STATE GEOLOGICAL SURVEY OF KANSAS

BULLETIN 18

THE GEOLOGY OF WALLACE COUNTY KANSAS

BY

MAXIM K. ELIAS

STATE GEOLOGICAL SURVEY OF KANSAS

Raymond C. Moore
State Geologist

Kenneth K. Landes
Assistant State Geologist

BULLETIN 18

The Geology of Wallace County Kansas

BY
MAXIM K. ELIAS

Printed by authority of the State of Kansas

April 1, 1931
Publications of the State Geological Survey are distributed from
Lawrence, Kansas
14-908

STATE OF KANSAS

HARRY H. WOODRING, *Governor*

STATE BOARD OF REGENTS

C. M. HARGER, *Chairman*

B. C. CULP.
FRED M. HARRIS.
W. E. IRELAND.
DREW MCLOUGHLIN.
C. B. MERRIAM.
O. S. STAUFFER.
LESLIE E. WALLACE.
C. C. WILSON.

STATE GEOLOGICAL SURVEY OF KANSAS

ERNEST H. LINDLEY, Ph. D.,
Chancellor of the University of Kansas, and
ex officio Director of the Survey.

RAYMOND C. MOORE, Ph. D.,
State Geologist.

KENNETH K. LANDES, Ph. D.,
Assistant State Geologist.

FOREWORD.

The following report on the geology of Wallace county is more than a county report. That is to say, it is not merely a description of features that pertain to Wallace county alone—its topography, rock formations, geologic structure and mineral resources—but it gives information that bears on the geology of a large part of the contiguous plains territory in western Kansas and eastern Colorado. Wallace county is peculiarly situated as regards the effective attack on several problems in the geology of the plains country. It offers some of the best exposures in Kansas of the Upper Cretaceous Pierre shale and shows many very interesting features of the overlying Tertiary deposits. The painstaking field investigations of Mr. Elias and his thorough studies in the preparation of his report have resulted in an important contribution to the knowledge of western Kansas geology. The stratigraphic subdivision of the Pierre shale which he has worked out is useful both from the standpoint of development of mineral resources, in making possible the more accurate delineation of geologic structure of the Pierre shale areas, and in providing the basis for detailed comparison with the younger Upper Cretaceous rocks of other areas. Also, in his studies of the Tertiary deposits, important new facts have been learned concerning the origin and stratigraphic sequence of various beds. In the case of certain fresh-water limestone some very interesting problems are presented which bear on the geologic history of the entire Great Plains country.

One result of the work by Mr. Elias in Wallace county and adjacent districts which is not contained in the present bulletin is the description of many of the interesting fossils that are contained in the Cretaceous and Tertiary formations of this region. A considerable number of these are new to science. Paleontologic papers on cephalopods of the Pierre shale and on a variety of fossil seeds from the Tertiary Ogallala beds have been completed and will be published in a separate bulletin. Western Kansas contains a truly remarkable record of the extinct life of parts of the geologic past. It is an interesting part of the geologist's work to make known the plant and animal organisms of the remote past in the history of Kansas.

Residents of Wallace county and visitors to this part of the state will find material in this report which should arouse their interest and appreciation, and there is also here offered for the first time detailed information concerning geologic features that are basic to the economic development of the region.

RAYMOND C. MOORE, *State Geologist.*

CONTENTS.

GEOLOGIC STRUCTURE—*Concluded:*

ILLUSTRATIONS.

TABLES (INSET).

The Geology of Wallace County, Kansas.

By Maxim K. Elias.

INTRODUCTION.

Geologic Exploration in Northwestern Kansas.

General Conditions. The northwestern part of Kansas, though not infrequently visited by geologists and paleontologists, has never been given systematic geologic study. Some particular natural resources of this region have received moderate attention. Water supplies and volcanic ash deposits have been described and possibilities for oil and gas have been discussed in a general way in papers on western Kansas. It is worthy of notice that the present detailed geological survey of the county by the Kansas Geological Survey revealed the presence of some other useful minerals that are or may become of commercial importance.

No topographic sheets of the northwestern part of Kansas have been issued by the United States Geological Survey, and this is a considerable handicap to the geologic study of the area. Though the lack of base maps showing positions and comparative elevations of topographic features has retarded the geologic study of northwestern Kansas considerably, their absence has not prevented paleontologists from collecting fossils. Northwestern Kansas has become famous because of the many excellently preserved specimens, chiefly of vertebrates, which have been found in the outcropping rocks of Upper Cretaceous and late Tertiary ages. The exact stratigraphic position of these fossils in the local beds, however, and even the exact geographic locations where many of the fossils were collected has been unknown. Tying of both the earlier and the newly collected fossils to the geographic localities and to the particular beds of the formations was one of the tasks of the present survey.

Erroneous geographic, and especially erroneous stratigraphic, references of fossils collected in various countries has led frequently to invalid conclusions and to controversies, the correction and settlement of which has taken much effort and time. On the other hand, the precise determination of the stratigraphic position of fossils not only brings important results for the area where they have been found, but also contributes considerably to the progress of geologic knowledge of the other regions and countries where formations of similar age were deposited.

The absence of topographic maps for northwestern Kansas is not the only difficulty that confronts the geologist who undertakes the survey of this area. The mantle of loess, which is 50 feet thick in many places and in the northwestern corner of the state 180 feet locally, conceals the underlying Tertiary and Upper Cretaceous formations, so that their outcrops are very scarce. The Upper Cretaceous rocks are in general exposed only along the canyons and larger draws, and these exposures are separated from one another by wide stretches of loess which conceal the underlying rocks entirely (Pl. XXIII B). This concealment of the bed rock is most nearly complete in the regions where the soft Pierre shale underlies loess (Pl. XXXV B). The monotonous lithology of the Upper Cretaceous and Tertiary formations that are commonly exposed in northwestern Kansas adds another difficulty to their study. The Pierre shale of Wallace and adjacent counties is mostly dull gray, and the slight variations in shade are mostly not characteristic of any stratigraphic subdivisions or members. There are no continuous hard ledges in the Pierre. The Tertiary of northwestern Kansas, called the Ogallala formation, is mostly arenaceous throughout. It contains prominent hard ledges, but these are not easily identified as to exact geologic horizon and traced from one outcrop to another.

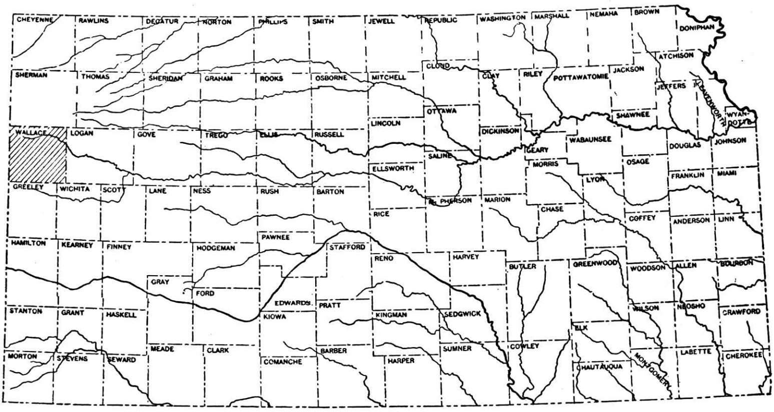


FIG. 1.—Index map of Kansas showing location of Wallace county.

The difficulties outlined above can be largely overcome by determined work. In most places in this area a geologic survey requires more caution and more checking and rechecking in the field than the survey of some other areas of the state, where the various members and beds of the exposed formations are easier to identify and to trace as continuous units. It may be stated that a proper selection of constant lithologic features and a selection of characteristic and easily identified fossils, where they are present, is essential for a successful surficial geologic survey in northwestern Kansas and in the adjacent territory. The task of selecting these features may be termed research in the field geology of the area.

The results of the survey of Wallace county here presented include topographic, geologic and structural maps of the county, geologic sections through the county and stratigraphic columns of the outcropping and of some underground formations. They include, also, data and discussion of the proved and potential mineral resources of the county. A special chapter is devoted to the phenomena of the local ground subsidences in northwestern Kansas, and a special paleontologic part is prepared in which some of the most important fossils of the area are described.

HISTORY OF GEOLOGIC EXPLORATIONS. In this chapter the explorations that concern directly the geology of Wallace county in its present limits (Fig. 1) receive chief mention, and only brief notes on some of the most important works of general application to the geology of western Kansas are added.

In 1868 E. D. Cope described a new huge swimming reptile, *Elasmosaurus platyurus,*[1] which was collected by Dr. Theophilus H. Turner, physician of the garrison at Fort Wallace. This was the first recorded vertebrate fossil obtained from the Upper Cretaceous of Kansas, where in succeeding years a great many of the most wonderful and beautifully preserved swimming and flying reptiles of the same period were collected.

A brief geologic note on the Upper Cretaceous rocks at Fort Wallace was made in 1869 by F. V. Hayden,[2] who concluded erroneously, as was proved later, that the No. 2 beds (or Fort Benton group) of Meek and Hayden's Upper Missouri section of Upper Cretaceous is exposed in this area.[3]

The first state geologist of Kansas, B. F. Mudge, made the earliest systematic collection of fossils from the Cretaceous of Kansas, including the vicinity of Fort Wallace. According to S. W. Williston,[4]

---

[1] In J. L. Leconte, 1868, p. 68.

[2] Hayden, 1869, pp. 13-14.

[3] Hayden and Meek, 1872, Part I, Chapter IV.

[4] Williston, 1898, pp. 28-29.

Mudge visited this area in the summer of 1870. The fossils collected by Mudge were identified by E. D. Cope.[5] Later in the same season (1870) an expedition from Yale college under the leadership of O. C. Marsh collected vertebrate fossils at Fort Wallace and at McAllaster (formerly Sheridan), chiefly along the north fork of Smoky Hill river. Marsh published a brief description of his discoveries in 1871.[6] Among the collected material a foot bone of a new gigantic flying reptile, now known under the name *Ornithostoma* (formerly *Pterodactile* and *Pteranodon*), was discovered after additional bones of the same beast were obtained by the expedition.[7]

Yale college continued to send expeditions each year to collect more reptile material from the same beds. E. D. Cope also visited the region in 1871 and, besides making some discoveries of new vertebrates, studied the stratigraphy and published some important notes concerning the geology of the beds from which the fossils were collected. He speaks of these beds as the "Niobrara group" or No. 3 of the Missouri section of Meek and Hayden.[8]

Marsh, in his descriptions of the reptiles collected by the Yale expeditions, refers them to "gray and blue Cretaceous shale" and to "yellow Cretaceous limestone." Possibly the fossils were collected from both the Niobrara and lowermost beds of the overlying Pierre, both of which formations, as we know now, outcrop in the area. In 1866 Mudge made first reference to chalk, which "is said to have been found" in the Cretaceous of western Kansas,[9] and in 1876 he gave a description of the physical features of the Niobrara and separated the Niobrara from the underlying Fort Hays.[10] He makes the important statement that Hayden mistook the exposures near Fort Wallace for Benton, and refers them to the Niobrara, to which formation he refers also a bed with *Baculites,* which he discovered near Sheridan (McAllaster). Mudge forwarded this fossil to F. B. Meek, who identified it as *Baculites anceps* and expressed a doubt that the form could come from the Niobrara, because elsewhere in the "far west" it has been found only in the Pierre and Fox Hills formations.[11] Williston in 1892 recognized for the first time[12] that the Fort Pierre formation actually outcrops at Wallace and McAllaster

---

[5] Idem, pp. 29-30.

[6] Marsh, 1871, pp. 447-459.

[7] Marsh, 1871 a, p. 472; Williston, 1898, p. 30.

[8] Cope, 1875, pp. 16-19.

[9] Mudge, 1866, p. 12.

[10] Mudge, 1876.

[11] Mudge, 1877, p. 284.

[12] Williston, 1893.

and expressed his support of Meek's opinion that *Baculites anceps* from near McAllaster belongs to the local Pierre, which is undoubtedly correct.

During his earlier explorations at Fort Wallace Mudge made some observations of moss agate in local Tertiary beds[13] and published the first description of these younger beds in Wallace county and elsewhere in western Kansas.

Among early geologists we must mention F. W. Cragin, who made some explorations in far western Kansas and named the shale exposed above the Niobrara "Lisbon shale" after the small Lisbon station (now abandoned) of the Union Pacific railroad about 2½ miles east of McAllaster. The "Lisbon shale" of Cragin corresponds to the Sharon Springs member of the Pierre formation described in this report. The name Lisbon is preëmpted in geologic literature and therefore cannot be retained for this shale member.

Some excellent remains of reptiles from the Pierre and Niobrara of Fort Wallace and McAllaster were collected by Charles H. Sternberg (1875 and later years), E. P. West (1890), H. T. Martin (between 1894 and 1922) and others.

The exploration of water resources of Wallace county began in 1893-'94, when Robert Hay was employed by the Division of Hydrography of the United States Geological Survey to make an investigation of "underflow" and subsurface waters of a typical area of the "semiarid west." The northwestern part of Wallace county was included in the stretch of country along the 102d meridian explored by Hay. The data on twenty-six water wells in Wallace county, collected by Hay, were published in the progress report of the Hydrography division,[14] and the general geologic description of the outcropping formation, and a discussion of the surficial and underground water resources of the area surveyed by Hay was published in a separate paper in the sixteenth annual report of the United States Geological Survey.[15] In this important paper a precise stratigraphic distinction is made between the three most important outcropping units of the rocks: The Cretaceous, the "Tertiary grit" (Ogallala formation of modern authors) and the "Plains marl" (loess, as now recognized). The names selected by Hay for the last two stratigraphic units indicated briefly the physical features of the rocks ("grit," "marl") that were thought by Hay, and really are,

---

[13] Mudge, 1874, pp. 113-117.

[14] F. H. Newell, 1895, pp. 116 and 124-126.

[15] Hay, 1895, pp. 535-588.

the most characteristic for the Ogallala and the Pleistocene deposits of the area. Such names for geologic formations became, however, a source of misunderstanding and gave ground for criticism, because in what Hay termed "Tertiary grit" there appear in places thick beds of clay and marl. On the other hand, also, the "Plains marl" or loess of the High Plains commonly becomes sandy at the base and in many places is underlain by "grit" or coarse sand and gravel, which also belong to the Pleistocene, and together with the overlying loess makes an indivisible stratigraphic unit which is here named Sanborn formation. It must be added that Hay himself observed the sandy basal facies of his "Plains marl," which shows again that the names "Tertiary grit" and "Plains marl" were introduced by this author for the stratigraphic units (and not merely for the types of rocks), which he recognized perfectly in the field outcrops and in well borings, and which we now term Ogallala and Sanborn formations, respectively. Hay was also aware that what he called "marl" has been called loess by geologists of both Nebraska and Colorado.[16] The relation of the underground waters of the High Plains to the above-mentioned stratigraphic units was also correctly explained by Hay, and he was the first to describe the local "sink holes" and give a plausible explanation of them.[17]

An important contribution to the understanding of the physical character of the Tertiary of western Kansas and a notably advanced explanation of the accumulation of the bulk of these deposits of the High Plains, the essential features of which are accepted by modern authorities in geology, was made by the former state geologist of Kansas, Erasmus Haworth.[18] This author also contributed considerably to our knowledge of the water resources of western Kansas, but this part of his geologic work does not much concern Wallace county.

In 1901 W. D. Johnson discussed at considerable length the water resources and the origin of the Tertiary deposits of the High Plains and expressed views somewhat modifying the conclusions reached by Haworth.

Neither of the last authors considered the mantle of loess of western Kansas, the "Plains marl" of Hay, to be a separate stratigraphic unit, and not until Darton's report on the Central Great Plains was the "smooth-surfaced, thick mantle" of loess of northern Kansas,

---

[16] Hay, 1895, p. 574.

[17] Idem, pp. 555-556, sink hole in Sherman county.

[18] Haworth, 1897, pp. 247-281.

"lying on a somewhat irregular surface composed of Tertiary deposits and the several upper Cretaceous formations," treated again as a distinctly different formation from the underlying Tertiary.[19] In Darton's report we find a separate brief paragraph on the water resources of Wallace county[20] with a special discussion on the possible water supply in the Dakota sandstone of the county.

Though the special study of the distribution and movement of underground water in western Kansas brought about a much better understanding of the physical properties and stratigraphy of local formations, a more precise and complete knowledge of their lithology, thickness, fossil content and mutual relations and areal distribution were obtained from very recent deep drilling and geologic surveys, the chief aim of which was to explore the possibilities of oil and gas accumulation. Two test wells for oil have been drilled in Wallace county—the Robidoux and the Wulfekuhler wells. Though these wells did not discover any commercial quantities of oil and gas, they nevertheless contributed much to our knowledge of the deeper formations, which do not outcrop in the county or in the surrounding area. In 1927-'28 a survey party (which included the writer) employed by the Etnyre Syndicate made a thorough topographic and geologic survey of the northwestern portion of the county. The stratigraphy and structural geology of this area was worked out by the writer with the able assistance of O. R. Smith as instrument man, and other members of the party. Systematic collection and identification of paleontologic material was started by William Wenk and continued and finished by the writer. The report on this survey (except the chapters on the underground formations) along with the geological and structural maps and cross sections was prepared by the writer in the spring of 1928. This report is the property of the Etnyre Syndicate and has not been published. W. L. Russell, who joined the survey crew early in 1928, made a detailed survey east and southeast of the area studied by the writer. To Russell belongs the credit for the separation, on lithologic and partly paleontologic grounds, of the Lower Weskan shale member of the Pierre formation of Wallace county, a member which is not exposed in the northwestern part of the county. In papers written by Russell on some stratigraphic and geologic problems of Wallace and adjacent counties, the preliminary results of the writer's work on the stratigraphy and key beds of Ogallala are included, though

---

[19] Darton, 1905, p. 155.

[20] Idem, p. 320.

the comparison of the topmost limestone of this formation with the caliche deposits belongs to Russell and is not shared by the writer.[21] This author also gives a very brief note on the stratigraphy of the basal 400 feet of the Pierre, apparently of Wallace county, within which he recognizes five members, distinguished by lithologic changes in the shale. No estimation for the separate thickness of these members is given.

The sudden local subsidence known as "Smoky Basin cave-in," east of Sharon Springs, in Wallace county, which occurred in 1926, attracted wide public attention. It was a subject of a note by the state geologist of Kansas, Raymond C. Moore, in which the cause of the subsidence was discussed.[22] A different theory as to cause of this and similar cave-ins of various ages in Wallace county and the adjacent area was advanced by W. L. Russsell.[23] The opinion of the writer on the same subject, which agrees more nearly with the theory advanced by Moore, was published in 1930[24] and is included in the section on local subsidences in this report.

In the last decade expeditions sent by the Museum of Natural History of the University of Kansas have collected many beautifully preserved remains of vertebrates, chiefly from the Tertiary of Wallace county, but recently also from the Pierre shale. H. T. Martin discovered a rich locality of Tertiary vertebrates at the Marshall ranch in the northeast corner of the county and opened there a quarry in the summer of 1925. The locality has yielded already a considerable amount of valuable paleontologic material and is far from being exhausted. In 1930 the Museum expedition was sent by Martin to collect from new localities of vertebrate remains in the Tertiary and in the Pierre shale discovered by the writer in the course of his surveys in 1927-'28 and in 1929-'30. During these surveys the writer also recognized and studied commercial deposits of diatomaceous marl and bentonitic clays, both of Tertiary age and not previously recognized in Wallace or in adjacent counties.

Some other references on the geologic explorations in western Kansas and adjacent states are given in appropriate parts of this report. A complete bibliography on the geologic and paleontologic papers pertaining to western Kansas up to 1892 has been published

---

[21] Russell, 1929, p. 599.

[22] Moore, 1926, pp. 95-96, and 1926a, pp. 130-131.

[23] Russell, 1929a, pp. 605-609.

[24] Elias, 1930, pp. 316-320.

by Robert Hay[25] and the history of the exploration of the Cretaceous of western Kansas up to 1898 by G. I. Adams.[26]

FIELD WORK AND MAPPING.

As mentioned above, the writer made his first acquaintance with the geology of Wallace county and the adjacent area in 1927-'28, when he studied the northwestern part of the county for the Etnyre Syndicate. The survey of all of Wallace county for the State Geological Survey of Kansas was made in part during six weeks in October and November of 1929 and was resumed in May and June of 1930, when five weeks additional were spent on this work.

As no detailed topographic base maps of the county existed, the writer used the county road map prepared by the county engineer, to which he added more detailed drainage, schoolhouses, farmhouses and other geographic details in the Wallace county atlas published by Geo. A. Ogle & Co., Chicago, 1908. The map compiled from these two sources was checked and corrected during the field work. To this map elevations taken by Paulin altimeter were added, and contours with 50 feet interval were then drawn. The following method of work with the altimeter was adopted: For base points the three railroad stations of the Union Pacific—Weskan, Sharon Springs and Wallace—were used, their elevations being known. The automobile was driven first along the principal roads of the county, chosen so as to make an open loop starting at one station and ending at another. The elevations on such loops were taken twice, the car returning along the same route to the initial point of observation. The points on the principal roads with the elevations thus obtained were used as secondary starting points for lateral loops of observation covering the rest of the county. The readings of the altimeter were taken on some of these points more than twice. The mean of the calculated elevations was usually accepted, unless one reading was outstandingly different from the other, owing to a sudden drop or rise of the atmospheric pressure or to an erroneous observation. In these cases the apparently erroneous readings were discarded. The temperature of the air was always observed and the temperature corrections made. During a complete day's work with the altimeter at least five or six readings were made on the points, the elevations of which were well established. This number of read-

---

[25] Hay, 1896, pp. 261-278.

[26] Adams, 1898, pp. 13-32.

ings was usually sufficient for plotting a curve of the daily variation of the air pressure. Altogether elevations of 250 points in Wallace county were observed and calculated, and based on these data, contour intervals of 50 feet were drawn on the topographic and structural maps of the county. The errors due to the imperfection of readings and to the differences between actual variation in the pressure of the atmosphere and that taken from the plotted curves of the daily variations are estimated by the writer to be as a rule hardly more than 10 feet in either direction.

ACKNOWLEDGMENTS.

During his field work the writer received the most friendly help of various kinds from the residents of Wallace county and adjacent territory, to whom he wishes to express his sincere appreciation. He is especially indebted to Messrs. Arthur Bowman, Joe De Tilla, J. Aug. Johnson, Roy Johnston, Worth Lacey, Frank T. Madigan, Jas. T. Madigan, Harry A. Wheeler, Guy Woodhouse, and L. H. Wulfekühler. The particular help that they rendered is mentioned at appropriate places in the report.

During the preparation of the report and identification of the fossils much help and useful suggestions have been rendered to the writer by W. H. Bradley, R. W. Chaney, R. G. Cuyler, F. H. Hilman, A. C. Hitchcock, W. H. Horr, G. L. Knight, K. K. Landes, H. T. Martin, Raymond C. Moore, R. G. Moss, J. W. Ockerman, J. B. Reeside, Jr., W. C. Stevens and Grace Wilmarth, to whom his thanks are due. The manuscript has been read by Raymond C. Moore and K. K. Landes. The photographs and sketches illustrating the report were made by the writer, unless otherwise acknowledged.

GEOGRAPHY.

LOCATION AND CULTURE.

Wallace county, one of the most western counties in the state (Fig. 1), is in the third tier south from Nebraska and is bordered by Colorado on the west. The county was created in 1868 and was named in honor of Gen. W. H. L. Wallace, a veteran of the Mexican War. At first it included the territory now forming Logan county, the next county east. This explains some early references to localities in Wallace county which are now in Logan county. Logan county was separated from Wallace in 1881 and was named St. John, the name being changed to Logan in 1885.

Fort Wallace, which had a central position in the original Wallace county, was established in September, 1865, and was first known as Camp Pond Creek. Pond Creek, named after Major Pond, joins south fork of Smoky Hill river 3 miles west of the fort. In 1866 the name was changed to Fort Wallace in honor of General Wallace, mentioned above. During the building of the Union Pacific railroad, which was completed to the fort in 1868, Fort Wallace was an important military post, but it was abandoned in 1882, no more military protection being needed from the activities of Indians. The memorial monument within the ruins of the fort and at Wallace cemetery is shown in Plate XXXIX. Time has little affected the ornamentation and inscription, the major damages being done by unknown vandals. Restoration of the monument and the walls at the cemetery was started in 1930, the necessary appropriation being provided by the state.

The town of Wallace, erected north of Wallace railroad station, was the county seat of the original Wallace county. Since 1887 the county seat of Wallace has been Sharon Springs, situated in the center of the county and on the Union Pacific railroad. The presence of a never-failing supply of pure water in the springs near the old Eagle Tail station was an important factor in the selection of the site in 1886, as a supply of good water is not everywhere available in western Kansas. The third station on the Union Pacific railroad, which traverses the middle of Wallace county, is Weskan, serving the smallest of the three towns of the county. According to the 1930 census the population of Sharon Springs is 792, and the population of the whole of Wallace county is 2,882.

The county is traversed by United States highway No. 40S, which runs parallel to the Union Pacific railroad and was recently greatly improved, several new bridges being erected. State highway No. 27 traverses the middle portion of the county in a north-south direction and is kept in good condition, though it is not graveled. Other important dirt roads run in a north-south direction through Wallace and Weskan. The road north from Weskan goes to Kanorado in Sherman county. Owing to the low cement bridge over Smoky Hill river on this road, the river, ordinarily having only underflow, flows over the road after heavy rains and stops travel. The road south from Wallace is nearly always open, as a small bridge has been built over Smoky Hill river. These and other less important roads and trails are shown on the accompanying map.

TOPOGRAPHY AND DRAINAGE—HIGHEST POINT IN KANSAS.

Wallace county lies within the High Plains of the west-central United States, which are bordered by the Rocky Mountains piedmont on the west and by the low plains of the Missouri and Mississippi river valleys on the east. The High Plains slope gently toward the east, the slope within Wallace county being 25 feet per mile except in the southeastern part, where it is only about 5 feet per mile.

The High Plain is dissected by a well-developed river system. In places the stream valleys have quite steep and rocky northern slopes, but in most parts there is a gentle topography, and the valley bottoms are easily reached by automobiles. The divides between the major streams rise 180 to 200 feet above the bottom of the valleys, and south of the south fork of Smoky Hill river the surface of the High Plains rises 250 to 350 feet (south of Wallace) above the valley (Pl. II A). The highest point within Wallace county and probably the highest point of Kansas is, according to barometric leveling by the writer, in sec. 12, T. 12 S., R. 43 W. This place is on "the divide between the two Smoky forks on the 102d meridian, near the head of the draws of Goose creek," which area was considered by Robert Hay[27] "to be the highest land in Kansas." The height of this "highest part of the 102d meridian" within the area explored by Hay was estimated by him to be "about 4,000 feet above sea level."

On the topographic map of Kansas compiled under the direction of Henry Gannett in 1898[28] the contour representing 4,100 feet elevation above sea level is shown to traverse the southwestern corner of Wallace county, which is apparently an error. The highest elevation in this part of Wallace county was found by the writer not to exceed 3,950 feet above sea level, which is in agreement with the earlier topographic map of the western part of Kansas published by Robert Hay.[29]

The above-mentioned highest point of Wallace county and probably of Kansas is a small separate hill on the high, slightly rolling divide between the basins of Goose creek and Willow creek and is in the SW¼ SE¼, sec. 12, T. 12 S., R. 43 W., about one-eighth of a mile from the state line. The hill, except its apex, consists of the topmost beds of the Ogallala formation, the capping rock of which,

---

[27] Hay, 1895, p. 544.

[28] Gannett, 1898, supplementary map.

[29] Hay, 1895, map opposite page 542.

the pink, concentrically banded, algal limestone, outcrops on the northern slope of the hill; the apex of the hill is formed by loess.

The elevation of the top of the hill, as well as of some other points of the surrounding area, was taken with a Paulin altimeter and, after due corrections for change of atmospheric pressure and for the temperature of the air, was determined to be 4,059 feet above sea level. Though this figure cannot be considered exact, it is not far from correct, because the point appears to be about 15 or 20 feet higher than the nearly level surface on the east line of the SE¼, sec. 12, whose elevation is 4,040.12 feet, according to the instrument (transit) survey of 1928 by topographer O. R. Smith, of the Etnyre Syndicate.

The lowest point in Wallace county is the channel of the south fork of Smoky Hill river, where it crosses the eastern county line in sec. 25, T. 13 S., R. 38 W. The elevation of this point, deduced from altimeter reading, is about 3,165 feet above sea level. The comparison of the highest and lowest points of Wallace county shows the maximum relief within the county to be nearly 900 feet.

The rivers and creeks of the area belong to the Smoky Hill river system, which drains finally into the Mississippi river. The direction of the larger streams is from west to east or parallel to the Arkansas river 70 miles south. Many of these streams, by an abrupt turn to the south, meet a larger river at an angle of 60° to 90°. In this fashion Goose creek joins the south fork of the Smoky Hill river in sec. 9, T. 13 S., R. 40 W. At a similar angle the north fork of the Smoky Hill joins the south fork in Logan county, Kansas. Another branch of the south fork of Smoky Hill river joins it at an angle approaching 70° near the boundary between Kansas and Colorado. The detailed geological survey has revealed that many of the larger streams, especially in the west, correspond to the larger latitudinal synclines of the area. These rivers run in a general easterly direction, parallel to the outstanding topographic and structural ridges, until they suddenly break through, apparently at structural lows or saddles. These lows in places develop within a structural ridge and may mark the point of closure of an anticline or an elongated dome.

Smaller drainage channels—for instance, Willow creek, Collins, and Schoolhouse draws—have a general direction from west-northwest east-southeast, but a closer study reveals that a west-east direction of parts of these streams is predominant, and that steplike turns in a south-southeast direction bring these streams gradually to the southeast until they join the larger rivers of the area previously described.

Willow creek, with its broad and well-developed valley, is to some extent an exception to this rule, running very straight in an east-southeast direction. This creek has an interesting relation to the outstanding structural feature of the area, which is here designated as the Willow creek anticline. Willow creek cuts this structural high across its highest elevation through the crest of the dome.

Another example of a stream cutting through a structural high is Salt Grass creek, which cuts the Salt Grass dome, a minor structural high, near the center. The minor creeks of the area run in various directions, but with them also a certain relation to the local structural features usually can be noticed. As previously stated, the larger river valleys, especially in the western part of the county, correspond to the larger synclines. The slopes of many of these valleys are the dip-slopes of the exposed rocks or nearly the same, and many of the outstanding topographic ridges are anticlines.

The south fork of Smoky Hill river runs along the Willow creek anticline, an outstanding structure. The northeastern side of this structure is marked by the lower portion of Willow creek valley, and the middle portion of Willow creek valley borders another outstanding structural high of the area, which enters Wallace county from the northwest between Willow creek and Goose creek. Goose creek flows in a syncline along practically its entire eastern course, but this structural depression is more pronounced in the Pierre strata and is only gently reflected in the overlying beds of the Ogallala, so that the slopes of the Goose creek valley are steeper than the dip of the Ogallala beds. Thus the chief escarpments of the Ogallala beds project through the southward slope of the valley, giving an impression of horizontal strata. The abrupt turn of Goose creek from an easterly to a southerly direction is a reflection of a change in the direction of the strike in the Pierre strata (Cretaceous), as revealed by the study of the exposures on the northeastern slope of the valley at Halsey School, in the northeast corner of sec. 11, T. 12 S., R. 42 W.

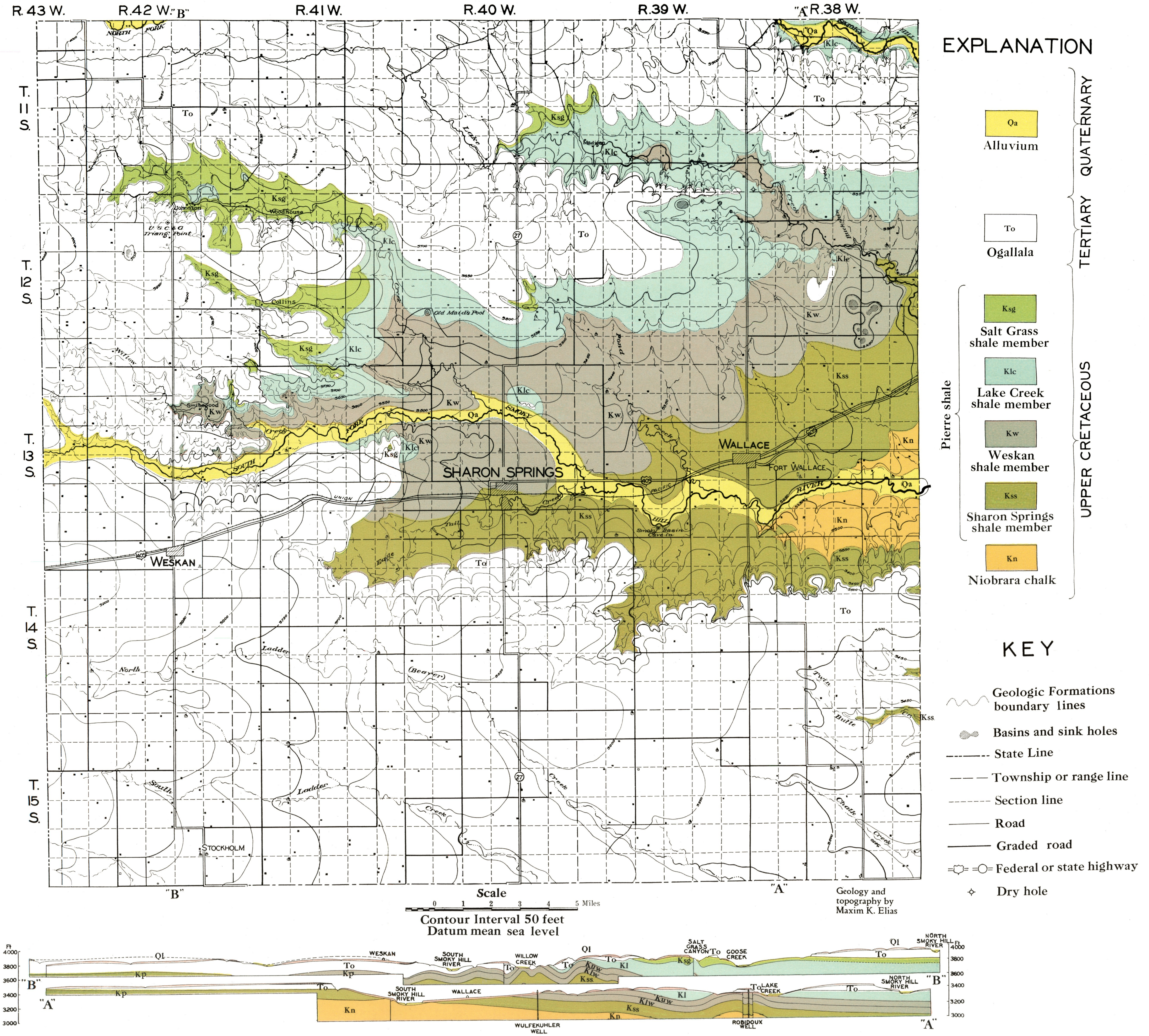
PHYSIOGRAPHIC EXPRESSION OF FORMATIONS.

In the local area there are five different rock types, each of which is characterized by certain distinctive peculiarities of the relief of its exposure. These types are:

1. *The Niobrara chalk.*

PLATE I.

Geologic Map and Geologic Sections of Wallace County.



Geology and topography by Maxim K. Elias

2. *The Pierre shale* and the bentonitic clays of the lower Ogallala.
3. *The resistant "mortar beds"* of the Ogallala formation.
4. *The loess* and gravel of Sanborn formation and redeposited loess of valley flanks.
5. *The river gravels and sands* of recent origin.

Recent river gravels, sands and silts cover the valleys of the larger streams (Pls. I and XXXI C). Extensive deposits of loess are usually also washed into the river valleys and in many places constitute the highest beds of alluvium. Nearly all the high land of the region is covered by loess (Pl. XXIV B), which forms the smooth or gently rolling surface of the High Plains. The loess where exposed is characterized by vertical escarpments (Pls. XX A, XXIV B, XXXV A and B), and in many places the loess outcrops have a step-like profile.

The hard "mortar" sand and gravel beds of the Ogallala formation build the most prominent escarpments of the area (Pls. II A, XX B, XXIII, XXIV, XXX, XXXVII and XL C). Usually these beds outcrop on the southern side of the valleys; elsewhere their relation to topography is varied. The most prominent and the most continuous escarpments are situated on the south side of south fork of Smoky Hill river valley (Pl. II A) and of Goose creek valley from Salt Grass creek (Pl. XXIV B) to the turn of Goose creek to the south. This escarpment forms a high erosional terrace or "step" on the south slope of the Goose creek valley, 100 to 140 feet above the valley bottom. The abrupt step of the Ogallala plateau south of Smoky Hill river stands 300 feet above the bottom of the valley.

The Pierre shale furnishes the least conspicuous exposures of the region (see Pls. III A, VIII A, X A, XV A and XXIV B), but these are the most valuable for an oil geologist. This shale is exposed occasionally on both sides of the larger and smaller valleys where erosion has removed the overlying loess, gravel and Ogallala beds, and it may be seen in the bottom of some valleys at the base of river-channel escarpments. Pierre shale exposures may be recognized by the series of small, bare, dark-colored hills, which occasionally occur in the lower half of valley or canyon slopes; usually the foothills of prominent Ogallala or loess escarpments are made up of Pierre shale.

The bentonitic clays of the Ogallala formation give the same type of exposures as the Pierre shale (Pl. XXX), but these outcrops are usually brightly colored in light-green or chocolate-brown shades, or both. The Niobrara chalk, of light-brown to orange color, is exposed only in the valley of the south fork of Smoky Hill river southeast of Wallace, where it makes more prominent and brightly colored escarpments than the overlying Pierre shale (Pls. III and XXXVI A).

CLIMATE.[30]

The mean annual temperature in Wallace county is about 55° Fahrenheit, and the climate is of semiarid type with an average annual precipitation of about 17 inches. The summer temperature rarely rises above 100° Fahrenheit, and the extreme recorded winter minimum is —31° (recorded at Colby). Owing to the dryness of the atmosphere on the plains the heat and cold are more endurable than the same temperatures would be farther east.

The lowest temperatures occur in cold waves or blizzards, usually lasting from three days to a week. The highest temperature in summer may last a week or more, but the nights are generally cool even after the warmest days. The interval between the last killing frost in the spring and the first in the fall is about 160 days, the average date of the last frost being April 22 and of the first frost October 2 (according to the records at Wallace).

Precipitation is least during the winter and increases until July, but the variation in the rainfall for any month from year to year is great. Usually the heaviest snow comes in March, April or even in May, but sometimes heavy snowstorms come as early as November. Unfortunately the low average moisture from precipitation is further decreased in its usefulness by the excessive evaporation due to low humidity of the air. The use of the best methods of conserving the soil moisture is, therefore, extremely necessary for successful farming in this area, which is not infrequently visited by years of drought.

The prevailing wind is southwest, especially in the summer months. This wind is dry and accelerates the removal of moisture by evaporation. It is a source of danger from the time when the land is broken for planting until the crop is matured. Dense clouds of dust are raised by the wind from dry, broken fields, especially on the high lands. Other common winds are northwest and south, the former being the wind of winter blizzards.

---

[30] Chiefly after Coffey and Rice, 1912.

VEGETATION.

The flora of Wallace county is typical prairie vegetation of the semiarid High Plains. The county is treeless except along the valleys and canyons (Pls. II A and C, and XXXI A), where cottonwood, willow and (rarely) hackberry grow. These are the only native trees now growing in Wallace county. Among shrubs, also restricted to valleys and canyons, *Rhus trilobata* and *Prunus besseyi* are most common (identification by W. C. Stevens, of the University of Kansas).

The herbaceous vegetation of the prairie is of the typical condensed type. The following extract from "Flora of Western Kansas" is applicable to the prairie flora of Wallace county:

"Most of the plants are compositæ, which are usually yellow or purplish, while the grayish tint of the prairies is largely due to the hairiness of the leaves, as most plants are more or less hairy, scabrous or resinous in this region. . . . One will also find the leaves of almost every plant either finely divided or very much reduced. . . . In fact the whole plant is reduced and often less than one-fourth the size of sister species in the eastern part of our state."[31]

The chief native grasses of the prairie are the short, bushy and monotonous gray buffalo grass, *Bulbilis dactyloides* Engelm., and the gramma grass, *Bouteloua oligostachya* Torr. Many other grasses are common, among which the reddish *Aristida purpurea* adds much color to the prairie in the late summer and fall. Among other herbs of the prairie the writer recognized *Lithospermum linearifolium* of the Borage family, the representatives of which are only sparsely distributed, being usually met near the edges of the canyons. The Borage family was more richly represented both in the number of species and in the number of individuals in the local prairie of the Lower Pliocene time.

Soap weed, *Yucca angustifolia* Ph., can be seen nearly everywhere in Wallace county, but is especially common on the slopes of the valleys and canyons. Where yucca grows cactuses also grow (Pl. II C), plants whose leaves are reduced to spines or minute scales and whose thick and fleshy stems contain green chlorophyll, which makes them look like leaves of ordinary plants. In fact, these stems perform the function of leaves, their epidermis being furnished with stomata or breathing openings. Among the cactuses the prickly

---

[31] Reed, 1893, p. 92.

pear, *Opuntia missouriensis* DC, is very common. Two species of the ordinary round type (Mamillaria), one with orange and the other with pink flowers, are also quite common in some parts of the county.

The Russian thistle, introduced in this country, is very common among the weeds. Sagebrush, *Artemisia tridentata,* the firewood of the pioneers of the west, is restricted to sandy areas, nearly all of which have their source of sand in the disintegrating rocks of the Ogallala formation.

The large content of alkali in the poor, clayey soil at and around the majority of exposures of the Pierre shale limits the vegetation of these places to the common salt grass, *Distichlis spicata,* and other "salt grasses." Such places are Salt Grass canyon and some other smaller creeks and canyons of the area. Only a few small spots of entirely bare "bad lands" are developed at the exposures of the Pierre shale. One of these places is the bluffy "Devil's half acre" about in the center of sec. 36, T. 13 S., R. 40 W.

STRATIGRAPHY.

Formations not Exposed.

Our direct information concerning the underground rocks of Wallace county is limited to the logs of the two deep dry holes that have been drilled in the eastern part of the county. Unfortunately the cuttings of these wells have not been preserved (except a few samples from the Wulfekuhler well), and consequently the precise correlation of the rocks penetrated by the two wells is considerably handicapped. The data available on the deep wells drilled in the immediate neighborhood of Wallace county are no better for study and correlation. In a little more distant area, north of Wallace county, several deep wells have been drilled recently, and the cuttings have been collected. The most valuable contribution to knowledge of the underground stratigraphy of the northwestern part of Kansas is given by the George Andrews No. 1 well of the Phillips Petroleum Co., in sec. 3, T. 2 S., R. 42 W., about one mile west of the Kansas state line. The well is 5,055 feet deep and is the deepest for a considerable area of western Kansas and northeastern Colorado.

G. W. Bastian, of Atwood, who drilled a well 3,076 feet deep at his ranch in sec. 5, T. 3 S., R. 34 W., in Rawlins county, Kansas, has preserved the cuttings from the depth of about 1,000 feet down to the bottom of his well. The cuttings of the well that is now drilling in the southwest corner of sec. 3, T. 2 S., R. 35 W., in Rawlins county, by the Danciger Refining Co., of Tulsa, Okla., belong to that company. The writer did not have an opportunity to study the cuttings of the latter well, but has made a preliminary examination of Mr. Bastian's samples, which have been kindly submitted for his study.

As the study of the cuttings of the other wells is now in progress by geologists of oil companies, there is no need to speculate as to the correlation of the formations penetrated by these wells on the ground of the well logs alone. It will suffice to note at present that the Andrews well was drilled through red beds and was continued down to 4,850 feet into interbedded gray to white limestone and blue shale of possibly Lower Permian and Pennsylvanian age. The top of the red beds was reached at 3,195 feet, and the base of the lowermost red rock of appreciable thickness was reached at 4,560 feet. A well in northwestern Kansas east of Wallace county, which also was undoubtedly drilled through red beds and entered the Permian-Pennsylvanian sequence of limestones and shales, is the Moffet and Andrews No. 1 well of Coons, in sec. 14, T. 14 S., R. 33 W., Logan county, Kansas. This well is 3,855 feet deep. The top of the red beds was reached at 1,500 feet, and the base of these beds at 3,165 feet, below which only a few thin red beds are recorded among the interbedded limestones and blue shales. The deep wells of eastern Wallace county have been stopped after penetrating 154½ feet (Wulfekuhler well) and 455 feet (Robidoux well) of red beds. These beds consist chiefly of interbedded sands, sandy shales and shales. The red beds that are exposed in eastern and south central Kansas are classified with the Permian. The red beds of Wallace county, either as a whole or at least their lower part, probably belong to this epoch. The upper part may belong to the lower Mesozoic (Triassic?), representing possibly equivalents of the "Red beds" of the Lykins formation of Colorado or of the Chugwater formation of Wyoming.

The 20 feet of "green shale," with possible addition of 30 feet of "light shale" below and 10 feet of blue shale above in the Wulfekuhler well, may correspond to Morrison marls of northeastern Colorado, and the sand and gravel between this shale and the red beds may be equivalent to the arenaceous Sundance formation. Both the sand and the shale above the red beds and below the overlying Dakota have been recorded also in the Robidoux well.

The sands with interbedded shale referred by the writer to the Dakota group are 365 feet thick in the Robidoux well and 405 feet thick in the Wulfekuhler well. Bass estimates the thickness of Dakota sandstone, a formation "consisting of sandstone, sandy shale, and clay," to be about 300 feet in western Kansas.[32] The upper limit of the formation is ordinarily fairly recognizable in the wells, owing to the change from shale of the Benton to sands, usually with a large flow of water, at the top of the Dakota. The lower limit of the formation, on the contrary, is not easy to define. In the Wallace county wells the lower limit of the Dakota group is arbitrarily placed at the base of the lowermost sand above the "green shale" of the provisional Morrison. Within the "Dakota group" thus limited there may be in Wallace county, besides the Dakota sands proper at the top, equivalents of the Fuson fine sands and shale in the middle and of the Lakota sandstone at the base.

The Benton group, which includes the rocks above the Dakota and below the Fort Hays and is among the most clearly recognized beds in the drilled wells, consists chiefly of shale with occasional sands and limestones. A bed of "brown limestone" only 5 to 6 feet thick is recorded in both the Robidoux and Wulfekuhler wells near the base of the Benton group. This bed may possibly correspond to the Lincoln limestone member. Slightly above this brown limestone there was met in both wells a thick (62 to 75 feet) bed of "white sand" with strong water and traces of oil and gas. If this "white sand" is merely a porous limy rock, it could correspond to the limy beds of the Fairport or to the upper beds of the Greenhorn.

The Codell sand, which is a topmost member of the Benton in west-central Kansas,[33] was not recorded in either of the two Wallace county wells, where "black shale" was met immediately below the "white lime" of the Fort Hays. However, according to the record of a boring at Cheyenne Wells in Colorado, about 17 miles west of Wallace county, 30 feet of fine sand has been encountered below 70 feet of chalky rock with brackish water, which is apparently Fort Hays.[34] The Fort Hays limestone in the wells of Wallace county is 55 to 60 feet thick, which corresponds fairly to the very persistent thickness of this limestone all over western Kansas.

---

[32] Bass, 1926, p. 85.
[33] Bass, 1926, p. 28.
[34] Darton, 1905, p. 329.

Upper Cretaceous Formations.

NIOBRARA CHALK.

The upper member of the Niobrara formation, the Smoky Hill chalk, is the oldest formation that crops out in Wallace county. Less than 100 feet of the uppermost beds of this member, which is about 750 feet thick, is exposed. The exposures are confined to the valley of Smoky Hill river, south and southeast of Fort Wallace (Pls. III, IV and XXXVI A).

The outcropping beds of the Niobrara are nearly everywhere orange-colored, which is a striking contrast to the ordinary dark-gray exposures of the Pierre shale of the area. However, when one attempts to find the precise contact between the two formations in the outcrops some difficulties are met with. The shale of the Pierre near the base is in places colored brownish-gray, owing to rusty weathering of the lowermost beds, which are impregnated with iron sulphide. Also, occasional large bands, lenses and less regular portions of the uppermost Niobrara are colored gray to dark gray at the outcrops, which makes them look very much like shale of the Pierre. The gray color of these portions is the original color of the chalk when it is not affected by weathering. Owing to the resemblance in the color of the unweathered portions of the Niobrara chalk and the Pierre shale the two formations were confused by the early paleontological expeditions, which collected the Cretaceous reptiles between Wallace and McAllaster, Logan county. These collectors referred both shale and chalk to the Niobrara until Williston proved the presence of exposures of both Pierre and Niobrara in the area.

It is apparent that color alone is often not a sufficient means for distinguishing the Niobrara from the Pierre in the outcrops. Unfortunately, the same is true concerning the two formations in the deep wells, because the rocks of both formations are gray when unweathered. It is a fact that generally the unweathered Niobrara chalk is of a lighter gray shade than the ordinarily dark-gray or black shale of the Pierre, but some particular beds within the lowermost member of the Pierre are light gray to nearly white in the exposures, are light in weight owing to their porosity, and altogether have a "chalky" appearance, though they cannot be classified with true chalk either chemically or stratigraphically. These chalklike beds of the Pierre do not contain calcium carbonate or dolomite. (See description of these beds in the chapter on the Pierre.) When studying the well logs with the descriptions of the rocks made by the drillers, the writer noticed that the change detected by them from "dark gray" or "black" shale to "blue" or "light" shale sometimes corresponds to the true boundary line between the Pierre and Niobrara, and sometimes it corresponds only to contacts of various kinds of shale within the Pierre or various kinds of chalky beds within the Niobrara. Ordinarily more than one change from a lighter to a darker shade of gray and to a lighter shade again may be detected both within the Pierre and the Niobrara.

It is the experience of the writer that only the test with dilute hydrochloric or other acid is a reliable means for identification of the Pierre shale from the Niobrara chalk at the exposures, the stratigraphic boundary between the two formations being understood to correspond to the lithologic change from the highly calcareous chalky rock of the Niobrara to argillaceous and noncalcareous shale of the Pierre. The writer has found that this contact in western Kansas is invariably sharp. The same sharp contact between the Niobrara and the Pierre was observed by G. S. Lambert, of the Phillips Petroleum Co., during his examination of the Andrews No. 1 well of the company, which is situated in Yuma county, Colo., less than half a mile from the state line of Kansas. This is one of the very few deep wells of the High Plains from which a complete set of samples has ever been studied by a geologist. In his answer to the inquiry by the writer on what basis the contact between the Pierre and Niobrara was recognized in this well, Lambert states:[35]

> "Samples from what we classified as Pierre were uniformly noncalcareous. Samples from what we classified as Niobrara were uniformly calcareous. In other words, our distinction between the Pierre and Niobrara rested on the appearance of lime as an integral part of the rock. Above the Pierre and Niobrara contact only occasional limes were found.[36]
>
> "I surmise that our contact corresponds with the contact established by you in the field. Of course, samples from a single well give very inadequate data as compared with surface work over a wide area. However, in this instance the contact was so sharp and the lithologic change so distinct and so in harmony with your basis of distinction that I believe the two can be correlated."

While tracing the contact between the Pierre and the Niobrara in Wallace and in the adjacent part of Logan county the writer used

---

[35] Personal communication to the writer, July 9, 1930.

[36] These must be in part calcareous concretions or less regular accumulations of calcium carbonate around some organic remains or the calcareous shells and similar calcareous organic remains themselves.—M. K. Elias.

the test with dilute acid whenever there was any doubt as to where to draw the boundary line between the two. The contact established by this means corresponds fairly well with the general change of color from dark gray in the Pierre to orange in the Niobrara, whenever the latter was observed. The contact between the two formations, furthermore, was often emphasized in the outcrops by difference in the degree of weathering. Exclusive of the zones with hard concretions, the Pierre shale is as a rule less resistant to weathering than the Niobrara chalk. Thus the top of the Niobrara often forms a distinct erosional bench underneath softer shale. (See Plate III A.)

The boundary line between the Pierre and Niobrara in the adjacent areas of Colorado and Nebraska appears to be about as sharp as in western Kansas. According to a recent geological report on the northeastern part of Colorado, "where observed, the two formations are conformable, and usually there is a variable transition zone, probably less than 10 feet in thickness, in which the yellow-cream or yellow-brown limy paper shales of the Niobrara are replaced by the dark-gray noncalcareous flaky shales of the Pierre."[37]

This and the subsequent detailed description of the Pierre and Niobrara, by the same authors, leaves no doubt as to the sharpness of the contact, which here is also recognized by the appearance of calcareous sedimentary material in the Niobrara.

According to the observations of the Niobrara in southwestern Nebraska, "whenever the formation is overlain by Pierre shale, the chalky beds continue to the top of the formation,"[38] which shows that here, too, the boundary between the calcareous Niobrara and the "unctuous" and "loose-textured, carbonaceous clays" of the Pierre is sharp.

The relation between the Pierre and the Niobrara is described by Meek and Hayden along the Upper Missouri river in south-central South Dakota and northeastern Nebraska. According to the final description of the "general section of the Cretaceous rocks" by these two authors there is at the base of the Pierre a local "dark bed of very fine unctuous clay containing much carbonaceous matter, with veins and seams of gypsum, masses of sulphuret of iron and numerous small scales of fishes." This bed is "filling depressions in the bed

---

[37] Mather, Gilluly and Lusk, 1928, p. 83.

[38] Condra, 1907, p. 17.

below," which means in the Niobrara.[39] It seems that here, also, the contact between the dark and unctuous clayey shale of the Pierre and the "lead-gray calcareous marl" of Niobrara is fairly distinct. It is interesting, however, that an unconformity between the Pierre and Niobrara was recorded by Meek and Hayden for this locality—an observation not repeated as yet elsewhere. Neither was any kind of unconformity between these two formations observed during the latest exploration of the area where formerly Meek and Hayden studied these rocks.[40] Condra noticed that there is in the Pierre a zone of "alternating beds of shaly chalk and clay, the former weathering reddish; these chalky beds are often mistaken for Niobrara chalk."[41] It would be interesting to determine whether these beds of shaly chalk in the Pierre contain calcareous matter or merely imitate the porous character of chalky rocks and are noncalcareous, as do the chalklike porous beds in the upper part of the Sharon Springs shale member of the Pierre in Wallace and Logan counties (see description of the rock in the chapter on the Pierre). Outside of this appearance of chalky, or possibly only pseudochalky, beds in the Pierre shale much above the contact with Niobrara, it appears that in northeastern Nebraska the contact between the Pierre and the Niobrara is also manifested by the change from calcareous to noncalcareous sediments and is fairly sharp.

According to Meek and Hayden the thickness of the Niobrara at the type locality is 200 feet.[42] Condra states that the total thickness of the Niobrara west of St. James, Neb., "at the margin of Pierre . . . is over 200 feet."[43] Toward the northwest the thickness of the Niobrara, according to well logs, increases to 375 feet in the north part of Ziebach county, S. Dak.,[44] and toward the southwest it increases also, reaching 300 to 400 feet. Along Republican river in southwestern Nebraska, according to Condra, the lower member of the formation, which is probably equivalent to the Fort Hays beds of Kansas, is 40 to 50 feet thick, and the upper member is about 300 feet thick.[45] The data from the well logs of northwestern Kansas and northeastern Colorado show a

---

[39] Meek, 1876, p. xxiv.

[40] Condra, 1908, pp. 13-15. For further discussion of the problem see pages 56 and 58 of this report.

[41] Idem, p. 16.

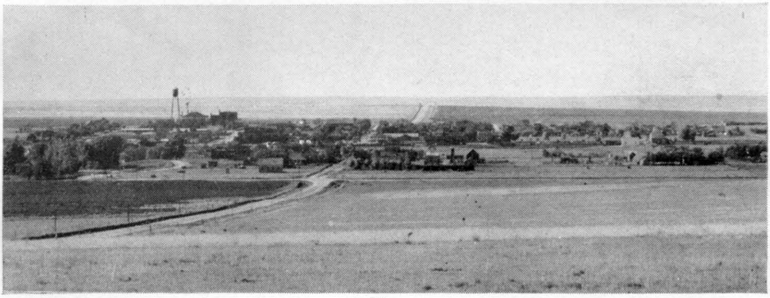
[42] Meek, 1876, p. xxv.

[43] Condra, 1908, p. 13.

[44] Russell, 1925, pp. 5-6.

[45] Condra, 1907, p. 17.

A



B

C

PLATE II.—*A.* Valley of south fork of Smoky Hill river south of Wallace. On the sky line is the rocky escarpment of the High Plains plateau composed of Ogallala. There is a veneer of Sanborn loess farther south. *B.* Sharon Springs looking north. Negative by Maddy, Sharon Springs. *C.* Valley of south fork of Smoky Hill river northwest of Sharon Springs. On the right is a typical combination of yucca and prickly-pear cacti, abundant on the valley slopes formed of loess.

further increase in thickness of the formations toward the south and west.

The thickness of the Niobrara of western Kansas was formerly underestimated.[46] The later figures, based on the study of the new deep wells of the area, are more accurate. Lupton, Lee and Van Burgh estimate the thickness of the Niobrara in Logan and Gove counties to be about 700 feet,[47] whereas Russell states that in Logan county "the thickness of the Smoky Hill chalk [alone] is known from well logs to be 700 feet, but decreases eastward." Considering the Fort Hays limestone, which has a very persistent thickness in the area, to be 50 to 60 feet thick, the total thickness of the Niobrara is 750 to 760 feet for Logan county, according to Russell. In his columnar section of the Smoky Hill chalk, based on field estimates, Russell gives the thickness of the chalk as only 600 feet, probably because the lower part of the member was measured east of Logan county, where it is thinner.[48] According to his estimation "the third subdivision," the base of which he places about 300 feet above the base of the Smoky Hill chalk, is "175 feet thick in eastern Logan county and 135 feet thick in eastern Gove county," which is a decrease in the thickness of the subdivision of 40 feet in six townships, or a little more than 1 foot to a mile. According to the estimate by Landes and Moss, the "Smoky Hill chalk member is 700 to 800 feet thick in the western end of the state" of Kansas.[49]

Unfortunately the cuttings of the two deep wells that have been drilled for oil in Wallace county are not known to have been examined by a geologist, and now only the logs of these two wells made by the drillers are available for examination. In the northern (Robidoux) well the undifferentiated "shale" which is recorded above the "white lime" of undoubtedly Fort Hays age, includes both Pierre and Niobrara. In the log of the other (Wulfekuhler) well a change from "green shale" above to "black shale" below is recorded at 325 feet, and a further change from black to "gray shale" is recorded at 375 feet, below which the "white lime," apparently the Fort Hays, was encountered from 965 to 1,025 feet. If the change from black to gray shale was at the Pierre-Niobrara contact, the thickness of the Niobrara in this well would only be 650 feet, which is 50 to 100 feet less than the estimate of the thickness of Niobrara

---

[46] Logan estimated it to be 350 feet (1897, p. 234), Williston considered it to be nearly 400 (1897, p. 237) and Darton placed it at about 350 feet (1905, p. 154).

[47] Lupton, Lee and Van Burgh, 1922, p. 71.

[48] Russell, 1929, p. 596.

[49] Landes, 1930, p. 16.

based on the more reliable identifications of the Pierre-Niobrara boundary line in the close neighborhood of Wallace county.

An important well for the estimation of the thickness of the Niobrara is the one drilled 8 miles east of the Wallace-Logan county line, in SE¼ SE¼, sec. 20, T. 12 S., R. 36 W. In the log of this well a change from "black" to "gray shale" is recorded at 65 feet below the surface. This change is interpreted as the contact between the Pierre and the Niobrara, the latter certainly being here not far below the surface. The writer examined the outcrops of the Pierre shale at the well and in the surrounding area and compared the elevation of these outcrops and the well by altimeter. His conclusion is that the well was started about in the middle of the lowermost or Sharon Springs shale member of the Pierre, which is about 155 feet thick, and therefore the change from black to gray shale in the well must correspond closely to the Pierre-Niobrara contact, as was previously concluded. As the Fort Hays limestone, which was recorded in the log as "white chalky rock," was met from 705 to 755 feet below the surface, the thickness of the Niobrara in this well must be 690 feet.

At Horace, in Greeley county, which is the next county south of Wallace, "the deep boring found the top of the formation [Niobrara] a short distance below the surface and apparently about 650 feet thick, although a portion of the topmost beds has been removed by erosion."[50] Farther southwest, in the Arkansas valley of Colorado, the thickness of the Niobrara is estimated to be about 700 feet.[51] The same estimate is given for the thickness of the Niobrara in Pueblo county, Colorado, by Darton,[52] who is inclined to give even a larger figure, about 740 feet, for the thickness of the Niobrara at Boone, Colo.[53]

The deep well at Cheyenne Wells, Cheyenne county, Colorado, according to Darton,[54] penetrated loess and a variety of apparently Ogallala sands down to 215 feet, when "black shale," undoubtedly Pierre, was encountered. The change from "black shale" to "white sandy shale with gas" was recorded at 534 feet, below which, at 1,260 feet, the "chalk rock with brackish water," having a thickness of 70 feet, was met. The latter rock is undoubtedly Fort Hays limestone, and if the change from black shale to white sandy

---

[50] Darton, 1905, p. 155.
[51] Gilbert, 1896, p. 566.
[52] Op. cit., p. 107.
[53] Idem, p. 357.
[54] Idem, p. 329.

shale with gas corresponds to the contact of the Pierre and the Niobrara, which is most probable, the total thickness of the Niobrara in this well is 796 feet.

In a well drilled north of Goodland, in Sherman county, which is the next county north of Wallace, the "lime shells" from 1,960 feet to 2,000 feet is probably Fort Hays, above which a "show of oil and gas" at 1,281 feet is recorded. If the latter depth corresponds to the top of the Niobrara, the thickness of Niobrara in this hole would be 719 feet. It is appropriate to notice that the gas horizon of Beecher Island, in Yuma county, Colorado, which is about 40 miles northwest from the Goodland well, is customarily considered to be at the top of the Niobrara. The estimate of the thickness of Niobrara at Beecher Island by the geologists of the U. S. Geological Survey,[55] compared with the data of the log of the Midfield Oil Co.'s well No. 2 at Beecher Island, shows that they share this opinion.

The above references as to the thickness of the Niobrara east, south, west and north of Wallace county seem to indicate that the thickness of this formation in Wallace county can hardly be less than 700 feet and most probably ranges from 700 to 750 feet.

Wherever observable the contact between the Pierre and the Niobrara in Wallace and Logan counties appears to be conformable.[56] Perfect conformity between the two formations was assumed to exist when reducing the elevations of the various outcropping key beds in Wallace county to the top of the Niobrara, which was chosen as the main key bed for the structural map supplementing this report.

Lithologically the chalk of the Smoky Hill member of the Niobrara formation is "made up of coccoliths, but with a considerable quantity of both rhabdoliths and foraminifera."[57] Besides these organic remains the sponge spicules and "certain round, yellowish bodies that were occasionally seen in the empty tests of foraminifera"[58] have been found in the chalk. The organic constitution of the Smoky Hill rock thus shown and its porosity fully justify the name chalk, now generally applied to the whole member. The difference between the Kansas chalk and the white chalk of England and western Europe is chiefly difference in color and is due to the

---

[55] Mather, Gilluly and Lusk, 1928, p. 111.

[56] For the discussion of other observations and opinions in regard to the contact between the two formations see pages 56 and 58 of the chapter on the Pierre formation.

[57] Williston, 1893, p. 109.

[58] McClung, 1898, p. 427.

impurities in the former. The original color of the Smoky Hill chalk, which can be seen in the deep-well cuttings and occasionally in some natural exposures, is for the most part gray to light gray, which when weathered turns to bright orange, cream-yellow or rarely pink, all these of soft pastel shades. In the lower half of the formation a snow-white chalk is found occasionally. The gray color of the unweathered chalk is undoubtedly due to the fine particles of iron sulphide (pyrite or marcasite), which are more or less uniformly distributed through the rock and most probably represent the residue of the decayed organic matter. Though the color of the larger bodies of iron sulphides (which are also occasionally met in the chalk) is golden yellow to bronze yellow, the color of the powdered iron sulphide is gray. In the portions of the chalk that have been affected by weathering the larger bodies of iron sulphide are converted on the outside into the yellowish-brown rust of the common hydrous oxide of iron (limonite). The weathering of the fine particles of the same sulphide embedded in the rock produces the change of color of the rock from gray to various light shades of yellow, brown and red, depending on the particular oxide or hydrous oxide into which the iron of the sulphide is converted and on the admixture of otherwise colored particles.

Two analyses of Kansas chalk were made by G. E. Patrick, who refers them to the rocks collected from 300 to 320 miles west of Kansas City, "within 3 miles of the Kansas Pacific railroad." The place thus located by this author is somewhere in Trego county, Kansas, and therefore the rock came from the lower half of the Smoky Hill chalk. The first analysis is of "a fine specimen of snowy whiteness," and, as Patrick states, "No. 2 had a light yellowish tinge and was as poor a sample as I could select."[59]

Analyses of Smoky Hill Chalk.

(G. E. PATRICK, Analyst.)

	No. 1.	No. 2.
Moisture	0.34	0.58
Insoluble in acids (silica, lime and alumina)	.69	11.40
Alumina (little oxide of iron)	.43	.97
Ferrous carbonate	.14	2.83
Calcium carbonate	98.47	84.19
	100.07	99.97

These two analyses show the variation of the amount of impurities in the Niobrara chalk, but also show that the calcareous matter is probably always predominant.

---

[59] Patrick, 1875 (reprint in 1906), pp. 13-15.

Two analyses of the Niobrara chalk from northeastern Nebraska have been published and are as follows:[60]

Analyses of Niobrara Chalk from Northeastern Nebraska.

(HOWISON CROUCH, Analyst.)

	Unweathered specimen.		Weathered specimen.	
Moisture	0.70		1.11	
SiO_2	4.52		6.02	
Organic matter	3.14		1.03	
SO_3	2.14		.85	
CO_2	37.80	87.46	37.11	85.09
CaO	49.66		47.98	
Fe_2O_3 and Al_2O_3	1.87		5.92	
MgO	Trace		Trace	

Probably the analysis of Patrick's rock No. 2 and the analyses of the Nebraska chalk are much closer to the average chemical constitution of the Smoky Hill chalk than Patrick's snow-white chalk, which is a comparatively rare variety in the formation. The amount of impurities in the more ordinary varieties of the rock, which are chiefly argillaceous matter and oxides of iron, are apparently not so great as to make the name chalk inapplicable.

Bass, who made a detailed study of the exposed parts of the basal 100 feet of Niobrara chalk in Ellis county, describes this portion of the formation as consisting of "marl beds alternating with chalk and thin beds of clay.[61] The thin beds of clay are referred by Bass to the bentonitic clays, and in the detailed descriptions of the sections marls are called chalky shale, chalky clay shale and clay shale. According to observations by Bass there are two "units" in the lower Niobrara, consisting of the interbedded chalk, chalky shale, shale and bentonitic clay, which are very persistent in their lithology and are "readily traceable beds in the Smoky Hill member exposed in Ellis county."[62] He also observed that "a series of hard and soft chalky shales and chalk with a few interlaminated bands of bentonitic clay," which belong to the upper part of the Niobrara, appear to be traceable in the exposures of Logan county.[63] During the Etnyre Syndicate survey in Logan county in 1927 a series of analyses of Niobrara rocks selected by O. E. Stoner was made in order to determine the constancy of the calcareous matter within some readily traceable beds. These analyses proved that the amount of calcium carbonate in these beds is fairly constant and that the

---

[60] Condra, 1908, p. 15.

[61] Bass, 1926, p. 19.

[62] Idem, p. 21.

[63] Idem, p. 20.

determination of it can be used for checking field correlations of key beds in the formations.

The pure or nearly pure chalk of the Niobrara is a porous rock, whereas the chalky shale with which it is interbedded is apparently less porous. The latter rock seems to predominate in the formation. The degree of porosity of these rocks, as far as known to the writer, has never been a subject of precise study. However, the deep wells that have penetrated the formation in western Kansas and eastern Colorado prove that there is no artesian water in the formation, though it is underlain by impervious shale and though a large supply of water, which rose high into the Niobrara (about 250 feet above the base of the Fort Hays), was met in Dakota sands in the Wulfekuhler well and in other wells. On the other hand, gas is nearly always encountered within the Niobrara, usually near the top, and brackish water in the Fort Hays was met in the well at Cheyenne Wells. These occurrences indicate that the formation is not entirely impervious, but contains some channels along which gas and water can pass. These channels may be provided by the more pervious portions of the formation or perhaps by a series of fissures, a network of which probably penetrates the rocks. All field observers agree that the Niobrara is much broken into tilted blocks. Furthermore, as the writer has observed, in some places in the formation a closely spaced cleavage about 45° to the bedding planes is developed (see Plate II B), which is probably a consequence of twisting. The atmospheric water performs its destructive work along these various fissures, as can be seen clearly in the eroded cliffs of Niobrara in Gove and Trego counties.[64] On the other hand, the writer observed the filling of some fault fissures with calcite in the SW¼, sec. 36, T. 13 S., R. 38 W., in Wallace county[65] (Plate IV). The calcite is dense and crystalline and is covered with slickensides. Apparently it crystallized from water solutions when the faulting process was not yet completed and when these uppermost Niobrara beds were buried under the overlying Pierre shale, which is now eroded away.

The presence of many fissures in the Niobrara, along at least some of which underground water apparently circulated, appears to explain satisfactorily the origin of caves within the formation, over which the local subsidences of the area occur. (See chapter on local subsidences.)

---

[64] Observations by K. K. Landes, oral communication to the writer.

[65] A similar observation of calcite deposited along fractures of fault planes in the chalk of western Kansas was made by R. C. Moore, 1926a, p. 3.

The scattered outcrops of Niobrara in Wallace county belong to the uppermost beds of the formation. The outcropping rocks appear to be nearly uniform in constitution and physical properties, containing no particularly prominent ledges that could be easily recognized in the field by their lithology or fossil content. As the outcropping portion of the Niobrara in Wallace county afforded no opportunity to study the detailed stratigraphy of this formation, the writer limits himself to a brief review and summary of the present data on the Niobrara stratigraphy in Kansas as given by other authors.

Generally the Niobrara of Kansas is divided into the Smoky Hill chalk above and the Fort Hays limestone below, the two members being comparatively easily recognized both in surficial exposures and wells. The Fort Hays is only 50 to 60 feet thick. The beds of this member are described by Rubey and Bass[66] and in still more detail by Bass.[67] The latter author gave also the first detailed description of the basal 70 feet of the Smoky Hill chalk, within which he recognized two well-exposed and prominent groups of beds, which he designated group A, from 55 to 70 feet, and group B, from 10 to 20 feet, above the base of the Smoky Hill member.[68] Russell attempted to divide the whole thickness of the Smoky Hill chalk of Logan, Gove and Trego counties into four subdivisions, and specified ten topographically prominent or otherwise noticeable groups of beds in the chalk, with intervals of beds less prominent or not exposed at all. The scheme of Russell, which is based on lithologic observations in the field alone, is presented in modified and generalized form in the table on pages 42 and 43.[69] The fossil content of the subdivisions or groups of beds of the Smoky Hill chalk is left out of consideration in Russell's scheme.

In another table the earlier subdivision of the Niobrara formation as given by Williston, chiefly on paleontologic but also on lithologic grounds, is presented.[70] Some additional names of invertebrates are added to this scheme after W. N. Logan.[71]

Thanks to the description by Williston of some of the most prominent and picturesque exposures of "yellow chalk" in Gove county, and with the help of the boundary line outlined by him between the

---

[66] Rubey and Bass, 1925, pp. 28-30.

[67] Bass, 1926, pp. 24-25 and pp. 62-63.

[68] Idem, pp. 19-23.

[69] Russell, 1929.

[70] Williston, 1892; also Williston, 1897 and 1898.

[71] Logan, 1898.

Hesperornis and *Rudistes* beds in northwestern Kansas, it is possible to conclude that the *Hesperornis* beds or yellow chalk of Williston corresponds to subdivisions III and IV of Russell, and that the *Rudistes* beds correspond to subdivisions I and II of Russell.

Paleontologic Subdivision of the Niobrara Formation.

(Modified after S. W. Williston, 1892, 1897 and 1898, with addition of invertebrates after W. N. Logan, 1898.)

Hesperornis beds or Yellow chalk:
- Yellow often buff or reddish chalk; smooth and soft to touch.
- Bivalves:
  - *Ostrea congesta* Conrad—not very abundant.
  - *O. larva* Lamarck—rare.
  - *Inoceramus pennatus* Logan.
  - *I. subtriangulatus* Logan.
  - *I. platinus* Logan.
- Arthropods: *Squama lata* Logan—at base of beds.
- Mosasaurs:
  - *Clidaster* and *Mosasaurus,* which are absent in the *Rudistes* beds.
  - *Platecarpus* and *Tylosaurus,* which are absent in Pierre.
- Pterodactyls (*Ornithostoma*) more numerous than in the *Rudistes* beds.
- Toothed birds: *Hesperornis, Ichthyornis,* etc.—restricted to these beds.

Rudistes beds:
- White or gray chalk, never deeply yellow.
- Shales of lighter blue.
- Ammonites and Belemnites rare.
- Bivalves:
  - *Ostrea congesta* Conrad—very abundant.
  - *O. larva* Lamarck—rare.
  - *Inoceramus* (*Haploscapha*) *grandis* (Conrad).
  - *I.* (*Haploscapha*) *niobraraensis* (Logan).
  - *I.* (*Haploscapha*) *eccentrica* (Conrad).
  - *I. concentricus* Logan.
  - *I. truncatus* Logan.
  - *I. platinus* Logan.
  - *Parapholas sphenoidens* White.
- Rudistæ: Gigantic *Radiolites maximus* Logan.
- Echinoderma: *Uintacrinus socialis* Grinnell—in top of beds.
- Arthropoda:
  - *Squama spissa* Logan—at base of beds.
  - *Stramentum* (*Pollicipes*) *haworthi* (Williston) Logan.
  - *S. tabulatum* Logan.

Mosasaurs: *Platecarpus* and *Tylosaurus.*

Fort Hays limestone:
- Bivalves:
  - *Inoceramus deformis* Meek—in top of limestone.
  - *I. browni* Cragin.
  - *I. flaccidus* White.
  - *I. simpsoni* Meek.

Lithological Subdivision of the Niobrara Formation.

(Modified after W. L. Russell, 1929.)

		Feet.
IV.	Brownish-yellow weathered calcareous shale. Many comparatively thick streaks of bentonite	125
III.	Calcareous shale weathered in places to massive, yellowish-white, cliff-making chalk. (Pyramid rock, Castle rock, etc., of Gove county, Kansas)	175

		Feet.
II.	Soft, thin-bedded, calcareous shale; no conspicuous hard or massive ledges. Many thin bentonite streaks. Round pyrite concretions especially abundant	150
I.	Upper part: Two thin, hard, white ledges with dark shale between (12 feet). Lower part: Many thin but persistent hard ledges with very thin bentonite streaks between (133 feet)	145
	Fort Hays limestone—considerably harder than Smoky Hill chalk	50-60

Pierre Formation.

In his classical description of the Cretaceous invertebrates of the "upper Missouri country," which is still the main source of our knowledge of the invertebrate paleontology of the Great Plains, Meek says:[72]

> "Fort Pierre group . . . is perhaps the most important member of the series, not only on account of its thickness and the extent of its geographical range, but also from the great number and the beautiful state of preservation of its organic remains."

The Pierre formation crops out over a considerable area of the central Great Plains from eastern North and South Dakota, through northern and southwestern Nebraska into Colorado, cutting the northwestern corner of Kansas, where the Pierre is the uppermost member of the local Cretaceous. The formation also covers a considerable area in Wyoming, Montana, easternmost Utah and Idaho, and extends far into Canada, where corresponding beds have been subdivided into Judith river, Claggett and Eagle Creek shales and sands. The equivalents of the Pierre extend, also, through Colorado into northeastern Arizona, New Mexico and Mexico. The Pierre shale of this enormous area represents sedimentation in a great inland sea of Upper Cretaceous time. This sea was connected by way of Mexico and Texas with another great sea, which covered parts of the Gulf coast, lower Mississippi valley, and southern Atlantic coast states.

The exposures of northwestern Kansas lie about in the middle of the eastern border of the Pierre outcrops. Should we remove in our imagination the youngest arenaceous formations of Wallace county, the alluvium, loess, gravel, Tertiary "mortar beds" and clays, we would find the whole county covered with the Pierre formation, except a very narrow zone on the south side of Smoky Hill river, southwest of Wallace, where the underlying chalk of the Niobrara formation is exposed. The Pierre formation is known to the citizens of Wallace county as "shale," the impervious bottom rock that supports the water in the majority of the local water wells.

---

[72] Meek, 1876, p. xxxiii.

The formation is about as fossiliferous in Wallace county as it is in the type locality along the Missouri river below Fort Pierre, and the Pierre of western Kansas is as thick as or even thicker than there. The well-preserved fossils, which are chiefly the remains of invertebrate organisms of the Pierre sea, are important not only as relics that teach us of the life on our planet in the remote past, but they are also tokens by which the several beds can be recognized. Unless the various outcropping beds of the 600 feet of the Pierre are grouped into members, no surface structure map of the area can be prepared, and consequently no particular place can be recommended in preference to others for an oil or gas test well. A structural map based solely on the observations of local dips of the strata is not reliable, because the dips in the Pierre shale (as well as in the underlying Niobrara) are very variable within a short distance, and often the locally observed dips are contradictory to the actual dip of the formation as established by the correlation of the outcrops. This is due to the small-scale tilting and occasional faulting of the formation or the slumping of the surficial portions of the shale. The unreliability of structural mapping in western Kansas based on observed dips alone has already been pointed out by a few authors (Twenhofel, 1925, pp. 1064-1065; Russell, 1929, pp. 603-604). Therefore the subdivision of the Pierre and correlation of its outcrops must be regarded as essential preparation for the structural mapping of the county. Though in a few exceptional places the correlation of beds can be based on the lithology alone, this means of correlation usually cannot be trusted unless checked by some other means, because various beds and zones belonging to different horizons have a similar lithology and can be easily confused. The writer has observed attempts to correlate some portions of the Pierre of Wallace county with the Pierre outcropping at Beecher Island, Yuma county, Colorado, on the sole basis of the existence of streaks of bentonite associated with limestone concretions in both areas. But observations by various geologists have revealed that streaks of bentonite are common throughout the whole Pierre as well as in the Niobrara and Benton formations of the Great Plains and elsewhere.[73]

The ammonites of the shale that is exposed at Beecher Island belong chiefly to the *Discoscaphites* group and include the species *D. conradi, D. abyssinus* and others, which elsewhere are exclusively

---

[73] See descriptions of Pierre and other formations by Mather, Gilluly and Lusk, 1928; by Pinkley and Roth, 1928; by W. L. Russell, 1929; by Baker, 1928; and others.

Fox Hills and uppermost Pierre forms. Contrary to this, in the Pierre shale of Wallace county these species are absent, while *Acantoscaphites nodosus* of middle Pierre and allied forms are very common. A nearly complete change of all other fauna is also noticed in the shale of Beecher Island from that of Wallace county, the same groups and genera of marine animals being represented by distinctly different species.

This paleontologic evidence is completely supported by the data of the deep wells in Wallace county and at Beecher Island. The particular shale of Wallace county (the Weskan shale), in which the bentonite streaks allegedly identical with those of Beecher Island were observed, is only about 300 feet above the top of the Niobrara, and the Pierre shale within Wallace county is nowhere more than 600 feet thick, whereas below the shale with bentonitic streaks outcropping at Beecher Island there is 1,400 feet of Pierre shale above the Niobrara. Allowing a certain amount of decrease in the total original preërosional thickness of the Pierre of Wallace county compared with the Pierre at Beecher Island, as is estimated below, we still conclude that the equivalents of the lower horizons of the Pierre exposed at Wallace cannot possibly outcrop at Beecher Island, being there hidden below about 600 to 700 feet of the upper Pierre shale.

The importance of the study of the lithology of the Pierre certainly cannot be questioned, and actually the appearance and constitution of the rocks is always the first thing that is observed and studied by a geologist in the field. But the lithology of the Pierre shale is so uniform that only a very careful and detailed study of the different beds, bentonite streaks, and concretions scattered or arranged in zones will make possible any correlation of the outcrops, and such a correlation should always be checked by some other means. This can be done by study of the fossil content of the beds and zones and sometimes by observing the succession of the beds.

Water wells drilled into the Pierre will strike no water supplies in this formation, for there are no sands or pervious limestones known in the Pierre of western Kansas and easternmost Colorado. Neither do any water-bearing horizons occur in the underlying Smoky Hill chalk. Several thick sandstone members are known in the Pierre of the Rocky Mountain region of east-central Colorado, where the formation reaches an enormous thickness of 8,000 feet or more, but all these sandstone members are local and pinch out before reaching the boundary line of Kansas. Beds of "impure chalk" and "chalky clay" have been noted in the lower Pierre along the Missouri river in northeastern Nebraska,[74] and in the upper Pierre of Ziebach county, Nebraska, calcareous shale was observed.[75] According to Fenneman the Pierre of the Boulder district, Colorado, though in general noncalcareous, has local limy beds.[76] "At places these form continuous strata, as, for example, 4 miles north of Boulder, one-half mile east of the contact with the Niobrara. Here for a thickness of nearly 40 feet strong limestone beds are so closely grouped as to give the outcrop the appearance of the basal Niobrara." These limestone beds appear to belong to the lower portion of the Pierre, below the Hygiene sandstone, according to the maps of the area by Fenneman[77] and by Henderson.[78] Fenneman adds: "At other places the limestone beds are smaller and more isolated," and "less prominent calcareous masses may be found at any horizon either in beds or more or less perfect concretions." Outside of this statement by Fenneman, which is repeated in some later papers, no other records of limestone beds in the Pierre of eastern Colorado are known to the writer. No calcareous beds were observed in the Pierre shale of Wallace county and the only calcium carbonate present was in concretions or very rarely in thin and discontinuous streaks.

Beds and lenses of a very peculiar light porous shale were observed by the writer in several outcrops of the Pierre about 100 to 150 feet above the top of the Niobrara in Wallace county. This shale is not "soapy" like the usual Pierre shale, but has a "chalky" appearance and somewhat resembles the Mowry shale of the Benton, except not being hard and siliceous. But this shale would not effervesce, either with cold or hot hydrochloric acid, and therefore does not contain any calcium carbonate or dolomite.

A few very thin and nonpersistent streaks and lenses of fine clayey sand were observed, but they are negligible in size and number. By decantation of the fine material in Pierre shale cuttings from a deep well at Beecher Island the writer invariably obtained a small quantity of fine sand together with some foraminifera and other organic remains. This sand is composed almost entirely of quartz grains. Its presence in such a small amount does not make

---

[74] Condra, 1908, pp. 15-17.

[75] Russell, 1925, p. 4.

[76] Fenneman, 1905, p. 31.

[77] Idem, map on p. 44.

[78] Henderson, 1920, map in pocket.

the shale sandy in appearance and does not add to the porosity of the rock to an appreciable degree. Except the peculiar porous shale occasionally found in the lowermost Pierre, which is light gray or nearly white when weathered, the Pierre shale of Wallace county is dark gray to black and is usually unctuous. It weathers to lighter shades and when much weathered may be greenish or brownish gray. Much of the Pierre shale is distinctly laminated, and in places it is minutely banded.

Pyrite or marcasite, chiefly in the form of minute casts of Foraminifera or in the form of a crust associated with other organic remains, is fairly uniformly scattered through the whole formation and can be found in every piece of fresh shale. These minerals, however, rapidly decompose near the surface and are replaced by iron hydroxide and by flakes or larger crystals of gypsum. Owing to this action the outcropping shale is usually full of rusty spots and almost always has thin crystals of selenite sparkling here and there but chiefly along the cracks. Some zones of the shale are especially impregnated with large crystals of gypsum, which crystallized along the bedding planes and the larger cracks, but nowhere do these crystals form anything like a bed, and neither are they sufficiently concentrated in the shale to make a commercially important deposit. Thin streaks and moderately large concretions of iron hydroxide in the form of limonite are abundant in places, but again the quantity is insufficient to make a commercial deposit of iron ore. In a few outcrops a little hard black manganite was found in small kidney-shaped concretionary crusts, which were associated with organic remains of invertebrates.

The Pierre shale of eastern Colorado, which does not differ much in constitution from the Pierre shale of western Kansas, was analyzed and physically tested by G. M. Butler, from whose report[79] the following selected analyses are quoted. They give a good illustration of the variable chemical and mineralogical content of the Pierre shale.

---

[79] Butler, 1915, p. 342.

Ultimate analysis (in percentages).

	(1)	(2)
SiO_2	54.30	66.31
Al_2O_3	15.02	13.69
Fe_2O_3	9.48	4.41
CaO	4.08	2.28
MgO	2.86	1.58
K_2O	2.64	2.22
Na_2O	.43	1.19
Loss on ignition	9.11	6.40
Moisture	1.68	1.68
CO_2	....	....
SO_3	Tr.	....
	99.60	99.76

Rational analysis (in percentages).

	(1)	(2)
Kaolin	28.83	23.55
Quartz	28.20[80]	39.86
Feldspar	19.22	23.22
Limonite	11.08	5.16
Calcite	....	4.08
Gypsum	12.58	....
	99.91	95.87

As mentioned already, the Pierre shale of Wallace county occasionally contains thin streaks of greenish or grayish-white or rarely brownish soapy rock (Pl. VII A), which is usually classed as bentonite of the Benton formation, an altered volcanic ash.[81] This rock of the Pierre, when immersed in water, swells considerably and disintegrates at once into a very fine mud. Mineralogically the rock consists chiefly of kaolinite or a related mineral, in which often flakes of biotite are present.

Concretions of varied size and constitution are very common in the Pierre. For the most part they are composed of calcium carbonate, of siderite and of limonite, and often of a mixture of two or three of these minerals. A more detailed description of these concretions is presented in the discussion of the members of the Pierre.

Often the concretions are more numerous along some particular bedding planes, and in places the limonite forms nearly continuous though thin concretionary beds. Both the limestone and the limonite concretions usually gather in some particular zones, being rare or absent in intermediate zones of the shale. These concretionary zones outcrop as prominent escarpments or form benches in the shales (Pl. IV, Pl. X A), thus furnishing local key beds that are

---

[80] In the table on page 342 of Butler's report 18.20 of quartz is shown, which is apparently an error of the printer. Compare the total and the content of SiO_2 of the ultimate analysis.

[81] Ross and Shannon, 1926.

usable in structural mapping. The best invertebrate fossils were collected in or around the concretions (Pls. VIII C, IX B, XII D), and helped to identify and correlate the concretionary zones. A detailed account of these zones and their fossils is given in the descriptions of the local members of the Pierre.

The maximum thickness of the Pierre in Wallace county, as measured on the outcrops and partly computed from the well logs, is about 600 feet, which, as will be shown below, is only the remaining lower half of the formation, the upper half being eroded away.

The regional dip of the Cretaceous formations in Wallace county is almost north, and its average is about 20 feet to a mile. However, owing to the general slope of the surface to the east, the boundary lines between the members of the local Cretaceous crop out approximately in the west-southwest east-northeast direction (see geologic map of the county). Southeast of Wallace, along the south side of Smoky Hill river, the base of the Pierre is seen resting upon the uppermost beds of the Smoky Hill chalk, and about two miles northwest of the town, at the Wulfekuhler deep test well, there is about 285 feet of Pierre shale above the top of the chalk, according to the interpretation and estimate of the writer. Seven miles farther north, at the Robidoux test well, the Pierre shale reaches the thickness of 375 feet, and about 28 miles from there in a northwesterly direction and north of Goodland, about 600 feet of shale overlies the chalk (all these figures according to the interpretation of the logs by the writer). In the northwest corner of Wallace county there is also about 600 feet of shale, which was computed on the outcrops.

The Andrews No. 1 well of the Phillips Petroleum Co., which was drilled in sec. 3, T. 23 S., R. 42 W., of Yuma county, Colorado, about 36 miles northwest of the above-mentioned Goodland well, passed through 1,430 feet of Pierre shale before it reached the top of the Niobrara (data on this well kindly furnished by the geologists of the company). The shale exposed around this well has nearly the same lithology and fossil content as the shale exposed about ten miles west, near Beecher Island, in Yuma county, Colorado, where nearly the same thickness of shale above the Niobrara was recorded. The fossil content of the outcropping shale of this area indicates the topmost beds of the Pierre or even a transitional zone between Pierre and Fox Hills. The tendency of these outcropping beds to approach the lithology of Fox Hills sandstones is indicated by a somewhat more solid and less "soapy" appearance of the shale, as if a larger quantity of fine sandy material was present. Furthermore, the increase of near-shore material in the formation is manifested by the appearance of the imprints of leaves of *Salix, Ficus, Celastrus*[82] and other trees, which were collected from the shale near the Andrews well. It appears, therefore, that 1,400 feet represents about the complete thickness of the Pierre formation in northeastern Yuma county of Colorado, and in northwestern Cheyenne county of Kansas, which is in the northwest corner of the state.

The Pierre shale of southwestern Nebraska was not estimated exactly, but is more than 1,000 feet along the western part of Republican river, according to Condra.[83] According to the writer's interpretation of the log of John Kelly No. 1 well, of the Prairie Oil and Gas Co., in sec. 33, T. 19 N., R. 55 W., in Banner county, western Nebraska, the thickness of the Pierre is here about 2,600 feet. The "dark gray lime" between 3,463 feet and 3,720 feet (257 feet thick) at the base of the great thickness of mostly "dark" shale is considered by the writer to belong to Niobrara, the thickness of which formation measured on the outcrops west of the well, in the Sherman quadrangle in Wyoming, is from 325 to 400 feet,[84] and north of the well, in the southern Black Hills region, it is 175 to 225 feet.[85] According to the elevation of the well (4,500 feet taken from the U. S. Geological Survey topographic map) and the geological map of the region[86] the well started in about the middle of the Brule clay (Oligocene). "Hard yellow pan" down to 400 feet, the intercalated "yellow mud," shale and sandy shale below to 815 feet and the "water sand" to 825 feet probably represent the sandy Chadron formation of the Oligocene and possibly the sandy Fox Hills formation of the Upper Cretaceous, which are known in distant exposures, west and north of the well. If this correlation is correct, the intermediate portion of shale having a few streaks of "sandy shale" between 825 feet and 3,463 feet of the well must correspond to the Pierre formation.

Darton gives approximate estimation of the exposed portion of the Pierre in the Black Hills region of South Dakota as about 1,200 feet, not including the uppermost bed,[87] and according to a recent estimate by Rubey the total Pierre of the southern Black Hills is

---

[82] For a more complete account of this flora see pp. 130 and 131 of the report.

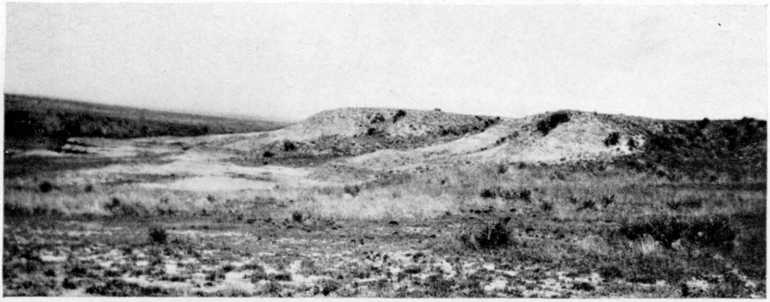
[83] Condra, 1907, p. 19.

[84] Darton and others, 1910, p. 18.

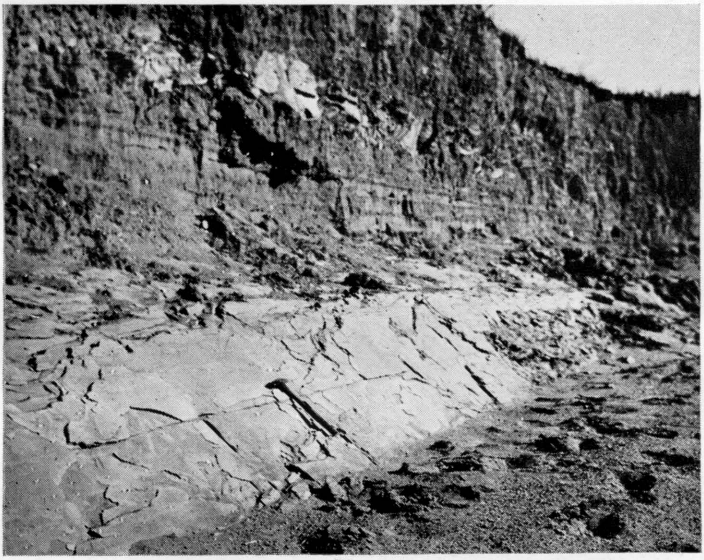
[85] Darton and Paige, 1925, p. 35.

[86] Darton, 1903.

[87] Darton and Paige, 1925, p. 14.

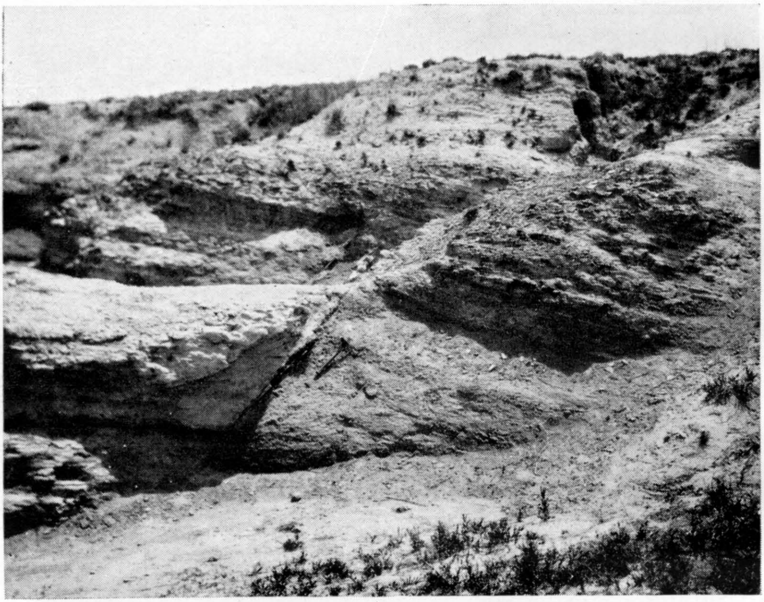


A



B

Plate III.—*A.* Contact of Pierre and Niobrara in the NE¼, sec. 1, T. 14 S., R. 38 W. Shows more pronounced bench of Niobrara chalk (at the left) compared with the overlying Pierre shale. *B.* Fine cleavage in Niobrara chalk with inclination about 45 degrees to the bedding planes. From the SE¼ SW¼, sec. 31, T. 13 S., R. 38 W. Above is reworked loess full of Niobrara debris.



A

B

Plate IV.—*A.* Fault in Niobrara chalk with crystalline calcite filling the fault fissure. From the NW¼, sec. 36, T. 13 S., R. 38 W. *B.* Slickensides in crystalline calcite which fills the fault fissure. Photographed on the other side of the little knob shown in A.

2,250 feet thick.[88] According to the study of the lithology and fossil content of the cores of a recent well in Ziebach county, South Dakota, the thickness of the Pierre in that area is between 1,165 and 1,446 feet.[89] Todd gives an approximate estimate of the thickness of the Pierre in the region of the upper Missouri river, between Fort Pierre and Cheyenne river, as about 1,000 feet.[90]

West of the northwest corner of Kansas the thickness of the Pierre increases rapidly. It is estimated to be 2,210 to 2,250 feet in the Acron-Padroni area of northeastern Colorado, which is about 60 miles from the northwest corner of Kansas, and it increases to 5,000 feet at Boulder, Colo.[91] According to the measure of the outcrops of the Pierre by J. D. Sears and J. Gilluly[92] "a minimum thickness of 8,000 feet may be attributed to the Pierre shale" at Fossil creek, south of Fort Collins, but it is around 7,000 feet at Wellington Dome.[93] The thickness of the formation decreases toward the north, being only about 5,000 feet at Horse creek, in Sherman quadrangle in Wyoming.[94] In the southern half of this quadrangle "on North Fork of Crow creek, where the entire thickness is exposed, and the beds are vertical, they measure 4,000 feet across, but are considerably crushed and much obscured by talus."[95] In northeastern Wyoming the Pierre has much less thickness, and various authors place it from 1,250 feet[96] to 2,500 feet.[97] The thickness of the Pierre decreases to about 2,500 or 2,600 feet at Pueblo,[98] and in the Walsenburg quadrangle the thickness is 1,900 feet, in the Huerfano valley, 1,750 feet south of Cuchara, and about 1,500 feet at the south boundary of the quadrangle.[99] The same thickness of the Pierre is given by Hills[100] for the northeastern part of Spanish Peaks quadrangle, and farther southeast the Pierre decreases to 1,250 to 1,300 feet in the southern half of Elmore quadrangle.[101]

---

[88] Mather, Gilluly and Lusk, 1928, p. 111.

[89] Russell and Stanton, 1925, pp. 4-5 and p. 8.

[90] Todd, 1908, p. 26.

[91] Fenneman, 1905, p. 31.

[92] Mather, Gilluly and Lusk, 1928, pp. 90-92.

[93] Idem, p. 114.

[94] Darton and others, 1910, p. 18.

[95] Idem, p. 10.

[96] Darton, 1907, p. 5; Collier, 1922, p. 86.

[97] Hancock, 1920, p. 21.

[98] Gilbert, 1897, p. 3: "A thickness of 2,200 feet appears in the district, but the top is not seen." In his paper on underground water of Arkansas valley (Gilbert, 1896, p. 557) this author shows the total thickness of the Pierre of the region to be about 2,500 to 2,600 feet (Fig. 46 on p. 571).

[99] Hills, 1900, p. 2.

[100] Hills, 1901, p. 1.

[101] Hills, 1898, p. 2.

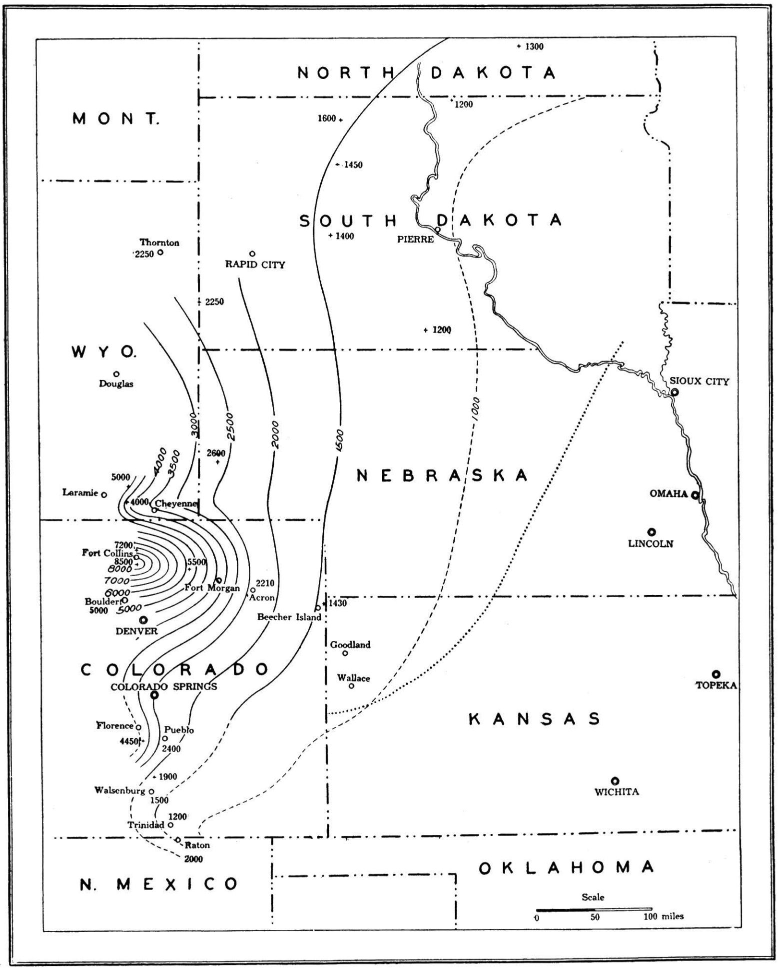


Fig. 2.—Map to show the original thickness of the Pierre formation in Midwestern states. Explanation: Contours in solid and in dashes indicate equal thicknesses of the formation; contour intervals, 500 feet; dotted line indicates eastern boundary of the present exposures of the Pierre.

South of Raton Mesa elevated plateau, however, the thickness of the Pierre increases again and is, according to Darton, "considerably more than 2,000 feet."[102] In the Florence oil field the thickness of the Pierre increases to 4,450 feet.[103]

These figures for the thickness of the Pierre in the central Great Plains are plotted on the accompanying map, figure 2, in which con-

---

[102] Darton, 1928, p. 43.

[103] Eldridge, 1892, p. 450.

tours connect the points of equal thickness. The map is generalized, of course, and does not give a very accurate representation of the original thickness of the Pierre, especially for the areas far away from the few points at which the thickness of the formation was established. It is hoped that the map will be gradually improved with the accumulation of new or more reliable data. Even in its present form a general idea is given of the variability of the original, preërosional thickness of the Pierre within the mapped area and a hint as to how far east the Pierre sediments must have been originally extended. The map has a particular and important value for stratigraphic study in Wallace and other counties of northwestern Kansas, because it helps to recognize the true stratigraphic position, or the position in relation to the complete preërosional section of the Pierre, of those exposed beds of this formation whose distance to the base of the Pierre can be established with the help of the deep wells. According to this map the original thickness of the Pierre in Wallace county must have been from about 1,000 to 1,300 feet. The actual measured thickness of the formation in this county, as was noted above, is only about 600 feet, which apparently represents only the lower half of the formation, the other half being eroded away. Comparison of the fossil content of the outcropping Pierre shale of the county with the paleontologic data from the Pierre in other regions confirms this conclusion, as will be shown below.

During the survey of Wallace county the local 600 feet of Pierre was subdivided into zones and members, on the ground of lithologic differences, together with some definite changes in fossil content. Owing to the little resistance to weathering of the soft shale, the Pierre formation in Wallace county is not widely exposed, and the same is true for nearly all other areas of the distribution of the Pierre in the Great Plains. For this reason and on account of the nearly featureless character of the shale throughout the thickness of the formation, few attempts to subdivide it have been made before. The method of field work employed by the writer has been briefly described. The concretionary zones, which form escarpments in the outcrops of the Pierre, were used as local key beds, but as these concretionary beds cannot be followed from one exposure to another, being covered in most places with a thick mantle of loess, detailed study of the sections of the Pierre in almost every observed outcrop was made. Owing to some lateral changes in the concretionary zones, but still more to the repetition of the lithology of some stratigraphically different beds of the Pierre, the correlation of the sections of the separated outcrops was always checked by the fossil invertebrates which, fortunately, could be collected in sufficient number from nearly every outcrop of the formation. Only the outcrops of the lowermost 155 feet of the Pierre, which are almost barren of the invertebrates, were correlated on the lithology aided by the great abundance of small fish remains. The lithologic features of this member of the Pierre are so different from those of the rest of the formation that there was no danger of confusing it with the overlying members, even without checking it by the contained fossils. This lowermost member of the Pierre, which is named here the Sharon Springs member, has been described by various authors at localities north of Kansas and is remarkably persistent both in lithology and thickness.

The subdivisions of the 600 feet of the lower Pierre shale exposed in Wallace county are as follows, from top to bottom:

Salt Grass member	60 feet	Upper. Middle. Lower.
Lake Creek member	200 feet	Upper. Lower.
Weskan member	170 feet	Upper, 80 feet. Lower, 90 feet.
Sharon Springs member	155 feet	Upper, 65 feet. Lower, 90 feet.
Total	585 feet.	

As far as one can judge from the outcropping contacts of the Pierre and Niobrara southeast of Wallace, the Pierre is quite conformable upon the Niobrara. The study of the logs of wells north and northwest from here and of the outcropping beds of the Pierre at these wells shows that there is no appreciable regional nonconformity between the Pierre and Niobrara in the south-north direction, which is the direction of the regional dip. In the adjacent area on the west, in northeastern Colorado, Mather, Gilluly and Lusk observed that "Although generally obscured, the contact of the Pierre with the underlying Niobrara is conformable."[104] According to Condra, "the Pierre shale rests conformably on the Niobrara" in southwestern Nebraska.

Russell, who studied the Niobrara of Trego, Gove and Logan counties of western Kansas, states that "toward the northwest the Smoky Hill chalk is overlain unconformably by the Pierre shale."[105]

---

[104] Mather, Gilluly and Lusk, 1928, p. 86.

[105] Russell, 1929, p. 599.

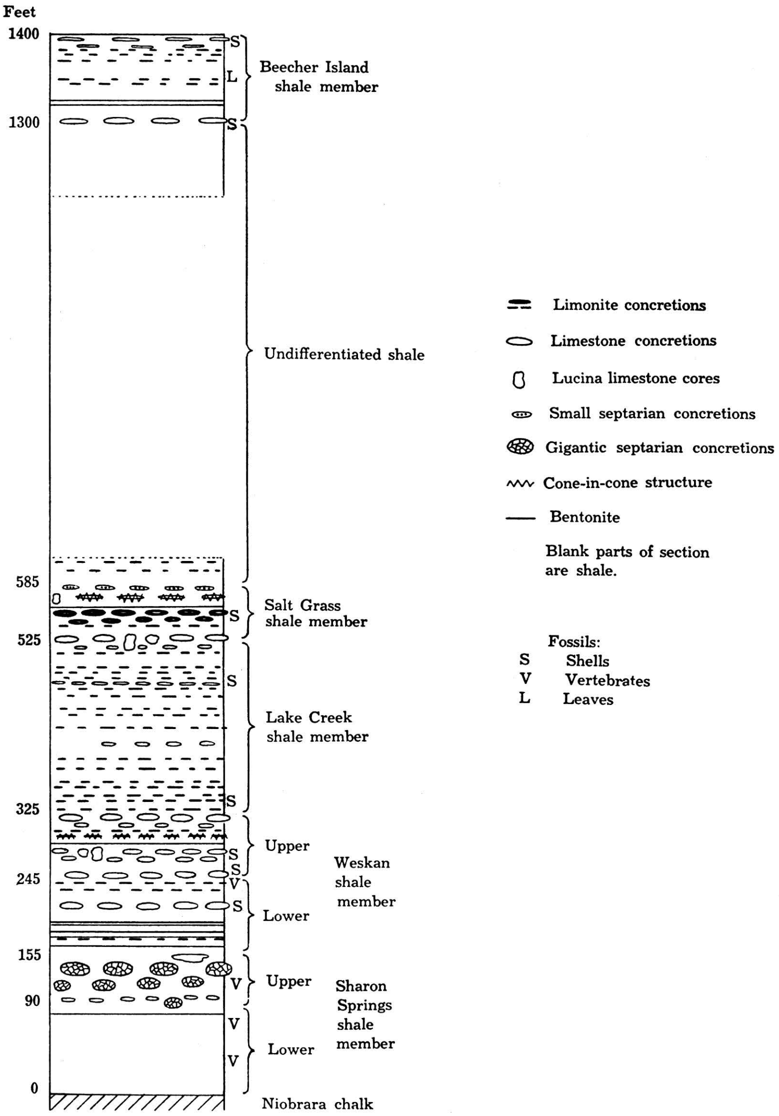


FIG. 3.—Generalized section of the Pierre formation in northwestern Kansas.

However, neither the data upon which this conclusion is based nor the character of the unconformity are mentioned by this author. Contrary to his conclusion is the following observation by Stoner for southern Logan county, which is based on the detailed survey and structural mapping of this area in 1927.

"It was found by careful measurements throughout an area of 2,000 square miles . . . that the intervals between the several beds of bentonite [in the uppermost 200 feet of the Niobrara] and *between them and the Pierre-Niobrara contact*[106] are extremely uniform . . . and that this relation did not differ more than 1 foot per mile in any direction."[107] Outside of the statement by Russell there is another allusion to an unconformity between the Pierre and Niobrara, and this is by Meek and Hayden for the exposures in northeastern Nebraska.[108] These authors observed that "at the base of the Fort Pierre group . . . there is at some localities along the Missouri below the Great Bend a local bed 10 to 30 feet in thickness, composed of very dark unctuous clay . . . [which] usually occupies depressions in the previously eroded upper surface of the formation beneath,"[109] which is Niobrara. However, this observation was not repeated by Condra, who studied recently the geology and water resources of northeastern Nebraska. It is true that Condra does not state directly whether the contact of the Pierre and Niobrara in this area is quite conformable or not, but he gives an observation of his that the base of the Pierre "lying on the Niobrara, slopes down slowly from western Cedar county to central Knox county, beyond which it is either horizontal or has a slight rise westward."[110] This seems to be a description of an apparent conformable contact of the two formations.

SHARON SPRINGS MEMBER.

The Sharon Springs is the lowermost member of the Pierre, and its lithology differs widely from that of the rest of the formation. The member consists of black, slightly bituminous shale, with which is interbedded dark-gray shale in the lower portion and about in the middle of the member. The shale is full of the remains of small fishes, which were probably the source of the bituminous matter in it. The small scales and bones of the fishes can be detected in

---

[106] Italics by the writer.

[107] Conclusions by O. E. Stoner as cited by Pinkley and Roth, 1928, p. 1021.

[108] A remark as to a "possible unconformity at or near the base" of the lowermost Pierre in northeastern Wyoming and southeastern Montana was made recently by Rubey (1930, p. 4), the particulars on this interesting possibility being probably reserved for the complete geological report by this author, which is announced to be in preparation.

[109] Meek and Hayden, 1861, p. 424.

[110] Condra, 1900, p. 15.

Subdivisions of the Pierre of Wallace County and the Adjacent Area.

Members.		Lithology.		Fossils.		
		Of the members.	Of the zones.	Most characteristic and abundant.	Characteristic but rare.	Abundant but less characteristic.
Beecher Island shale, about 100 ft.		Gray shale. Irregular concretionary limestone with *Lucina* near the top. Many limonite concretionary streaks and occasionally cone-in-cone rusty streaks in the upper part and in the middle. Few thin beds of bentonite and large limestone concretions in the lower part.		*Tardinacara (Pseudoptera) fibrosa.* *Inoceramus sagensis.* *Baculites grandis.* *Discoscaphites abyssinus.*	*Anchura americana.* *Baculites clinolobatus.* *Discoscaphites conradi.*	*Lucina occidentalis.* *Lingula* sp. Scales and bones of small fishes.
Not studied, 500-600 ft.		Shale. Only the following have been studied: 80 feet or more black shale at the top; no concretions. 30 feet or more gray shale with a few thin streaks of rusty limonite at the base.		Not studied.		
Salt Grass shale, 60 ft.		Gray clayey shale, with few thin bentonite beds. Medium sized limestone concretions, many with cone-in-cone structure and limonite concretionary streaks in abundance.	Rusty cone-in-cone lenses and small septarian limonite concretions in abundance.	None.	*Discoscaphites nicolleti* var. *saltgrassensis.* *Pteria* cf. *linguiformis.*	*Baculites* sp.
			Limonite concretionary streaks with limy cores and many baculites.	*Baculites pseudovatus* var. *A.*	*Baculites compressus* var. *reesidei.*	
			Concretions and thin and short beds of limestone. Irregular cavernous bodies of limestone with Lucina shells.	*Acantoscaphites nodosus* s. s. *A. nodosus* var. *brevis.*	*Scaphites reesidei.* *S. plenus.* *Baculites compressus* var. *reesidei.* *B. pseudovatus* var. A.	*Serpula Kansasensis* n. sp. *Inoceramus saltgrassensis* n. sp. *Lucina occidentalis.* *Anchura sublævis.*
Lake Creek shale, 200 ft.		Mostly dark-gray and black flaky shale. Bentonite rare or absent. Many limonite concretionary streaks and small soft limestone concretions. Large tough limestone concretions very rare. Poor cone-in-cone structure rarely developed. Gypsum in places very abundant.	Black shale with abundant small fish bones and scales.	Scales and bones of small fishes and *Lingula.*		
			Pancake-like limestone concretions in abundance.	*Baculites compressus* var. *reesidei.* *B. compressus* var. *corrugatus.*		*Serpula* cf. *lineata.* *Inoceramus saltgrassensis.* *Acantoscaphites nodosus* s. s. *A. nodosus* var. *brevis.*
			Yellow, rusty limonite concretionary streaks.			
			Concretions less abundant. Gypsum very abundant.	None.		
			Limonite concretionary streaks with white limy cores in abundance.	*Serpula (?) wallacensis.* *Baculites compressus* s. s. *Acantoscaphites nodosus* var. *quadrangularis.*	*Pholadomia hodgii.* *Anisomyon centrale.* *Baculites* cf. *ovatus.*	*Inoceramus convexus.* *I. proximus.* *I. proximus* var. *subcircularis.* *I. venuxemi.*
Weskan shale, 170 ft.	Upper Weskan, 80 ft.	Gray clayey shale with few thin beds of bentonite. Large, tough limestone concretions, rusty cone-in-cone lenses and thin streaks of concretionary limonite.	Large unfossiliferous gray limestone concretions (Bed No. 12).	None.	Fragments of *Inoceramus* sp.	None.
			Thin streaks of limonite (No. 11), cone-in-cone lenses at the base (No. 10).	*Serpula (?) wallacensis* n. sp. *Acantoscaphites nodosus* var.?	*Baculites compressus* s. s.	Fragments of *Baculites* sp. and *Scaphites* sp.
			Large gray to white limestone concretions with fossils in abundance (Nos. 6, 7 and 8).	*Anomia subtrigonalis.* *Ostrea* aff. *lugubris.*	*Crassatella evansi.* *Baculites compressus* s. s. *B. pseudovatus.*	*Ostrea congesta.* *Inoceramus convexus.* *I. proximus.*
			Thin streaks of limonite and siderite concretions (Nos. 4 and 5).	None.		
			Large gray limestone concretions with few fossils (Nos. 1, 2 and 3).	*Crassatella evansi.*		*Baculites* sp., *Scaphites* sp. *Placenticeras meeki.*
	Lower Weskan, 90 ft.	Gray clayey shale with comparatively abundant beds of bentonite. Large limestone concretions common; here and there thin streaks of purple-brown limonite.	Shale with few small concretions.	*Anomia subtrigonalis.*	*Amauropsis* cf. *punctatus.*	
			Main beds of bentonite and many large limestone concretions; few limonite streaks.			
			Few limonite streaks. Small round "perforated" limestone concretions.	None.		
Sharon Springs shale, 155 ft.	Upper Sharon Springs, 65 ft.	Flaky somewhat bituminous black shale and rarely porous light-gray shale, both with abundant fish scales. Gigantic septarian and smaller ordinary tough limestone concretions; also soft concentric concretions in abundance. Very few thin bentonite streaks.	Short lenses of creamy limestone. Soft oval concretions with cone-in-cone crust.	Bones and scales of small fishes.	cf. *Pteria haydeni.* *Heteroceras* cf. *tortum.* *Baculites aquilaensis.*	*Inoceramus proximus.*
			Gigantic septarian concretions.		Large fishes: *Protosphyræna gigas.* Plesiosaurs: *Polycotylus latipinnis.* *Elasmosaurus platyurus.* Mosasaurs: *Tylosaurus* sp. Marine turtles: *Toxochelis latiremis.*	
			Many medium-size tough gray limestone concretions and soft concentric concretions. In places oval cone-in-cone concretions near the base.			
	Lower Sharon Springs, 90 ft.	Flaky, somewhat bituminous black shale with abundant small fish bones and scales. Also gray, somewhat rusty shale. Thin rusty limonite streaks rare. Concretions nearly absent.				
Niobrara, about 750 ft.	Smoky Hill chalk, about 100 ft. on top studied.	Gray shaly chalk, usually weathers to orange. Locally many small concretions of iron sulphide. Very few thin bentonite streaks.				*Ostrea congesta.* *Inoceramus* sp. Teeth of sharks.

nearly every piece of the black shale. The Sharon Springs member can be conveniently subdivided into Upper and Lower Sharon Springs. The Upper Sharon Springs, which is about 65 feet thick, can be recognized by the abundance of concretions, many very large (Pl. V), whereas in the Lower Sharon Springs the concretions, none of which are large, are very scarce and in many places practically absent. The shale of the Upper Sharon Springs is also somewhat different from that of the Lower Sharon Springs. Some beds of the former resist weathering more than the ordinary shale of the formation and appear as slightly prominent bands in the outcrops. In some exposures a thick band of much harder shale was observed in the lower part of the Upper Sharon Springs. The shale of this band is chocolate-brown colored and is densely crowded with the small scales and bones of fishes. Another kind of shale, which somewhat resembles the softer samples of Mowry shale of the Graneros and is remarkably light in weight,[111] appears locally in slightly prominent bands near the top of the Upper Sharon Springs. This shale is light gray to nearly white when much weathered, and is porous and unpleasant to touch, being not "soapy" like the ordinary Pierre shale, but somewhat "chalky." However, no calcium carbonate or dolomite could be detected in this rock. This is largely a clayey rock, but it does not swell or disintegrate in water like bentonite, to which apparently it is not related. The thin section shows a moderately fine-grained, yellowish-gray, clayey texture with many small black bituminous bodies arranged along the bedding planes. The structure resembles that of Mowry shale, as shown on the thin section by Rubey,[112] except the absence in Wallace county shale of the "larger masses . . . of partly crystallized opal or glass," which are "unusually abundant in this section" of Rubey. The absence of the siliceous matter in the soft, though rigid, Wallace county shale appears to be the chief difference of this shale from the Mowry shale of the Black Hills region.

According to Rubey the silicification of the Mowry shale is a secondary feature, the silica being chiefly derived from the alteration of volcanic ash of the associated beds above, which was unusually siliceous. Therefore the absence of silicification in the Sharon Springs shale does not necessarily indicate an environment for the deposits of this shale different from that of the Mowry shale of the

---

[111] The specific gravity of the pieces of this shale was found by K. K. Landes to be below 2.

[112] Rubey, 1929, Plate 16-B, opposite p. 159.

Black Hills region. The interesting points of similarity are the bituminosity of these shales, the comparative coarseness of texture and the abundance of small fish scales combined with the exceeding rarity of the invertebrate marine remains. The radiolarians have not been found yet, but they were not especially hunted for. In the Mowry shale "in no specimens were these fossils common, and even in thin sections cut especially to examine as many radiolarians as possible they constituted less than 5 per cent of the rock."[113]

Iron sulphide, probably in the form of marcasite, is very abundant in the Upper Sharon Springs, but decomposes rapidly, so that springs originating within this shale have usually yellowish-brown water, on which a "false rainbow," resembling the iridescence of oil seepages, often can be seen, for instance, in the SW¼, sec. 1, T. 14 S., R. 38 W. Flakes of gypsum and small spots of rust, which are also the products of decomposition of the iron sulphides of the shale, are very common throughout the thickness of the Sharon Springs member, but larger crystals of gypsum are found only locally and chiefly in the lower part of the Lower Sharon Springs. The photograph (Pl. XIII C) shows large rosettes of gypsum at the type locality of the member.

Bentonite is rarely found in the Sharon Springs member. Sparsely scattered streaks of this rock, not exceeding 1 cm. in thickness, were observed in the upper part of the member. Perhaps the most persistent of these very thin streaks is about 20 feet below the top of the heavy septarian concretions. (See description below.)

Concretions are very plentiful in the Upper Sharon Springs shale, and enable this part of the member to resist weathering much better than the Lower Sharon Springs, the exposures of which are scarce. Near the top of the Upper Sharon Springs a zone of very large to gigantic septarian concretions, up to 6 feet in diameter or more, is developed (Pl. V C). These concretions are traversed by an irregular network of comparatively wide veins, which are filled with light-brown calcite containing barite in many places. The matrix of the concretions is a very compact, finely crystallized, dark-gray limestone. The calcite of the veins forms characteristic kidney-like incrustations (Pl. VI B), the largest 1½ inches thick, with radial fibrous structure and some with faint rhythmic concentric banding. Over this phase of crystallization in many places a crust of yellowish crystals of calcite has been deposited, and occasionally

---

[113] Idem, p. 154.

beautiful groups of colorless transparent Iceland spar have been crystallized. Together with crystalline calcite of this later phase of crystallization occasionally large crystals of semitransparent bluish-gray barite are found. A rare transparent variety of the local barite is of beautiful wine-brown color. Crystalline gypsum often furnishes an outer crust of the septarian concretions (Pl. VI A), and saurian bones were noticed in places on their top. No fossils were ever found in the matrix of the typical septarian concretions, but a few fish scales and poorly preserved invertebrates were collected from some dark-gray concretions in which the crystalline veins were poorly developed. The zone of the septarian concretions is in places 30 feet thick, the heaviest concretions being usually concentrated at the top of the zone (Pl. V). The zone of these concretions forms the most prominent escarpments and mesas of the Pierre in Wallace and Logan counties. McAllaster buttes and other prominent hills around McAllaster station on the Union Pacific railroad are capped with the large concretions of this zone and with grit of the Ogallala (on the south side of McAllaster buttes). No concretions comparable in size or structure with these septarian concretions of the Sharon Springs member were ever observed by the writer in the other members of the Pierre, and therefore they can be considered typical for the lowermost member of the Pierre in this region and probably elsewhere. Septarian concretions of somewhat similar size, shape and nature have been observed in the Apishapa member of the Niobrara in southeastern Colorado,[114] and in the Blue Hill member of the Carlile shale in Ellis county, Kansas,[115] and elsewhere.

Among other peculiar types of the concretions of this member the concentric concretions that are locally scattered below and above the septarian zone should be mentioned. The concentric concretions immediately above the septarian zone are of moderate size, are nearly spherical and are composed of calcite, rusty limonite, gypsum and soft, rotten shale. They are fragile and usually have the outer crust made of gypsum and this crust filled with rotten shale (Pl. VII B). The concentric concretions below the septarian zone are small to medium size, are spherical or flat and are made of alternating thin concentric layers of white gypsum and gray shale. With these are more ordinary concretions made of tough, solid dark-gray limestone. These are flat and oval or biscuitlike in

---

[114] Gilbert, 1896, p. 567, and other authors.
[115] Bass, 1926, p. 29.

shape, two of which are occasionally linked together, forming a flattened dumb-bell shape (Pl. VII C). In a few exposures large gray limestone concretions, having almost exclusively a cone-in-cone structure, were observed in the lower part of the septarian zone. Where the latter concretions were found the septarian concretions were nearly absent, as in the exposure on the south side of Lake creek, NW¼, sec. 24, T. 12 S., R. 38 W. A little more constant zone of the cone-in-cone structure was observed above the septarian zone, where the cone-in-cone calcite, which weathers to "chop-wood" fragments, furnishes an outer crust on some large, oval concentric concretions (Pl. VII A).

At the very top of the Sharon Springs member there appear occasionally large lenslike bodies of light-gray to yellowish-white laminated limestone. Several species of invertebrates, which are practically absent in the whole member below, were found on thin limestone, but only rarely are they sufficiently well preserved for identification. The following is the list of the identified forms:

Invertebrates from the Upper Sharon Springs member.

Inoceramus proximus Tuomey, Meek.
Inoceramus altus (?) Meek.
Inoceramus sublœvis Hall and Meek.
Ostrea cf. *congesta* Conrad.
cf. *Pteria haydeni* Hall and Meek.
Anisomyon centrale Meek.
Baculites sp. (much compressed in cross section and having smooth flanks and venter).
Heteroceras cf. *tortum* Meek and Hayden.
Aptychus sp.

About in the middle of the member, fragments of *Inoceramus* sp. of medium size have been found together with saurian bones. A little lower in the geologic section good specimens of plesiosaurs, mosasaurs and other reptiles were found by both the early and the recent expeditions of the University of Kansas museum. References to these and other vertebrates will be found in the descriptions of the localities.

A very interesting specimen, "a large mass of baculite,"[116] was collected by Mudge near the old town of Sheridan, now McAllaster station, in Logan county, Kansas. The specimen was believed by Mudge to belong to the Niobrara, but Meek, who identified the cephalopod as *Baculites anceps*,[117] expressed doubt that the specimen could come from Niobrara and not from a higher horizon of the Upper Cretaceous. Williston, who visited the locality in 1891, supports the view held by Meek and states that the beds at Sheridan "are either of the Fort Pierre group or transition beds to that

---

[116] Williston, 1893, p. 110.

[117] Mudge, 1877, p. 284.

group."[118] He describes the outcropping beds at the locality as having "a deep blue color, with numerous large septaria in which are found large and beautiful crystals of barite"[119] and noticed that "of the vertebrates that I know from these beds, all seem different from those of the beds below"[120] (which is Niobrara).

The description of the outcrops by Williston leaves no doubt that the beds belong to what in this report is described as the Sharon Springs member of the Pierre shale. The writer examined a specimen of coquina, more than 1 foot long and composed almost entirely of *Baculites aquilœnsis* var. *separatus* Reeside[121] shells and casts, in the collection of the University of Kansas. The specimen was not labeled, but in all probability is the one collected by Mudge. Though the writer did not collect any specimens of this kind in Wallace county or Logan county, he believes that the specimen at the University of Kansas could come from the Upper Sharon Springs member, in which large septarian concretions and lenses of limestone are common. Besides *Baculites* the writer recognized in the specimen also a few pelecypods and fish scales. The pelecypods belong to *Inoceramus proximus* and *Ostrea congesta,* which do not contradict the conclusion that the specimen came from the top of the Sharon Springs shale member. If this conclusion is correct, *Baculites aquilœnsis* var. *separatus* could be added to the list of fossils in this member of the Pierre.

It is worth while to describe the peculiar weathering of the uppermost beds of the Upper Sharon Springs, which tinges these beds bright greenish-yellow to straw colors. These colors are due to an iron hydroxide ochre. The shale and concretions of the beds become impregnated and incrusted with this ochre, which is in places as much as one centimeter thick and quite dense. When subject to a red-hot heating the ochre changes the yellowish color to the brick-red color of iron oxide.[122]

DISTRIBUTION OF SHARON SPRINGS MEMBER IN WESTERN LOGAN COUNTY. The section of the Sharon Springs member that was originally studied by the writer and set apart from the rest of the Pierre shale lies east of McAllaster station in Logan county. On a left tributary to Smoky Hill river, about 2

---

[118] Williston, 1893, p. 110.

[119] Idem, p. 111.

[120] Idem, p. 111.

[121] This species and its varieties were established by Reeside in 1927 and, as noted by Reeside, they resemble *B. asper* Morton in many respects.

[122] "Concretions of yellow phosphate of iron" are recorded by Cragin for the "Lisbon shale" (Sharon Springs shale member) in Logan and Wallace counties (Cragin, 1896, p. 52). The greenish-yellow incrustations collected from the shale by the writer, according to a test made by K. K. Landes, do not contain phosphorus at all.

miles east of McAllaster buttes, the following section was measured from the top down:

Section east of McAllaster buttes, Logan county.

		Feet.
17.	Dark-gray limestone concretions with fragments of *Inoceramus*.. to	0.5
16.	Shale, gray	2.90
15.	Bentonite	.05
14.	Shale, gray	2.00
13.	Occasionally large concretions with cone-in-cone, weathered to chop wood (Pl. 7A), limy crust and limonitic soft core... up to	1.2
12.	Shale, gray, with spots and crusts of greenish-yellow iron hydroxide ochre; occasional concentric concretions consisting of a fibrous gypsum outer crust and a core of limonite and soft, rotten shale (Pl.7B),	7.05
11.	Gigantic septarian concretions with fibrous calcite veins and crystalline gypsum outer crust. Saurian bones on top. (Pls. 5 and 6)... to	4.0
10.	Shale, gray, coarsely laminated	3.70
9.	Limonite concretions, small.	
8.	Shale, gray, coarsely laminated	6.05
7.	Shale, dark gray, finely laminated. Large beautiful rosettes of gypsum were observed in this shale (Pl. 13C)	8.00
6.	Bentonite	.05
5.	Shale, chocolate brown, full of scales and bones of small fishes	15.00
4.	Limestone concretions, gray, with cone-in-cone outer crust... to	.50
3.	Shale, gray	4.25
2.	Limestone concretions, gray... to	.30
1.	Shale, gray	1.30
	Total	56.75

For a graphic representation of this section see Plate IX-5. The size of concretions in the sections of this plate is much exaggerated.

To the Sharon Springs member most probably belong the remains of a turtle *Toxochelys latiremis* Cope, which were described by G. Wagner.[123] According to this author "fragments of a lower jaw" which belong to this species, were "discovered by Sydney Prentice near Lisbon, Wallace county, Kansas." Wagner adds "that the formation whence the specimen came is Fort Pierre is evident from the invertebrate fauna." Lisbon was a small town in Logan county, which was formerly a part of Wallace county, and is 2½ miles east of McAllaster. According to the field observations by the writer there are no Niobrara outcrops and only the Upper Sharon Springs shale is exposed in the vicinity of Lisbon. To the Upper Sharon Springs shale belongs the skull of the same species of turtle discovered by Williston at Eagle Tail creek near Sharon Springs, Kansas, where also only this shale is exposed.[124]

From the exposures of the Upper Sharon Springs shale north of

---

[123] Wagner, 1898, pp. 201-203.

[124] This skull was also described by G. Wagner, 1898, p. 201.

the type locality of the member apparently came the remains of the fish *Protosphyrœna gigas* Stewart, which were collected "one mile east of Lisbon, Logan county, Kansas, in the outcrops just north of the track of the Union Pacific railroad."[125]

In the SE¼, sec. 20, T. 12 S., R. 36 W., and about 3½ miles east-southeast of McAllaster, the Armstrong well was drilled by the Smoky Valley Oil and Gas Co., and in this well, as recorded in the well log, 65 feet of "sand, soil and Pierre" were encountered on the top of the "Niobrara limestone." The elevations taken on the top of the Upper Sharon Springs member, which is exposed less than 1 mile southwest of the well and also farther north, show the relative differences between the elevation of the well and the top of the member to be about 90 feet (66 feet to 115 feet). These measurements indicate that the total thickness of the member at the type locality is about 155 feet.

The Upper Sharon Springs shale, with its top zone of the heavy septarian concretions, forms McAllaster buttes 1 mile east of McAllaster; also the prominent hills north of the station. It appears as if an anticline, with its axis in the direction west-northwest east-southeast, runs about a quarter of a mile northeast of the station. If this is correct the dry hole drilled at the station is situated on the south flank of this anticline. The last exposure of the Upper Sharon Springs shale north of McAllaster was observed by the writer in sec. 35, T. 11 S., R. 37 W. Farther north the Weskan shale and still higher members of the Pierre are exposed.

Sharon Springs shale is widely exposed in the central and southern parts of Logan county, where probably no higher members of the Pierre were saved from erosion.

DISTRIBUTION OF SHARON SPRINGS MEMBER IN WALLACE COUNTY. *T. 14 S., R. 38 W.* Sharon Springs shale is extensively exposed in the hills south of Smoky river from Culom canyon, which is about 2 miles east of the western county boundary, to the big draw 1 mile west of the county highway, which runs from Wallace to Leoti, Wichita county. The base of the member is seen here resting on the exposed Niobrara chalk, and the top of the member is overlain by the Ogallala, which forms the prominent rocky escarpment of the hills. The septarian zone of the Upper Sharon Springs is exposed immediately below the Ogallala in the eastern part of the exposures, but in the western canyons only a very few scattered septarian concretions were found, the top of the member apparently having been

---

[125] Stewart, 1899, pp. 107-112; see, also, Stewart, 1900, pp. 367-368, Pl. LXII.

eroded before the deposition of the Tertiary. The following is the section of the Upper Sharon Springs shale in the NW¼, sec. 12, T. 14 S., R. 38 W., from top to bottom:

Section of Upper Sharon Springs shale in sec. 12, T. 14 S., R. 38 W., Wallace county.

		Feet.
29.	Very large septarian concretions	to 1.5
28.	Shale	3.5
27.	Septarian concretions, scarce	1.5
26.	Bentonite, white	.05
25.	Shale	3.5
24.	Septarian concretions, scarce	to 1.0
23.	Shale	.5
22.	Bentonite, white	.05
21.	Shale	1.0
20.	Septarian concretions	1.2
19.	Shale	1.3
18.	Concentric concretions, scarce, made of gypsum, limonite and soft shale	.8
17.	Shale, much crystalline gypsum	1.5
16.	Limestone concretions, scarce	to .5
15.	Shale	4.0
14.	Bentonite, white	.05
13.	Shale	3.5
12.	Limestone concretions, scarce	to .2
11.	Shale	1.3
10.	Limestone concretions, flattened	to .3
9.	Shale	5.0
8.	Limestone concretions	to .5
7.	Shale	1.5
6.	Limestone concretions	to .3
5.	Shale	2.7
4.	Limestone concretions	to .4
3.	Shale	.5
2.	Septarian concretions	.8
1.	Shale with crystalline gypsum	3.5
	Total	42.5

In the large draw east of the county highway the section of the middle part of the Sharon Springs member was taken in the SW¼, sec. 6, and NW¼, sec. 7, T. 14 S., R. 38 W.

Section of Middle Part of Sharon Springs member in sec. 7, T. 14 S., R. 38 W., Wallace county.

		Feet.
	Top. Grit of Ogallala formation.	
15.	Shale, same as 13, with very small and scattered concretions	17.5
14.	Limestone concretions with cone-in-cone structure	to .3
13.	Shale, gray, with rusty spots and scattered gypsum	6.0
12.	Bentonite, not persistent	.1

		Feet.
11.	Shale, same as 13	5.0
10.	Lenslike limy concretion	to .2
9.	Shale, same as 13, with scattered flat limonite concretions up to .5 inch in diameter. Fragments of a moderate-sized *Inoceramus,* and saurian bones	20.0
8.	Shale, same as 13	31.0
7.	Shale, black, with much scattered gypsum; scales of small fishes abundant	5.0
6.	Shale, same as 7 except having less gypsum	5.0
5.	Septarian concretion 1.5 feet long	.35
4.	Shale, same as 7	1.5
3.	Rusty streak	.05
2.	Shale, same as 7	4.0
1.	Shale, black, little gypsum and rust, few fish scales	10.0
	Total	105.0

To the lower part of this section probably belongs the paddle of the plesiosaur *Polycotylus latipinnis* Cope, which was collected by G. R. Allman and described by Williston.[126] The specimen was deposited in the natural history museum of the University of Kansas. Collections of 1895, No. 1320. Another plesiosaur, *Elasmosaurus platyurus* Cope, a nearly complete series of vertebræ of the genotype which were collected in the vicinity of Fort Wallace, belongs, according to Williston,[127] to Pierre and therefore to the Sharon Springs shale, the only member exposed in the area. Bones of *Tylosaurus* sp. are also known to have been collected from this locality.

T. 13 S., R. 39 W. The shale exposed in the steep walls of Smoky Basin cave-in, which is in sec. 33, T. 13 S., R. 39 W., belongs to Upper Sharon Springs. A typical section of this shale was taken on the downthrow side of the fault line that traverses the east wall of the cave-in. The following beds and concretions were observed from top down:

Section in east wall of Smoky Basin cave-in, sec. 33, T. 13 S., R. 39 W., Wallace county.

		Feet.
10.	Shale, dark gray	2.5
9.	Septarian concretion	to 1.5
8.	Shale, dark gray	11.0
7.	Shale, chocolate-brown, abundant scales and bones of small fishes	1.5
6.	Limestone concretions with outer shell of crystalline gypsum	to .5
5.	Shale, same as 7	4.0
4.	Concentric concretions made of rusty limonite and soft shale with gypsum outer crust	to .08

---

[126] Williston, 1903, p. 67.

[127] Idem, p. 9.

	Feet.
3. Shale, same as 7	1.7
2. Streak of rusty limonite and gypsum	.5
1. Shale, same as 7	1.0
Total	25.0

The fault line has an inclination from 45° to 60° northwest. (See Pl. XL A.) The section was taken on the north side of the line. The shale that is exposed south of the fault line is uniformly gray with small rusty spots and some scattered gypsum. No concretions of any kind were observed in it. There is hardly any doubt that this shale belongs to the middle or lower part of the Sharon Springs member, and that the fault is therefore a normal fault with a downthrow in a northwesterly direction. The top of the Niobrara must be about 130 feet below the present water level of the cave-in on the downthrow side of the fault and closer to the surface on the southeastern or upthrow side of the fault. The vertical displacement of the beds must be not less than 30 to 35 feet, which brings the top of Niobrara to not more than 100 feet below the level of Smoky Hill river on the upthrow side of the fault. (For a discussion as to the origin of Smoky Basin cave-in see the last chapter of this report). In the outcrops on the southwest side of Pond creek north of the Union Pacific railroad only the topmost 20 to 30 feet of the Sharon Springs shale with the well-developed septarian zone are exposed. The shale of these exposures shows a gentle dip toward the southwest and west. Large crystals of barite are found occasionally in the septarian concretions.

Good exposures of the same type were observed on both sides of the county highway north of Wallace in sec. 1, T. 13 S., R. 39 W., and in sec. 16, T. 13 S., R. 38 W. A dip of the beds of 2° to 3° northeast was measured at the exposure west of the highway. Here among the large septarian concretions there are lenses of light-gray, roughly laminated limestone, in which some fish scales and a few rather poorly preserved invertebrates were collected. *Pteria* cf. *haydeni, Ostrea* cf. *congesta, Inoceramus sublœvis* and *Anisomyon centrale* were recognized.

T. 13 S., R. 40 W. Upper Sharon Springs shale is beautifully exposed along the south side of Eagle Tail creek south of Sharon Springs. The so-called "Devil's Halfacre," in about the center of sec. 36, T. 13 S., R. 40 W., is a picturesque little spot of exposures of Upper Sharon Springs shale of the "bad-land" type. The zone of heavy septarian concretions is well developed in all exposures south

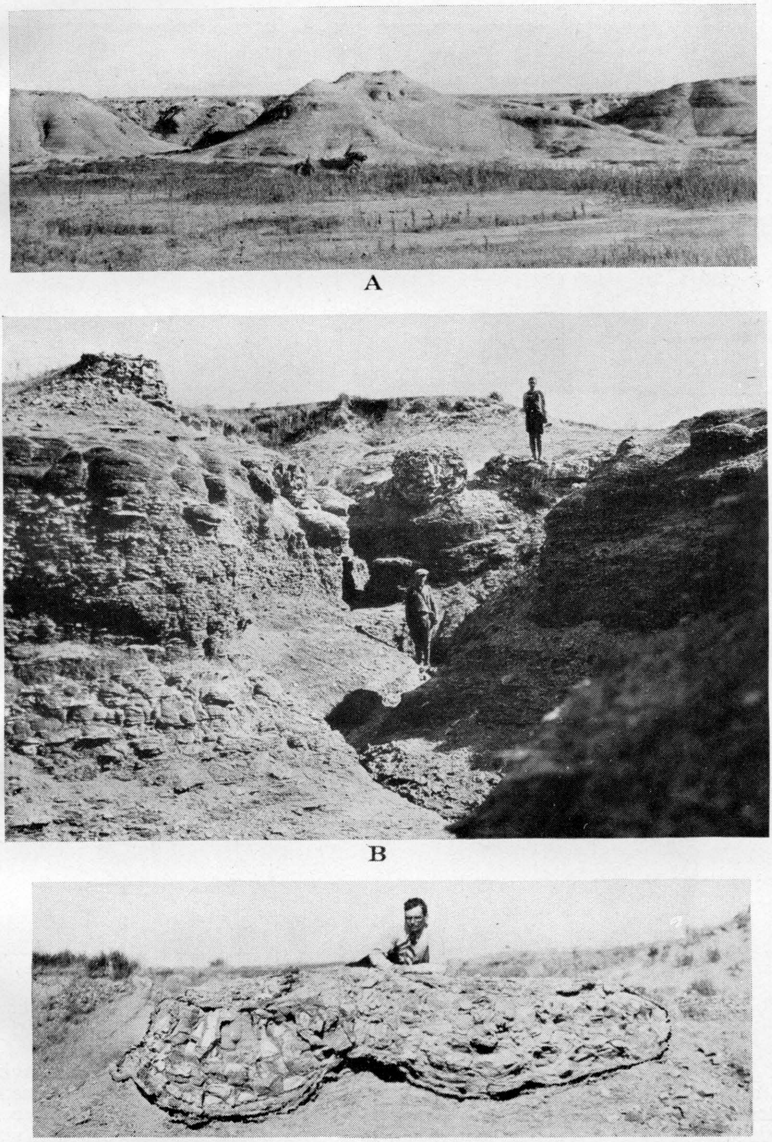


PLATE V.—*A*—Upper Sharon Springs shale member, two miles east of McAllaster, Logan county. *B*—Detail view of part of the exposure shown in A. Shows gigantic septarian concretions in flaky shale. *C*—Gigantic septarian concretion of the exposure shown in A and B

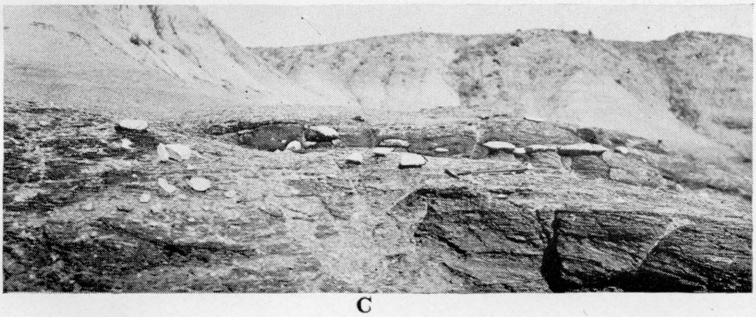
A

B

PLATE VI.—*A*—Detail view of the structure of a septarian concretion having a crust of crystalline gypsum. From a locality two miles east of McAllaster, Logan county. *B*—Kidneylike incrustations of the fibrous calcite that constitutes the first crystalline generation of the septarian fissures. Natural size. Negative by Charles Rankin.

A

B



C

PLATE VII.—*A*—"Chop-wood" weathering of cone-in-cone crust around large concentric concretions near the top of Sharon Springs shale member. From a locality two miles east of McAllaster, Logan county. *B*—Concentric concretions with fibrous gypsum crust and clayey limonite core. Same exposure as A. *C*—Oval and biscuit-shaped concretions of gray compact limestone in flaky shale in lower part of Upper Sharon Springs shale member. From a locality one mile northeast of McAllaster, Logan county. Shows toadstool weathering of concretions and shale.

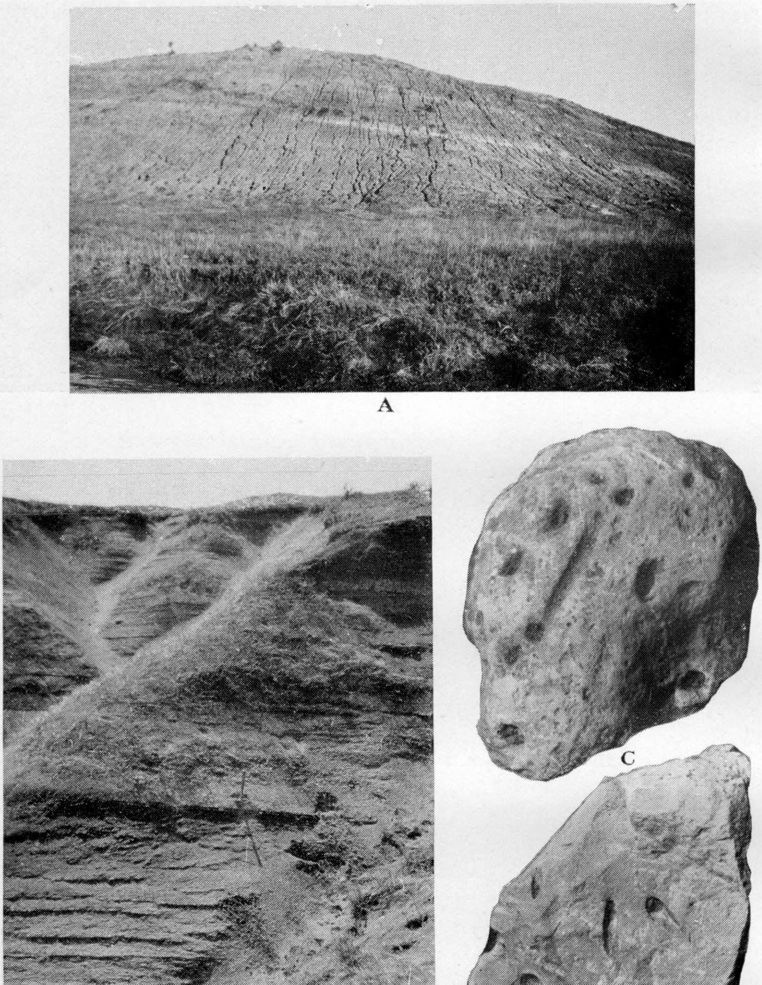


Plate VIII.—*A*—Exposure of Lower Weskan shale member at type locality, in the SW¼ SW¼, sec. 4, T. 13 S., R. 40 W. White streaks represent bentonite. *B*—Detail of an exposure at the same locality. *C* and *D*—"Perforated" concretions from Lower Weskan shale member in the northwest corner of sec. 24, T. 12 S., R. 38 W.

of Eagle creek and in some outcrops there are in addition large lens-like bodies of cream-colored limestone above the septarian zone.

T. 14 S., R. 40 W. The following section of the topmost Upper Sharon Springs beds was taken in sec. 2, T. 14 S., R. 40 W., on the east side of a steep canyon.

Section of Sharon Springs beds in sec. 2, T. 14 S., R. 40 W., Wallace county.

	Feet.
Limestone concretions, dark-gray with fragments of *Inoceramus* sp.... to	1.0
Shale, light-gray, porous	6.0
Limestone, cream-colored, roughly laminated, with *Inoceramus proximus, I. altus, Heteroceras* cf. *tortum, Baculites* sp. and *Aptychus* sp..... to	1.0
Gypsum and rust	.5
Shale with occasional round concentric concretions made of white gypsum and shale	14.0
Heavy septarian concretions	2.0
Shale with scattered very large septarian concretions up to 1.5′ thick	7.0
Shale, black, abundance of gypsum, especially in the upper part	9.0
Shale with thin (up to 3″ thick) septarian concretions with a crust of gypsum	1.0
Shale, black	10.0
Septarian concretions ... to	.7
Shale, black	....
Total	52.2

T. 14 S., R. 41 W. A locality of *Tylosaurus* sp. bones was discovered by W. B. Mead on the south side of Eagle Tail creek in the NE¼, sec. 10, T. 14 S., R. 41 W. The bones were collected and identified by Curtis J. Hesse in 1930. They came from about the middle part of the Sharon Springs member.

T. 12 S., R. 38 W. In the exposure of the Upper Sharon Springs shale on both sides of Lake creek, in secs. 24 and 25, T. 12 S., R. 38 W., the septarian zone is well developed, but the outcrops on the south side of the creek, at the bridge in the northwest corner of section 24, show only a few septarian concretions and some large-scale cone-in-cone structures in large dark-gray limestone concretions. The dark-gray, partly porous shale full of fish remains at this exposure and the abundant concentric concretions made of gypsum and shale permit identification of the beds as the topmost part of the Sharon Springs member. This correlation is further checked by the appearance of typical Weskan shale at the top of the exposure.

DISTRIBUTION OF SHARON SPRINGS MEMBER OUTSIDE OF KANSAS. *Upper Missouri River.* The dark color and abundant remains of many small fishes in the lowermost member of the Pierre have been noticed since Meek and Hayden's description of the Upper Missouri

Cretaceous, where the lowermost beds of the "Fort Pierre Group" are described as follows: "Dark bed of very fine unctuous clay, containing much carbonaceous matter, with veins and seams of gypsum, masses of sulphuret of iron, and numerous small scales of fishes. Local, filling depressions in the bed below."[128]

The last remark by Meek and Hayden raises a question whether part of the described lowermost beds of the "Pierre group" does not belong to the underlying Niobrara, the topmost beds of which in western Kansas are in places dark gray and contain abundant small fish scales and many pyrite or marcasite concretions of moderate size. On the other hand, the description of the lowermost beds of the "Upper Missouri" Pierre fits the lithology of the Sharon Springs shale member of Wallace county.

Condra describes the Niobrara beds of the same areas that were explored by Meek and Hayden, as:

"Lead-gray chalk rock . . . with a variable admixture of clay and sand . . . The upper surface is usually weathered, leaving a relatively larger percentage of clay, iron, and sand than is found in the more massive beds below." The presence of chalky beds is recorded, also, in the Pierre, description of the lowermost beds being as follows: "At its base there is a dark carbonaceous clay, resembling coal, which is exposed along the Missouri. . . . The next horizon above is made up of dark and bluish plastic clays with thin seams of iron ore. Above this are alternating beds of shaly chalk and clay, the former weathering reddish" and "often mistaken for Niobrara chalk."[129]

Condra gives the total thickness for the Niobrara as "over 200 feet," which is the same as recorded by Meek and Hayden. It is not quite clear to the writer whether the top of the Niobrara as defined in northeastern Nebraska corresponds to the top of the Niobrara of western Kansas,[130] and therefore he does not venture to correlate any particular beds in this region with the Sharon Springs shale member of Wallace and Logan counties, Kansas.

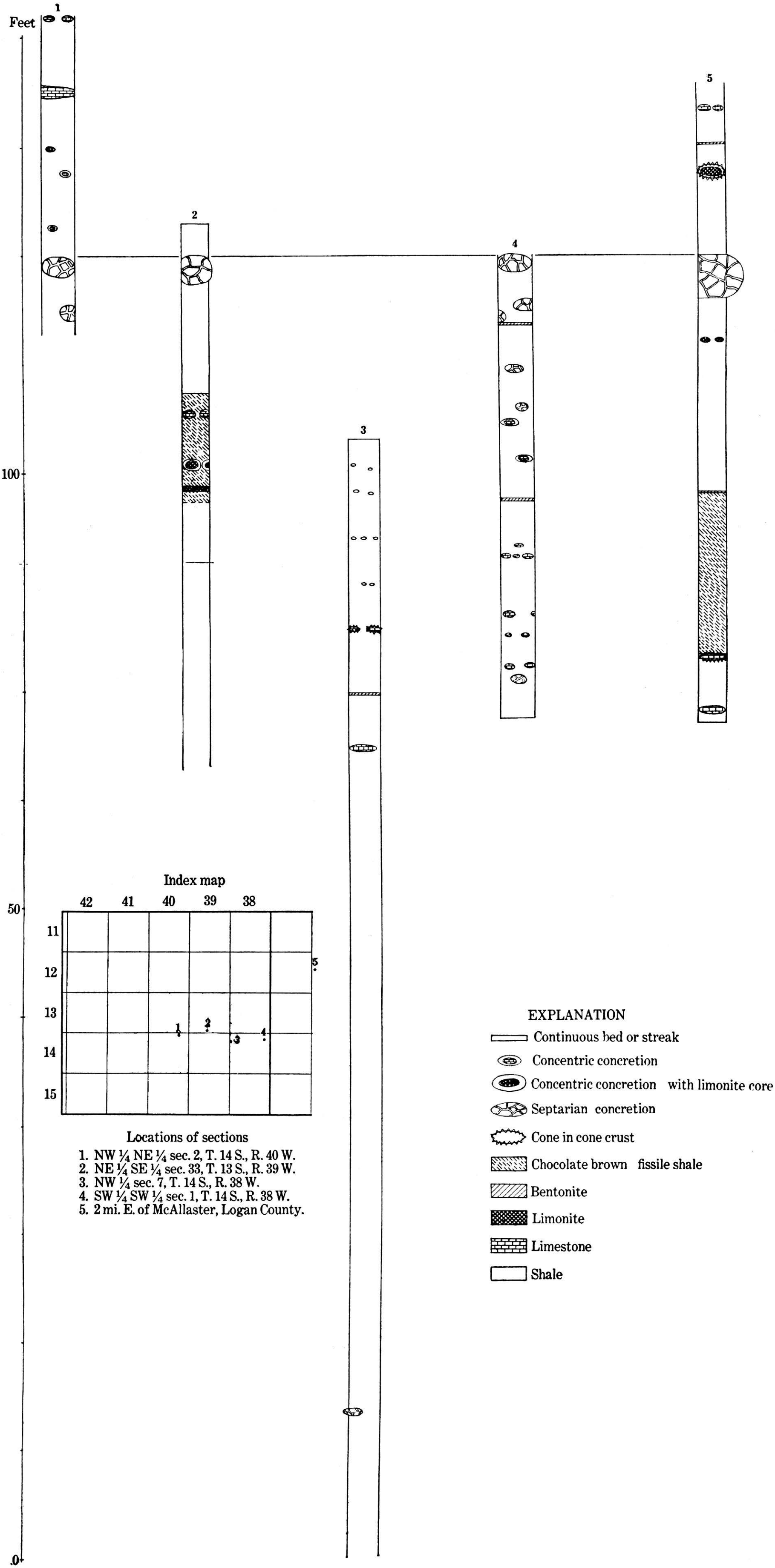
Ziebach County, South Dakota. A much better comparison of the Niobrara and Pierre of western Kansas can be made with the corresponding beds of Ziebach county, South Dakota. Following is a description of the basal beds of the Pierre in that county:

---

[128] Meek, 1876, p. XXIV; the thickness of these beds is only 30 feet. See Meek and Hayden, 1861, p. 424.

[129] Condra, 1908, pp. 15-16.

[130] Compare the limits of Niobrara in Montana, see opp. p. 130.



Locations of sections
1. NW ¼ NE ¼ sec. 2, T. 14 S., R. 40 W.
2. NE ¼ SE ¼ sec. 33, T. 13 S., R. 39 W.
3. NW ¼ sec. 7, T. 14 S., R. 38 W.
4. SW ¼ SW ¼ sec. 1, T. 14 S., R. 38 W.
5. 2 mi. E. of McAllaster, Logan County.

PLATE IX.—Geologic sections of the Sharon Springs member, Pierre formation.

"Very dark gray shale, from which oil may be distilled. Crumbles up to a soft mud when placed in water. Parts of it are slightly dolomitic. Contains fish scales, spines, bones and vertebræ."[131]

The description is made from the cores of a deep well. The thickness of the "very dark gray shale" is 140 feet. This shale rests upon 375 feet of calcareous shale belonging to the Niobrara and it is overlain by "light bluish-gray clay shale in which no fish scales are recorded."[132] In western Haakon and eastern Pennington counties the same "dark bluish gray or grayish black bituminous shale" at the base of the Pierre is estimated to be 200 feet thick.[133]

Southern Black Hills. The basal member of the Pierre exposed in the southern part of the Black Hills region of South Dakota and Wyoming is, according to the description by Darton, remarkably similar to the Sharon Springs member at McAllaster. Darton says:

> "At the base of the formation, overlying the Niobrara chalk, there is always a very distinctive series of black, splintery, fissile shales, containing three beds of concretions. These shales have been included in the Pierre, although they have not yet been found to contain distinctive fossils. They are about 150 feet thick in the southern Black Hills, where they give rise to a steep slope, often rising conspicuously above the lowlands eroded in the Niobrara chalk. The concretions exhibit a curious sequence. The lower ones are biscuit-shaped, hard and siliceous; those in the layers next above are similar in shape and composition, but are traversed in every direction by deep cracks filled with calcite and sometimes scattered crystals of barite; and those in the uppermost layers are large lens-shaped, highly calcareous, and of a light straw color, consisting of well-developed cone-in-cone."[134]

The "three beds of concretions" described by Darton are very similar to the successive zones of concretions at the section of the Sharon Springs member near McAllaster, where the writer observed solid limestone concretions in the lower portion of the Upper Sharon Springs shale, septarian concretions with calcite veins and occasionally barite in the zone above, and lens-shaped concretions with cone-in-cone outer crust in the topmost layer of the shale. The thickness of the Sharon Springs member also is the same in both areas, being about 150 feet.

Geographic limits of the typical Sharon Springs member. Considering the above-outlined data as to the character of the lowermost beds of the Pierre in the north-central High Plains we are justified in concluding that the Sharon Springs member of this formation is

---

[131] Russell, 1925, p. 5.

[132] Idem, p. 5.

[133] Russell, 1926, p. 12.

[134] Darton, 1905, p. 41; same description in Darton, 1901, p. 536.

remarkably similar in lithology and thickness in the region of northwestern Kansas and southern South Dakota, and possibly also in Nebraska and northeastern South Dakota. The Sharon Springs member of this area can be recognized chiefly by the dark-gray to chocolate-brown or black color of the bituminous shale, by the abundance of scales and bones of small fishes, which can be found in nearly every specimen of the rock, and by the presence of large septarian concretions near the top of the member. These concretions are irregularly traversed by veins, which are filled with calcite and occasionally contain crystals of barite. Remains of large reptiles, large fishes and marine turtles are met occasionally in this member of the Pierre, but shells of invertebrates are practically absent except in the topmost beds, where *Inoceramus* and a few other mollusks have been found occasionally.

Lowermost Pierre of eastern Colorado. In the regions west and south of western Kansas the Sharon Springs member does not seem to be typically developed, as far as one can judge from published descriptions. In the thick section of not less than 8,000 feet of Pierre along Fossil creek, south of Fort Collins, Colo., which was measured by Sears and Gilluly,[135] the following were observed overlying the top of Niobrara: "Dark-gray fissile shale with a few beds of bentonite, some 8 inches thick; some iron concretion beds ('rusty bands') an inch or more in thickness—192 feet." Above this shale, the description of which does not correspond very well to the Sharon Springs shale of western Kansas, a "zone of sporadic concretions" 28 feet thick was measured, but "some septarian concretions" were observed in a zone of shale 1,500 feet higher in the section. Of course, considering the enormous thickness of the Pierre in this locality, one cannot expect the lower member of the formation to retain necessarily its normal 150-160 feet of thickness, but if the "septarian concretions" of the Fossil creek section correspond to the septarian zone of Sharon Springs shale, this member of the Pierre is represented at Fort Collins by about 2,000 feet of the shale with only a few sandy zones in it. One must remember, on the other hand, that the underlying Niobrara in this and other localities of northeastern Colorado is appreciably less thick than the corresponding formation of western Kansas, and it is possible that part of the overlying shale of Colorado, though lithologically a continuation of the typical Pierre, may be contemporaneous with the uppermost

---

[135] Mather, Gilluly and Lusk, 1928, 90-92.

beds of the Niobrara in Kansas. If this is a fact, the 40-foot zone of limestone beds, which was observed in the lower Pierre north of Boulder by Fenneman,[136] may correspond to the top zone of what is considered Niobrara in Kansas.

Darton describes fine-grained lens-shaped limestone concretions "traversed by cracks filled with calcite" in the Pierre of the Denver and Pueblo regions, but does not make clear where these particularly belong, remarking in a general way that the concretions "begin to be abundant above the first 400 or 500 feet of basal members in the formation."[137] According to Finlay,[138] however, the similar large septarian concretions, which "when broken open exhibit many radiating veins of amber-colored calcite," are found in the lowermost 500 feet of Pierre in the Colorado Springs region, whereas Gilbert, who originally set apart the lowermost 400 to 500 feet of the Pierre shale of eastern Colorado, says that this zone "contains so few concretions that their scarcity serves to distinguish it from the next zone (above) where they are abundant."[139] This observation is identical with the above quoted statement of Darton, which is apparently based partly on observations by Gilbert, but the particular large septarian concretions, which have attracted the attention of all students, were not attributed by Gilbert to any one of the Pierre shale zones at all. He placed them in the underlying Apishapa formation, which is considered to be "the upper part of the Niobrara group."[140]

The problem of the correlation of the Apishapa formation does not appear simple. It seems to be possible that this formation is more argillaceous toward the north, and that some beds in northern Colorado now classified with Pierre may correspond to the Apishapa of the south.

WESKAN SHALE MEMBER.

The name for this member is derived from the town of Weskan in Wallace county, 5 miles north of which is the type locality of the member. The Weskan shale, which is about 170 feet thick, may be divided into an upper part, about 80 feet, and a lower part, about 90 feet. The type locality of the Upper Weskan shale is on a small creek north of Swisegood ranch, in SE¼, sec. 2, T. 13 S., R. 42 W., and the best exposure of Lower Weskan shale is on the south side of

---

[136] Fenneman, 1905, p. 31.
[137] Darton, 1905, p. 108.
[138] Finlay, 1916, p. 8.
[139] Gilbert, 1896, p. 568.
[140] Idem, p. 567.

Goose creek, in SW¼, sec. 4, T. 13 S., R. 40 W. The Weskan is characterized by the comparative abundance of bentonite streaks in the dark-gray unctuous shale (Pls. VIII A and VIII B) and by the presence of several zones of rather large concretions, consisting of dark-gray compact and hard limestone, only here and there traversed by very thin veinlets of light-brown calcite. Abundance of invertebrate fossils is another characteristic feature of the member. Limonite concretions are observed in the lower part of the Lower Weskan shale and are very abundant in the whole upper part of the Weskan member, where the zones of limestone concretions and the zones of limonite concretions usually alternate.

LOWER WESKAN SHALE MEMBER. Almost everywhere in the Lower Weskan shale there are some scattered "perforated"[141] concretions (Pl. VIII C and VIII D), 2 inches to 3 inches across, which have a somewhat rounded outline and are so full of irregularly connecting tubular holes that some of them are very light for their bulk. Much of the clayey limestone of their matrix is weathered, is comparatively soft and somewhat rough to the touch. The hollow tubes of these concretions may be worm burrows, but their weathered walls do not show any structural features to prove this suggestion.

The large limestone concretions of the Lower Weskan shale are chiefly concentrated about 30 feet below the top of the subdivision, which arbitrarily is taken at the base of the lowermost heavy concretionary zone of the Upper Weskan shale. The concretions of the zone 30 feet below the top of the Lower Weskan shale may reach half a foot in thickness and several times as much across, and many contain invertebrate fossils. In the 40 feet of shale below these concretions the principal beds of bentonite, some of them 12 inches thick, are found (Pl. VIII A and VIII B). Limestone and some limonite concretions are scattered through this 40-foot zone. Most of the limonite concretions are dark purple brown, and ordinarily they are densely arranged along bedding planes, thus making almost continuous limonitic streaks. The lowermost 20 feet of the member consists of an ordinary, featureless, dark-gray shale.

The Lower Weskan shale has less fossils than the Upper, both in number of species and in number of individuals. By far the most common fossil is *Anomia* cf. *subtrigonalis,* which is here somewhat larger than the same species from the Upper Weskan shale (Pl. XI A, right side). Occasionally *Amauropsis punctata* is found together with the *Anomia.* This gastropod is two or more times larger

---

[141] The term belongs to W. L. Russell.

than the somewhat similar *Anchura sublœvis,* which is common in the Salt Grass member of the Pierre. Fragments of a moderate-sized *Inoceramus* are common, and occasionally more complete specimens are found. *I. convexus* Hall and Meek and *I. cripsii* var. *barabini* Morton were identified. Large fragments of *Placenticeras meeki* Boehm were found but once. It is remarkable that not a single specimen of *Ostrea,* either free or attached to *Inoceramus,* has ever been found by the writer in the Lower Weskan shale, whereas *O. congesta* (Pl. XI A, left side) and *O.* aff. *lugubris* were collected in great number from the middle limestone concretionary zone of the Upper Weskan shale, in which they are almost invariably associated with *Anomia* cf. *subtrigonalis,* the most common species of both Upper and Lower Weskan shale.

UPPER WESKAN SHALE MEMBER. The Upper Weskan member has three prominent zones of large gray limestone concretions, between which two zones of smaller limonite concretions can be recognized. The upper and lower boundaries of these concretionary zones are, however, not sharp, and the zones vary somewhat in thickness. At the type locality the lowermost zone (beds Nos. 1, 2 and 3) consists of heavy dark-gray limestone concretions, which are arranged chiefly along three bedding planes a few feet apart. The largest concretions are 1 foot thick and some are many times more across. These concretions are not rich in fossils; a few shells of *Crassatella evansi, Pteria* sp. and very young *Baculites* sp. and *Scaphites* sp. were collected. Large ammonites of the Pseudoceratites group, though much scattered, are comparatively common in this zone; *Placenticeras meeki* and fragments of a very large *Placenticeras* sp. were identified. Bones of a mosasaur (Pl. XI B) were found by the writer at the base of this zone at the type locality of the member. The bones were later collected by Curtis J. Hesse, of the University of Kansas museum of natural history expedition, in the summer of 1930, and were recognized as a new species of *Platecarpus* by the late H. T. Martin.

In the lower zone of thin limonite concretions (beds Nos. 4 and 5), which separates the basal limestone concretionary zone from the middle zone of the Upper Weskan shale, fossils are practically absent. Only poorly preserved remains of *Baculites* sp. and *Scaphites* sp. were recognized. At the top of this zone was found a very large *Inoceramus symmetricus* n. sp.

The middle limestone concretionary zone (beds Nos. 6, 7 and 8) of the Upper Weskan shale is by far the most fossiliferous zone of this member of the Pierre. *Anomia* cf. *subtrigonalis, Ostrea congesta* (Pl. XI A), and occasionally *O.* aff. *lugubris,* can be found in nearly every large dark to light-gray limestone concretion (Pls. X A and X B) of this zone. The oysters are usually attached to large shells of *Inoceramus* (Pl. XI A), but are also found free, especially *Anomia* cf. *subtrigonalis,* and the large shells of *Inoceramus* sp. are found often without any smaller shells attached (Pl. XI C). The concretions of the zone are usually arranged along the bedding planes of the shale, and in many places three or more horizons of the concretions are observed. The uppermost concretions (bed No. 8) are the richest in fossil content, but in the lower concretions (bed No. 6) a small, round and plump pelecypod *Crassatella evansi,* which is absent from the upper concretions, was found fairly often. This form persists down to the lower concretionary limestone zone (*Placenticeras* zone, beds Nos. 4 and 5), as has already been noted. *Serpula* (?) *wallacensis* (Pl. XII B) makes its first appearance in the upper concretions of the middle concretionary zone (*Ostrea* aff. *lugubris* zone, beds Nos. 6, 7 and 8). In the NW¼, sec. 18, T. 13 S., R. 41 W., the appearance of *Lucina occidentalis* in great abundance in the peculiar irregular bodies of cavernous "Lucina limestone" (Pl. XV C) was observed. This is the lowest appearance of the species in the local Pierre. In the ordinary compact dark-gray limestone concretions which were observed in the "Lucina limestone" of the latter locality a well-preserved cast of *Baculites pseudovatus* n. sp. was found.

The complete list of fossils from the middle zone of Upper Weskan shale is as follows:

Invertebrates from the middle zone of the Upper Weskan member.

Serpula sp.
Serpula (?) *wallacensis* Elias n. sp.
Ostrea congesta Conrad.
Ostrea aff. *lugubris* Conrad.
Ostrea plumosa Morton.
Anomia cf. *subtrigonalis* Meek and Hayden.
Pecten venustus Morton.
Pteria sp.
Inoceramus convexus Hall and Meek.
Inoceramus proximus Tuomey, Meek em.
Inoceramus symmetricus Elias n. sp.
Nemodon n. sp. aff. *sulcatinus* Evans and Shumardt.
Nucula planimarginata Meek and Hayden.
Nucula n. sp.
Crassatella evansi Hall and Meek.
Nuculana bisulcata Meek and Hayden.
Nuculana sp.
Lunatia n. sp.
Lucina occidentalis Morton.
Dentalium gracile Hall and Meek.
Amauropsis punctatus (Gabb).
Baculites pseudovatus Elias n. sp.
Baculites sp.
Scaphites sp.
Aptychus sp.
Placenticeras meeki Boehm.
Tentaculites n. sp.

A few streaks of bentonite were observed in the middle of *Ostrea* aff. *lugubris* zone of the Upper Weskan shale, but none of these streaks is thicker than 1 inch. Some are found directly below the limestone concretions.

The upper limonite zone, which is next above *Ostrea* aff. *lugubris* zone, contains many thin concretionary streaks of limonite and few very thin streaks of bentonite. Fossils are not rare in this zone, but only *Serpula* (?) *wallacensis* n. sp. (Pl. XII B) was found in profusion here and there. *Baculites compressus* s. s. was identified from a single specimen. Among other fossils of the zone are a small ovate *Baculties ovatus* var. *haresi* and a *Scaphites nodosus* var. *quadrangularis* which are not rare but usually fragmentary and too much weathered for the details of septa to be observed. *Inoceramus* sp. was also found in fragments only. At the base of the zone from one to three ranges of scattered pinkish-brown concretions with cone-in-cone outer crust are present, and these are taken arbitrarily as the lower limit of the zone. A thin streak of bentonite was observed in many places immediately below the topmost cone-in-cone concretions. The cone-in-cone concretions consist of a fine-grained mixture of lime, iron hydroxide and clay, and are softer than ordinary limestone or limonite concretions of the Upper Weskan shale. Where the cone-in-cone outer structure of these concretions is poorly developed or absent, invertebrate fossils are frequently observed, *Inoceramus* sp., *Anomia* cf. *subtrigonalis* and *Ostrea congesta* being recognized.

The large limy concretions of the type previously described are found occasionally in the shale of the next zone above, where also very often thin bentonite streaks were observed, but only on the top of this uppermost or "barren" zone of Upper Weskan shale are the heavy limestone concretions present in such great number as to form prominent escarpments in the shale. In the type locality, also in some other exposures, the concretions are in the form of very long bodies arranged parallel to each other and lying along the same bedding plane. Thus they make erosional banks consisting of prominent parallel ridges spaced a few feet apart (Pl. XII A). These ridges are about 1 to 1½ feet across and many times as long and are often "sliced" by close-set parallel cleavages perpendicular to the axes of these bodies.

Somewhat similar and equidistantly spaced, cylindrical concretions have been noticed in a few outcrops of the basal concretionary zone of the Salt Grass member described below. The regular spacing of the concretions along a bedding plane is puzzling. The concretions are elliptical in cross section and can hardly be interpreted as secondary deposition of calcium carbonate along and beyond possible vertical joints in the shale. Their equidistant spacing might be due to wave or current action, and thus they could be classified with pararipples or large ripples with wave lengths measured by feet (Bucher, 1919, p. 258, or Twenhofel, 1926, p. 455). This interpretation of the regular spacing of the concretions of the Pierre formation implies original deposition of a certain amount of calcareous sand, because the supposed ripple marks do not originate in very fine sedimentary material. The pararipples of this sand must have been subsequently recrystallized and somewhat reshaped to form the fine-grained calcareous cylindrical concretions that now appear.

In some exposures the large concretions of the top of the Upper Weskan shale member are crossed by a net of thin veinlets of crystalline light-brown calcite, which makes them resemble slightly the septarian concretions of the Sharon Springs shale. But the calcite veinlets of these concretions never exceed a few millimeters across, whereas the calcite veins of the septarian zone are several centimeters thick. In places an additional horizon of limestone concretions is observed immediately below the topmost heavy and densely spaced concretions of the Upper Weskan shale, and dark purple-brown limonite concretions may be found immediately above this range.

All the heavy concretions are made of very dense dark-gray limestone, probably with a considerable admixture of siderite, which is indicated by the brownish color of the weathered fragments. Fossils are practically absent from this zone, only very small and poor fragments of *Inoceramus* sp. being occasionally observed. Dark-gray cone-in-cone outer crust, nowhere more than 1 cm. thick, was observed in places around the heavy limestone concretions of the zone.

These densely spaced and heavy dark-gray unfossiliferous topmost concretions and the concretions of the *Ostrea* aff. *lugubris* zone, much lighter in color and rich in *Inoceramus* and oysters, are the best and most easily recognizable keybeds of the Upper Weskan shale.

DISTRIBUTION OF LOWER WESKAN MEMBER. *T. 13 S., R. 40 W.* The best exposure of the Lower Weskan shale is in the southwest corner of sec. 4, T. 13 S., R. 40 W., on the south side of Goose creek about 1 mile from the junction of this creek with Smoky Hill river. (Pl. VIII A). The following section was measured here, from top to bottom.

Section of Lower Weskan member in SW corner, sec. 4, T. 13 S., R. 40 W., Wallace county.

	Feet.
Shale	3.0
Large and comparatively densely spaced dark-gray limestone concretions with *Anomia* cf. *subtrigonalis, Amauropsis punctatus* and *Inoceramus* sp.	to .6
Shale	.5
Bentonite	.05
Shale	4.0
Bentonite	.1
Shale	1.5
Bentonite	.35
Shale	2.0
Bentonite	.1
Shale	1.0
Bentonite, gray, not soapy	.5
Bentonite, light gray	.8
Shale with scarce limestone concretions	.3
Bentonite	.1
Shale	1.0
Scattered limestone concretions	to .2
Shale	4.5
Bentonite	.1
Shale	1.2
Scarce limestone concretions	to .2
Shale	.3
Bentonite	.1
Bentonite, gray	.1
Bentonite, white	.8
Shale	1.0
Limonite, soft, purple-brown, very persistent concretionary streak, occasionally small limestone concretions below	.1
Shale	.5
Scarce limestone concretions	.2
Shale	2.0
Shale with three thin streaks of bentonite	1.0
Scarce limestone concretions	.2
Shale	2.0
Scarce limestone concretions	to .4
Shale	4.5
Bentonite	.1
Shale with very few "perforated" concretions	10.0
Limestone concretions	.5
Shale	5.0
Total	50.9

On the east side the exposure is traversed by a nearly vertical fault, the direction of which is E 11° S. The downthrow is on the eastern side, the displacement being about 12 feet. The shale on the east side of the fault dips 12° S, 30° W; the shale on the west side dips 3½° S, 57° W.

Large fossiliferous limestone concretions belonging apparently to the upper portion of the Lower Weskan shale are exposed immediately below loess in a little canyon on the south side of Smoky Hill river in the northwest corner of sec. 16, T. 13 S., R. 40 W. In these numerous large concretions, which are arranged along bedding planes dipping south at an angle of 2° to 5°, many specimens of *Anomia* cf. *subtrigonalis* were collected. Several individuals of *Amauropsis punctatus* also were found. A good specimen of *Inoceramus cripsii* var. *barabini* Morton and a large fragment of *Placenticeras meeki* Boehm were collected from the limestone concretion at the head of the little canyon.

Other exposures of Lower Weskan shale were studied immediately east of the road on the south side of Smoky Hill river, in the northwest corner of sec. 17, T. 13 S., R. 40 W., and in the NW¼, sec. 18, of the same township and range. In both of these localities many *Anomia* cf. *subtrigonalis* and "perforated" concretions were observed.

T. 13 S., R. 41 W. West of these exposures only the topmost beds of Lower Weskan shale were observed to underlie the Upper Weskan shale in the SW¼, sec. 10, and in the NW¼, sec. 18, in T. 13 S., R. 41 W.

T. 13 S., R. 39 W. East of Sharon Springs the Lower Weskan shale is exposed in the SW¼, sec. 16, T. 13 S., R. 39 W. In the center of this section, on the south side of Pond creek, the septarian zone of Sharon Springs shale, with the observed dip about 2° W, builds an escarpment. West of this escarpment is a small draw, on the western side of which one observes shale with scattered "perforated" concretions and dark purple-brown limonite, and farther west heavy limestone concretions with *Anomia* cf. *subtrigonalis*. *Inoceramus barabini* and *Inoceramus* sp. are exposed on the very gentle slope of the hill. The same concretions can be seen here and there on the western slopes of Pond creek valley, in the NE¼, sec. 17, and in sec. 8, T. 13 S., R. 39 W.

Large concretions with the same *Anomia* were observed in the NE¼, sec. 1, T. 13 S., R. 39 W., where they outcrop between typical Upper Weskan shale in the NW¼ and the septarian zone of the Sharon Springs shale in the SE¼ of the same section. In the small but beautiful exposure at the county highway in the SW¼, sec. 31,

T. 12 S., R. 38 W., the creamy bentonite about 1 foot thick, accompanied by dark purple-brown limonite concretions, can be seen in the ditch at the base of the exposed section. In about 15 feet of shale above the thick bed of bentonite a few thin streaks of bentonite and a few scattered large limestone concretions were observed. This section is correlated with the middle portion of Lower Weskan shale.

T. 12 S., R. 38 W. The lower portion of the same shale member, having streaks of purple-brown limonite and scattered "perforated" concretions, is exposed immediately above the Sharon Springs shale on the south side of Lake creek near the bridge in the NW¼, sec. 24, T. 12 S., R. 38 W. The member is exposed, also, in the SW¼, sec. 13, T. 12 S., R. 38 W.

Upper Weskan Member. *T. 13 S., R. 42 W.* The Upper Weskan shale, which is undifferentiated from the Lower Weskan on the geologic map, is best exposed in the canyons around Swisegood ranch on Willow creek. The type locality is north of Swisegood ranch, where the complete section of the shale member outcrops at the center of a dome, which is the northern part of the Willow creek anticline. The central part of the dome is traversed by several faults, which put some difficulties in the way of compiling the complete section of the shale member, the beds of which are repeated in the faulted blocks. It appears as if the observed variations in the stratigraphic distances between the various concretionary beds of the member are at least partly due to distortion of the faulted blocks. The estimation of the total thickness of the Upper Weskan shale, which was made on these type exposures, was checked at the exposure in the NW¼, sec. 18, T. 13 S., R. 41 W. In the type exposures on the west side of the bank of shale that faces Willow creek from the north, in the northeast corner of sec. 11, T. 13 S., R. 42 W., the following beds, which represent the upper half of Upper Weskan shale, are exposed from top down:

Section of Upper Weskan member in NE corner, sec. 11, T. 13 S., R. 42 W., Wallace county.

	Feet.
Densely spaced heavy concretionary ridges made of dark-gray compact calcium carbonate, probably mixed with siderite; concretionary ridges finely laminated or "sliced" across the axis of the ridges; no fossils except very small fragments of large *Inoceramus* (bed No. 12)..... to	1.2
Scattered heavy concretions of limestone immediately below........ to	1.0
Shale, poorly exposed..	16.0
Shale with many streaks of concretionary brown limonite (bed No. 11)..	11.7
Shale	5.6
Light-brown to pinkish limy concretions with cone-in-cone crust (bed No. 10)	.6

	Feet.
Shale	.5
Bentonite, white	.1
Shale	5.9
Bentonite (bed No. 9)	.2
Shale	5.7
Heavy gray to light-gray limestone concretions; *Anomia* cf. *subtrigonalis, Ostrea congesta, Inoceramus* sp. (bed No. 8)	1.0
Shale	7.1
Bentonite	.1
Shale	4.5
Heavy gray to light-gray limestone concretions (bed No. 7); fossils same as in zone No. 8 but less plentiful	1.0
Total	62.2

The trend of the concretionary ridges of bed No. 12 at the top of the section is N 50° E.

East of the above section is a fault of about north-south strike, which is concealed by alluvium of a little draw. On the east side of this draw, on the downthrow side of the fault, the following section was measured, from top down:

Section of Upper Weskan member in W. of sec. 11, T. 13 S., R. 42 W., Wallace county.

	Feet.
Light brown to pinkish concretions occasionally with cone-in-cone crust (bed No. 10) to	.8
Bentonite	.1
Shale	3.7
Bentonite (bed No. 9)	.05
Shale	7.30
Heavy gray concretions with *Anomia* cf. *subtrigonalis, Ostrea congesta, Ostrea* aff. *lugubris* and *Inoceramus* sp. (bed No. 8) to	1.0
Shale	6.8
Bentonite	.05
Shale	7.1
Heavy gray concretions with the same but less plentiful fauna as in bed No. 8 (bed No. 6)	1.0
Shale	12.1
Streak of gypsum and rust	.1
Shale	8.6
Limestone concretions with *Inoceramus* sp. and *Crassatella evansis* (bed No. 3)	.8
Shale	6.5
Bentonite	.1
Shale	5.5
Limestone concretions	.8
Total	62.4

In the east side of the bank of shale two more faults were observed. All the faults of the group appear to radiate in south and southeast directions, the apparent continuation of the faults being found on the south side of Willow creek in sec. 12, where the beds corresponding to Nos. 7, 8, 9, 10 and 11 were observed. In bed No. 8 of the southwest corner of sec. 12, *Ostrea congesta* attached to *Inoceramus* sp. and *Anomia* cf. *subtrigonalis* were found, and crusts and kidneylike bodies of manganite were observed in the shale near the concretions. In limonite beds No. 11 *Scaphites nodosus* var. *quadrangularis* (?), *Baculites compressus* s. s., *B. pseudovatus* and *Serpula* (?) *wallacensis* were collected.

At the corner of secs. 1, 2, 11 and 12 of T. 13 S., R. 42 W., the complete geologic section of the Upper Weskan shale is exposed, but the uppermost beds of the section are here too closely spaced. This close spacing suggests a local thinning of the upper zones of the shale, which perhaps is not an original condition, but is due to the stretching of the plastic shale in connection with the folding. The section was taken in the southeast corner of sec. 2, where the following beds are exposed from top down:

Section of Upper Weskan member in SE corner, sec. 2, T. 13 S., R. 42 W., Wallace county.

	Feet.
Heavy, dark-gray limestone concretions. No fossils (bed No. 12).... to	1.0
Shale	3.0
Shale with several streaks of concretionary limonite (bed No. 11)	4.5
Shale	1.75
Light-brown to pinkish concretions with cone-in-cone crust (bed No. 10),	1.0
Shale	2.9
Gray limestone concretions	.8
Shale	4.8
Gray limestone concretions (bed No. 7)	.8
Shale	6.0
Gray limestone concretions (bed No. 6?)	.3
Shale	.2
Brownish-gray siderite concretions (bed No. 5)	.2
Shale	5.0
Shale with few streaks of limonite (bed No. 4)	7.6
Shale	6.0
Dark-gray limestone concretions with *Pteria* sp. and fragmentary *Inoceramus*; fragments of a very large *Placenticeras placenta*	1.0
Shale	3.1
Dark-gray limestone concretions	1.0
Dark-gray limestone concretions immediately below	.5
Shale	5.5
Heavy dark-gray limestone concretions; invertebrate fossils very scarce, except *Crassatella evansi*, *Baculites* sp., *Scaphites* sp. The mosasaur *Platecarpus* n. sp. was found here	1.0
Total	57.95

The exposures of Upper Weskan shale, in which beds 8 and 7 with their rich oyster fauna are easily recognized, are scattered all around the large northern tributary of Willow creek, which traverses secs. 2, 1 and 12 of T. 13 S., R. 42 W., except at the heads of this tributary creek in the north and west, where Ogallala Tertiary rocks are exposed. In the east part of section 2 the lower portion of Lake creek shale is exposed, also, directly above the heavy concretionary ridges of bed No. 12. Limestone concretions with an oyster fauna were occasionally observed, also, in the NW¼, SW¼ and SE¼ of sec. 11 and in the SW¼, sec. 12, T. 13 S., R. 42 W., below the prominent escarpment of Ogallala "mortar beds."

On the south side of the prominent divide between Willow creek and Smoky Hill river, east of the Weskan-Kanorado county road, the same concretionary limestone with oysters attached to large *Inoceramus* shells is exposed in the middle portions of the larger draws and below the basal beds of the Ogallala. A large new species of *Inoceramus* (*I. symmetricus*), with no oysters attached, was found in the limonite streak below the limestone concretions in the SW¼, T. 13 S., R. 42 W., and *Crassatella evansi* was found in fragments of limestone from a shallow abandoned well in the NE¼, sec. 23, T. 13 S., R. 42 W. The concretionary limestone with a rich fauna of *Anomia* cf. *subtrigonalis, Ostrea congesta* and *O.* aff. *lugubris* attached to large *Inoceramus* shells was the main key bed on which the Willow creek structure was mapped. In the many exposures of a comparatively deep and much-dissected southern dry tributary to Willow creek, which traverses the NE¼, sec. 13, T. 13 S., R. 42 W., and the NW¼, sec. 18, T. 13 S., R. 41 W., the whole thickness of Upper Weskan shale outcrops, except the uppermost heavy concretions of bed No. 12 which either was not developed here or has been eroded away. The other zones and beds of the member are typically developed in these exposures. Some local details of these zones are as follows:

At the base of the upper limonite concretionary zone (bed No. 11), in which *Serpula* (?) *wallacensis* is very abundant, three ranges of rusty to pinkish lenslike concretions with outer cone-in-cone crust are developed (bed No. 10). The middle limestone concretionary zone (beds Nos. 5 to 8) is quite typically developed with rich oyster fauna in the upper beds (Nos. 7 and 8) and with *Crassatella evansi* not rare in the lower beds (No. 6).

T. 13 S., R. 41 W. Only in one place, in the exposures of the NW¼, sec. 18, large irregular bodies of dark-gray to brownish-gray

"Lucina limestone" were observed, which represent a local lateral variation of this concretionary zone (the lithologically and partly faunistically[142] similar "Lucina limestone" of the Salt Grass shale member, which is described below, is of a lighter gray color and is much more abundant there). In the ordinary concretions of dark-gray and compact limestone that are exposed near by the moderate-sized *Baculites pseudovatus* n. sp. and *Aptychus* sp. were collected. Below bed No. 8 and immediately below a large limestone concretion of the lowermost zone of Upper Weskan shale large shells of *Placenticeras meeki* Boehm were collected.

The limestone concretions, which contain some oysters and *Inoceramus,* are seen immediately below the "mortar beds" in the beautifully exposed syncline in the west part of sec. 17, T. 13 S., R. 41 W., on the south side of Willow creek.

Heavy ridges of dark-gray limestone concretions of bed No. 12, which dip about 2° or 3° west-northwest, form the western slope of a small hill in the center of sec. 7, T. 13 S., R. 41 W. On a slope east of here and in the stratigraphically lower shale a few limonite concretions and one specimen of *Serpula* (?) *wallacensis,* which are indicative of bed No. 11, were observed. Similar concretions are exposed in the SE¼, sec. 4, T. 13 S., R. 41 W., and the NW¼, sec. 9, on the sides of a large draw, each exposure being in the vicinity of an abandoned farmhouse; and the lower half of the same shale member and the top of Lower Weskan shale are exposed in the NE¼, sec. 9, and the NW¼, sec. 10, T. 13 S., R. 41 W.

T. 13 S., R. 40 W. The upper beds of the shale member are also exposed in the NW¼, sec. 18, and in S½, sec. 6, T. 13 S., R. 40 W. The latter locality extends into the SE¼, sec. 1, T. 13 S., R. 41 W.

T. 12 S., R. 40 W. The shale, which outcrops on the south side of Old Maid's Pool, in the northeast corner of sec. 30, T. 12 S., R. 40 W., is provisionally referred to the base of Upper Weskan shale member on the evidence of the heavy dark-gray limestone concretions, in which the fossils are very scant, only young *Scaphites* sp. being identified.

T. 12 S., R. 39 W. The next exposure of the Upper Weskan shale toward the east is in the southwest corner of sec. 30, T. 12 S., R. 39 W. The large limestone concretions with rich invertebrate fauna build a slope dipping gently northeast on the south side of Pond

---

[142] However, only *Lucina occidentalis* is the common form in both, the rest of the fossil content being different.

creek. The following fauna was collected here: *Serpula* (?) *wallacensis, Anomia* cf. *subtrigonalis, Ostrea congesta, O.* aff. *lugubris, Pecten venustus, Inoceramus* sp. *Nuculana bisulcata.* The fauna and the lithology indicate beds Nos. 8 and 7 of the middle limestone concretionary or *Ostrea* aff. *lugubris* zone of the Upper Weskan shale.

T. 13 S., R. 39 W. In the NW¼, sec. 1, T. 13 S., R. 39 W., on the northeast side of the hill, capped by a prominent knob of Quaternary gravel, limestone concretions with the same type of oyster fauna as in sec. 30, T. 12 S., are exposed, and for a short distance form the dip slope of the hill. This bed of concretionary limestone was traced from here into the S½, sec. 36, T. 12 S., R. 39 W., where the following fauna was collected: *Serpula* (?) *wallacensis, Anomia* cf. *subtrigonalis, Ostrea congesta, O. plumosa, Lithophaga* (?) sp., *Inoceramus* sp., and *Amauropsis punctatus.* Here, also, a very small pteropod of *Tentaculites* type was found in profusion in some fragments of concretionary limestone.

T. 12 S., R. 38 W. The bed of large dark-gray limestone concretions with thin cone-in-cone crust and no fossils except *Serpula* (?) *wallacensis,* which was noted above, is exposed near the base of the Lake creek shale in the northwest corner of sec. 7, T. 12 S., R. 38 W., and probably corresponds to bed No. 12 of the Upper Weskan shale.

T. 11 S., R. 39 W. The beds of this shale member were identified and their fauna collected in many exposures along Lake creek. Coming down the stream we find the first exposures of the member in the W½, sec. 27, and in the NW¼, sec. 34, T. 11 S., R. 39 W. Here the exposed large dark limestone concretions are traversed with a net of thin veinlets filled with light-brown crystalline calcite and contain only very few fossils. In the exposure immediately south of the road, in the NW¼, sec. 34, a small fauna was collected in which *Anomia* cf. *subtrigonalis, Ostrea congesta* and *Inoceramus* sp. were identified.

Below these concretions a few streaks of brown concretionary limonite with *Serpula* (?) *wallacensis, Scaphites nodosus* and *Baculites sp.* are exposed.

T. 11 S., R. 38 W. The same large nonfossiliferous concretions with veinlets of calcite, which are identified as the topmost bed No. 12 of the Upper Weskan shale, are well exposed around the Robidoux well, which is in the SW¼, sec. 31, T. 11 S., R. 38 W., but here are also exposed the other zones of the Upper Weskan, which contain a rich and typical fauna (beds No. 8 and No. 7) and thus verify the identification of the member. From this locality the following fauna was identified: *Anomia* cf. *subtrigonalis, Ostrea congesta* (?), *O.* aff. *lugubris, Inoceramus convexus, Inoceramus* sp., *Crassatella evansi, Nucula* (?) n. sp.

The limestone concretions with this fauna are here only 10 to 15 feet below the bed that is assumed to be bed No. 12 at the top of the Upper Weskan. This and other exposures along Lake creek demonstrate a change in the vertical spacing of limestone concretions in this shale member as compared with the type locality at Swisegood ranch on Willow creek. These changes, which are not surprising in outcrops separated by a distance of about 20 miles, do not affect the general lithologic character of the Upper Weskan shale, which here also has a very typical middle limestone concretionary zone with a rich oyster fauna and a top zone of heavy unfossiliferous limestone concretions. The geology around the Robidoux well is discussed in the chapter on geologic structure of the county.

T. 12 S., R. 38 W. Large outcrops of Upper Weskan shale are in the NE¼, sec. 16, and in the northwest corner of sec. 15, T. 12 S., R. 38 W. A prominent hill, with an abandoned house on the top, rises here nearly 200 feet above the level of Lake creek and is cut on its north side by deep draws, which are tributary to the creek. The following section was taken in the draw west of the section line between sections 15 and 16 and on the west and upthrow side of the fault, the direction of which is N 28° E. From top down:

Section of Upper Weskan member in E½, sec. 16, T. 12 S., R. 38 W., Wallace county.

	Feet.
Dark-gray large limestone concretions rich with fauna: *Anomia* cf. *subtrigonalis, Ostrea congesta, O.* aff. *lugubris, Inoceramus* sp., *I. proximus* (bed No. 8)	.3
Shale	11
Dark-gray large limestone concretions; same fauna but less abundant (bed No. 7)	.3
Shale	6.0
Dark-gray large limestone concretions. Rich fauna: *Inoceramus* sp. with no oysters attached, *Nemodon* n. sp. aff. *sulcatinus, Nucula planimarginata, Nuculana* (?) sp., *Lunatia* n. sp., *Dentalium gracile, Scaphites* cf. *nodosus* (bed No. 6)	.3
Shale	18.0
Streak of gypsum	.1
Shale	....
Total	34+

The shale dips 6° to N 10° W.

The large unfossiliferous concretions of bed No. 12 are exposed about 25 feet above and west of the section and dip 4½° S, 85° W. The same bed, No. 12, outcrops on the east or downthrow side of the fault at about the elevation of bed No. 8 on the upthrow side, which places the vertical throw of the fault at about 25 feet. The section of the upper beds of the Upper Weskan shale was taken in the canyon east of the section line between sections 15 and 16, where also the section of the lowermost portion of the Lake Creek shale was measured. The section of Upper Weskan shale is as follows, from top down:

Section of Upper Weskan member in W½, sec. 15, T. 12 S., R. 38 W., Wallace county.

Shale of Lake Creek member:	Feet.
Limestone concretions, large, dark gray with veinlets of calcite; vertical cleavage of the "slicing" type; no fossils except few fragments of *Inoceramus* sp. (bed No. 12)	.4
Shale	5.0
Bentonite, white	.25
Shale	2.0
Bentonite, white	.1
Shale	1.5
Bentonite, white	.05
Shale	3.0
Rusty bentonite	.05
Shale	4.0
Gray limestone concretions, weathering into pink; here and there thin cone-in-cone outer crust. Few fossils: *Anomia* cf. *subtrigonalis,* large *Inoceramus* sp. with no oysters attached (bed No. 10?)	.3
Shale	10.0
Limestone concretions, gray, with *Anomia* cf. *subtrigonalis* and *Inoceramus* sp. (bed No. 8)	.3
Shale	5.0
Bentonite, white	.35
Shale with numerous but thin streaks of bentonite	5.0
Total	37.3

In the exposure of shale in the NE¼, sec. 14, T. 12 S., R. 38 W., on the north side of Lake creek, the fauna, consisting of *Ostrea congesta* attached to *Inoceramus* sp., was collected. No large limestone concretions were noticed, but the fauna indicates the middle portion of Upper Weskan shale. Other exposures of shale, the lithology and fauna of which suggest either Upper or Lower Weskan shale, are in the NE¼, sec. 15 and in the SW¼, sec. 2, T. 12 S., R. 38 W., where large concretions suggestive of bed No. 12 (see chart, opp. p. 58) of the Upper Weskan shale were observed.

Logan County, T. 11 S., R. 37 W. Exposures of Weskan shale member are found in Logan county, where shale with similar lithology and fauna was observed in a draw west of the north fork of Smoky Hill river, in sec. 27, T. 11 S., R. 37 W. The shale dips gently to the north. The following fossils were collected and identified: *Anomia* cf. *subtrigonalis, Inoceramus convexus, I. proximus, Dentalium gracile, Baculites* cf. *compressus.*

The possible equivalents of the Weskan shale member of the Pierre outside of Kansas are discussed further on in the chapter.

LAKE CREEK SHALE MEMBER.

The Lake Creek shale member of the Pierre differs from the Weskan shale below and from the Salt Grass shale above by the total absence or by great scarcity of the large limestone concretions that are so common in the members above and below. On the other hand, limonite concretions and concretionary streaks are very common through the whole thickness of the member and give a typical rusty appearance to all the exposures of this shale. It must be taken into account, however, that limonite concretionary zones are also common in both Weskan and Salt Grass shale members, where these rusty zones alternate with zones of heavy limestone concretions.

The name of the Lake Creek shale is taken from a stream in the northwest part of Wallace county along which the most extensive outcrops of the shale member are exposed, but the thickness of the member was estimated on the outcrops in sec. 5 and sec. 7 of T. 13 S., R. 41 W., where both the upper contact with Salt Grass shale member and the lower contact with the Weskan shale are observed. Two estimates gave nearly the same amount, about 200 feet.

The sections of Lake Creek shale member are very uniform in appearance and contain innumerable streaks of concretionary limonite, which do not exceed two-tenths of a foot in thickness. Small, usually yellowish-white or light-gray limestone and marl concretions are nearly always mixed with the limonite concretions and concretionary streaks and are often present as an oval core around which a thick limonite crust is deposited. Rarely the white concretions are gathered in pure limy streaks, but a few horizons of thin pancakelike gray to dark-gray limestone concretions are observed in the uppermost Lake Creek shale, and similar but nearly white concretions were observed in the lowermost Lake Creek shale. These limy concretions do not exceed one-tenth of a foot in thickness, and they are comparatively soft, or at any rate they are never as tough as the dark-gray limestone concretions of the Weskan shale. The limonite concretions are usually light to dark brown, but in the Upper Lake Creek shale many are quite yellowish and rusty in appearance. Some acquire a pinkish tint, and there are some concretions, made of compact mixtures of lime and iron hydroxide, which show a pleasant though somewhat dull "strawberry and milk" color. These concretions are also confined to the upper half of the shale member.

Poorly developed cone-in-cone structure was occasionally observed around these concretions, but no good cone-in-cone structures comparable to those of Salt Grass and Weskan shales were noticed in Lake Creek shale. Crystalline gypsum was occasionally met with in various parts of this shale (Pl. XIII B), but bentonite was never observed except in the lowermost beds, where very few and thin streaks were found.

No prominent and reliable key beds could be chosen from among the many concretionary streaks of this shale member. Invertebrate fossils are common through the whole thickness of the Lake Creek shale and help materially to distinguish the upper part of this shale member from the lower part of it, as the lithology of the shale is more or less uniform through the whole thickness. The most common and important index fossil for the lower half of the shale member is *Serpula* (?) *wallacensis,* the medium-sized short and often fusiform or pipelike bodies of which are found in places in profusion. *Baculites compressus* s. s. was mostly found in the Lower Lake Creek shale, whereas in the Upper Lake Creek shale *Baculites compressus* var. *reesidei* gradually takes its place. The variety *corrugatus* of the latter form is restricted to the uppermost Lake Creek shale. In some localities of the northwestern Wallace county area there is a bed of black shale, which is harder than the ordinary shale of the Pierre and contains many rusty streaks and abundant fish bones and scales. This shale is exposed slightly below the lower limestone concretionary zone of the Salt Grass shale member and therefore belongs to the top of the Lake Creek shale.

A complete list of invertebrates of the Lake Creek shale is as follows:

Invertebrates from the Lake Creek member.

Serpula (?) *wallacensis* Elias n. sp.
Serpula kansasensis Elias n. sp.
Serpula aff. *lineata* (Weller).
Ostrea cf. *congesta* Conrad.
Anomia cf. subtrigonolis Meek & Hayden.
Lithophaga sp.
Pteria aff. *linguiformis* Evans and Shumard.
Inoceramus convexus Hall & Meek.
Inoceramus proximus Tuomey, Meek em.
Inoceramus proximus var. *subcircularis* Meek.
Inoceramus vanuxemi Meek & Hayden.
Inoceramus saltgrassensis Elias n. sp.
Crassatella evansi Hall & Meek.
Thetis circularis Meek & Hayden.
Lucina subundata Hall & Meek.
Lucina occidentalis Morton.
Pholadomia (*Procardia*) *hodgii* Meek.
Anchura sublævis Meek & Hayden.
Anisomyon centrale Meek.
Acmaea cf. *parva* Meek & Hall.
Baculites compressus Say em. Meek.
Baculites compressus var. *reesidei* Elias n. var.
Baculites compressus var. *corrugatus* Elias n. var.
Acantoscaphites nodosus Owen.
Acantoscaphites nodosus var. *brevis* Meek.
Acantoscaphites nodosus var. *quadrangularis* Meek & Hall.
cf. *Discoscaphites constrictus* var. *tenuistriatus* (Kner).
Ammonites sp.
Placenticeras meeki Boehm.
Aptychus sp.

The vertebrates that were found in this shale member are mentioned in the descriptions of the localities.

DISTRIBUTION OF LAKE CREEK MEMBER. *T. 13 S., R. 42 W.* The lowermost 20 to 30 feet of the Lake Creek member are well exposed in the SE¼, sec. 2, T. 13 S., R. 42 W., where the member overlies the Upper Weskan beds. Many streaks of concretionary limonite, some with cores of white lime, build benches in the Lower Lake Creek shale. Among the fossils, which are not rare, *Serpula* (?) *wallacensis* and fragmentary *Inoceramus* sp. are most common. One specimen of *Pholadomia hodgii* was found here. Two thin streaks of bentonite were observed at the very base of the exposures.

T. 13 S., R. 41 W. Shale of the same character is poorly exposed in the center of sec. 7, T. 13 S., R. 41 W., where it lies between white limy concretions of the base of Salt Grass member on the west and dark-gray limestone ridges of the top of the Weskan member on the east. The gentle north-northwest dip of the two inclosing beds permits the estimating of the thickness of the shale between them. The basal portion of Lake Creek shale is exposed in the SE¼, sec. 8, T. 13 S., R. 41 W., and very good and almost continuous exposures of the whole thickness of the shale member lie along the large draw marked by the two abandoned houses in secs. 5, 8 and 3 of T. 13 S., R. 41 W. In the northeast corner of section 8, near the very base of the member, the following fossils were collected: *Acantoscaphites nodosus* var. *quadrangularis, Anchura sublævis, Lithophaga* sp. attached to *Acantoscaphites, Inoceramus saltgrassensis, Inoceramus* sp., *Serpula* (?) *wallacensis,* numerous *Serpula* cf. *lineata* and vertebræ of a mosasaur. In the upper portion of the shale member, in the NW¼, sec. 5, T. 13 S., R. 41 W., many specimens of *Baculites compressus* var. *reesidei* and especially the large variety *corrugatus*, roughly corrugated on the siphonal edge, were collected. A little lower in the section fragments of *Acantoscaphites nodosus* s. s. were found associated with a yellow, rusty limonite streak. *Inoceramus* sp. fragments were commonly observed. The dip of the shale is invariably northwest, which permitted another estimate of the total thickness of the Lake Creek member. Typical beds of the Lake Creek shale member were observed but not studied in detail at NE¼, sec. 4, and NW¼, sec. 3, T. 13 S., R. 41 W., where they underlie the Salt Grass shale member, dipping north, and in the center of sec. 13, T. 13 S., R. 41 W., where the shale dips gently to the south.

T. 13 S., R. 40 W. Lake Creek member was observed at SW¼, sec. 6, T. 13 S., R. 40 W., and west of sec. 18, T. 13 S., R. 40 W., where it overlies Upper Weskan shale. A lone exposure of probably the lower portion of the member is on the north side of Goose creek, north of the center of sec. 11, T. 13 S., R. 40 W. The shale dips gently south and is overlain by a small thickness of "mortar beds." The following fossils were collected in the shale: *Serpula kansasensis, Scaphites nodosus* var. *quadrangularis, Inoceramus* sp. and *Acmeœ* sp. cf. *parva.*

T. 12 S., R. 41 W. The member is exposed in southeast corner of sec. 27, in southwest corner of sec. 22, in SE¼ and NE¼, sec. 10, and in NW¼, sec. 12, T. 12 S., R. 41 W., where the Upper Lake Creek shale underlies the basal limestone concretionary zone of Salt Grass shale member. In the last-named locality several specimens of *Baculites compressus* var. *reesidei* and var. *corrugatus* were collected in the zone of gray limestone pancakelike concretions. In a lone exposure of the upper portion of Lake Creek shale with pancakelike limestone concretions in SE¼, sec. 33, T. 12 S., R. 41 W., a complete skeleton of the large fish *Empo* was discovered (Pl. XIII A). The beautiful large rosette of gypsum shown in PI. XIII B was photographed in the ditch beside the road in the west central part of sec. 11, T. 12 S., R. 41 W., a few feet below the limestone bodies with *Lucina* shells (Pl. XV C) which belong to the base of the Salt Grass member.

T. 12 S., R. 40 W. Several exposures of the Lake Creek Shale member were studied at the head of the Pond Creek basin, in SE¼, sec. 23, SW¼, sec. 24, SW¼, sec. 13 and in sec. 25 of T. 12 S., R. 40 W. In the uppermost Lake Creek shale, immediately below the basal concretionary zone of the Salt Grass member, in

SE¼, sec. 23, the following fossils were collected: *Baculites compressus* var. *reesidei, Inoceramus saltgrassensis* and a vertebra of a mosasaur. In the SW¼, sec. 24, the same uppermost portion of Lake Creek shale yielded the following forms: *Serpula kansasensis, Ostrea* cf. *congesta, Inoceramus saltgrassensis, I.* sp., *Anysomion* cf. *centrale, Baculites compressus* var. *reesidei, B. compressus* s. s. (?), *Scaphites nodosus* var. *brevis,* and in sec. 25 *Serpula* cf. *lineata, Baculites compressus* var. *corrugatus, Placenticeras meeki* were collected.

T. 12 S., R. 42 W., and T. 11 S., R. 42 W. The topmost part of the Lake Creek shale member is exposed below the lowermost limestone concretionary zone of the Salt Grass formation in the southwest corner of sec. 36, T. 11 S., R. 42 W., and in the SE¼ NE¼, sec. 2, T. 12 S., R. 42 W. The exposed shale below the limestone concretionary zone of the first exposure is as follows (see, also, Pl. XIX-3):

Section of Lake Creek member in SW¼, sec. 36, T. 11 S., R. 42 W., Wallace county.

	Feet.
Large lenticular limestone concretions at the base of Salt Grass shale member	.3
Shale, gray	4.1
Streaks of limonite concretions	.1
Shale, gray	2.7
Rusty streak	.05
Shale, gray	11.2
Bed of rusty limonite	.3
Dark gray to black shale with many rusty streaks and abundant bones and scales of fishes	6.3
Rusty streak with occasional cone-in-cone structure	.1
Shale	3.8
Siderite concretions	.1
Shale	6.5
Siderite concretions	.1
Shale	3.2
Total[143]	38.85

In the same uppermost dark shale of the Upper Lake Creek member, which is exposed in the core of the small structural height of Salt Grass canyon, in the NE¼, sec. 12, T. 12 S., R. 42 W., many rusty streaks and a considerable quantity of crystalline gypsum, often making large rosettes, were observed.

T. 11 S., R. 40 W. The most extensive exposures of Lake Creek shale were observed along Lake creek, or Turtle creek, beginning a

---

[143] For the upper continuation of the section see page 109.

little east of state highway No. 27 and extending down the stream. The uppermost beds, having almost no fossils and few thin streaks of rusty limonite and a streak of very flat light-brown cone-in-cone concretions, are exposed in a deep draw in the W½, sec. 35, and in a little draw in the middle south part of sec. 26, T. 11 S., R. 40 W. A little lower bed of the Lake Creek shale is exposed in the SE¼ SW¼, sec. 25, T. 11 S., R. 40 W. Several streaks of concretionary limonite, pinkish limy concretions and a few very thin bentonite streaks were observed and one specimen of *Baculites compressus* var. *reesidei* was collected. The shale is exposed, also, in the NW¼, sec. 36, T. 11 S., R. 40 W.

T. 11 S., R. 39 W. The Lake Creek member is exposed in the SW¼, sec. 30, and the NW¼, sec. 31, T. 11 S., R. 39 W. In these two localities only dark-brown streaks of concretionary limonite and small light-gray to nearly white limy concretions were observed. Many shells of *Inoceramus saltgrassensis* and fragments of larger *Inoceramus* sp. and *Scaphites* cf. *nodosus* were collected. In the NW¼, sec. 29, T. 11 S., R. 39 W., *Inoceramus saltgrassensis, I. proximus* var. *subcircularis* and a large *I.* sp. were collected in similar shale. In the SE¼, sec. 29, T. 11 S., R. 39 W. *B. compressus* var. *corrugatus* was collected by Joe De Tilla and cordially submitted to the writer. The beautiful specimen was made by him the type of var. *corrugatus*. Good exposures of Lake Creek shale were observed in every one of the many and short draws on the south side of Lake creek in T. 11 S., R. 39 W. In the SE¼, sec. 33, the following fossils were collected: *Serpula kansasensis, Inoceramus saltgrassensis, I.* cf. *convexus, Lucina subundata, Anchura sublævis, Baculites compressus* var. *reesidei, Scaphites nodosus* var. *brevis*. In the NW¼, sec. 34, the collected fauna includes *Inoceramus convexus, Ostrea* cf. *congesta, Baculites compressus* var. *reesidei, Acantoscaphites nodosus* s. s. (?). In the middle of sec. 35 and in the west part of sec. 36, T. 11 S., R. 39 W., typical thin pancakelike limy concretions and rusty limonite concretions of the upper Lake Creek shale are exposed. The following fauna belongs to these exposures: In section 35 *Inoceramus saltgrassensis, I. sp., Pteria* sp. aff. *linguiformis, Thetis circularis, Anchura sublævis, Acme* cf. *parva, Baculites compressus* var. *reesidei, Baculites* sp. cf. *pseudovatus, Acantoscaphites nodosus* var. *brevis;* in section 36 *Serpula* cf. *lineata, Inoceramus convexus, I. vanuxemi, I. saltgrassensis, Lucina occidentalis* (a young individual), *Baculites compressus* var. *rees-*

idei, B. compressus var. *corrugatus, B.* sp. cf. *compressus* s. s., *Acantoscaphites nodosus* s. s., *Ammonites* sp.

On the north side of Lake Creek in the SW¼, NW¼, sec. 27, T. 11 S., R. 39 W., streaks of dark purple-brown limonite concretions with white limy cores overlie the heavy limestone concretions of the Upper Weskan shale. In the shale which apparently represents the lowermost beds of the Lake Creek member the following fossils were collected: *Serpula* (?) *wallacensis, S.* cf. *lineata, Inoceramus proximus, Baculites* sp. cf. *compressus* s. s.

T. 11 S., R. 38 W. Lowermost beds of Lake Creek shale are exposed above the Weskan shale at the Robidoux well, in the SW¼, sec. 31, T. 11 S., R. 38 W. The following fossils were collected: *Serpula* (?) *wallacensis, Baculites* sp. cf. *pseudovatus, Acantoscaphites nodosus* var. *quadrangularis, Placenticeras* sp. and *Mosasaurus* ribs.

T. 12 S., R. 39 W., and T. 12 S., R. 38 W. Many good exposures of Lake Creek shale are located on each side of the large southern tributary to Lake Creek in secs. 1, 2, 11 and 12, T. 12 S., R. 39 W., and in secs. 7 and 18, T. 12 S., R. 38 W. The shale that is exposed in the southwest corner of sec. 7, T. 12 S., R. 38 W., contains brown limonite concretions with thin yellow rusty crust and small flat oval limy concretions. Among the collected fossils the following forms were recognized: *Serpula* cf. *lineata, Inoceramus* cf. *proximus, Lucina* cf. *subundata, Baculites compressus* s. s., *B. compressus* var. *reesidei.* North of this exposure, in the northwest corner of sec. 7, T. 12 S., R. 38 W., in the ditch beside the county road large dark-gray limestone concretions with a thin cone-in-cone crust are exposed with a streak of purple-brown limonite below. *Serpula* (?) *wallacensis* was found in the shale at the top of the exposure. This is probably the topmost bed, No. 12, of Upper Weskan shale and the overlying shale belongs to the base of the Lake Creek member. In the exposure in the N½, sec. 12, T. 12 S., R. 39 W., the following fossils were collected: *Serpula* cf. *lineata, S.* (?) *wallacensis, Inoceramus* cf. *proximus, Baculites compressus* var. *corrugatus.* In the center of sec. 2, T. 12 S., R. 39 W., *Acantoscaphites nodosus* var. *quadrangularis* and *Baculites compressus* var. *reesidei* were found. The shale of the last two sections probably belongs to the middle portion of the Lake Creek member. The shale exposed in the northeast corner of sec. 11, T. 12 S., R. 39 W., contains many flat oval white limestone concretions with *Ostrea* cf. *congesta, Inoceramus* sp. and

Acantoscaphites nodosus var. *brevis,* and probably belongs to the higher beds of the Lake Creek member. To the upper beds of the Lake Creek member belongs, also, the shale exposed in the S½, sec. 7, and in the N½, sec. 18, T. 12 S., R. 38 W., where the following fossils were collected: *Serpula* (?) *wallacensis, S.* cf. *lineata, Anomia* cf. *subtrigonalis, Inoceramus saltgrassensis, I.* sp., *Thetis circularis, Pholadomia* (*Procardia*) *hodgii, Baculites compressus* var. *corrugatus, B.* sp., and *Scaphites* sp.

A section of Lower Lake Creek shale was measured in the exposures at the head of a deep but short canyon in the northwest corner of sec. 15, T. 12 S., R. 38 W., where this shale is underlain by the Upper Weskan member. The following beds of the Lake Creek shale are exposed from top to bottom.

Section of Lake Creek member in NW corner sec. 15, T. 12 S., R. 38 W., Wallace county.

	Feet.
Shale with few small limonite and white limestone concretions	10.0
Shale with streaks of small brown limonite and white limestone concretions on top; fragments of *Inoceramus* sp., *Baculites* cf. *compressus* s. s. and *B.* cf. *pseudovatus*	15.0
Streaks of brown limonite concretions with *Serpula* (?) *wallacensis*	.1
Shale with two thin streaks of rust	7.0
Scattered brown to dark-gray concretions with thin crust of cone-in-cone structure	.2
Shale with many streaks of brown concretionary limonite with white limy cores. Abundant *Serpula* (?) *wallacensis,* also *Inoceramus* sp. and *Scaphites* sp.	8.0
Very persistent streak of dark-brown limonite and gray to white limestone concretions	.2
Shale with few limonite concretions	14.0
Large concretions of dark-gray limestone on top of Weskan shale.	

Beds of the Lake Creek member are also exposed at the head of Buckskin creek in the NW¼, sec. 3, T. 12 S., R. 38 W., and in the SE¼, sec. 30, T. 11 S., R. 38 W. In sec. 2, T. 12 S., R. 38 W., *Baculites compressus* var. *corrugatus* was found.

T. 11 S., R. 38 W. The shale of this member outcrops, also, occasionally on the south side of the north fork of Smoky Hill river in the northeast corner of T. 11 S., R. 38 W. Here in the shale with many streaks of concretionary limonite having occasional imperfect cone-in-cone crust, *Baculites compressus* var. *reesidei* and *Scaphites* sp. were found. In the exposure of similar limonite concretionary beds at the county line in the E½, sec. 12, T. 11 S., R. 38 W., the following fossils were collected: *Serpula* cf. *lineata, S.* (?) *wallacensis, Inoceramus* sp., *Baculites compressus* var. *reesidei* and var. *corrugatus* and bones of a mosasaur. Small concretions of manganite in crystalline kidneylike forms were found in a number. The shale of this exposure probably belongs to the middle part of the Lake Creek member.

The possible equivalents of the Lake Creek shale member outside of Kansas are discussed farther on in this chapter.

SALT GRASS SHALE MEMBER.

The name of this member is derived from Salt Grass Canyon, the southern tributary to Goose creek in secs. 1 and 12, T. 12 S., R. 42 W. Many exposures of the shale member on both sides of the broad and not very steep canyon permit study of the zones and beds of the member in detail. The average thickness of the member estimated in this locality is about 60 feet. The shale is lighter in color than the dark-gray to black shale of the top of the Lake Creek member. The Salt Grass shale can be conveniently subdivided into three zones: The lowest zone contains large limestone concretions (Pl. XV) in which occasionally a rich fauna of cephalopods and pelecypods is observed; the middle zone has many streaks of concretionary limonite with white limy cores containing abundant *Baculites* but practically no other fossils; and the upper zone has beautifully developed cone-in-cone concretions of rusty limestone (Pl. XVI E) and small septarian cores in concretions of limonite (Pl. XVI A), practically bare of fossils. In some exposures above these beds about 30 feet more of shale is exposed on the top of the upper zone. This 30 feet of shale is nearly featureless. No fossils were found, and only a few thin streaks of ordinary rusty limonite were noticed in this shale.

The lowest zone of the Salt Grass shale member in many places contains several layers of light-gray to nearly white limestone concretions, to which rarely a few smaller streaks of limonite concretions are added. The limestone of the concretions is fine-grained and compact and often contains no fossils at all. Occasionally, however, the fossils appear in a considerable number of specimens, usually on the top (Pl. XV D) or at the base of the concretions. The concretions are commonly oval in outline (Pl. XV A), flattened horizontally and traversed by many vertical cracks. Among these ordinary concretions there appear in places larger irregular bodies of limestone in which *Lucina occidentalis* (Pl. XV C) is very abundant. The limestone of these bodies is full of irregular veinlets which are partly or completely filled with yellowish crystalline calcite. The weathered surface of this limestone is quite rough.

Many of these peculiar bodies of limestone are elongated vertically (Pl. XV B). Similar and still larger bodies from Pierre of the Arkansas valley in eastern Colorado were originally described by Gilbert and Gulliver as "tepee cores," so named on account of the position of each core of limestone in a "conical hill of shale, with the limestone projecting slightly at top."[144] This limestone is also full of *Lucina occidentalis* shells, which are believed to be the main source of the calcium carbonate of the "tepee cores." The corresponding limestone bodies in the Pierre of Wallace county only rarely occur as cores of isolated conical hills resembling Indian tepees, but usually appear in horizontally spaced groups and form somewhat irregular benches and escarpments on the slopes of the hills. They can be conveniently called "Lucina limestone" from their content of *Lucina* shells, other fossils being found in these bodies in comparatively small number. "Lucina limestone" was rarely found in the other zones of the local Pierre, where it appears, also, as a local lateral change in the limestone concretionary zones. The sole outcrop of the similar "Lucina limestone" in the middle concretionary limestone zone of the *Ostrea* aff. *lugubris* zone of the Upper Weskan shale member has been described already. In the upper limestone zone of the Salt Grass member, also, "Lucina limestone" bodies were observed only once. Similar limestone occurs also in places near the top of the uppermost shale of the Pierre exposed at Beecher Island, Yuma county, Colorado.

Some large limestone concretions of the lowest limestone zone of the Salt Grass have a crust of cone-in-cone structure, but the cone-forming arrangement of the crystalline fibers in this crust is not pronounced, the fibers being nearly parallel. Owing to this the cone-in-cone crust weathers into debris like "chopwood" (Pl. XVIII D), somewhat similar to the structure around some concretions at the top of the Sharon Springs shale member (Pl. VII A).

In a few concretions *Lingula* sp. and scales and bones of small fishes were collected. The following is a complete list of invertebrates collected from the lower limestone concretionary zone of the Salt Grass shale member:

Invertebrates from the lower zone of the Salt Grass member.

Serpula kansasensis Elias n. sp.
Lingula sp.
Inoceramus vanuxemi (?) Meek and Hayden.
Inoceramus barabini Morton.
Inoceramus saltgrassensis Elias n. sp.
Yoldia evansi Meek and Hayden.
Yoldia scitula Meek and Hayden.
Lucina occidentalis Morton.
Lucina subundata Hall and Meek.
Anchura sublaevis Meek and Hayden.

---

[144] Gilbert, 1896, p. 569; see, also, Gilbert and Gulliver, 1895.

Baculites compressus var. *reesidei* Elias n. var.
Baculites compressus var. *corrugatus?* Elias n. var.
Baculites pseudovatus var. A, Elias n. var.
Acantoscaphites nodosus Owen.
Acantoscaphites nodosus var. *brevis* Meek.
Acantoscaphites nodosus var. *quadrangularis* Meek.
Scaphites plenus Meek and Hayden.
Scaphites reesidei Wade.

The middle concretionary zone of the Salt Grass shale is characterized by small limonite concretions arranged in several streaks and usually with creamy to white limy oval cores. Some of these cores are made by casts of *Baculites,* which is the only fossil very common in the zone. The limonite of the concretions is usually a uniform light brown, differing from the commonly observed dark-brown, pinkish-brown and yellow colors of the limonite of the Lake Creek shale member. A very thin streak of bentonite at the base of the middle concretionary zone and a much thicker one at the top of the zone are locally observed, but altogether bentonite is rarely found in this shale member. Among the *Baculites* casts, which are confined mostly to the upper two streaks of concretionary limonite, the following two species were recognized: *Baculites pseudovatus* var. A (very common), B. *compressus* var. *reesidei* (rare). The most common casts, which have an ovate cross section, smooth surface and show no septa, must belong to *B. pseudovatus* and not to *B. ovatus,* the typical suture of *ovatus* never being observed on these specimens. Among other fossils which are only rarely found in this middle zone, the following species are recognized: *Pecten venustus* Morton, *Valvata* cf. *subumbilicata* Meek & Hayden, *Aptychus* sp.

The highest zone of the Salt Grass shale consists of several streaks, which for the most part have a rusty appearance, but locally change to more limy material and in a few places into nearly pure limestone. One to three closely spaced layers of flat and usually round lenses of cone-in-cone rusty brownish limestone (Pls. XIII, XIV and XV) constitute the most persistent streaks in the middle of the zone. In many places these cone-in-cone lenses form prominent escarpments and benches in the shale, providing the best key bed of the member. Above the cone-in-cone bed, but sometimes also below it, appear one to two streaks of limonite concretions with thin lenslike septarian cores of light-brown to cream-colored marly material. These cores are perpendicularly broken into angular fragments, which are partly cemented together by crystalline calcite (Pl. XVI A). The concretionary streaks above the cone-in-cone bed are considered to be the topmost beds of Salt Grass member.

Fossils are exceptionally scarce in the highest zone of the shale member, but in one locality in Roy Johnston canyon, where a gradual lateral change of cone-in-cone bed into "Lucina limestone" was observed, a collection of fossils was made among which the following species were recognized:

Fossils from the top of the Salt Grass member.

Serpula kansasensis Elias n. sp.
Serpula cf. *lineata* (Weller).
Pteria aff. *linguiformis* Evans & Shumard.
Lucina occidentalis Morton.
Baculites sp.
Discoscaphites nicolleti var. *saltgrassensis* Elias n. var.

In another exposure of the member fossil wood of a conifer with burrows of *Teredo* sp. was collected. Bones of mosasaurs were also occasionally collected.

The shale of the Salt Grass member often has a light greenish tint, which is probably due to an ancient, pre-Ogallala weathering.

The writer has had an opportunity to study the cuttings of Pierre shale from a deep well in the Beecher Island area, from which he extracted and identified several specimens of foraminifera. The total thickness of the complete Pierre section in this locality is about 1,450 feet. The following foraminifera which were collected from the shale between 735 feet and 790 feet, or slightly below the middle of the section, must belong to a zone approximately corresponding to the Salt Grass shale of the Pierre in Wallace county.

Foraminifera from the Salt Grass member.

Nodosaria communis d'Orbigny.
Nodosaria obliqua Linney.
Globigerina rosetta Carsey.
Orbitolina sp.
Rubulus (Cristellaria) cultratus (Montfort).

Distribution of Salt Grass Member. Salt Grass shale is widely distributed in the northwestern part of Wallace county, and though the member is less than one-third as thick as the underlying Lake Creek shale, it outcrops over a larger area than the latter member. This appears to be due to the stronger resistance to weathering offered by the Salt Grass shale member which is reinforced by the heavy concretionary limestone zones. This shale apparently was the capping rock of the hills and divides of the pre-Ogallala topography. The next zone below it in the Pierre section that resists weathering well is the Weskan shale, that is also reinforced with heavy limestone concretions. The Weskan shale capped the pre-Ogallala hills south and southeast of the area of distribution of the Salt Grass member.

Goose Creek. *T. 11 S., R. 42 W.* The following outcrops of the

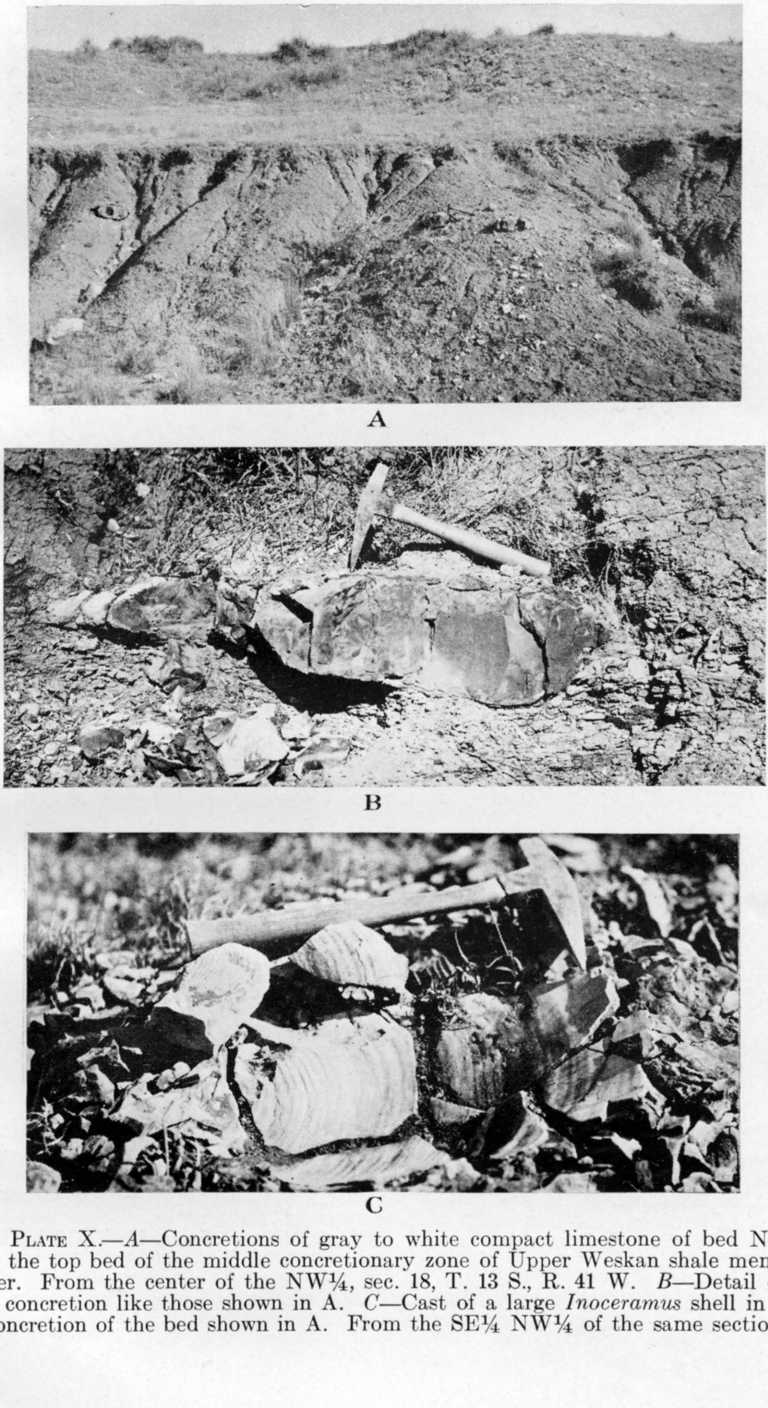
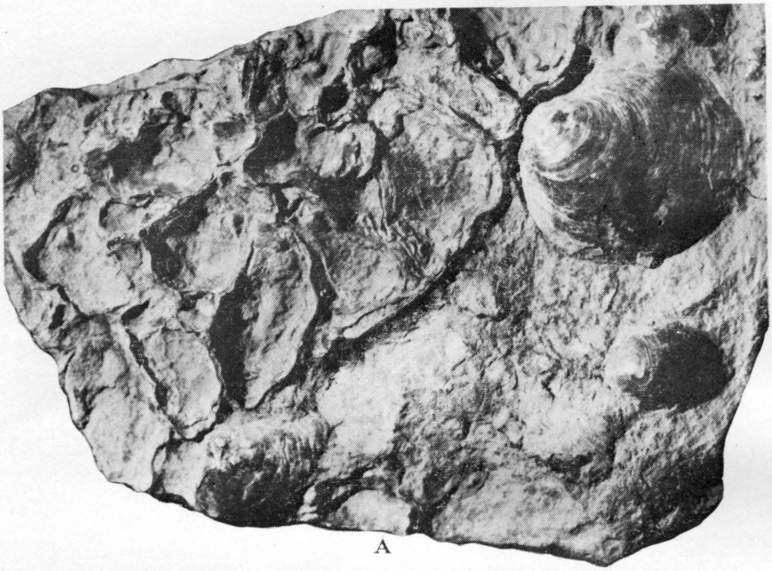


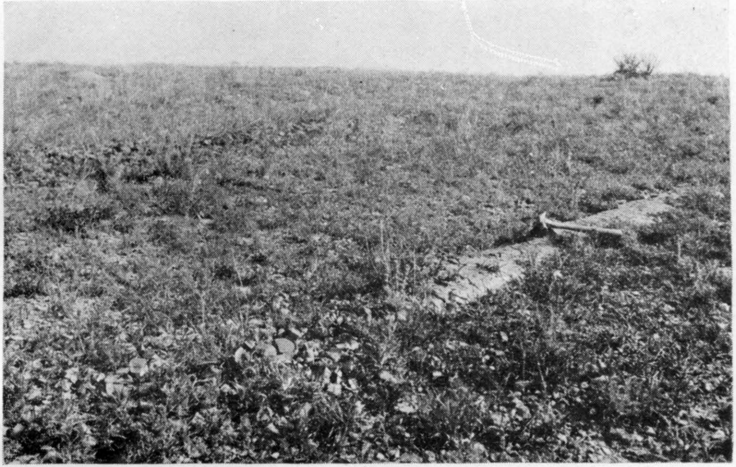
PLATE X.—*A*—Concretions of gray to white compact limestone of bed No. 8, the top bed of the middle concretionary zone of Upper Weskan shale member. From the center of the NW¼, sec. 18, T. 13 S., R. 41 W. *B*—Detail of a concretion like those shown in A. *C*—Cast of a large *Inoceramus* shell in a concretion of the bed shown in A. From the SE¼ NW¼ of the same section.



A

B

PLATE XI.—*A*—*Ostrea congesta* and *Anomia* cf. *subtrigonalis* (at the right) attached to a large and nearly flat *Inoceramus* shell. From the top of a large limestone concretion of bed No. 8, Upper Weskan shale member, in the center of the NE¼, sec. 11, T. 13 S., R. 42 W. Slightly enlarged. *B*—Large concretion of hard compact limestone with skeleton of *Platecarpus*. From base of Upper Weskan shale member in the northeast corner of sec. 11, T. 13 S., R. 42 W.



A

B

Plate XII.—*A*—Long oval concretions in parallel and regular arrangement along a bedding plane of shale on the top of Upper Weskan member at the type locality in the NE¼ NW¼, sec. 11, T. 13 S., R. 42 W. The concretions consist of very tough dark-gray ferruginous limestone and are often "sliced" across into thin and broken plates. *B*—*Serpula* ? *wallacensis*, n. sp., in natural position in shale in the center of the SE¼, sec. 12, T. 13 S., R. 42 W. The circular fragment in lower right corner is planted to show the characteristic cross section of the fossil. Upper part of Upper Weskan shale member. One-half natural size. Negative by Charles Rankin.

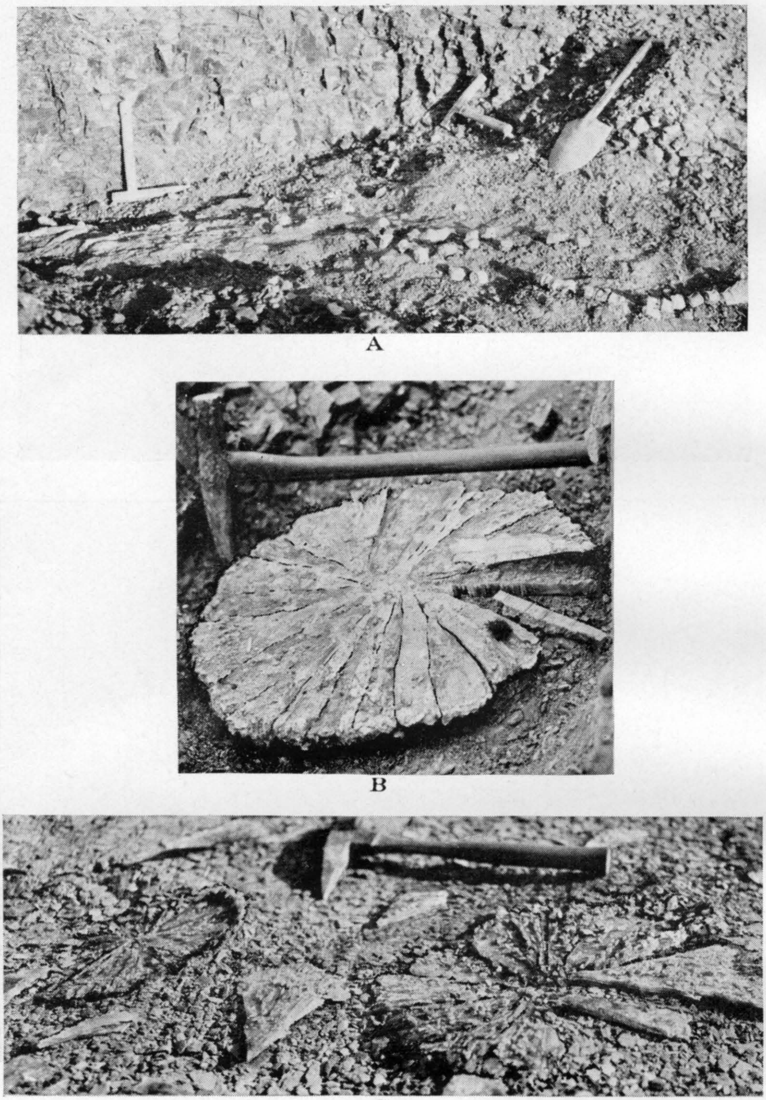


Plate XIII.—*A*—Skeleton of a large fish (*Empo* sp.) in shale near the top of Lake Creek shale member, in the NE¼ SE¼, sec. 33, T. 12 S., R. 41 W. *B*—Rosette of gypsum in shale near the top of Lake Creek shale member, in the SW¼ NW¼, sec. 11, T. 12 S., R. 41 W. *C*—Rosettes of gypsum in shale of the lower part of Upper Sharon Springs shale member. From locality two miles east of McAllaster, Logan county.

Salt Grass shale were studied along the upper part of Goose Creek basin. In T. 11 S., R. 42 W., in the center of section 33, cone-in-cone lenses of the upper zone; in W½, sec. 34, the same bed and overlying shale with rusty streaks of limonite; in S½, sec. 27, flat large limestone concretions of the lower zone; in SE¼ NE¼, sec. 34, same limestone concretions; in NE¼ SE¼, sec. 34, cone-in-cone lenses and overlying septarian marl concretions; in southwest corner of sec. 36 a large exposure of shale with the lower zone of limestone concretions on the top. The fault that throws the shale of the eastern part of this exposure down, crosses the exposure in about the middle, and its strike probably is about north-south. The dip of the shale is 2° to 3° northeast. The following section was measured from top to bottom:

Section of the Salt Grass member at SW corner sec. 36, T. 11 S., R. 42 W., Wallace county.

	Feet.
Shale	1.0
Scattered limestone concretions with *Baculites pseudovatus* var. A......	.2
Shale	2.6
Scattered limestone concretions	.2
Shale	1.8
Large lenticular concretions made of tough gray limestone............	.3

The shale below belongs to the uppermost beds of Lake Creek member; for the continuation of the section see page 97.

At the head of the large northern tributary to Goose creek in the NE¼, sec. 25, rusty cone-in-cone lenses and septarian marl concretions are exposed.

T. 12 S., R. 42 W. The exposures in T. 12 S., R. 42 W., are in NW¼ and in SE¼, sec. 3, cone-in-cone lenses of the upper zone, and in NE¼, sec. 3, large limestone concretions of the lower zone with *Baculites* cf. *pseudovatus*, *B. compressus* var. *reesidei*, *Lingula* sp. and small fish scales. On the right side of the mouth of the Roy Johnston canyon the same limestone concretions are exposed, above which outcrops the middle zone with streaks of limonite concretions having white limy cores. Here, also, *Baculites pseudovatus* var. A was recognized. Farther up the canyon the limestone concretions of the lower zone of the member cease to outcrop and only the middle limonite zone and the upper zone with cone-in-cone rusty lenses and septarian marl concretions are exposed. A little south of the center of section 2 there is a very interesting exposure on a small hill near the bottom of the draw. Here one can observe a gradual change of the regular rusty cone-in-cone lenses of the upper zone of the member into somewhat rounded large bodies of "Lucina limestone." The bodies of "Lucina limestone" of the western part of the exposures decrease in size and become nearly spherical toward the east, and a crust of cone-in-cone structure appears around them. Farther toward the southeast and south the limestone bodies decrease still more in size and flatten horizontally and at the same time become rusty instead of light gray with a more intensively developed cone-in-cone crust. The appearance of septarian marl concretions above the same cone-in-cone bed in the near-by exposures verifies the identification of the upper zone of the Salt Grass member. The fossils collected in the "Lucina limestone" at the locality and in the accompanying smaller limestone concretions of the zone have been listed already in the general description of the upper zone of the member (p. 104). On the east side in the lower part of the next southern tributary to Goose creek, which is called Camp Canyon, in the NW¼, sec. 1, the middle limonite zone of the member with *Baculites pseudovatus* var. A was observed. Farther up the east side of the canyon, in the SW¼, sec. 1, the limestone concretions of the lower zone are exposed.

Many exposures were studied and measured around the Salt Grass canyon, the type locality of the shale member, which is in the SE¼, sec. 1, and in the E½, sec. 12, T. 12 S., R. 42 W. In the left fork of the canyon in the NW¼ NE¼, sec. 12, the upper zone with two cone-in-cone layers and two septarian marl layers above are exposed. Here the fossil wood with *Teredo* burrows was collected. Farther up the left side of the main canyon the middle and lower zones of the member gradually appear toward the crest of the local minor "Salt Grass structure." In the "Lucina limestone" exposed near the top of the anticline *Baculites compressus* var. *reesidei* was collected, and in the middle zone of the limonite concretions which are exposed farther south *Baculites pseudovatus* var. A, *Pecten vanustus* and *Valvata* cf. *subumbilicata* were found. The following section, which represents the upper half of the Salt Grass shale, was measured in NW¼ NE¼, sec. 12, from top down:

Section of Salt Grass member in NW¼ NE¼, sec. 12, T. 12 S., R. 42 W., Wallace county.

	Feet.
Limonite concretionary streak	.1
Shale	4.5
Rusty streak	.05
Shale	1.0
Septarian marl and limonite concretionary streak	.1

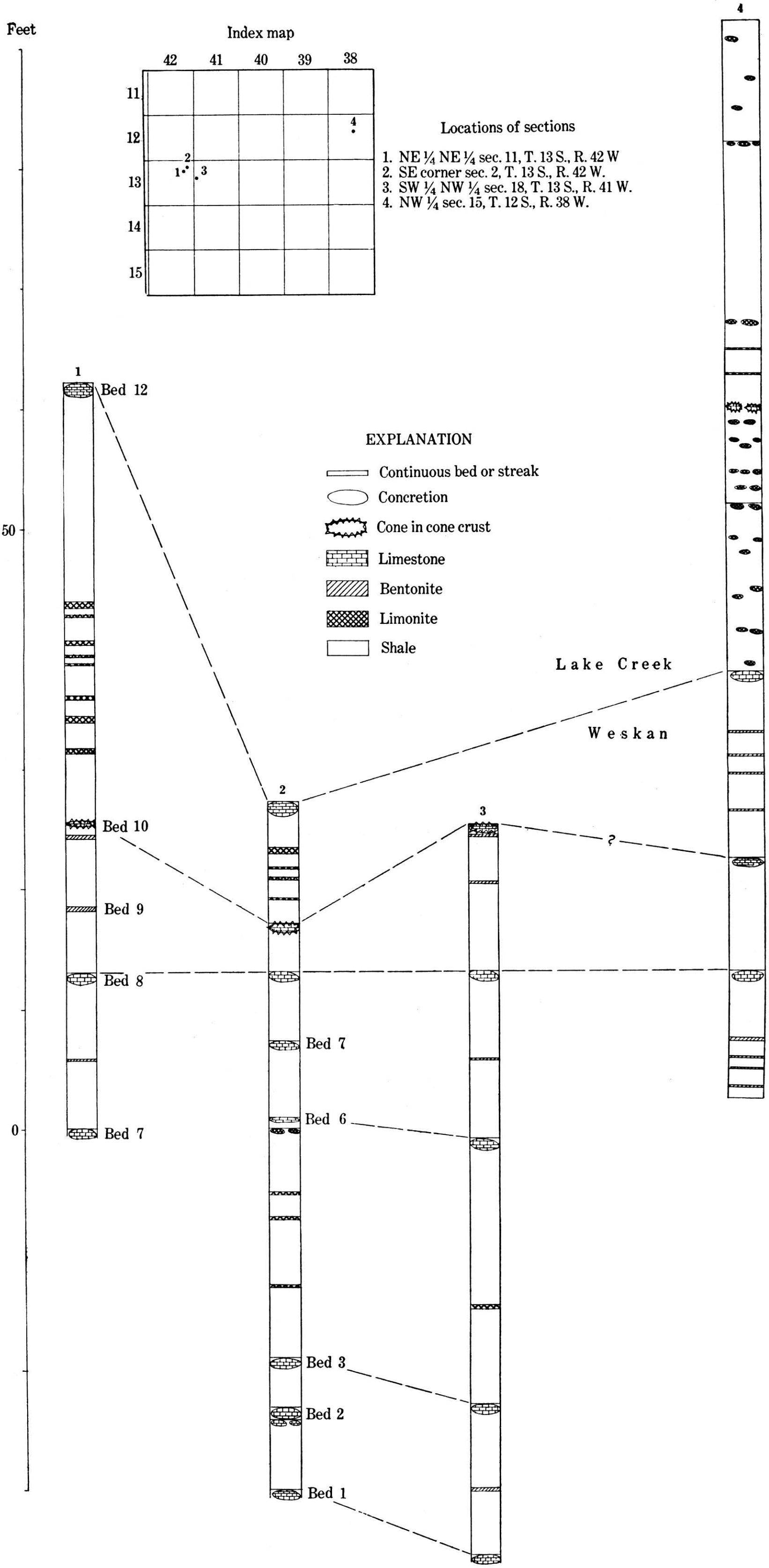


Plate XIV.—Geologic sections of Weskan and Lake Creek members.

	Feet.
Shale	2.5
Septarian marl and limonite, concretionary streak	.1
Shale	2.5
Cone-in-cone rusty bed	.1
Shale	1.0
Large round cone-in-cone lenses made of rusty limestone	.25
Shale	2.1
Laminated, rusty limestone streak	.1
Shale	3.1
Rusty streak	.05
Shale	1.0
Limonite concretions	.1
Shale	5.0
Streak of laminated, rusty limestone changing laterally to limonite	.2
Shale	2.3
Small limestone concretions	.2
Shale	2.0

Farther south, on the west side of the draw, on the south or downthrow side of the fault which traverses the canyon and crosses the apex of Salt Grass anticline, the following section of the lower half of the Salt Grass shale was measured:

Section of Salt Grass member in SW¼ NE¼, sec. 12, T. 12 S., R. 42 W., Wallace county.

	Feet.
Shale	.5
Small limestone concretions	.15
Shale	2.1
Small limestone concretions	.1
Shale	1.8
Bentonite, light-brown to light-gray	.8
Shale	4.5
Limonite concretionary streak	.1
Shale	1.7
Limonite concretionary streak with abundant *Baculites pseudovatus* var. A	.15
Shale	2.5
Limonite concretionary streak	.1
Shale	4.2
Limonite concretionary streak	.1
Shale	2.1
Limonite concretionary streak	.1
Shale	5.2
Bentonite	.05
Shale	7.5
Large limestone concretions	.2
Shale	1.3
Streak of gypsum	.05
Shale	1.0
Total	36.30

At the head of the canyon, in the SE¼, sec. 12, only poor exposures of the upper zone of the member were observed. On the east side of the canyon a complete section of the member is exposed on the northern or upthrow side of the above-mentioned fault. The following section was measured:

Section of Salt Grass member in SE¼ NE¼, sec. 12, T. 12 S., R. 42 W., Wallace county.

	Feet.
Shale	13.8
Rusty limestone with cone-in-cone structure	.15
Shale	8.0
Shale with streaks of gypsum	.2
Limonite concretions	.2
Shale	7.1
Limonite concretions	.2
Shale	4.3
Bentonite, light-gray to brown	.8
Streak of gypsum and rust	.2
Shale	3.9
Limonite concretions with limy cores. Abundant *Baculites pseudovatus* var. A	.25
Shale	6.7
Limonite concretions	.15
Shale	12.1
Large concretions with soft limy core and outer crust made of manganite, rust and gypsum	.6
Shale	1.5
Limestone concretions, lateral change to north to thinner but almost continuous limestone streak with light-gray to creamy cone-in-cone structure. Weathered to "chopwood"	.3
Shale	3.8
Thick streak of crystalline gypsum[145]	8.0
Total	72.3

Another nearly complete section of the member was measured on the prominent hill in the northeast corner of section 12 opposite the large left tributary of Salt Grass canyon. The following beds are exposed:

Section of the Salt Grass member at NE¼ NE¼, sec. 12, T. 12 S., R. 42 W., Wallace county.

Loam of Ogallala formation.	Feet.
Streak of rusty limonite	.05
Shale	2.5
Septarian marl and limonite concretions	.1
Shale	3.1
Septarian marl and limonite concretions	.1
Shale	3.8
Rusty limestone streak, laterally changing to cone-in-cone structure	.2

---

[145] The last three beds belong to the top of the Lake Creek shale member.

	Feet.
Shale	3.8
Large round lenses of rusty limonite with cone-in-cone structure	.2
Shale	2.7
Rusty limestone streak, laterally changing to cone-in-cone structure	.2
Shale	3.5
Limonite concretions	.1
Limonite concretions almost immediately below	.1
Shale	.2
Limonite concretions with coral-like structure	.1
Shale	2.5
Limonite concretions	.1
Shale	3.25
Limonite concretions, here and there *Baculites pseudovatus* var. A	.1
Shale	1.45
Limonite concretions	.1
Shale	2.9
Limonite concretions	.1
Shale	11.7
Limonite concretions	.1
Shale	7.5
Rusty limestone with cone-in-cone structure	.2
Total	50.75

The upper zone with cone-in-cone lenses of rusty limestone and the lower zone with large light-gray limestone concretions are exposed in places on the eastern side, down the canyon.

T. 11 S., R. 41 W. In T. 11 S., R. 41 W., the Salt Grass shale exposures were observed in the southwest corner, in the center and in the northwest corner of section 31. In the best locality, in the center of section 31, a complete typical section is exposed, the beds here dipping south about 1° to 2°.

T. 12 S., R. 41 W. In T. 12 S., R. 41 W., on the south side of Goose creek, the beds of Salt Grass shale are exposed in places beneath the prominent escarpments of the Ogallala "mortar beds." In the small canyon in the SE¼ SW¼, sec. 6, the lower limestone concretionary zone and the overlying beds are exposed, and farther northeast, on the right side of the canyon, heavy cone-in-cone structures of the upper zone were observed.

"Lucina limestone" of the lower zone is exposed on both sides of the county road about half a mile south of Goose creek in sections 10 and 11 (Pl. XV B). The beds dip north more gently than the slope of the hill. The limestone concretions of the same zone outcrop at the head of the little draw west of the road, in the southeast corner of section 10, where also overlying limonite concretions with many *Baculites pseudovatus* var. A are exposed.

The whole thickness of the Salt Grass member is exposed in the NW¼, sec. 12, on the left side of Goose creek, opposite Halsey school. Here the limestone concretions of the lower zone of the member are in the form of large parallel cylindrical bodies which extend north 26° east. The dip of the bed that forms an escarpment is 3° north.

Collins draw. T. 12 S., R. 42 W. The Salt Grass member is well exposed along the whole length of Collins draw. In T. 12 S., R. 42 W., the upper zone with cone-in-cone lenses of the rusty limestone and the underlying limonite beds with *Baculites pseudovatus* var. A. are exposed on the southwest side of the draw in sections 14, 13 and 24.

T. 12 S., R. 41 W. In T. 12 S., R. 41 W., the same beds of the member are exposed in the NW¼ SW¼, sec. 19, in the NE¼ NW¼, sec. 29, and in the NW¼, sec. 28. In the large exposure in the southwest corner of section 22 the lower zone of limestone concretions, occasionally with cone-in-cone crust, was observed. *Serpula kansasensis, Inoceramus saltgrassensis* and *Acantoscaphites nodosus* var. *brevis* and var. *quadrangularis* were collected. In the central part of section 27 many exposures of the Salt Grass member beneath the prominent escarpments of Ogallala "mortar beds" were observed. In the north and northwest parts the lenses of cone-in-cone rusty limestone of the upper zone outcrop, and in the NE¼ SW¼, section 27, the beds of septarian marl and limonite concretions were noted below the cone-in-cone concretions, which is the reverse of their normal position above the cone-in-cone beds. On the east or upthrow side of the fault, which traverses the shale in about the north-northeast direction but does not affect the overlying beds of Ogallala, the limestone concretions of the lower zone of the member are nearly continuously exposed along the foothills for about a quarter of a mile. Locally larger bodies of "Lucina limestone" were observed.

Draw marked by abandoned schoolhouse. T. 12 S., R. 41 W. In the "Schoolhouse" draw, which is south of Collins draw and is the next large right-hand tributary to Goose creek, there are also many exposures of Salt Grass shale. The nearly white limestone concretions of the lower zone outcrop on the right side and near the bottom of a small canyon in the center of the NW¼, sec. 32. Many small shells of *Anchura sublævis* and a few young individuals of *Lucina occidentalis* were collected. On the right side of the mouth of this little canyon several streaks of concretionary limonite with

Baculites pseudovatus (?) are exposed. In the NE¼ SE¼, sec. 32, are several exposures of the lower and middle zones of the member.

T. 13 S., R. 41 W. The shale member is extensively exposed in the group of hills traversed by the short canyons in the NE¼, sec. 4, and in the northern part of sec. 3 in T. 13 S., R. 41 W. In the large irregular bodies of "Lucina limestone" and in the surrounding concretions of the ordinary compact limestone of the lower zone the following fossils were collected: *Pecten* cf. *venustus, Lucina occidentalis, Anchura sublavis, Baculites compressus* var. *reesidei,* and *Scaphites plenus.*

Northern tributaries to Willow creek. T. 13 S., R. 42 W. The shale of the following exposures on the northern tributaries to Willow creek is correlated with the Salt Grass shale. In the NE¼ SE¼, sec. 1, T. 13 S., R. 42 W., on both sides of the right fork of "Bone Gulch" the shale, which dips northeast, contains large cone-in-cone concretionary lenses of rusty limestone, below which is a zone containing many limonite concretionary streaks, some with cores of white limestone and abundant *Baculites pseudovatus* var. A.

T. 13 S., R. 41 W. A little farther down the draw, at the junction of the two forks, "Lucina limestone" is exposed at the foot of the right side of the canyon. On the left side of the left fork of the draw, in the SW¼ NW¼, sec. 6, T. 13 S., R. 41 W., the same cone-in-cone lenses and the underlying limonite concretionary zone with abundant *Baculites pseudovatus* var. A are exposed. Still farther down the draw the white limestone concretions of the lower zone begin to appear and are extensively exposed in the southwest corner of section 6, where the following fossils were collected: *Inoceramus barabini, I. saltgrassensis, Baculites compressus* var. *reesidei* and *Scaphites reesidei* Wade. In the deep basin at the head of the little draw in the center of the NW¼, sec. 7, T. 13 S., R. 41 W., the same zone of concretionary white limestone accompanied by larger bodies of rough "Lucina limestone" is well exposed and contains in places a number of small *Inoceramus saltgrassensis* shells. The limonite concretionary zone above the limestone concretions is exposed in the northwest part of the little basin, where also cone-in-cone rusty limestone appears. The white limestone concretions and limonite concretions containing *Baculites pseudovatus* var. A outcrop also in the SE¼ NW¼, sec. 7, where they overlie the Lake Creek shale member and dip gently northwest.

Tributaries to Smoky Hill river. T. 13 S., R. 41 W. The lower zone of the Salt Grass member is extensively exposed on both sides of the draw marked by the two abandoned houses in the NE¼, sec. 6, T. 13 S., R. 41 W. The zone of limestone concretions, accompanied by many bodies of "Lucina limestone," dips gently southeast, forming with the overlying "mortar beds" of the Ogallala the northwest flank of a syncline (Pl. XXIII B).

A small exposure of Salt Grass shale appears at the very head of a small southern tributary to Smoky Hill river in the SW¼ SE¼, sec. 13. Here the white limy concretions, "Lucina limestone," and probably also the overlying limonite concretionary zone crop out.

T. 12 S., R. 40 W. The lower limestone zone of Salt Grass member outcrops extensively at the top of the Lake Creek shale, at the head of the south fork of Pond creek on state highway No. 27, in secs. 22, 23 and 26 of T. 12 S., R. 40 W. In the NW¼ NE¼, sec. 26, the following fossils were collected: *Serpula kansasensis, Inoceramus vanuxemi* (?), *I. saltgrassensis, Lucina subundata, Anchura sublœvis, Baculites compressus* var. *reesidei, Acantoscaphites nodosus* s. s., *A. nodosus* var. *brevis.* In sec. 23: *Serpula kansasensis, Inoceramus saltgrassensis, Anchura sublœvis* and *Baculites compressus* var. *corrugatus.*

Lake Creek. T. 11 S., R. 39 W. Only one outcrop of Salt Grass shale was found in the basin of Lake creek. This is situated on the east side of the north tributary to the creek about two miles north of Madigan ranch, in the NE¼, sec. 18, T. 11 S., R. 39 W. In the abundant exposed limestone concretions the following fossils were collected: *Inoceramus* sp., *Baculites compressus* var. *reesidei* and *B. pseudovatus* var. A. The limonite concretionary streaks were observed above the limestone concretionary zone.

EQUIVALENTS OF SALT GRASS, LAKE CREEK AND WESKAN SHALE MEMBERS OUTSIDE OF WALLACE COUNTY.

The Salt Grass, Lake Creek and Weskan shale members of the Wallace county Pierre cannot be correlated very easily with the members of the "Pierre group" elsewhere, chiefly because very little has been done in subdivision of the Pierre in other regions, and usually the collected and studied fossils have not been very well tied to the several zones of this formation. Nevertheless, the main features of the members of the Wallace county Pierre described in this paper can be recognized in the somewhat schematical subdivisions as outlined by Gilbert for the Pierre of the Arkansas valley in eastern Colorado, and a better correlation can be approached

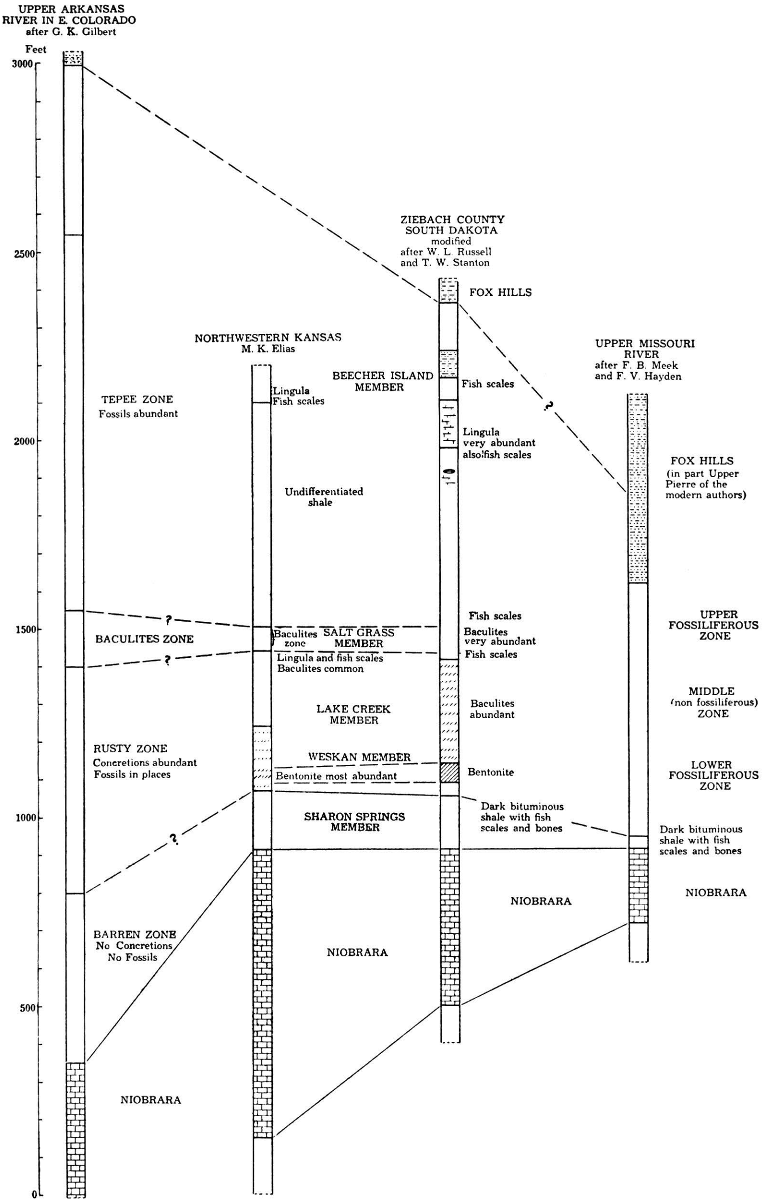


Fig. 4.—Correlation of the zones of the Pierre in some of the midwestern states.

with the Pierre of South Dakota, a complete set of diamond-drill cores from which formation was studied recently by Russell and Stanton.

Gilbert's subdivisions of the Pierre in the Arkansas Valley of Colorado are presented in graphic form on Fig. 4. As has been shown already, the "Barren zone" of Gilbert corresponds at least in part to the Sharon Springs shale member of western Kansas. The "Rusty zone," which overlies the "Barren zone" of the Pierre in the Arkansas valley, has, according to Gilbert's brief description, the combined features of the Lake Creek and Weskan shales of Wallace county. It contains the same kind of large concretions "4 to 8 inches thick and two or three times as broad" "dark-gray, tough fine-textured," as are found in the Weskan shale of Wallace county, and its fragments of concretions weathered to "color of iron rust" that cover the slopes of the hills and give them a "reddish-brown color" are in this respect very much like the innumerable weathered concretions of the Lake Creek shale. The thickness of the "Rusty zone" is a little more than one and one-half times as large as the combined thickness of the Lake Creek and Weskan shales, which is about the same ratio as that between the thickness of the Salt Grass shale and that of the "*Baculites* zone" of Gilbert, which are the next members of the Pierre in Wallace county and in the Arkansas valley, respectively. The features of similarity between the Salt Grass member and the "*Baculites* zone" of Gilbert include the lighter shade of the shale in these members than that in the "Rusty zone" and in the Lake Creek shale below them. The much greater abundance of the *Baculites* in the "*Baculites* zone" and in the Salt Grass member than in the zones below appears to be more than a mere coincidence. Unfortunately, we do not know which particular species of *Baculites* belongs to the "*Baculites* zone" of Gilbert. He refers his specimens to *Baculites compressus,* but the photograph that is given by Gilbert in Plate LXII[146] under the name *B. compressus* does not give enough evidence to verify his identification.

If the suggested correlation is correct, the "Tepee zone," the next higher zone of Gilbert's scheme, which he estimates to be 1,000 feet thick, corresponds to the upper half of the Pierre, which is eroded in Wallace county. It is possible, also, that the "*Baculites* zone" of Gilbert corresponds to the uppermost part of the Lake Creek

---

[146] Gilbert, 1896, table opposite page 568.

shale of Wallace county, in which the *Baculites compressus* var. *reesidei* is very abundant. In this case the Salt Grass shale with the abundant "Lucina limestone" bodies at the base corresponds to the basal portion of the "Tepee zone," in which the "Lucina limestone" cores are very characteristic. It is possible, also, that the "*Baculites* zone" of Gilbert includes both the Salt Grass member and the uppermost part of the Lake Creek member of the Pierre of Wallace county.

A more precise correlation of the Wallace county Pierre with the Pierre of South Dakota appears to be possible. Although the subdivisions of the Pierre exposed along the upper Missouri river, as set forth by Meek and Hayden (see table p. 117), are too schematic and perhaps in part erroneous, the detailed description of the lithology and fossil content of the Pierre based on the study of cores obtained from a test well in northern Ziebach county, South Dakota, offers somewhat reliable grounds for correlation. It has been pointed out already that the lowermost 140 feet of the very dark gray bituminous shale, containing many bones and scales of fishes, of the Ziebach county well most probably corresponds to 155 feet of the Sharon Springs shale member. Above this dark bituminous shale ordinary unctuous shale with many streaks of bentonite was observed. The bentonite even predominates over the ordinary shale in the lower 200 feet, but is less abundant in the 160 feet of shale above. The invertebrate fossils, among which *Baculites* and *Inoceramus* are most abundant, are decidedly more numerous in the lower 200 feet. It appears probable that the lower part of the total 360 feet of bentonite shale corresponds to Weskan shale and the upper part to Lake Creek shale of Wallace county, the total thickness of these two members being 370 feet.

In the next beds above in the Ziebach county well abundant remains of *Baculites* are especially noted. The zone of abundant *Baculites* is about 60 feet thick and a little below it a bed of shale with fish bones and scales is recorded. This fish-scale bed appears to correspond to the dark shale with many fish scales a little below the base of the Salt Grass member in Wallace county. It is remarkable that between this thin bed with fish bones and scales and the lowermost 140 feet of dark-gray bituminous shale with abundant fish bones and scales no remains of fishes were recorded in the cores of the Ziebach county well. During his survey in Wallace county the writer paid special attention to the presence or absence of fish remains in the local Upper Cretaceous, and he succeeded in collecting a considerable amount of well-preserved scales of small fishes from the upper part of the Niobrara, from the Sharon Springs member of the Pierre and from the base of the Salt Grass member and a little below it, also, in Beecher Island shale, but he did not find fish scales in either the Weskan or the Lake Creek member, except at the very top of the latter member.

Considering the fact that the Pierre shale of Wallace county was studied on the outcrops, whereas the Ziebach county Pierre shale was studied in the cores of a well, the above-noted features of similarity between the corresponding portions of the sections must be considered to be very striking and more important than certain dissimilarities, most of which are apparently due to differences in the sampling of the rocks. It is quite clear, for instance, that the concretions, which appear to be so plentiful in the Pierre of Wallace county, are actually spaced so much apart that only very few of them have a chance to be met by a drill making cores of about 2 inches or less in diameter. Therefore all the important concretionary zones on which the precise subdivision of Pierre of Wallace county is based are apparently not recognizable in the cores of the well. Furthermore, it is apparent that the fossils in the cores come chiefly from the shale and few from the concretions, most of which were not met by the drill, whereas in the field work the fossils were collected largely from the concretions, the shells in the shale being usually very fragile and most of them broken into small fragments during the process of weathering of the shale. It is possibly partly due to this different origin of the fossils that the very few species of shells that were specifically identified from the lower half of the Pierre of the Ziebach county well do not appear in the identified lot of invertebrates of the Wallace county Pierre.

Another important difference between the corresponding members of the Pierre of the two localities is the apparent considerable amount of bentonite beds in the zone of Ziebach county Pierre corresponding to the Lake Creek member of Wallace county, in which streaks of bentonite were only rarely observed. The corresponding decrease of bentonite content is noticeable, also, in the Weskan shale of Wallace county as compared with the corresponding division of the Pierre in the Ziebach county well, where bentonite is the predominant rock. It is true that the name bentonite is not mentioned in the description of the shale of the Ziebach county well,[147] but in the description of the shale "from 1,050 on down to 1,445" there are

---

[147] Russell, 1925.

"numerous strata of light bluish-gray clay shale, that when immersed in water will swell to many times their original volume, turning to a soft plastic mud." This is the common property of the clays of the bentonite group, and therefore the writer arbitrarily refers this "clay shale" of the Ziebach county well to this rock. In the 200 feet of shale of this well that apparently corresponds to the Weskan shale of Wallace county "nearly all the strata" consist of the rock that swells, and the streaks of nearly white bentonite in the Weskan shale of Wallace county make only about 3 per cent of the whole volume of the shale. It was noticed, however, that at least a few more beds of ordinary gray shale in the type locality of the Lower Weskan shale, in the southwest corner of sec. 4, T. 13 S., R. 40 W., also have the property of swelling and disintegrating into fine mud when immersed in water. A remarkable tendency toward cross-bedding was noticed in the portion of the exposed shale, which is immediately below the lower thick white bentonite streak and contains several thin streaks of this rock. (See Pl. VIII A.) It is interesting that in the bentonite shale of the Ziebach county well "from 1,360-1,410 the dip is generally at a high angle, in some cases as high as 25 degrees, as indicated by the way the core breaks, by the indistinct laminations and by the inclined fossils." [148] If this is the original inclination of the strata, it must have originated not in the mud but in a somewhat coarser material that was altered into clayey matter after the deposition took place. As bentonite was proved to be nothing but altered volcanic ash, it can possibly be originally inclined or cross-bedded.

The writer did not try to test all the ordinary gray shale of the Wallace county Pierre in order to determine whether it has or has not the properties of bentonitic clays, and therefore he regards it as quite possible that the bentonitic clays may have a somewhat larger distribution in the local Pierre than is stated in this report.[149] Only light-gray to creamy and to light-brown streaks, which differ strikingly in color from the rest of the dark-gray shale and which showed the property of swelling and almost instant disintegration in water, are recorded as beds of bentonite in this report. At any rate the Weskan shale member of the Pierre and particularly the Lower Weskan shale have a proportionately larger amount of bentonite clays than the other members of the formation, which is in accord

---

[148] Idem, p. 5.

[149] Those selected specimens of ordinary gray shale of Lower Weskan member which were tested did not show the properties of bentonite.

with the general observations of the cores from the corresponding zones of Pierre in the Ziebach county well.

The Pierre subdivisions of Wallace county cannot be precisely correlated with the zones of Pierre in northeastern Colorado at present, on account of the considerable difference in the thickness of the formation in the two regions together with differences in lithologic nature and in fossil content. Several thick sandy members of the Pierre in northeastern Colorado have no lithologic equivalents in the Pierre of Wallace county, where no sand beds have ever been noted. Correlation of the members that differ in lithology could be made on the basis of fossil content, but comparatively few fossils have been collected and identified from definite horizons of the thick section of the Pierre of northeastern Colorado. The following fossils were collected in the Larimer sandstone on Fossil creek south of Fort Collins and identified by Reeside:[150]

Inoceramus sagensis Owen.
Anisomyon centrale Meek.
Anisomyon subovatus Meek & Hayden.
Baculites compressus Say.
Scaphites nodosus Owen.

The fossils, though regarded as wide-ranging species, were noticed to be especially abundant in the Larimer sandstone.[151] According to Reeside[152] *Exogyra costata* Say from Fossil Ridge, near the locality on Fossil creek, which he described, came from the Rocky Ridge or the Larimer sandstone, from which also the many fossils reported by Henderson[153] were collected. These fossils, according to Reeside, indicate Upper Campanian age. The following of the Fossil Ridge forms were found in the Pierre shale of Wallace county:

Inoceramus barabini Morton.
Inoceramus proximus Tuomey.
Inoceramus vanuxemi Meek & Hayden.
Anisomyon centrale Meek.
Baculites compressus Say.
Acantoscaphites nodosus (Owen).
Discoscaphites nicolleti (Morton).
Placenticeras meeki (*whitfieldei*) Boehm.

Although not all of these species recorded from the Fossil Ridge may strictly correspond to the species described under the same names in this report, the whole fauna, and especially the presence together of such important index fossils as *Acantoscaphites nodosus* and *Discoscaphites nicolleti,* suggest the correlation of the Larimer and Rocky Ridge sandstones with the Salt Grass and possibly upper Lake Creek shale members of Wallace county. The presence among the Fossil Ridge fauna of *Inoceramus vanuxemi,* which in Wallace

---

[150] Mather, Gilluly and Lusk, 1928, p. 89.
[151] Idem, p. 89.
[152] Reeside, 1929, p. 271.
[153] Henderson, 1907, pp. 149-152; 1908, pp. 179-192 and 1920, pp. 31-32.

county was not found below the Lake Creek shale member, supports this correlation, and none of the other comparatively wide-ranging forms contradicts it.

The Larimer and Rocky Ridge sandstones of northeastern Colorado were found a little below the middle of the local Pierre,[154] and the Salt Grass and upper Lake Creek shale members of Wallace county are also about in the middle or slightly below the middle of the original preërosional deposit of the local Pierre. If this is correct, it indicates that the thickening of the Pierre toward the west affects the lower and upper halves of the formation in about equal proportion.

It is important to point out that the areas of distribution of the Pierre in which this formation can be subdivided into members more or less strictly comparable in lithology and thickness to those into which it is here subdivided in northwestern Kansas are aligned from southeastern Colorado through the northeastern part of that state and the northwestern corner of Kansas, and farther north in southern and central South Dakota. In the western part of Nebraska, which lies in line with these comparable Pierre deposits, this formation is not exposed. The total thickness of the Pierre along this broad belt is fairly uniform, being in average about 1,500 feet with a gradual increase toward the west and a decrease toward the east. It is reasonable to conclude that these lithologically and paleontologically similar sediments, which thus constitute a belt of regular thickness and width, were deposited in similar environments of the Pierre sea and that this belt extended parallel to the general trend of the Upper Cretaceous sea. The depth and other features of this sea apparently changed in an east-west direction, which explains the great change in thickness and some changes in lithology of the Pierre west of the above-outlined belt in the piedmont region of the Rocky Mountains.

The proposed correlation of the Pierre shale members of Wallace county and adjacent area with the best known Upper Cretaceous formations and faunal zones of North America and Europe is presented in graphic form in the table opp. p. 130.

UPPER PART OF THE PIERRE FORMATION.

The writer has had opportunity to study the fossils from the Pierre shale of the Beecher Island area, Yuma county, Colorado, collected by various members of the survey party of Mentor Etnyre

---

[154] Mather, Gilluly and Lusk, 1928, pp. 90-92.

in 1927-'28. He made, also, a brief personal examination of the shale and its fossil content in the field. As the shale of the Beecher Island area continues into Cheyenne county, Kansas, it is desirable to include a brief description of the rocks and fossils of this shale, which comprises the uppermost beds of the Pierre, and may be conveniently designated as the Beecher Island shale member.

BEECHER ISLAND SHALE MEMBER.

The Beecher Island shale member is chiefly light-gray shale having a distinct greenish tint on many outcrops. Thin streaks of white and brownish bentonite are found only in the lower part of the shale, where also limestone concretions, the largest 1 foot thick, are common. In the middle and upper parts of the shale thin streaks of limonite and rusty limestone, some of the latter with cone-in-cone structure, are numerous. Irregular-shaped and comparatively small limestone bodies with *Lucina,* seen near the top of the section, constitute the uppermost concretionary zone of the Beecher Island member. Casts of *Lucina* are occasionally found, also, in the slightly calcareous shale of the same horizon, above which about 5 to 10 feet more of shale with rusty limonite streaks are exposed. The total thickness of the Beecher Island shale member reaches 100 feet. Below the lowermost concretionary zone of the member, which consists of large limestone concretions, some 1 foot thick, and a group of bentonite streaks above, a considerable thickness (more than 80 feet) of black, nearly featureless shale with practically no concretions and none of the larger invertebrate fossils is exposed in the southern part of the Beecher Island area. Fossils are abundant in nearly all concretions of the section, but the greater part of the collected material came from the lowest concretionary zone. Large, beautiful casts of *Baculites grandis* and less abundant casts of *B. clinolobatus* n. sp. came from the limestone concretions of this zone, from which also many *Discoscaphites abyssinus* were collected. The best specimens of the abundant and very typical *Tardinacara* (*Pseudoptera*) *fibrosa* and *T.* (*P.*) *whitii* were collected from the limonite streaks of the middle and upper parts of the section, where also *Inoceramus* and gastropods were chiefly found. The fauna of the Beecher Island shale member exhibits a nearly complete change compared with that of the lower half of the Pierre as seen in Wallace county; only such long-ranging forms as *Lucina occidentalis, Ostrea* cf. *congesta* and *Inoceramus proximus* survived

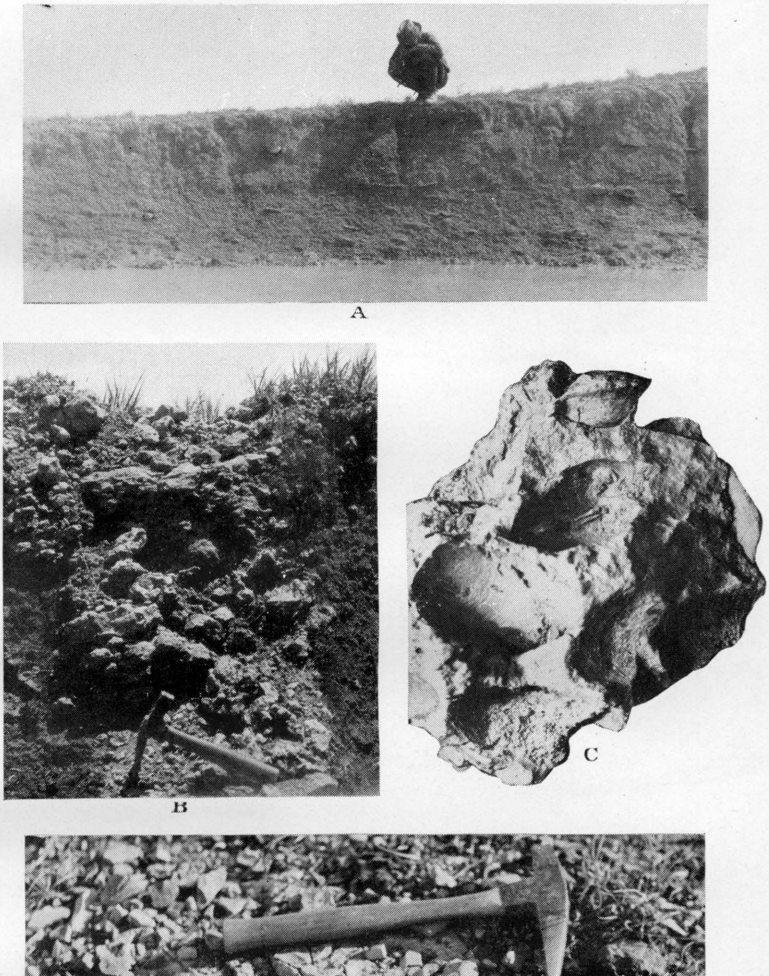


Plate XV.—*A*—Zone of gray to white limestone concretions at the base of Salt Grass shale member in the southwest corner of sec. 6, T. 13 S., R. 41 W. *B*—"Lucina limestone" in a columnar body near the base of Salt Grass shale member. From a ditch on the east side of the road, in the SW¼ NW¼, sec. 11, T. 12 S., R. 41 W. *C*—Casts of *Lucina occidentalis* in cavernous "Lucina limestone." From the NW¼ NW¼, sec. 3, T. 13 S., R. 41 W. Natural size. *D*—Cast of *Baculites compressus* var. *reesidei* on the top of a large limestone concretion near the base of Salt Grass shale member. From the NW¼ NE¼, sec. 3, T. 12 S., R. 42 W.

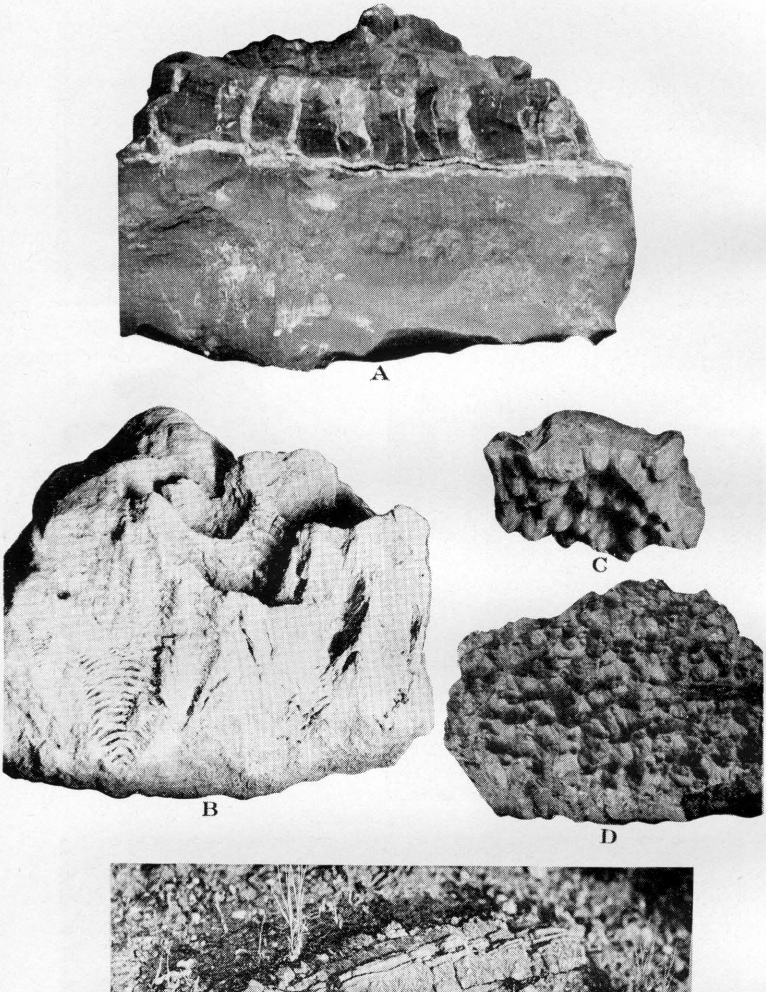


PLATE XVI.—*A*—Limonite concretion with a septarian core of calcareous limonite and with veinlets of calcite. Natural size. From the upper zone of Salt Grass shale member in the NE¼, sec. 12, T. 12 S., R. 42 W.

Rusty marl concretions with cone-in-cone structure. From the upper zone of Salt Grass shale member in the same locality: *B*—Craterlike depressions in place of fallen-out or weathered cones. Six-tenths natural size. *C* and *D*—Cone-in-cone structure broken across; cones are on the piece above (*C*) and their impressions on the piece below (*D*). Natural size. *E*—Lenslike concretion with cone-in-cone structure throughout, except in the core.

Plate XVII.—Rusty marl concretions with cone-in-cone structure. "Grand Canyon" style of weathering in the outer crust of the structure. Natural size. From upper zone of Salt Grass member in the NE¼, sec. 12, T. 12 S., R. 42 W.

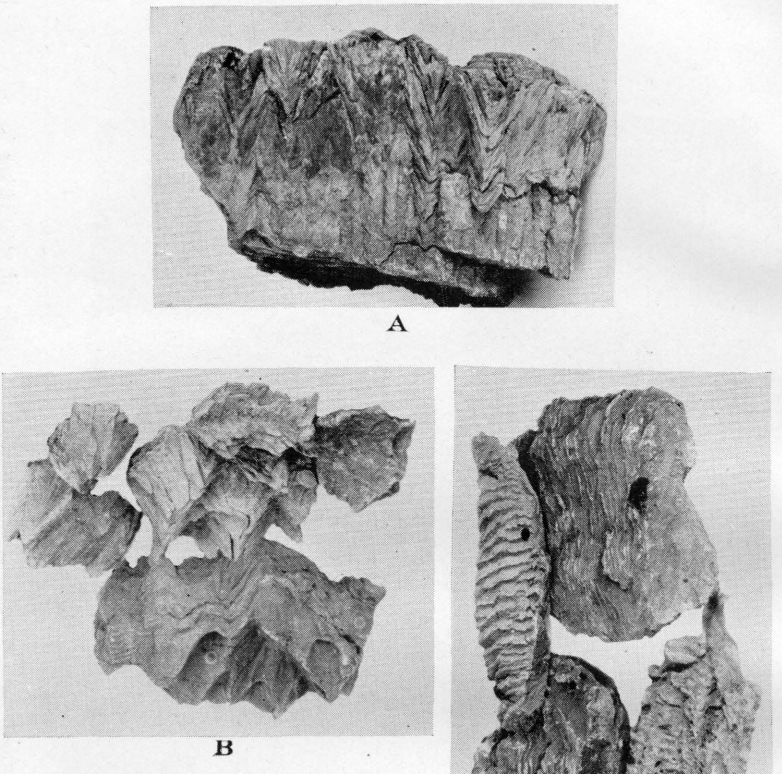


PLATE XVIII.—Rusty marl concretions with cone-in-cone structure. Natural size. *A, B* and *C* from upper zone of Salt Grass shale member in the NE¼, sec. 12, T. 12 S., R. 42 W. *A*—Typical sample. *B* and *C*—Typical weathering of cone-in-cone structure. *D*—"Chopwood" weathering of nearly fibrous variety of cone-in-cone structure. From lower zone of Salt Grass shale member in the NE¼, sec. 12, T. 12 S., R. 42 W.

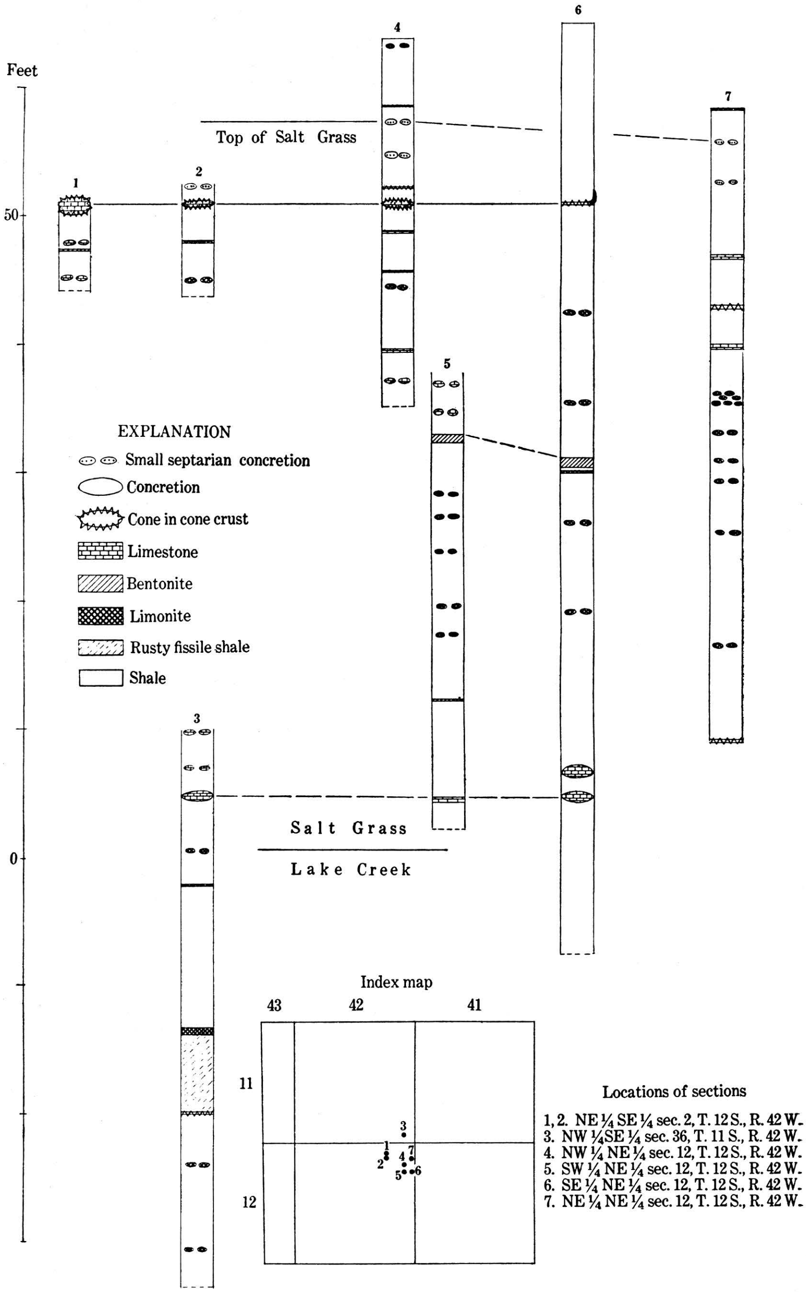


PLATE XIX.—Geologic sections of Salt Grass and Lake Creek members.

into Beecher Island time. The complete list of the identified fossils from the Beecher Island shale is as follows:

Serpula sp.
Lingula sp.
Ostrea cf. congesta Conrad.
Ostrea pellucida Meek and Hayden.
Pecten cf. *venustus* Morton.
Tardinacara (*Pseudoptera*) *fibrosa* (Meek & Hayden) Elias.
Tardinacara (*Pseudoptera*) *whitii* (Toepelman) Elias.
Inoceramus sagensis Owen.
Inoceramus proximus Tuomey, Meek em.
Volsella sp. (n. sp.?).
Solemya subplicata Meek and Hayden.
Lucina occidentalis (Morton).
Lucina subundata Hall and Meek.
Acmae cf. *parva.*
Anisomyon sp. (n. sp.?).
Cymbophora (*Mactra*) *gracilis* Meek & Hayden.
Melania sp. cf. *wyomingensis* Meek.
Anchura americana Evans and Shumard.
Fasciolaria cf. *buccinoides* Meek and Hayden.
Fasciolaria (*Cryptorhytis*) cf. *flexicostata* Meek and Hayden.
Valvata sp. (n. sp.?).
Baculites grandis Hall and Meek.
Baculites meeki Elias n. sp.
Baculites clinolobatus Elias n. sp.
Discoscaphites conradi (Morton).
Discoscaphites conradi cf. var. *gulosus* Morton.
Discoscaphites abyssinus Morton.
Bones of mosasaurs.
Scales and bones of small fishes.

Reeside[155] reports the following species from apparently the same shale member, collected "from sec. 2, T. 2 S., R. 43 W., Arikaree river, south of Wray, Colo.":

Lucina occidentalis Morton.
Lunatia sp.
Baculites sp.
Discoscaphites sp.

He reports, also, *Inoceramus fibrosus* Meek and Hayden (*Tardinacara* [*Pseudoptera*] *fibrosa* of the writer) from beds in many localities, which he refers to the same "transition zone between Fox Hills and Pierre." That the Beecher Island shale most probably represents the transition zone between these two formations is also the opinion of the writer, which was expressed by him in 1928.[156]

The well of 1928 at Beecher Island was started in the upper part of the Beecher Island shale. Examination of the cuttings from this well revealed no distinguishable foraminifera down to about 95 feet. In the samples from 95 to 110 feet, which correspond to the shale slightly below the base of the Beecher Island member, the following species were identified:

Anomalina taylorensis Carsey.
Gumbelina (*Textularia*) *globulosa* Ehrenberg.
Rotalia cretacea Carsey.
Gumbelina (*Textularia*) *globifera* Reuss.

In the Pierre shale at about the same horizon as the Beecher Island shale member, near the Phillips Petroleum Co.'s Andrews No. 1 well, which is in sec. 3, T. 22 S., R. 42 W., Yuma county, Colorado, a few fragmentary dicotyledon leaves were collected, among which the writer identified the following forms:

Salix cf. *gardneri* Knowlton.
cf. *Ficus minima* Knowlton.
cf. *Celastrus artica* Heer.
Cinnamomum (?) sp.
Eucalyptus (?) sp.

---

[155] In Mather, Gilluly and Lusk, 1928, p. 112.

[156] Report on the Paleontology of Beecher Island area for the Etnyre Syndicate.

Table of Correlation of the Upper Part of the Upper Cretaceous of Kansas, with the Contemporaneous Formation of Eastern North America and Western **Europe.**

Standard section of Europe.			Standard section of Great Plains.			Typical section of southern and central Montana.	Typical section of northwestern Kansas.				Typical section of Gulf and Atlantic Coasts.		
Age.		Faunal zones.	Formations.		Faunal zones.		Members.			Faunal zones.	Formations.		Faunal zones.
Danian.		*Hercoglossa danica.*	Laramie.		No cephalopods *Calyptraphorus.*				Wanting.	Wanting.			
Maestrichtian.		*Parapachydescus neubergicus.*	Montana.	Fox Hills.	*Discoscaphites conradi, D. iris.*	Bearpaw.					Ripley (of Tennessee).	Owl Creek. *Discoscaphites iris.*	*Exogyra costata* zone.
		Bostrychoceras polyplocum.		Transitional beds.	*Sphenodiscus lenticularis.*		Montana.		Beacher Island shale.	*Discoscaphites conradi.* *D. abyssinus.*			
				Pierre.	*Discoscaphites nicolleti.* *Acantoscaphites nodosus.*	Judith River.			Undifferentiated.			McNairy.	
Senonian.	Upper Campanian.	*Hoplites varians.*			*Acantoscaphites nodosus.* *Scaphites plenus.*	Claggett.			Salt Grass shale.	*Baculites pseudovatus* var. A. *Scaphites reesidei, S. plenus.*		Coon Creek. *Scaphites reesidei.*	
									Upper Lake Creek shale.	*Acantoscaphites nodosus* s. s. *Baculites corrugatus.*		Selma chalk (of Tennessee).	*Exogyra cancellata* subzone.
									Lower Lake Creek shale.	*Baculites compressus* s. s.			
	Lower Campanian.	*Scaphites hippocrepis.* Upper limit of *Scaphites* s. s. in Europe.			*Scaphites hippocrepis.*	Eagle.			Upper Weskan shale.	*Anomia* cf. *subtrigonalis.* *Ostrea* aff. *lugubris.*	Eutaw (of Tennessee).	Snow Hill (of Carolinas). Taylor marl (of Texas).	*Exogyra ponderosa* zone.
									Lower Weskan shale.	*Anomia* cf. *subtrigonalis.*			
									Sharon Springs shale.	Small fishes.			
	Santonian.	*Discoscaphites aquisgranensis.*	Colorado.	Niobrara.	*Desmoscaphites bassleri.*	Telegraph Creek.	Colorado.	Niobrara.	Orange chalk.	*Hesperornis.*		Austin chalk (of Texas).	*Mortoniceras* subzone.
Emscherian or Coniacian.		*Discoscaphites arnaudi.* *Scaphites lamberti.*			*Scaphites vermiformis.* *S. ventricosus.*	Niobrara.			Blue and white chalk.	*Rudistes.*			
									Fort Hays limestone.	*Inoceramus deformis.*			
Turonian.	Augoumian.	*Scaphites geinitzi.*		Benton.	*Scaphites warreni.* *Prionocyclus wyomingensis.* *Scaphites larvæformis.* *Prionotropis woolgari.*	Carlile.		Benton.	Blue Hills shale.	*Prionocyclus wyomingensis.*		Eagle Ford.	*Exogyra upatoensis* zone.
	Ligerian.	*Mammites nodosoides.*			*Metoicoceras whitei.* *Inoceramus labiatus.*	Greenhorn.							
						Graneros.							

The flora, though very imperfectly preserved, appears to be nearest to the Vermejo formation assemblage of plants of Raton Mesa, Colorado, which is considered to be of upper Pierre or Fox Hills age.

UNDIFFERENTIATED PIERRE.

The part of the Pierre between the Beecher Island shale member and the Salt Grass shale member was not studied by the writer. It is possibly exposed in some river valleys of Cheyenne county, Kansas, and the adjacent counties east and south. The uppermost 80 feet of this shale, which is exposed below the Beecher Island shale in the valley of Arikaree river, consists of nearly featureless dark-gray to black shale with practically no concretions in it, and the lowermost 30 feet, occasionally exposed above the Salt Grass shale member in Wallace county, consists of gray shale with a few thin, rusty limonite streaks.

In the approximately corresponding part of the Pierre in the Arkansas river valley of eastern Colorado and in the southern Black Hills region the limy cores of the so-called "Tepee Buttes" are plentiful, and fossils were collected from these bodies and from the surrounding ordinary limestone concretions. In the concretions of this zone Gilbert found the following fossils, which he regards as typical for the "Tepee zone" of the Pierre:

Inoceramus sagensis.
Inoceramus cripsi (probably var. *barabini,* as it seems to the writer).
"Large baculite," which is referred to *Baculites compressus,* but the size of which, "2 or 3 inches in diameter," [157] oval cross-section and broad lateral undulations, as shown on Pl. LXII, suggest *Baculites grandis* Hall and Meek.
Scaphites nodosus, which looks like *S. nodosus* Owen and not like any one of the many varieties of this species (Pl. LXV-2, *Idem.*).
Heteroceras nebrascense.
Placenticeras placenta.

The same fossils, together with many other forms, are recorded by Henderson from the Pierre shale "above the Hygiene sandstone" north of Boulder[158] or from about the same zone of the Pierre.

Tertiary.

OGALLALA FORMATION.

The Ogallala formation of Wallace county is usually buff colored to pinkish and consists chiefly of unsorted sand and gravel, usually mixed in various proportions with fine dust (loesslike fine sand or silt), which makes the rocks of the formation rough to the touch.

---

[157] Gilbert, 1896, opposite p. 568.

[158] Henderson, 1920, p. 27; see, also, Stanton, 1888, pp. 184-187.

However, in some areas fine unctuous clays of pleasant light-green and reddish-brown colors constitute important beds in the lower part of the formation (Fig. 5), and in the middle and especially in the uppermost parts of it lenses and beds of white and pinkish limestone are not infrequently observed. Beds of gravel and sorted sand, some with a distinct cross-bedding, occur in places in the formation, the sands being usually colored light gray or greenish. Bluish-gray volcanic ash and light-gray to snow-white diatomaceous marl are locally found in the lower and middle parts of the Ogallala, and variously colored chert in the form of nodules and in small irregular lenses and beds is occasionally seen. Calcium carbonate is present in almost all of the Ogallala rocks. It is distributed through the rocks both as fine material and in the form of small and medium-sized nodules. Calcium carbonate in many places binds the sedimentary material of the Ogallala so firmly as to produce a series of hard ledges, interbedded with only slightly cemented beds. The hard ledges are usually unevenly cemented and form roughly weathered benches and cliffs which resemble mortar and accordingly are often referred to as "mortar beds."

TYPICAL OGALLALA BEDS.

Darton, who proposed the term Ogallala, considers this formation "to be a stratigraphic unit and to be continuous from the type locality near Ogallala[159] station in western Nebraska" across the western parts of Nebraska and Kansas to the Syracuse and Lakin quadrangles in western Kansas.[160] Darton[161] says: "The principal material of the Ogallala formation is sand, which differs in texture from place to place and in different beds. In most places there are at several horizons, especially toward and at the base, deposits or streaks of small gravel mixed with the sand in greater or less amount, and much of this coarser material is cemented into a loose conglomerate or coarse sandstone. Throughout the formation irregular bodies of calcium carbonate have been deposited about the sand grains and make a soft 'grit,' as it is termed. This material ranges in texture from coarse conglomerate to a fine-grained mixture of calcium carbonate and silt, often called 'magnesia.'" He also mentions "a thin bed of nearly pure limestone which caps the high summits" in the northwestern and central Syracuse quadrangle.

---

[159] As the geographic name from which the name of the formation is derived is spelled on all modern maps and in official communications Ogallala (not Ogalalla), this spelling has been adopted by the U. S. Geological Survey and is followed by the writer.

[160] Darton refers to Ogallala, also the Tertiary beds in northern New Mexico.

[161] Darton, 1920, p. 5.

Darton never described the particular section of the Ogallala at the type locality of the formation, but the "section of Tertiary grit along the North Platte northwest of Ogallala, Neb.," was described by Hay, who was cognizant of the stratigraphic distinction between the "Tertiary grit" and the buff-colored "Plains marl" or loess.[162] The following description of Ogallala formation at the type locality is quoted from Hay.[163]

		Feet.
1.	White "magnesia" limestone	40
2.	Reddish-brown marly limestone	
3.	Gravel, slightly cemented, 5 to 10 feet	
4.	Rough, hard, mortar-bed grit	25
5.	A softer layer	
6.	Reddish, sandy, marly grit	
7.	Pebbly grit, 3 or 4 feet	
8.	White grit, weathering rough	40
9.	Pebbly grit, a few feet	
10.	Hard ledges with few pebbles	
11.	Reddish clay with harder streaks, 3 feet	
12.	Hard whitish bed	35
13.	Polishing powder	
14.	Limy, whitish bed	80
15.	Hard, white rock	
16.	Faint cream-colored grit	
17.	Hard white rock	
18.	Softer white rock, 15 feet	
		220
19.	To river bed below Tertiary grit	240

"The beds run into one another so much that it is difficult to separate them. An escarpment showing 15, 16 and 17, had also a bed of gravel halfway across. . . . Beds 3, 7 and 9 give the hummocky gravelly hills to the outcrop, but the interjection of gravel in No. 16 indicates that other levels may also supply gravel."

The "polishing powder" of bed No. 13 is probably volcanic ash, a deposit of such ash being observed by the writer in about the same position in the section of Ogallala two miles east of Ogallala station.

Bed 19 is not described by Hay from the outcrop, but he gives a brief record of rocks from "a boring at Paxton, Neb., 19 miles east of Ogallala," which he regards as continuing the section downward thus:

---

[162] Hay, 1895, pp. 569-577, 580-584. In this paper Hay states that what he calls Plains marl "has been called loess by geologists of both Nebraska and Colorado," and admits that "its formation may have been in part contemporaneous with that of the loess." (p. 574.)

[163] Idem., p. 580.

	Feet.
Hard red clay with hard, limy streaks and sand streaks, some several feet thick	100
Similar material with hard ledges 5 or 6 inches thick	58
Hard white limestone	10
Red material with hard streaks	80
Total	248

It appears justifiable not to regard this additional 248 feet of rocks as a continuation of the 200 feet of Ogallala, because the rocks do not outcrop at Ogallala town, because they are somewhat different lithologically, and because the thickness of the formation as traced from here across southwestern Nebraska, northeastern Colorado and western Kansas is very uniform and does not seem ever to exceed 210 feet.

As far as known to the writer no fossils have ever been described or recorded from the type locality of Ogallala. It is the general character of the formation, consisting of poorly sorted, always somewhat pinkish material with the presence of prominent escarpments formed of partly cemented "mortar beds," that was commonly used for recognition. On a recent trip to the type locality the writer collected some fossils which appear to verify the correlation of the late Tertiary beds of western Kansas and northeastern Colorado with the formation exposed at Ogallala. The writer intends to publish in a separate paper a description of the lithology of the Ogallala at the type locality and the fossils collected there.

Prior to Darton's work in the Great Plains region the vertebrate paleontologists described many late Miocene and early Pliocene bones from what they customarily called the "Loup Fork" formation, a term originally applied to Pleistocene deposits in eastern Nebraska. The Loup Fork formation of Hayden, Leidy, Marsh, Cope and in part of Scott, Hatcher and Osborn, may be regarded as corresponding to the Ogallala of Darton. To this formation, also, belongs the Republican river formation of Osborn (1910, p. 348) and part of the Snake creek formation of Cook and Matthew (1924).

The lower limit of the Ogallala in Kansas and Colorado is well defined, both lithologically and stratigraphically. Ordinarily the formation rests unconformably on various members of the Upper Cretaceous of the plains. According to observations by Darton along the south side of the North Platte valley in western Nebraska and on exposures in northeastern Colorado, Ogallala beds are unconformably underlain by sands of the Arikaree formation of Lower Miocene age. The lithology and age of the rocks that underlie the Ogallala formation at the type locality is but little known at present. These rocks, according to the description of well cuttings by R. Hay quoted above, do not correspond lithologically to the Arikaree formation of Darton.

The eroded surface of the Ogallala is usually covered with a mantle of unconsolidated gravel, sand and loess of Pleistocene and Recent age, but in places some harder young rocks are observed, the relation of which to the Ogallala formation is difficult to determine. In Meade county, Kansas, in strata that appear to be typical "mortar beds" an early Pleistocene fauna is found, but, as Darton remarks, some portions of younger deposits of the McPherson formation type "cemented by calcium carbonate might be expected to resemble the Ogallala closely." The writer observed some sands in the valley of Smoky Hill river in western Wallace county, which were richly impregnated with calcium carbonate, but which are apparently much younger than the near-by typical Ogallala "mortar beds."

Darton estimates the thickness of the Ogallala properly so called in Syracuse and Lakin quadrangles to be about 190 feet,[164] but he also refers to the Ogallala in a broad sense the total of about 300 feet of post-Mesozoic sediments that were penetrated in the wells of these quadrangles, because "no separation is practicable in this region."[165] This "300 feet or more of beds that constitute the Ogallala formation comprise deposits elsewhere separable, even including locally in their upper part a representative of the McPherson formation ('Equus beds')." The thickness of the "Tertiary grit" that is exposed northwest of Ogallala is estimated by Hay to be 220 feet. The writer measured the section of the outcropping beds of Ogallala formation northeast of Ogallala town and in Ash Hollow on the North Platte river, about 27 miles northwest of the town. At the first locality only 105 feet, which belongs to the upper part of the formation, is exposed. In Ash Hollow about 200 feet, or probably the whole thickness of the formation, is exposed.

The writer found the thickness of the typical Ogallala formation of Wallace county to reach 210 feet, which corresponds closely to the estimate of the Ogallala formation in the restricted sense in the Syracuse and Lakin quadrangles and to the estimate of the formation at the type locality. Only these beds which consist chiefly of the grit partly cemented with calcium carbonate and have a typical

---

[164] Darton, 1920, p. 3.

[165] Idem, p. 6.

"mortar beds" appearance or which are paleontologically proved equivalents are referred to Ogallala in this report.

On the top of these beds there was observed a peculiar and remarkably persistent hard limestone, which was traced not only over the larger part of Wallace county but also far north, west and south in the adjacent area. This ledge of limestone is only 2 to 3½ feet thick. It has an irregularly pitted surface (see Pls. XXI A and XXII A) and is made of unstratified, hard, compact, usually pinkish limestone and has a peculiar concentrically banded structure, which resembles closely that of the algæ reefs and irregular pisolites of the Green River formation recently described by Bradley.[166] The position of the bed, always on top of the local Ogallala (Pls. XX A, XX B, XX C and XXIII A) and often at the same level over a considerable distance (especially in the south part of Wallace county), suggests that this limestone was deposited in a nearly horizontal position, no other beds like it being noticed by the writer in the local post-Mesozoic rocks. The bed is parallel to the other beds of the Ogallala (Pl. XX B) and wherever the formation has been folded, which has occurred most extensively in the west-central part of the county, the concentrically banded limestone is involved in the folding. It is quite clear from this that the bed belongs to the Ogallala and is the capping rock of the section. It is everywhere underlain by a somewhat softer, porous or spongy, cream to nearly white limestone (Pls. XX B and XX C) with a mixture of sand grains. Some parts of this white limestone are harder than the rest and contain small lenses and bands of transparent or milk-white chert. In a few exposures shells and casts of a very small fresh-water gastropod, *Planorbis,* were found near the top of the white limestone. The white porous limestone is usually 10 to 20 feet thick and grades downward into the ordinary grit of the Ogallala. Owing to its peculiar appearance, prominence in the exposures and definite stratigraphic position the pink concentrically banded limestone makes an especially important key bed for structural mapping of the Tertiary.

The pink concentrically banded limestone usually does not outcrop as a solid ledge, but is broken into irregularly oval or angular and somewhat flattened cobbles a few inches to a foot or more in horizontal diameter (Pl. XX C, also Pl. XXXIX B). The texture of the bed may be called irregularly pisolitic, the limestone being traversed by a very fine more or less concentric rhythmic banding (Pls. XXI A and XXI B). The fine banding presents an alternation of creamy,

---

[166] Bradley, 1929.

light-brown, brick-red and otherwise shaded reddish-brown irregularly concentric bands, the cores of which and the matrix between the irregularly oval "ovulites" are usually colored in nearly uniform light creamy or pinkish shades. The rock is usually full of scattered grains of colorless quartz and pink feldspar, the size of which ranges from tens of microns to a few millimeters. Very rarely much larger pebbles of quartz are observed in the rock. Some of the sand grains are found in the center of the smaller and more regular pisolitic "ovulites," but the vast majority of these grains have no relation to the banding at all and are scattered uniformly through the rock. Many of the larger loops of banding embrace groups of smaller concentric structures. A few fragments, also, with nearly parallel banding have an enveloping crust of fine concentric banding. This and other examples of interrupted and resumed growth are fairly frequent. The thin section reveals a cryptocrystalline structure, the banding of which is due to the zonal arrangement of nearly opaque calcium carbonate, a little more crystallized and more transparent buff-colored bands of the same substance and occasionally still more transparent layers of the same carbonate with a faint radial (transverse) structure. The first two kinds of bands are not sharply separated, the nearly opaque substance presenting lobate and digitate outgrowths into the lighter bands. Locally there are much thinner and closer spaced brick-red bands of iron oxide and buff-colored calcium carbonate. In the broader bands may be noticed a few small spherical bodies with comparatively thin outer zone made of a mosaic of comparatively coarse-grained colorless calcite, much like the walls of the hollow spheres representing the individual cells of *Chlorellopsis coloniata* Reis, the microscopic alga of the Green River formation reefs.[167] Some of the spherical bodies from the Ogallala rock are hollow also. The more important difference between the spheres from the limestones of the two formations is the smaller diameter of the spheres from Ogallala. The measured diameter of seven spheres from the Ogallala is as follows (in microns): 85, 63, 65, 75, 97, 63, 62, whereas the diameter of the spheres of *Chlorellopsis coloniata* Reis ranges from 110 to 140 microns in the Miocene algal reefs of the Rhine valley in Germany[168] and from 103 to 122 microns in the Green River Eocene of Wyoming, Colorado and Utah.[169] It appears as if the spherical bodies from the concentrically banded limestone of the Wallace county Ogallala, which

---

[167] Compare p. 207 and Pl. 32-A, Bradley, 1929.

[168] Reis, 1923, pp. 107-109. Translated and quoted by Bradley, 1929, p. 207.

[169] Bradley, 1929, p. 207.

is of Lower Pliocene age, if correctly interpreted as individual cells of an alga, belong to a different species of *Chlorellopsis.*

After the above notes were written the writer received the following account of an examination of this algal limestone by W. H. Bradley, to whom the writer sent two samples of the rock:

"The sections of the deposits from the Ogallala formation from Wallace county, Kansas, and from sec. 7, T. 25 S., R. 42 W., Hamilton county, Kansas, are so nearly alike that they can be discussed together. In general all parts of these reefs appear to have been more extensively recrystallized than many others that I had available for study from the Green River formation. Nevertheless, I agree with you that a large part of these deposits was apparently formed by an organism much like *Chlorellopsis.* The cells are indeed smaller than the species which I described and probably should be referred to a different species. They show a similar habit of growth in roughly concentric layers much the same as those that I described. Many of them, however, especially those detached from the areas showing systematic growth layers are enlarged by external coatings. I think your interpretation of these enlarged cells is probably right, namely, that it is an inorganic incrustation perhaps quite independent of the original algal cell. This seems the more probable because associated with the parts of the reef showing definite algal structure are undoubted oölites. Some of the *Chlorellopsis* cells apparently have been flattened during the compaction of the deposits. So far as I recall, I did not observe that in the Green River reefs. In addition to the layered *Chlorellopsis* structure there is apparently some algal deposit like that which I called, for the want of a better name, the spongy structure."

"The oölites associated with the algal deposits in these reefs are of quite various sizes. Their nuclei are of irregular particles of clay or marl. These oölites usually show concentric growth, but a few consist of radial fibrous crystals. Areas of these oölites, however, are usually mixed with more or less clastic material and are rather easily distinguished from areas built up by systematic growth of algæ."[170]

In view of this confirmation of his opinion the writer feels justified in distinguishing the *Chlorellopsis* of the Ogallala limestone, the cells of which are distinctly smaller than those of *C. coloniata,* by giving this alga a name. He proposes to call it *Chlorellopsis brad-*

---

[170] From personal letter Jan. 15, 1931, to the writer.

leyi after W. H. Bradley. The diameter of the spherical cells of this species is usually 62 to 65 microns, but it is often larger, reaching nearly 100 microns.

The rhythmic banding similar to that of the Ogallala limestone is interpreted by many authors as due to a chemical precipitation of calcium carbonate[171] or to the action of bacteria.[172] It is quite possible that either of these two factors, or both of them, played a part in the deposition of the Ogallala concentrically banded limestone. This, however, would not exclude the algal precipitation of the other part. In fact the texture of the Ogallala limestone resembles most closely those specimens from the Green River formation that are interperted by Bradley as compound reef with "alternating zones of algal and inorganic limestone."[173] It appears to the writer that the thinner bands of calcium carbonate and iron oxide, deposited around the nuclei of quartz and feldspar and producing more or less regular small-sized ovulites scattered through the Ogallala limestone, are most probably due to inorganic precipitation, whereas the larger-scale banding with only occasional thin zones of iron oxide is most probably, at least in part, due to the precipitation of calcium carbonate by the algæ. At any rate the Ogallala limestone must be classified with those oölitic and pisolitic beds that are interpreted as marine or lake deposits, whether they are explained as being due to organic or inorganic precipitation.

The writer is familiar with the secondary rhythmic banding of the rocks, which was described first by Tarr[174] and later by a few other authors[175] in some tuffs and lavas, and is also occasionally observed on some sedimentary rocks—sandstones, conglomerates, shales and others. The secondary rhythmic banding of the rocks is explained as precipitation of iron oxides, manganese dioxide and other substances from the circulating solutions. In many beds it is only a local feature, but in other cases it is a persistent property of some particular beds in the sedimentary series.[176] In a very few cases, as in the rhyolite tuff described by Tarr, the coloring substance is observed to develop from inside outward around the nuclei, which evidently contained this substance (manganese dioxide in the case

---

[171] Linck, 1903; Schade, 1909 and 1910; Bucher, 1918. See, also, Grabau, 1913, pp. 336-338, and Twenhofel, 1926, pp. 539-543.

[172] Vaughan, 1914, pp. 49-54.

[173] See Bradley, 1928, Pls. 43-46, especially Pl. 44A and Pl. 46B.

[174] Tarr, 1917, pp. 610-617.

[175] Stamp and Chhibber, 1925; Chhibber, 1927, p. 7.

[176] The writer has observed a persistent zone of rhythmic banding in the Lower Triassic sandstones and conglomerates near Vladivostok, eastern Siberia.

described by Tarr). In most cases, however, the secondary rhythmic banding of a formation grows from outside inward, as always observed by the writer in rocks of sedimentary origin. In cases like this apparently no nuclei in the centers of rhythmic concentric banding exist, and the coloring matter enters with the solution from without. In the Ogallala concentrically banded limestone the grains of quartz and fresh feldspar are occasionally the nuclei of small concentric structures, and it is apparent that these grains certainly have not been the source of the iron oxide of the colored banding. Therefore the explanation of this banding as a secondary concentric coloration of the originally uniformly colored rock is improbable.

The writer does not share the opinion that the "hard thin limestone of peculiar appearance" with "minute curved brownish bands," as the capping limestone of Ogallala has recently been described,[177] "resembles very closely the caliche deposits of the arid west and was probably formed in the same manner." The term caliche, in its strict sense, has long been applied in geologic literature to the nitrates, sulphates and other readily soluble salts which form efflorescences in the arid regions of Chile and other parts of the Americas. Recently the term caliche has often been applied, also, to those calcareous deposits of the semiarid regions of southwestern North America that are supposed to originate in a similar way. The writer does not know of any scientific publication in which calcareous caliche has been described as a dense limestone with concentrically banded or pisolitic structure. The definition of "caliche" applied in Mexico and southwestern United States, as given by A. H. Fay,[178] is as follows: "Gravel, sand or desert débris cemented by *porous*[179] calcium carbonate, also the calcium carbonate itself."

There are known some deposits of secondary calcium carbonate in soils and subsoils, also in the semiarid regions of the Americas, which are called hardpan in the United States and tosca in Argentina, and which some students possibly do not distinguish from the caliche type of deposits. These deposits, which are formed always slightly below the surface,[180] are ordinarily quite dense, the calcium carbonate cementing the soil into a very hard and compact bed. The texture of this cemented soil is, however, "the same as the

---

[177] Russell, 1929; p. 599.

[178] Glossary of Mining and Mineral Industry, U. S. Bureau of Mines Bull. 95, 1920.

[179] Italic by the writer.

[180] Compare Willis, 1912, p. 25

material immediately above and below it,"[181] which is, of course, natural for this cementing type of secondary calcium carbonate. The concentrically banded capping limestone of the Ogallala, though dense, has a very insignificant admixture of sand grains and is of entirely different texture from the porous and cavernous white sandy limestone, or limy grit, which directly underlies it.

The pink concentrically banded limestone of the Ogallala, which, as shown above, is most probably a compound (phytogenic and hydrogenic) sheet reef, preserves a remarkably persistent texture and uniform thickness (2 to 3½ feet) in all studied exposures, and the impression of the writer is that this rock was deposited on the nearly flat bottom of a very large and very shallow lake at the close of Ogallala time.

As the Ogallala beds are now considered by most students to be typical fluviatile sediments, deposited by many changing streams which ran from the Rocky Mountain piedmont, one might be tempted to explain the origin of the concentrically banded limestone as precipitation by the same agents, as suggested by the writer, only not in a shallow lake but along these streams. The alga of to-day related to fossil *Chlorellopsis,* however, is known to precipitate calcium carbonate along the shores of lakes and not in running waters. It is not probable, furthermore, that a series of streams could deposit such an extensive bed of such remarkably uniform texture and thickness as the above-described Ogallala limestone. This bed was traced from a locality south of Syracuse, Kan., northward to the northern parts of Cheyenne and Rawlins counties, covering a meridianal stretch of about 140 miles with a width, as traced during the 1929 and 1930 field seasons, of about 30 to 40 miles. In April, 1931, the writer and K. K. Landes observed the very same bed at the top of the Ogallala exposed at the following localities: (1) Three miles northwest of Alamota, Lane county, and along highway 96 on the east border of Lane county. (2) Two miles southwest of Alberta, Barton county. This observation extends the known distribution of the bed about 175 miles east of the Colorado-Kansas line in latitude 38° 30′. Throughout the whole of the area of known exposures the bed maintains the same texture and thickness.

As the Ogallala of the area was undoubtedly deposited upon the uneven erosional surface of Cretaceous deposits, it is more satisfactory to refer, whenever possible, the stratigraphic position of the

---

[181] Gardner and Steward, 1900, p. 102.

other important Ogallala beds to the capping limesone rather than to the base of the Ogallala, which varies considerably in stratigraphic distance from the top rock in various areas of Wallace county. The original thickness of the Ogallala was 150 to 200 feet in the northwest, west, southwest and south parts of the county, but in the southeastern portion it decreased to 80 or 90 feet south of Wallace and to 25 feet southeast of Wallace, at the Logan county line in sec. 12, T. 14 S., R. 38 W. Another considerable decrease in the thickness of the formation occurred in the northeast corner of T. 12 S., R. 42 W., where possibly some very local heights (probably structural heights) of the Cretaceous rocks were never covered by the Ogallala sediments (part of sec. 12, T. 12 S., R. 42 W.). The original decrease (not due to subsequent erosion) of the thickness of the Ogallala was noticed, also, in the southeastern part of T. 11 S., R. 40 W., and the northeastern part of T. 12 S., R. 40 W., where the thickness of the Ogallala from the base to the capping limestone does not exceed 120 feet. In the northeast corner of the county the observed thickness, reaching 120 feet, does not include the uppermost portion of the normal Ogallala section, which is probably eroded away. The original thickness of the formation here was probably nearly 200 feet. The observed range of the original thickness of the Ogallala in Wallace county, from 0 to about 200 feet, appears to represent the relief of the pre-Ogallala topography of the area, the divides and hills of which time apparently were rarely raised more than 200 feet above the level of the valleys. The present topography is rougher and the relief greater, being carved in both the relatively hard Ogallala formation and in the underlying Cretaceous rocks, whereas the pre-Ogallala surface was modeled in the soft Pierre shale, which is only slightly reinforced by harder concretionary zones.

Near the base of the most complete sections of Ogallala in many places in southwestern Wallace county is a hard light-gray ledge made of cross-bedded coarse sand and gravel. It is not everywhere the basal member of the formation, unconsolidated grit and gravel being observed below it locally. In most places, however, the hard gray cross-bedded ledge is the lower of the hard ledges of the Ogallala. The stratigraphic distance between the concentrically banded limestone at the top of the lower Ogallala and the cross-bedded ledge at or near the base of it in Wallace county is about 170 feet.

The sediments of the Ogallala between the cross-bedded ledge

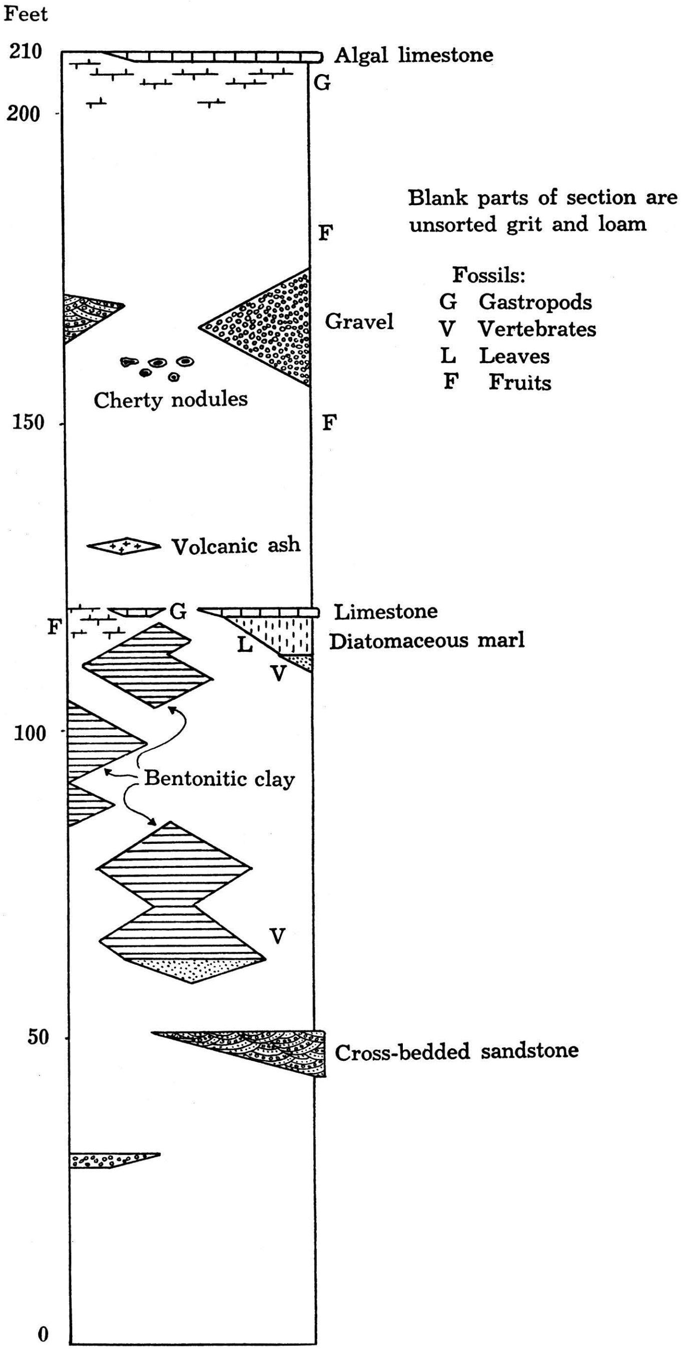


FIG. 5.—Generalized section of Ogallala.

Plate XX.—*A*.—Bench of upper Ogallala grit capped with algal (*Chlorellopsis*) limestone shown on the skyline. Below are steep cliffs of stratified redeposited loess with cobbles of algal limestone. In the SE¼ SE¼, sec. 29, T. 15 S. R. 39 W. *B*.—Upper part of Ogallala with capping algal (*Chlorellopsis*) limestone marked *a*. Shows perfectly parallel stratification of all beds of the section, including the algal limestone. On north side of south fork of Smoky Hill river half a mile west of Kansas-Colorado state line. *C*.—Algal (*Chlorellopsis*) limestone on the top of exposure. Shows sharp but somewhat irregular contact of the limestone with underlying calcareous loam, a softer and darker rock distinctly but somewhat irregularly stratified. In railroad excavation three miles east of Kanorado, Sherman county, Kansas.

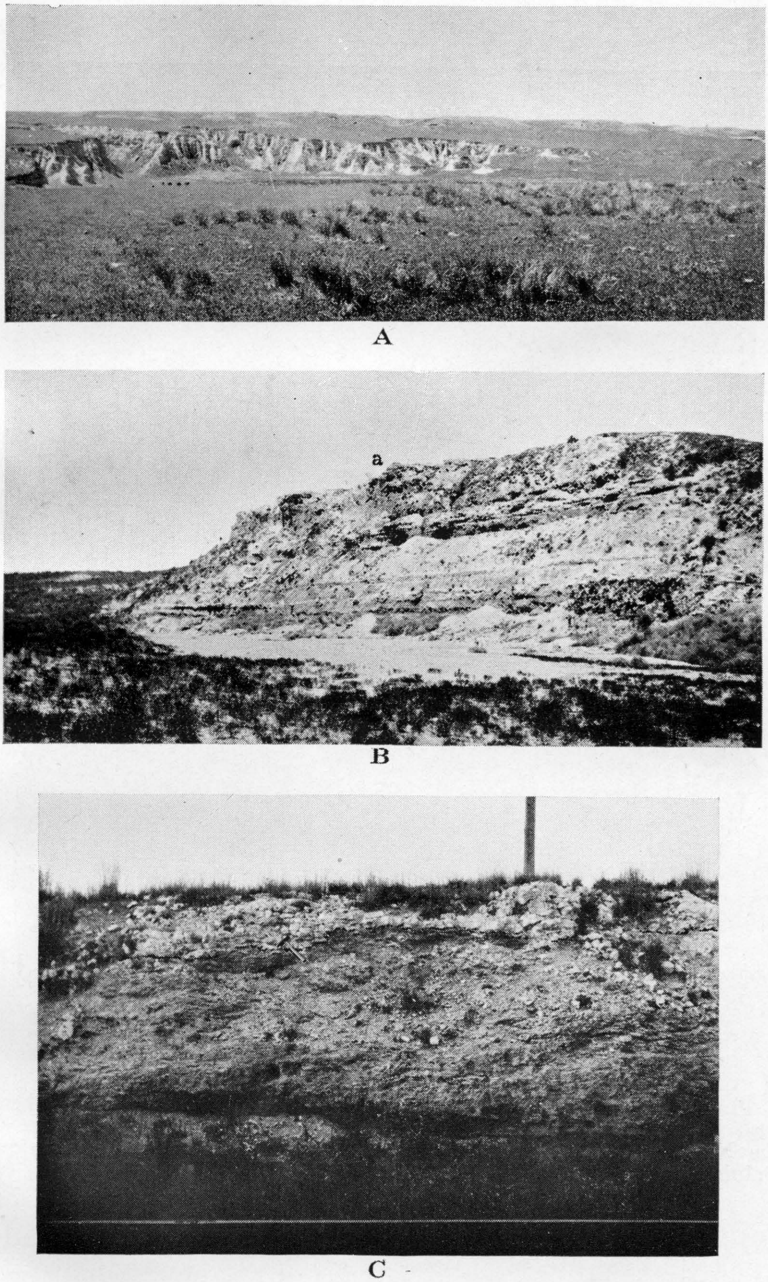
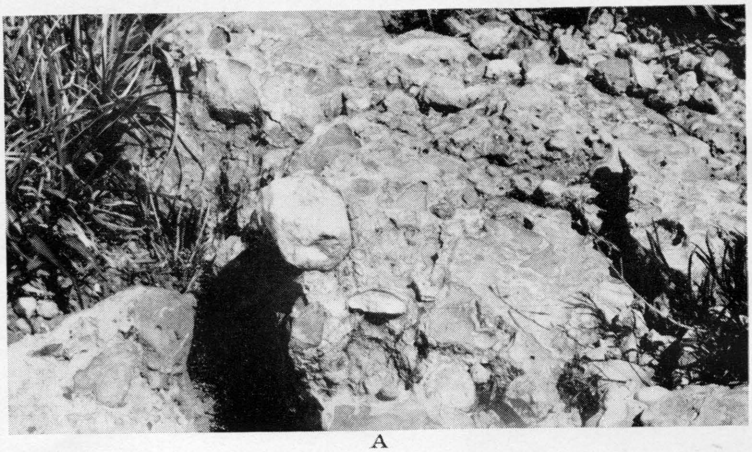
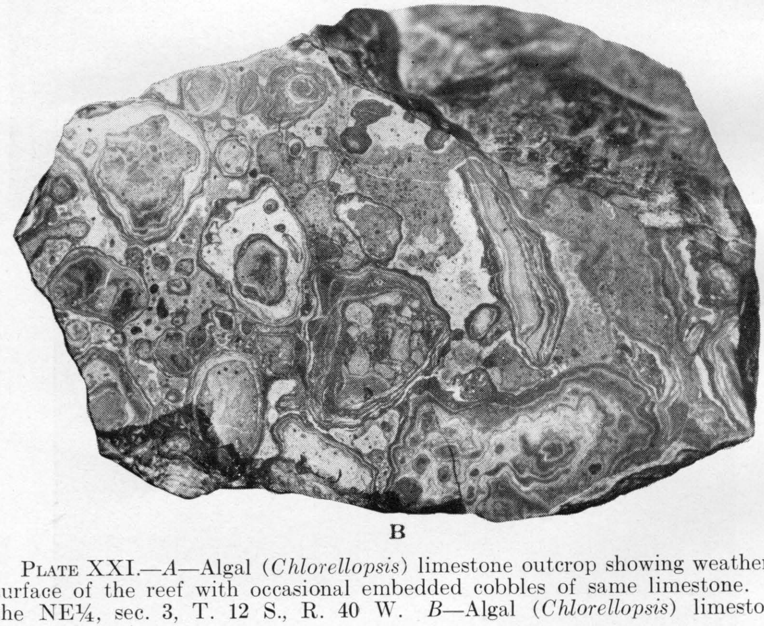


Plate XX.

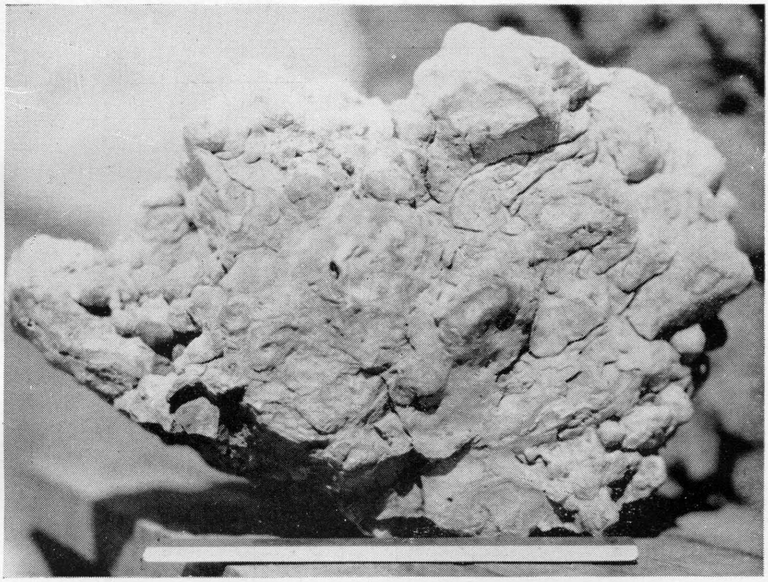


A

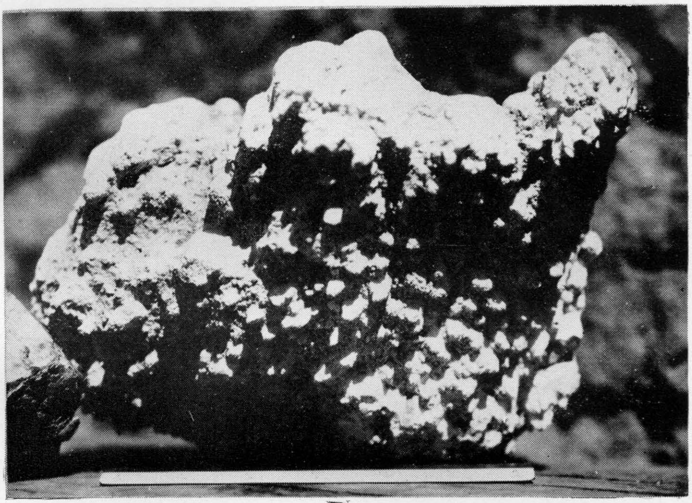


B

PLATE XXI.—*A*—Algal (*Chlorellopsis*) limestone outcrop showing weathered surface of the reef with occasional embedded cobbles of same limestone. In the NE¼, sec. 3, T. 12 S., R. 40 W. *B*—Algal (*Chlorellopsis*) limestone. Polished section.



A



B

PLATE XXII.—*A*—Algal (*Chlorellopsis*) limestone. Upper surface of a boulder with etching produced by the roots of living grasses and other herbs, four-tenths natural size. In the NE¼, sec. 3, T. 12 S., R. 40 W. *B*—Algal (*Chlorellopsis*) limestone. Lower surface of a boulder covered with small dripstones, three-tenths natural size. Same specimen as *A*.

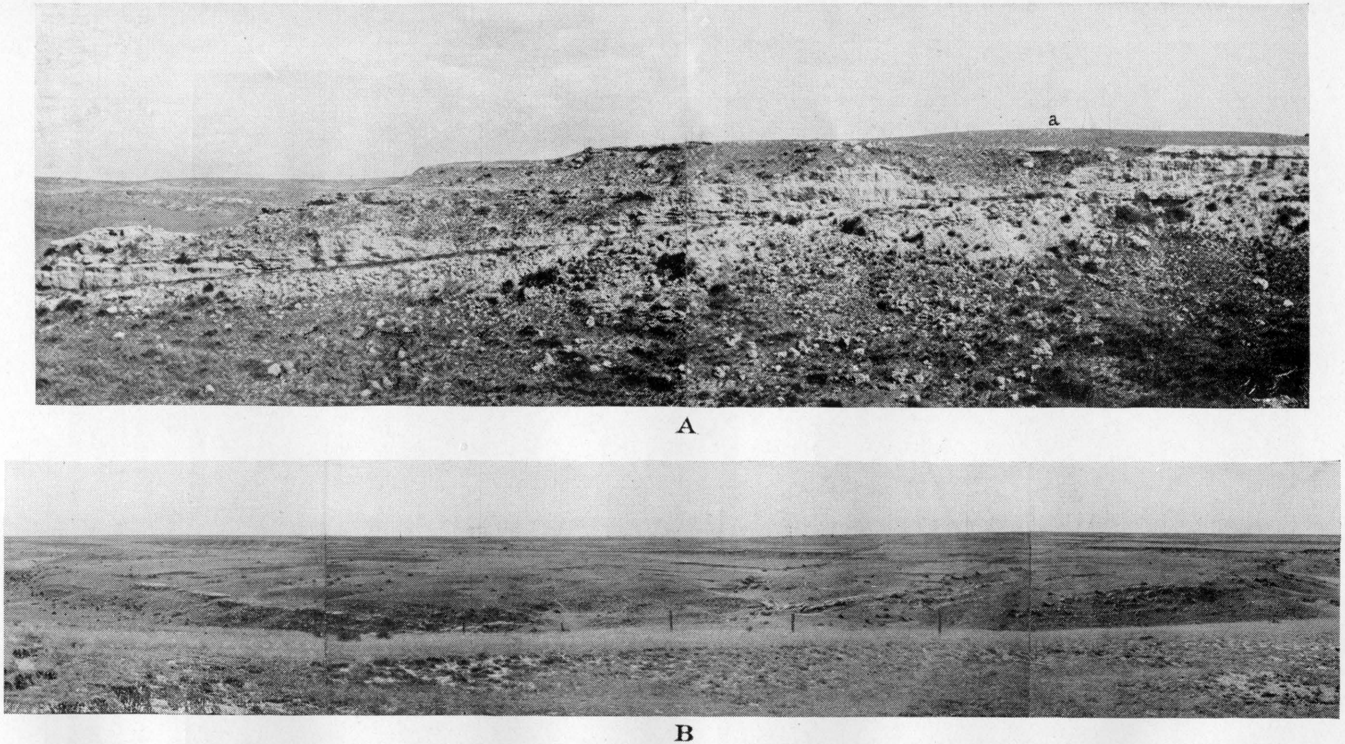


PLATE XXIII.—*A*—Upper part of Ogallala in the cut of abandoned road on the line between secs. 12 and 7, T. 14 S., Rs. 39 and 38 W., looking east. Compare diagrammatic columnar view of the section on Plate XXXII-2. Algal (*Chlorellopsis*) limestone marked *a*. *B*—Syncline in Ogallala with axis running southwest and across a large intermittent unnamed creek. In the SE¼, NE¼, sec. 6, T. 13 S., R. 41 W., looking southwest. Shows mantle of loess completely covering Ogallala beds and forming gently rolling prairie in the distance.

near the base and the limy zone at the top consist chiefly of "mortar beds" interbedded with unconsolidated grit and loam. In western Wallace county a fairly persistent bed of loose heavy gravel, in places 17 feet thick, appears between about 25 and 95 feet below the capping limestone. In the southeastern part of Wallace county the writer noticed a local large-scale cross-bedding in the partly cemented "mortar bed" consisting of gravel and sand and located about 40 feet below the top of the Ogallala and 30 feet above the base of it. This ledge is the equivalent of the upper gravel bed of western Wallace county rather than of the basal nearly always cross-bedded coarse sand and conglomerate bed of the formation. A hard ledge of a similar cross-bedded sand and gravel was observed, also, near the base of the sections in secs. 3, 35 and 36, T. 11 S., R. 40 W. This bed must be about 100 feet from the top of the formation and therefore belongs to the middle zone of it. In a few places irregular bands of fine gray sand are observed. This sand contains much white mica, which together with its gray color and fineness of sorted grains make it quite unlike the ordinary grit and loam of the Ogallala, in which mica is sparsely distributed. Much of the micaceous sand is partly cemented with calcium carbonate, the cemented masses being very irregular in shape. In many places this sand shows good small-scale crossbedding. Stains and incrustations of rusty limonite were observed in some beds of the micaceous sand. In a few sections thin and comparatively short lenses of white hard limestone were observed in different stratigraphic positions in the section, but none in the lowest portion of it. All these limestones contain diatoms and remains of fresh-water gastropods, *Planorbis, Physa* and others, which usually appear as external casts only (Pl. XXVI B). Some of these limestones are penetrated by somewhat irregular but approximately vertical thin canals (Pl. XXVI A), which are probably casts of herbaceous stems and roots. Many vertically oriented, fragile, petrified calcareous stems of grasses were found in the greenish sand immediately below a bed of such limestones (in theNW¼, sec. 6, T. 13 S., R. 41 W.).

A number of fossilized fruits (Pls. XXVII A, XXVII B and XXVII C) were collected from poorly sorted grayish-pink semi-cemented grit and loam, which constitute the larger part of the Ogallala. Ordinarily the remains of fruits are scattered through the rocks and are small, being 2 millimeters upward and rarely 1 centimeter in length. They are snow white, and some are composed of silica and others of calcium carbonate. This is very unlike the ordinary occurrence of fossil plants, which are commonly collected in fine-grained sedimentary formations, such as fine sands, marls, volcanic ash and especially clayey rocks. The color of the plant remains that are commonly found in these rocks is usually darker than that of the matrix; many of them are black, dark brown or have some other dark color. No plant remains from Wallace county were found by the writer in fine sands, marls or clayey beds of the Ogallala except a few impressions of dicotyledon leaves in the diatomaceous marl near the Marshall ranch (p. 160).[182] Contrary to general rule the Ogallala plant remains are abundant in some beds of grit and loam, even where a considerable quantity of small pebbles is noticed in the material of these rocks. In spite of the presence in the rock of coarse grains and even pebbles, the fossil fruits scattered among this coarse material usually show little if any abrasion of their delicate outer sculpture. This appears to indicate that the fruits were not transported with débris from the Rocky Mountain area, but probably were buried in the sediments when their transportation was nearly finished. It appears as if the fruits were dispersed by the aid of wind or animals and were scattered upon the ground, but for some reason—perhaps owing to too large a loss of water or to a local excess of alkali on the surface—did not germinate and were mixed up and buried with the next portion of débris that mantled the prairie. The flora consists of the following forms:

TRUE GRASSES:
- *Panicum elegans* Elias n. sp.
- *Stipa kansasensis* Elias n. sp.
- *Berriochloa glabra* (Berry) Elias n. comb.
- *Berriochloa* (?) *aristata* (Berry) Elias n. comb.[183]

HERBS OF BORRAGE FAMILY:
- *Biorbia rugosa* (Berry) Elias n. comb.[184]
- *Krynitzkia auriculata* Elias n. sp.
- *Krynitzkia* (*Cryptantha*) *coroniformis* Elias n. sp.
- *Krynitzkia* (*Oreocarya*) *chaneyi* Elias n. sp.

ULMACEÆ:
- *Celtis* cf. *willistoni* (Cockerell) Berry.

---

[182] Foliage of arboreous plants has been collected and reported by F. W. Cragin and later by E. C. Case from the Tertiary diatomaceous marl of Beaver county, Oklahoma, and a little collection by the latter was described by Berry (Berry, 1917, pp. 627-636) and referred to Upper Miocene or possibly to Pliocene. A much larger collection by Case, from the same locality, was deposited at the University of Kansas.

[183] Described by E. W. Berry but not collected by the writer as yet.

[184] *Berriochloa* and *Biorbia* are new genera described by the writer in a forthcoming paleontologic paper.

The fruits of the fossil herbs that are described in a forthcoming paleontological report were collected only in the middle part of the Ogallala, but the stones of hackberry were collected, also, near the top of the formation, and some were found not far above the cross-bedded ledge at the base of the Ogallala. Stones of hackberry or *Celtis* (Pls. XXVII A and XXVII B) are apparently the most abundant among recognizable organic remains, but they are by no means restricted to the Ogallala. *Celtis* stones of fairly similar appearance are known from the Eocene of Clark's Fork basin, Wyoming, and from the White River Oligocene of South Dakota. They are recorded, also, from the Pleistocene of California and from loess of the southeastern states.

Among the collected remains of fossil herbs *Biorbia rugosa* and *Berriochloa glabra* were found in several localities and *Celtis* stones have been usually found near by in the bed. *Biorbia rugosa* was found fairly often in the upper two-thirds of the Ogallala except in the uppermost 25 to 30 feet, where no plant remains except rare *Celtis* stones have been found. *Biorbia rugosa* fruits are comparatively easy to recognize, are not fragile and are abundant. As far as present experience indicates they are the most valuable index fossil of the Ogallala in the restricted sense. Outside of Wallace county, Kansas, they have been collected by Hatcher in the "Loup Fork" formation of Phillips county, Kansas (Berry, 1928), by H. T. Martin in "mortar beds" of Gove and Logan counties, Kansas, and by the writer in type locality of Ogallala in Nebraska, at Beecher Island, Yuma county, Colorado, and in Cheyenne and Rawlins counties, Kansas. *Berriochloa glabra* might be considered as good a marker for Ogallala as *Biorbia,* except that its fruits are found less frequently and many of them are very fragile, which makes their collection and preservation difficult.

Owing to the abundance of these fossil fruits the middle portion of the Ogallala may well be called the zone of fossil herbs. It measures about 130 feet in thickness. The fruits of fossil herbs and *Celtis* stones are found chiefly about in the middle and near the top of the zone.

Some peculiar stemlike and rootlike bodies made of calcium carbonate were observed in many "mortar beds" of the fossil-herbs zone. These calcareous formations are white, cylindrical, slender, straight or somewhat irregularly curved, usually a few millimeters and rarely reaching 2 or 3 centimeters in diameter. Usually they stand nearly or quite erect or they lie horizontal. They are scattered through some of the typical semicemented "mortar beds," but in some exposures they are present in great numbers and form a tangled mat like that formed by roots in ordinary sod (Pls. XXVIII A and XXVIII B). These slender bodies do not have enough structural features to permit identification of any particular kind of plants. Nothing like joints has been observed in either the smaller or the larger cylindrical bodies. They are invariably smooth or only gently and irregularly striated on the outside and are solid, some with a slight irregular porosity in the middle. They can hardly belong to the stems of the true grasses, but they probably represent roots of grasses and stems and roots of some other herbs and shrubs the original anatomy of which has been altered during fossilization. No foliagelike organs or fruits of any kind have ever been observed on or near these bodies, but often fruits occur in the beds with them or in the nearest beds above or below in the section.

Irregular shaped but usually more or less rounded concretionlike white bodies of limestone, usually with compact cherty core or made of chert alone, were observed in several "mortar beds" of the Ogallala. Usually these bodies are scattered along some particular planes parallel to the zones of cementation, and most of them are associated with the above-described masses of petrified roots. These bodies may be also petrified roots, but the study of them is not advanced enough to warrant a more definite conclusion at present.

Fragments of white fossilized bones, which clink when struck with a hammer, are occasionally found in the lower part of the typical Ogallala formation, and a few localities with better-preserved remains of the vertebrates are found. Remains of a large land turtle were collected by the writer from a bed of bentonitic clay about 25 feet above the base of Ogallala and about 90 feet below the concentrically banded limestone in the SE¼, sec. 2, T. 12 S., R. 42 W. Remains of another turtle (see Pl. XXIX B) in a large detached mass of typical "mortar bed," in the SE¼ NE¼, sec. 3, T. 12 S., R. 42 W. were shown to him by Roy Johnston. They came from about 10 feet above the base of the Ogallala and about 90 feet below the concentrically banded limestone. The specific identification of these remains is not yet made, but according to H. T. Martin they undoubtedly belong to the genus *Testudo* (*Xerobites*) and are closely related to the big turtles of the Upper Miocene of the Great Plains and those of the Lower Pliocene of Texas, which were described by Cope, Hay and other authors.

An important collection of well-preserved mammalian remains was made by Hesse and assistants of the expedition of the University of Kansas museum in 1930 from the locality discovered earlier in the year by the writer in the SE¼, sec. 27, T. 12 S., R. 41 W. The local section of the Tertiary is very small, only about 40 feet thick, and consists of practically one "mortar bed" (Pl. XL C) of grit locally with a considerable amount of scattered cobbles in it and greenish sand below it. The bed probably belongs somewhat above the middle of the Wallace county Ogallala. The mammalian remains were found in the sand, which is partly cemented into a very tough rock. According to preliminary identifications by H. T. Martin the following forms were collected:

PERISSODACTYLS: *Pliohippus* cf. *leidyanus*; *Aphelops* sp. indet.
ARTIODACTYLS: *Procamelus* sp.; *Paracamelus* sp.
CARNIVORA: Canidæ; *Acturodon sœvus* Matthews.

The presence of *Pliohippus* cf. *leidyanus,* according to Martin, places the beds definitely in Lower Pliocene. The presence of the large land *Testudo* (*Xerobites*) at the Roy Johnston ranch in beds that belong to about the same horizon in the section is not inconsistent with rating the age of the middle part of the typical "mortar beds" of Wallace county as Lower Pliocene. No identified bones were collected near the base or near the top of the Ogallala of Wallace county, but the unbroken continuity of the formation, which is composed largely of coarse material and is only about 200 feet thick, suggests the possible completion of its sedimentation within the Lower Pliocene.

BENTONITIC CLAY OF THE OGALLALA.

The typical Ogallala section of Wallace county, which is made up largely of pinkish grit with many semicemented "mortar beds" in it, shows a lateral lithologic change in its lower half near the Roy Johnston ranch, in secs. 2 and 1, T. 12 S., R. 42 W. In the basal part of the local exposures of Ogallala there appear beds of fine plastic greenish and maroon-brown bentonitic clays interbedded with soft, dusty grit and sands. A comparatively thick zone of micaceous sand with occasional ripple marks (see Pl. XXV C) and small-scale cross bedding, and with many hard streaks cemented with calcium carbonate, overlies the zone of the clays. The upper part of the sandy zone changes laterally toward the southwest and west into ordinary soft grit and "mortar beds" in which rounded nodules of lime with cherty cores, also hackberry stones and fruits of herbs are common. Farther west the lower part of the sandy zone and the bentonitic clays below it are also replaced by ordinary grit and "mortar beds" of the Ogallala, in which also petrified fruits and limy nodules are occasionally found. East of the Roy Johnston ranch the Tertiary bentonitic clays disappear, but the micaceous sands are still present, resting directly on the Pierre shale. Farther east, in the western and southern parts of Salt Grass canyon, in sec. 2, T. 12 S., R. 42 W., there was apparently a prominent hill in Ogallala time built by the Pierre shale of the minor anticline of Salt Grass canyon in the E½, sec. 12, and SE¼, sec. 1, T. 12 S., R. 42 W. The top of this pre-Ogallala hill was probably never covered by Ogallala sediments, the typical beds of this formation making a distinct overlap (see Pl. XXIV B; also see geologic cross section Pl. I). This clearly exposed overlap is on the east side of the pre-Ogallala hill. The overlapping beds of Ogallala consist of soft pinkish loam below and loam and grit semicemented into "mortar beds" above. By a gradual addition of new beds from below the Ogallala formation attains its normal thickness for this area of about 80 to 100 feet in the exposures toward the east, where also a considerable thickness of greenish and chocolate-brown plastic bentonitic clays, sandy clays and sorted sands crop out below the typical "mortar beds" of the Ogallala (NW¼, sec. 8, T. 12 S., R. 41 W.).

The exposures of bentonitic clay are grouped west and east of the pre-Ogallala hill of Salt Grass canyon (Fig. 6). An exposure of green clay with white limy nodules and some white soft lime was observed north of Roy Johnston canyon in the NE¼, sec. 26, T. 11 S., R. 42 W., and south of the same canyon in the SE¼, sec. 14, T. 12 S., R. 42 W., green and chocolate-brown clays have been found. East of here, on the meridian of Salt Grass canyon, only the Pierre shale is exposed, but farther southeast along the same valley (Collins draw), in the SW¼, sec. 19, T. 12 S., R. 41 W., there is a considerable exposure of bentonitic clays, which attain here probably their greatest thickness, reaching 30 feet in the south side of the right tributary to Collins draw. In the northern part of the same tributary canyon the clays decrease in thickness from below, and besides are interbedded with sandy clays and sands and pass gradually upward into ordinary loam and grit of the Ogallala. The upper part of the loam and grit is cemented into typical "mortar bed" in which fruits of *Biorbia rugosa* have been collected, and in the clays below a few fragmentary bones were found. Smaller beds of green bentonitic clay are exposed among the beds of Ogallala grit and gravel in the NW¼ NE¼, sec. 30, T. 12 S., R. 41 W., and in the NW¼ NE¼, sec. 29, of the same township the green clay outcrops below a bed of white limestone, which contains molds of gastropods. Another small outcrop of bentonitic clay was found in the SW¼ NW¼, sec. 6, T. 13 S., R. 41 W.

West and southwest of the Guy Woodhouse ranch, in the right tributary canyon on Goose creek, bentonitic clays are also exposed. In the exposure at the head of the canyon in the NW¼ SW¼, sec. 8, T. 12 S., R. 41 W., green clay with limy nodules is overlain by "mortar beds" and yielded a few fragments of a large turtle carapace and other bones. In the much larger exposures of bentonitic clays at the mouth of the canyon, on the north side of the NW¼, sec. 8, the thick beds of green clay rest on sand, the top of which is white at the exposure (Pl. XXX A and XXX B). The green clays pass into chocolate-brown clays toward the top, and the latter are interbedded with loam and gravel (Pls. XXX A and XXX C), which in turn pass gradually upward into ordinary grit of the Ogallala. Near the base of the green clay some fragmentary bones of a rhinoceros and other mammals were collected by the writer, and a tooth of a horse and a fragment of a camel's jaw were collected here by the expedition of the University of Kansas museum in 1930. This fragmentary material awaits a final identification by a detailed comparison with more complete faunas. According to H. T. Martin the only conclusion that can be made at present is that these bones are hardly older than Miocene and may be as young as Ogallala formation.

When the writer observed for the first time these bright-colored and plastic clays near the base of typical Ogallala "mortar beds" he was impressed by this definite lower position of the clays in relation to the mortar beds and by their striking difference in lithology, and was inclined to regard the plastic clays as an older formation than the Ogallala of Wallace county. He named these clays Woodhouse clays, from a locality one mile west of Woodhouse ranch. The contrast of these highly plastic unctuous clays with the nonplastic and calcareous argillaceous members of ordinary Ogallala outcrops, which are unpleasant to touch or, if we may say "dusty," is indeed very striking. So are the bright mottled colors of the clays, the pale green making a vivid contrast with the reddish-brown to chocolate-brown, very different from the monotonous dull (pastel) pink to light-buff and to light-gray colors of ordinary

Ogallala beds elsewhere. The absence in the plastic Woodhouse clays of any traces of fine loesslike dust or loam, which is ordinarily an integral part of all coarser and finer sediments of the Ogallala, appeared to be unexplainable except by a hypothesis that the plastic clays have been deposited under different physiographic conditions in a different epoch. It appeared as if these clays might belong to the Oligocene, during which epoch a considerable quantity of clay was deposited in the basin of White river in Nebraska.

The further study of the problem of correlation of the Woodhouse clays led, however, to a different conclusion, and the clays are now regarded by the writer as a local lateral change in lithology of the lower half of the Ogallala formation. The University of Kansas museum has a collection of remains of vertebrates from the Brule clays of Nebraska and the late H. T. Martin kindly supplied the writer with a sample of typical clay in which these remains are imbedded. The comparison of this clay with samples of Woodhouse clays of Wallace county showed but little in common between the two, the clay of the Brule formation being light pink, somewhat porous and not as plastic as the Woodhouse clays. The preliminary examination by Mr. Martin of the remains of vertebrates from Woodhouse clays, as was mentioned above, showed decisively that they do not belong to Oligocene, but they may belong to either Miocene or Lower Pliocene, or to the age of the Ogallala formation of Wallace county.

A sample of Woodhouse clays was sent for preliminary examination to the department of ceramic engineering of the University of Illinois, and the report was: "We have made some examination of the sample which you sent and find that it is probably a bentonite."[185]

The suggestion that the clays are related to bentonite, and thus are probably a product of weathering of volcanic ashes, appears to have support in the mottled coloration of the clays in pale-green and maroon brown. Though some beds are more or less evenly colored with one or the other of these colors, there are nearly always considerable intermediate zones between these beds, which are mottled with irregular greenish spots and bands on a maroon or pinkish-brown ground. The local change of red color to green in sedimentary rocks is ordinarily attributed to the reducing action of organic remains in the rock. However, no traces of organic re-

---

[185] From the letter of November 4, 1930, by R. K. Hursh, acting head, Dept. Ceramic Eng., Univ. of Illinois.

mains within the greenish spots in these clays could be detected, and it seems to be more probable that the mottled greenish and reddish coloration in this material is due to reaction between gases trapped in the volcanic ash and the ash itself, the clays being most probably the product of the decomposition of the ash. The similar intimate combination of greenish and reddish colors has been frequently observed in tuffs and related volcanic materials of different ages in central and northeastern Asia.

When making the simple water test with the samples of Woodhouse clays from various localities in Wallace county the writer observed that some samples of the clays swelled and disintegrated into fine mud, whereas others did not show these effects at all. It seems to be possible that the clays represent an intimate mixture of altered volcanic ash of the Ogallala with the clayey products of disintegration of the Pierre shale of the pre-Ogallala hill near Salt Grass canyon of to-day. The Woodhouse clays have been deposited both west and east of this hill. There are no traces of local volcanic activity in this ancient hill or in any other part of western Kansas, but it seems probable that the drifting volcanic dust from a distant volcano accumulated on the lee side of this prominent hill in the same way as drifting snow accumulates on the lee side of hills and other obstacles. The writer thinks that the east side of Salt Grass hill of pre-Ogallala and Ogallala times was probably the lee side with regard to the prevailing winds which brought the volcanic dust or "ash" from somewhere in the Rocky Mountain region.

The presence of similar bentonitic clays some distance west of this hill can be explained as due to an accumulation of volcanic dust on the lee side of the next, probably less prominent, hill of the "Weskan anticline" (Fig. 6). This meridianal structural and topographic ridge, which in all probability was formed by differential settling of the sediments over a deep-seated "buried ridge," presented a topographic prominence also in pre-Ogallala and Ogallala times. The distribution of Pleistocene volcanic ashes in western Kansas, according to K. K. Landes, appears to indicate the prevalence of southwesterly winds in this epoch with the source of the volcanic dust in northeastern New Mexico.[186] A bed of unaltered bluish-white volcanic ash was found by the writer in the outcrop of Ogallala southeast of Wallace. This bed is 4½ feet thick and is about 76 feet below the topmost Ogallala bed, the concentrically banded limestone, and about 6 feet from the base of the local

---

[186] Landes, 1928, pp. 935-937 or 1928*a*, pp. 17-19.

Ogallala section. Many other localities of Tertiary volcanic ash in western Kansas are described by Landes,[187] who also mentions some clays associated with volcanic ash deposits which he thinks may be bentonitic clays.[188] W. L. Russell, who became acquainted with the Woodhouse clays of Wallace county through the writer in 1928, observed that:

> "In Rawlins, Graham, Phillips and northern Trego counties there is in places a series of Tertiary strata, which lies beneath the known Ogallala and which differs in appearance from the typical Ogallala. At the base of these pre-Ogallala strata there is a dense, flinty, pinkish- or greenish-gray sandstone with nodules of greenish chert and plentiful pebbles and grains of pink feldspar. Over this there are greenish-gray or pinkish-gray clays and laminated, fine, white micaceous sandstones. Vertebrate fossils are more plentiful in this series than in the typical Ogallala." [189]

These beds are possibly equivalents of the Woodhouse clays of Wallace county. As Woodhouse clays most probably represent locally altered volcanic ash, possibly mixed with the clayey products of disintegration of the local Pierre shale, their origin in Ogallala time is no longer puzzling, the presence of beds of volcanic ash in the Ogallala of western Kansas being not a rare occurrence. In many exposures of Wallace county the bentonitic clays are interbedded with ordinary grit and loam of the Ogallala and are replaced laterally by these rocks. The stratigraphic position of these clays in relation to the more typical Ogallala beds of the same and of neighboring exposures is shown in the correlation table, Pl. XXXIII, and on Fig. 5. It appears probable that the Woodhouse clays correspond, at least in their upper part, to the Ogallala of Wallace county, which in turn appears to correspond to the type Ogallala (about 200 feet thick) in Nebraska. The lower portion of the Woodhouse clays, in which the bones of the type locality one mile west of Woodhouse ranch were collected, may be somewhat older than the strictly Ogallala beds and may possibly belong to Upper Miocene. It is possible that the Tertiary clays in the counties east and northeast of Wallace also belong in part to slightly earlier time than the typical Ogallala beds of Wallace county, which are undoubtedly of Lower Pliocene age.

---

[187] Landes, 1928.

[188] Idem, p. 42.

[189] Russell, 1929, pp. 599-600.

"RHINOCEROS HILL" BEDS AND DIATOMACEOUS MARL OF THE OGALLALA.

In the northeast part of Wallace county, in the basin of the north fork of Smoky Hill river near the Marshall ranch, a somewhat different type of Tertiary sediments is observed, which according to the rich invertebrate fauna collected in these beds must be contemporaneous with the typical "mortar beds" of Wallace county referred by the writer to the Ogallala. The local Tertiary section, which here reaches 115 feet in thickness, begins with a deposit of grit as much as 100 feet thick. This grit has very thin streaks and nodules of calcium carbonate in 15 to 20 feet of the basal portion, above which is a 3-foot to 4-foot bed of loose and partly cemented gravel. Farther up in the grit there is only one slightly cemented bed that resembles closely the "mortar beds," but the bed is not persistent. Stemlike and rootlike remains and calcareous nodules are common in this bed, but no fossil fruits of any kind so common in Ogallala elsewhere were found in it or in neighboring beds of the section. About 10 feet above the bed and apparently conformable with it there lies a ledge of snow-white diatomaceous marl, which forms the most prominent escarpment of the locality (Pl. XXXI A). The bed of marl is 4 to 11 feet thick and was traced for about 3½ miles along the south side of the valley. A thick lens of greenish-gray sand is locally found underneath the marl; and in the upper portion of this sand, almost immediately below the marl, the bones of Lower Pliocene mammals were collected.

Microscopic examination and chemical analysis show that the diatomaceous marl is composed of tests of fresh-water diatoms and of flaky calcium carbonate in about equal proportion by volume. The flaky calcium carbonate is made partly of crushed shells of fresh-water gastropods, and to a much less extent those of pelecypods and ostracodes, the larger fragments of which are not infrequently observed along the bedding planes of the marl, and complete shells of which are plentiful in the limestone at the top of the marl.

Among the tests of diatoms in the marl long, thin and smooth spicules of sponges are scattered. This organic material constitutes about nine-tenths of the silica in the marl; the rest of the silica is of inorganic origin and consists of sand grains. These grains are of fine to medium size and are made chiefly of colorless quartz and to a much less extent of pinkish feldspar. A closer megascopic examination of the rocks discloses that these sand grains are gathered close together to form apparently crushed tubes, which resemble closely the caddis-worm cases of larvæ of the living caddisflies (Trichoptera). (See Pl. XXXI B.) The aquatic larvæ of these insects, which are especially common on the shores of lakes, construct the portable cases, in which they live, of a great variety of materials and very often of sand grains.

Occasionally skeletons and scales of small fishes are scattered in the diatomaceous marl and in the capping limy rocks above it. In the easternmost exposure of the diatomaceous marl, southeast of Marshall ranch, a fragment of a dicotyledon leaf was collected in a somewhat harder part of the rock near the base of the ledge. This leaf undoubtedly belongs to poplar and is closely related to *Populus* cf. *balsamoides* Goeppert of the Upper Miocene auriferous gravels of California,[190] and to some varieties of *Populus alexanderi* Dorf from Lower Pliocene of the Pacific coast of the United States.[191] A careful search through the bed of diatomaceous earth will probably reveal more dicotyledon leaves and other fossils, which will be of considerable scientific interest.

The diatomaceous marl is capped by a thin ledge of white limestone, which is usually full of hollows, representing molds of *Planorbis, Physa* and rarely of other fresh-water gastropods (Pl. XXVI B). Above this bed nearly 10 feet of slightly cemented grit was observed, forming the uppermost part of the local Tertiary.

In the greenish-gray loose sand that locally underlies the diatomaceous marl a rich fauna of vertebrates has been collected by expeditions of the University of Kansas Museum of Natural History. The quarry in which the collections were made is situated on Rhinoceros Hill, so named by the head of the expeditions, H. T. Martin, in the SE¼ NE¼, sec. 11, T. 11 S., R. 38 W., of Wallace county. The following is the list of identified forms kindly supplied by Mr. Martin for this report:

PERISSODACTYLS:
- *Pliohippus* cf. *leidyanus.*
- *Protohippus* cf. *P. secundus.*
- *Hipparion lenticulare.*
- *Aphelops.*
- *Teleoceros.*

CARNIVORA:
- Mustelidæ:
  - *Brachypsalis marshalli.*
- Felidæ:
  - *Pseudœlus.*
  - *Machærodus.*

---

[190] Lesquereaux, 1883, Pl. LV, figs. 3-5, especially 5.

[191] Dorf, 1930, Pl. 7, fig. 3 and others.

ARTIODACTYLS:
  Prosthenops serus.
  Prosthenops crassigensis.
  Procamelus sp.
  Paracamelus sp.
  Leptotylopus sp.
  Blastomeryx.
RODENTIA:
  Mylogaulus sp.
  Sciurus.
CARNIVORA:
 Canidæ:
  Boraphagus cyonoides.
  Aelurodon.
  Leptocyon.
PROBOSCIDIANS:
  Trilophodon sp.
  Amebelodon fricki.
AVES:
  Gruss nannodes n. sp.
CHELONIA:
  Testudo sp.
REPTILIA:
  Lacatilia gen. indet.
AMPHIBIA:
  Annura sp. indet.
  Plioambystoma kansasensis.

The fragments of bones are scattered at several outcrops east and west of Rhinoceros Hill in secs. 10, 11 and 12, T. 11 S., R. 38 W., the remains apparently coming in part from the beds immediately below the diatomaceous marl and a few fragments coming from the grit above the diatomaceous marl. The fauna of Rhinoceros Hill belongs, according to Martin, to Lower Pliocene or to the same age as the above-noted fauna from the base of the typical "mortar beds" in Collins draw, in the SE¼, sec. 27, T. 12 S., R. 41 W., where also *Pliohippus* cf. *leidyanus* was identified. Therefore the "Rhinoceros Hill" beds of the north fork of Smoky Hill river must be considered to be contemporaneous with the "mortar beds" of Wallace county, which are referred to Ogallala in this report. A more exact relation of these beds to the typical Ogallala of southern and western Wallace county is discussed below.

About three miles north and slightly west of Rhinoceros Hill, in the SW¼, sec. 26, T. 10 S., R. 38 W., in Sherman county, another "sand quarry" in the "fine silty deposit" of the Tertiary was opened by Martin,[192] the fauna of which, though closely related to the "Rhinoceros Hill" vertebrates, includes some varieties that are considered by him to indicate a slightly greater age than the latter, though still in the Lower Pliocene. It appears to the writer that these unconsolidated "fine silty" beds of Sherman county, which are called by Martin "Edson beds" (from a small town in Sherman county), must belong somewhere low in the "Rhinoceros Hill" section, probably about 50 to 80 feet below the bed from which the fauna of "Rhinoceros Hill" was collected. The underlying Pierre

---

[192] Adams and Martin, 1929, p. 504.

shale must be not far below the "Edson beds" of Sherman county and at a somewhat lower elevation than the fossiliferous sand of Rhinoceros Hill.

Diatomaceous marl similar to that of the Marshall ranch or "Rhinoceros Hill" deposits was observed by the writer in two more localities toward the southwest. If the diatomaceous marl of these localities can be considered nearly or quite contemporaneous with the bed of the same rock of the Marshall ranch, the "Rhinoceros Hill" beds will correspond to about the middle of the typical "mortar bed" section of Wallace county Ogallala, which appears to be very probable. This correlation is shown in the table of Tertiary sections on Pl. XXXIII. The white diatomaceous marl outcrops in the southeast corner of sec. 35, T. 11 S., R. 39 W., at the head of one of the many short draws on the south side of Lake creek valley,[193] where it overlies about 20 feet of slightly cemented grit. The thickness of the poorly exposed diatomaceous marl of this locality appears to be several feet, the quality of the rock being the same as that of the Marshall ranch deposits.

Another deposit of diatomaceous marl, which is slightly darker and is capped by limestone with gradual lateral change to buff-colored chert, was studied in the north-central part of sec. 29, T. 12 S., R. 41 W. Capping limestone and chert are full of beautifully preserved fresh-water gastropods (*Planorbis, Physa* and others) and pelecypods (*Muscilium*), and together with them scales of small fishes and small smooth beanlike shells of ostracodes are often found. The diatomaceous marl is underlain by light-gray clay and sand, below which pinkish grit constitutes the base of the local Tertiary, resting unconformably on Pierre shale. The diatomaceous marl of this exposure and the accompanying thin grayish clay and sand below and chert and limestone above apparently pinch out rapidly. In the next exposure east, only about 100 yards away, the gastropod limestone is underlain by green bentonitic clay. In the next exposures west, south and east of the locality the regular pink grit with "mortar beds" and occasionally with cross-bedded sandstone and conglomerate near the base are exposed. Considering the general decrease of the local Ogallala section, nearly the lower half of it being absent, the base of all these exposures will be probably about 100 feet below the concentrically banded limestone, which is only rarely exposed in the north-central part of Wallace county.

---

[193] The locality was courteously shown to the writer by Jas. T. Madigan.

The diatomaceous marl of Rhinoceros Hill and surrounding exposures near Marshall ranch appear to belong, also, to about the middle of the Ogallala, and all the exposed beds of the diatomaceous marl in the north-central and northeastern parts of Wallace county may be considered to lie at the same or nearly the same horizon of the section, as they are correlated on the accompanying chart.

Quaternary.

SANBORN FORMATION.

The name Sanborn formation is proposed for the loess, with some gravel and sand at the base, which is widely distributed on the divides in western Kansas. The name is intended as a substatute for the old terms "Tertiary marl" or "Plains marl" introduced for this formation by Robert Hay. The new name is derived from Sanborn, Neb., which is the nearest town to a locality of the formation in the northwestern corner of Cheyenne county, Kansas, where loess attains a thickness of 180 feet. Loess is exposed here in steep bluffs of numerous canyons on the south side of Arikaree river. Loess is underlain here by a few feet of Ogallala and by the Pierre shale.

The basal portion of the Sanborn loess is always sandy and in many cases coarse gravel was observed at the base of the formation.

Gravel. A wide distribution of coarse gravel was noticed chiefly in the northern half of Wallace county. The average diameter of the round stones of this gravel is from 1 to 6 inches, but in many localities there is in addition a considerable number of boulders some of which are 1½ feet in diameter, and a few boulders have been observed that were 2 or 2½ feet in diameter. (See Pls. XXXIV A and XXXIV B.) These large blocks have a more or less angular shape, but their angles are smoothly rounded, and all the surface of the blocks is smooth and shiny, though at the same time irregularly pitted, as if the surface of the blocks had been fused and smoothed by lightning. The blocks are invariably equally smooth all over their surfaces, and this smoothness can hardly be explained by repeated action of lightning, which causes only local fusion of a very small part of a rock. One could think that the evenly smooth and shiny surface of the blocks may be a result of corrosion during their transportation, but the large Pleistocene boulders of pink quartzite of northeastern Kansas, which are comparable in hardness, are only moderately smooth and never have the fusion-like polish of the western Kansas blocks just described. The cause of the exceedingly high smoothness of these blocks is therefore in doubt.

The blocks consist of medium to coarse-grained arkose cemented by secondary silica. The feldspar grains are so fresh that in thin sections they cannot be distinguished from the predominant quartz grains unless examined in polarized light. It is important to note that the siliceous cement does not entirely seal the spaces between the grains and leaves small openings in the rock. This seems to indicate that the process of cementation of the sand was interrupted and probably took place near the surface as far as it went. The rock is very tough and is not easily broken with a hammer. It is usually evenly colored gray with a slight yellowish-brown tint, which, in connection with the toughness, makes it seem like metamorphic quartzite or flint, except that the rock is always somewhat porous and cavernous. Many of the caverns have the form of straight and nearly parallel channels suggestive of molds of slender plant stems.

In many respects the blocks of arkose seem to resemble the "flint" of the South Dakota Oligocene described by Todd,[194] who observed the scattered blocks and boulders of "flint" with "frequent casts of stems and branches of shrubs, as though this flint formed around them while in their natural position, the same as may now be observed in the siliceous waters of the National Park, in Wyoming." Todd observed only one place "where this flint stratum has been found in position," which is "the top of Cave Hills, but blocks of it are scattered very generally over the whole area, sometimes in great number" . . . and "such as are found scattered upon the top of Rabbit butte indicate that their original location was several feet higher."

No microscopic description of the "flint" is given by Todd. He assumes that the rock was formed in marshes by "a chemical deposition of flint" around the stems and branches of growing plants. If the large boulders of Wallace county belong to the same formation, the latter boulders could not possibly be of local origin, because no Oliogocene deposits have ever been discovered in Wallace county or in the adjacent territory of western Kansas and eastern Colorado. The nearest known Oligocene deposits are in western Nebraska more than 100 miles north and northwest of Wallace.

A few of the heaviest boulders are made of somewhat coarser

---

[194] Todd, 1908, pp. 37-38.

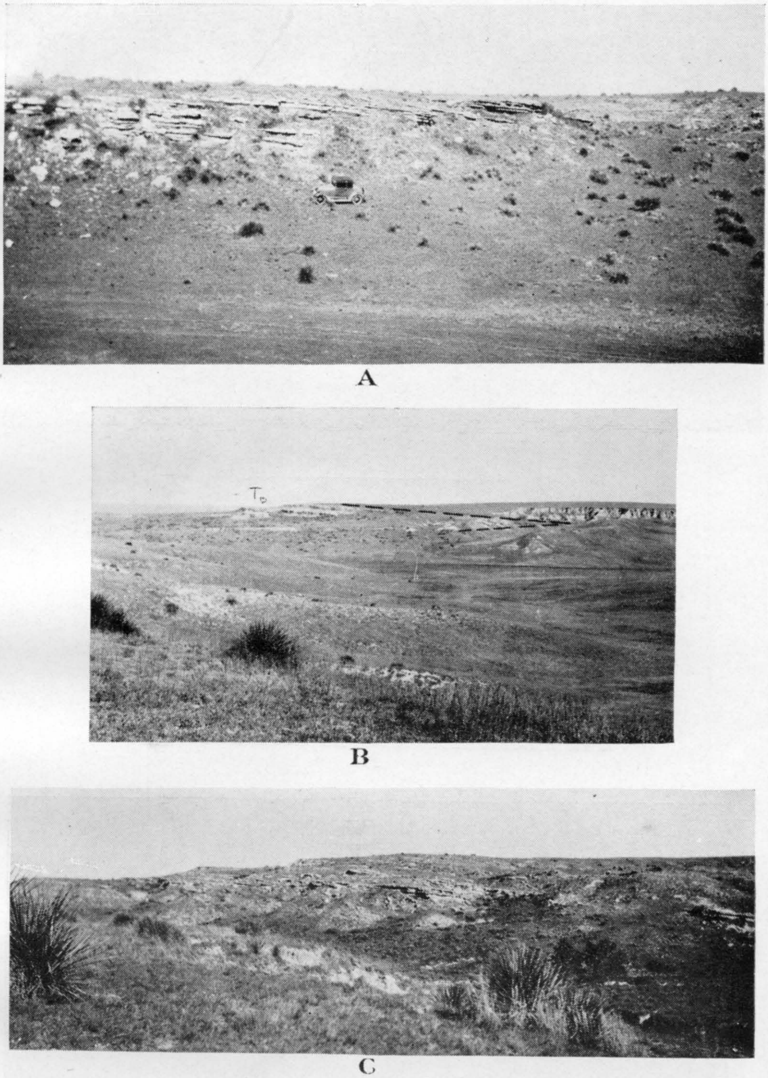


PLATE XXIV.—*A*—Series of many parallel thin "mortar beds" in sand and loam of Ogallala. In the SW¼ SE¼, sec. 6, T. 12 S., R. 41 W. *B*—Unconformity and overlap of Ogallala (*To*) over the Salt Grass shale member of the Pierre (*Ksg*). On the upper right side are vertical cliffs of Sanborn loess with lighter arenaceous and calcareous portion at the base. In the SW¼, sec. 6, T. 12 S., R. 41 W. *C*—Apparent dip of Ogallala on the south side of Swisegood dome of Willow Creek structure. In the SE¼, sec. 11, T. 13 S., R. 42 W., looking east.

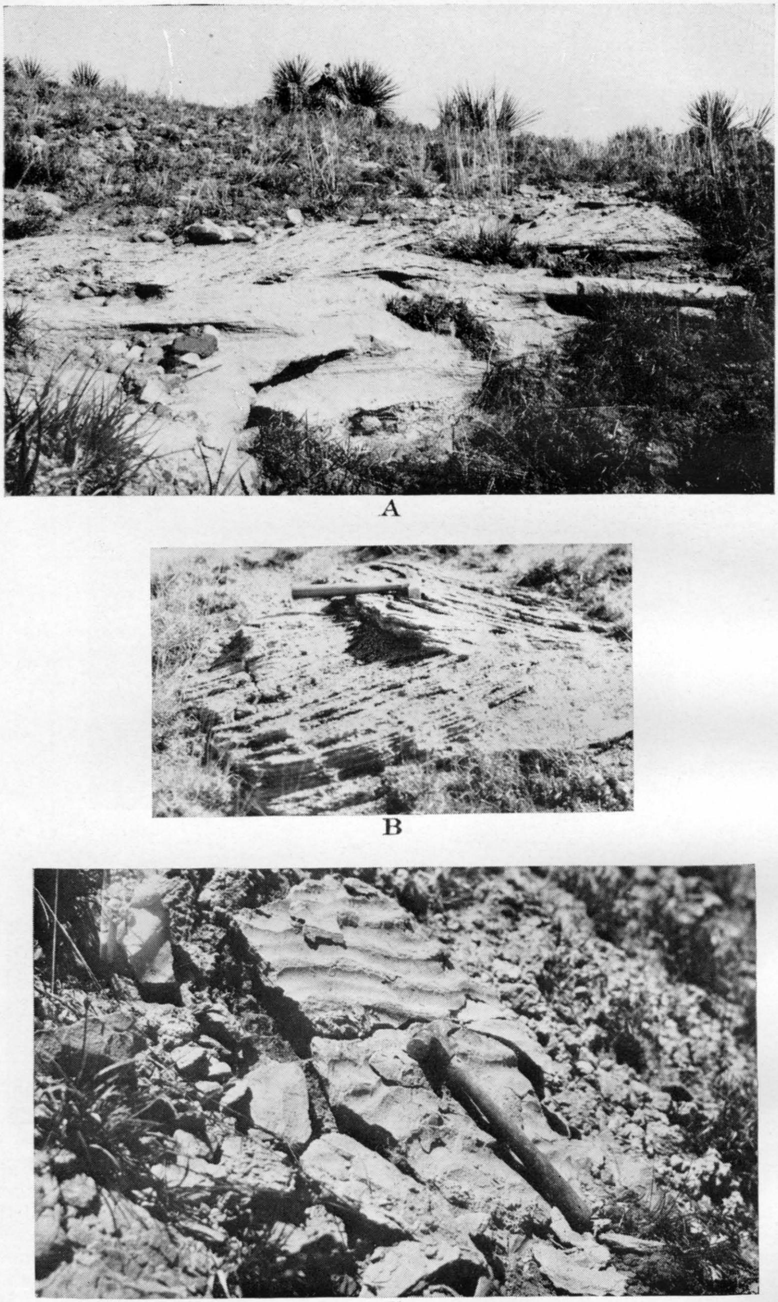
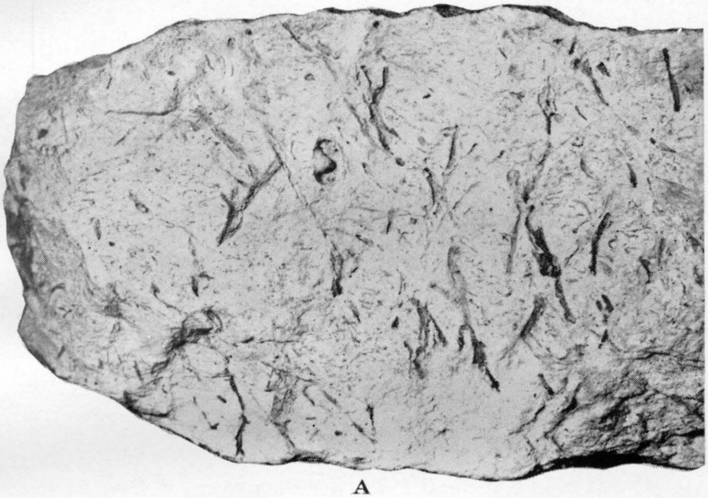
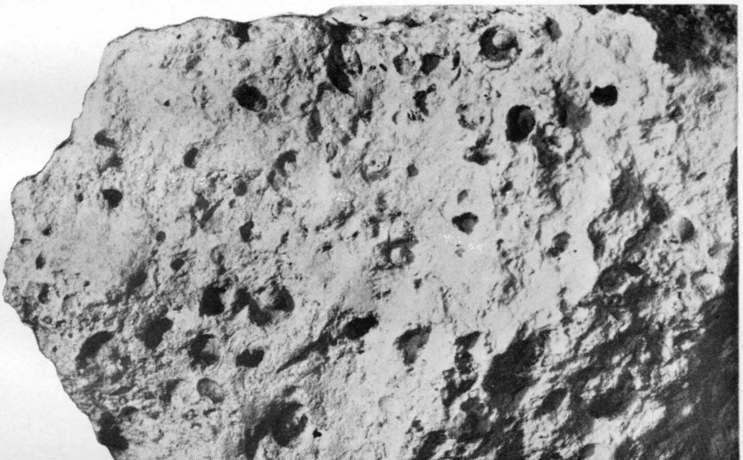


PLATE XXV.—*A*—Ogallala hard stratified and cross-bedded ledge of sorted coarse sand to fine conglomerate. Pleistocene (?) gravel above. In the SW¼ NW¼, sec. 35, T. 11 S., R. 40 W. *B*—Same bed in the SW¼ NE¼, sec. 3, T. 13 S., R. 41 W. *C*—Ogallala fine semicemented micaceous sand with ripple marks. In the SE¼ NE¼, sec. 2, T. 12 S., R. 42 W.



A



B

PLATE XXVI.—*A*—Ogallala porous limestone with admixture of diatoms molds of gastropods (*Planorbis* and rarely others) and molds of roots (?) *B*—Ogallala porous limestone with admixture of diatoms and molds of *Planorbis.*

PLATE XXVII.—*A*—Cluster of *Celtis willistoni* stones in Ogallala grit abcut 50 feet below *Chlorellopsis* limestone. One-half natural size. In the SW¼ SE¼, sec. 11, T. 13 S., R. 42 W. *B*—*Celtis willistoni* in grit about 15 feet above the base of Ogallala at Beecher Island, Yuma county, Colorado. Natural size. Negative by Charles Rankin. *C*—*Krynitzkia coroniformis* Elias, n. sp. Nutlets in calcareous loam about 20 feet above the base of Ogallala at Beecher Island, Yuma county, Colorado. Natural size.

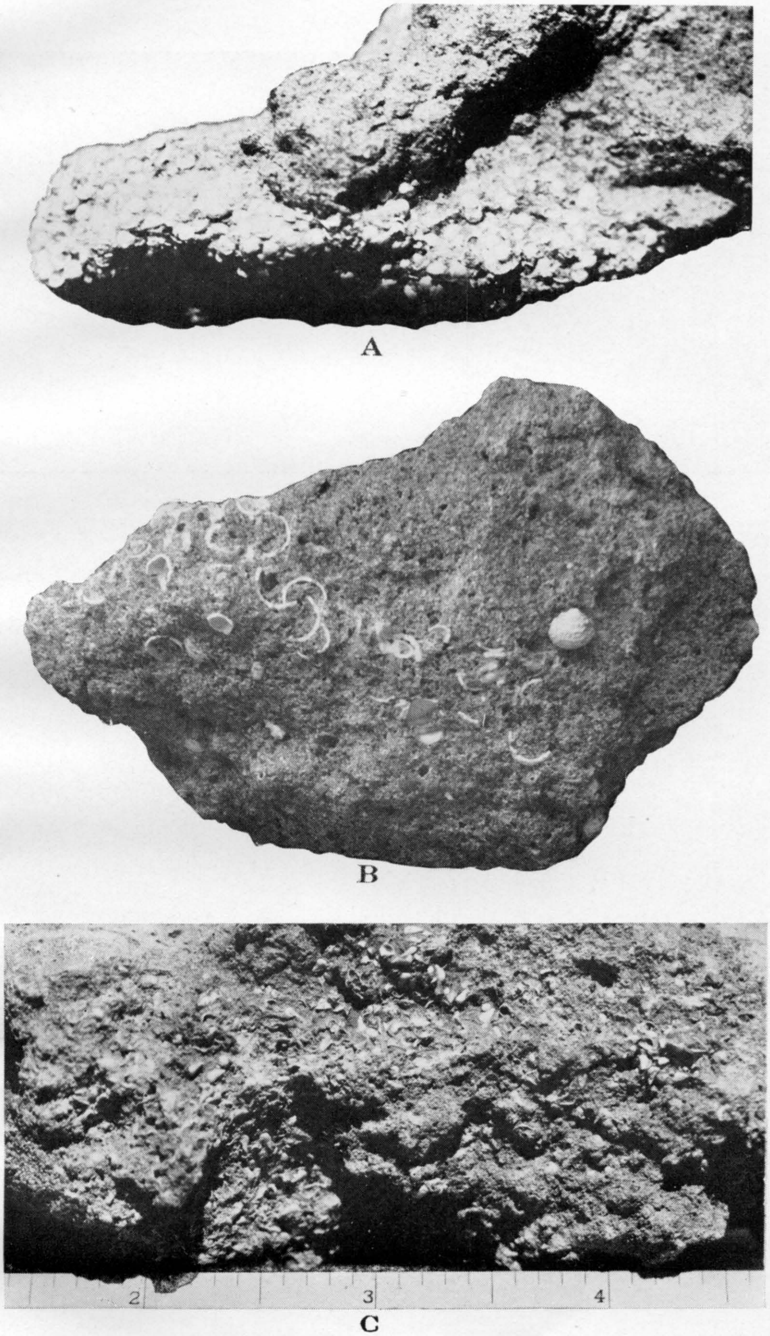


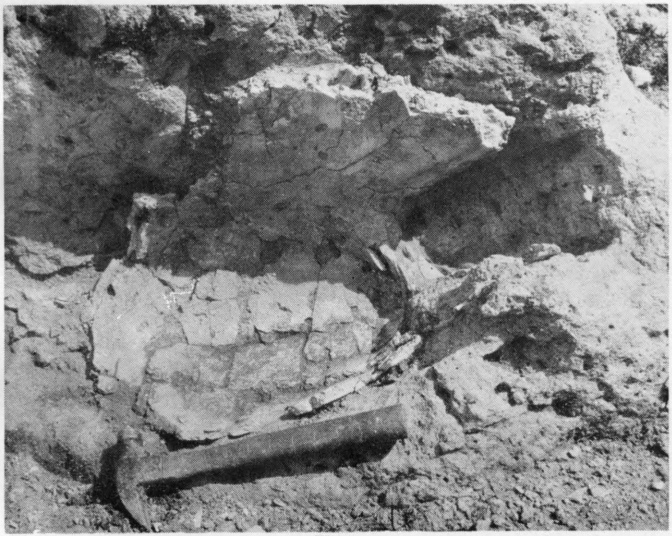
PLATE XXVII.

A

B

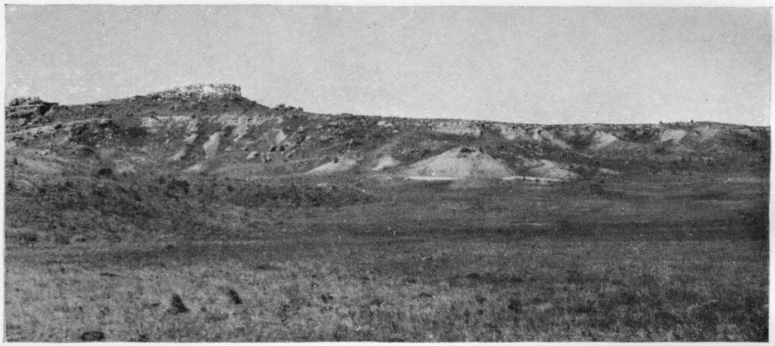
Plate XXVIII.—*A*—Petrified (calcareous) roots in grit and living roots, marked by arrows, about 30 feet above the base of Ogallala at Beecher Island, Yuma county, Colorado. *B*—Same bed as shown in *A* with an addition of larger rootlike bodies made of chert. Same locality.

A

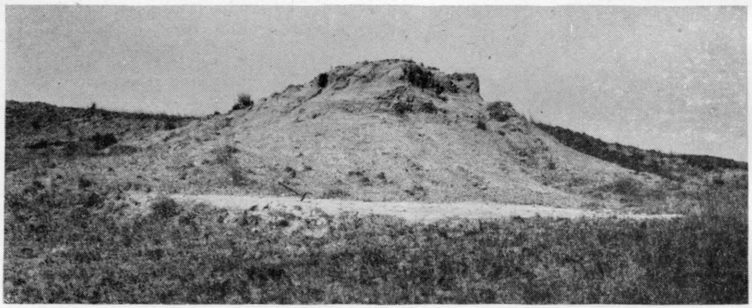


B

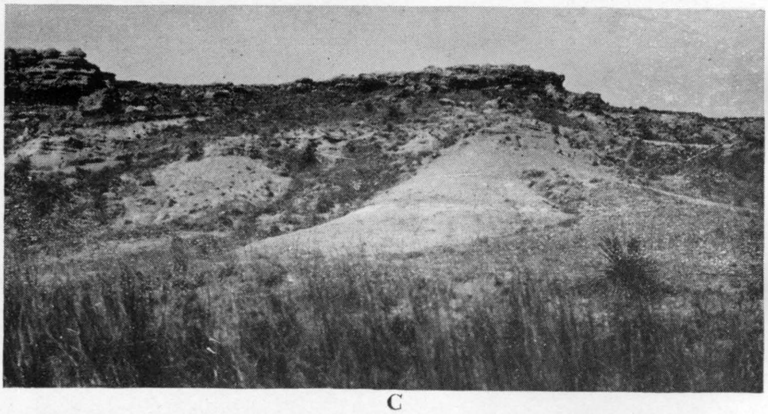
PLATE XXIX.—*A*—Mold of bark of a tree (?) in grit of Ogallala. *B*—Part of carapace of the turtle *Testudo* (*Xerobites*) cf. *orthopigia* in grit about 90 feet below *Chlorellopsis* limestone of Ogallala. In the NE¼ SE¼, sec. 3, T. 12 S., R. 42 W



A



B



C

PLATE XXX.—*A*—General view of type locality of Woodhouse bentonitic clays of Ogallala. For columnar section see Plate XXXIII-3. In the NW¼ NW¼, sec. 8, T. 12 S., R. 41 W., looking southwest. *B*—Detail of the same exposure as *A*. White sandstone is shown at the base of green bentonitic clay. *C*—Detail of southwestern part of the locality shown in *A*. Green bentonitic clay below; white streak corresponds to limy nodules and infiltrations; on the top are "mortar beds."

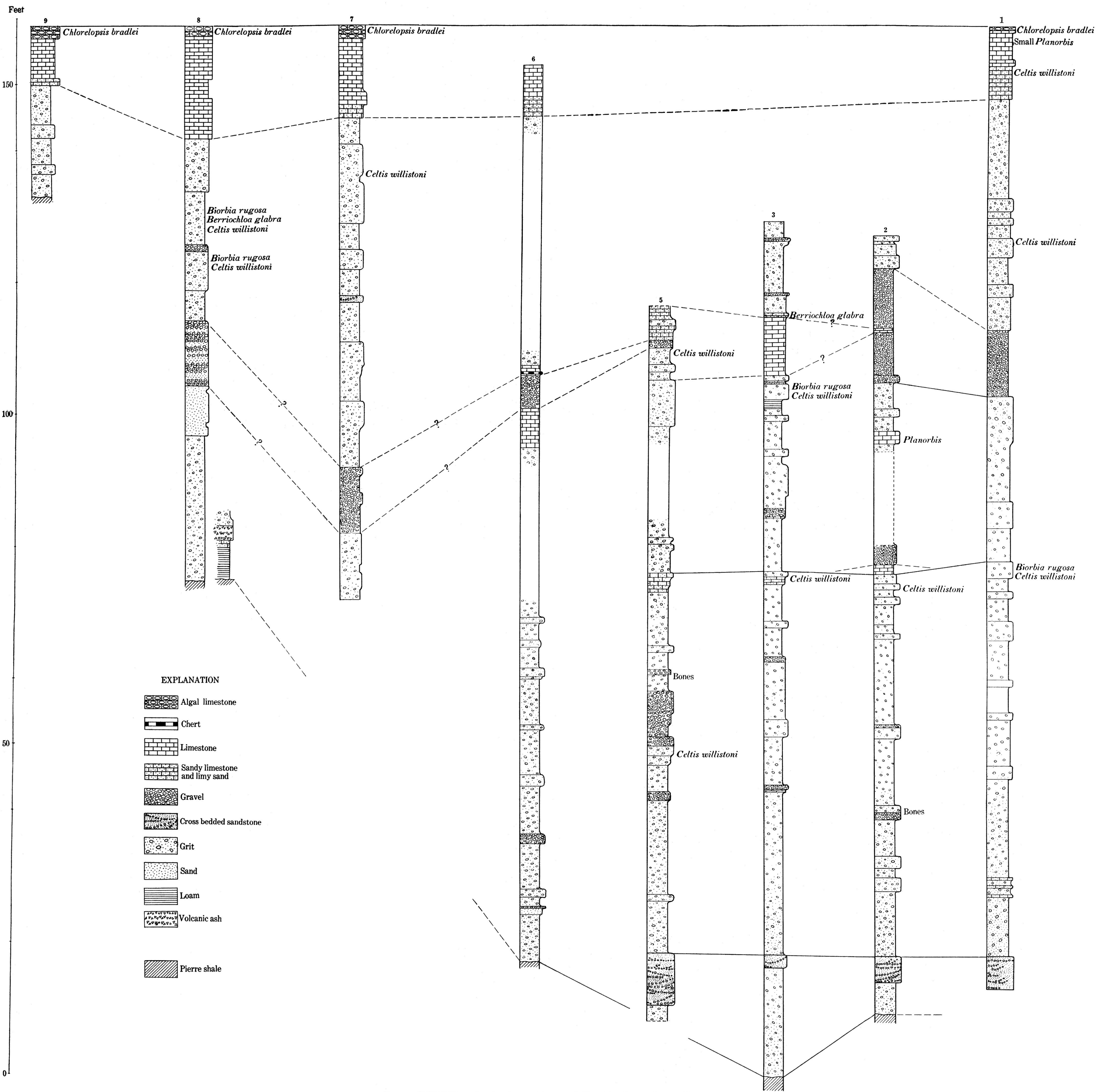
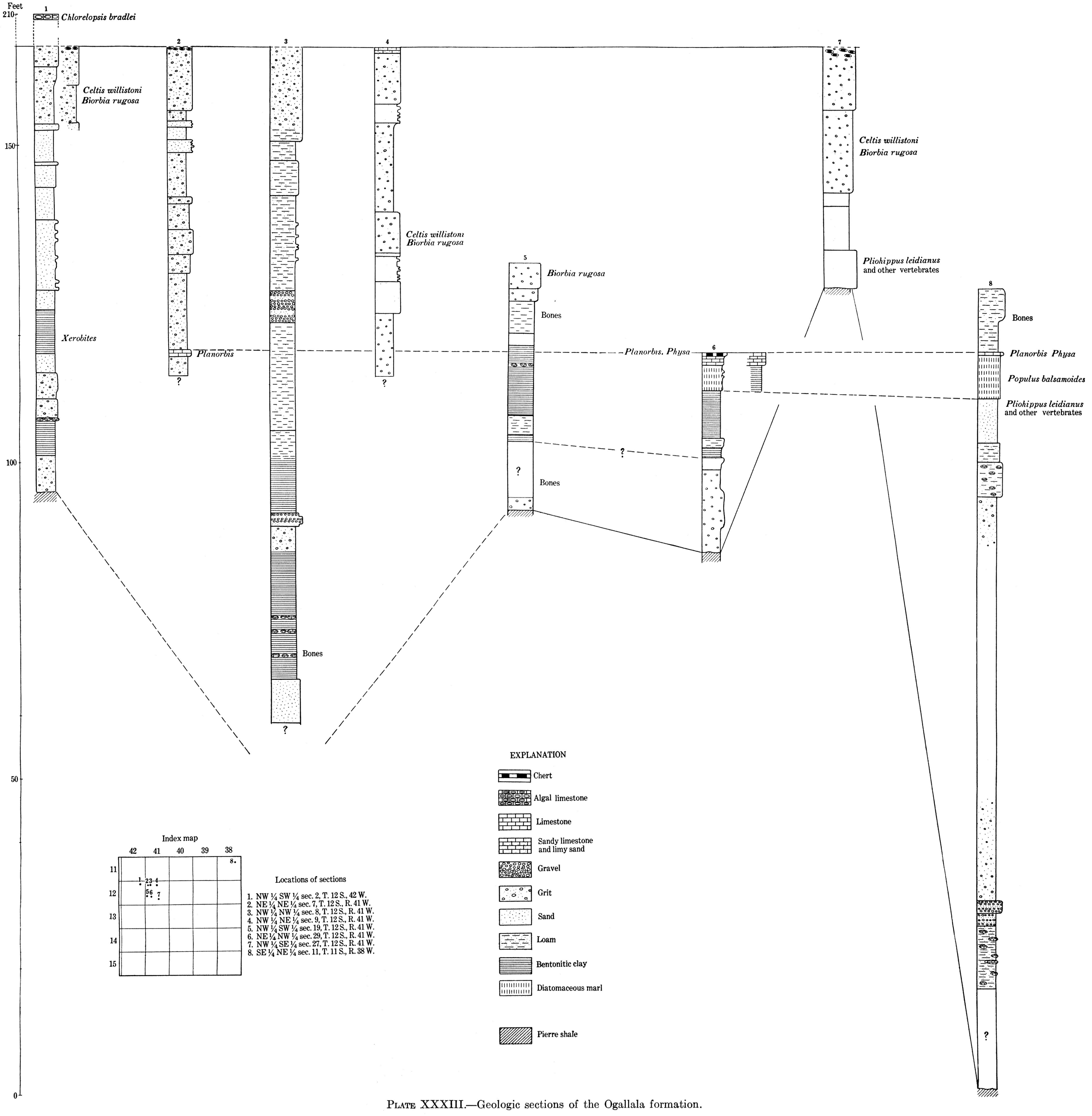


Plate XXXII.—Geologic sections of the Ogallala formation.

Locations of sections

1. SE ¼ sec. 10, T. 13 S., R. 42 W.
2. Center SW ¼ sec. 11, T. 13 S., R. 42 W.
3. NE ¼ SE¼ sec. 11, T. 13 S., R. 42 W.
4. SW ¼ SW ¼ sec. 12, T. 13 S., R. 42W.
5. SE ¼ sec. 35, T. 12 S., R. 42 W.
6. NE ¼ NW ¼ sec. 16, T. 14 S., R. 40 W.
7. NW ¼ SW ¼ sec. 7, T. 14 S., R. 38 W.
8. SE ¼ sec. 8, T. 14 S., R. 38 W.
9. SE ¼ NE ¼ sec. 12, T. 14 S., R. 38 W.



Locations of sections

1. NW ¼ SW ¼ sec. 2, T. 12 S., 42 W.
2. NE ¼ NE ¼ sec. 7, T. 12 S., R. 41 W.
3. NW ¼ NW ¼ sec. 8, T. 12 S., R. 41 W.
4. NW ¼ NE ¼ sec. 9, T. 12 S., R. 41 W.
5. NW ¼ SW ¼ sec. 19, T. 12 S., R. 41 W.
6. NE ¼ NW ¼ sec. 29, T. 12 S., R. 41 W.
7. NW ¼ SE ¼ sec. 27, T. 12 S., R. 41 W.
8. SE ¼ NE ¼ sec. 11, T. 11 S., R. 38 W.

PLATE XXXIII.—Geologic sections of the Ogallala formation.

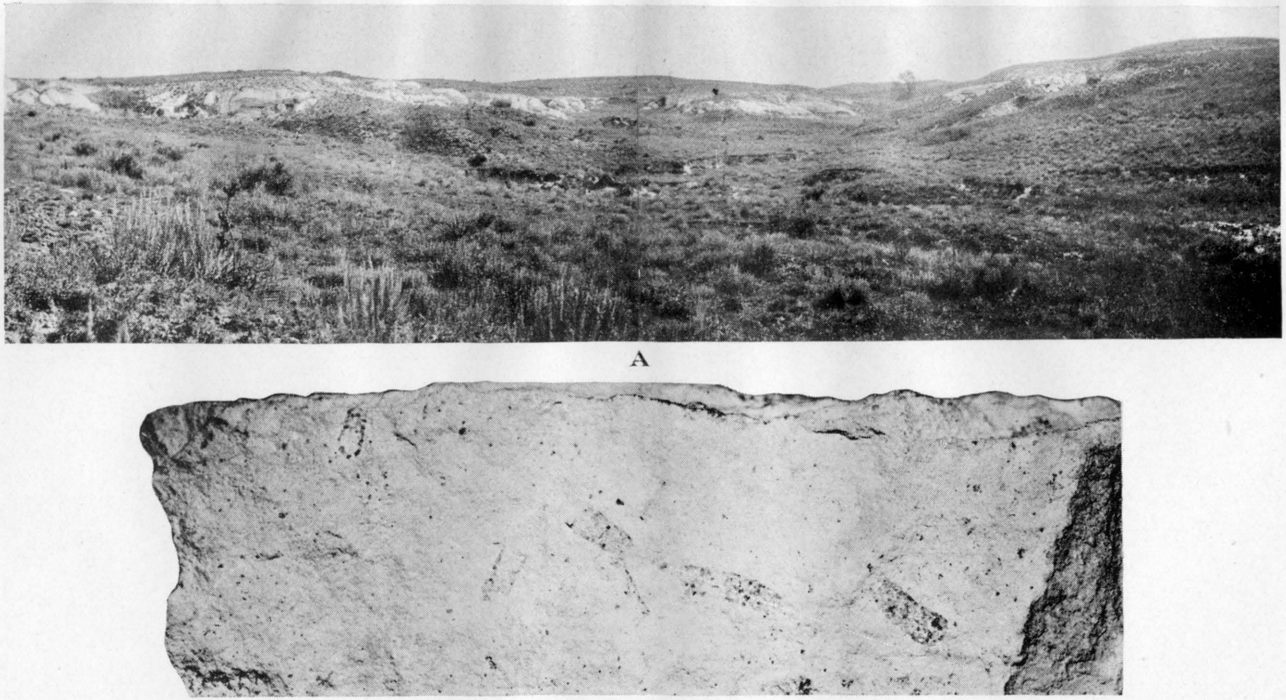
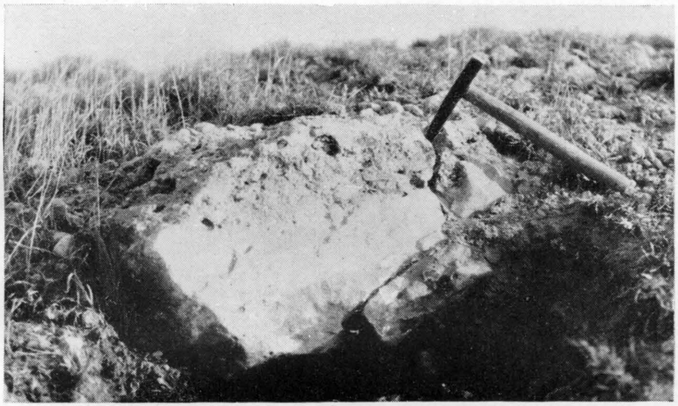


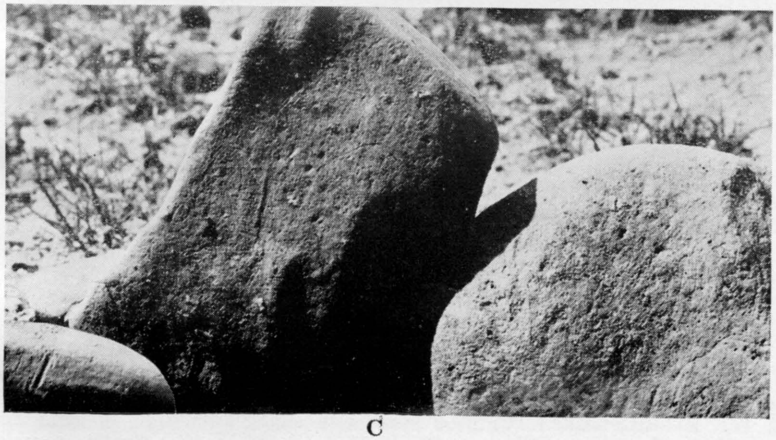
Plate XXXI.—*A*—Diatomaceous marl of Ogallala. Exposures west of Rhinoceros Hill on south side of north fork of Smoky Hill river, in the NE¼ SE¼, sec. 11, T. 11 S., R. 38 W. *B*—Diatomaceous marl of Ogallala, with flattened cases of caddis worms made of sand grains. Natural size. Same locality.

PLATE XXXIV.—Pleistocene gravel. *A*—Boulder of tough, greenish, coarse arcose with siliceous cement. From the NE¼ SW¼, sec. 27, T. 12 S., R. 41 W. *B*—Boulder of gray to brownish cavernous arcose. From the NW¼ NW¼, sec. 32, T. 12 S., R. 41 W. *C*—Scratched cobbles of porphyry. Two-thirds natural size. From the NW¼, sec. 35, T. 11 S., R. 40 W.



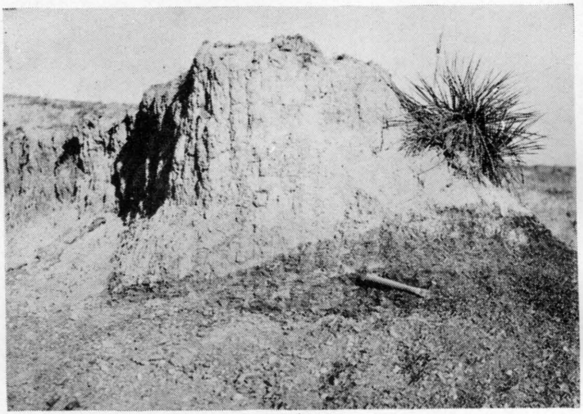
A

B

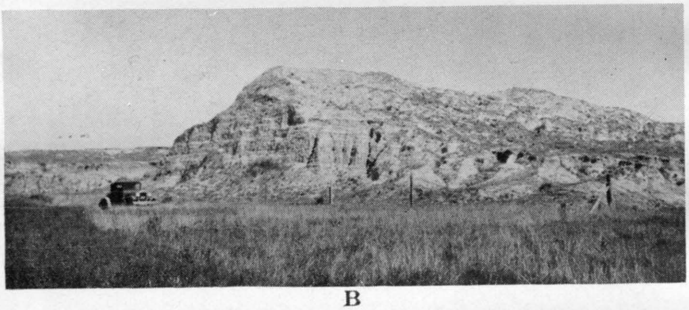


C

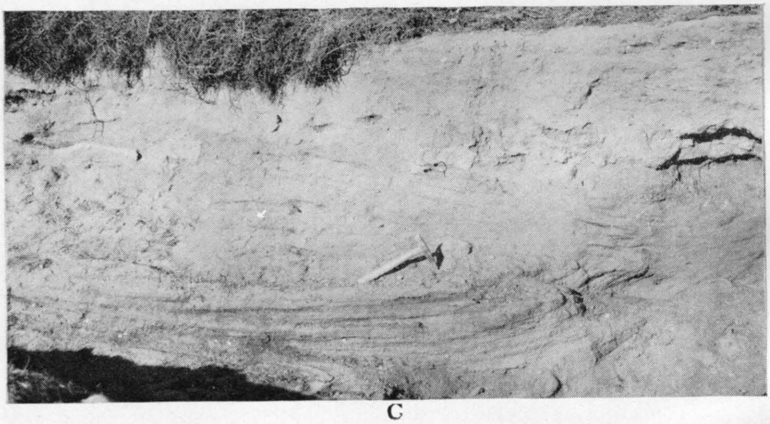
Plate XXXIV.



A



B



C

PLATE XXXV.—*A*—Sanborn formation. Typical loess with vertical cleavage resting upon Pierre shale. In the center of the NE¼, sec. 12, T. 13 S., R. 42 W. *B*—Redeposited stratified loess with slight admixture of sand and gravel. In the SE¼ SW¼, sec. 12, T. 13 S., R. 42 W. *C*—Sandy alluvium with cross-bedding. In the channel of Goose creek, in sec. 36, T. 11 S., R. 43 W.

arkose, which is brightly colored greenish to yellowish green and contains pink feldspars. This arkose is also cemented by secondary silica into a very tough rock. The regular round stones of the gravel are made chiefly of various kinds of igneous and metamorphic rocks, among which were recognized granite of various kinds, pegmatite, various porphyries, basalt, quartz (rock crystal, colorless, and smoky), flint, jasper, quartzite and other hard rocks. Rounded fragments of wood petrified into flint are not rare, and a very few specimens of gray and brownish flint containing fusulinids, *Productus* and *Spirifer,* of probable Pennsylvanian age, have been collected in NW¼, sec. 35, T. 11 S., R. 40 W. There is hardly any doubt that all or nearly all of these rocks have been transported from the Rocky Mountains. Not a single cobble or boulder of pink quartzite, which is the most common rock in the glacial drift of northeastern Kansas, has ever been noticed in this material.

Among the medium-sized cobbles some were occasionally found with scratched surface. Almost all of these were composed of greenish-gray porphyry, a comparatively soft and thus comparatively easily scratched rock, containing scattered crystals of unaltered, nearly transparent feldspar and a few of hornblende. The phenocrysts usually project slightly above the surface of the cobbles, but many fall out and leave small cavities (Pl. XXXIV C). Occasionally short but comparatively deep and angular grooves stretch from these cavities or from broken crystals, as if the grooves had been produced by the crystals being torn under considerable pressure through the surface of the inclosing rock. The majority of the scratches are, however, faint and are visible only under strong tangential illumination. Nearly all of the scratches are short and straight or slightly curved, but some are curved pronouncedly. Only in one locality have there been found (by W. L. Russell) cobbles of another porphyry of reddish-brown color and with few, if any, phenocrysts. This is also a comparatively soft rock easily scratched with a pocket knife.

The writer noticed that pronounced weathering of many cobbles has occurred since they were deposited. This weathering is manifested by exfoliation in some cobbles, and in others by the development of irregular transverse cracks. It is interesting, also, that among the cobbles now scattered on the surface many have the so-called "desert varnish," a thin black shiny coating on the side turned up. Some of the scratched cobbles have this black coat covering both the polished surfaces and the scratches. Other scratched cobbles have been exfoliated, and the scratches can be observed only on the remnants of the old polished surface here and there on the cobble.

The coarse gravel with scratched cobbles in it does not belong to the Ogallala formation, but is of later age. It is true that there are gravels within the Ogallala that are composed of the same rocks, the Rocky Mountains being the common source for the material of both, but the writer has never been able to observe in the undoubted beds of Ogallala gravel either the scratched cobbles or the large angular boulders of arkose. At one place he observed a few of the arkose boulders clearly above the outcropping topmost bed of Ogallala—the concentrically banded algal limestone (in the NW¼, sec. 2, T. 12 S., R. 40 W.). In many exposures the gravel was observed directly below loess of the divides and above the Ogallala and the Pierre. In these outcrops the upper part of the gravel is mixed with loess. The thickness of the gravel varies and hardly exceeds 15 feet at the most; it is difficult to measure exactly on the outcrops because the gravel is unconsolidated. The best way to distinguish this gravel from the gravels of the Ogallala formation is to find fragments of Ogallala rocks in the material of the later gravel. Fragments of Ogallala limestones have been found by the writer in several exposures of the gravel.

Whatever theory as to the origin of this gravel is proposed must explain the presence of scratched cobbles and heavy boulders among the material. It is apparent that no stream or flood of water could have brought it from the Rocky Mountain region, the slope of the valleys and of the prairie of the Great Plains being inclined too gently. The presence of very large boulders and of scratched cobbles suggests transportation by ice, but as no glaciers of the Pleistocene are known to have advanced over this region, it seems that river or flood ice is the only possible agency that could bring the heavy boulders, some being 2½ feet in diameter. The same river ice could scratch any cobbles frozen into it against other rocky material during possible river jams comparable to those on the Mackenzie and other Arctic rivers of to-day.

Loess. The loess of the Pleistocene of western Kansas, which is here defined as constituting the major part of the Sanborn formation, was first recognized as a distinct stratigraphic unit and set apart from the older (Ogallala) deposits by Robert Hay. The descriptions and geologic cross sections by this author indicate clearly that the formation, which he named "Plains marl," is what we now call loess. According to Hay it overlies unconformably the "Tertiary grit" or what is now called Ogallala.[195] Hay remarks that what he calls "Tertiary marl" or "Plains marl" (a later term) "has been called loess by geologists of both Nebraska and Colorado." (Hay, 1895, p. 574). Haworth compares the "Plains marl" of Hay to loess in the following words: "In general character this is surprisingly similar to the glacial loess so well known in many parts of the world. . . It is probable that many of the properties of the plains marl are largely due to the action of wind."[196] He acknowledges, also, the frequent occurrence of the "Plains marl" above the "mortar beds."[197] Darton speaks of the loess of northern Kansas mantling "a somewhat irregular surface composed of Tertiary deposits and the several Upper Cretaceous formations."[198] Loess of western Kansas is treated as a separate post-Tertiary formation in the modern papers on the underground resources of Kansas.[199]

The loess of Wallace county, which is locally called "yellow dirt," "badger dirt," etc., covers not less than nine-tenths of the county, being found both on the divides and on the slopes and bottoms of the valleys. It seems to the writer that only the loess that covers the divides can be considered to be of Pleistocene age, the loess of the valley slopes and bottoms being largely if not wholly redeposited from the divides, the redeposition having taken place probably for the most part in late Pleistocene and Recent times. At any rate redeposition of the topographically higher loess to the lower areas is still going on, the wind and surficial waters being the chief agents of transportation.

In Wallace county the loess of the divides (Pl. XXIV B on the right and Pl. XXXV A) varies in thickness, having an average of about 20 to 40 feet, and probably does not exceed 60 feet thick. The loess of the divides is yellowish buff, is porous, not stratified and builds perfectly vertical cliffs. All these features are typical physical properties of loess in the restricted sense, as recently set forth by G. B. Barbour.[200] Toward the base it becomes sandy and grades into the gravel described above. The name Sanborn forma-

---

[195] See many geologic sections by Hay, 1890, and the sections on Pl. XLII, between pp. 548-549, Hay, 1895.

[196] Haworth, 1897, p. 275.

[197] Idem, p. 280; also Haworth, 1897*a*, p. 58.

[198] Darton, 1905, p. 155.

[199] Moore and Landes, 1927, p. 32.

[200] Barbour, 1927, p. 281, and Barbour, 1930, p. 463.

tion is introduced for this loess of the divides alone, including its sandy base and the underlying gravel.

The loess of the valley slopes, which is reworked loess of the divides and must not be called Sanborn formation, attains a thickness of 50 feet, but approaches that thickness in only a few places, usually along a narrow zone high on the slopes. This loess is usually distinctly stratified (Pls. XX A and XXXV B), which is due to the interbedded layers composed of fragments of locally outcropping rocks (chiefly Ogallala) mixed with loess. The valley-bottom loess (Pl. XXXV C, upper part) is more evenly distributed and is usually 10 to 15 feet thick. It passes downward into alluvial sands and gravel, and it also must be regarded as a part of the alluvial deposits. The river loess is usually colored not as brightly yellow as the loess of the divides, but is yellowish-gray to gray, the dull tinge being apparently due to admixture of humus.

An analysis of Wallace county loess was kindly supplied to the writer by Harry C. Wheeler. The sample analyzed was taken from the basement of Mr. Wheeler's house at Sharon Springs, and the analysis was made by J. A. Stadler, chemist of the Lehigh Portland Cement Co., Iola, Kan. It is remarkable that this western Kansas loess, which so many writers hesitated to call by its proper name, is closer in chemical constitution to the loess of China, or to the loess of the type locality of this interesting rock, than all other loesslike rocks and adobe soils of Europe and North America that were many years ago compared with Chinese loess.[201]

Analyses of loess from various localities.

	Loess of Wallace county, Kansas.	Typical Chinese loess.	"Loess soil" of Cherokee county, Kansas.	Loess at Kansas City, Mo.
SiO_2	63.33	62.22	69.66	74.46
Al_2O_3	12.92	18.1	12.71	12.26
Fe_2O_3	3.34		4.89	3.25
CaO	5.44	6.31	1.09	1.69
MgO	1.96	2.09	1.28	1.12
Na_2O	......	.22	1.17	1.43
K_2O	......	.99	2.42	1.83
CO_2	*......	4.10	......	.49
H_2O (at 110°)	......	.73	......	2.70
Loss on ignition	9.62	1.81	......	......

The writer did not succeed in finding any fossils in the loess of the divides of Wallace county or the Sanborn loess of western Kansas, though in the stratified loess on valley slopes and in the grayish loess of the valley bottoms he has occasionally found bones of buffalo.

---

* Included in loss on ignition.

[201] Compare analyses in Clarke, 1924, p. 514, and Barbour, 1927, pp. 282-283.

ALLUVIUM.

The valleys of Wallace county are surfaced with alluvial deposits, which ordinarily consist of sand and gravel below (Pl. XXXV C, lower part) and of more or less sandy river loess above (Pl. XXXV C, upper part). In the areas of the widest distribution of the outcrops of Ogallala, as in the basin of the south fork of Smoky Hill river, west of Wallace, or on Goose creek at about the same meridian, the alluvial sands and gravels attain in places a thickness of 40 feet. They show distinct cross-bedding (Pl. XXXV C, lower part) in the exposures and at a few places show a slight cementation with calcium carbonate, thus imitating some sands and gravels of the Ogallala.

In other areas the thickness of the alluvium rarely exceeds 20 feet, which includes the sandy river loess.

GEOLOGIC STRUCTURE.

INTRODUCTION.

Below the comparatively thin veneer of post-Tertiary alluvium, loess and gravel, which mantles the eroded surface of the older rocks of Wallace county, lie Tertiary and Cretaceous deposits, which show various inclinations of their strata and occasional abrupt interruptions of the continuity of the beds. The character and the origin of these irregularities of the outcropping Tertiary and Cretaceous deposits will now be discussed.

Very little can be inferred as to the structural features of the underlying and unexposed formations, for very few deep wells have been drilled in Wallace county and the adjacent area.

GENERAL FEATURES.

The two larger outcropping stratigraphic units, the Ogallala of the Tertiary and the Pierre and Niobrara of the Upper Cretaceous, are separated by a distinct and pronounced unconformity, which indicates a prolonged erosional interval extending from the close of the Cretaceous to the end of the Miocene. During this time local tilting of the earth's crust occurred, which is indicated by the marked regional nonconformity between the Upper Cretaceous and the Ogallala. The Upper Cretaceous sediments show a distinct regional dip to the north in the eastern part of Wallace county and to the north and northeast in the western part. The rate of this dip is on the average about 20 feet to the mile. The overlying Ogallala deposits, on the other hand, have a distinct general inclination to the east with an average rate of about 20 feet to the mile in the western half of the county, but only about 5 feet to the mile in the southeastern quarter of the county.

As was stated in the chapter on the physiography of Wallace county, the river valleys descend only a little more steeply in an eastern direction than the dip of the sediments and thus cut gradually deeper into the great terrace of the High Plains, which is built of hard ledges of Ogallala and an overlying mantle of gravel and loess.

Owing to the apparent pre-Ogallala tilting of the Upper Cretaceous deposits and their subsequent differential erosion, the Ogallala rests upon various members of these older deposits in different parts of the area. In central Logan county Ogallala rests upon the topmost beds of Niobrara chalk and on various beds of the lowermost or Sharon Springs member of the Pierre, whereas in Wallace county the same Tertiary formation directly overlies the Sharon Springs member of the Pierre in the east and southeast areas and the higher Weskan, Lake Creek and Salt Grass members of the Pierre at various places in the northern and northwestern parts of the county. Taking into account the general gradual decrease of the thickness of the Pierre toward the east, which was discussed in the stratigraphic chapter, we may estimate the average amount of the regional nonconformity between the Upper Cretaceous and Ogallala to be about 5 or 6 feet to a mile in an eastern direction. The nonconformity in a northern direction is much more pronounced, being on an average about 15 feet to a mile.

Upon the block of Upper Cretaceous and Tertiary beds with the above-described regional inclinations and mutual relations there are superimposed folds and faults having various directions and magnitudes, as is illustrated on the accompanying structural map of Wallace county and on the two geologic sections across it.

Method of Structural Mapping.

The structural map of Wallace county, which is shown on Plate XLII, is made by determining the altitudes of the outcropping beds subsequent to their correlation. The elevations taken on the several beds chosen as key beds were reduced to the two main key beds—the top of the Niobrara chalk of the Upper Cretaceous, and the top bed of the Ogallala, or the concentrically banded, pink algal (*Chlorellopsis*) limestone. The latter was used as the main key bed in the southern, western and northwestern parts of Wallace county, where the Cretaceous rocks are very poorly or not at all exposed.

The structural map is not based, therefore, on the local dips observed in the beds, as is sometimes done, but these dips, especially where persistent, were not altogether neglected, but were used for a better spacing of the structural contours in those areas where the outcrops are scant. Necessary caution was exercised in their use, and the local dips of some areas have been found so varied and in places so contradictory to the structural features established by observation of the altitudes of the key beds that they were entirely discarded for the purposes of the structural mapping. The unreliability of the observed local dips in the Cretaceous strata of western Kansas has been pointed out already by Twenhofel[202] and other authors. The causes of the surficial and other local deformations of the outcropping beds of Wallace county that obscure their main structural features will be discussed below.

KEY BEDS IN THE UPPER CRETACEOUS.

In Wallace county the top of the Niobrara chalk or the contact between the Pierre and the underlying Niobrara (Pl. III A) is exposed only in some canyons on the south side of the south fork of Smoky Hill river south and southeast of Wallace.[203] The Niobrara is little exposed in Wallace county, and in the few uppermost scores of feet of thickness of the exposed chalk the writer did not find any particularly remarkable beds or zones that could be conveniently used as key beds.

The contact between the Pierre and Niobrara in the studied exposures appears to be quite conformable, and all the elevations taken on the various key beds in the Pierre have been reduced to the top of Niobrara on the assumption that the Pierre overlies the Niobrara conformably all over Wallace county. The top of Niobrara was used as the main key bed in the Cretaceous.

KEY BEDS IN THE PIERRE.

The Pierre shale is exposed in many more places than the Niobrara, and the key beds in the Pierre naturally have been much more used for the structural mapping than the rarely exposed top of the Nio-

---

[202] Twenhofel, 1925.

[203] The recognition of the contact is discussed on pages 29-31 of this report.

brara chalk. Some of the most important concretionary zones of the Pierre, which form prominent escarpments in the outcrops of the formation, have been the only beds in the Pierre used for the structural mapping. Thanks to their prominence in the outcrops they can usually be found comparatively easily and their lithology can be readily studied. These zones also usually yield most of the fossils in the formation, and hence their correlation can be checked by the important paleontological method.

Following is a list of the most important key beds in the Pierre of Wallace county with their characteristics and a comparison with the somewhat similar beds for which they can be mistaken. The distances of these key beds to the top of the Niobrara chalk, adopted for the structural mapping of Wallace county, are added. The key beds are listed from bottom up:

1. Zone of gigantic septarian concretions with veinlets 1½ to 2 inches thick on the top of the Sharon Springs shale member (Pls. V *A,* V *B,* V *C,* VI *A* and VI *B*). Occasional presence of barite in large crystals in the fibrous and crystalline calcite veinlets of the concretions is typical. Few or no other fossils than fish scales and bones in shale and in the gray tough fine-grained limy matrix of the concretions. The large limy concretions on the top of the upper Weskan shale member have sometimes a net of calcite veinlets, but these veinlets are not more than one-fourth of an inch thick; besides these concretions are never as large as those of the Sharon Springs shale. Gigantic septarian concretions, as big as or bigger than those of the Sharon Springs shale member, are common in the Blue Hill shale of the Carlile. The zone of these concretions is about 25 feet below the base of Fort Hays[204] limestone, or nearly 1,000 feet below the septarian zone of the Sharon Springs shale member.

2. Zone of somewhat scattered limestone concretions about 30 feet below the top of the upper Weskan shale member. The concretions are about 6 inches thick and several times as much across and are made of tough finely crystallized bluish-gray limestone. They are much like the concretions of key bed No. 3 described below, having also occasional *Anomia* shells and fragmentary *Inoceramus,* but *Ostrea* shells have never been found in these concretions. Nor has *Serpula* (?) *wallacensis* been found in this zone. The presence of scattered small "perforated concretions" in the shale helps to identify this zone, as well as the presence of comparatively thick (some 1 foot) bentonite streaks below the concretionary zone. This is the only zone in the Lower Weskan shale member which can be used, with some caution, as a key bed.

3. Zone of limestone concretions in the middle of the Upper Weskan shale member (Pls. X *A* and X *B*). The concretions reach 6 inches in thickness and several times as much across and are made of bluish-gray to nearly white tough limestone. *Anomia* and *Ostrea* shells, many of them attached to large and nearly flat *Inoceramus* shells, are very abundant. *Serpula* (?) *wallacensis*

---

[204] Bass, 1926, p. 63.

is abundant in the surrounding shale. The concretionary zone usually consists of two or three layers of concretions within 10 to 20 feet thickness of the shale. The fauna is more abundant in the uper layers of the concretions. The only other key bed that resembles this zone is key bed 2. The two other limestone concretionary zones, one at the top and the other at the base of the upper Weskan shale member, contain a different, poorly preserved fauna. The top of this zone was largely used as the key bed for the structural mapping of Wallace county.

4. Zone of dark-gray to brownish-gray tough limestone concretions on the top of the upper Weskan shale member. Siderite is usually mixed with calcite in the matrix of these concretions, owing to which the outer part of the concretions is brownish. Some of the concretions form long cylindrical bodies, the largest 1 foot in diameter, lying parallel and regularly spaced in a plane parallel to the bedding of the shale (Pl. XII *A*). Other concretions are round and are traversed by a net of veinlets (not more than one-fourth of an inch thick) of yellowish to orange calcite. Fossils are very rare and poor except fragmentary *Inoceramus*. Being situated at the base of the Lake Creek shale member, within which no reliable key bed can be chosen, this zone was occasionally used as a key bed for structural mapping.

5. Zone of limestone concretions at the base of the Salt Grass shale member (Pl. XV *A*). Light-gray to nearly white concretions made of tough limestone, some of them 6 inches thick, and a few times larger across. Many of the concretions are only 2 inches to 3 inches thick, but are very broad and long, the mass resembling a regular limestone bed much broken by vertical cleavage. In some of these broad and flat concretions cone-in-cone structure is developed. Fossils are found in fair quantity and consist chiefly of *Baculites, Scaphites* of the *nodosus* group and of small and medium-size *Inoceramus*. Bodies of the rough peculiar limestone (Pls. XV *B* and XV *C*), locally having a profusion of *Lucina occidentalis* shells, are present in places among the regular concretions of this zone. The zone was often used as a key bed.

6. Zone of limonite streaks with buff to white lenslike cores of limestone and an abundance of medium-sized *Baculites* with ovate cross section. The zone is in the middle of the Salt Grass shale member and is 15 to 25 feet thick. The zone was occasionally used as a key bed.

7. Zone of rusty limestone lenslike concretions usually with beautifully developed cone-in-cone structure (Pl. XVI *E*). In the few rare exposures where this cone-in-cone structure is absent the concretionary zone can still be recognized by the rusty-brown color of the limestone. The lenslike concretions are 1 to 2 feet thick and to 1½ feet in diameter. No fossils are usually found in this zone, but in one place a lateral change to bodies of rough limestone with *Lucina* shells and other fauna was observed. The presence of small cores of septarian concretions (Pl. XVI *A*) made of compact marl in the limonite streaks above this zone or rarely below it is characteristic for the zone. This uppermost concretionary zone of the Pierre shale exposed in Wallace county was extensively used as the key bed for the structural mapping.

As said already, the elevations taken on all described key beds of the Pierre have been reduced to the main key bed, for which the contact of the Pierre and the underlying Niobrara was selected.

The stratigraphic distances of the various key beds to this contact or to the main key bed were assumed to be constant throughout the county, though actually it is not so, because the thickness of the Pierre decreases gradually toward the east. There is reason to suppose that this decrease in thickness affects all the members of the Pierre formation proportionally to their thickness. However, this cannot be proved at present for every member of the formation, and therefore the mean stratigraphic distances were used in reducing elevations taken on various key beds to the main bed. It was noticed that some local visible variations in the thickness of members of the Pierre are apparently due to stretching and compression during the folding of the formation. The errors due to the difference between the actual local stratigraphic distances and the assumed mean stratigraphic distances will affect mostly the determined absolute elevations of the main key bed shown by the 50-foot contours on the structural map, but these errors will not effect very much the relative elevations of the neighboring anticlines and synclines. This is especially true of the structural depressions and elevations amounting to 50 or more feet in vertical distance.

KEY BEDS IN THE OGALLALA AND THE POST-OGALLALA WARPING.

In some areas of west-central Kansas the Tertiary beds are not thick, and their outcrops are widely separated by erosion. Owing to this and to their irregular unconformable contact with the underlying Cretaceous and other formations, they may be practically useless for the structural mapping in these areas, but they are of much more value in the extreme northwestern part of Kansas, where they are less eroded and contain some distinct and persistent key beds that are at least of local stratigraphic importance. The Tertiary beds in west-central Kansas are, furthermore, of little value for the structural mapping, because there the underlying Cretaceous rocks are extensively exposed, and being deeper-seated sediments have a more direct relation to the underground structures, with which the potential accumulation of oil is connected. However, in the extreme northwest part of Kansas the outcrops of Cretaceous beds are so scarce that the possible use of the overlying Tertiary beds for structural mapping is an important practical problem which can be gradually solved by detailed observations in the field and subsequent deep borings into the underlying formations.

The writer was able to observe in several places that a gentle folding (not merely slumping) of the Ogallala formation in Wallace county has a fairly apparent reflection in corresponding disturbances in the underlying Cretaceous beds. An account of these observations is given below. Other observations show that the apparent warping of Ogallala beds is not a mere reflection of the pre-Ogallala topography, but is a true folding of the formation subsequent to the deposition of the sediments. The presence of some fairly distinct and persistent beds in the Ogallala of Wallace county and the adjacent area has made these observations possible.

1. The outstanding good key bed is the pink, compact, tough limestone with a peculiar concentrically banded to pisolitic texture (Pls. XXI A and XXI B), which most probably represents an extensive sheet reef built chiefly by the precipitation of calcium carbonate by the minute fresh-water algæ (*Chlorellopsis bradleyi*) in a great but a very shallow basin at the close of Ogallala time. The thickness of this bed is very uniform and measures 2 to 3½ feet, the smaller figure probably being partly due to erosion of this bed in its position as capping rock of the Ogallala. The bed is underlain by white porous and cavernous sandy limestone (Pls. XX B and XX C), which grades downward into limy grit and loam and finally into the common pink or buff grit and loam of the Ogallala. This bed, persistent in both lithology and in geographic extent, appears in the exposures of the Ogallala everywhere in Wallace county except the northeastern part. The bed furnishes a convenient stratigraphic datum from which the distances to the other key beds of the Ogallala and to the base of the formation can be measured. The post-Ogallala erosion has cut deeply into this and the underlying Tertiary beds and into the Cretaceous and has divided the once continuous sheet of pink algal limestone, which now outcrops on the high divides and in a few lower places on the slopes, where it was thrown by the post-Ogallala disturbances of the earth's crust.

Other less important and only locally occurring key beds of the Ogallala are the following, in descending order:

2. The bed of loose gravel composed of well-sorted round stones, chiefly of granite and pegmatite and of various porphyries, quartz, agate and other material from the Rocky Mountains. Thickness ranges from 5 to 20 feet. Stratigraphic position varies slightly, being 40 to 50 feet below the top of the formation (pink algal limestone.) The bed was observed in the southern and southwestern

parts of Wallace county. Its possible equivalent in the southeastern part of the county is the hard sandy ledge described next.

3. The upper, cross-bedded, hard ledge of sorted and bedded coarse sand and fine gravel, which has a very sparse development south of Smoky Hill river in the southeastern part of the county, is 45 feet below the top of the formation and grades laterally into a common hard mortar grit.

4. Some of the most prominent "mortar beds" can be distinguished from the others by the abundance of tangled masses of root-like fibers (Pls. XXVIII A and XXVIII B), many of them accompanied by small petrified fruits, but still more prominently characterized by the cherty "nodules" and elongated bodies, which concentrate in zones a few feet thick. The permanence of these zones with cherty bodies is not yet established for very long distances, but locally, for instance on the upper part of Goose creek, a zone of this kind furnishes a prominent and permanent key bed. Here this zone must be about 45 feet below the pink algal limestone of the top of the Ogallala, which along Goose creek is mostly eroded away.

5. The lower bed of gray sorted coarse sand and fine conglomerate with well-developed large-scale cross-bedding (Pls. XXV A and XXV B), which usually makes a prominent escarpment near the base of the more fully developed Ogallala sections, ordinarily has a well-defined top and base, being overlain by the unconsolidated and unsorted pinkish grit and underlain by the unconsolidated coarse sand and gravel. This hard cross-bedded ledge is therefore not the lowermost Ogallala bed, but it appears to be the first cemented bed of the formation. Its thickness ranges from 5 to 12 feet. Owing to the magnitude of the relief upon which the Ogallala was deposited, this bed is absent from many of the less complete sections of the formation. In other areas, however, it seems as if the bed pinched out or possibly is not cemented and thus does not outcrop. The bed is 130 to 180 feet below the top of the Ogallala in Willow creek valley.

6. In the Ogallala of the northwest corner of the county, which differs somewhat lithologically from the Ogallala elsewhere in Wallace county, the snow-white ledge of diatomaceous earth (Pls. XXXI A, XXXVII A, XXXVIII A, XXXVIII B and XXXVIII C), from 4 to 11 feet thick, capped by a thin hard ledge of limestone with gastropods, is an excellent local key bed. However, both the

diatomaceous earth and the gastropod limestone are rarely observed in the Ogallala sections outside of this area.

Only the topmost Ogallala bed, the pink concentrically banded limestone, was used extensively as the key bed for the structural mapping of those areas of Wallace county in which the Cretaceous rocks are not exposed. Other beds of the Ogallala were used only as subsidiary key beds for the structural mapping of those limited areas in the northwestern part of Wallace county where the Cretaceous exposures are scarce, and the Ogallala, being folded together with the underlying Pierre shale, can be considered to be locally conformable with it, especially in an east-west direction.

SURFICIAL DISTURBANCE IN THE UPPER CRETACEOUS AND OGALLALA.

Though beds of the Upper Cretaceous and Ogallala, as usually observed, are only slightly inclined, and in many places nearly or quite horizontal, they are found locally to be much disturbed and very rarely show extremely steep inclination of the bedding planes, some reaching the vertical or even being overturned. Close examination invariably shows that the most violent disturbances are limited to small outcrops and, excepting the drag at some faults, are of surficial origin and have no direct relation to the major structural features of the formations. These violent though limited disturbances arrest the observing eye of a geologist as well as of a careful amateur student, and demand explanation.

One of the most common of the surficial disturbances is the slumping of masses of rock down the steep slopes of valleys and canyons. Heavy limestone concretions of the Pierre shale often slump down together with a portion of the underlying shale. On those valley slopes that are slightly steeper than the dip of the exposed shale, the gradual slump of an exposed concretionary zone develops a drag down the slope and tends to give the appearance of a steeper dip of the shale toward the valley bottom than the actual inclination of the strata. Many concretions break down during the slumping, which helps to show that this process is surficial. Where such slumping has taken place the apparent dip of the exposed concretionary zone must be checked and corrected by observation of the actual dip of the shale in the near-by ravines and canyons that cut deeper into the shale. That is to say, though the concretionary zone which is chosen as a key bed can be still used as such, and the elevation for the structural mapping should be taken on the top of it, the dip of the formation, which may be helpful for the structural mapping, is preferably taken on layers of shale farther down. The dip can be taken on the fine stratification of the shale or along the cracks parallel to it or still better on the bentonite and other differently colored streaks, but as a rule not on gypsum streaks, which may be secondary filling of the cracks and variously oriented in relation to the bedding of the shale. On steep bluffs and in deep canyons large masses of shale part along cracks, and when they slump change their orientation. Many of the slumped blocks are buried under the next portions of disintegrated shale, gravel and mud and may be exposed again later by a change of drainage and thus exhibit a local disturbance of the shale that may puzzle the observer. These slumped blocks of shale can be recognized by the twisted and cracked portions in them, often accompanied by irregularly distributed slickensides, also by veinlets of mud, sand and gravel and other secondary features which originate in the shale during slumping.

The slumping is particularly common on the edges of Ogallala escarpments. The atmospheric precipitation drains through the grit and other arenaceous Ogallala rocks and weakens the shale beneath, carrying part of it away and penetrating the rest along the cracks, until finally large blocks of Ogallala break away from the escarpment and slump down with a portion of the underlying shale. Still larger portions of Ogallala have been observed capping small mesas and separated from the continuous escarpment by erosion. Some of these outliers of Ogallala have a slightly but distinctly different inclination from that of the same formation in the continuous escarpment of which they were formerly a part. This phenomenon can be observed on the south side of Goose creek, in T. 12 S., R. 41 W. It appears as if differential erosion had removed the bentonitic clays, which are here observed at the base of the Ogallala, and probably also the underlying Pierre shale, and caused uneven settling of these "islands" of Ogallala with little or no breaking of the block.

The sink holes, or cave-ins, which are common in Wallace county and elsewhere in western Kansas and which are described in a separate chapter of this report, usually do not affect the dip of the beds in the walls around the hole, as is clearly demonstrated in the Smoky Basin cave-in and in some ancient sink holes of the county. However, in some cases they may cause a local abnormal dip in part of the wall. It seems that the cause of the abnormally steep inclination of the Ogallala on both sides of the "gate" at the old circular hole, apparently a cave-in, on the south side of the canyon in the SW¼, sec. 27, T. 12 S., R. 41 W., is the differential slump of Ogallala blocks at the edge of the escarpment toward the hole (Pl. XL C). Other unusually steep dips in some large blocks of Ogallala have been most probably caused by differential undermining and subsequent slumping. A large block of Ogallala with inclination over 45° was observed on the left side of the creek in NE¼ NE¼, sec. 6, T. 13 S., R. 41 W., and a block with about 90° was observed on the south side of a small nearly circular canyon head in the NW¼, sec. 7, T. 13 S., R. 41 W. (Pl. XXXVI C). In both localities the blocks are lower in elevation than the nearest Ogallala escarpments, a part of which they formerly were. These blocks probably overturned when undercut by local erosion. A 45° and even steeper dip of a considerable portion of the Ogallala escarpment in the SW¼ NE¼, sec. 3, T. 13 S., R. 41 W., is not so easy to explain (Pl. XXXVI B). The steeply inclined portion of the Ogallala escarpment is here not inclined in the direction of the slope of the valley, but dips in the reverse direction. Comparison with the nearly horizontal position of the escarpment shows that the steeply inclined portion of Ogallala did not slump down more than a very few feet.

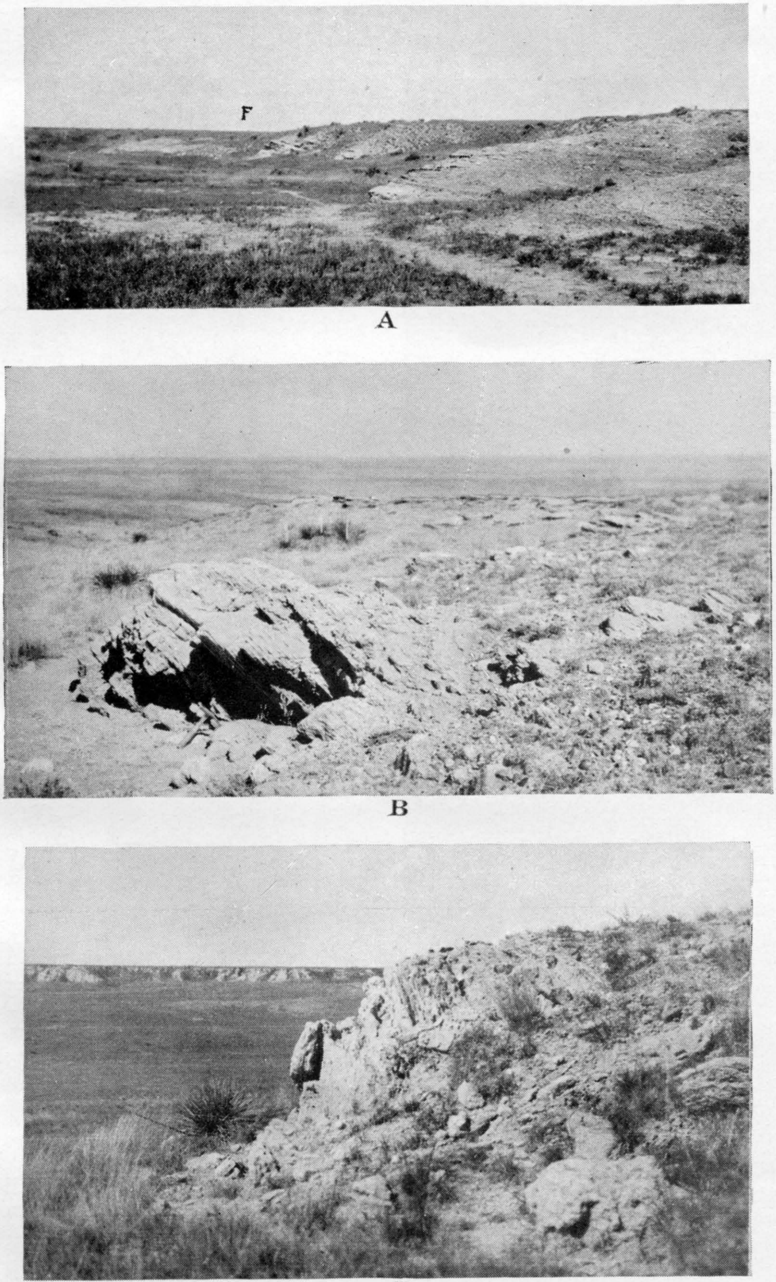
The direction of the steep inclination of the bed is to the east. This is the direction of the rushing water of Pleistocene age. Pleistocene gravels, in which some very large boulders occur, are not uncommon in Wallace county and are present here. The writer suggests as a possibility that ice jams comparable to those of the Mackenzie and other Arctic rivers of to-day could have occurred behind outcropping rocky ledges of the Ogallala, causing sufficient pressure against the edges of the escarpment to overcome the resistance and tear off and tilt large blocks of the rock. Part of the boulders and gravel carried by the ice would be dropped around the tilted blocks.

Some pronounced but purely local disturbances in the Pierre shale, which are apparently confined to the portions of this shale near the edges of escarpments of overlying Ogallala—for instance, in the SW¼, sec. 12, T. 13 S., R. 42 W.—may have originated in a somewhat similar way as the small-scale folds in the shale underneath the "erosion thrust" in the Appalachian mountains shown by Bailey Willis.[205] A pronounced folding of the Ogallala, probably partly

---

205. Willis, 1893, p. 223 and Pl. LIV-7, opposite p. 232.

PLATE XXXVI.—*A*—Marked change of dip in Niobrara chalk, the steepest being near the edge of fault *F*. In the NW¼, sec. 1, T. 14 S., R. 38 W. *B*—Unusually steep local dip (not to be confused with still steeper cross-bedding) in the cliff of Ogallala coarse sandstone. Shows nearly horizontal position of the same ledge and on the same level in the distant continuation of the same bench. The ledge rests on Pierre shale. In the SW¼ NE¼, sec. 3, T. 13 S., R. 41 W. *C*—Coarse sandstone of Ogallala in erect position. In the SW¼ NE¼, sec. 7, T. 13 S., R. 41 W.

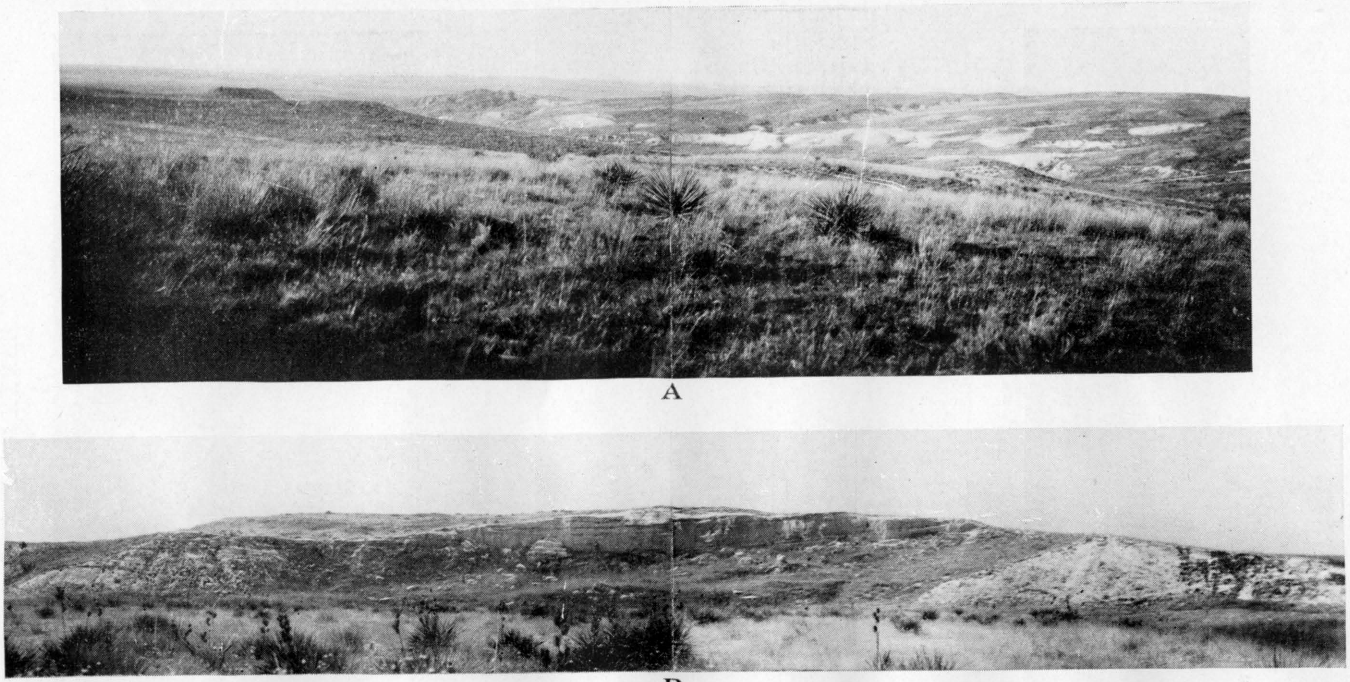


A

B

C

Plate XXXVI.


A

B

Plate XXXVII.—*A*—Syncline in Ogallala. In the NE¼, sec. 11, T. 11 S., R. 38 W., looking north and east. *B*—Synclinal fold involving both Ogallala and underlying Pierre, looking southwest along the axis of the syncline. The axis corresponds to the crest of the divide between Smoky Hill river and Willow creek near their junction. In the W½, sec. 17, T. 13 S., R. 41 W.

due to compression, was observed in this area and mapped in detail in 1927-'28. If the folding of these strata continued after erosion cut through the Ogallala beds, a small-scale folding could have been developed in the underlying Pierre shale, whereas the rigid Ogallala at the edge of the escarpment would slide along the contact with the shale and over the exposure of the shale. The minor folding of the Pierre below Ogallala could be explained, also, as a mere local plication of incompetent rocks (clayey shale) near contact with Tertiary grits in a competent fold (explanation suggested by K. K. Landes).

It remains to mention that the local steep dips in the Pierre shale and in the Niobrara chalk, which are closely connected with the faults in these formations, apparently represent the drag of the beds at the fault plane.

FOLDING OF UPPER CRETACEOUS AND OGALLALA.

As was shown in one of the preceding chapters, there are many beds in the Ogallala which reflect the original subhorizontal deposition of the sedimentary material of the formation, and which thus can be used as key beds for structural mapping, the Ogallala being not different in this respect from ordinary sedimentary formations. The observations and the structural mapping of this formation prove that there was a pronounced, though possibly local, folding (Pls. XXIII B, XXXVII A and XXXVII B) and faulting of Ogallala together with the underlying Upper Cretaceous. There is good evidence that the Upper Cretaceous formation have been folded and faulted also in pre-Ogallala time, but for the most part the traces of earlier orogenic movements cannot be clearly differentiated from the marks of post-Ogallala deformations, and probably part of these movements took place along the same anticlinal and synclinal axes. Though the structural map of Wallace county (Pl. XLII), based on the scattered outcrops, is far from an exact representation of the actual surficial structure of the area, the general features of the structure that it shows are not far from the actuality. This map reveals that, as a rule, the folds of Wallace county stretch in two general directions—one is from north to south and the other from west to east, or more exactly west-northwest to east-southeast.

The meridianal direction of the folds is the direction of the most pronounced folds elsewhere in Kansas, and most probably all of these folds that have approximately the same direction have a common origin. It is true that the meridianal anticlines of Wallace county, as they are manifested in the surficial formations, are of much less magnitude than, say, the famous anticline, the "granite ridge" of eastern Kansas, that covers the richest oil pools of the state. But if all the meridianal arches of the state are of the same origin, which appears to be most probable, it is only natural that the folds of western Kansas, which reflect the ridges buried by a much thicker series of sedimentary formations and are separated from the ridges by two additional erosional unconformities,[206] are not so pronounced as their eastern equivalents. It is quite possible that the meridianal anticlines of western Kansas may prove to be more pronounced farther underground and thus represent more prominent underground structural features than their reflection in the surficial formation would suggest.

Two meridianal ridges, each representing a chain of several uplifts that are stretched along a north-south direction, can be recognized in Wallace county. One runs through Weskan and can be called the Weskan structural ridge or anticline. There is a slight topographic prominence, especially north of Weskan, which corresponds to this ridge and most probably is due to this structural uplift. The other structural ridge runs slightly west of Sharon Springs and can be called the Sharon Springs ridge or anticline. The eastern slope of this structural ridge has a distinct reflection in modern topography, especially in the high plateaus south of Sharon Springs. Still another, but much less pronounced, nearly meridianal structural ridge is possibly present between Sharon Springs and Wallace. This ridge with a north-northwest trend can be detected only for some distance north of Smoky Hill river. Naturally there are structural depressions or synclines, or rather chains of synclines, which separate the above-mentioned structural ridges.

A prominent system of folding, which cuts across the meridianal structural ridges and depressions, is most pronounced in the middle latitudinal stretch of Wallace county and chiefly north of Smoky Hill river. As will be related in the detailed description of the structures, the latitudinal folding effects both the Pierre and the Ogallala with nearly the same intensity. This indicates that the latitudinal folding is of late origin and that we may expect the Upper Cretaceous beds concealed under Ogallala deposits in the

---

[206] One between the Permian and the Dakota of Upper Cretaceous and the other between the Upper Cretaceous and the Ogallala.

north and south parts of Wallace county to be probably hardly much more folded in this direction than the Ogallala sediments. This conclusion has also a strong support in the fact, which can be clearly observed on both the structural map and the north-south geologic section through the western part of the county, that the latitudinal folds of the central part of Wallace county form an anticlinorium with the most pronounced anticline in the middle and with series of gradually decreasing folds north and south of it.

The east-west series of folds enters Wallace county from Cheyenne county, Colorado, stretches through the whole of Wallace county and continues to Logan county on the east. These folds appear to be more pronounced in the west and to become less pronounced toward the east.

In the description of the details of the Wallace county structure the writer starts with the Weskan anticline and describes it from south to north and continues his description toward the east in the same manner, covering Sharon Springs anticline and the next structural features east.

In the southwest corner of Wallace county, on the high, slightly dissected plateau, there is an area of about nine square miles along the south fork of Ladder creek in which all the wells dug or drilled to the top of the Pierre shale are dry. This area is shaded on the structural map of the county. It seems to the writer that the absence of water in the wells can be accounted for by the presence of a very low and broad structural hill (Stockholm dome) of shale covered with Ogallala and loess. Unfortunately the exact depth of the wells and the record of the rocks that were encountered are mostly unknown at present. The depth of one dry well at the northeastern edge of the dry area is 140 feet (to shale). The water wells north of the dry area are 150 to 163 feet deep; the water well at Stockholm, southeast of the dry area, is 200 feet deep, and one water well west of the dry area has the same depth. The information on all the dry and water wells of the area was kindly supplied to the writer by J. August Johnson, of Weskan.

The above-described area, which has no water available at the top of the Pierre, is leased by an oil company, the geologists of which were led to this area while tracing structural elevations southwest of it in Colorado.

The absence of buildings and water wells southwest of Weskan and north of the Stockholm dome, together with evidence from the few outcrops of Ogallala north, east and south of Weskan, are suggestive of another structural dome of smaller area but of more pronounced height. Both this dome and the Stockholm dome lie in the line of Weskan structural ridge or anticline.

About one mile north of Weskan is a distinct and comparatively sharp syncline with approximately east-west direction of the axis, and beyond a narrow structural uplift farther north there comes the pronounced syncline that coincides with the broad valley of Smoky Hill river. On the north side of the river, east of Weskan road, both the Ogallala and the underlying Pierre, which is exposed in the left canyons tributary to Smoky Hill river, show a persistent though locally slightly variable inclination southward. Pierre shale is not exposed west of here either in the valley of Smoky Hill river or in the tributary draws.

The pronounced divide between Smoky Hill river and Willow creek north of it corresponds to the most prominent structural high of Wallace county. In the eastern half of this structural high, which was named Willow creek anticline, both Ogallala and underlying Pierre are exposed, but west of Weskan road Ogallala alone outcrops. The eastern half of the structure was studied and mapped first, and in it the stratigraphic and structural relations between these two formations examined. It was in this eastern area that the character and the degree of nonconformity between the two formations were established, and it was found that the major folding affects both Pierre and Ogallala in equal degree. There were discovered some local small-scale folds in the Pierre near the edges of the Ogallala escarpment, but these do not affect the major structural relation of the two formations and are possibly due to the development of erosional thrusts, as previously explained. It was established that the nonconformity between the Ogallala and the Pierre develops here for the most part very gradually and amounts to about 10 feet to a mile in meridianal direction, the regional dip of the Pierre being as usual to the north. The nonconformity between the two formations in an east-west direction was found to be locally so small as to be unnoticeable within the three miles of the studied stretch of the exposures. The top of the middle limestone concretionary zone or bed No. 8, with typical *Ostrea* and *Anomia*, was used as the key bed in the Pierre exposures of the eastern half of the structure, and only in a few places have the top of the cone-in-cone zone No. 10 and the topmost heavy concretionary limestone or bed No. 12, all of the upper Weskan shale member, been used as the subsidiary key beds. Some prominent ledges of the Ogallala, chiefly the crossbedded, sorted gravel and sand or the first hard ledge of local Ogallala from the base, and one of the most prominent and at the same time very limy mortar beds, and rarely some other beds, have been used as the key beds in the Ogallala in the eastern half of the structure. This was not so much for the sake of the structural mapping of the eastern half as for the study of the relation of these Ogallala beds to the underlying beds of the Pierre, so that they could be used for the structural mapping of the western half of the Willow creek anticline, where the beds of the Pierre are not exposed. Owing to the excellent and continuous exposure of Ogallala beds on the south side of Willow creek, east of Weskan road (Pl. XXIV C), it was possible for the rodman to walk out the chosen most prominent "mortar-bed" escarpments of Ogallala, while the geologist and instrument man watched from the side so as not to let him lose the key bed where few interruptions occurred or where the chosen bed began to be less conspicuous compared with the neighboring "mortar beds" of the sections. Owing to the sufficient amount of Pierre exposures with the recognizable key beds, is is possible to map structurally this area without any help of Ogallala key beds, but in some parts of this half of the structure the Ogallala key beds helped to map some very interesting details of the structure and helped to establish the presence of a fault near the top of the divide between Willow creek and Smoky Hill river, where the Pierre is not exposed. The used key beds of Ogallala have been reduced to the key beds of the Pierre, taking into account the degree of nonconformity in meridianal direction. The latitudinal nonconformity was assumed to be zero on account of its negligible rate.

The western half of the structure, or the part west of the Weskan road, was mapped on the Ogallala key beds alone. The topmost bed of Ogallala, the concentrically banded limestone, the top of the heavy gravel bed 40 feet below it, the limy "mortar bed" and the cross-bedded prominent ledge near the base have been used as the key beds. The elevations taken on these beds have been reduced to that of the main key bed of the Pierre of the eastern half of the structure, the limestone No. 8 of upper Weskan shale member. The stratigraphic distance of the Ogallala beds to this Pierre bed was assumed to be the mean distance established for the east half of the structure and the nonconformity to be zero in all directions. This makes the structural map of the western half of Willow creek anticline less precise, so that the elevations reduced to the main key bed in the eastern half of the structure can be considered to be correct within an error of 10 feet in either direction, and the reduced elevations of the western half are correct within an error of 15 to 20 feet. The error in the eastern half is chiefly due to the impossibility of a more precise identification of the top of the concretionary zones of the Pierre, which have been used as the key beds.

Altogether about 200 elevations have been taken on the key beds within the Willow creek anticline. The following is the description of this structure.

The Willow creek anticline lies in the townships 13 south of ranges 41 and 42 west, Wallace county, Kansas. The center of the structure is five miles north-northeast of Weskan. On the south the structure is bordered by the valley of South Smoky Hill river. This valley has an easterly trend, but opposite the structure it makes a broad turn toward the south and runs parallel to the structural contours of the south flank of the anticline. The South Smoky Hill river flows through a syncline, which closes the Willow creek structure on the south: This syncline is named the Smoky syncline.

The northern closure of the structure lies in the divide between Willow creek and Schoolhouse draw. A deep and comparatively sharp syncline was found here at the heads of the several northern tributaries to Willow creek. This syncline was named the Bone syncline after Bone draw, which is at the east end of the syncline. The axis of Bone syncline makes a bow toward the north with the center of the bow at the head of Ammonite draw. The southwest end of this syncline comes down to Willow creek at the mouth of Bug gulch, its northern tributary. Here a structural depression is developed in which the uppermost part of the Ogallala formation is exposed. In this depression lies the northeast end of the next syncline, which closes the Willow creek anticline on the northwest. This syncline extends in a southwesterly direction with only a slight bend toward the northwest. The syncline apparently meets the Smoky syncline near the junction of the two large forks of South Smoky Hill river. This junction lies in an outstanding topographic basin, which indicates a reflection of a large structural depression at the meeting of Smoky and the northwestern synclines, and marks the extreme western end of the Willow creek anticline. The extreme eastern end of the structure lies near the junction of Willow creek and Smoky Hill river. Here Smoky syncline meets the syncline that closes the structure on the northeast.

The main structural highs, which constitute the Willow Creek structure, are Western anticline on the west, Swisegood dome on the north and Bat anticline on the south. These anticlines are connected by saddles and thus make up a larger structure, within which many minor structural highs and structural depressions can be recognized. The highest elevations of Western and Bat anticlines are marked by the 4,020-foot contour; the top of the Swisegood dome is apparently 20 feet higher and is considered from available data to be the highest point of the structure. Willow creek cuts across the Swisegood dome in the middle, and the alluvium of the broad valley of the creek conceals exposures. The top of the dome was found at the intersection of the axes of the two anticlines, Western anticline and the north-south minor anticline that runs one mile east of the Weskan road. The area covered by the lowest closing contour of the anticline is about 1,000 acres, and the closure is about 160 feet.

The detailed mapping of Willow creek anticline revealed many interesting features which help to understand the character and origin of the folding that produced it. The cross sections of the detailed structural map (which belongs to Etnyre Syndicate) show distinctly that the latitudinal synclines are sharper than the broadly rounded latitudinal anticlines. This shape is typical for the upper zone of the "parallel folds," to which type the latitudinal folds of Wallace county apparently belong. This shape, together with the observations that both Pierre and Ogallala are equally affected by the folding, seem to indicate recent folding of the lateral compression type.

The detailed map revealed the presence within the structure of several small closed saucerlike synclines. These are not sink holes, because they are not circular; many of them are shaped like somewhat rounded rhombs with the opposite angles in meridianal and latitudinal directions. These rhomblike closed synclines are arranged in rows in nearly meridianal and latitudinal directions and are spaced between the minor domes within the structure in checkerboard manner. The regular development of these closed synclines in rows within the Willow creek structure is probably due to the origin of the structure as an intersection of two systems of folds.

North of Willow creek structure lies another structural high, which reaches to Goose creek, and which is perhaps of not less importance than the former structure. Unfortunately a thick mantle of loess covers the whole top of this anticline and does not permit a better estimate of the closure than that obtained by extrapolation of the flanks of the anticline toward the center, and the study of these flanks is based on very few exposures. These were sufficient to establish, however, that the western slope of the anticline is steeper than the eastern slope, and that the northern slope is many times gentler than the southern slope. The outcrops are most plentiful northeast and east of the axis, and it was established that in these quarters the anticline gives out a group of noselike and fingerlike minor structures, which are parallel or nearly parallel to each other and run nearly northeast. On one of these "fingers" the minor dome of Salt Grass canyon, which was worked out in some detail, is situated. The Pierre shale of this dome furnishes many exposures of the type locality of Salt Grass shale member, and on the northwest side of the canyon can be observed an excellent overlap of the Pierre shale hill by the beds of Ogallala formation. (See Pl. XXIV B.)

West of Weskan anticline, between Willow and Goose creeks, the few Ogallala exposures with the prominent key bed furnished by the concentrically banded limestone permits establishment of the eastern flank of a prominent structural high, which enters Wallace county from Colorado. There are not very many exposures of the Ogallala and none of the Pierre north of the valley of Goose creek on the line of the Weskan anticline, and the northern continuation of this important structural ridge was not established by the writer.

The structural mapping based on the concentrically banded limestone of Ogallala, as the key bed in the high plateau south of Sharon Springs, revealed the presence of a considerable dome south and southwest of Sharon Springs. This dome, which has a comparatively sharp slope eastward, is connected through a noselike structural ridge with the structural elevation south of Weskan. Northwest of Sharon Springs the broad topographic low of the junction of Smoky Hill river with Goose creek is structurally a medium-size high. This structural high was established in the exposures of Pierre shale alone and is the eastern end of a comparatively long latitudinal structural and topographic ridge of the divide between Smoky Hill river on the south and "Schoolhouse draw" on the north. A smaller latitudinal ridge parallel to this is in the next divide north, between "Schoolhouse draw" and "Collins draw."

A long structural ridge which belongs to Sharon Springs anticline was established between the mouth of "Schoolhouse draw" and Lake creek. The northern continuation of this anticline was not mapped on account of the absence of exposures of Pierre shale. The few

Ogallala exposures of this area, in the eastern part of R. 41 W. and the western part of R. 40 W., do not contain easily recognizable key beds. The valley of the upper part of Goose creek corresponds to a gentle latitudinal syncline, the valley slopes being steeper than the flanks of the syncline.

The high plateau south of Wallace is also a structural flat, at least as far as Ogallala deposits are concerned, but within the exposures of the Pierre and the Niobrara on the south side of Smoky Hill river and southeast of Wallace there is a distinct latitudinal structural ridge. This ridge is cut by several faults, only one of which, the most prominent, is shown on the structural map. This ridge appears to be connected with a longer and a more prominent anticline, which runs east-southeast, and the axis of which nearly touches Wallace. The structural high on this ridge was drilled by Wulfekuhler in 1926. The location for the well was chosen with the aid of geologic reconnaissance. The elevations taken by the writer on the top of the septarian zone of Sharon Springs shale member, which outcrops in a few places in the area, and the more reliable dips that have been observed and established by the differences in elevation of the key beds enabled the writer to show that the crest of the structural high is probably about two miles southwest of the Wulfekuhler well.

North of the well lies the area in which the normal regional dip in the shale is observed, but a few miles south of Lake creek there is a topographic depression, which corresponds to a syncline. North of this syncline is a medium-sized structural (as well as topographical) ridge, on which the Robidoux well is situated. However, this dry well was drilled about in the middle of a pronounced *graben* or structural trough between two faults of nearly latitudinal direction. West of the Robidoux structure there appears to be a broad dome, the center of which is about 1½ miles southeast of Madigan ranch.

The Ogallala that is exposed on the south side of north fork of Smoky Hill river in the northeast corner of the county and that contains a continuous bed of diatomaceous earth capped by a thin but persistent limestone, is folded and faulted (see Pl. XXXVII A), but these local and not very pronounced disturbances have not been worked out structurally in detail.

MINERAL RESOURCES.

PETROLEUM AND NATURAL GAS.

Though neither gas nor oil has been found as yet in paying quantities in Wallace county, or in the surrounding area of Kansas, Nebraska and Colorado, the presence of commercial supplies of gas or oil in this part of the country is a possibility which fascinates both the local residents and the oil scouts from outside, who often visit this country. The big oil concerns also occasionally send their geologists to examine this part of the Great Plains, to lease this or that portion of it and to undertake various geologic explorations for oil and gas, but little drilling has yet been done. The majority of the test wells in the area have been drilled by local residents as individuals or united in small exploration companies. The location of some of the wells drilled by them was based on geologic explorations for which private geologists were employed, but the location of the majority of them seems to have been chosen on questionable geologic data or on no geologic ground at all.

Those who know how insufficient have been the geologic data upon which the great majority of these wells have been located do not regard the discouraging results of the drilling as proof that there are no commercial supplies of oil or gas in the area, and one may question whether these results really are as discouraging as they seem to be. In nearly every one of these wells a show of oil and gas was encountered in various "sands" of the underground formations. Therefore the presence of these valuable minerals in northwestern Kansas is established. It remains to be proved, however, whether there are any natural accumulations of gas or oil that will pay for their exploitation. The largest among the local accumulations of gas so far discovered is at Beecher Island, in Yuma county, Colorado, about 50 miles northwest of Wallace county. The gas is dry and was burned safely and without odor for both lighting and heating by the exploration party in 1927-'28. The initial output of one of the old holes was 2,000,000 cubic feet per day under 450 pounds pressure. The combined steady output of one of the old wells and a new one drilled in 1928 was sufficient for running the drilling machine of the next deep well in 1929. The gas horizon of Beecher Island is at the top of Smoky Hill chalk of the Niobrara formation.

The oil-producing area in Kansas that lies nearest to Wallace county is in Russell and neighboring counties, about 100 miles east, and in 1929 oil was discovered, also, in Ness county, about 80 miles east-southeast. The main pay zone lies near the base of the Pennsylvanian and is encountered at a depth of about 3,000 feet. If the Permian and Pennsylvanian formations are of the same thickness in Wallace county as they are in Russell and Ness counties, the stratigraphic horizon corresponding to the oil-producing sand of those counties would be found in Wallace at about 4,500 feet below the surface. The Phillips Petroleum Co.'s well, 5,055 feet deep, drilled east of Beecher Island near the state line of Kansas, proved that it is easily possible to drill in the area down to this depth. There are, however, sands at much less depth in northwestern Kansas which could serve as reservoirs for commercial accumulations of oil and gas, providing enough oil or gas is present. In fact some of these higher strata are oil producers in Colorado. The oil and gas now being produced at Fort Collins, about 180 miles northwest of Wallace county, are derived from the uppermost beds of the Dakota group, and good showings of oil have been reported from the Codell sandstone, which is at the base of the Fort Hays and is regarded as a possible oil-producing bed in the vicinity of the Kansas-Colorado boundary.[207] The recent (1930) discovery of a new possibly commercial oil and gas field north of Orchard on the Fort Morgan anticline, which is about 130 miles northwest of Wallace county, is reported in the newspapers to have been made at the top of the Dakota sandstone, at 6,666 feet from the surface. This figure appears to give a larger thickness of rocks overlying the Dakota in this area than was supposed, but there are hardly any other sands below the Dakota which could be mistaken for this easily identified formation.

Following is a list of the potential producing sands in Wallace county and their stratigraphic distance from the top of the Niobrara, the elevation of which above sea level is represented by the solid contours on the structural map of the county.

(1) *Smoky Hill chalk.* The formation is partly pervious, and gas is produced from its top beds at Beecher Island, in Colorado. A show of oil and gas at the top of the formation is recorded in the deep wells north of Goodland, Sherman county, Kansas. Gas was discovered in an unknown horizon of the formation in the old wells at Cheyenne Wells, Cheyenne county, Colorado, and in the Robidoux well of Wallace county a show of gas is recorded 260 feet above the base of the Niobrara.

---

[207] Mather, Gilluly & Lusk, 1928, p. 107.

(2) *Fort Hays limestone.* At Cheyenne Wells, in Colorado, the "chalk rock" at the base of the Niobrara, which apparently corresponds to the Fort Hays, is saturated with brackish water.[208] The top of the limestone is about 700 feet below the top of the Niobrara.

(3) *Codell sand.* This sand may be present below the Fort Hays, in the western part of Wallace county. The top of the sand is about 750 feet below the top of the Niobrara.

(4) *Uncorrelated sand.* White sand, possibly limy, lies 350 to 370 feet below the base of the Fort Hays or 1,100 to 1,120 feet below the top of the Niobrara. Strong supply of water reported in both the Wulfekuhler and Robidoux wells; show of oil and gas in the former well.

(5) *Dakota sand.* Artesian water came from the Dakota in the Wulfekuhler, Robidoux and other wells of northwestern Kansas, and a light show of oil in the Wulfekuhler well. It is the oil-producing sand of northeastern Colorado. The top of the Dakota in Wallace county is about 500 feet below the Fort Hays or 1,250 feet below the top of the Niobrara.

(6) *Uncorrelated sand* (possibly Sundance). Sand and gravel lying on the top of the red beds. Water reported in Wulfekuhler well. It is about 370 feet below the top of the Dakota or about 1,620 feet below the top of the Niobrara.

(7) *Sands in red beds.* Several beds of sand within the red beds have been found to contain water. "Oil sand showing dead oil" is recorded about 1,500 feet below the top of the red beds, or about 1,900 feet below the top of the Dakota in the Moffett and Andrews No. 1 well in Logan county, Kansas.

Though the series of sedimentary rocks penetrated by deep borings in northwestern Kansas undoubtedly includes several pervious beds, which are interbedded with impervious clayey shales and thus provide good reservoirs for the accumulation of water, oil and gas, only a few "black" and thus presumably bituminous shales are recorded in the wells below the Niobrara. Hence a doubt may be expressed as to whether there is any local "mother rock" of petroleum in the local Cretaceous (except in the outcropping Pierre), in the Permian or in the drilled part of the Upper Pennsylvanian formation. Even if there is no such mother rock, however, the possibility of migration of oil and gas from more distant beds into the local pervious sands is not entirely excluded.

Besides the actual presence of oil and gas and the presence of reservoirs made of pervious beds inclosed between impervious rocks, there is a third requirement for an accumulation of these in commercial quantities, and this is the presence of some trap which may check the migration of oil and gas through the "sands" and thus

---

[208] Darton, 1905, p. 329.

create a "pool." Among the various kinds of traps that are known to oil geologists, closed anticlines and dome types are the most common and hence are looked for most in geologic explorations for oil. The appreciable folding of both Upper Cretaceous and Tertiary rocks in Wallace county was described and discussed in the chapter on geologic structure. At least two phases of folding, one in post-Cretaceous and pre-Ogallala time and the other in post-Ogallala time, have taken place in Wallace county and the surrounding area. The principal folds trend in one of two directions, and in some places the folds of the two systems cross each other. It seems as if the largest closed structural highs of the area have been formed in these intersections. One of these, and possibly the largest in Wallace county, is the Willow Creek anticline north of Weskan. Many other anticlines and domes are scattered through nearly the whole of the county. Among these are the structural highs on the flanks of which the Robidoux and Wulfekuhler wells were drilled. The writer believes that neither of these two wells is situated close to the apex of a structural high.

This statement does not mean, however, that the writer believes that commercial pools of oil, gas or both will be necessarily tapped if the apices of the most prominent closed anticlines of Wallace county are drilled, because, first of all, there might not be enough oil and gas in the area, or at least in the upper portion of the local sector of the earth's crust, to accumulate in paying quantity. The structural map of an area far from proved oil fields merely helps a proper selection of places for test wells by showing the most prominent anticlines of the area and the structurally low spots, which, according to the anticline theory of accumulation of oil and gas, are not likely to be the sites for such accumulation. The exception to this rule concerns only those very few oil fields in which there is no underground water, and where oil, taking the place of the water, accumulates in the structural lows. There is plenty of water in both the surficial and in the deeply buried sands in Wallace county and in the surrounding area, and therefore this exception to the rule is not applicable here.

It is important, furthermore, to guard against exaggerating the usefulness of a map showing the structure of the outcropping formations when a deep boring is to be made. To begin with, the folds observed in the surficial formations may gradually die out in the underlying beds. On the other hand, they may develop into greater folds farther down. The actual condition may be ascertained only after a series of deep holes has penetrated the deep-seated formations. A general hint as to the possible continuance in depth of anticlines and domes is their areal size—the larger the folds the less is the chance of their dying out in a short distance downward. It must be kept in mind, furthermore, that the axial planes of these anticlines and domes are not necessarily always vertical, and therefore their apices may be deflected in depth, which is actually the case with many. It appears to be advisable, therefore, not to drill very deep holes on the basis of the structural map alone, which shows the folding and faulting of surficial formations. Greatest attention should be given to the proper record of the rocks encountered in every new deep well in the area, because with the increase of the number of these wells accurate knowledge of the general features of the underground structure of the area will be gradually gained.

The writer has made a preliminary attempt to plot the results of the deep wells already drilled in Wallace county and the surrounding area. Though not all the desirable data concerning these wells have been collected yet, the preliminary plotting shows that the prominent group of folds that traverses Wallace county generally persists into as deep-seated beds as the Fort Hays limestone and the Dakota sandstone.

CLAYS.

The clays of Wallace county belong to the Pierre and to the Ogallala. Loess, also, can be considered a clay to some extent, but it has properties peculiar to it, and is not used in the ceramic industry.

The whole thickness of the Pierre is made of clayey shale, but the commercial value of most of this shale is low. The systematic and thorough examination of the shale of the same formation in the neighboring area of eastern Colorado gave results that are generally applicable to the clayey shale of the Wallace county Pierre and is quoted here.[209]

> "The Pierre is essentially a formation of low-grade brick shales. Almost all the shales will fuse below cone 5, and over 60 per cent will burn red; while, of the remainder, about 90 per cent will burn pink. Over 40 per cent of the samples tested, however, are so deficient in tensile strength that they are unadapted to the manufacture of stiff-mud brick or earthenware. Twenty per cent of all the beds tested are probably worthless, and the same proportion might be used in making other products besides brick. The worthless beds sampled all lie near the top of the formation, except one case where a lower

---

[209] Butler, 1914, pp. 115-116.

shale has been metamorphosed or changed by the intrusion of a mass of igneous rock. Fifteen per cent of the samples vitrified fairly well, but none gave much reason to suppose that a good paving brick could be made from them.

"While much of the formation will make good red brick, the product is not usually so attractive as that obtained from the Graneros and Carlile shales, and the absorption is apt to be rather high."

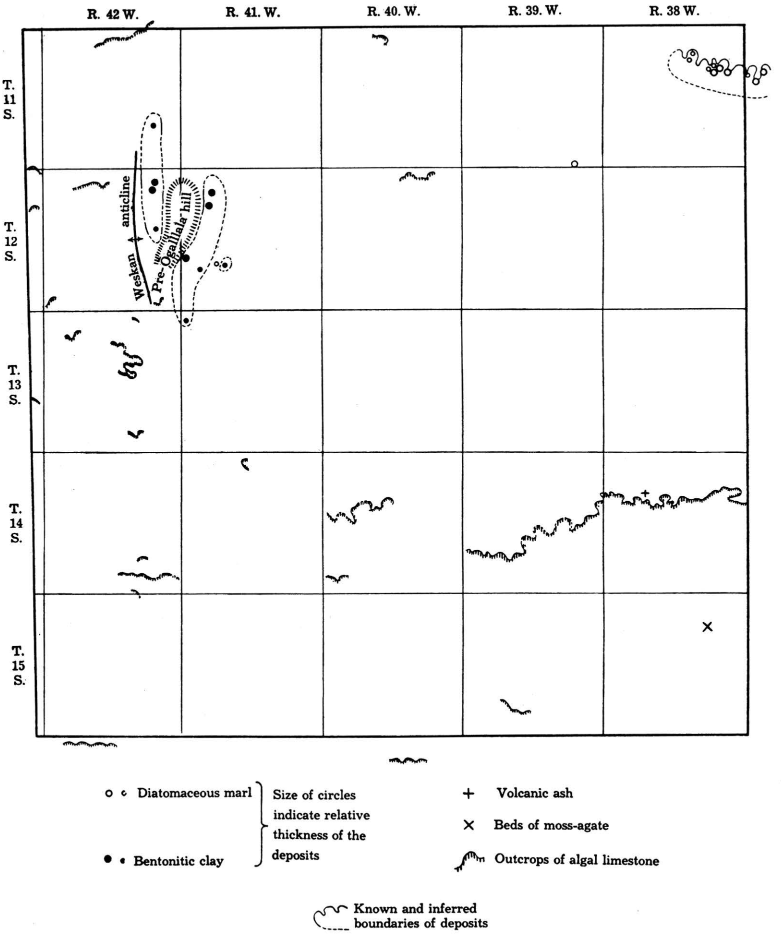


FIGURE 6.—Map of the mineral resources of Ogallala, Wallace county.

The field examination of the Pierre shale of the county shows a variable proportion of unevenly distributed calcium carbonate, calcium sulphate (gypsum) and sulphate, carbonate, and hydroxides of iron, all of which have a more or less harmful influence on the usefulness of the clays. The flaky black shale of the Sharon Springs and Lake Creek members of the formation is the poorest kind of shale for making bricks. The best shale, some of which is nearly free from the above-listed harmful impurities, is the gray clayey shale with interbedded thin bentonite streaks, which belongs to the Lower Weskan member of the Pierre. The best outcrop of this clayey shale is in the SW¼, sec. 4, T. 13 S., R. 40 W., on the south side of Goose creek, about four miles northwest of Sharon Springs; it outcrops, also, in the SW¼, sec. 6, SW¼, sec. 8, and in other places in the same township. The outcrop in SW¼, sec. 31, T. 12 S., R. 38 W., about three and one-half miles north of Wallace, also seems to have few damaging impurities.

The bentonitic clays of the Ogallala formation are more interesting from a commercial standpoint, but their usefulness and value can be established only after research work or special commercial tests. Only a few of these Ogallala clays can be used for making bricks, because many of them contain calcium carbonate and calcium sulphate. On the other hand, they may possibly be valuable for oil refining.

It is recommended to those who are interested in the production of bentonite that they "should make a careful investigation of the commercial possibilities of the deposit in question before investing heavily. Such a study should include the possibility of marketing the product, the specifications demanded, the price obtainable, the cost of mining, treating, and shipping to market, the size of the deposit and the nature of the crude bentonite. Most consumers desire a homogeneous product that will remain uniform over a period of years,"[210] which implies that a commercial deposit of bentonite must be of considerable size and fairly homogeneous.

The Ogallala bentonite beds (Pls. XXX A, XXX B and XXX C) of Wallace county are fairly thick and range from 6 to 30 feet of a uniform grade of clay. Laterally these beds may not be very extensive, but some that are exposed could be traced in the field over several hundred yards. Perhaps the largest deposit is in the SW¼, sec. 19, T. 12 S., R. 41 W. A bed of pale-green clay in places 30 feet thick and of an apparently uniform texture is here exposed. The exposure extends for about 150 yards in a west-east direction and lies at the head of a wide, basin-like canyon, which is a southern tributary to Collins draw. The overburden consists of Pleistocene gravel and loess and is in places 20 feet thick. In the

---

[210] Davis and Vacher, 1928, p. 29.

Roy Johnston canyon two beds of bentonitic clay, one 6 feet and the other 7 feet thick, are exposed. The later, which is the upper bed of the two, is exposed on several branches of the repeatedly forking Johnston canyon. The bentonite of this canyon has a considerable overburden (40 feet or more) and therefore cannot be stripped and must be mined. The lower bed of bentonitic clay at the mouth of the canyon, one mile west of Woodhouse ranch, reaches 20 feet in thickness and is exposed for 300 yards or more. Only part of the bentonite of this exposure can be stripped.

In all of these beds bentonitic clays contain efflorescences and nodules of calcium carbonate and veins of gypsum (the latter in the deposit in the SW¼, sec. 19, T. 12 S., R. 41 W.). However, taking into account the fact that most crude bentonites contain a considerable amount of impurities of this and other sorts, which must be removed by expensive washing, the Wallace county Ogallala bentonites do not seem to be exceptionally impure. All in all they appear to be uniform enough and extensive enough for a commercial prospecting and testing.

Bentonite is used in refining crude oils and fats, as a binder and filler for various products and in many other ways. For particulars in regard to bentonite and its commercial uses see Davis and Vacher, Bentonite, its property, mining, preparation and utilization: Technical paper 438, Bureau of Mines, 1928; also Bentonite, properties, sources, geology, production: Bulletin 107, Silica Products Co., Kansas City, Mo., 1930.

The "yellow dirt" or loess of Wallace county (Pls. XX A, XXXV A and XXXV B), which is in all ways comparable to the loess of China (see chapter on loess), is a wonderfully fertile subsoil of the county and is a good material for holding water in dams and irrigation ditches, but can hardly be used for commercial purposes as clay, having too high a percentage of calcium carbonate.

VOLCANIC ASH.

The known volcanic ash beds of Wallace county are not extensive. The writer found only one bed of bluish-white volcanic ash near the base of the Ogallala in the SE¼, sec. 8, T. 14 S., R. 38 W. The bed is only 2 feet thick and has a very large overburden.

Some localities of probably Pleistocene ash in Wallace county have been recorded by M. Etnyre.[211]

---

211. Landes, 1928, p. 46.

GRAVEL AND SAND.

Both gravel and sand are very common in Wallace county. There is a thick and persistent bed of loose gravel in the upper part of the Ogallala. This bed in places is 20 feet thick and is exposed extensively on the north and south sides of Willow creek and on the north side of the south fork of Smoky Hill river, north of Weskan. Owing to its high position in the Ogallala section, this gravel is exposed high on the flanks of the river valleys. Good exposures of probably the same bed of gravel are on the south side of the north fork of Smoky Hill river along the north county line, in T. 11 S., R. 42 W. Another locality is in the SW¼, sec. 35, T. 11 S., R. 40 W. This gravel bed of Ogallala pinches out or becomes thinner and cemented in the southeastern part of Wallace county.

A widespread gravel bed is that of the Pleistocene at the base of the loess formation, but the thickness of this bed varies greatly. Good outcrops of this gravel, some as much as 30 feet thick, have been noted in the following localities:

Northeast corner of sec. 4, T. 11 S., R. 28 W. Low on the valley on the north side of north fork of Smoky Hill river; 30 feet thick. This gravel may also belong to alluvium of the river.

Sec. 22, T. 12 S., R. 40 W., near the head of the draw; 10 to 20 feet thick.

NE¼, sec. 6, and SE¼, sec. 13, T. 13 S., R. 41 W., thickness unknown.

West side of sec. 1, T. 13 S., R. 39 W. Two prominent knobs on the hill. Probably 10 to 15 feet thick. Also in other places.

The alluvial sands (Pl. XXXV C), which grade into gravel in places, fill up the river valleys wherever Ogallala is extensively exposed. They are distributed through the valley of the south fork of Smoky Hill river, in western Wallace county, and gradually become thinner toward the east, where the river loess becomes predominant in the valley.

On the upper part of Goose creek the sands are heavy and they thin gradually toward the east, and then toward the south along the valley.

There is plenty of sand on the north fork of Smoky Hill river in the northeast part of T. 11 S., R. 38 W., and especially in the valley of its southern tributary in secs. 23 and 24, T. 11 S., R. 38 W. The sand is present in the valleys of nearly all other creeks and draws of the county on the slopes of which Ogallala is exposed. At present the sands and gravels of Wallace county are used but little.

The sands of the south fork of Smoky Hill river are dug at the main roads north and northwest of Weskan in secs. 23 and 18, T. 13

S., R. 42 W. Gravel for ballasting railroad tracks is dug in a small pit northeast of Weskan, in the NE¼, sec. 35, T. 13 S., R. 42 W.

STONE.

BUILDING STONE. The massive chalk that forms prominent cliffs between softer chalky beds of the Niobrara has been used as building material, but the chief exposures of this kind of chalk are in Logan county east of Wallace. The massive chalk is very uniform in texture, is of pleasant creamy to orange color and is so soft that it can be sawed easily into almost any size blocks. The walls at Fort Wallace, now in restored condition, are built of the sawed blocks of chalk, and the same material was used for the memorial monument (see Pl. XXXIX A). In spite of its softness the chalk resists weathering strongly. Even the finest details of the carved ornaments on the monument at Fort Wallace have not been obliterated, and the monument was erected sixty-three years ago.

Unfortunately the buildings made of sawed chalk blocks are too rigid to resist exceptionally severe tornadoes, but in this respect they are no more dangerous than brick buildings. To make these rigid constructions as much tornado-proof as possible the bricks or blocks must be tied together firmly. The same rules for safe construction that are followed in zones of earthquakes are equally applicable to the areas visited by tornadoes. A few houses and barns in the Smoky Hill river valley southeast of Wallace, which were built of sawed blocks of chalk, were apparently wrecked by a fierce blow of wind and have not been restored.

Another building stone that is sometimes used by the residents of Wallace county is the hard limestone of the Ogallala formation. The three beds of limestone that have been used for this purpose are the white limestone at the top of the diatomaceous marl, exposed near the Marshall ranch, on the south side of the north fork of Smoky Hill river, in T. 11 S., R. 38 W.; the white limestone grading into chert on the top of the diatomaceous marl, exposed east of the Collins ranch, in sec. 29, T. 12 S., R. 41 W.; and the pink concentrically banded limestone at the top of the Ogallala. Plate XXXIX B shows a small quarry opened in the last-mentioned limestone in sec. 4, T. 11 S., R. 42 W. All these limestones are in beds from 1 to 4 feet thick and as a rule break into irregular-shaped slabs and are altogether much inferior to Niobrara chalk as building stones. The limestone of the Marshall ranch was used for the foundation of the old Robidoux ranch house, and out of the Collins ranch limestone the whole house, now abandoned, in sec. 22, T. 12 S., R. 41 W., was built.

Ornamental Stones. Among the material of the gravels of the Ogallala and the Pleistocene there are occasionally found well-worn pebbles and some crystals of transparent and colorless or smoky rock crystal. Fairly good gems have been cut out of some of these pebbles by local citizens. Fragments of green and red jasper, of agate and of silicified wood are more common, but less attractive, stones among the material of the conglomerates.

The pink concentrically banded compact limestone at the top of the Ogallala takes polish nicely (Pl. XXI B) and in a nontechnical sense can be called marble. It is a beautiful stone but can be used only for small ornaments, because it occurs broken into slabs and blocks of moderate to small size.

Moss agate is another ornamental stone of Wallace county. The first state geologist of Kansas, B. F. Mudge, discovered and described this stone from a locality in the Tertiary (Ogallala) south of Fort Wallace.[212] The writer examined a bed of variously colored semitransparent moss agate in the Ogallala exposure on the east side of the canyon in the NW¼, sec. 11, T. 15 S., R. 38 W., which is possibly the locality referred to by Mudge. The stone takes grinding with comparative ease and without getting cracked. It takes, also, a good polish. The bed to which the moss agate belongs is about 2 feet thick and is made of spongy siliceous matter with irregular bands of only slightly porous to solid, opallike, milk to nearly transparent material with small black, irregular dendrites in it. The cliff of Ogallala in which the bed of moss agate was observed consists of the following beds from the top down:

		Feet.
5.	White spongy limestone, hard, with irregular bands of milky chert....	3
4.	Same limestone, softer, no chert....	5
3.	Hard spongy and cavernous chert with moss agate....	2
2.	Calcareous grit, soft, becoming harder toward the base....	3.5
1.	Grit, medium hard with larger pebbles....	5.5

Diatomaceous Marl.

Three areas of diatomaceous marl in Wallace county have been discovered and studied by the writer. The largest one, on the Marshall ranch on the north fork of Smoky Hill river, has been called "chalk rock" by local residents and also has been supposed to be volcanish ash, as similar white rock with abrasive or polishing

---

[212] Mudge, 1874 (reprinted in 1896), p. 15.

qualities is widely distributed in western Kansas. A microscopic examination under high magnification (300 times or more) discloses the fact that this rock in Wallace county consists almost entirely of the siliceous tests of fresh-water diatoms and of flaky calcium carbonate.

CONSTITUTION OF THE MARL. Preliminary quantitative analysis of an average sample, prepared from the upper 5 feet, which is about half of the bed at the Marshall ranch, showed that dry rock with moisture expelled at about 105° C. consists of about 81 per cent of matter soluble in hydrochloric acid. This is chiefly if not entirely fine, flaky calcium carbonate. About 90 to 95 per cent of the insoluble part consists of siliceous tests of diatoms and siliceous spicules of sponges. Fine to medium grained quartz sand with a slight mixture of feldspar constitutes the balance of the insoluble part. Owing to the construction of the box-shaped empty tests of diatoms the percentage of the volume occupied by these tests is much greater than the percentage by weight. Roughly estimated about one-half of the rock by volume is made up of diatoms.

POSSIBLE USES. The large content of calcium carbonate makes it appropriate to call the rock a diatomaceous marl instead of a diatomaceous earth. Another reason for this term for the Marshall ranch rock lies in the difference between the practical uses that can possibly be made of diatomaceous marl and those of the pure or nearly pure varieties of diatomaceous earth obtained from southern California and other localities.

The diatomaceous earth, which consists chiefly or entirely of the tests of diatoms, is a highly porous rock and is used now chiefly as a sound and heat insulator in building construction, as a filter for purifying drinking water and for other uses in which high porosity, neutrality to acids, or the hardness or sharpness of the minute tests of diatoms composing it are of advantage. The rock from the Marshall ranch might be regarded as a diatomaceous earth mixed with a large quantity of flaky calcareous matter. It is softer and much less porous than regular diatomaceous earth and far from neutral to acids. Thus, though the diatomaceous marl of Wallace county can probably be used for some purposes for which diatomaceous earth is now employed (for instance, as sound and heat insulators, as an abrasive, etc.), it is obviously an inferior material compared with the purer grades of the latter. On the other hand, the intimate mixture of diatomaceous tests with calcium carbonate appears to have peculiar useful properties of its own, which will decide its place and its value among other mineral resources of this country.

It was noticed that if the amount of silica, and to a much less extent alumina and some other impurities, in some limestones of Europe is increased to about 12 per cent or more, lime manufactured from these rocks begins to acquire the property known as "hydraulicity," that is, it can harden or "set" under water. The natural cement made of these limestones is known as "hydraulic lime." Hydraulic lime is white and in this and some other important respects differs from the ordinary yellow or brown natural cements of the "Roman cement" type, which contain a much smaller amount of calcium carbonate and in which alumina and iron constitute a considerable part. A typical natural cement of this latter kind is manufactured at Fort Scott, Kan. The limestone from which the Fort Scott hydraulic cement is made contains: Silica, 18.09 per cent; alumina, 3.44 per cent; iron oxide, 4.27 per cent; lime, 35.32 per cent; and magnesia, 4.62 per cent (average analysis, Eckel, 1928). The most famous and typical hydraulic lime is that known as Le Teil or La Farge, made from a limestone found in Ardèche, France. This limestone consists of calcium carbonate very intimately intermixed with finely divided silica. It contains very little alumina and oxide of iron, which are the constituents generally necessary to bring about the union of silica and lime to form a cement, but in spite of this the silica is so finely divided and so well distributed that it unites readily with the lime when the limestone is burned at a sufficiently high temperature. When subsequently a little but proper quantity of water is poured in, it slakes or disintegrates into fine powder and thus does not need to be ground, which is an unavoidable expense in the manufacture of ordinary cements of both the Portland and the natural hydraulic cement (Roman) types.

As has been said, the Wallace county diatomaceous marl is a chalky substance with about 18 to 19 per cent of silica. It is composed chiefly of very fine tests of diatoms intimately mixed with flaky calcium carbonate. There may be a trace of alumina. It remains to be seen if the two most important components of the Marshall ranch rock, calcium carbonate and silica, are fine enough and mixed intimately enough to produce a good natural hydraulic lime after being burned.

One hundred pounds of the diatomaceous marl from the Marshall ranch has been shipped by the Kansas Geological Survey to the United States Bureau of Standards, which has agreed to make tests in order to find out if the rock can be used for manufacture of hydraulic lime. The experiments of the Bureau of Standards are not completed, but preliminary study shows "from the work up to date it would appear that this material can be burned so as to produce a lime having hydraulic properties."[213]

Hydraulic lime has some properties that make it different from Portland cement and from natural hydraulic cements. It sets more slowly than these cements, but ultimately becomes as strong as Portland cement. The slow setting is an advantage for some special purposes, as for foundations and abutments where settling may occur. The structure is free to take its permanent position before the lime sets, and cracks are thus avoided. It is used, for instance, in place of Portland cement as grouting outside the cast-iron tubes used for lining tunnels made by the shield system. Being low in iron and soluble salts, hydraulic lime is light-colored and does not stain masonry, having thus a fair market for architectural uses in cities, especially in the east and southeast parts of the United States, where this cement is now imported annually.[214]

The available American and French literature lacks precise description of the lithologic characters of the Le Teil marl, but the reported chemical constitution is almost identical with that of the Marshall ranch diatomaceous marl. The following are analyses of some European limestones from which hydraulic lime is manufactured.[215]

	Le Teil, France.		Senonches, France.	Hansbergen, Germany.
Silica (SiO_2)	12.40	16.80	17.00	11.03
Alumina (Al_2O_3)	.60	.81	1.00	3.75
Iron oxide (Fe_2O_3)	.50	trace	*.....	5.07
Lime (CaO)	47.49	45.50	44.80	43.02
Magnesia (MgO)	*.....	*.....	.71	1.34
Carbon dioxide (CO_2)	37.31	35.67	35.99	35.27

* Not determined.

The Marshall ranch diatomaceous marl is a fresh-water deposit of lower Pliocene age, whereas the siliceous marl of Le Teil constitutes the *Criocera* marls of the marine Lower Neocomian of the Cretaceous. The source of the finely distributed silica in the beds

---

213. Letter of Bureau of Standards, Dec. 29, 1930.

214. Eckel, 1928, p. 178.

215. Idem, p. 180.

from Le Teil is unknown. The possibility of the presence of diatoms in these rocks is not excluded, for the tests of these organisms are known in marine Cretaceous limestones of European Russia and of California.

DESCRIPTION OF THE MARSHALL RANCH DEPOSIT. The Marshall ranch diatomaceous marl (Pls. XXXI A, XXXVIIA , XXXVIII A, XXXVIII B and XXXVIII C) outcrops on the south side of the north fork of Smoky Hill river in secs. 10, 11 and 12, T. 11 S., R. 38 W., in Wallace county, and extends into sec. 7, T. 11 S., R. 37 W., in Logan county. The total length of the exposures, interrupted in places by loess, is slightly more than three miles. The thickness of the bed ranges from 2 or 3 feet, in the middle of section 11, to 11 feet in the eastern part of this section. The average thickness from here to the easternmost exposure in Logan county is about 7 feet. In the west half of section 11 the diatomaceous marl is more limy and is hard, but in the NW¼, sec. 10, it is somewhat softer. On the top of the bed there is nearly always a thin hard ledge of white limestone, usually full of small cavities representing molds of fresh-water gastropods. This limestone is a few inches to a foot thick. At the base of the diatomaceous marl there is generally a light-gray clay (Pl. XXXVIII C) with some mixture of calcareous matter and diatoms, but locally there is greenish sand in place of clay at the base. A number of mammalian and other bones have been found in this sand.

The constitution of the diatomaceous marl is fairly uniform throughout. It is everywhere a snow-white chalky rock, light and very fragile. However, it resists weathering, and together with the capping thin limestone forms low cliffs and benches on the southern slope of Smoky Hill river valley. In a few places erosion has formed separate cliffs of the diatomaceous marl, which are scattered on the smooth, gently descending slope of the valley. The rock is usually massive and is cut by widely spaced vertical joints into large blocks (Pl. XXXVIII B). However, it has also a distinct horizontal stratification and can be broken with comparative ease along the closely spaced bedding planes.

The Ogallala formation, to which the diatomaceous marl bed belongs, is slightly folded in this area (Pl. XXXVII A) and consequently the bed is not at the same elevation at all places along the outcrop. It is about 60 feet above the level of Smoky Hill river at the west end of the exposure, and ranges from 80 to 120 feet above it in the middle and eastern parts, whereas the river drops about 50 feet in the interval.

The overburden above the diatomaceous marl consists of the thin hard limestone and in some places of nearly 15 feet of Ogallala grit, slightly cemented with calcium carbonate. Above this lie gravel and loess of the Pleistocene. The specific gravity of air-dry rock is about 1.53, which is approximately three times as much as that of pure diatomaceous earth from California.

The supply of diatomaceous marl at the Marshall ranch locality can be roughly estimated in the following way. The length of the exposures of the marl with average thickness of 6 feet is about 2½ miles. The zigzag arrangement of exposures along this length makes it possible to observe that the thickness of the bed does not decrease appreciably within at least one-eighth of a mile at right angles to the general trend of the outcrop. The overburden ranges from 0 to 30 feet in thickness. Considering that this strip of diatomaceous marl, which is 2½ miles by one-eighth of a mile in area, is decreased by about one-half by the many canyons and gulches in which the rock is eroded away, the total volume of the remaining diatomaceous marl on the divides between the small canyons is about 26,136,000 cubic feet. As the diatomaceous marl weighs about 85 pounds to a cubic foot, this volume corresponds to more than 1,000,000 tons. This estimate does not pretend to be exact, but gives the correct idea as to the amount of diatomaceous marl which could be stripped where overburden does not exceed 30 feet.

OTHER DEPOSITS OF DIATOMACEOUS MARL. Two other outcrops of diatomaceous marl in Wallace county have been studied. One that was shown to the writer by James T. Madigan is in the SE¼ SE¼, sec. 35, T. 11 S., R. 39 W., at the very head of one of the many draws on the south side of Lake creek. The soft snow-white diatomaceous marl, with apparently the same qualities as possessed by that of the Marshall ranch, makes here a small, inconspicuous outcrop. The small size of the outcrop is probably due to the absence of the hard limestone at the top of the bed. The thickness of the outcropping rock is about 3 or 4 feet, but neither the base nor the top is visible. A few feet above the outcrop loess can be seen in the bluffs at the head of the canyon, and below and somewhat down the canyon there are a few outcrops of Ogallala grit.

The third locality of diatomaceous marl and the one in which the diatoms were first recognized by the writer in 1928, is in the northeast corner of the NW¼, sec. 29, T. 12 S., R. 41 W., about half a mile east of the Collins ranch. The diatomaceous marl of this locality is of somewhat different color and texture from the other deposits. It is light gray and is softer than the rock from Marshall ranch. There is probably less calcium carbonate and more diatoms in this rock, and it contains an admixture of clayey material. It is slightly harder at the top and is capped by limestone partly silicified into compact, tough chert. The bed is 4 feet thick and is underlain by greenish-gray clay. The lateral extent of the bed seems to be insignificant.

Soft light-colored rocks in which diatoms constitute a considerable part are known in southwestern and western Nebraska and in Beaver county, Oklahoma, from which locality they probably extend into Meade and Seward counties of southwestern Kansas. The diatomaceous deposits of Nebraska belong chiefly to the Pleistocene,[216] but at Agate, Sioux county, is a deposit considered by H. J. Cook to belong to the lower Harrison formation of lower Miocene age.[217]

The Beaver county, Oklahoma, diatomaceous marl was explored by Cragin, who calls it "chalk marl" and refers it to the "Loup Fork Tertiary" on the strength of some mammalian remains that he collected.[218] Cragin cites the identification of several species of diatoms in the marl by Francis Wolle, to whom he sent a sample for microscopic examination. The same locality was visited in 1893 by Case,[219] who collected there a great many beautifully preserved impressions of dicotyledonous leaves and other fossils, which are deposited at the University of Kansas. A much smaller collection of leaves, also gathered by Case, was studied by E. W. Berry, who concludes that they belong to the upper Miocene, but possibly also to the lower Pliocene.[220]

According to Case "the chalk appears in limited outcrops for about thirty miles along both sides of the Beaver, at a distance of three or four miles from the immediate river valley" between Beaver City and Alpine, the outcrops being "capped with flint." The largest bed of chalk "is that on the south bank of the Beaver, about four miles up a small tributary called 'Gypsum creek.' "[221] Neither Case nor Cragin measured the exact thickness of the bed, but one

---

[216] Barbour, Eleanore, 1910, pp. 3-4.

[217] Personal communication of H. J. Cook to the writer, March 18, 1930.

[218] Cragin, 1891, pp. 29-32.

[219] Case, 1894, pp. 143-147.

[220] Berry, 1918, pp. 627-636; also in Gould & Lonsdale, 1926, pp. 34-39.

[221] Case, 1894, p. 145.

may infer from their descriptions that the bed must be more than 5 feet thick.

Another locality of diatomaceous marl in Beaver county, closer to the Kansas boundary line, is described by Buttram in the east central part of the NW¼, sec. 4, T. 5 N., R. 27 W. This occurs in a bed 12 feet thick and contains: SiO_2, 10.68 per cent; Fe_2O_3-Al_2O_3, 23.49 per cent; and CaO, 35.55 per cent.[222] The material contains abundant diatoms, which are believed to account for practically all the silica in the rock.

Adams has briefly described[223] "a soft chalky limestone about 10 feet in thickness," which is exposed on both sides of the Cimarron river in Seward county, Kansas. He compared it with the beds in Beaver county, Oklahoma, described by Cragin and Case. It is thus probable that the Tertiary diatomaceous marls of Oklahoma extend into southwestern Kansas. Whether these beds belong to the Ogallala formation in a restricted sense and whether they can be equivalents of the Marshall ranch diatomaceous marl remains to be determined. Plenty of fossils from the Beaver county locality have been collected and recorded by Cragin and Case, but except the few dicotyledonous leaves described by Berry none have been described.

UNDERGROUND WATER.

Except on a few stretches of land where little water is obtainable from shallow wells, the residents of Wallace county have a good supply of wholesome water for domestic use and for cattle. This is largely a "sheet water" from sands and gravels of Ogallala, especially from the base of this formation. The underlying Pierre shale and, in the southeastern part of the county, the underlying shaly chalk of the Cretaceous constitute the impervious floor which supports the sheet water at the base of the Ogallala. The same Cretaceous formations constitute the impervious bottom of the valleys, upon which rest the alluvial sands and gravels saturated with water of "underflow." This "underflow water" is usually good and plentiful. The valleys of Rose creek and Eagle Tail creek are especially noted for their rich supply of water, even in years of drought that occasionally strike western Kansas. The water of these creeks is supplied by the large number of springs flowing from the base of the Ogallala, which builds the nearly horizontal high plateau of the southern part of the county. Eagle Tail creek and especially Rose

---

[222] Buttram, 1914, p. 40.
[223] Adams, 1902, pp. 301-303.

creek developed deep and extensive basins in this southern plateau. It has been noticed since the explorations of water resources of the High Plains by Robert Hay that wherever the sandy Ogallala formation of the divides is poorly developed or not present at all, and the mantle of loess rests directly on the Cretaceous, there is but little or no sheet water in the irregular bodies of sand and gravel at the base of the loess. Loess, though a porous rock and usually saturated with water, acts as an impervious barrier and is successfully used for water storage in irrigation dams and ditches. This quality of loess is due to its having an extremely fine capillary porosity, so that it absorbs greedily a considerable quantity of moisture but does not part with it easily and does not let it through, thus checking its migration.

The areas of wide development of Ogallala, with little loess over it or with the overlying loess cut by a net of ravines or by groups of nearly circular depressions, are areas of the greatest imbibition of atmospheric precipitation in the High Plains.

The deep Robidoux and Wulfekuhler wells proved that the Dakota sandstone, the top of which is from 1,100 to 2,000 feet below the surface of Wallace county, yields a considerable supply of artesian water, which is, however, much inferior to the sheet and underflow water for drinking. In the Wulfekuhler well the artesian water of the Dakota was capped at 1,437 feet, and the water rose 700 feet in the hole. Another water sand, also within the Dakota, was reached at 1,511 feet, and the hole became filled with water.

In the following list the available information in regard to the supply of sheet water of the divides and the underflow of the valleys is given for every township in the county.

Water resources of the townships.

T. 11 S., R. 42 W. Sheet water within Ogallala and at the base of it; valley water along larger streams; 160 feet to water in the NW¼, sec. 8; 120 feet to water in the SE¼, sec. 4; 41 to 58 feet to water in section 24.

T. 11 S., R. 41 W. Sheet water within Ogallala and at the base of it; valley water along larger streams.

T. 11 S., R. 40 W. Sheet water within Ogallala and at the base of it; valley water along larger streams; 68 to 76 feet to water in the NE¼, sec. 2; 125 feet to water in section 14; 60 feet to water in the east part of section 22. Dirt dam is built across the draw in the NW¼, sec. 27, to hold water for irrigation.

T. 11 S., R. 39 W. Chiefly valley water along Lake creek and along its larger left tributaries. Less water in the north. Little or no water on the right or south side of Lake creek.

T. 11 S., R. 38 W. Sheet water at the base of Ogallala; valley water along larger streams; 180 feet to water in the NW¼, sec. 14; 45 feet to water in the SE¼, sec. 13.

T. 12 S., R. 42 W. Sheet water chiefly at the base of the Ogallala; valley water along larger streams; 108 to 130 feet to water in section 10; 90 feet to water in the east part section 18; 140 feet to water in the NE¼, sec. 19; 160 feet to water in the east part of section 30. No water encountered though "black shale" was struck at depth over 100 feet. Large depression in sections 9 and 16, east of abandoned schoolhouse, always wet in the bottom. Little or no sheet water in the central part of the township, which is on the line of Weskan meridianal structural ridge.

T. 12 S., R. 41 W. Chiefly valley water along larger streams. Little sheet water in west central and no sheet water in east central part of the township where Ogallala thins out and loess overlies Pierre shale directly; 24 feet to water in Collins draw in section 22.

T. 12 S., R. 40 W. Sheet water in northern half of the township and valley water along larger streams. Less or no sheet water in south and southeast parts where Ogallala thins out and loess overlies Pierre shale directly. Dip circular basin, "Old Maid's pool," in the northeast corner of section 30 never dries up; 17 feet to water in Goose creek valley in the southeast corner of section 32.

T. 12 S., R. 39 W. Little or no sheet water in the northern half of the township. Valley water along larger streams. All old basins and cave-ins in northeastern part of the township are dry except one recent cave-in in section 1, which cuts through the channel of the intermittent stream and is full of water.

T. 12 S., R. 38 W. Chiefly valley water along larger streams. No or very little sheet water in central, southern and southeastern parts of the township where loess overlies the Pierre shale directly with only insignificant local remnants of Ogallala between. However, the large basins in the southeastern part of the township are wet on the bottom.

T. 13 S., R. 42 W. Plenty of sheet water within Ogallala and at the base of it and valley water in Smoky Hill river and in Willow creek; 80 feet to water in the northeast corner of section 3; 60 feet to water in the NW¼, section 10; 10 feet to water in the valley of Smoky Hill river in section 24; 157 feet to water in section 28 and 159 feet in section 34; 40 feet to water in section 32. The water in the last place is considered hard. Geologic study of the area indicates that the water comes from a sand in the upper part of the Ogallala formation. The hardness of the water is most probably due to calcium carbonate dissolved from Ogallala sediments, which are especially rich with lime near the top of the formation.

T. 13 S., R. 41 W. Sheet water at the base of the Ogallala. Valley water along larger streams; 50 feet to water in section 24; 16 to 30 feet to water in the north of section 34.

T. 13 S., R. 40 W. Mostly valley water along the main streams. Very little water in the central part of the township north of Sharon Springs, and little or no sheet water in the north, northeast, and southwest parts, where loess overlies the Pierre shale directly; 27 to 39 feet to water in the southern part of section 27 and in the northern part of section 34, the water being supplied by the underground stream of the intermittent Eagle Tail creek; 20 feet to water in Smoky Hill river valley in the NE½, sec. 24.

T. 13 S., R. 39 W. Little sheet water, the Ogallala being absent from most parts and loess overlying the Pierre shale directly. Valley water along the larger streams; 40 feet to water in Eagle creek valley in the NW¼, sec. 30; 16 feet to water in Smoky Hill river valley in the west of section 26.

T. 13 S., R. 38 W. Chiefly valley water along the larger streams.

T. 14 S., R. 42 W. Sheet water within and at the base of the Ogallala. Valley water along North Ladder creek. Probably little water southwest of Weskan, on the line of Weskan structural ridge; 143 feet to water in the NE¼, sec. 3.

T. 14 S., R. 41 W. Sheet water within Ogallala and at the base of it. Valley water along the larger streams; 85 feet to water in the SE¼, sec. 15; 70 feet to water in the NE¼, sec. 22; 115 feet to water in the NW¼, sec. 36.

T. 14 S., R. 40 W. Sheet water within Ogallala and at the base of it; little sheet water in the northwest corner of the township, where loess overlies the Pierre shale directly. Valley water along the larger streams; 120 feet to water in the SE¼, sec. 18; 170 feet to water in the NE¼, sec. 17; 135 feet to water in the SW¼, sec. 16, and in the NE¼, sec. 12.

T. 14 S., R. 39 W. Sheet water within and at the base of the Ogallala. Valley water along larger streams except in the large draw in the northeast corner of the township, which has but little underground water.

T. 14 S., R. 38 W. Sheet water within and at the base of the Ogallala in the middle and southern parts of the township. Valley water in larger streams in the south. Little water and most of it not fit to drink in the many canyons on the slope of Smoky Hill river valley. Dirt dam is built in the canyon in the SE¼, sec. 1, which holds water for irrigation.

T. 15 S., R. 42 W. Sheet water at the base of the Ogallala and valley water along the larger streams. No water in the central part of the township (area shaded on the structural map) probably because the area is on the middle of an underground hill projecting into the Ogallala; 150 feet to water in the NW¼, sec. 2, and 163 feet to water in the west part of section 2; 150 feet to water in the NE¼, sec. 1; 200 feet to water in the SW¼, sec. 36; 200 feet to water in the SW¼, sec. 7.

T. 15 S., R. 41 W.; T. 15 S., R. 40 W.; T. 15 S., R. 39 W.; and T. 15 S. R. 38 W. Sheet water in Ogallala and valley water along the larger streams; 150 feet to water in the NW¼, sec. 4, T. 15 S., R. 41 W.

LOCAL SUBSIDENCES.

An abrupt sinking of ground, producing deep steep-sided holes and basins, has been recorded in many places in western Kansas. The first scientific record of ground subsidences known to the writer was made by Robert Hay, who described sink holes in sec. 23, T. 8 S., R. 42 W., in Sherman county. These were in the form of "a series of broad cracks, some over 2 feet across, running in every direction . . . and extending over several acres. . . . When the cracks were discovered men went down some of the large fissures, from 6 to 8 feet deep, and under the parts where the cracks were narrow, as in a tunnel."[224] These cracks and sink holes were noticed after "very heavy rains and almost a cloudburst at this point," at the end of May in 1894, but, as Hay remarks: "The storm of last May probably only completed a process of widening natural channels that percolating waters had been busy performing for ages." The area of subsidence is described by Hay as part of a broad but inconspicuous basin on a long slope inclining to Beaver creek on the south, where the Tertiary grit (Ogallala) is exposed. Hay points out that "here are large fissures in the soil which will carry down to the porous grit itself all the water falling on the area," which is described as a region of great imbibition, supplying the sheet water in the grit (Ogallala). The explanation given by Hay of the immediate cause of these lenticular sink holes in the broad basin of the area seems to be satisfactory, but no attempt was made by him to explain how the old broad basin itself originated. The latest phases of the development of the basin perhaps could be explained by the repeated occurrence of sink holes like those of 1894, but as Hay noticed, "the bottom of the old basin is a little farther down the slope," and, nevertheless, the cause that started the subsidences resulting in the broad basin remains unexplained. The subsoil of this area is "plains marl" of Hay, or yellow dirt of common parlance, or loess, as it is called in this report. This is a material through which water does not readily circulate, as is explained in discussing underground water. There must have been, therefore, some causes within the underlying formation, the pervious "Tertiary grit" of Hay (or Ogallala) or farther below, which started the subsidence of the impervious loess above. It seems as if a caving, probably repeated several times, in the underlying Ogallala or in the formations below it, started an initial subsidence, and that in the further development of a broader basin out of this initial subsidence, opening of successive cracks in the loess and undermining work of surficial water along these cracks, in the way explained by Hay, played an important rôle. The gradual development of a system of cracks around sink holes and a "gradual basining of a large tract" around the holes are explained and beautifully illustrated by Johnson,[225] who studied in detail the

---

[224] Hay, 1895, pp. 555-556.
[225] Johnson, 1901, pp. 705-713.

local subsidences in Meade county, Kansas, and in the adjacent area.

Though Johnson makes a rather sharp distinction between "basins" and "sink holes" of this area and offers a different explanation for the origin of each kind of depression, he concludes generally that all "the innumerable hollows in the High Plains surface, large and small alike, are due to ground settlement rather than to some process either of original construction or of subsequent erosion."[226] He rejects the origin of even most shallow basins and "buffalo wallows" by wind excavation on account of the surface being "too firm." It is protected by a close-knit sod, and besides "the soil beneath is adobe, comparatively hard."[227]

However, Darton explains the origin of the "buffalo wallows" by a combined action of buffaloes and wind. He[228] states that the "large circular pits, called buffalo wallows," which are common on the plains, "were started by buffaloes either in wet spots or at places where there is salt or alkali, which the animals lick. The tramping of the hoofs of the heavy animals wears the sod thin, and then the wind soon blows out a cavity, or if water collects in it the mud is carried out in large amounts in the shaggy coats of the buffaloes, who delight to wade or roll in a water hole."

Shallow basins of the "buffalo wallow" type are observed here and there on the flat divides in Wallace county. The writer does not see any objection to the explanation of their origin that is set forth by Darton and that seems to be implied in the common name, "buffalo wallows."

Johnson accepted the view that pronounced "sink holes such as St. Jacobs Well and the Salt Well, also the great depressed areas, such as Big Basin and the much larger Meade Basin, . . . may be attributed to caving, resulting from removal of soluble masses within the underlying rocks," but he believed that "the innumerable upland basins, especially where the floor is Cretaceous to great depths, are clearly to be ascribed to grain-by-grain process of readjustment and compaction at work within the Tertiary only."[229]

The chief difficulty, as he saw it, "in the way of accepting caving within the rocks of the floor . . . is the fact that the Tertiary of the High Plains does not everywhere rest directly upon the Red Beds . . . and over the greater part of western Kansas, for ex-

---

[226] Idem, p. 702.
[227] Idem, p. 702.
[228] Darton, 1915, pp. 36-37, footnote 2.
[229] Johnson, 1901, p. 711.

ample, Cretaceous rocks, mostly sandstones and shales to a great depth, constitute the floor; yet small basins are no less numerous there."[230] There is hardly any doubt that the solution of great portions of salt and gypsum in red beds cause the caving of overlying formations, as was explained by Haworth, Johnson and other students of the problem, but the possible similar solution, though probably not on as large a scale, of the portions of chalk and limestone of the Upper Cretaceous of the High Plains is far from being impossible and in fact is now regarded as the most probable cause of the local subsidences in Wallace county and the adjacent area.[231]

The explanation offered by Johnson for the origin of the comparatively shallow and not abrupt depressions or "saucer-form hollows" is the differential "settling within the Tertiary."[232] A somewhat similar explanation was advanced earlier by Haworth,[233] whose views are as follows: "Swales" of "the Tertiary plains in the West" are most probably "located in places where the Tertiary materials were not quite as solid and firm as elsewhere, consequently, by the natural settling process, a difference in the surface was produced. As soon as such a depression was formed the rain waters from the higher grounds around would drain into it, and consequently a greater movement of water immediately under it would take place. This accumulation of water would dissolve and carry away by downward percolation a greater amount of matter than would be dissolved elsewhere."

Johnson explains that the "appearances indicate basining of the alluvial surface as a consequence, first, of rain-water accumulation in initial faint unevennesses of the plain; second, of percolation of this ponded surface water downward to the ground water in increased amount from these small areas of concentration, rather than from over the whole surface uniformly, with the result that the alluvial mass is appreciably settled beneath the basins only. The inference is at once suggested that this settlement takes place as the combined effect of mechanical compacting of the ground particles and chemical solution of the more soluble particles. Finally, these effects should be cumulative, resulting in the growth noted, since, with enlargement of the basins, concentration of rain water within them will be on an increased scale."[234]

---

[230] Johnson, 1901, p. 705.
[231] Moore, 1926, pp. 96-97; Elias, 1930, pp. 316-320.
[232] Johnson, 1901, pp. 703-705.
[233] Haworth, 1897, pp. 20-21.
[234] Johnson, 1901, pp. 703-704.

When offering their explanation of the origin of sink holes in the areas outside the known distribution of gypsum-bearing and salt-bearing red beds, these authors did not regard the loess of the High Plains (plains marl of R. Hay or Sanborn loess of this paper) as a formation distinct, widespread and stratigraphically wholly independent of the arenaceous Tertiary ("Tertiary grit" of R. Hay, or Ogallala), and Johnson apparently even did not differentiate the loess of the High Plains from "alluvium." The very distinct mantling of the comparatively thick and impervious loess formation over both the Tertiary and the Upper Cretaceous of the High Plains, is, however, a very important structural feature of the area, especially in connection with the movement of surficial and shallow waters, as was demonstrated first by Hay. The thickness of the loess is ordinarily from 30 to 50 feet on the divides, but it attains even 180 feet in the northwest corner of the state. The water that gathers in shallow depressions on this mantle does not have any better chance to drain through the practically impervious[235] loess than elsewhere. In fact, the water in very shallow basins, which can be seen here and there very high on nearly level surfaces of the divides, stands as ponds and small lakes for many days and even weeks after heavy rains until finally it evaporates, but it is not drained through the loess. Only from depressions that are so deep as to penetrate the mantle of loess down to the sandy and agglomeratic lower zone of the Pleistocene, can water collected in them enter the pervious basal zone of the Pleistocene and the arenaceous Ogallala below. But until this depth is reached the developing of the depressions can go on only with the help of settling or caving of the underlying rocks of Ogallala or of the still deeper formations.

It does not seem probable to the writer that differential mechanical settling within the Ogallala, which is not more than 200 feet thick, could be so uneven as to produce differences in thickness of tens of feet, which would make possible any surficial depressions penetrating the mantle of loess. It appears to be quite possible, however, that underground water of the Ogallala works out small cavities in this formation by dissolving calcium carbonate, with which this formation is richly impregnated. The gradual settling or sudden caving of the Ogallala over the places of greater solution may, of course, result in some settling of loess above. However, depressions thus formed will probably never develop into much

---

[235] See chapter on Sanborn loess.

larger or much deeper basins, so we must conclude that the larger basins must have been caused by the solution of rocks in deeper strata than those of the Ogallala.

A deep and sudden subsidence in a place where Tertiary rocks are absent and where the red beds with possible soluble rocks are too deep for consideration occurred in 1926 near Sharon Springs. This caving of the ground created much excitement among the local residents and attracted much attention from geologists and from visitors. A sign "Smoky Basin Cave-in" has been erected at the crossing of the dirt road to the subsidence with U. S. highway 40 S., four miles east of Sharon Springs. From this crossing one has to go two miles south and about two miles east, and then a turn to the left (north) through gates will bring the visitor to the cave-in. This nearly circular and steep-sided hole now has a connection with the usually dry channel of Smoky Hill river. The cave-in extends even below the channel of the river and has its bottom much below the water level of the Smoky Hill river underflow, so it is now always filled with water; but originally the hole was dry. The following is a description of the subsidence as it appeared in 1926:[236]

> "The present dimensions of the basin formed by the subsidence are about 350 feet from east to west by 250 feet from north to south. At first the hole was much smaller, and it had a considerable but unmeasured depth, estimated by early visitors at 300 to 500 feet. Although Smoky Hill river is here dry, water from the underflow gradually filled the depression, forming a pond which, at the time of the writer's visit, was 75 feet below the adjacent upland to the east. Systematic soundings showed a gradual increase in depth of the water to about 50 feet, and then in the middle part of the depression a practically vertical-sided hole in which the depth of water was 165 to 170 feet. The computed volume of the depression is approximately 1½ million cubic feet.
>
> "Pierre shale is exposed in the walls of the sink, and near by there are very good exposures of this formation. The overlying Niobrara chalk is exposed a short distance east of the sink, south of Wallace."

Since this description was written the hole somewhat increased in diameter by the sliding down of the walls along concentric cracks, which developed around the subsidence, but this process, tending toward filling of the basin, is now much slower than it was in the year when it began. The walls are still very steep, and the bottom lake is deep.

Moore offered the following explanation for this and similar subsidences in Wallace county.[237]

---

[236] Moore, 1926*a*, pp. 95-96; see, also, Moore, 1926, pp. 130-131.

[237] Idem, p. 96.

> "The structural relationships of the Cretaceous rocks show that water entering the Niobrara in eastern Colorado throughout a large area northeast of Las Animas may be expected to migrate down the dip to this soluble and more or less porous formation, emerging at the exposures 1,500 feet or more nearer sea level in Logan and other counties farther east in Kansas. It seems evident that the subsidence near Sharon Springs is due to the formation of a cavity of considerable size in the upper part of the chalk, following which, failure of the roof caused the cave-in.
>
> "The occurrence of craterlike depressions of varying size at several places in Wallace county under conditions that show clearly a depression of the Cretaceous rocks, the Tertiary being very thin or absent, indicates that solution of the chalk followed by subsidence of the overlying materials has taken place from time to time in the recent geologic history of the region."

Another explanation was offered by Russell, who believes that his observations in Wallace, Logan and other counties in western Kansas exclude the possibility of the dissolving of underground chalk, "because of the impervious and relatively insoluble nature of the chalk, and because the solution could take place only at the outcrop.[238] He suggests that large caverns in the Niobrara formation could be produced by tensional faults, "the thinness of the overlying strata" together with "the relatively rigid character of the Smoky Hill chalk" providing sufficient causes for accidental caves between the walls of a fault, the walls of the cavities being "sufficiently strong to resist the pressure for a considerable time." The time for the occurrence of such cavities dates back, according to Russell, to "late Pliocene or early Pleistocene," when the tensional faulting of the Ogallala occurred. This means that the walls of the supposed cave-ins, produced by tensional faulting of this time, resisted the pressure of overlying rocks for 500,000 to 1,000,000 years of Pleistocene and Recent times before collapsing.

If large cavities in underground strata of Niobrara chalk could originate in connection with faulting of post-Ogallala (early Pliocene) time, the sudden subsidence over these supposed "tensional" cavities hundreds of thousands of years later seems to be mechanically unsound, unless some sort of gradual weakening of the roof of the cavities occurred. However, if destructive undermining work of ground water is completely excluded, as suggested by Russell, there seems to be no agency that would gradually weaken the roof and cause its final collapse. No such agency is suggested. The daily change of temperature, which is an important factor in disintegration of the rocks on the surface, certainly has no effect on rocks buried hundreds of feet below the surface. There is perhaps a

---

[238] Russell, 1929*a*, p. 605.

slight chance that the roof of an underground cavity in the Niobrara might yield very gradually with time, if the pressure of overlying strata was just a fraction higher than the elastic limit of the Niobrara rocks. However, even if such a condition existed at the time of origin of the "tensional" voids, the gradual erosion of overlying beds would soon change the condition, decreasing the overlying load to a point well below the elastic limit of the cavern's walls. As a matter of fact, the thickness of overlying beds since Ogallala time has been reduced to about one-half of the original thickness of the beds above the underground chalk of the Smoky Basin cave-in. The thickness of the Pierre shale overlying the Niobrara chalk at the Smoky Basin cave-in is now hardly more than 200 feet,[239] although at the time of faulting there was not less than 100 to 150 feet of additional thickness of shale, now eroded away, and above the shale there was about 100[240] feet, constituting the local section of Ogallala.

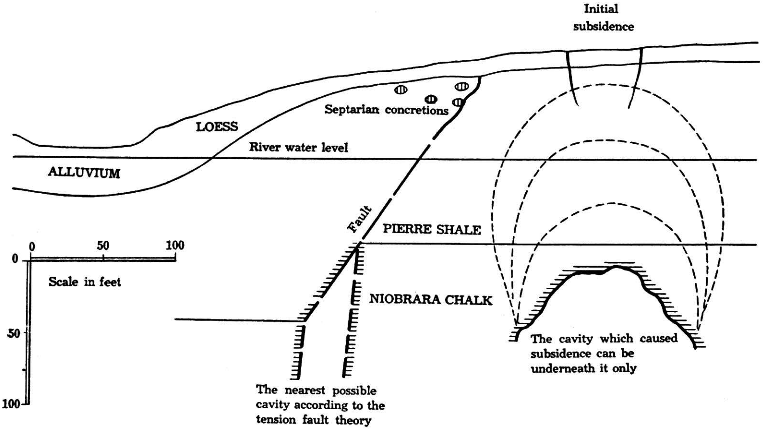


FIGURE 7.—Diagram of Smoky Basin cave-in.

As noted by Russell, there is a fault, which can be seen in the north wall of the Smoky Basin cave-in, cutting the area of present subsidence about in the middle. The fault was examined by the writer and can readily be recognized by the change of color and some other lithological features, such as a profusion of fish scales and concretions on the northwest or downthrow side of the fault. However, the presence of this fault can hardly help the "tension cavities" theory. This fault seems to be truly a normal or tension

---

[239] In the paper published by the writer in 1930 the thickness according to his preliminary estimate was stated as "hardly more than 350 feet—probably less."

[240] According to direct measure in the nearest outcrop south.

fault, but the plane of faulting is much inclined toward the northwest (45° to 60°), and the starting place of the subsidence is on the east side of the present basin, or east of the surface line of the fault (Pl. XL A).

If the underground dip of the fault does not differ appreciably from the surficial dip just stated, which is only a natural extrapolation of surficial observation, then the place of the supposed "tensional cavity" in the Niobrara chalk will be west of the center of the present cave-in basin and still farther from the initial place of subsidence.

Figure 7 shows the eccentric position relative to the Smoky Basin cave-in of the nearest possible tension-fault cavity in the underground beds of Niobrara chalk. The thickness of overlying Pierre shale is shown according to the estimate by the writer. The allowance of 700 feet of shale above the cavity, as suggested by Russell, would place the nearest possible tension-fault cavity about 400 feet farther from the subsidence.

The position of a cavity directly below the initial subsidence is shown on the sketch (Fig. 7). According to the laws of rock subsidence as established by J. Callon, H. Fayole, and others, based on extensive studies in mines, a subsidence over an undermined area of horizontally stratified rock is propagated in a fairly straight vertical direction. A system of subsequently developed domelike cracks is formed, and along these cracks parts of strata tear off and fall down.

The Cretaceous formations at the Smoky Basin cave-in are nearly or quite horizontal; therefore no other than a vertical cave-in over an underground cavity in these formations may reasonably be inferred. The cavity is presumably located in the top layers of Niobrara chalk, but it could be formed equally well in deeper layers of Niobrara. The vertical scale of the sketch is not exaggerated.

The writer is inclined to think that the fault of the Smoky Basin cave-in might be only an indirect cause for the occurrence of the subsidence, its influence being limited to allowing the surface water to enter the chalk through fissures developed in connection with the faulting. Observations in coal mines show that faults are rarely quite dry, but that ordinarily a large or small amount of surficial water moves along the fault planes. The coal-bearing formations are commonly fairly argillaceous, a condition, however, that does not generally lead to a complete sealing of the fault fissures.

The lower part of the Pierre shale, which overlies the Niobrara chalk in the area of the Sharon subsidence, does not consist of clayey shale alone but is made of alternating beds of clayey shale, flaky shale, and porous and rigid pseudochalky shale. It seems to be quite possible, if not probable, that zones of cracks or breccia, which might develop in places along the fault, provided channel ways through which circulating surficial waters could descend to the Niobrara chalk.

Surficial waters that entered fissures at and around the Smoky Basin fault have certainly been charged with carbon dioxide and thus could aid greatly in the solution of the chalk, but this could be done, also, by water not carbonized at all. Davis justly emphasizes the fact that "limestone is, as compared to sandstone and shale, rather readily soluble in noncarbonated water," and "it is well to bear in mind that some share, perhaps a large share, in the solutional excavation of caverns may be accomplished, very slowly to be sure, by noncarbonated water."[241]

It seems clear that whether underground water in the Niobrara chalk migrated from distant outcrops of the formation or descended directly through the fissures along fault zones, the solution of the chalk would not be uniform. There are doubtless more soluble and more pervious parts of the chalk traversed by various fissures, along which the water would circulate more readily. This would result in differential solution of the calcareous matter in the chalk, which could lead to the formation of caves and could contribute to the collapse of their roofs.

It is quite interesting to note that according to Weller, who studied the origin of caves in various limestones, those "comparatively porous limestones which offer free passage for the water in all directions do not commonly develop sink holes and caves unless, for some reason, the circulation of the water is concentrated locally," while, on the other hand, "sink holes and caves are developed to their maximum perfection" in beds of limestone "practically impervious to water except along fissures or bedding planes," where "consequently solution is localized along certain lines."[242]

It seems apparent to all students of the origin of underground caves that the water that is capable of solution and corrosion of calcareous rocks does not necessarily fill up either the particular paths along which it moves or the caves caused or enlarged by its circulation. Therefore, a subsidence over such a cave, as was true

---

[241] Davis, 1930, p. 487.

[242] Weller, 1927, p. 45.

of Smoky Basin cave-in, may have initially a dry bottom, the amount of water in the cave being only enough to fill the space between the blocks and fragments of the collapsed roof, which covered the floor.

It appears to be quite possible that caverns of deformation, such as the tensional fault cavities suggested by Russell, or of a similar sort, could have been actually produced in the comparatively rigid Niobrara, which, as observations show, is much broken into larger and smaller tilted blocks. However, as was shown above, the particular cave-in east of Sharon Springs is not situated above a possible tension cavity in connection with the fault discovered in the wall of the cave-in. It is possible and even probable that in other places the fissures, the fault breccia and similar more-permeable zones along faults served as canals for water circulation and were in places gradually enlarged and finally caved in. However, the cavities produced by faulting could not possibly collapse long after their origin without the action of some undermining water, as was explained above.

In secs. 1, 2 and 3, T. 12 S., R. 39 W., there are four cave-ins in a row, the smallest and the most recent of which (Pl. XL B) is somewhat south of the center of section 1. These subsidences, which have already been described by Russell,[243] are possibly arranged along an arching fault through which the underground water of the Niobrara, which here is about 500 feet below the surface, is circulating. According to James T. Madigan, the cave-in south of the center of section 1 (see Pl. XL B) originated about 1900. This cave-in cuts across the channel of the local draw and is filled with water from the underflow. The next two subsidences west of here are situated on the north side of the valley, their rims being about at the base of the valley slope. They have dry bottoms, and their walls are only moderately steep owing to prolonged erosion. The fourth and westernmost subsidence of this group is much larger in area but is very shallow, which is probably, at least in part, due to a much older origin of the cave-in. The gradual filling of cave-ins of this type by the slumping of the walls is described in detail by Johnson, who studied similar subsidences in Meade county, Kansas.[244]

Though the arrangement of the four subsidences just mentioned along a curved line suggests a group of underground cavities along

---

[243] Russell, 1929*a*, p. 606.

[244] Johnson, 1901, pp. 705-712.

a fault, there are other subsidences in Wallace county which are either isolated or are arranged in irregular groups. A group of large and ancient subsidences in the southeastern corner of T. 12 S., R. 38 W., has no particular order of arrangement. The bottoms of these basins are usually wet, being on the level of sheet water of the sandy base of the local loess formation.

The solitary Old Maid's Pool (Pl. XLI A), in the northeast corner of sec. 30, T. 12 S., R. 40 W., is perfectly circular and has always water at about the same level, which is also apparently the level of the sheet water at the base of the loess formation. Pierre shale is exposed on the south side of the basin.

Another large basin, probably an old cave-in, is on the middle of the line between secs. 9 and 16, T. 12 S., R. 42 W. The bottom of this basin is usually wet.

North of Wallace county two subsidences are reported by Russell,[245] six miles south of Goodland, near state highway No. 27, and south of Wallace county the nearest known cave-ins are in Hamilton county. The latest sudden subsidence in this area occurred late in 1929 and was reported by Mr. Herbig, of Irene post office, in the following words:

> "We are having lots of snow. Some wind. On Sunday morning, November 10, 1929, there occurred a strange thing in the way of a sink hole seven miles northwest of here. On the northeast corner of sec. 22, T. 25 S., R. 43 W., a place about 20 feet in diameter sank about 20 feet deep." [246]

The place of the subsidence was visited by K. K. Landes in the summer of 1930, by Bass, Stryker and Ver Wiebe on August 29, 1930, by the writer early in October of the same year and again by the writer in company with Landes April 10, 1931. The subsidence was described in detail by Bass[247] and by Landes.[248] The circular hole, with vertical walls rising about 6 feet above the water level, was about 50 feet in diameter when visited by the writer in 1930 (Pl. XLI B). According to Herbig the hole was dry until after heavy rains. The subsidence is situated at the edge of the bottom of a dry valley that runs from here southeastward. Many similar but more ancient sink holes are scattered along this valley. One of these, named "Devils Hole," is in the SW¼ SE¼, sec. 30, T. 25 S.,

---

[245] Russell, 1929*a*, p. 606.

[246] From personal letter of November 12, 1929, to S. D. Flora, of Topeka, forwarded to state geologist.

[247] Bass, 1931, pp. 201-205.

[248] Landes, 1931, p. 708.

R. 42 W., and was, according to Herbig, about 15 feet deep forty-four years ago, but now is only about 10 feet deep.

At the time of the last visit of Landes and the writer the slumping of the walls of the hole advanced to such an extent that the public road has been engulfed across its entire width. This slumping also exposed the shale, which is undoubtedly Benton shale, in the eastern side of the hole beneath alluvium. This observation permits us to conclude that "the original cavern was formed in pre-Dakota strata, because very little soluble rock is found in the Graneros or Dakota formations.[249] Landes concludes that "dissolution of soluble pre-Dakota strata, possibly salt but more probably gypsum, caused the formation of the original cavern underlying the Hamilton county sink."

---

[249] Landes, 1931, p. 708.

BIBLIOGRAPHY.

Adams, George I. 1898. Upper Cretaceous of Kansas; A Historical Review: Kansas Univ. Geol. Survey, vol. 4, p. 13.

——— 1902. Note on a Tertiary Terrane New in Kansas Geology: Am. Geologist, vol. 29, p. 301.

Adams, L. A., and Martin, H. T. 1929. A New Urodele from the Lower Pliocene of Kansas: Am. Jour. Sci., 5th ser., vol. 17, p. 509.

Anonymous. 1930. Bentonite, Property, Sources, Geology, Production: Silica Products Co., Bull. 107, Kansas City, Mo.

Baker, C. L. 1928. Panuco Oil Field, Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 12, p. 395.

Barbour, Eleanore. 1910. Preliminary Notice of a Newly Discovered Bed of Miocene Diatoms: Nebraska Geol. Survey, vol. 3, pt. 12.

Barbour, G. B. 1925. The Loess of China: China Jour. Sci. and Arts, vol. 3, pp. 454, 509. Reprinted in Smithsonian Inst. Ann. Rept. for 1926, p. 279, 1927.

——— 1930. Loess Problem of China: Geol. Mag., vol. 57, p. 458.

Bass, N. W. 1926. Geologic Investigations in Western Kansas: Kansas Univ. Bull. 11.

——— 1931. Recent Subsidence in Hamilton County, Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 15, p. 201.

Berry, E. W. 1918. Fossil Plants from the Late Tertiary of Oklahoma: U. S. Nat. Mus. Proc., vol. 54, p. 627.

Bradley, W. H. 1929. Algæ Reefs and Oölites of the Green River Formation: U. S. Geol. Survey Prof. Paper 154-G.

Bucher, W. H. 1918. On Oölites and Spherulites: Jour. Geology, vol. 26, pp. 593, 609.

——— 1919. On Ripples and Related Sedimentary Forms and Their Paleogeographic Interpretation: Am. Jour. Sci., vol. 47, pp. 149-210, 241-269.

Butler, G. M. 1914. Clays of Eastern Colorado: Colorado State Geol. Survey Bull. 8.

Buttram, Frank. 1914. Volcanic Dust in Oklahoma: Oklahoma Geol. Survey Bull. 13.

Calvert, W. R., Beekly, A. L., Barnett, V. H., and Pishel, M. A. 1914. Geology of the Standing Rock and Cheyenne River Indian Reservations, North and South Dakota: U. S. Geol. Survey Bull. 575.

Case, E. C. 1894. A Geological Reconnaissance in Southwest Kansas and No Man's Land: Kansas Univ. Quart., vol. 2, p. 143.

Chhibber, H. L. 1927. Rhythmic Banding of Rerric Oxide in Silicified Rhyolite Tuff: Geol. Mag., vol. 64, p. 7.

Clarke, F. W. 1924. Data of Geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770.

Cockerell, T. D. A. 1919. Some American Cretaceous Fish Scales: U. S. Geol. Survey Prof. Paper 120, p. 165.

COFFEY, G. N., and RICE, T. D. 1912. Reconnaissance Soil Survey of Western Kansas: U. S. Dept. Agr. Bur. Soils Field Operations, 1910.

COLLIER, A. J. 1922. The Osage Oil Field, Weston County, Wyoming: U. S. Geol. Survey Bull. 736-D, p. 71.

CONDRA, G. E. 1907. Geology and Water Resources of the Republican River Valley and Adjacent Areas, Nebraska: U. S. Geol. Survey Water Supply Paper 216.

——— 1908. Geology and Water Resources of a Portion of the Missouri River Valley in Northeastern Nebraska: U. S. Geol. Survey Water Supply Paper 215.

COOK, H. J., and MATTHEW, W. D. 1909. Pliocene Fauna from Western Nebraska: Am. Mus. Nat. Hist. Bull. 26, p. 361.

COPE, E. D. 1875. Vertebrata of the Cretaceous Formations of the West: U. S. Geol. Survey Terr., vol. 2.

CRAGIN, F. W. 1891. On a Leaf-bearing Terrane in the Loup Fork: Am. Geologist, vol. 18, p. 29.

——— 1896. On the Stratigraphy of the Platte Series, or Upper Cretaceous of the Plains: Colorado College Studies, vol. 6, p. 49.

DARTON, N. H. 1905. Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains: U. S. Geol. Survey Prof. Paper 32.

——— 1909. Geology and Underground Waters of South Dakota: U. S. Geol. Survey Water Supply Paper 227.

——— BLACKWELDER, E., and SIEBENTHAL, C. E. 1910. U. S. Geol. Survey Geol. Atlas, Laramie-Sherman, Wyo. Folio (No. 173).

——— *and others.* 1915. Guidebook of the Western United States, Part C, The Santa Fe Route: U. S. Geol. Survey Bull. 613.

——— 1920. U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin, Kan., Folio (No. 212).

——— and PAGE, SIDNEY. 1925. U. S. Geol. Survey Geol. Atlas, Central Black Hills, S. Dakota, Folio (No. 219).

——— 1928. Red Beds and Associated Formations in New Mexico: U. S. Geol. Survey Bull. 794.

DAVIS, C. W., and VACHER, H. C. 1928. Bentonite, Its Property, Mining, Preparation and Utilization: U. S. Bur. Mines Tech. Paper 438.

DAVIS, W. M. 1930. Origin of Limestone Caverns: Geol. Soc. America Bull., vol. 41, p. 475.

DORF, ERLING. 1930. Pliocene Floras of California: Carnegie Inst. Washington Pub. 412.

ECKEL, E. C. 1928. Cements, Limes and Plasters: New York, John Wiley & Sons.

ELDRIDGE, G. H. 1891. The Florence Oil Field, Colorado: Am. Inst. Min. Eng. Trans., vol. 20, p. 442.

——— 1896. Mesozoic Geology; in Geology of Denver Basin of Colorado: U. S. Geol. Survey Mon. 27, p. 51.

ELIAS, M. K. 1930. Origin of Cave-ins in Wallace County, Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 14, p. 316.

FAY, A. H. 1920. Glossary of Mining and Mineral Industry: Bur. Mines Bull. 95.

FENNEMAN, N. M. 1905. Geology of the Boulder District, Colo.: U. S. Geol. Survey Bull. 265.

FINLEY, G. I. 1916. U. S. Geol. Survey Geol. Atlas, Colorado Springs, Colo., Folio (No. 203).

GANNETT, HENRY. 1898. Gazeteer of Kansas: U. S. Geol. Survey Bull. 154.

GARDNER, F. D., and STEWARD, JOHN. 1900. A Soil Survey in Salt Lake Valley, Utah: U. S. Dept. Agr. Bur. Soils Rept. 64, Field Operations, p. 77.

GILBERT, G. K., and GULLIVER, F. P. 1895. Tepee Buttes: Geol. Soc. America Bull., vol. 6, p. 333.

GILBERT, G. K. 1896. Underground Water of the Arkansas Valley in Eastern Colorado: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2f, p. 551.

——— 1897. U. S. Geol. Survey Geol. Atlas, Pueblo, Colo., Folio (No. 36).

GOULD, CHAS. N., and LONSDALE, J. T. 1926. Geology of Beaver County, Oklahoma: Oklahoma Geol. Survey Bull. 38.

GRABAU, A. W. 1913. Principles of Stratigraphy.

HANCOCK, E. T. 1920. Geology and Oil and Gas Prospects of the Huntley Field, Mont.: U. S. Geol. Survey Bull. 711*g*.

HAWORTH, ERASMUS. 1897. Physical Properties of the Tertiary: Kansas Univ. Geol. Survey, vol. 2, p. 247.

——— 1897*a*. Geology of Underground Water in Western Kansas; in Rept. Board Irrig. Survey and Exper. for 1895-'96, Topeka, p. 49.

——— 1913. Special Report on Well Waters in Kansas: Kansas Univ. Geol. Survey Bull. 1.

HAY, ROBERT. 1890. A Geological Reconnaissance in Southwestern Kansas: U. S. Geol. Survey Bull. 57.

——— 1895. Water Resources of a Portion of the Great Plains: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 535.

——— 1896. Bibliography of Kansas Geology: Kansas Acad. Sci. Trans., vol. 14, p. 261.

HAYDEN, F. V. 1869. Preliminary Field Report of the U. S. Geol. Survey of New Mexico and Colorado: Dept. of the Interior, pp. 103-251 (Reprint 1873).

——— and MEEK, F. B., 1872, U. S. Geol. Survey of Nebraska and Portions of Adjacent Terr. Final Rept.: 42d Cong., 1st sess., H. Ex. Doc. 19.

HENDERSON, JUNIUS. 1907. Scientific Expedition to Northeastern Colorado; Paleontology: Colorado Univ. Studies, vol. 3, pp. 149-152.

——— 1908. The Sandstone of Fossil Ridge in Northern Colorado and Its Fauna: Colorado Univ. Studies, vol. 5, pp. 179-192.

——— 1920. Foothills Formations of North Central Colorado: Colorado Geol. Survey Bull. 19, p. 58.

HILLS, R. C. 1898. U. S. Geol. Survey Geol. Atlas, Elmoro, Colo., Folio (No. 58).

——— 1900. U. S. Geol. Survey Geol. Atlas, Walsenburg, Colo., Folio (No. 68).

——— 1901. U. S. Geol. Survey Geol. Atlas, Spanish Peaks, Colo., Folio (No. 71.)

Holms, H. N. Rhythmic Banding: Science, n. ser., vol. 46, p. 422.

Johnson, W. D. 1901. High Plains and Their Utilization: U. S. Geol. Survey Twenty-first Ann. Rept., Part IV, p. 609.

Landes, K. K. 1928. Volcanic Ash in Kansas: Geol. Soc. America Bull., vol. 39, p. 931.

——— 1928*a*. Volcanic Ash Resources of Kansas: Kansas Univ. Bull. 14.

——— 1930. Geology of Mitchell and Osborne Counties, Kansas: Kansas Univ. Bull. 16.

——— 1931. Recent Subsidence in Hamilton County, Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 15, p. 708.

Le Conte, J. L. 1868. Notes on the Geology of the Survey for the Extension of the Union Pacific Road, Eastern division, from Smoky Hill to Rio Grande, Philadelphia.

Lesquereux, Leo. 1883. Contributions to the Fossil Flora of the Western Territories, pt. 3, The Cretaceous and Tertiary Floras: U. S. Geol. Survey Terr. Rept. 8.

Linck, G. E. 1903. Die Bildung der Oölite and Rogensteine: Neues Jahrb., Beilage Band 16, p. 500.

Logan, W. N. 1897. Upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, vol. 2, p. 195.

——— 1898. The Invertebrates of the Benton, Niobrara and Fort Pierre Groups: Kansas Univ. Geol. Survey, vol. 4, p. 431.

Lupton, C. T., Lee, W., and Van Burgh, L. R. 1922. Oil Possibilities of Western Kansas: Am Assoc. Petroleum Geologists Bull., vol. 6, p. 69.

Marsh, O. C. 1871. Notice of Some New Fossil Reptiles from the Cretaceous and Tertiary Formations: Am. Jour. Sci., 3d ser., vol. 1, p. 447.

——— 1871*a*. Note on a New and Gigantic Species of Pterodactyle: Am. Jour. Sci., 3d ser., vol. 1, p. 472.

Mather, K. F., Gilluly, J. and Lusk, R. G. 1928. Geology and Oil and Gas Prospects of Northeastern Colorado: U. S. Geol. Survey Bull. 796-B, p. 65.

McClung, C. E. 1898. Microscopic Organisms of Upper Cretaceous: Kansas Univ. Geol. Survey, vol. 4, p. 413.

Meek, F. B., and Hayden, F. V. 1861. Descriptions of New Lower Silurian (Primordial), Jurassic, Cretaceous and Tertiary Fossils Collected in Nebraska Terr.: Acad. Nat. Sci. Philadelphia Proc., p. 415.

Meek, F. B. 1876. Report on the Invertebrate Cretaceous and Tertiary Fossils: U. S. Geol. Survey Terr., vol. 9.

Moore, R. C. 1926. Note on Subsidence near Sharon Springs, Wallace County, Kansas: Kansas Univ. Bull. 11, p. 95.

——— and Landes, K. K. 1927. Underground Resources of Kansas: Kansas Univ. Bull. 13.

Mudge, B. F. 1866. First Ann. Rept. (for 1864) on the Geology of Kansas, Lawrence.

——— 1874. Pliocene Formation of Kansas: Kansas Acad. Sci. Trans., vol. 3, p. 113. (Reprinted in 1896.)

——— 1876. Notes on the Tertiary and Cretaceous Periods of Kansas: U. S. Geol. and Geog. Survey Terr. Bull. 2, p. 211.

——— 1877. Notes on the Tertiary and Cretaceous Periods of Kansas: U. S. Geol. and Geog. Surv. Terr. Ninth Ann. Rept., p. 277.

——— 1878. Geology of Kansas: Kansas State Board of Agr. First Bien. Rept., p. 46.

Newell, F. H. 1895. Report of Progress of the Division of Hydrography for 1893 and 1894: U. S. Geol. Survey Bull. 131.

Osborn, H. F. 1910. Age of Mammals, New York.

Patrick, G. E. 1875. Kansas Chalk: Kansas Acad. Sci. Trans., vol. 4, p. 13. (Reprinted in 1906.)

Pinkley, G., and Roth, R. 1928. Altered Volcanic Ash from the Cretaceous of Western Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 12, p. 1015.

Reed, Minnie. 1893. Some Notes on Condensed Vegetation in Western Kansas: Kansas Acad. Sci. Trans., vol. 13, p. 91.

Reeside, J. B., Jr. 1923. New Fauna from the Colorado Group of Southern Montana: U. S. Geol. Survey Prof. Paper 132-B, p. 25.

——— 1929. *Exogyra olisiponensis* Sharpe and *Exogyra costata* Say in the Cretaceous of the Western Interior: U. S. Geol. Survey Prof. Paper 154-I, p. 265.

Reis, O. M. 1923. Kalkalgen and Seesinterkalk aus dem Rheinpflalzischen Tertiar: Geogn. Jahresh., vol. 36, p. 107.

Ross, C. S., and Shannon, E. W. 1926. Minerals of Bentonite and Related Clays and Their Physical Properties: Am. Ceramic Soc. Jour., vol. 9, p. 79.

Rubey, W. W., and Bass, N. W. 1925. Geology of Russell County: Kansas Univ. Bull. 10.

Rubey, W. W. 1929. Origin of the Siliceous Mowry Shale of the Black Hills Region: U. S. Geol. Survey Prof. Paper 154-D.

——— 1930. Lithologic Studies of Fine-grained Upper Cretaceous Sedimentary Rocks of the Black Hills Region: U. S. Geol. Survey Prof. Paper 165-A.

Russell, W. L. 1925. Well Log in Northern Ziebach County: South Dakota Geol. and Nat. Hist. Survey Circ. 18.

——— 1925*a*. Possibilities of Oil in Western Ziebach County: South Dakota Geol. and Nat. Hist. Survey Circ. 20.

——— 1926. Possibilities of Oil in Western Carson County: South Dakota Geol. and Nat. Hist. Survey Circ. 27.

——— 1926*a*. Structures in Western Haäkon and Eastern Pennington Counties: South Dakota Geol. and Nat. Hist. Survey Circ. 28.

——— 1929. Stratigraphy and Structure of the Smoky Hill Chalk in Western Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 595.

——— 1929*a*. Local Subsidence in Western Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 605.

Schade, Heinrich. 1909. Zur Entstehung der Hornsteine und ähnlicher Konzentrich geschichteter Steine organischen und unorganischen Ursprungs: Zeitschr. für Chemie und Industrie der Kolloide, vol. 4, p. 175.

——— 1910. Ueber Konkrementbildungen beim vorgang der Tropbigen Entmischung von Emulsions Kolloiden: Kolloidschemische Beihefte, vol. 1, p. 375.

STAMP, L. D., and CHHIBBER, H. L. 1925. Igneous and Associated Rocks of the Kabwet Area, Upper Burma: Min. and Geol. Inst. India Trans., vol. 20.

STANTON, T. W. 1888. Paleontological Notes, Fort Pierre Fossils Near Boulder, Colo.: Colorado Sci. Soc. Proc., vol. 2, p. 184.

——— 1925. Fossil Content (To Well Log in Ziebach County): South Dakota Geol. and Nat. Hist. Survey Circ. 18, p. 8.

STEPHENSON, L. W. 1918. Contribution to the Geology of Northeastern Texas and Southern Oklahoma: U. S. Geol. Survey Prof. Paper 120-H, p. 129.

STEWART, ALBAN. 1899. Notice on Three New Cretaceous Fishes with Remarks on the *Saurodontidæ* Cope: Kansas Univ. Quart., vol. 8, p. 107.

——— 1900. Teleosts of the Upper Cretaceous: Kansas Univ. Geol. Survey, vol. 6, p. 257.

TARR, W. A. 1917. Rhythmic Banding of Manganese Dioxide in Rhyolite Tuff: Jour. Geology, vol. 26, p. 610.

THOM, W. T., JR. 1922. Oil and Gas Prospects in and Near the Crow Indian Reservation, Mont.: U. S. Geol. Survey Bull. 736-B, p. 35.

TODD, J. E. 1908. Preliminary Report on the Geology of the Northwest-Central Portion of South Dakota: South Dakota Geol. Survey Bull. 4.

TWENHOFEL, W. H. 1925. Significance of Some of the Surface Structures of Central and Western Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 9, p. 1061.

——— 1926. Treatise on Sedimentation: Baltimore, Williams & Wilkins Co.

VAUGHAN, T. W. 1914. Preliminary Remarks on the Geology of the Bahamas: Carnegie Inst. Washington Pub. 182, p. 49.

WAGNER, GEORGE. 1898. On Some Turtle Remains from the Fort Pierre: Kansas Univ. Quart., vol. 7, p. 201.

WELLER, J. M. 1927. Geology of Edmonson County: Kentucky Geol. Survey, ser. 6, vol. 28.

WILLIS, BAILEY. 1912. General Geologic Notes: in Hrdlicka, Early Man in South America: Smithsonian Bur. Am. Ethnology Bull. 52.

——— 1893. Mechanics of Appalachian Structure: U. S. Geol. Survey Thirteenth Ann. Rept., Part II, p. 217.

WILLISTON, S. W. 1893. Niobrara Cretaceous of Western Kansas: Kansas Acad. Sci. Trans., vol. 13, p. 107.

——— 1897. Kansas Niobrara Cretaceous: Kansas Univ. Geol. Survey, vol. 2, p. 235.

——— 1898. Addenda to Part I, Upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, vol. 4, p. 28.

——— 1898*a*. Mosasaurs: Kansas Univ. Geol. Survey, vol. 4, p. 81.

——— 1903. North American Plesiosaurs, Part 1: Field Columbian Mus. Pub., Geol. ser., vol. 2, p. 1.

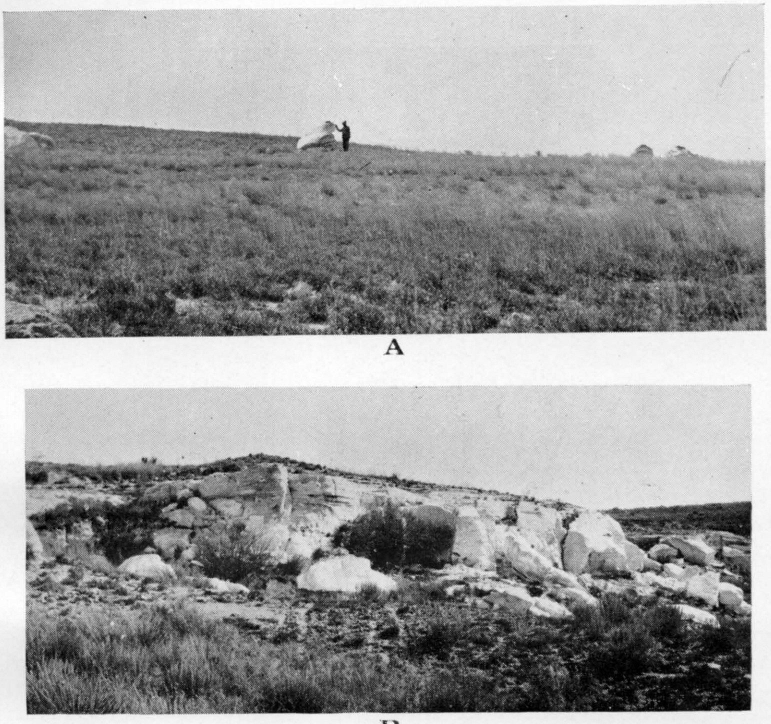
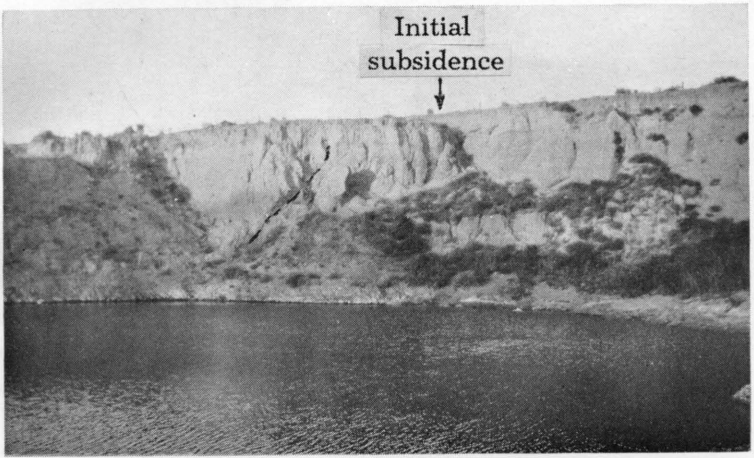
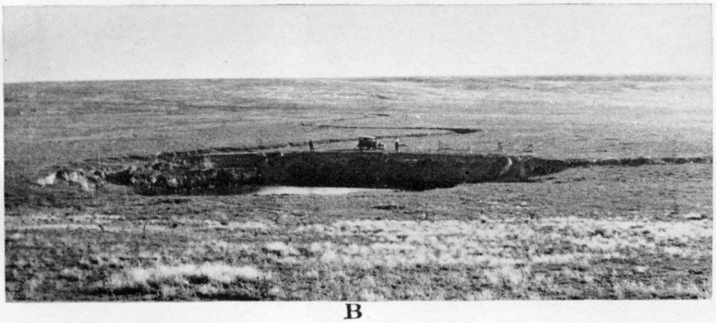


PLATE XXXVIII. — Diatomaceous marl of Ogallala. *A* — Remnants of slightly harder portions of the marl on the divide between two canyons. In the SW¼ NE¼, sec. 11, T. 11 S., R. 38 W. *B*—Marl weathered into large blocks. In the NE¼ SE¼, sec. 11, T. 11 S., R. 38 W. *C*—Complete section of the bed shown in *A* and *B* with capping limestone above and chalky clay at the base. (The man stands on the contact.) Same locality.

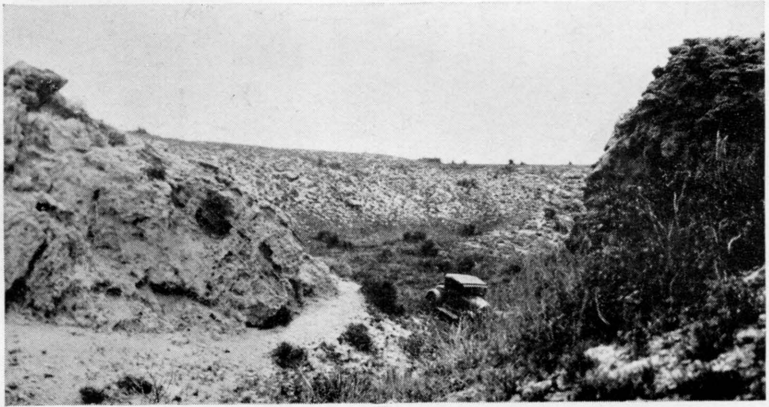
Plate XXXIX.—*A*—Memorial monument made of Niobrara chalk, erected in 1867 at Fort Wallace. *B*—Small quarry opened in algal (*Chlorellopsis*) limestone of Ogallala. Shows comparatively small size and somewhat irregular shape of slabs into which the limestone weathers in the exposures.



A



B



C

PLATE XL.—*A*—Smoky Basin cave-in as it appeared in 1929. View of eastern wall of the basin, showing traces of the initial subsidence and the line of fault. In the NE¼ SE¼, sec. 33, T. 13 S., R. 39 W. *B*—Thirty-year-old cave-in across the channel of a small intermittent creek. In the S½, sec. 1, T. 12 S., R. 39 W., looking southeast. *C*—Circular basin and "gates" in Ogallala. In the NE¼ SW¼, sec. 27, T. 12 S., R. 41 W., looking south.

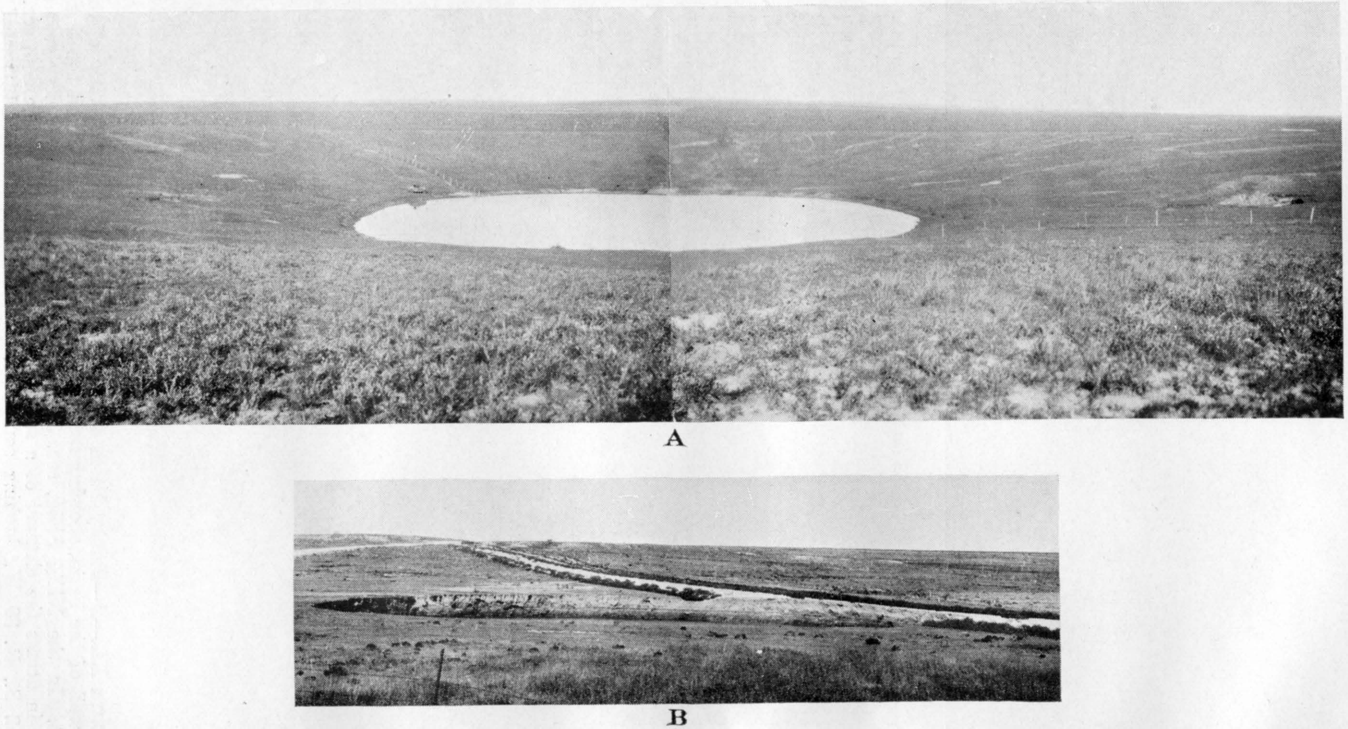


Plate XLI.—*A*—Old Maid's Pool, an old cave-in. In the northeast corner of sec. 30, T. 12 S., R. 40 W. *B*—Recent subsidence, which undermined county road in the northeast corner of sec. 22, T. 25 S., R. 43 W., in Hamilton county, Kansas. Photograph taken in May, 1930.

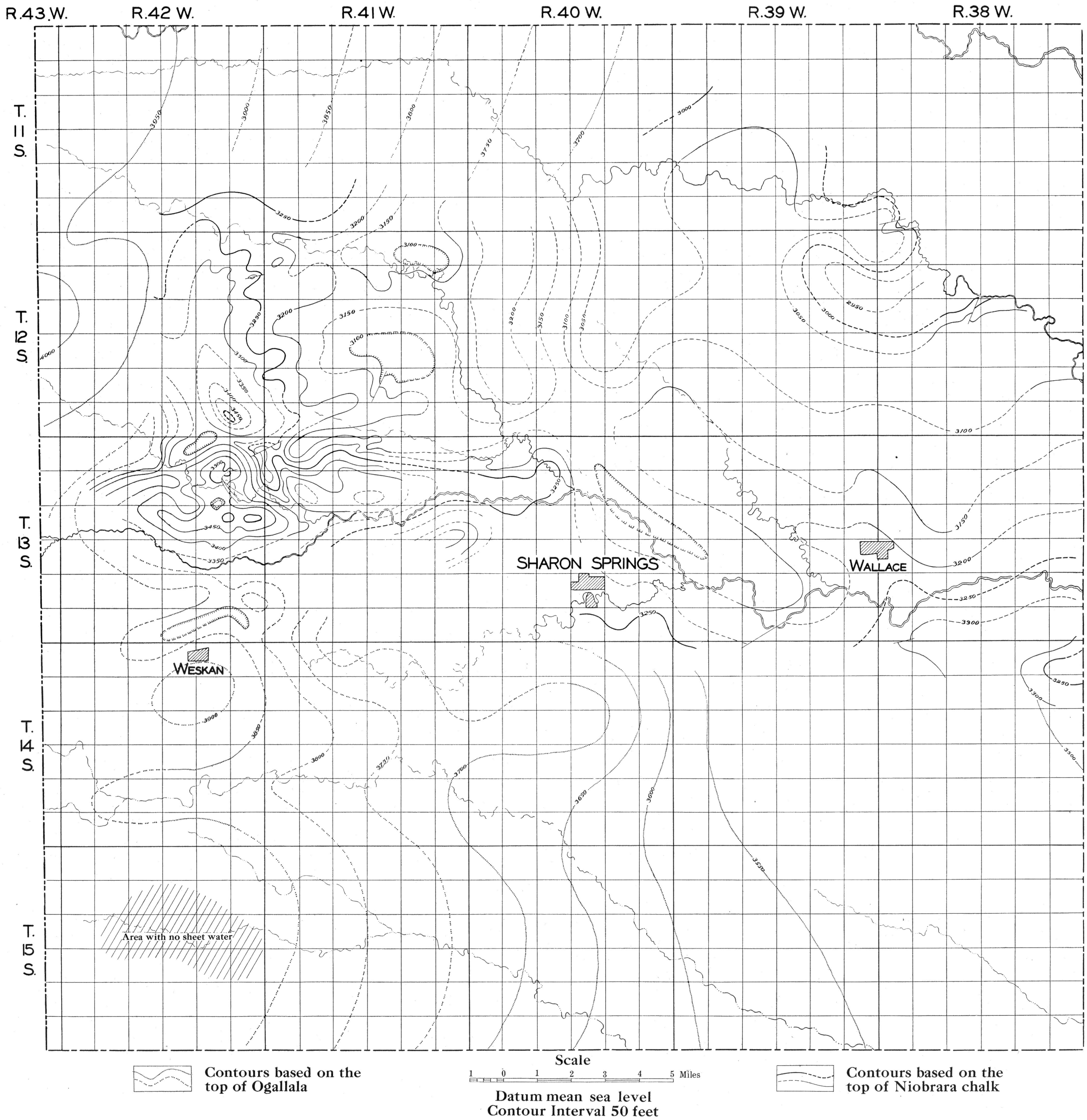


PLATE XLII.—Structural map of Wallace county.

INDEX OF ENGLISH NAMES.

(Those marked by asterisk are new formation names introduced in this paper.)

INDEX OF LATIN NAMES

(Those marked by asterisk are new names described in forthcoming papers. Figures refer to page numbers in this book.)

□