. The increment of yellow may be attributed to small quantities of hydrated ferric oxide or maghemite (γFE_2O_3) which are not detectable by the x-ray diffraction techniques used. Furthermore, according to Van

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Houten (1948, p. 2098), hematite having a low degree of agglomeration and small crystal size may impart a yellow color to sands. The unimportance of coloration from chlorite seems to be due to iron oxide coatings on the smaller chlorite flakes. Thus purple color (owing to mixing of red from iron oxide and green from chlorite) is extremely rare.

The uniform orange-red color of the mid-continent Permian may be attributed to thorough redistribution of ferric oxide from complex colloids in contact with the highly alkaline Permian sea water at the same time that the authigenic layer lattice silicates (particularly chlorite) were being formed. Excess iron may have been expelled from the developing crystal lattice and hence thoroughly coated the surfaces of the flakes with iron oxide. Actual production of "new" hematite under conditions of high pH and high Eh helps to account for the remarkable uniformity of red coloration. Not all of the red hematite, however, was formed as such at the time of deposition; some of it was obviously transported into the basin of deposition as coatings on sand and silt grains, and some doubtless was associated with true detrital clay minerals. Some feldspars contain red iron oxide along cleavage planes.

Possible sources of the older iron oxide coatings are twofold: (1) in the upland primary source areas; and (2) in the more local regions of gentle warping and erosion of nearly contemporaneously deposited redbeds.

The extensive literature on the origin of redbeds and on the causes for their color has been carefully reviewed by Van Houten (1948), and a fourfold classification of redbeds has been made by Krynine (1949). Krynine's classification is herein summarized as follows.

1. *Redbeds produced from red soils (primary redbeds).* Pigment developed by weathering of iron-bearing minerals at source area. Pigment incorporated into resulting sediment
   (a) after erosion and transport (primary detrital redbeds);
   (b) by local reworking of regolith (primary reworked redbeds);
   (c) by lithification of regolith with little or no reworking (primary residual redbeds).

2. *Redbeds produced from nonred detritus by oxidation within the sediment*
   (a) immediately after deposition (post-depositional redbeds);

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(b) after burial, emergence, and deep subsurface oxidation (postdiagenetic redbeds).

3. *Redbeds produced by reworking of older redbeds (second cycle or secondary redbeds).*
4. *Redbeds produced chemically by precipitation from solution within basin of sedimentation*
   (a) under marine conditions;
   (b) under freshwater conditions;
   (c) authigenically and intrastratally by infiltration.

The Permian redbeds of Kansas seem to belong in the first group: primary detrital redbeds. That is, they were produced from red soils, and their pigment was developed by weathering of iron-bearing minerals at the source areas, and incorporated into the resulting sediment after erosion and transport.

Other possibilities may be eliminated as follows. The deposits are obviously not primary residual or primary reworked redbeds, because there is no feldspathic regolith in the area. Field evidence from nonred areas within the redbeds indicates that their original color was red and that the iron was reduced shortly after deposition rather than being oxidized after deposition. Thus postdepositional and postdiagenetic redbeds are eliminated.

There is no evidence for extensive reworking of older redbeds to produce the Kansas Permian sediments. That a slight amount of such reworking may have taken place, however, is shown by occasional quartz and feldspar grains having red clay coatings which are covered by seemingly worn overgrowths. Such grains, however, are not common. Any significant reworking of older redbeds is considered to be the result of gentle warping which may have subjected only slightly older material to erosion. This does not involve more than one major cycle.

The Kansas redbeds are not considered to have been produced chemically by precipitation from solution, because such precipitation should have formed at least a few layers or lentils of comparatively pure iron oxide rather than just coatings on other grains. The proposed reorganization of the colloidal hydroxides and oxides at the site of deposition is a chemical process, but the hematite was not produced by precipitation from ionic solution, and the resulting redbeds are not related to the true chemical redbeds which form important ore deposits.

The primary detrital nature of the Kansas redbeds and their differences from primary detrital continental redbeds (as typified

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by the Triassic of Connecticut) will be discussed in the remainder of this section.

SIGNIFICANCE OF EVAPORITES AND SALT CASTS

The traditional textbook association of gypsum and halite with conditions of aridity is well known. Although the association of redbeds with aridity is no longer considered valid (Krynine, 1950), there is good reason for attributing the presence of evaporites to a dry climate. The only statement, however, that can be made with reasonable certainty concerning the climatic significance of Kansas evaporites is that they indicate an excess of evaporation over precipitation plus runoff from land areas. Arid conditions are therefore suggested but not proved.

The more important significance of the thin, wide-spread evaporites is twofold: (1) they indicate relative tectonic stability of the area with only gentle warping, and at least a partial barrier to the open sea[1]; (2) they suggest the chemical nature of the water in which the sediments were deposited. The presence of thin beds of chemically precipitated dolomite, anhydrite-gypsum, and salt, and the common salt casts (Pl. 14B) at many horizons throughout the redbed section shows that a high concentration of dissolved salts must have been available and important in modification of the deposits.

ABSENCE OF FOSSILS

The only fossils associated with the redbed section in Kansas (aside from two teeth and an unidentified bone in the Ninnescah shale) are the brine shrimp, *Cyzicus* (Pl. 22A). These animals, which are also common in the Wellington shale, are restricted to nonred bedding units. They are not found stratigraphically higher than the mid-Ninnescah shale. According to Zittel (1937, p. 734) this genus (*Estheria*) occurs mostly in brackish and shore deposits. Moore, Lalicker, and Fischer (1952, p. 544) state that the brine shrimp is able to live in excessively saline lakes and lagoons.

Problematical worm borings are present in a few calcareous and dolomitic siltstones of the Ninnescah shale.

No vertebrate fossils or tracks have been observed in the post-Wellington redbeds of Kansas, and no plant remains are known.

[1] In a recent paper Rutten (1954) postulates that the world's large salt deposits, such as the Zechstein, formed in inland basins fed by fresh-water springs and had no connection with the sea.

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Plate 22. Sedimentary structures, Leonardian rocks, **A**, *Cyzicus,* Wellington shale; NW¼ NW¼ sec. 15, T. 24 S., R. 1 E., Harvey County. ×1.3. **B**, Cross-bedding in buff-colored very fine-grained calcareous feldspathic sandstone, Ninnescah formation; W½ sec. 14, T. 35 S., R. 3 W., Sumner County. ×1.

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If animals and plants were present, their remains must have been completely destroyed by oxidation. Absence of tracks may possibly be ascribed to general nonterrestrial conditions of deposition. On the other hand, conditions of high salinity may have made most forms of life impossible.

The Verden channel sandstone in the lower part of the Whitehorse formation in northern Oklahoma contains a molluscan fauna which has been shown to be marine (Newell, 1940). Although there is no general agreement as to the origin of the Verden and similar channels, the marine character of the fauna is significant. One of the later studies of the Verden sandstone (Evans, 1949) suggests that the sand body was formed by salinity or tidal currents flowing through a strait or pass, connecting the restricted basin with the more open and fossiliferous Whitehorse sea to the south.

Tomlinson (1916, p. 172) notes that in general the distribution of gray and green colors in the redbeds of western United States coincides closely with distribution of organic remains in so far as such remains are present. He believes that organic remains now obliterated explain at least the greater part of the remaining gray and green areas. He (p. 169) attributes the green spots, which are so common in the red sandstones and shales, to the former presence of minute specks of organic matter (such as vegetable fiber or minute organisms of any kind), which reduced the ferric iron in their immediate vicinity. He notes the actual presence of such organic specks in green-spotted redbeds elsewhere. The remarkably evenly spaced distribution of the green spots in some of the Kansas redbeds suggests that the reducing agent responsible for them may in some way have been organic colloids present in the water which brought in the other colloidal sediments.

Some of the green spots are obviously associated with carbonates. Plate 23B shows extreme development of such spots in the Ninnescah shale (specimen from E. line W½ sec. 14, T. 35 S., R. 3 W., Sumner County). In this particular specimen many of the spots are hollow and are lined with calcite crystals. The association of calcite with decaying organic matter has been described recently by Weeks (1953) who attributes it to an inrease in pH caused by evolution of ammonia as the organic matter begins to decompose. The association of brownish specks of organic matter

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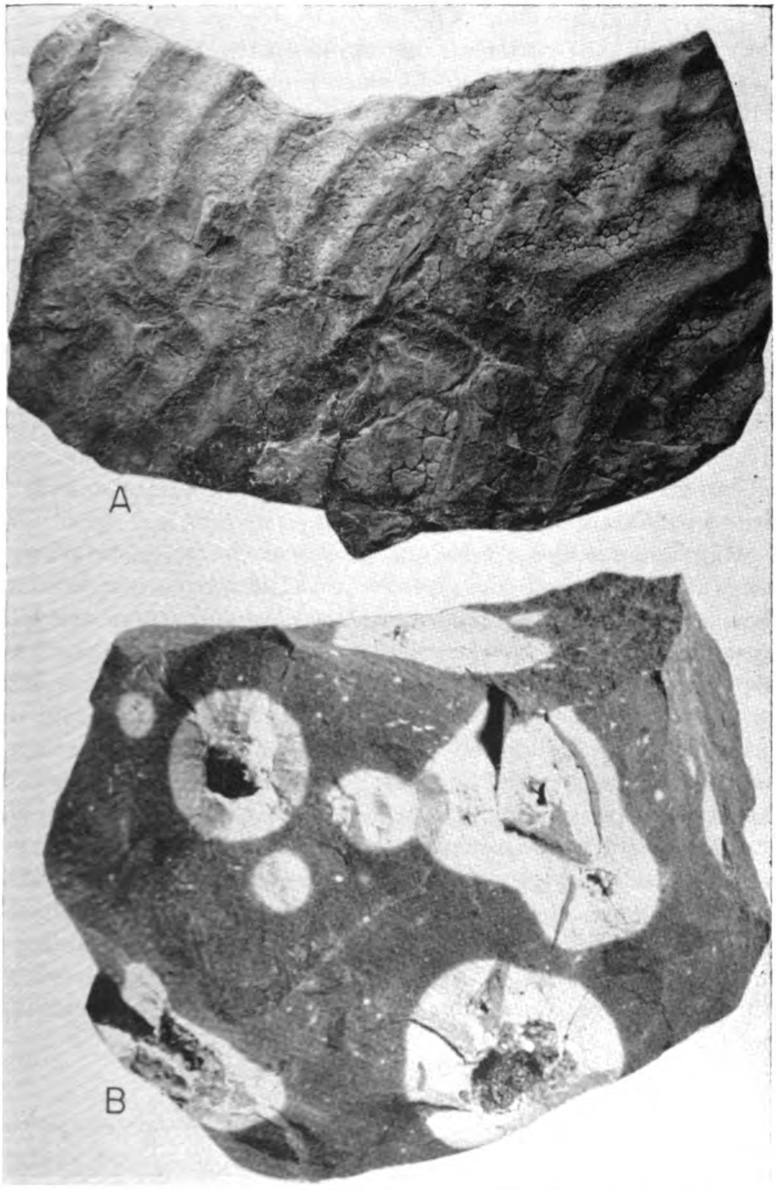

PLATE 23. Sedimentary structures, Leonardian rocks. **A,** Ripple marks and mud cracks in light greenish-gray dolomitic feldspathic siltstone, Ninnescah shale, Bed 2; NE¼ sec. 4, T. 27 S., R. 4 W., Sedgwick County. ×0.3. **B,** Extreme development of green spots in red Ninnescah shale; W½ sec. 14, T. 35 S., R. 3 W., Sumner County. ×1.1.

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with certain thin carbonate layers, as in the Dog Creek shale, may perhaps be ascribed to the same process.

The only other features noted by me which are suggestive of the former presence of organic matter are rare particles of pyrite (some of them associated with glauconite) in certain white sandstones, such as that in the Relay Creek? dolomite and sandstone member of the Whitehorse sandstone.

RIPPLES, RAIN PRINTS, MUD CRACKS, CROSS BEDDING

Ripple marks and mud cracks are common at many horizons in the redbed section. Some distinctive beds of calcareous or dolomitic siltstone which can be traced over distances of many miles are characterized by oscillation ripples on their upper surfaces. A slab from one such bed, which also displays mud cracks, is shown in Plate 23A.

Ripples and mud cracks are of course characteristic of shallow-water deposition. The presence of mud cracks, suggests, but does not prove, temporary emergence. These features are most common in the lower part of the section (Ninnescah through Salt Plain) and in the Dog Creek shale, but are also present in other formations. Problematical rain prints are observed in only one locality, in gray Wellington shale. Rain prints are more characteristic of actual terrestrial deposits than of subaqueous deposits.

Cross bedding and oölites, which are common, are other characteristic features of shallow-water deposition. Some of the cross bedding, particularly in the Whitehorse sandstone, is rather large scale, and some is microscopic. No eolian cross bedding is observed. Plate 22B shows moderately small-scale cross bedding in a very fine-grained calcareous feldspathic sandstone from the Ninnescah shale. The compass direction of the cross bedding is variable.

MINERALOGY

Certain features of the mineralogy have particular genetic significance in the interpretation of the deposits. These features have been described in the section on petrography and will be only summarized here.

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Condition of Feldspars

The presence in the feldspars of all stages of weathering (within a single specimen) suggests an erosional history similar to that of Krynine's tectonic arkoses; that is, rapid erosion in V-shaped canyons under humid tropical conditions. The preservation of the feldspars under conditions of long transport is probably in part a function of their relatively small particle size, and in part a function of the chemical composition of the water in which they were transported and deposited. The direction was in the production of overgrowths rather than in the destruction of the mineral.

Coarse (Detrital) Micas

The presence of chlorite flakes in large quantities is not typical of arkosic material derived from granite rocks. Most of these flakes are judged to have been altered from biotite by the magnesium-bearing water in which they were deposited. Various stages of alteration from biotite to chlorite are observed. Some chlorite could have been derived from schists intruded by granitic stocks, as in Connecticut, or from metamorphosed sediments of the Ouachita region.

The well-rounded character of the micas (chiefly muscovite) in the Salt Plain formation is worthy of note. Krynine (1950, p. 83) describes similar muscovite flakes having almost perfectly rounded coinlike shapes from lacustrine beds of the Triassic of Connecticut and also from Pleistocene glacial lake deposits of Connecticut. Wear of the mica flakes by gentle bottom currents rather than by fluviatile currents is thus indicated. This picture agrees well with the evidence from the size-sorting data from the Salt Plain samples which indicate much reworking of the material.

Clay Minerals

Little or no kaolinite is observed in the redbeds, and there is no evidence for gibbsite. Although these minerals should have been contributed from humid tropical source areas, they were probably completely altered after deposition. The large quantities of chlorite and illite seem to have developed authigenically within the sediments, and they were probably produced in part at the expense of kaolinite and gibbsite. Millot (1949) has shown that

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the clay minerals observed in a sediment are in large part a function of the cations present, and that kaolinite is not likely to grow in the presence of calcium ion. Magnesium ion, on the other hand, leads to the growth of chlorite minerals. Millot (1953) notes that illite and chlorite (but not kaolinite) are typical of the deposits of large supersaline lakes more or less linked with the sea. According to him, the mechanism of inheritance would appear inadequate to explain such a general phenomenon, and he considers it necessary to postulate the building up of the micaceous network in a basic milieu. Rivière (1953), on the other hand, believes that most clay minerals are transported and deposited without alteration. He writes that the lagoonal milieu of evaporation corresponds to a relatively dry climate in which the evolution of the soils of the watersheds scarcely passes the illitic stage. The presence of deeply weathered feldspars and the abundance of hematite, together with the paucity of unstable minerals in the Kansas Permian redbeds do not support Rivière's hypothesis.

The abundance of chlorite and illite, rather than kaolinite, is the factor which places the argillaceous siltstones in the low-rank graywacke field of Krynine's (1948) diagram (Fig. 10). This is seemingly a matter of diagenesis and therefore does not have the implied tectonic significance, except in so far as the Kansas area can be called part of a mild autogeosyncline.

Van Houten (1948, p. 2100) reports illite as the predominant clay mineral in various western redbeds, including the Chugwater, Spearfish, and Chinle formations, and does not find even subordinant kaolinite in these redbeds. In a study of clay minerals in sedimentary rocks and derived soils, Van Houten (1953) reported illite and some montmorillonite as the predominant clay mineral groups in Permian "Cimarron" (term discarded by Kansas Geological Survey) red sandstones and siltstones from Sumner, Harper, and Barber Counties, Kansas. The fact that chlorite is not mentioned by Van Houten does not necessarily indicate that it is not present. The importance of chlorite in the fine fractions of sediments has only recently been recognized by clay mineralogists, and it is quite possible that this mineral was not recognized as such at the time the work was done. Preliminary treatment of Van Houten's (1953, p. 70) samples with HCl may also have destroyed any chlorite present. Van Houten (1953, pp. 72-73) suspected the presence of a colloidal magnesium silicate

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mineral in two of his Kansas redbed sediments because he found high MgO content coupled with low CO_2. He suggested indirectly that this colloid might be related to attapulgite or sepiolite.

The point to be stressed is that illite rather than kaolinite is the predominant clay mineral in the redbeds. This is in direct opposition to the observation of kaolinite and gibbsite in the Triassic of Connecticut by Krynine (1950). In my opinion this merely points out the environmental difference between terrestrial redbeds and those deposited under water in a broad saline basin.

The presence of large quantities of montmorillonite in the Whitehorse and Taloga formations may be related to volcanic activity in Mexico during Guadalupian? time. Bentonites are common in the Guadalupian rocks of west Texas. Adams and Frenzel (1950, p. 296) report that bentonite is common in the Grayburg (upper Guadalupian) formation, and they suggest that it is derived from a volcanic area in Mexico. Adams and Frenzel (1950, p. 304) also state that bentonite "was probably widely distributed over the southern Permian Basin, but it is seldom recognized in the anhydrite and salt sections."

Present-day soils developed on the Kansas redbeds have approximately the same clay mineralogy as do the redbeds themselves (Van Houten, 1953). During the interval between the close of Permian deposition and the beginning of Cretaceous deposition in the area, however, kaolinite developed in the now-buried zone of alteration formed on the Permian redbeds.

TEXTURE

The fine particle size of most of the grains in the Kansas redbeds suggests low energy levels of transportation, an only moderate supply of clastics, and great distance from source areas. The large rounded quartz and chert grains which are scattered among the finer sediments in the upper part of the section obviously had a different source or sources and are believed to have been derived from isolated mountain uplifts to the south within the basin; their coarseness increases markedly into Oklahoma. The large quartz and chert grains are typical of second-cycle orthoquartzites, and they seem to have been derived from erosion of Cambro-Ordovician rocks. Adams and Frenzel (1950, pp. 299, 304) describe similar large quartz grains from the upper Guad-

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alupian Yates, Seven Rivers, and Queen formations of the Capitan barrier reef area, Texas and New Mexico. According to Adams (personal communication), scattered rounded quartz grains are present in the upper Permian rocks throughout the Permian basin. Honess (1923, p. 59) describes similar well-rounded, strained quartz grains from Ordovician sandstones of the Ouachita mountains of Oklahoma. The Ouachita complex may have been the chief source of these large grains and may also have provided much detrital chlorite to the redbeds.

Sedimentary Processes, Source Areas, Diastrophic Background, and Landscapes

By way of summarizing the conclusions drawn from a petrographic study of the Permian redbeds of Kansas, it may be enlightening to compare, point by point, the general characteristics of the Kansas redbeds with the Triassic redbeds of Connecticut as described by Krynine (1950). The comparison is shown in Table 8.

The general picture of the area in post-Wolfcampian Permian time is one of a broad, shallow, fairly stable basin, bounded on the west by the Front Range and Wet Mountains, which supplied most of the feldspathic debris. The orogenic movement, which started to produce arkose in Pennsylvanian time and continued into the Permian, is not a typical post-geosynclinal orogenic stage but was more limited in extent and was probably characterized more by folding than by block faulting.

On the north and east the Permian basin was probably bounded by low-lying land areas which supplied little or no debris. To the south of the Anadarko basin was a restricted connection with the open sea, and several local uplifts which formed islands of mountain ranges, such as the Arbuckles, the Wichitas, and possibly intermediate mountains. Other possible land areas are the Ozark uplift and the Ouachita system.

It is thought that the source of the large rounded quartz and chert grains was in the Cambro-Ordovician orthoquartzitic sediments that underlay the entire area and were exposed to erosion locally in the isolated uplifted areas. Such a wide-spread source would account for the ubiquitous distribution of these grains.

Almost no clastics coarser than silts reached the Kansas outcrop area before Cedar Hills time, when numerous wide-spread

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TABLE 8.—*Comparison of post-Wellington Permian of Kansas with Triassic of Connecticut*

Feature	Triassic of Connecticut*	Post-Wellington Permian of Kansas
Sedimentary series	Tectonic arkose	Tectonic arkose, plus second-cycle orthoquartzite
External morphology	Prism	Thin blankets
Distance from source	Adjacent	Several hundred miles
Thickness	More than 15,000 feet	About 2,000 feet
Lithologic types	Coarse arkosic sandstones and conglomerates; siltstones, red and black shales, very subordinate limestones	Very fine feldspathic sandstones, siltstones, and shales (chiefly red); many thin, persistent dolomites, limestones, gypsum beds
End members	Coarse-grained arkosic detritus	Fine-grained feldspathic sand and silt (chiefly red)
	Fine-grained detrital clayey matrix (red or black)	Clayey matrix, largely authigenic, chiefly red
	Carbonate cement (chiefly calcite)	Carbonates and sulfates (chiefly dolomite and gypsum)
		Salt in subsurface
Types of deposits	Channel, lacustrine, floodplain; limited extent. Continental piedmont	No obvious channels. Very extensive thin beds; some problematical floodplain. Chiefly restricted marine
Source of carbonates, etc.	Post-diagenetic circulating solutions due to structural activity Waters of lakes and swamps	Water in which sediments were deposited
Accessory minerals	Abundant and varied: up to 7.7 percent heavy minerals	Sparse; less than 1 percent heavy minerals
Evaporites	Infrequent casts of soluble salts	Abundant salt casts; dolomite, gypsum, anhydrite, and halite beds
Fossils	Wood throughout entire section; other plant remains common. Abundant reptilian tracks; fish in black shales	Brine shrimp in lower part of section. No tracks reported in Kansas
Clay minerals	Kaolinite, gibbsite, sericite-illite	Illite, chlorite, some montmorillonite
Distribution of iron oxide	Variegated. Grain coatings, and also concretions similar to those of soils (indicating subaerial weathering); 52 percent red rocks	Uniformly distributed as coatings, except where reduced; 87 percent red rocks
Desiccation marks and other structures	Mud cracks, rain prints, tracks; very common	Mud cracks common in some parts of section. Ripple marks and noneolian cross bedding common. No post-Wellington rain prints observed
Climate	Hot and humid at source and probably also at site of deposition	Hot and humid at source; probably dry at site of deposition

*Krynine, 1950.

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very fine sandstones were deposited. Cedar Hills deposition was followed by another period of extremely fine clastic supply, and the Flowerpot shale was deposited in quiet water rich in calcium and sulfate ions. This episode culminated in deposition of widespread evaporite deposits (Blaine gypsum-anhydrite). An influx of fine feldspathic sand, perhaps both from the west and south, produced the Whitehorse formation. The supply of medium-grained clastic material gradually diminished during Whitehorse time, and montmorillonitic (bentonitic?) clays were deposited, as was also a thin persistent dolomite (Day Creek). The poorly sorted sands and silts of the Taloga formation suggest the incidence of slight instability and perhaps the deposition of poorly reworked flood-plain materials before the Permian seas withdrew entirely from the area.

ECONOMIC GEOLOGY

Within the past 80 years the Permian redbeds of Kansas have yielded building stone, clay for bricks, gypsum, salt, paint pigment, riprap, and road material. At the present time, however, commercial production from the Leonardian and younger Permian rocks is (with the exception of one brick plant) limited to the evaporites in the section—salt, gypsum, and dolomite.

Starting with the evaporites, the various commercial materials and the history of their utilization (so far as it is known to me) are described briefly in this chapter. There will also be some mention of potential ceramic uses of some of the silty clays.

Halite

All the Permian salt beds which have been exploited commerically for salt to date are restricted to the Hutchinson salt member of the Wellington formation. The history of development of Kansas salt industry has been ably summarized by Taft (1946) and much of the following discussion is adapted from his report.

The Hutchinson salt member at Hutchinson was first discovered in 1887 by Ben Blanchard, who was prospecting for oil. By 1888 salt was being produced from brine wells by 13 different plants, with an annual production of 900,000 barrels. The number of producers operating in any one year has varied greatly since that time, but from 1889 to the present, Kansas has been among the top five salt-producing states. In 1952, the total

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Kansas production was 911,744 short tons, having a dollar value of $6,850,027 (W. H. Schoewe, personal communication). Average annual production is about 800,000 tons.

Five mines are in operation at the present time, and several wells also produce salt. They are located at Lyons, Kanopolis, and Hutchinson. A view of the Carey Salt Company mine at Hutchinson is shown in Plate 24C. This mine, which has been in operation since 1923, is producing from a 7 to 12-foot layer of salt 645 feet below the surface.

Salt beds farther west and stratigraphically higher are used for storage of hydrocarbons.

Commercial deposits of potassium minerals have not yet been found in Kansas salt beds, although small quantities of polyhalite have been described from several localities (Smith, 1938; Runnels, Reed, and Schleicher, 1952; Swineford and Runnels, 1953). Minable quantities of potassium salts conceivably may be discovered in the future.

Gypsum and Anhydrite

Within the area of this report, commercial deposits of gypsum are restricted to the Blaine formation. To the north, however, older Permian rocks contain workable gypsum deposits. In the vicinity of eastern Saline County are several layers of minable gypsum in the Wellington formation. Still farther north, in Marshall County, gypsum is mined from the Council Grove group of late Wolfcampian age.

The only active mine in the Blaine formation is located in the Medicine Lodge member southwest of Sun City in Barber County, where the gypsum attains a total thickness of about 30 feet. The mine is operated by the National Gypsum Company, and the rock is processed in a mill at Medicine Lodge.

Blaine gypsum has also been mined in other near-by areas. Several abandoned pits may be seen in the vicinity of sec. 19, T. 30 S., R. 15 W., in the northwest corner of Barber County. The gypsum industry in Kansas started in 1872 in Blue Rapids, but the first mill in the southern Kansas area was not built until 1889 (Jewett and Schoewe, 1942, p. 140).

Thin discontinuous beds of gypsum in the Wellington formation have been exploited occasionally in southern Marion County, northeast Sedgwick County, and eastern Sumner County, four

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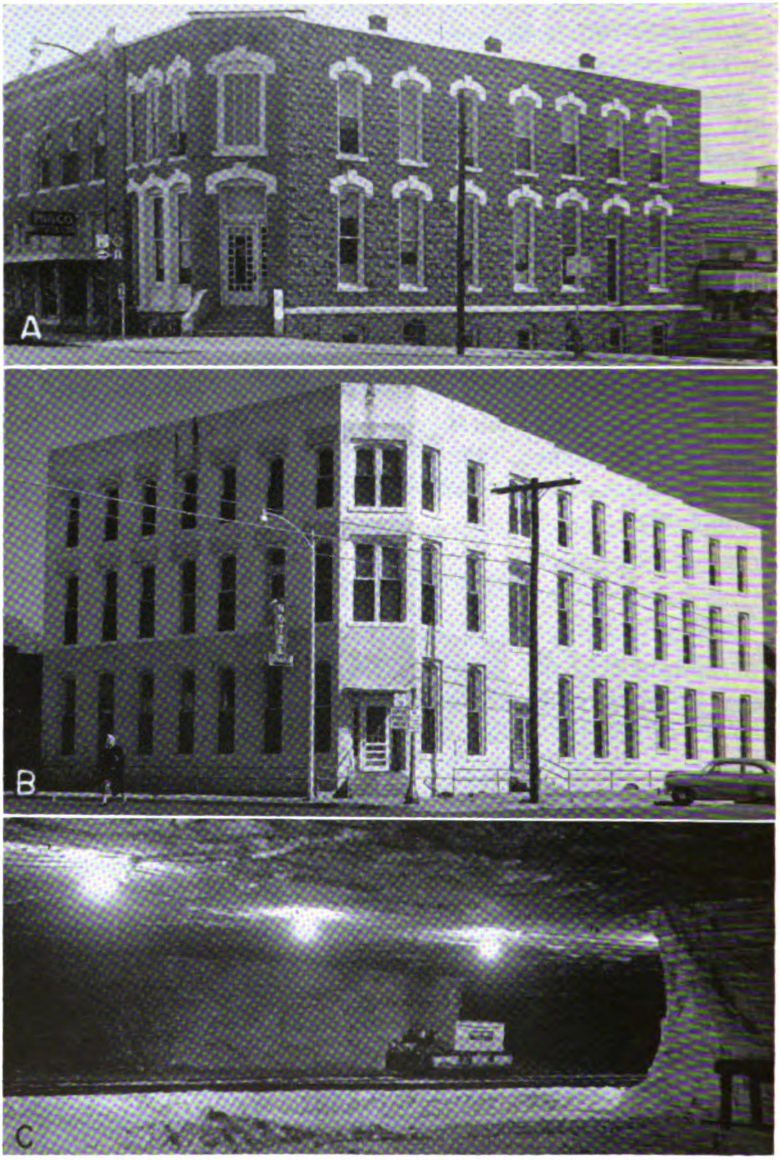

PLATE 24. **A**, Building in Caldwell, built of stone from Ninnescah formation. **B**, Hotel in Medicine Lodge, built of brick made from Cedar Hills sandstone. **C**, Interior of Carey Salt Company Mine, Hutchinson.

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miles northwest of Geuda Springs (Grimsley and Bailey, 1899, p. 69). Gypsum was mined for building stone at this last locality sometime between 1878 and 1889 (Hay, 1890; Grimsley and Bailey, 1899, p. 69), and the cut stone was used in a large business block in Wellington.

The gypsum is normally used as a retarder in Portland cement, as plaster of Paris, cement plasters, and fabricated products such as wall board and insulating material.

Anhydrite is produced at the Sun City mine and is discarded at the site. This waste product may conceivably become a minor source of sulfur in the future. In England and Germany anhydrite is treated with ammonium hydroxide and carbon dioxide for the manufacture of ammonium sulfate. In England sulfuric acid and Portland cement are made from anhydrite (E. K. Nixon, personal communication). Anhydrite is used in some areas—notably Virginia—as a soil conditioner. Much research has been done on the use of anhydrite as a retarder in Portland cement, and in plaster. The general sparseness of resistant rock in the area has led to some use of anhydrite as facing material in earth dams for stock ponds; conceivably it may last until the pond is silted. The mineral might perhaps be used for some diluents or fillers.

Dolomite

Two dolomites thick enough to be of commercial value exist in the stratigraphic section of the area. These are the Stone Corral of Rice County and the Day Creek dolomite in Clark County.

The Stone Corral, which attains a maximum thickness of 6 feet, is quarried along the southwestern bluff of Little Arkansas River, in eastern Rice County, as in sec. 15, T. 20 S., R. 6 W. The dolomite is used as crushed rock and formerly also was quarried for building stone (Fent, 1950, p. 15).

The Day Creek dolomite, which maintains an average thickness of 2½ feet over a large area in Clark County, is more uniformly dense than the Stone Corral, and in many localities has very little overburden. It has been used as crushed rock for roads and as riprap for earth banks, as at the U. S. Highway 160 bridge over Kiger Creek. It was formerly used as a building stone, and was reported to be durable but difficult to trim because of its erratic fracture (Cragin, 1896, p. 44).

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The two dolomite formations are potential sources of magnesium (Jewett and Schoewe, 1942, p. 111).

Ceramic Raw Materials

In the early days of Kansas settlement, the general scarcity of lumber and building stone in the area promoted the use of local shales and siltstone for building brick. Some of the structures made from local bricks are still standing. One of the most impressive of these is the hotel in Medicine Lodge (Pl. 24B). Raw material for the bricks used in this building was obtained from the Cedar Hills sandstone in a canyon southwest of Medicine Lodge (S½ sec. 15, T. 32 S., R. 12 W.) in the 1880's (George Horney, oral communication). It is chiefly red feldspathic argillaceous siltstone.

Several brick plants were utilizing shale from the Wellington and Ninnescah formations in the period from 1920 to 1930. Landes (1937, p. 87) reports that clay (from the Wellington formation) was utilized in Wichita in two plants, one a face brick plant, and the other a brick and tile plant. Neither plant was operating as late as 1936. In 1918 a plant was producing ordinary brick from the Wellington formation at Marion. Ninnescah shale was used at approximately the same time in Lindsborg for the manufacture of common bricks. A brick plant in Salina has been using clay from the Wellington formation from 1920 to the present day.

According to Norman Plummer (oral communication) clay from the Ninnescah shale is in general more satisfactory for the manufacture of bricks than is clay from the Wellington formation. The Wellington clay has a rather short firing range owing to its high calcium carbonate content.

Samples from the Wellington and Ninnescah formations have been tested for use as lightweight ceramic aggregate (Plummer and Hladik, 1951, pp. 63-64). Satisfactory aggregate can be produced from the Ninnescah shale, particularly if a sintering machine is employed.

Plummer (oral communication) also reports that shale from the Ninnescah formation makes an excellent brown slip glaze for insulators.

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Miscellaneous Uses

Building stone has been produced at various times in the past from thin resistant beds in the Leonardian and Guadalupian section. Building stone from the Stone Corral and Day Creek dolomites and from a gypsum bed in the Wellington formation have been mentioned in the foregoing sections. Other formations which have supplied building stone include the Ninnescah shale, Harper sandstone, and Whitehorse sandstone.

Dense, calcareous fine-grained sandstone, or, more properly, coarse-grained siltstone from the lower part of the Ninnescah shale has been quarried south of Caldwell, Sumner County, and was formerly used extensively as building stone in that city. Several buildings erected half a century ago are still in use and are apparently in good condition (Pl. 24A). According to Norton (1939, p. 1770) a sandy limestone in the Ninnescah (his bed 3) has been quarried along the outcrop as foundation stone for farm buildings.

Thin sandy siltstones of the Harper formation were at times quarried extensively for dimension stone. Norton (1939, p. 1783) reports fairly recent production of such stone from a series of bench-forming, well-cemented, even-bedded hard sandstones in the lower part of the Chikaskia member. Toward the end of the nineteenth century soft, brownish-red mottled siltstone from the Harper and underlying Permian redbeds was quarried at several localities near Harper, Kiowa, Hazelton, Attica, Milan, Spivey, Arlington, and other towns (Cragin, 1896, pp. 18-19) for dimension stone. According to Cragin, this material was soft enough to be dressed fairly easily, but became harder by seasoning, and constituted an excellent dimension stone. Very few structures built from this material, however, are still in existence. In the City of Harper, a few sandstone buildings are still standing, but much of the stone is crumbled and patched. In the course of the field work for the present study, an attempt was made to find some of the old quarries near Harper. However, the rock was apparently so soft that the quarries are no longer recognizable as such. A siltstone bed exposed in a road ditch in the SW¼ sec. 29, T. 32 S., R. 6 W., Harper County, is reported by a long-time resident to have been quarried for building stone. Most of the beds utilized were from 8 to 18 inches thick. The rock tends to slake

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off fairly rapidly on exposure to the weather, and rounded, bulging surfaces are produced.

Cragin (1896, p. 42) referred to the use of selected portions of the Whitehorse sandstone (Red Bluff) for building stone, and described the material as "fairly durable." He did not give locations of any quarries or structures.

During an indefinite period prior to 1896, red and gray silty shales from the Harper formation near Kingman were exploited for paint pigment. According to Cragin (1896, p. 20), these shales "form the basis of the 'Cherokee Brown Mineral' and 'Silver Gray' manufactured by the Kingman Paint Company, and which has had considerable demand in the paint-trade of Topeka, Kansas City, and other markets."

The only other use of the upper Permian rocks, known to me, is as a fill for road beds and as a topping for secondary roads. Rock for road fill has been removed by most counties from most of the formations. Some of the shale is reported to pack down and form a hard surface on roads. At one time soft limestone from the Wellington formation was used for surfacing, but it was found to be too dusty.

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