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STRATIGRAPHY OF THE OGALLALA FORMATION (NEOGENE) OF NORTHERN KANSAS

By

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STRATIGRAPHY OF THE OGALLALA FORMATION (NEOGENE) OF NORTHERN KANSAS

By John C. Frye, A. Byron Leonard, and Ada Swineford

ABSTRACT

Fluvial late Tertiary (Neogene) deposits underlie the surface of the dissected plateau that is the High Plains, and extend from Texas to South Dakota in a belt several hundred miles wide. The stratigraphy and paleontology of the Neogene Ogallala formation have been studied in northern Kansas and correlations made with type sections of the Ogallala formation, and Valentine, Ash Hollow, and Kimball members in Nebraska. Ogallala sediments were deposited by streams flowing eastward from the Rocky Mountain region in broad, relatively shallow, erosional valleys cut in Cretaceous bedrock. Initial alluviation of these valleys is represented by the Valentine member. As alluviation proceeded, sediments progressively overlapped gentle valley slopes, and minor divides were buried by sediments of the Ash Hollow member. The Kimball member transgressed most major divides, producing a coalescent alluvial plain. This surface is marked by an accumulation of calcium carbonate. The Ogallala contains fossil vertebrates, mollusks, and seeds. Fossil vertebrates, although having time significance, are of little local stratigraphic value. Molluscan faunas show an orderly progressive change bridging the interval from late Miocene (?) to earliest Pleistocene, and present distinctive assemblages in Valentine, Ash Hollow, and Kimball members. Abundant and widely dispersed fossil seeds are the most usable organic remains for regional stratigraphic work. Ten petrographically distinct volcanic ash falls occur in the Ogallala; seven have proved valuable in precise correlations throughout the region and with type localities in Nebraska.

Lithologically, the Ogallala formation is heterogeneous, but each member presents certain gross characters distinguishing it from the others. The Valentine member is predominantly gray to greenish-gray feldspathic sand, only loosely cemented with calcium carbonate; it includes some clay and silt and local opal-cemented sandstone lenses. The Ash Hollow member is typified by gray to brown, feldspathic sand, silt, and gravel having irregular calcareous cementation; soft limestone; and numerous lentils of volcanic ash. The Kimball member, although containing local lentils of coarse gravel in the base, is predominantly calcareous feldspathic sandy silt capped by a massive to nodular sandy and silty calcium carbonate zone.

INTRODUCTION

Northward from central western Texas and southeastern New Mexico, across western Oklahoma, eastern Colorado, western Kansas and Nebraska, and into South Dakota extends a dissected blanket of late Tertiary deposits. This region, approximately 800 by 400 miles in extent, is clearly the largest expanse of almost continuously exposed nonmarine Neogene (Miocene and Pliocene) sediments on the North American continent. Although the existence of this depositional province has been known to geologists since the early scientific expeditions (e.g., Meek and Hayden, 1862; King, 1878), and the fluviatile origin of most of these sediments has been generally accepted for more than half a century (Gilbert, 1896, p. 576; Haworth, 1897; Johnson, 1901), little effort has been directed toward study of details of the stratigraphy and correlation. It is the purpose of this report to present results of stratigraphic and paleontologic studies of the late Tertiary (Neogene) deposits in the northern half of Kansas.

Modern study of the Tertiary of western Kansas was begun by Elias (1931) primarily in Wallace County, but was not followed up, except for a brief reconnaissance of Rawlins and Decatur Counties (Elias, 1937), until geologists of the State and Federal Geological Surveys, in a cooperative program of ground-water investigations, undertook county by county studies in the region. The first of these county ground-water reports giving major consideration to the Ogallala formation in the northern area was that on Thomas County (Frye, 1945), which is underlain in its entirety by this formation beneath a thick blanket of Pleistocene sediments, but work on the Norton County area (Frye and A. R. Leonard, 1949; Frye and Swineford, 1946; Swineford and Frye, 1946), provided the first opportunity to make significant additions to stratigraphic data obtained by Elias. Other published ground-water reports that contain data on Ogallala stratigraphy in this region are those for Cheyenne (Prescott, 1953), Scott (Waite, 1947), Lane (Prescott, 1951), and Sherman (Prescott, 1953a) Counties.

The upper Tertiary of northern Kansas is richly fossiliferous. Fossil vertebrates have been known from these deposits since the early scientific expeditions in the region, and some localities, as for example, those in the area tributary to Republican River in northwestern Kansas (Osborn, 1909, p. 80), have long been well known. The abundant fossil seeds (Elias, 1942), however, are of far more significance to the field stratigrapher and are to be found in virtually any good exposure of the Ogallala formation in northern Kansas. Fossil mollusks, although heretofore not described from this formation, occur through most of its stratigraphic span and provide an additional tool for correlation.

Prior to the work of Elias, the unconsolidated deposits of the region, although several hundred feet thick, were referred to in general terms as "Mortar beds", "Tertiary grit", or "Magnesia beds", and were not clearly subdivided into Tertiary and Quaternary portions. As early as 1866, Hawn (p. 101) recognized his "Bluff formation" as distinct from the general expanse of the Plains Tertiary, and in 1885 Hay subdivided the post-Cretaceous deposits of Norton County into a lower unit that he considered to be of Miocene age (Ogallala of present classification) and an upper unit of silt that he called Pliocene (the Pleistocene Sanborn formation of present classification). When Haworth reviewed the Tertiary of western Kansas in 1897, however, he pointed out that although fossil remains showed clearly that, at least locally, some of these unconsolidated deposits were of Pleistocene age, they should all be regarded as part of a single formation ranging through a considerable span of time. Elias' work in Wallace County was the first to differentiate sharply the Pleistocene deposits from the Tertiary of the region. During the last decade, intensive studies of the stratigraphy of the Pleistocene deposits of Kansas (Frye and Leonard, 1952) have served to set them clearly apart from the Tertiary. Because much of the Pleistocene sediment is derived from the subjacent upper Tertiary of the Plains, the materials of the two ages have strong lithologic similarities.

The field work on which this report is based has included some time in northwestern Kansas each summer from 1942 through 1954. During many of these seasons, however, work on Tertiary stratigraphy was incidental to other projects centered primarily on Pleistocene geology and paleontology, petrography, or groundwater geology, and only during the seasons of 1952, 1953, and 1954 was field work directed primarily toward study of the stratigraphy of the Ogallala formation. Most of the sections were measured and fossils collected during those three seasons, although many data were gathered during re-examination of localities visited earlier.

We wish to acknowledge assistance given us in this work by members of the State and Federal Geological Surveys working in northern Kansas, particularly personnel of the cooperative ground-water program; by the paleontologists of the University of Kansas Museum of Natural History; and by the Nebraska Geological Survey and State Museum of the University of Nebraska.

General Aspect of the Formation

The Ogallala formation of northern Kansas is a heterogeneous complex of clastic deposits. The thickness of the formation ranges from more than 300 feet to less than 3 feet; the texture ranges from coarse gravel containing pebbles as much as 3 inches in long diameter to clay; and the sorting ranges from good to poor. Cementing material, not everywhere present, includes tough opal, disseminated white opal, and various amounts of calcium carbonate. Colors of the deposits are dark to pale green, pink, reddish brown, tan, buff, pastel grays, and ash gray. Lentils of volcanic ash, marl or marly limestone, and bentonite contrast with the predominant stream-laid clastics. Throughout this heterogeneous assortment of sediments there is virtually no distinctive bed that can be traced appreciable distances in the field. The formation's topographic expression includes flat uplands, gentle erosional slopes, and sharp cliffs.

A striking characteristic of the coarser materials in the Ogallala is their lack of uniformity in the reflection of local sources. In general, the coarse materials indicate a source in the Rocky Mountain region to the west, but in some places the gravels are predominantly of Cretaceous chalk typical of the adjacent bedrock and at others a smaller but significant percentage of shale, chalk, or sandstone pebbles may be observed mixed with a larger portion of typical Rocky Mountain materials.

The surface on which the Ogallala rests is a subaerial erosion surface of gentle declivities (Merriam and Frye, 1954) cut on shales, chalky shales, chalky limestones, and locally sandstones of Cretaceous age. This surface slopes gently eastward and has an erosional relief (normal to the direction of major drainage) of somewhat less than 300 feet. The topography of this buried surface reflects the position of relatively resistant units in the Cretaceous bedrock (e.g., Fort Hays limestone, Greenhorn limestone). The Ogallala formation in northwestern Kansas dips eastward at the average rate of approximately 15 feet per mile and is arched along an axis extending eastward from central Sherman County (Smith, 1940). Regional dips to the north and to the south from this axis average 1 1/2 or 2 feet per mile, but are not uniform.

The Ogallala is locally very well exposed in bluffs along major valleys and tributary canyons, but large areas of flat High Plains surface, because they are blanketed by upper Pleistocene loesses, present no usable exposures of the formation. As a result, detailed stratigraphic studies, including the collection of fossil plant material, fossil mollusks, and samples of volcanic ash for petrographic study (Swineford, Frye, and Leonard, 1955), were concentrated along the lower portions of valleys tributary to Republican River (Cheyenne, Rawlins, Decatur, Norton, and Phillips Counties), the digitate eastern edge of the outcrop area (Smith, Rooks, Ellis, Trego, and Ness Counties), and the margins of the Smoky Hill River valley (Wallace, Logan, Scott, and Gove Counties). In the extensive flat High Plains upland areas, typified by Sherman and Thomas Counties and adjacent areas, knowledge of the Ogallala formation is of necessity derived principally from the logs of test holes drilled as a part of the cooperative Federal and State ground-water program.

Definitions and Type Localities

The stratigraphic classification of the Neogene deposits of northern Kansas is based entirely on subdivisions and type localities in Nebraska (Moore and others, 1951). The name Ogallala formation (but spelled Ogalalla at that time) was introduced by Darton in 1899. His original definition is in part as follows (Darton, 1899, p. 734): "Extending from Kansas and Colorado far into Nebraska there is a calcareous formation of late Tertiary age to which I wish to apply the distinctive name *Ogalalla formation* . . . . " And (p. 735), "In its typical development the Ogalalla formation is a calcareous grit or soft limestone containing a greater or less amount of intermixed clay and sand, with pebbles of various kinds sprinkled through it locally, and a basal bed of conglomerate at many localities . . . . The pebbles it contains comprise many crystalline rocks, which appear to have come from the Rocky Mountains." And further (p. 741), "The general thickness of the Ogalalla formation varies from 150 to 300 feet, the greater amount being along the Wyoming line in the northwestern corner of Kimball County . . . . As before explained, it is in the main, the extension of the 'Tertiary grit', 'Magnesia', or 'Mortar beds' of the Kansas geologists."

There is little doubt as to which deposits Darton intended to include in this formation, although in 1899 and a subsequent report (Darton, 1905, p. 178) he failed to designate a type section or locality, or to define clearly the span of the unit. He partly corrected this omission in 1920 (Darton, 1920, p. 6) when he wrote concerning the Syracuse-Lakin, Kansas, area: "The Ogalalla formation is believed to be a stratigraphic unit and to be continuous from the type locality near Ogalalla station in western Nebraska . . . . It is believed that the bones of Pleistocene age found in some places are in local deposits of later age that overlie the true Ogalalla, which appears more likely to have been laid down in Pliocene and late Miocene time."

Thus, in 1920, Darton designated a type area and clearly indicated that he did not intend to include the younger, Pleistocene deposits within the formation, in contrast to Haworth's (1897) contention that they were indistinguishable.

This remained the typical definition of the Ogallala formation until Elias (1931) and Hesse (1935) re-examined the exposures in the vicinity of Ogallala, Nebraska, proposed a type section on Feldt Ranch approximately two miles east of the town (SE¼ sec. 33, T. 14 N., R. 38 W.), and described the vertebrate fossil fauna. Shortly thereafter, Lugn (1938; 1939) published the official classification of the Nebraska State Geological Survey, in which Ogallala was assigned the rank of group with four contained formations, in descending order, Kimball, Sidney, Ash Hollow, and Valentine. Although using Nebraska terms, the Kansas Geological Survey has classed Ogallala as a formation and recognized Kimball (including Sidney), Ash Hollow, and Valentine as members (Moore, Frye, and Jewett, 1944; Moore and others, 1951). Each of these three members has its own type description.

The Ash Hollow was first described by Engelmann (1876, p. 260) as follows: "They [rocky strata] continue along the South Fork, cropping out at intervals at one or the other side of the river, and were found most developed in Ash Hollow, where they attain a thickness of over 250 feet. This series is composed of an alternation of loose, finely sandy, and of harder rocky strata, the latter consisting of fine to coarse drift-sand, generally cemented by carbonate of lime, forming more or less calcareous sandstones, and gritty, very impure limestones . . . . Their age is, probably, the Pliocene-Tertiary; but I have no paleontological proof of it." Engelmann also recognized fossil seeds in these rocks (1876, p. 261). "In these rocks, near the flanks of Platte River, I found numerous fossilized seeds of the size of a small cherry stone, apparently related to the living genus *Celtis*, which have improperly been called *Lithospermum* . . . ."

Modern use of the term Ash Hollow dates from Lugn's classification (1938, p. 223) of the Nebraska Tertiary, in which he used this term in a sense almost identical to that of Engelmann. A year later he (Lugn, 1939) cited the same exposures in Ash Hollow canyon as the type section of the unit.

Deposits now included in the lowest, or Valentine, member of the Ogallala were first called "Valentine beds" by Barbour and Cook in 1917 (p. 173) from exposures east of the town of Valentine in Cherry County, Nebraska. This general area had earlier yielded collections of fossil vertebrates, but formal stratigraphic names had not been applied to the deposits, which were generally included within the "Loup River beds" of Meek and Hayden (1862). After the introduction of the term Valentine, it was used intermittently (e.g., Thorpe, 1922) until 1935 when Johnson restudied the stratigraphy of the area and redescribed this unit. In that same year Stirton and McGrew (1935) in a description of mammalian faunas proposed the names "Niobrara River" for the lowest beds, "Burge" for the intermediate beds, and "Valentine" for the uppermost beds, in this vicinity. This proposed subdivision radically changed the definition of Valentine as described by Johnson, and set off a controversy concerning the usage of the term Valentine (Colbert, 1938; Johnson, 1938; Lewis, 1938; Lugn, 1938; McGrew and Meade, 1938). Lugn (1938; 1939) presented the official position of the Nebraska State Geological Survey, which was, in effect, the acceptance of the Valentine as defined by Johnson in 1935. Johnson (1935, p. 467) had designated: "The type locality of the Valentine beds is on the south side of a drainage cut between the old and new railroad grades . . . in the NE¼ Sec. 17, T. 33 N., R. 27 W., Cherry County, Nebraska. It is the site of a vertebrate-fossil quarry which was discovered by Mr. J. B. Burnett in 1915."

At the time of his official endorsement of Johnson's usage of Valentine, Lugn (1938, p. 223) also stated that the beds exposed above the type section and termed the "cap rock bed" by Johnson should be included in the Ash Hollow formation of the official classification of the Nebraska Geological Survey. Although there has not been complete agreement among all workers concerning the usage of Valentine, since 1938 the definition proposed by Johnson has been official usage of the Kansas and Nebraska Geological Surveys and will be adhered to in this report.

The Kimball, or uppermost member of the Ogallala, was named and defined by Lugn in 1938 (p. 224) as follows: " . . . from its typical occurrence at the highest remnant levels of the High Plains in Kimball County, Nebraska. The thickness of the Kimball formation ranges from 30 to 40 feet when present in its full development; and it consists of silt, clay, fine sand more or less cemented with caliche, with one or two algal limestone beds at the very top." A year later Lugn (1939, p. 1262) restated the definition, modified to give a range in thickness of 25 to 50 feet.

In the reclassification of the Ogallala in Nebraska (Lugn, 1938; 1939) the Sidney gravel formation was defined as occurring stratigraphically between the Ash Hollow and Kimball. It was named from typical exposures at Sidney, Nebraska, and was described as a gravel unit 15 to 50 feet thick included in the upper part of the *Biorbia fossilia* seed zone. On the basis of those exposures where coarse gravel occurs at this stratigraphic position, we judge it to be a lenticular body of channel gravel that is not continuously traceable over long distances. The Kansas Geological Survey has not recognized this unit as of member rank but rather has included it as a local basal gravel phase of the Kimball member (Moore, Frye, and Jewett, 1944; Moore and others, 1951).

Methods of Correlation

The approach to stratigraphic correlation within a complex of fluviatile deposits is of necessity quite different from the approach generally used for marine strata. Within the volume of sediments under consideration here are no continuous limestone beds, enclosed in shales and marked by distinctive faunas that are susceptible to virtually continuous tracing for hundreds of miles, as is true of the upper Paleozoic and Mesozoic rocks of this general region. In fact, within the Ogallala deposits of the central Great Plains there is no lithologic unit (with the exception of the "Algal limestone" at the stratigraphic top of the formation) that can, with certainty, be traced as much as 10 miles. This fact in itself clearly indicates that the members of the Ogallala are not generally mappable units, that they do not possess the distinct physical contrast with adjacent members (Pl. 1), generally regarded as essential for formal rock-stratigraphic units, and that their correlation must be based primarily on evidence of age relationships. Their status as members is justified, however, by the fact that when viewed grossly and regionally, they do possess general lithologic characters that contrast one to another.

In view of these facts, it is clear that many of the common techniques of correlation are unusable within the Ogallala formation and that it has been necessary to develop little-used or new techniques to establish age relationships within this mass of alluvium. Relations at both the top and bottom have been helpful to correlation; the top is locally marked by a distinctive limestone that serves as a reference, and the configuration of the lower surface indicates location of preexisting valleys and the most likely locale of earliest sedimentation. Correlation by petrographic character of lentils of volcanic ash (Fig. 1), a technique not commonly utilized in study of Neogene strata, has served to establish time equivalence from place to place. Paleontology constitutes the most generally usable line of evidence, fossil plant material being of paramount importance (Fig. 1). Each of these methods of correlation will be briefly discussed.

The "Algal Limestone"

The bed within the Ogallala formation that is clearly the most controversial and one of the most distinctive was described by Elias in 1931 and in the Kansas literature is generally referred to as the "Algal limestone" (Pl. 2A). In part his description was as follows (Elias, 1931, p. 136):

> "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

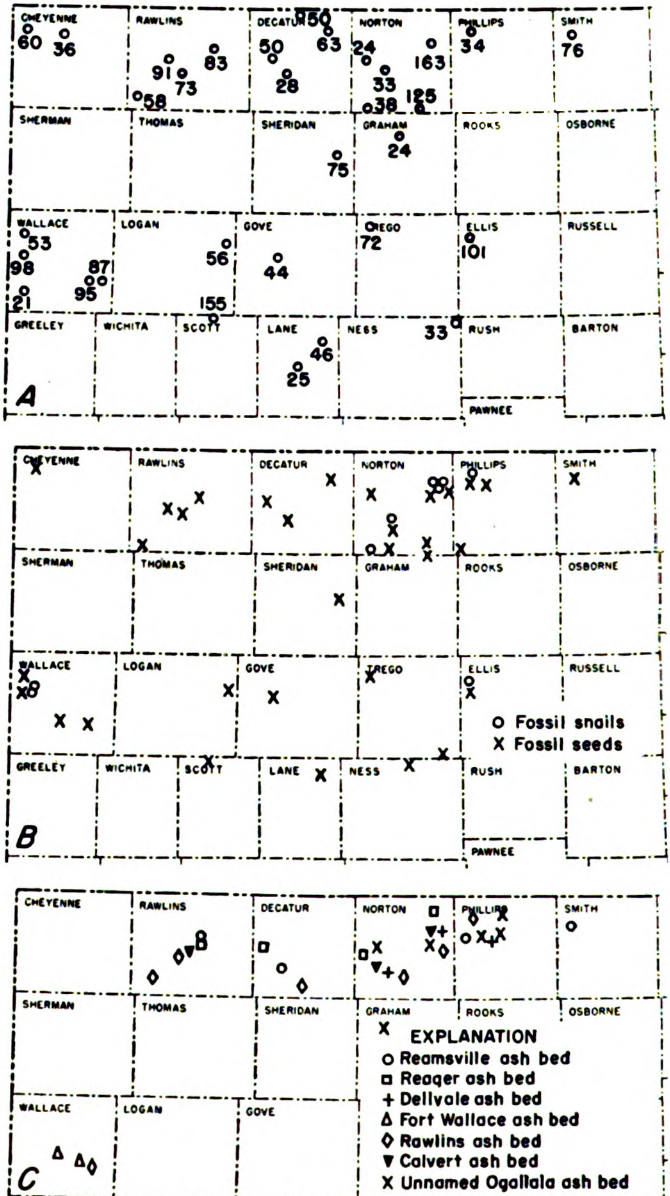


FIG. 1.—Maps showing locations of measured sections, localities from which plant fossils and fossil mollusks were collected, and Ogallala volcanic ash deposits in northwestern Kansas. **A.** Location of measured sections. Figures indicate thickness of Ogallala strata measured at each location. **B.** Localities from which plant fossils and fossil mollusks were collected. Circles indicate mollusk collections; crosses indicate plant collections. **C.** Ogallala volcanic ash deposits.

> ledge of limestone is only 2 to 3½ feet thick. It has an irregularly pitted surface and is made of unstratified, hard, compact, usually pinkish limestone and has a peculiar concentrically banded structure, which resembles closely that of the algal reefs and irregular pisolites of the Green River formation . . . . It is quite clear . . . that the bed belongs to the Ogallala and is the capping rock of the section."

He further stated concerning the *Chlorellopsis* limestone (Elias, 1931, p. 141):

> "... 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."

Not only has the presumed equivalent of this bed in the southern Great Plains been a subject of contrasting interpretations, but Elias' concept of origin of the bed in western Kansas has brought discussion in the literature. In 1940 Smith critically discussed the origin of the bed, stating (Smith, 1940, p. 90):

> "The considerable difficulties attending this hypothesis are mainly those of satisfactorily explaining the origin of such ponding."

He discussed at some length the structural complications and hydrologic problems involved in such an extensive late Pliocene lake.

Frye (1945a) presented an hypothesis of "Algal limestone" formation in lakes that occupied consequent depressions and abandoned channel segments, after deposition had virtually ceased on the piedmont plain of alluviation that marked the top of the Ogallala deposits.

If this bed was produced in either of these environments—or if we deny evidence of fossil algae and postulate a mode of origin by development of a mature to senile lime-accumulating soil, later modified by solution and redeposition with resultant topographic lowering—the stratigraphic utility of the bed remains equally good. Since Elias first described the bed, there has been no field evidence observed that would deny that it occurs without exception at the stratigraphic top of the Ogallala and is clearly distinguishable from the capping units or calcareous paleosols that mark the termination of deposition of the several Pleistocene cycles of alluviation. In this region it has never been observed conformably overlain in a sequence of deposits. This is in strong contrast to the western Texas—eastern New Mexico region (Bretz and Horberg, 1949; Price, Elias, and Frye, 1946) where beds of similar appearance are reported to occur both within and as the capping bed of stratigraphic units of several ages, ranging well up into the Pleistocene. Thus, the "Algal limestone" bed can be used in northern Kansas as a datum that marks the top of the formation and the top of the Kimball member. As the Kimball member is relatively thin, and inasmuch as its base is not clearly definable, exploration of its internal stratigraphy has been aided by vertical measurements downward from this bed.

Bedrock Configuration

The base of the Ogallala is useful stratigraphically in a very different way than is the top. Whereas the "Algal limestone" marks a constant stratigraphic position wherever observed, the basal beds at any two localities are unlikely to be at precisely the same stratigraphic position, nor precisely of the same age. All lines of evidence indicate that the Ogallala was deposited by streams flowing in a general easterly direction and that alluviation started in the lowest parts of broad, gently sloping erosional valleys. Therefore, it is expectable that the lowest, hence oldest, members be present in low areas of the bedrock, higher and younger beds transgressively overlapping the gently sloping valley flanks. As this concept has been checked repeatedly by other lines of evidence, it is therefore possible to use it for rough stratigraphic placement of deposits at localities where other evidence is lacking.

The relation of the configuration of the erosional surface at the base of the Ogallala to the stratigraphy of the formation has been fully recognized only recently (Merriam and Frye, 1954). The control exerted on the lower members by the erosional topography of this surface is strikingly illustrated in the generalized cross sections presented in Figure 2, and emphasized by the vertical exaggeration therein. Within the last decade detailed information concerning this surface has become available as a result of test drilling done under the cooperative State and Federal ground-water program. Much of this information recently has been summarized on a map showing areal geology and generalized contours (Merriam and Frye, 1954, pl. 1). Although in southwestern and central Kansas the erosion surface upon which the

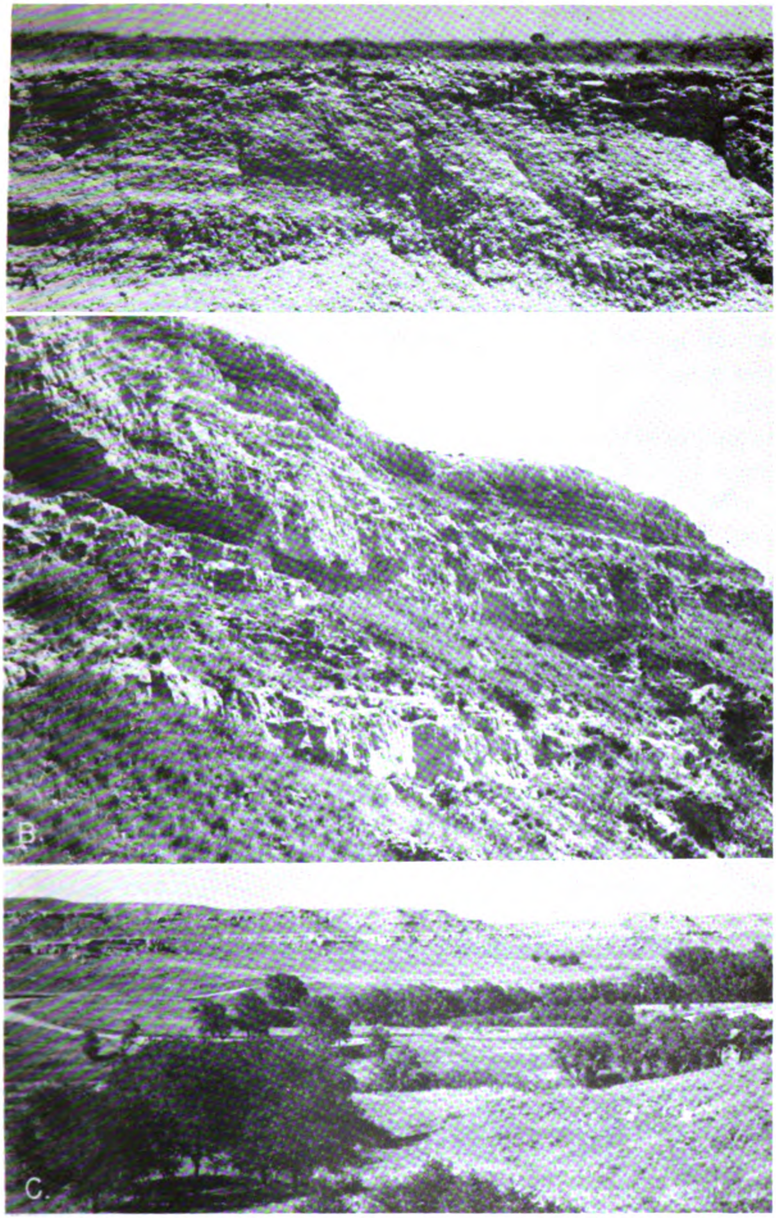


PLATE 2. Ogallala formation in west-central Kansas. **A**. Kimball member with "Algal limestone" bed at top, NW¼ NW¼ sec. 30, T. 18 S., R. 28 W., Lane County (June 1954). **B**. Middle and Upper Ash Hollow member, Ogallala formation, NW¼ NW¼ sec. 11, T. 16 S., R. 33 W., Scott County (June 1954). See Scott County State Lake section. **C**. View toward northeast from NW¼ NW¼ sec. 11, T. 16 S., R. 33 W., Scott County, showing exposures of Ash Hollow member, Ogallala formation, along Ladder Creek valley (June 1954).

Ogallala was deposited has been modified significantly by Pleistocene erosion and local faulting, in the northwestern quadrant of the state, which is the area under consideration here, the bedrock surface depicted on the map is essentially the same as it was when Ogallala deposition began.

Volcanic Ash Lentils

The establishment of age equivalence of separated lentils of volcanic ash is judged to be the most precise method of time correlation available to us. The utility of this method for regional correlation of Pleistocene deposits has been demonstrated (Frye, Swineford, and Leonard, 1948), and recently the petrographic characters of the known volcanic ash falls recorded in the Miocene and Pliocene strata of the Great Plains have been described (Swineford, Frye, and Leonard, 1955). The characters of these ash falls will not be redescribed here. It was stated by Swineford, Frye, and Leonard (1955) that the several distinctive falls were differentiated from each other on the basis of differences in index of refraction, shape and thickness of shards, and other factors including chemical composition.

Volcanic ash from as few as two localities but known to be from the same fall may prove of value in stratigraphic correlation. Six ash falls in the Ogallala deposits of Kansas and Nebraska satisfy this minimum requirement, and have been described and named. One of these was studied at eight localities in the two states. Five of these volcanic ash falls are grouped in the middle part of the formation.

Distinctive Rock Types

With the exception of the "Algal limestone" and the volcanic ash lentils, there is a general lack of distinction of lithology among the Ogallala deposits (Pl. 2, 3, 4). There are, however, a few other uncommon rock types that possess, or have been thought to possess, stratigraphic significance. The most distinctive of these are the opal-cemented sandstone and conglomerate; white to gray porcelaneous chert and opal that have replaced calcium carbonate in silty beds; bentonitic clay; and soft limestone or marl, locally containing molds of snail shells.

Opal-cemented rock.—The petrography of the opal-cemented rock was described by Frye and Swineford (1946), who believed

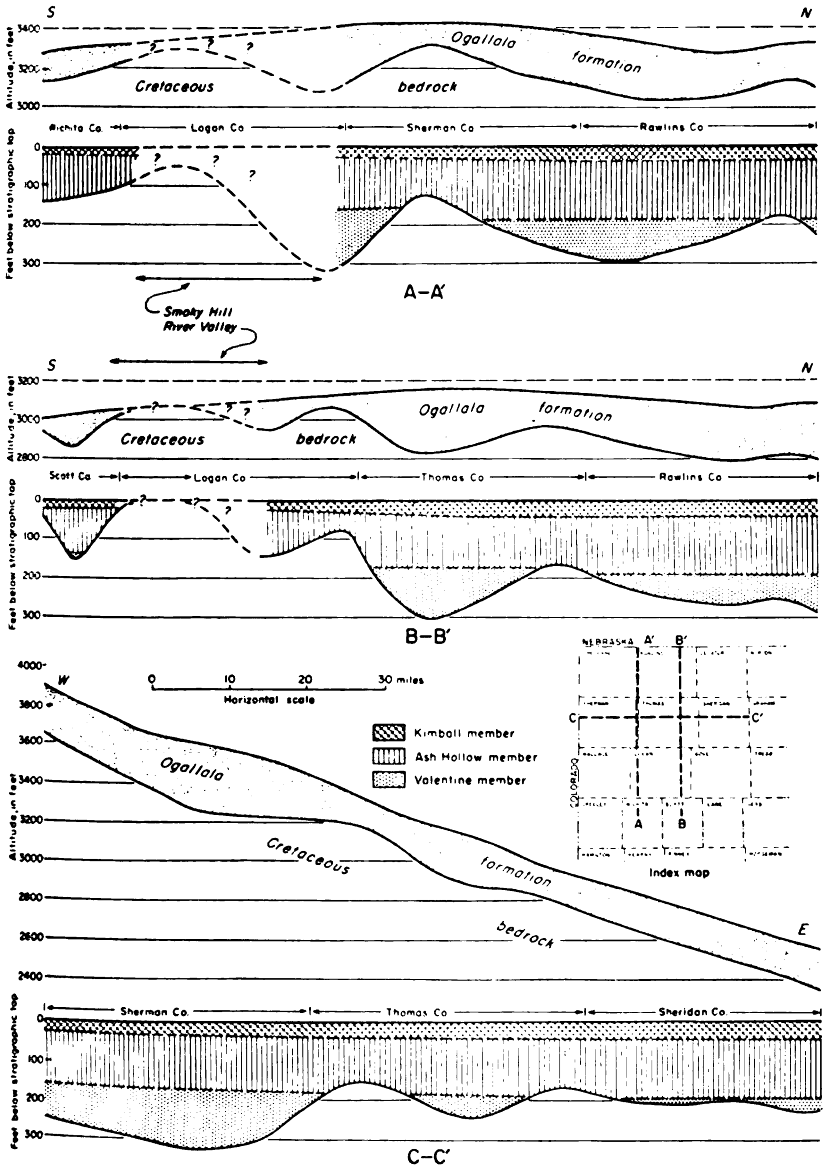


Fig. 2.—Diagrammatic cross sections of the Ogallala formation in northwestern Kansas. Based on maps by Merriam and Frye (1954) with schematic conversions of the cross sections to a horizontal plane at the stratigraphic top of the formation.

that rocks of this particular lithology occur only in the lower part of the formation, below the zone within which the volcanic ash lentils are concentrated. They concluded that the source of the silica was the numerous lentils of volcanic ash at and above the stratigraphic position of the opaline sandstone (Frye and Swineford, 1946, p. 57) and thus these distinctive lentils have a general stratigraphic significance. The color of the cement (various tints of green) and its hardness and resistance to erosion make this particular rock type easily recognizable in the field.

Chert.—The zones of white to gray chert, opal, and calcium carbonate rocks that generally lack clastic quartz grains coarser than silt or fine sand have a stratigraphic implication, different from that which may be inferred from the occurrence of opal-cemented rocks. Elias (1931, p. 136) described chert and moss agate a few feet below the "Algal limestone" in Wallace County and elsewhere. This rock is petrographically quite different from the green opaline sandstone (Frye and Swineford, 1946) and has been observed at many places in western Kansas in the Kimball member. Where its stratigraphic relation to the "Algal limestone" has been determined it occurs within 10 or 15 feet below that bed. Although the origin of this particular lithology is not clear, the chert seems to be genetically related to the relatively stable surface that developed on the alluvial plain after termination of Ogallala deposition. Although by no means a definitive stratigraphic marker, rock of this unusual lithology has some local utility.

Bentonitic clay.—Relatively pure clay beds are not a common type of rock in the Ogallala, but they have been observed at several localities. Elias (1931, p. 153-158) discussed at some length the occurrence of these clays at the base of the Ogallala in Wallace County and elsewhere in northwestern Kansas. He stated (Elias, 1931, p. 153):

> "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."

He applied the name "Woodhouse clays" from a locality one mile east of Woodhouse ranch in Wallace County. The clay beds at all localities described are at or near the base of the Ogallala formation and he concluded that the deposits were for the most part the product of weathering of volcanic ash that had been deposited

PLATE 3. Ash Hollow member, Ogallala formation, in northern Kansas. **A.** Middle Ash Hollow member, center W line of the SW ¼ sec. 7, T. 8 S., R. 26 W., Sheridan County (June 1954). See measured section for seed lists. **B.** Lower Ash Hollow member resting on uppermost Valentine member, exposed in south bluff of Sappa Creek valley NW¼ NE¼ sec. 34, T. 1 S., R. 27 W., Decatur County (July 1953). Abundant and diversified fossil seeds listed in measured section. **C.** Middle Ash Hollow member, SW¼ sec. 30, T. 5 S., R. 22 W., Norton County (June 1954). Fossiliferous Valentine member exposed below Ash Hollow member at this locality. Fossil seeds listed in Edmond measured section.

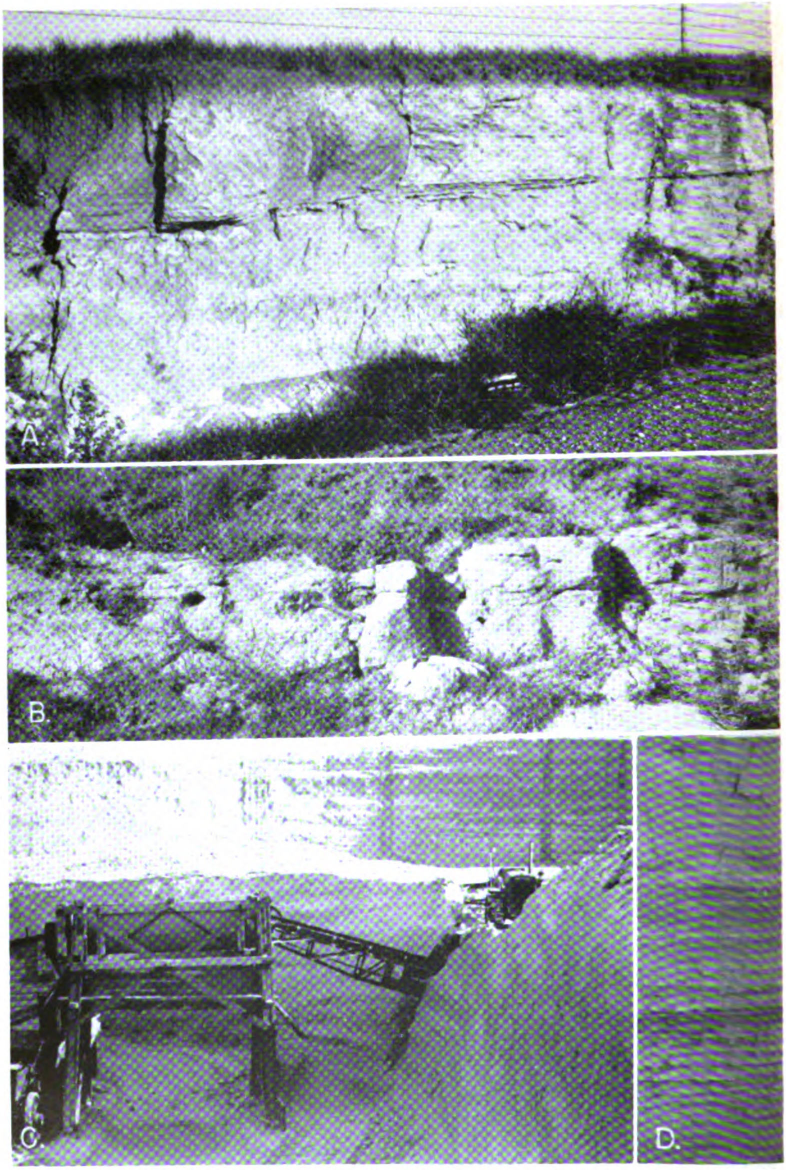


PLATE 4. Ogallala volcanic ash. **A.** Dellvale volcanic ash bed, middle Ash Hollow member, NW¼ NW¼ sec. 2, T. 4 S., R. 24 W., Norton County (June 1954). The pick marks the base of the volcanic ash bed; fossil seeds are listed in measured section. **B.** Rawlins volcanic ash bed; lower Ash Hollow member, SE¼ SE¼ sec. 8, T. 14 S., R. 38 W., Wallace County (June 1954). See measured section. **C.** Calvert volcanic ash bed at type locality. Upper Valentine member, at Calvert, Norton County. The pit is operated by Wyandotte Chemical Corporation (1945). Fossil seeds are listed in Figure 3. **D.** Ripple marks in volcanic ash at Calvert mine.

on the surface of the Cretaceous shale and chalk before the Ogallala was deposited, or very early during the deposition of these beds (Elias, 1931, p. 156-157). Subsurface samples of clay of similar appearance from the base of the formation in Thomas County have been described (Frye, 1945, p. 67) but it was suggested that this clay might be a weathering product of the underlying Cretaceous Pierre shale. Similar clays in Phillips County (Landes and Keroher, 1942) and in Norton County (Frye and Leonard, 1949; Byrne, Beck, and Bearman, 1949) have been described. Although clays of this type are clearly not restricted to one stratigraphic position, they are known principally from the basal part of the formation, but a few thin bentonite lentils are also observed at higher stratigraphic positions within the Ogallala. One such bed, about a foot thick, occurs above the volcanic ash in the Calvert ash mine in Norton County. Thin bentonites also occur interbedded with sand and gravel in an abandoned opaline-sandstone quarry near Woodruff. Bentonites are also reported in the lower part of the Ogallala in test holes in Phillips and Norton Counties (Frye and A. R. Leonard, 1949, p. 114, 117).

Bentonite lentils are seemingly restricted to the Valentine member of the formation; the alteration of the ash to montmorillonite may be related to high ground-water levels that obtained during the deposition of the Valentine and to the availability of magnesium ion from nearby Cretaceous marine shales.

Marl.—Soft, silty to sandy diatomaceous limestone or marl is another distinctive rock type within the formation (Frye and Leonard, 1949). Although rocks of this lithology are more common in the lower half than the upper half of the formation, they are present at many stratigraphic positions and therefore have little stratigraphic value. At many places, however, rocks of this type contain molds and casts of fossil snails, which contribute greatly to our knowledge of the molluscan faunas.

Stratigraphic Sequence

One of the oldest techniques of stratigraphical geology is the comparison of sequences of rocks at different localities. The classic procedure of measuring a rock sequence and noting the relative position therein of distinctive fossils or of significant rock types and other data remains a fundamental tool of the stratigrapher, whether he is dealing with thin-bedded marine strata, or, as we are here, with a thick alluvial blanket. It is true that many of the details observed in a sequence of rocks have in themselves small utility in correlation, but they may give meaning to other criteria used. Thus, in the Ogallala formation, few individual beds have stratigraphic significance, but in general the beds fall into an indistinct but observable pattern that changes in character from the bottom to the top of the formation. This changing pattern is discernible in the graphic sections on Plate I, and in more detail in the descriptive sections at the end of this report.

Fossil Vertebrates, Mollusks, and Plants

Fossil vertebrates have generally proved of greatest value in regional correlation of Cenozoic deposits, but have been utilized also for broad intercontinental correlations on the one hand and purely local correlations on the other. The assignment of Neogene age to the Ogallala deposits in northwestern Kansas, for example, has rested for many years on evidence based on a few collections of fossil vertebrates. For the detailed correlations attempted here, however, the collections available are inadequate because of their erratic vertical and areal distribution. Additional collecting would undoubtedly prove profitable, but inasmuch as such collections, well distributed throughout the stratigraphic section and the area, are not known to us our correlations depend but little on evidence from fossil vertebrates.

Elias, Frye, and others have noted fossil mollusk shells in a few places and molds of mollusk shells in limestone at many localities within the Ogallala but they did not determine the kinds of mollusks in the formation nor their vertical and regional distribution. Our studies have been limited, partly because of the labor involved in casting the molds, to the molluscan faunules at eight stratigraphically significant localities, but molds of mollusks are known to occur at many other localities. The small number and circumscribed distribution of the localities from which fossil mollusks have been obtained has severely restricted the use of these fossils in detailed correlation studies, but suitable collections of fossil mollusks permit correct placement of Ogallala beds in the recognized members.

Fossil plant remains, consisting of the excellently preserved hulls of grass seeds and nutlets or fruits of other plants, are widely distributed in Ogallala sediments in northwestern Kansas:

this fact, and the pioneer work of Elias (1942) in establishing the approximate vertical range of the several kinds of plants represented in Neogene sediments in Kansas and Nebraska, give these fossils prime importance in both local and regional correlations in the area covered by Ogallala deposits. Most local assemblages of fossil seeds are sufficiently distinctive to permit recognition of at least the member of the Ogallala formation and, in the Ash Hollow, to permit stratigraphic placement even within the lower, middle, or upper part of the member.

Volcanic Ash Falls

The use of petrographically distinctive volcanic ash lentils for the establishment of time lines has been demonstrated in the Great Plains region (Frye, Swineford, and Leonard, 1948). As this technique represents a new approach to the problems of intra-Ogallala correlation, it merits special attention in a discussion of the stratigraphy of the formation. The petrography and stratigraphic occurrence of volcanic ash in the Miocene and Pliocene of western Kansas and Nebraska have recently been described by Swineford, Frye, and Leonard (1955) and the following descriptions are chiefly a summary of this detailed work.

All the Ogallala volcanic ash deposits are predominantly vitric tuffs. They have been differentiated petrographically by the character of the glass shards, including average value and range of index of refraction; thickness, shape, and color of the shards; presence or absence of small second-order vesicles in the glass; and chemical composition of the glass. Most of these characters (i.e., refractive index, color, and chemical composition) are more or less affected by weathering of the glass and therefore must be evaluated with caution.

Some ash falls are characterized by shards that are simple and so thin that iridescence is observed in a few fragments. Other falls contain coarse glass shards 20 microns thick or thicker. Glass in some deposits shows a small radius of curvature of the bubble walls, or frothy to fibrous aspect caused by numerous bubbles, or multiple bubble junctures in one shard. The chemical composition of most of the samples analyzed is typically rich in silica, or approximately that of rhyolite.

Ten petrographically distinctive volcanic ashes in the Ogallala formation of northern Kansas have been described and six of these have been judged to warrant the application of formal bed names. Of these ten ash falls, eight are definitely placed in the lower three-fifths of the Ash Hollow member, the stratigraphic position of one (represented by a single exposure) is not certain, and the other ash fall is placed in the upper part of the Valentine member. Fortunately, regional correlation is possible because two of these falls are also judged to be represented by lentils in Nebraska that occur in the Valentine and Ash Hollow type sections. In all, lentils of Ogallala volcanic ash from 28 localities in northern Kansas were described and the stratigraphic relations of 13 of these lentils are given in the measured sections included with this report. The distribution of known Ogallala volcanic ash localities is shown on the map in Figure 1c, and the field appearance of some typical exposures is shown on Plate 4.

The four unnamed ash falls known from the northern Kansas Ogallala have little or no stratigraphic significance and will be mentioned only briefly. Only one of these is known from more than one locality. Samples of this ash were collected in the NW¼ NE¼ sec. 12, T. 3 S., R. 22 W., Norton County, and the SW¼ NE¼ sec. 3, T. 2 S., R. 19 W., Phillips County, from a bed judged to be about one-third of the distance above the base of the Ash Hollow member. Another lentil in the lower third of this member is exposed in the NE¼ NE¼ sec. 19, T. 2 S., R. 18 W., Phillips County. An ash lentil exposed in the SE¼ SW¼ sec. 25, T. 2 S., R. 25 W., Norton County, is judged to lie stratigraphically at approximately the middle of the member.

A volcanic ash of uncertain stratigraphic position is exposed in the NE¼ NE¼ NE¼ sec. 2, T. 7 S., R. 24 W., Graham County. The details of the local stratigraphy are given in the measured section with this report.

In the following paragraphs the named ash beds in the Ogallala of northern Kansas are briefly described. The Calvert bed is in the Valentine member; the Rawlins, Fort Wallace, Dellvale, Reager, and Reamsville beds occur in the lower three-fifths of the Ash Hollow member.

Calvert bed.—The Calvert ash bed was named from exposures in the commercial ash mine at Calvert (NW¼ SW¼ sec. 25, T. 3 S., R. 22 W.), Norton County. In this area the bed attains a maximum thickness of 22 feet, which is the maximum known thickness of any Ogallala volcanic ash. The Calvert bed has also been identified in exposures in the SE¼ SE¼ sec. 25, T. 3 S., R. 25 W., Norton County, and the NW¼ NW¼ sec. 33, T. 3 S., R. 34 W., Rawlins County. As this bed has been correlated with partly altered ash occurring 185 feet above the base of the type section of the Valentine member, Cherry County, Nebraska, it has been of value in the delineation of the Valentine-Ash Hollow boundary in the Ogallala of northern Kansas. The Calvert ash bed is in the upper one-fifth to one-sixth of the Valentine member and although the thickness of the Valentine varies from place to place this relative position is judged to hold generally.

Rawlins bed.—The Rawlins ash bed is known from seven localities in northern Kansas and the type section of the Ash Hollow member in Nebraska. The Rawlins ash was described from exposures at the center of the west line of the SW¼ sec. 4, T. 4 S., R. 34 W., Rawlins County, where the bed is 3½ feet thick (see measured section for stratigraphic association). Its stratigraphic relationships are well illustrated in measured sections, included here, from Norton County (W½ sec. 16, T. 2 S., R. 21 W.), Phillips County (NW¼ NE¼ sec. 30, T. 1 S., R. 19 W.), Rawlins County (SE¼ SE¼ sec. 20, T. 5 S., R. 36 W.), and Wallace County (SE¼ SE¼ SE¼ sec. 8, T. 14 S., R. 38 W.). This bed has also been studied at exposures in the NE¼ SE¼ sec. 27, T. 4 S., R. 23 W., Norton County, and NE¼ NW¼ sec. 10, T. 5 S., R. 29 W., Decatur County.

The Rawlins bed lies within the lower part of the Ash Hollow member. The correlation of this bed with ash in the type Ash Hollow section, and its association in northeastern Norton County with the Calvert bed, which is correlated with ash in the type Valentine section, provide new evidence for the placement of the boundary between these two members in northern Kansas, as shown in Plate 1. As will be described, the evidence of these two volcanic ash falls is in harmony with paleontological and stratigraphic evidence.

The succeeding ash falls, progressively higher within the Ash Hollow member, aid in correlation within Kansas, but as they are not known from the Nebraska type section, they have little value in definition of units.

Fort Wallace bed.—The Fort Wallace bed is known only from Wallace County. Its stratigraphic relations are shown by the measured section at its type locality in the west line of the SW

¼ sec. 7, T. 14 S., R. 38 W. It was also sampled from a one-foot bed in the NE¼ NE¼ sec. 16, T. 14 S., R. 40 W.

Dellvale bed.—The Dellvale bed is also relatively local in its known geographic extent. The associated stratigraphy is shown by two measured sections in Norton County, the type locality of the bed southeast of Dellvale (NW¼ NW¼ sec. 2, T. 4 S., R. 24 W.), and the Almena section (W½ sec. 16, T. 2 S., R. 21 W.). It has also been described from exposures in the NE¼ NE¼ sec. 19, T. 2 S., R. 18 W., Phillips County.

Reager bed.—The Reager bed is known from four localities distributed over a distance of approximately 70 miles. It was named from exposures in an abandoned pit in the SW¼ SE¼ sec. 2, T. 3 S., R. 25 W., southeast of Reager, Norton County. It was also studied in the SE¼ SE¼ sec. 16, T. 1 S., R. 21 W., Norton County, NE¼ NE¼ sec. 15, T. 3 S., R. 30 W., Decatur County, and SW¼ SE¼ sec. 2, T. 3 S., R. 33 W., Rawlins County. In Rawlins County the measured section shows the close stratigraphic relation of this bed with the next higher, Reamsville ash bed.

Reamsville bed.—The Reamsville bed is the highest named volcanic ash bed in the Ogallala formation (Pl. 1) and is known from four localities distributed over an east-west distance of more than 100 miles. Its stratigraphic association is shown by three measured sections; the type locality south-southwest of Reamsville in Smith County (center of the west line of the SW¼ sec. 32, T. 1 S., R. 14 W.), a section in Decatur County (SE¼ SW¼ sec. 8, T. 4 S., R. 29 W.), and in the same section with a Reager ash bed in Rawlins County (SW¼ SE¼ sec. 2, T. 3 S., R. 33 W.). The bed was also studied in the NW¼ SW¼ sec. 31, T. 1 S., R. 19 W., Phillips County.

PALEONTOLOGY

Fossil Vertebrates

The placement of the beds originally described as Ogallala within the Neogene of the standard time scale is based entirely on the contained vertebrate fossils. Vertebrate fossils also are the primary evidence used in the controversial question of Miocene *vs.* Pliocene age for all or part of the Valentine member. However, only four known localities in northwestern Kansas yield assemblages of fossil vertebrates that can be used for regional stratigraphic purposes. One locality in Yuma County, Colorado, is near enough to our area to be stratigraphically significant in this study. The four local faunas in Kansas are not well distributed over the area under study, as two are in Wallace County, another in adjacent Sherman County, and the fourth in Phillips County. Other collections are too poorly known or too fragmentary to be of use.

No significant studies of vertebrate fossils from the Ogallala formation in northwestern Kansas have been made in the 20 years from 1935 to 1955. It is our judgment, based on field observations made over a period of 15 years, that further detailed collecting of vertebrate fossils in Ogallala sediments in northwestern Kansas would be profitable, and might contribute greatly to a knowledge of detailed stratigraphy of the formation. In general, bones in Ogallala sediments are silicified, and hence well preserved.

We are indebted to Robert W. Wilson, vertebrate paleontologist in the Museum of Natural History, The University of Kansas, for the following lists of vertebrates represented in local assemblages in the Ogallala formation of northwestern Kansas and nearby Colorado. Wilson has searched the literature for all available records, and has brought the names of the several species up to date as far as possible, but we, of course, assume full responsibility for any errors that may be present.

Wray local fauna.—Ogallala formation, Hemphillian, Yuma County, Colorado (Cook, 1922, 1922a, 1927, 1930; Cook and Cook, 1933; Stirton, 1936, 1944; Frick, 1937; Wood and others, 1941; Simpson, 1933). A tentative faunal list based on the above citations follows:

Osteoborus pugnator
Machairodus coloradensis
Amebelodon hicksi
Amebelodon paladentatus
Neohipparion occidentale
Pliohippus, sp. indet.
Teleoceras [*Paraphelops*] *yumensis*
?*Peraceras ponderis*
Aphelops longinaris
Prosthennops sp.
Megatylopus cf. *M. gigas*
?*Alticamelus* sp.
Sphenophalos? figginsi
Pediomeryx

As nearly as can be determined from all the evidence available, the Wray local fauna occurs in lower Ash Hollow deposits.

Edson local fauna.—Ogallala formation, Hemphillian, sec. 25 T. 10 S., R. 38 W., Sherman County, Kansas (Hibbard, 1939; Simpson, 1933; Stirton, 1936; Wilmarth, 1938; Wood and others, 1941).

Plioambystoma kansensis
Scaphiopus pliobatrachus
Bufo arenarius
Bufo hibbardi
Chelydra sp.
Testudo sp.
Grus nannoides
Colymbus nigricollus
Scolopacidae, sp.
Corvidae, sp.
Talpidae, sp.
Mylagaulus monodon
Kansasimys dubius
Sciurus sp.
Perognathus dunklei
Prodipodomys kansensis
Peromyscus martinii [*Onychomys martinii* acc. Hoffmeister, 1945]
Oryzomys? pliocoenicus
Osteoborus cynoides
Leptocyon shermanensis [*Vulpes?* acc. to Stirton]
Martinogale alveodens
Plesiogulo marshalli
Adelphailurus kansensis [*Pseudaelurus* acc. to Simpson]
Machairodus cf. *M. catacopis*
Pliohippus interpolatus
Nannippus nr. *N. lenticulare*
Aphelops mutilus
Prosthennops serus
Megatylopus gigas
Pliauchenia sp.
Procamelus sp.

Stratigraphically the position of the Edson local fauna is clearly in the upper part of the Ash Hollow member. The Kimball-Ash Hollow contact was not observed at this locality; it may be only a few feet above the position of the fauna.

Rhinoceras Hill local fauna.—Ogallala formation, Hemphillian; SE¼ NE¼ sec. 11, T. 11 S., R. 38 W., Sherman County, Kansas (Hesse, 1935; Stirton, 1936; Wilmarth, 1938; Wood and others, 1941).

Osteoborus nr. *O. cynoides*
Machairodus catacopis
Amebelodon fricki
Pliohippus interpolatus
Neohipparion sp.
Nannippus? sp.
Aphelops mutilus
Teleoceras fossiger
Megatylopus? sp.
Pliauchenia? sp.
Cervidae sp.
Capromeryx altidens

On the basis of all evidence available, the Rhinoceras Hill local fauna occurs in the middle of the Ash Hollow member.

Lost Quarry local fauna.—Ogallala formation, Hemphillian; NW¼ sec. 1, T. 15 S., R. 38 W., Wallace County, Kansas (Hibbard, 1934; Stirton, 1936).

Osteoborus cynoides
?*Aelurodon haydeni*
Agriotherium sp.
Pratifelis martini
?*Pliohippus interpolatus*
Nannippus sp.

The stratigraphic position of this local assemblage is not well known, but seemingly it is in the upper part of the Ash Hollow member.

Long Island Quarry.—Ogallala formation, Hemphillian?; Overton Farm, south of Long Island, Phillips County, Kansas. This quarry has yielded few fossils other than *Teleoceras fossiger*,

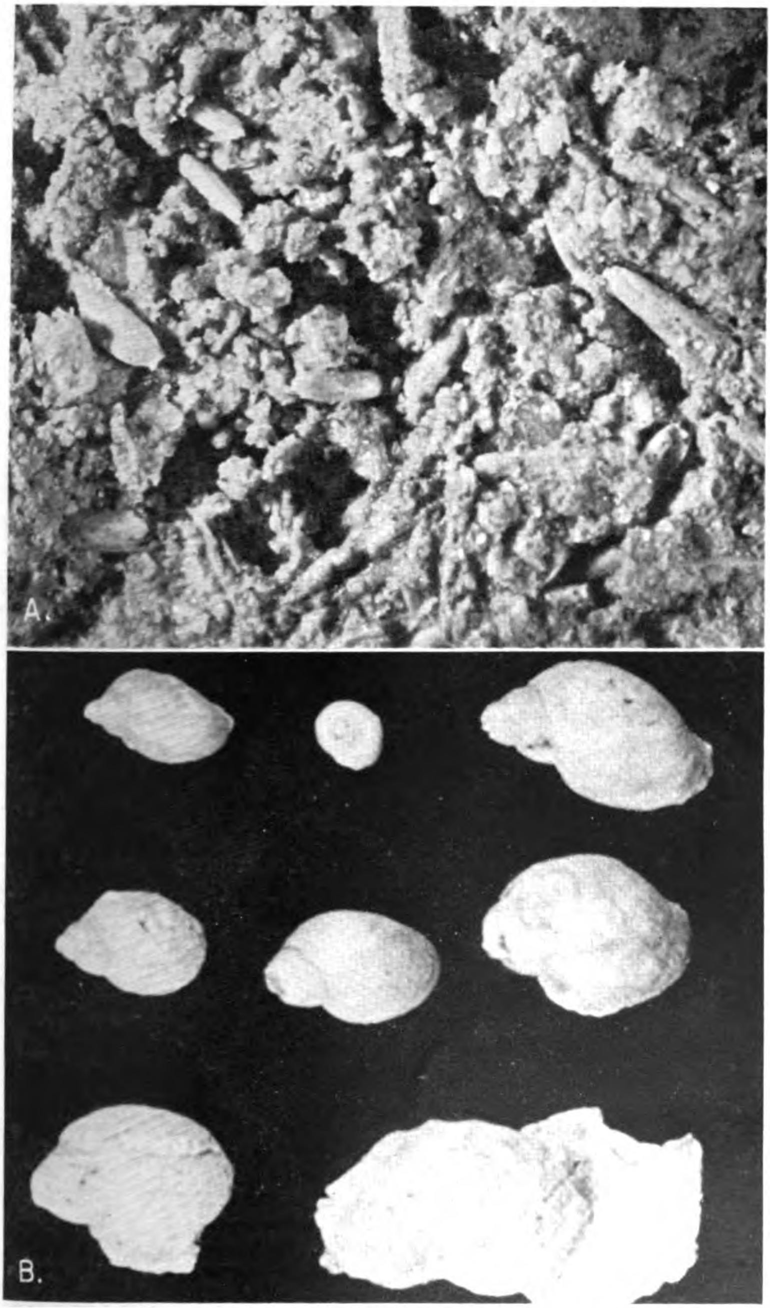


PLATE 5. Details of fossils in Ogallala rocks. **A.** Hulls of *Stipidium* as they appear in matrix; NW¼ NE¼ sec. 34, T. 1 S., R. 27 W., Decatur County, Kansas. **B.** Natural casts of *Lymnaea lavernensis* and *Helisoma valens* from soft diatomaceous limestone; center W line, sec. 3, T. 12 S., R. 20 W., Ellis County, Kansas.

but on the bases of its topographic position and of the occurrence of fossil plants in nearby localities it is judged that this quarry is situated in the lower to middle part of the Ash Hollow member.

The occurrence of these local fossil vertebrate faunas in the Ash Hollow member of the Ogallala formation not only firmly establishes the Pliocene age of this member in northwestern Kansas but allows firm correlation with the Ogallala formation (group according to Nebraska classification) in Nebraska, where fossil vertebrates from rocks of this age are said to be better known. It is obvious, however, that detailed stratigraphic correlations cannot be made on the basis of these meager and poorly distributed assemblages of fossil vertebrates. As a matter of fact, we did not find it possible to utilize these faunas in local correlations.

The question of delineation of the Pliocene-Miocene boundary line in the Great Plains region is not within the province of this report. This is a problem involving the correlation of vertebrate faunas from this region with fossil assemblages in Europe, and the further correlation in Europe of the beds containing fossil vertebrates with the typical marine units originally defined as Pliocene and Miocene. The term Neogene, which is used generally in Europe to include both of these units, is therefore used as a general age designation for the Ogallala formation, as it comprises a sedimentary and lithologic unit.

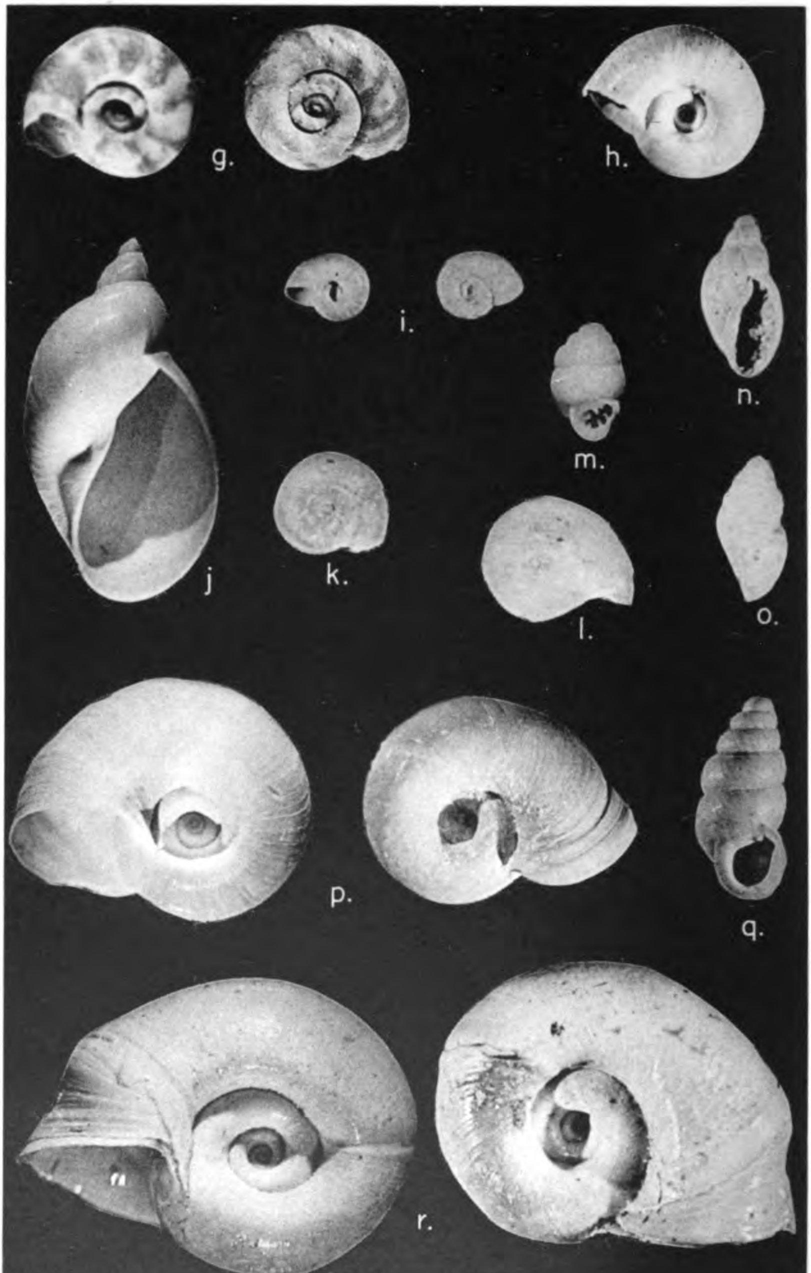
Fossil Mollusks

Fossil molluscan assemblages have been used extensively for stratigraphic purposes in the Pleistocene of the Great Plains region, but hitherto have not been used for stratigraphic correlation of nonmarine Pliocene or Miocene beds in interior North America. They have proved useful to us, however, in stratigraphic studies of the Ogallala formation in this region.

Determination of the kinds of mollusks in the Ogallala formation has been attended by unusual difficulties, because except for a single locality in Wallace County (center North line sec. 29, T. 12 S., R. 42 W.) where a few entire shells are preserved in silty

Plate 6. Fossil mollusks from Ogallala formation. *a. Physa hawni* Lea *b. Physa anatina* Lea *c. Calipyrgula hibbardi* Leonard and Franzen *d. Calipyrgula senta* Leonard and Franzen *e. Lymnaea lavernensis* Leonard and Franzen *f. Lymnaea macella* Leonard. All figures × 5, except *e*, × 3.

FRYE, LEONARD, AND SWINEFORD — Fossil mollusks from the Ogallala



Frye, Leonard, and Swineford — Fossil mollusks from the Ogallala clay or in silicious nodules, mollusks in the Ogallala sediments are represented only by more or less imperfect external molds of the shells that were entombed in soft, diatomaceous limestone. Thus, for the most part, species have been determined by comparison of known species from older or younger rocks with casts made from these molds of shells. This method has been generally satisfactory, but not entirely so, and a few species remain undetermined.

Casts of gastropods were made by the following method. Large pieces of limestone, selected in the field because molds (cavities) were obvious on a weathered surface, were sawed into slabs about ¾ inch thick, and carefully dried in an oven. "Ward's Bioplastic" was heated to 140° F. after the addition of the catalyst; heating reduces the viscosity of the syrupy plastic and increases the penetrability of the plastic into the rock. Slabs of limestone were placed in the warmed plastic contained in dishes of convenient size and these were evacuated and maintained at a pressure of approximately one-fifth atmosphere for 30 minutes. This treatment drew the air from the porous rock and allowed the plastic to penetrate the molds. After the catalyzed plastic had congealed, the blocks of limestone encased in plastic were sanded on all free surfaces to expose the rock. These were etched in hot dilute hydrochloric acid, which removed all the denser parts of the rock not infiltrated by plastic. The residue after acid treatment is a reticulum of plastic, duplicating the former pore spaces of the limestone, within which the casts of gastropod molds may be found. Many satisfactory casts were obtained by this tedious method, but several difficulties were encountered. Secondary deposits of calcite or other minerals in some molds prevented satisfactory casting, and in a few slabs the limestone was too dense to allow satisfactory penetration of the viscous plastic to the molds. The elapsed time during which the slabs of rocks are in plastic under reduced pressure is critical; too short a period does not allow proper penetration of the molds by the plastic. If possible, it is best to allow

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PLATE 7. Fossil mollusks from Ogallala formation. *g. Promenetus blancoensis* Leonard *h. Helisoma goodrichi* Leonard and Franzen *i. Helisoma parallelum* Leonard and Franzen *j. Pseudosuccinea columella* (Say) *k., l.* Plastic casts of *Promenetus blancoensis* Leonard *m. Vertigo ovata* Say *n.* Immature example of *Lymnaea macella* Leonard *o.* Plastic cast of immature example of *Lymnaea macella* Leonard *p. Helisoma antrosum* (Conrad) *q. Pupoides albilabris* (C. B. Adams) *r. Helisoma valens* Leonard and Franzen. All figures × 5.

the limestone to remain under reduced pressure until the plastic has congealed.

At one locality (center West line sec. 3, T. 12 S., R. 20 W., Ellis County) almost perfect natural casts, especially of large species of gastropods, were found in diatomaceous limestone lentils. Many of these casts could be removed merely by breaking the rock. Natural casts of *Lymnaea lavernensis* and *Helisoma valens* are shown on Plate 5 B.

Bioplastic casts made by this infiltration technique are almost as useful as the actual shells for identification of species. The shape and dimensions of the shell, the number and relative convexity of the whorls, the shape and size of the aperture, and even the details of surface sculpture of the original shell are more or less perfectly reproduced in a cast. Inasmuch as most of the molluscan species in Ogallala rocks may also be represented by well-preserved shells in older or younger rocks, comparison of the casts with shells of known species made firm identifications relatively easy. The apertural lamellae of pupillid gastropods are not, of course, reproduced in plastic casts, but generally speaking, other characters can be used for identification; several gastropods thought to represent species of pupillids still remain unidentified, however, because of the failure to cast all details of their tiny shells.

Fourteen species of mollusks have been identified with certainty from Ogallala sediments in northwestern Kansas; the occurrence of these fossils at eight localities is shown on Figure 3. Molds of mollusks have been observed in soft diatomaceous limestone lenses at other localities, but inasmuch as the labor involved in preparing, removing, and cleaning satisfactory casts is considerable, only those localities judged to be stratigraphically significant are considered here. The details of the chalky-white casts are difficult to photograph, so shells from other sources have been used to illustrate the faunas, shown on Plates 6 and 7.

Generally speaking, the molluscan fauna preserved in the Ogallala formation in northwestern Kansas is characterized by species of planorbid snails; these animals are pulmonate (air-breathing) aquatic gastropods, generally capable of living in temporary pools subject to complete drying from time to time; the two species of *Physa* have similar environmental tolerances. The ecological requirements of *Lymnaea macella* are not known, but judging from its faunal associations, it lived in permanent bodies of water. *Lymnaea lavernensis* is an extinct animal, but it is best known from lake-bed deposits in northwestern Oklahoma (Leonard and Franzen, 1944) where it is associated with large populations of branchiate (gill-breathing) gastropods, from which it may be concluded that it thrives best in permanent bodies of water. *Pseudosuccinea* is often found out of water, but in regions where it survives today, it frequents permanent bodies of water more often than not. The two species of *Calipyrgula* are branchiate gastropods present in enormous populations in lacustrine deposits of northwestern Oklahoma, from which it may be concluded that their occurrence is limited to permanent lakes or ponds. They are associated there with a species of *Viviparus*, also a branchiate gastropod.

Location / Molluscan species	Cen. N. line sec. 5 T. 1 S., R. 14 W. Smith Co.	NW¼ NE¼ sec. 30, T. 1 S., R. 19 W. Phillips Co.	W½ sec. 16, T. 2 S., R. 21 W. Norton Co. (Almena section)			NW¼ NW¼ sec. 2, T. 4 S., R. 24 W. Norton Co.	Cen. N. line sec. 34, T. 5 S., R. 25 W. Norton Co. (New Almelo section)	Cen. W. line sec. 3, T. 12 S., R. 20 W. Ellis Co.	SW¼ sec. 7, T. 11 S., R. 37 W. Logan Co.	Cen. N. line sec. 29, T. 12 S., R. 42 W. Wallace Co.
			V	AH	K					
Vertigo ovata		●		●	●	●			●	●
Lymnaea macella					●				●	●
Promenetus blancoensis					●				●	●
Pupoides albilabris	●	●		●	●		●	●	●	●
Physa anatina		●		●			●			●
Physa hawni	●		●	●		●		●	●	●
Helisoma antrosum	●	●		●	●	●	●	●	●	●
Helisoma parallellum										
Pseudosuccinea columella	●	●	●	●		●	●	●		●
Helisoma goodrichi			●			●		●		
Helisoma valens	●	●	●			●	●	●		●
Calipyrgula hibbardi			●					●		
Calipyrgula senta			●							
Lymnaea lavernensis			●					●		
Total number of species	5	6	7	6	5	6	5	8	6	9

FIG. 3.—Check list of fossil mollusks. The symbols V, AH, and K indicate the occurrence of mollusks in the Valentine, Ash Hollow, and Kimball members in the Almena section.

Terrestrial snails are poorly represented in Ogallala sediments, as far as known; only two species have been identified with certainty, *Pupoides albilabris* and *Vertigo ovata*. Both are known from the Laverne of northwestern Oklahoma and from sediments of early Pleistocene age in southwestern Kansas; both are living in western Kansas. *Pupoides albilabris* frequents the grasslands of the plains; its ability to survive long periods of aridity and high temperature is well known. *Vertigo ovata* is limited in distribution in western Kansas to a marsh habitat in the Meade Artesian Basin. It is likely, judging from the usual associates of *Pupoides albilabris* and of *Vertigo ovata*, that other genera and species of pupillid gastropods occur in Ogallala sediments, especially as a diversity of such mollusks occur either in older or in younger rocks in the plains region. Perhaps their small size, which may preclude or render difficult long preservation of the molds of their shells in soft limestone, accounts for their seeming absence. The absence of shells of large forest-dwelling gastropods, such as *Polygyra* and *Anguispira*, conforms to the general picture of a prevalent grassland habitat in northwestern Kansas during the deposition of Ogallala rocks, a picture firmly drawn from the widespread remains of grasses and forbs, and the almost complete absence of remains of trees (fruits of the hackberry, *Celtis willistoni*, being a notable exception) in Ogallala sediments.

The known molluscan fauna from the oldest Ogallala deposits in northwestern Kansas is composed of species characteristic of the Laverne faunal assemblages known from northwestern Oklahoma, and that from the youngest Ogallala rocks mostly of species represented in Pleistocene (Nebraskan) rocks in southwestern Kansas. This trend is best seen in the faunules collected from three horizons at the Almena section (W½ sec. 16, T. 2 S., R. 21 W., Norton County) where mollusks occur in Valentine, Ash Hollow, and Kimball members. The Valentine assemblage is preserved as imperfect molds of gastropods in soft limestone, but the known species are characteristic of the Laverne fauna; *Lymnaea lavernensis*, *Helisoma valens*, and two species of *Calipyrgula* are common here, and there is evidence of the occurrence of a species of *Viviparus*, but identifiable casts of this gastropod were not obtained. In Ash Hollow rocks at this locality *Lymnaea lavernensis* does not occur, nor does either of the two species of *Calipyrgula*, but a few Laverne species, such as *Pseudosuccinea* *columella*, persist into this member. The Kimball assemblage, represented by numerous well-preserved molds in limestone near the top of the section, lacks all diagnostic Laverne species, and the complexion of the assemblage is essentially similar to that of earliest Pleistocene faunas (Frye and Leonard, 1952, pl. 14, fig. 6, and p. 148-155). Both the Ash Hollow and the Kimball assemblages are predominantly composed of planorbid species, which fact suggests that the ponds in which the mollusks lived were not necessarily permanent. The limestones in the Ogallala formation in which molds of fossil mollusks occur in northwestern Kansas are without exception richly diatomaceous. Unfortunately, the contained diatom floras have not been studied, and therefore are not reported here.

The faunal assemblages of mollusks in the Ogallala formation undergo a typological evolution (and perhaps some organic evolution as well) in which there is an orderly but gradual change in the complexion of the assemblages from Valentine to Kimball. Therefore in terms of stratigraphic utility the assemblages present a different aspect than that of the molluscan assemblages in the overlying Pleistocene formations, in which wide-scale extinctions, migrations, and other changes in faunas come with dramatic suddenness. Instead of the abrupt faunal discordances present in Pleistocene deposits in northwestern Kansas, Ogallala sediments in the same region show unmistakable change of the molluscan faunas by gradual transitions throughout Ogallala time. More than 75 percent of the mollusks in the Valentine assemblage at the Almena section (Frye and Leonard, 1952, pl. 6, 7; fig. 4) consist of diagnostic Laverne species; less than 50 percent of the mollusks in Ash Hollow deposits at this locality and others are diagnostic Laverne species, and less than 10 percent of the Kimball fauna at the Almena section are typical Laverne mollusks. In summary, it is possible to place molluscan faunas of the Ogallala formation in stratigraphic sequence in any section in which there is a reasonably good assemblage of mollusks, but the unusual precision of stratigraphic placement possible in the Pleistocene in this region is not feasible in the Ogallala. In at least one locality, for example, local conditions seem to have been favorable for the survival of certain Laverne species into the lower Ash Hollow; in the sequence of Ogallala sediments exposed in a road cut in the center of the West line of sec. 3, T. 12 S., R. 20 W., Ellis County, *Lymnaea lavernensis, Helisoma valens*, and other Laverne species occur in strata that seem to be lower Ash Hollow beds. The stratigraphic placement of this fossiliferous limestone lentil, however, is not conclusively shown, because plant fossils have not been found in close stratigraphic proximity to the molluscan remains. If our judgment of this local situation is correct, it may be assumed that although certain species characterize Valentine strata, they are not limited to beds of Valentine age. Generally speaking, however, Valentine, Ash Hollow, and Kimball molluscan assemblages are so distinctly characterized that confusion among them is extremely unlikely.

Fossil Plants

For stratigraphic correlations fossil plants are the most useful of the several kinds of organic remains preserved in Ogallala rocks. Hulls of grass seeds and fruits of various forbs are numerously represented in Ogallala sediments in the region here considered; these plant remains are generally well preserved and can be collected, properly preserved, and stored without expensive equipment, and without excessive expenditure of time and effort; diagnostic characters are generally so well shown that accurate determinations can be made; vertical ranges of most species are limited and generally well known; and finally, seeds are so numerous, both vertically in the succession of Ogallala rocks and geographically over the area of Kansas covered by Ogallala deposition, that these plant fossils assume primary importance as a tool for local as well as for regional stratigraphic correlations. It is rare indeed that an exposure of Ogallala rocks does not reveal at least one kind of fossil seed, and more frequently than not, general stratigraphic placement of even isolated small exposures can be made on the evidence presented by fossil seeds.

Those interested in stratigraphic problems of late Cenozoic deposits in the plains region of Kansas and Oklahoma are indebted to Dr. Maxim K. Elias, whose notable studies of fossil seeds (Elias, 1942) provided stratigraphers with a new and highly usable tool for correlation studies in this segment of the rock column. We wish to express our gratitude to Dr. Elias, who has provided us with much valuable information, and who generously confirmed the identifications of many of our seed collections.

Without exception, so far as known, seeds in the Ogallala formation of northwestern Kansas are opalized. Seeds of *Biorbia fossilia* were analyzed spectrochemically by John Schleicher of the Geochemical Laboratories of the Kansas Geological Survey; his analysis is given below:

> "The fossil seeds from the Ogallala are mostly silica ... However, there is some calcium and aluminum present ... about 2 to 3 percent calcium and the same amount for aluminum, both calculated as the metal. There is about 0.5 percent iron, 0.2 percent magnesium and a trace of copper. The remainder is silica."

The fact that the predominant mineral present in the fossilized seeds is opal makes it feasible to use dilute hydrochloric acid to remove seeds from sediments cemented by calcite.

Fossil seeds in Ogallala clastics can be found merely by examining surfaces of rocks that have been exposed to weathering, although close attention to detail is necessary because seeds may be discolored or even covered by growths of moss, lichens, or algae. Seeds of many species are small, being no more than 2 mm in diameter, and some experience is required to find them, even where they may be numerous. Strangely, fossil seeds, including the seemingly delicate hulls of grass seeds, are found in all varieties of sediments, and they occur in large numbers in some coarse angular sands or gravels. Obviously, they could not have been transported any significant distance with these clastics, a fact that increases their value for stratigraphic purposes.

Seeds commonly occur in local dense aggregations of twenty to several hundred individuals in rocks where single seeds are rare. Not infrequently, such a local aggregation is the only collection from an exposure, and more than once we have carefully searched a suitable exposure and decided it was barren of fossil seeds, only to return later and find a rich collection at some small, previously overlooked spot on the outcrop. The reason for this unusual distribution within the rocks is not understood, but Elias has suggested that some of these aggregations result from passage through animals, that is, they are the remains of fecal deposits; others may be the result of minor eddy currents in sluggish water.

Such erratic distribution is not universal; in many beds seeds may be found almost uniformly dispersed. It is not usual to find seeds uniformly distributed vertically through great thicknesses of section; generally speaking, worth-while collections can be made only from certain strata, others being almost or totally devoid of fossil seeds. There seems to be no correlation between the nature of the sediments and the numbers of contained fossil seeds; at one locality seeds may be most abundant in fine sand, at another in coarse sands and gravels, or seeds may occur in both types of rock at the same locality. It is our judgment that this phenomenon reflects primarily the nature of Ogallala deposition in a complex series of channel-ways, so that at the same time seeds might become entombed in fine sands and silts, or in coarse sands and gravels, depending upon local conditions in the depositing channel.

Grass hulls commonly occur in loose sand, in an elongate pattern of distribution, and mixed with various kinds of organic debris, suggesting drift along the border of a stream. Seeds commonly occur in sediments that have undergone some degree of induration, and from these rocks the seeds must be removed by knife or awl, or pieces of the rock may be taken to the laboratory and the seeds removed, or at least loosened from the rock, by treatment with dilute hydrochloric acid. At least part of the cementing mineral that binds the "mortar beds" in the Ogallala is acid-soluble. Calcite is not the predominant cementing substance everywhere, however; at many localities, especially in the northern tier of counties in Kansas, the predominant cementing mineral is not acid-soluble and is presumed to be opal or fine-grained chert. Hulls of *Stipidium* illustrated in Plate 5A occur in medium to coarse indurated sands in which only a small part of the cementing material is acid-soluble, so of course removal of the fossils from the matrix is difficult. The source of the silica that forms the cementing substance is not known; it could come from weathering of feldspathic sands in the rocks themselves, or from thin, widespread volcanic ash falls that have subsequently disappeared through weathering. The latter hypothesis seems more tenable, as the sands show few signs of weathering whereas volcanic ash lentils are common, and bentonitic clays, although not conspicuous, are widespread.

The fossil seeds from the Ogallala formation (Pl. 8, 9; Fig. 4) may be divided into three major, stratigraphically significant groups: (1) seeds that occur in the Valentine member, represented in Kansas by a single species of grass, *Stipidium commune;* (2) a large assortment of grasses and other herbs characteristic of the Ash Hollow member, among which *Biorbia fossilia* is most diagnostic, most widespread, most numerous, and usually most easily found; and (3) a small group diagnostic of the Kimball member, including *Prolithospermum johnsoni* and *Berrichloa minima.* In addition, floral subzones permit a rough subdivision of sediments in the Ash Hollow into upper, middle, and lower zones (Fig. 5).

The fruits of the hackberry tree, *Celtis willistoni,* are widespread and in many places abundant, but are found at all stratigraphic levels of the Ogallala formation, hence are of no stratigraphic significance.

Seeds from the Valentine member.—The single diagnostic fossil seed found within sediments of the Valentine member is that of the grass *Stipidium commune,* related to the *Stipa* grasses now growing in northwestern Kansas and elsewhere on the plains. According to Elias (1942, p. 80) *Stipidium commune* "... extends also into the succeeding *Krynitzkia coroniformis* zone of the Ash Hollow formation [member of Kansas classification] but in higher horizons is replaced by *S. kansasense* and other larger species of *Stipidium.*" We have found *S. commune* in northwestern Kansas in a few localities (Fig. 4), but never in direct association with *K. coroniformis* or other species of *Stipidium,* and it is our judgment that in this region *S. commune* may be taken to be diagnostic of the Valentine member. The species undoubtedly ranges through great thicknesses of Valentine beds, but in northwestern Kansas only the upper part of the Valentine member is exposed, and that at relatively few localities.

Stipidium commune exists in the Ogallala formation as the opalized hulls of the seeds of this grass, but fortunately the characters on the hull (palea and lemma) are those most valuable for taxonomic classification. Hulls of *S. commune* are illustrated on Plate 8*a*. The length of the hull ranges from 3 to 8 mm, the diameter from 0.7 to 1.3 mm. The smallest individuals are densely tuberculate over their entire length, but most large individuals are smooth over their posterior one-third to one-half. The slender form, general size, and finely tuberculate sculpture are the characters most usable for recognition of this fossil plant. *S. commune* differs from *S. dawsense* from the Miocene Sheep Creek formation by its larger size and general tuberculation; *S. kansasense*, which succeeds *S. commune* in the lower part of the Ash Hollow member, is larger and more coarsely tuberculate.

Seeds from the Ash Hollow member.—Fifteen species of fossil seeds are here reported from Ash Hollow deposits in northwestern Kansas; most of these are illustrated on Plates 8 and 9, and the known distribution at 27 stratigraphically significant localities is shown on Figure 4; lesser collections from other localities judged to have minor stratigraphic significance are not re-

Locations	NE¼ NE¼ sec. 3, T. 12 S., R. 42 W. Wallace Co.			SE¼ sec. 11, T. 13 S., R. 42 W. Wallace Co.			Cen. W. line, NW¼ sec 35, T. 14 S., R. 42 W. Wallace Co.			NW cor. SE¼ sec. 16, T. 14 S., R. 40 W. Wallace Co.			W½ SW¼ sec. 7, T. 14 S., R. 38 W. Wallace Co.			SE¼ SE¼ sec. 20, T. 5 S., R. 36 W. Rawlins Co.			SE¼ SE¼ sec. 13, T. 3 S., R. 35 W. Rawlins Co.			Cen. W. line SW¼ sec. 4, T. 4 S., R. 34 W. Rawlins Co.			SW¼ SE¼ sec. 2, T. 3 S., R. 33 W. Rawlins Co.			SW¼ NW¼ sec. 24, T. 3 S., R. 30 W. Decatur Co.			[illegible]			[illegible]
Members	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V
Plant fossil species																																		
Prolithospermum johnsoni									●			●			●																			
Berrichloa maxima									●			●			●																			
Panicum elegans																							●											
Berrichloa glabra														●			●																	●
Berrichloa conica														●																				●
Stipidium tubus																							●											●
Celtis willistoni		●			●				●					●	●		●			●			●			●			●					●
Stipidium elongatum														●						●						●								●
Stipidium grande																													●					
Biorbia fossilia		●			●									●						●			●			●			●			●		●
Stipidium aristatum																							●									●		●
Stipidium nebraskense		●																																●
Stipidium kansasense																																		
Stipidium variegatum					●																		●			●						●		
Berrichloa amphoralis					●									●			●						●			●								
Berrichloa tuberculata					●																													
Krynitzkia auriculata		●			●																								●					
Krynitzkia coroniformis																																		●
Stipidium commune																																		
Total number of species		4			6				3			2		6	3		3			3			7			5			4			3		

FIG. 4.—Check list of fossil seeds. Occurrences in Valentine, **Ash**

ported here. Elias (1942) has reported other fossil seeds from the Ash Hollow member in Nebraska, so that the entire flora is somewhat larger than that reported by us.

By far the most widely dispersed, most numerous, and most characteristic fossil seed in the Ash Hollow member is *Biorbia fossilia;* we have treated it (as did Elias) as a fossil diagnostic of the Ash Hollow member.

Biorbia fossilia is a borrage, represented by small ovoid nutlets; these range from 2 to 3 mm in length and 1.75 to 2.5 mm in

Cen. E. line sec. 34, T. 5 S., R. 25 W. Norton Co. (New Almelo section)			NW¼ NW¼ sec. 2, T. 4 S., R. 24 W. Norton Co.			Sec. 35, T. 5 S., R. 24 W. Norton Co. (Lenora section)			Cen. W. line sec. 29, T. 2 S., R. 22 W. Norton Co. (Calvert section)			W½ sec. 30, T. 5 S., R. 22 W. Norton Co. (Edmond section)			W½ sec. 16, T. 2 S., R. 21 W. Norton Co. (Almena section)			Sec. 17, T. 5 S., R. 20 W. Phillips Co.			NW¼ NE¼ sec. 30, T. 1 S., R. 19 W. Phillips Co.			SW¼ SW¼ sec. 31, T. 1 S., R. 19 W. Phillips Co.			Cen. W. line SW¼ sec. 32, T. 1 S., R. 14 W. Smith Co.			SE¼ SE¼ sec. 2, T. 16 S., R. 33 W. Scott Co. (Scott County State lake section)			NE¼ NE¼ sec. 23, T. 12 S., R. 32 W. Logan Co.			SE¼ sec. 16, T. 11 S., R. 25 W. Trego Co.			Cen. N. line SW¼ sec. 7, T. 8 S., R. 26 W. Sheridan Co.		
V[1]	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K	V	AH	K
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	3			3			4		1	6		1	5		1	7		1				5			5			7			3			2			5			5	

[1] Kimball members are indicated by symbols V, AH, and K.

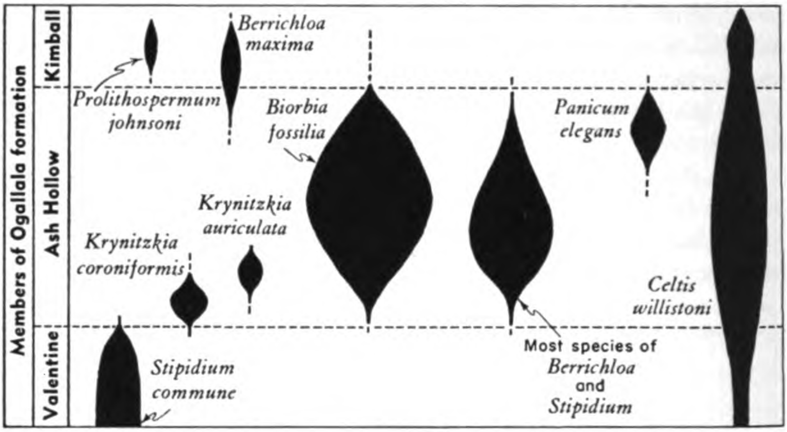

FIG. 5.—Diagrammatic representation of stratigraphic range of fossil plants in the Ogallala formation of Kansas.

diameter (Pl. 9*o*). The nutlet is asymmetrically compressed, the dorsal side being more convex than the ventral. There is a keel over the cuspidate apex or tip of the seed to the scar of attachment, where the keel assumes a lateral position to one side of the scar. The scar of attachment is round and elevated, consisting of two raised rings, one inside the other. The rims, especially that of the inner ring, are dentate or slightly fluted. The surface of most seeds is rugose, the sculpture being formed of an irregular pattern of winding elevated ridges, which coalesce here and there to form a sort of honeycombed or reticulate pattern. Many seeds, presumably of the same species, are quite smooth and some of these have a polished appearance. The ratio of rugose to smooth forms differs widely from place to place. At some exposures of Ash Hollow rocks only rugose forms are found, even in large collections comprising several hundred individuals; at other localities, not obviously different lithologically or otherwise, a few smooth seeds may be found interspersed among rugose seeds to the extent of ten percent or even more. At a few localities smooth seeds have been found exclusively. Whether this situation represents the occurrence of a mutation that produced smooth seeds in various proportions according to the genetic constitution of the local population, or whether the smooth seeds represent another species of *Biorbia* has not been determined.

Elias (1942, pl. 17) divided the Ash Hollow member into three floral subzones; we have found these subzones generally valid and have utilized local floras of fossil seeds in conjunction with other types of data, including assemblages of fossil mollusks and the distinctive properties of volcanic ash falls, to determine the approximate placement of sediments in the lower, middle, or upper part of the Ash Hollow member.

Characteristic seeds from the lower third of the Ash Hollow member, which Elias (1942, pl. 17) referred to as the *Krynitzkia coroniformis* subzone, include the tiny nutlets of *K. coroniformis* (Pl. 9*n*), *Stipidium kansasense,* and *K. auriculata;* others less characteristic of the lower strata of the Ash Hollow member, include *Berrichloa conica, B. amphoralis, Stipidium variegatum,* and *S. elongatum. Stipidium aristatum* probably belongs at the top of the lower zone of the Ash Hollow member. There is no question of *Krynitzkia coroniformis* and *K. auriculatum* being diagnostic of the lower third of the Ash Hollow; other species associated with these, including *Biorbia fossilia,* which is not numerous at this level, are not diagnostic. *S. kansasense* probably is nearly as diagnostic of this lower seed zone as the two species of *Krynitzkia,* but its usefulness is less because it is less widely dispersed.

The middle third of the Ash Hollow member is characterized by large populations of *Biorbia fossilia,* which reach their peak here after feeble beginnings in the lower Ash Hollow; populations of *B. fossilia* decline above the middle of the Ash Hollow member, and are virtually absent in the Kimball member. Other seeds associated with *B. fossilia* in middle Ash Hollow rocks include *Stipidium grande, S. nebraskense, S. elongatum, S. intermedium, Berrichloa conica, B. tuberculata,* and locally *B. amphoralis.* These associated seeds are typically present in middle Ash Hollow rocks, but cannot be said to be diagnostic of this portion of the member, because all occur less commonly at other stratigraphic positions within the member. An additional characteristic of the floral assemblages present in the middle portion of the Ash Hollow member is the complete absence here of *Krynitzkia coroniformis* and *K. auriculata,* which are restricted to the lower part of the Ash Hollow, and the absence or rare occurrence of *Panicum elegans* and *Stipidium tubus,* which are characteristic of the upper third of the Ash Hollow.

The upper part of the Ash Hollow member is characterized by *Panicum elegans, Stipidium tubus,* and *Berrichloa maxima*

(*Panicum elegans* subzone of Elias), although it is our observation that *B. maxima* is almost restricted to sediments of the Kimball member.

Seeds from the Kimball member.—The fossil seed flora in deposits of the Kimball member is sparse; we have found *Prolithospermum johnsoni* to be restricted to this member, although it is not numerous in it.

The nutlets of *Prolithospermum johnsoni* (Pl. 8*h*) superficially resemble in size and shape those of the smooth variety of *Biorbia fossilia,* but differ from them in several important details. The ventral keel of the nutlet of *P. johnsoni* extends over the cuspidate apex as does that of *Biorbia fossilia,* but whereas the keel on the seed of *B. fossilia* extends completely to the scar of attachment, that on the seed of *P. johnsoni* dwindles in size as it approaches the scar of attachment, and disappears well in front of the scar. The scar of attachment on the seed of *P. johnsoni* is relatively much larger than that on the seed of *B. fossilia,* the rim rises higher, and the scar is buttressed anteriorly by a swelling or ridge that extends toward the apex. This ridge is lacking on the nutlets of *B. fossilia. P. johnsoni* can be distinguished easily from the rugose nutlets of *B. fossilia,* but can be confused with the smooth variety of the seeds of *B. fossilia* unless strict attention is paid to the details mentioned.

Berrichloa maxima, which is known to occur also in the uppermost part of the Ash Hollow member, is a common associate of *P. johnsoni*. Elias (1942, p. 97) reports *Berrichloa minuta* in association with *P. johnsoni* and *Berrichloa maxima* at a locality 4 miles south of Sharon Springs, Wallace County. We failed to find *B. minuta* at these exposures; the "small variety of *Biorbia*" that Elias mentions as another associate of *P. johnsoni* at this locality is likewise missing from our collections.

The sparseness of the flora in deposits of the Kimball member may be due in part to local unfavorable ecological conditions prevalent at the time of deposition of these sediments, but we judge that another, equally tenable explanation may be found. The heavy accumulations of caliche, common in the upper portions of the Kimball member, may render the seeds more difficult to find, or the seeds may have been destroyed in the processes that produced the accumulations of caliche, or both.

In summary, it must be emphasized that for the field stratigrapher interested in local and regional correlations, fossil seeds are the most useful stratigraphically of all the kinds of organic remains found in the Ogallala sediments. Furthermore, distinctive floral assemblages are known as far down the geologic column as the Harrison formation of Miocene age, so that stratigraphic framing of the Ogallala sediments is possible in regions where older Cenozoic strata exist. A thorough knowledge of fossil seeds and an awareness of the distinctive qualities of the several ash falls in Neogene strata in the western plains region are necessities for anyone who pursues detailed stratigraphic studies in this part of the geologic column.

Stratigraphy

The Ogallala of northern Kansas meets all the stated requirements of a formation (Ashley and others, 1933). Although it contains a wide range of lithologic types, it is essentially a continuous blanket of alluvium that may be regarded as "homogeneous in its heterogeneity"; it is considered a conformable sequence, as the multitude of minor diastems it contains are typical of this environment of sedimentation; it is marked at the base by a profound unconformity easily recognizable in the field, and at the top by a distinctive bed and an unconformity; in age it is entirely within the late Tertiary Neogene (Miocene-Pliocene); and it is readily mappable on conventional scales. The subdivision of the formation, however, is not so clear-cut. As is true in any alluvial complex, continuous "marker beds" do not exist and the establishment of rock units that can be defined entirely on the basis of their lithology and that can be mapped by conventional field methods has not been possible.

At the type localities (in Nebraska) of the units with which we are concerned, relatively minor attention has been given to the problem of lithologic definition. In fact, the members of the Ogallala formation in the central Great Plains region are time-stratigraphic units that possess average lithologic characters that are sufficiently distinctive to distinguish them one from another in a general way, but which are not adequate to permit a sharp delineation of members in any particular section. The members become meaningful when we consider them to possess approximate age equivalence from place to place. It is in this sense that the members will be used in the following descriptions.

Thickness also is not a constant factor in the Ogallala, particularly in the lower and thicker two of the three members. Deposition of the Valentine member was confined entirely to erosional valleys, and most of the Ash Hollow member also was restricted by bedrock divides. Therefore, the great bulk of the formation (all except the relatively thin Kimball member) was controlled in its rate of deposition by particular factors that obtained in individual valley sources. The uppermost part of the Ash Hollow member and the Kimball member transgressed many, if not all, of the former divides of this region to form an essentially continuous plain of alluviation, and these parts of the formation present a much greater degree of consistency of thickness. This range in thickness is strikingly shown on Plate 1, where it is noted that the interval from the top of the Ash Hollow member down to the top of the Rawlins volcanic ash bed ranges from 50 feet in Wallace County to 175 feet in the type section of the member in western Nebraska.

As the deposition of at least the lower two-thirds of the Ogallala in northern Kansas was controlled by pre-existing valleys cut in Cretaceous rocks it is important to have at least a general knowledge of these earlier valley patterns. This is available primarily from subsurface data that have been presented in the form of a contour map by Merriam and Frye (1954). As the control, although fairly evenly distributed, is sparse, the picture available is of necessity generalized. A few conclusions are unmistakable from an examination of these data.

The general trend of the bedrock valleys is easterly. Major buried divides extend in an easterly direction from southern Wallace County and from southern Sherman County. The divide in southern Sherman County was of regional importance, standing more than 200 feet above major valley floors both north and south of it; it extended in a sinuous line toward the east, the crest passing through northeastern Logan County and northern Gove County; and it may have bifurcated, one branch extending into northern Thomas County. This divide clearly separated the depositional province in the northern two tiers of Kansas counties from the area to the south, during the deposition of all the Valentine and much of the Ash Hollow. Much, if not all, of the area of Kansas

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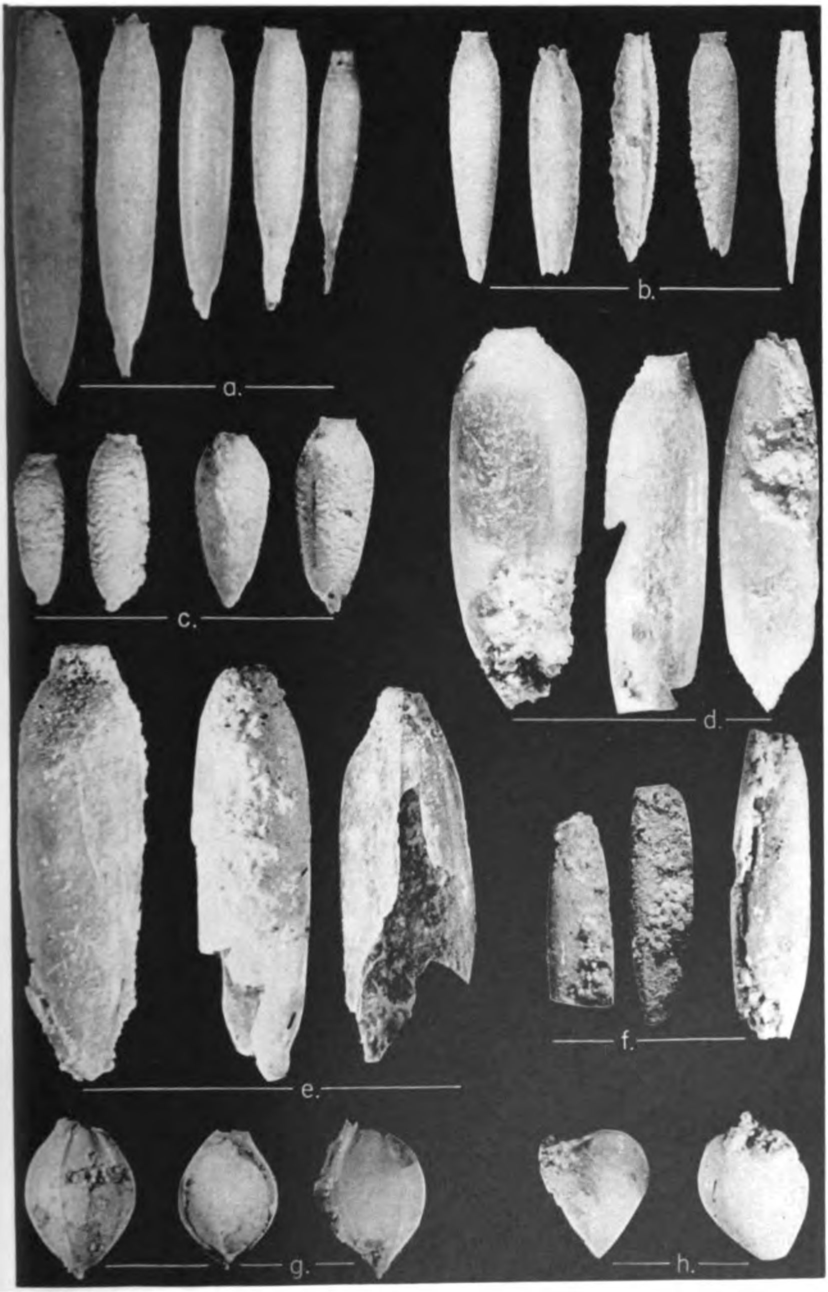
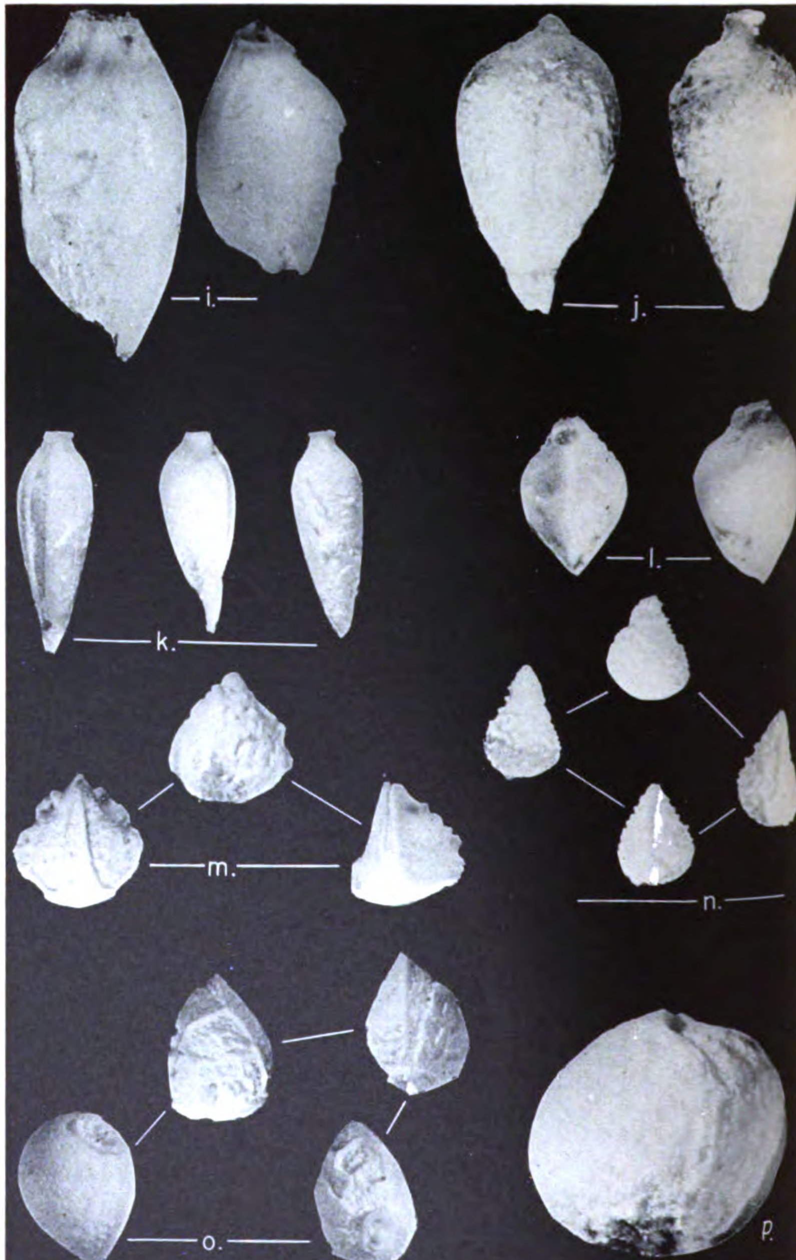
PLATE 8. Fossil seeds from Ogallala formation. *a. Stipidium commune* Elias *b. Stipidium elongatum* Elias *c. Stipidium variegatum* Elias *d. Stipidium grande* Elias *e. Stipidium nebraskense* Elias *f. Stipidium aristatum* (Berry) Elias *g. Panicum elegans* Elias *h. Prolithospermum johnsoni* Elias. All figures × 6.



Frye, Leonard, and Swineford — Fossil seeds from the Ogallala



Frye, Leonard, and Swineford — Fossil seeds from the Ogallala north of this divide was part of an integrated drainage pattern—but this valley system may have been isolated from the area of the Ash Hollow type locality farther north by an as yet unknown divide or divides in southern Nebraska. The pre-Ogallala topography in southern Logan and Gove Counties is not known because of the present wide erosional valley of Smoky Hill River; this area may have been part of a broad upland divide area on the Cretaceous surface. A minor bedrock valley extended eastward from southeastern Wallace County across the northern parts of Wichita, Scott, and Lane Counties. South of this minor valley, another bedrock divide served to isolate the region of southwestern Kansas as a depositional province until it was overlapped by upper Ash Hollow or perhaps Kimball sediments. As this study is concerned with northern Kansas, stratigraphy of deposits south of the province represented by this minor bedrock valley across northern Wichita, Scott, and Lane Counties will not be described.

It has been suggested that the Ogallala represents a series of coalescent alluvial fans of vast extent, sweeping outward from the Rocky Mountains. Such a hypothesis cannot be accepted, as it would imply progressive eastward stratigraphic overlap with little regard to the pre-existing topography. All available evidence runs counter to such an interpretation. Although some slight eastward overlap may exist near the eastern margin of the formation, the Ogallala is in the main composed of a series of valley fillings, overlapping laterally from the axes of the major drainageways onto the gentle erosional slopes of the valley sides. Sedimentation eventually culminated in the complete overlap of most if not all of these divides and the final development of a coalescent alluvial plain.

The tectonic events that controlled the late Tertiary history of the central Great Plains are not fully understood. Northern Kansas was probably subject to subaerial erosion from the beginning of Tertiary time until the beginning of Ogallala deposition, and erosion of the gently sloping Cretaceous divide areas must have continued during all but the latest stages of Ogallala

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PLATE 9. Fossil seeds from Ogallala formation. *i. Berrichloa maxima* Elias *j. **Berrichloa tuberculata*** Elias *k. Berrichloa conica* Elias *l. Berrichloa amphoralis* Elias *m. **Krynitzkia auriculata*** Elias *n. Krynitzkia coroniformis* Elias *o. **Biorbia fossilia*** (Berry) Elias *p. Celtis willistoni* (Cockerell) Berry. All figures × 6.

deposition. Stream-laid sediments started to accumulate much earlier to the north in Nebraska, where a thick sequence of Oligocene and Miocene underlies the Ogallala (Lugn, 1939), and in the regional view it could be argued that there is a general overlap from northwestern Nebraska southward to the divide north of Arkansas River in western Kansas. There is, in general, a thinning of the several units southward across this region. This suggests either a differential downwarping of the Plains or a differential upwarping of the source areas to the west.

It is certain that erosion in the Rocky Mountains was coincident with Ogallala deposition in northern Kansas. The relief in the mountains, however, must have been more subdued than it was during at least some intervals of the Pleistocene, as the texture of the sediments reaching Kansas was in general finer. Furthermore, the change in texture through the Ogallala does not indicate a strong uplift followed by stability. Such a structural history should produce coarse materials in the base of the formation, overlain by progressively finer sediments upward, whereas the actual progression is from finer in the Valentine to coarser in the Ash Hollow and basal Kimball (Sidney) to much finer in the middle and upper Kimball. This sequence may indicate that during late Tertiary time there were differential structural movements of small magnitude at different times.

One item of Rocky Mountain history seems clearly inferable from plains stratigraphy; by the end of Ogallala deposition there was a period of relative stability with subdued relief in the mountains, and the streams were transporting eastward only fine sediments. It is judged that the major erosion surface of the Rocky Mountains (Atwood and Atwood, 1948) was continuous with the surface of alluviation at the top of the Ogallala. The character of the sediments and particularly the extensive accumulation of calcium carbonate at and below the surface of this alluvial plain indicate that relative stability continued for a significant period of time. This stability was interrupted at the approximate beginning of Pleistocene time by an episode of erosion throughout the plains (Elias, 1948; Frye, 1948) and at least part of the mountains, which is judged to have been produced by structural movements that also produced arching of the Ogallala (Smith, 1940) in northwestern Kansas. The earliest post-Ogallala sediments of the central Great Plains are coarser than those of the upper Ogallala, and Pleistocene materials subsequently transported eastward from the Rocky Mountains to western Kansas are considerably coarser than any of the Ogallala materials. Thus it is judged that the relief of the mountains and also the eastward gradients of the transporting streams were greater during the Pleistocene than during the deposition of the Ogallala; that the topography across the entire region in late Pliocene (Kimball) time was relatively well adjusted, and that minor uplifts occurred in the Front Range during the time of deposition of Ash Hollow and earliest Kimball (Sidney) sediments.

The details of the stratigraphy of the Valentine, Ash Hollow, and Kimball members in northern Kansas will be described with a minimum of reference to specific localities. For specific locality data the reader is referred to the 31 measured sections from 16 counties in northwestern Kansas included with this report and to previously published measured sections in several counties in this part of the state (Frye, 1945; Elias, 1931; Frye and Leonard, 1949; Frye and Swineford, 1946; Prescott, 1953).

Valentine Member

The Valentine member is not well exposed in northern Kansas and it is concluded that age equivalents of little more than the upper half of the type Valentine section of Cherry County, Nebraska, are exposed in this part of Kansas. Correlation of the Valentine in Kansas with the type section is based on somewhat altered, partly indurated lentils of volcanic ash in the type section, which are judged to be equivalent to the Calvert volcanic ash bed of northern Kansas, and on abundant fossil plant material, with some supplemental evidence from fossil vertebrates and mollusks. Although exposures of rocks correlated with the Valentine member were studied in Phillips, Rawlins, Rooks, Graham, Ellis, Trego, Ness, and Scott Counties, most of our knowledge of the Valentine member was obtained from exposures in Norton County. Here these beds are best exposed along the south side of Prairie Dog Creek valley northeast of Norton and along the south side of North Fork Solomon River, from Lenora eastward to Logan.

These Valentine exposures lie in at least two completely separated depositional provinces. The localities in northern Scott and Ness Counties and extreme southern Trego County are in the minor bedrock valley that extends eastward from southern Wallace County, and the member is thin in this province. In many places it strongly reflects a local source and is characterized by bentonitic clays (e.g., measured section, Scott County), silts, and opaline-cemented Cretaceous chalk rubble (e.g., measured section, Ness County). Scarcity of fossil plant material and the absence of the Calvert volcanic ash bed and of fossil mollusks makes the establishment of even a thin Valentine section doubtful in most of this area; the stratigraphic relations of the overlying Ash Hollow member, however, provide a basis for the conclusion that the volume of the Valentine member in this province is small and that its lithology is not typical of the more extensive deposits of Valentine farther north in the state.

For an understanding of the Valentine member we turn to eastern Norton County and to subsurface data farther west. Eastern Norton County provides more data for drawing a distinction between the Valentine and Ash Hollow members than any other area in Kansas. As has been pointed out, such a distinction is, of necessity, arbitrary. In this area the Calvert ash bed (correlated with altered volcanic ash in the upper part of the type Valentine) and the Rawlins ash bed (correlated with an ash bed that occurs about three-fifths of the distance down from the top of the type Ash Hollow) occur in close proximity and in close stratigraphic association with fossil plant material and fossil snails. It seems clear that the boundary separating the two members must be drawn arbitrarily between the stratigraphic positions of these two ash beds and somewhat closer to the Calvert than to the Rawlins. This line is shown on correlated section A-A′ of Plate 1.

In this area fossil snail faunas and assemblages of fossil plants have been collected short distances above and below this arbitrary boundary. A fossil molluscan fauna with close affinities to the Laverne assemblage of fossil mollusks (Leonard and Franzen, 1944) occurs near the base of the Almena section (Pl. 1; Fig. 3) in soft, diatomaceous limestone in stratigraphic proximity to the fossil grass, *Stipidium commune*, diagnostic of the Valentine member. The molluscan fauna includes *Lymnaea lavernensis, Helisoma valens, H. goodrichi, Calipyrgula hibbardi,* and *C. senta,* which are species that occupy a prominent place in the molluscan populations of the Laverne fauna. In the Ogallala formation these molluscan species are unknown in Ash Hollow deposits, or occur in the lowermost part of this member (Fig. 3, Almena section, V and

AH). *Krynitzkia coroniformis,* a fossil seed diagnostic of the lowermost Ash Hollow, invariably occurs stratigraphically above zones that yield *S. commune* (Pl. 1; Fig. 4. Compare stratigraphic occurrence of *S. commune* and *K. cororniformis,* as shown on Fig. 4). Although it has been necessary at some localities to draw the line between the Valentine and Ash Hollow members arbitrarily, this has been necessitated, not by lack of suitable criteria *per se,* but only because of the failure to find at precise stratigraphic levels in a particular outcrop the evidence that would permit application of the criteria.

Some generalities about the character of the Valentine can be drawn from these exposures in Prairie Dog Creek and North Fork Solomon River valleys, augmented by subsurface data farther west. The member probably attains a thickness in excess of 100 feet in central Sherman County, northern Thomas County, northwestern Sheridan County, eastern Decatur County, and northwestern Norton County. In southern Norton County it is probably not more than 75 feet thick, and it thins eastward to approximately 30 feet in the exposures south of Edmond. The Valentine member is composed preponderantly of fine to medium, relatively well sorted, gray to greenish-gray feldspathic sand, containing disseminated calcium carbonate and tubules and irregular concretions of opal. Greenish-gray, olive-drab, and gray silts containing irregular nodules and streaks of calcium carbonate are common; greenish-gray to drab bentonitic clays are fairly common in northwestern Phillips County, are exposed at a few places in Norton County, and have been penetrated in test drilling in Thomas County and a few other places. Coarse feldspathic gravels are rare but at many of the places where they do occur in the member they are cemented in groups of large, lenticular masses by green opal (e.g., southeastern Norton County and southern Phillips County; Frye and Swineford, 1946), and because of their hardness have an exaggerated prominence in the outcrops. At a few places pebbles of Cretaceous chalk are prominent lithologic constituents, and soft limestone or marl lentils (e. g., Almena section) are known. Tints of red brown, so common in the overlying Ash Hollow member, are rare in the Valentine member.

Although the Valentine member is in the main quite different lithologically from the other members of the Ogallala, the upward change is transitional rather than abrupt. It is judged that deposition was relatively slow and took place at a fairly uniform rate and that the water table remained near the surface during the period of deposition. This latter condition is indicated primarily by the ferrous state of the iron, which imparts the greenish and olive-drab tints to the sediments, by the greater abundance of branchiate snails, by relative rarity of fossil *Celtis willistoni,* and by local alteration of volcanic glass to montmorillonite.

Because of the scarcity of adequate exposures, it has not been practicable to obtain detailed knowledge of the internal stratigraphy of the Valentine to the degree possible for the other two members. On the basis of all available data, however, we judge that the oldest Valentine beds in northern Kansas are not as old as the basal part of the type Valentine section in Cherry County, Nebraska.

Ash Hollow Member

Almost all of the Ogallala exposures observed in northern Kansas fall within the stratigraphic span of the Ash Hollow member. Unlike the Valentine member, which is restricted to bedrock valley areas, the Ash Hollow, at least its upper part, was originally deposited over most if not all of this region. The relatively thin overlying Kimball member has been removed by post-Ogallala erosion from much of northern Kansas. The early workers therefore referred particularly to the Ash Hollow as the "Mortar beds" and "Tertiary grit". Furthermore, this member displays a greater degree of uniformity across the region than does the Valentine, although it too is composed of contrasting lithologic types. Correlation within the member has been facilitated by a concentration of volcanic ash falls in its lower half and a profusion of fossil plant remains throughout.

As has been pointed out, definition of members of the Ogallala in northern Kansas is in part arbitrary. In the exposures in eastern Norton County the Valentine-Ash Hollow boundary is defined for our purposes as falling between the positions of the Calvert and Rawlins volcanic ash beds and marked by paleontological zones. The Valentine member contains the diagnostic *Stipidium commune* fossil seed zone and an assemblage of distinctive fossil mollusks; the basal Ash Hollow deposits are characterized by the *Krynitzkia coroniformis* fossil seed zone and by molluscan assemblages that lack such characteristic Valentine species as *Calipyrgula hibbardi*, *C. senta*, *Helisoma goodrichi*, and *Lymnaea* *lavernensis*. In general, molluscan faunal zones are slightly less well defined than fossil seed zones at the Valentine-Ash Hollow boundary, but are sufficiently characteristic to permit positive identification if a suitable assemblage of fossils is available. We feel certain that the genus *Calipyrgula* does not persist above the Valentine, but this does not necessarily mean that collections can be made in uppermost Valentine exposures; similarly, *K. coroniformis* is the first diagnostic seed to appear in Ash Hollow sediments in this area, but there is no assurance that fossiliferous beds bearing this seed will be found in lowermost Ash Hollow deposits at any particular locality. For this reason, at many places the Valentine-Ash Hollow boundary must be drawn arbitrarily somewhere between the noncontiguous fossiliferous zones or on the basis of the position of the Calvert and Rawlins volcanic ash beds.

Although the Ash Hollow member of northern Kansas is correlated with the type section in Nebraska by the Rawlins ash bed, it probably does not include all of the span of the type section (Pl. 1). The lowermost beds at the type Ash Hollow section may be equivalent in age to the uppermost beds of the type Valentine. It is our judgment that the Ash Hollow member of northern Kansas includes age equivalents of all but the basal one-fifth of the type section.

The upper limit of the Ash Hollow member locally coincides with a distinct lithologic change to coarse gravel. In Kansas usage, the Sidney gravels are classed as the basal unit of the Kimball, so the base of this coarse gravel, where it is present, serves to mark the boundary between the two members. This is strikingly illustrated at the type locality of the Ash Hollow in Nebraska (Pl. 1), and in northern Kansas a similar abrupt change in lithology is well displayed in measured sections in western Wallace County, central Rawlins County, northern Scott County, and elsewhere. At many places in northern Kansas, however, the Sidney gravel lentils are missing and the base of the Kimball is marked by a progressive upward decrease in grain size of the sediments and progressive increase in calcareous material. Locally (e.g., Norton County) a soft limestone or marl forms the base of the overlying Kimball member. Distinctive volcanic ash lentils have not been described from this part of the section and therefore in the areas where a lithologic basis cannot be used for distinguishing the top of the member we must turn to a paleontologic definition.

The top of the Ash Hollow member is marked by the decline and disappearance of *Biorbia fossilia*, the occurrence of such seeds as *Stipidium tubus*, *Berrichloa maxima*, and *Panicum elegans*, and the absence of *Prolithospermum johnsoni* and *Berrichloa minuta*, which are restricted to the overlying Kimball sediments. Uppermost Ash Hollow deposits are characterized by the last occurrences of fossil mollusks characteristic of the Laverne fauna; fossil molluscan assemblages in the Kimball contain only far-ranging molluscan species of little stratigraphic significance, together with species such as *Promenetus blancoensis* and *Lymnaea macella*, characteristic of earliest Pleistocene molluscan faunas. In the uppermost fossiliferous limestone (base of Kimball member) at the Almena section the molluscan fauna (Fig. 3) contains a gastropod that is probably *Gyraulus enaulus*, another characteristic early Pleistocene species, but identification from plastic casts is not conclusive. Again, the actual boundary between the Ash Hollow and Kimball members must be drawn arbitrarily at many places, not because suitable criteria are lacking, but because the material evidence may be lacking at precisely desired levels.

It is generally true that in this region of Kansas the Kimball member is commonly 35 to 45 feet thick, so where the "Algal limestone" is present the top of the Ash Hollow member may be located approximately by vertical measurement.

The local thickness of the Ash Hollow member ranges between wide limits, partly because of its overlap onto Cretaceous rocks. Where the full stratigraphic span of the member is present, however, there is a general thickening northward from west-central Kansas to west-central Nebraska. An average thickness for the member in Wallace County is approximately 75 feet, whereas in Norton County, near the Nebraska state line, it is at least 130 feet, and in the North Platte valley in Nebraska the Ash Hollow ranges to 200 feet in thickness.

The lower part of the Ash Hollow is restricted to the same major bedrock valleys that controlled the deposition of the Valentine member, but as alluviation progressively overlapped the valley sides, this member occupies a progressively larger area (Pl. 1; Fig. 2). The upper part of the member transgressed most, if not all, former divides and formed a virtually continuous coalescent sheet of alluvial material throughout northwestern Kansas and southwestern Nebraska.

The fact that the lower part of the member was restricted to pre-existing valleys indicates that the trend of the depositing streams continued to be generally eastward. The presence of thin Kimball deposits resting directly on Cretaceous Greenhorn limestone uplands in central Kansas is evidence that Ash Hollow deposits did not form a general alluvial plain eastward from Smith, Osborne, and Russell Counties, but were here restricted to valleys. It is judged, however, that some Ash Hollow sediments were deposited in the bedrock valleys some distance eastward from the area of general distribution, because of the presence of local remnants of this member in northeastern McPherson County. Here, Ash Hollow beds constitute the lower part of the unit formerly called "Delmore formation" (Williams and Lohman, 1949; Hibbard, 1952), which is the easternmost known occurrence of the Ogallala formation in Kansas. Although even here much of the sediment indicates a Rocky Mountain source, a sizable part of the clastic materials included in the Ogallala of McPherson County was probably derived from the Cretaceous rocks of central Kansas.

The McPherson County deposits probably indicate the easternmost extent of eastward-trending Ogallala drainage; they may have accumulated in a major southward-trending valley that was in general aligned with the strike of the Permian bedrock and located on the belt of shales at the western limit of the long gentle dip-slopes from the crest of the Flint Hills. The fact that streams originating farther west did not cross the Flint Hills in Ogallala time is demonstrated by the nature of the deposits within the Flint Hills and farther east in the Osage Cuesta Plains (Frye and Leonard, 1952; Frye, 1955). Late Tertiary deposits in this region consist entirely of materials typical of the bedrock east of the McPherson County localities, and contrast strongly in lithology with the Ogallala to the west. Therefore, the eastward-trending Ogallala streams must have joined a major stream flowing southward out of the region and toward Oklahoma. Although present evidence is not conclusive, it indicates that relatively short tributaries to this major south-flowing Ogallala drainageway joined it from the east, down the dip-slope of the Permian cherty limestones of the Flint Hills. The term Ogallala has not been applied to the Tertiary chert gravels of the Flint Hills region—even though some of them are probably of the same age as the Ogallala—primarily because lithologically these chert gravels contrast strongly with typical Ogallala and because they represent a distinct and independent depositional province.

Fine to coarse feldspathic sand is the predominant clastic constituent of the Ash Hollow member. Although gravel and silt predominate locally in some zones, and a small percentage of silt is commonly present in the sand zones, their combined volume is only a fraction of the bulk of the sand. Clay is present in very small amount, but volcanic ash is estimated to constitute more than five percent of the lower half of the member. The coarse sand and gravel that forms the conspicuous ledges so characteristic of this member generally contains a large percentage of granitic materials. In the Valentine member there are local gravel beds derived from a nearby bedrock source, but such beds are relatively rare in the Ash Hollow. Sediments of the Ash Hollow have a greater degree of uniformity of source, and therefore of general lithology, than those of the Valentine.

As shown by the measured sections and Plate 1, there is little if any regular gradation of texture through the member—gravel and silt are known to occur locally at any stratigraphic position. A progressive change in color, however, seems clear. The underlying Valentine member is predominantly gray or greenish gray, and shades of pink and pinkish drab become prominent about at the arbitrary boundary between the two members. The color transition continues through the lower one-third to one-half of the Ash Hollow member, hues of red becoming more prominent upward except where they are masked by a large percentage of calcium carbonate cement. In the upper half of the member, shades of green are absent, and where the color is not masked by the gray of the cement, shades of red and tan are everywhere present. Locally the reddish zones have the appearance of the B horizons of a surface soil (e.g., beds 8 and 9 of Scott County State Lake section), but at many places where such an origin cannot clearly be demonstrated the color may be due to weathering in the zone of aeration above the water table.

Much of the contrast in appearance between the Ash Hollow and Valentine members may be caused by a lowering of the water table and resultant different effect of surface weathering during the relatively slow deposition of the Ash Hollow member. The generally poorer sorting and lack of cross bedding in the Ash Hollow materials suggest rapid but intermittent sedimentation, with little opportunity for reworking, each deposit remaining for relatively long periods in a near-surface position thus allowing some mixing by surface processes. The general lack of any apparent bedding in zones many feet thick suggests some alteration of the sediments before they were deeply buried. The form of some of the calcium carbonate cemented zones (Pl. 2B, 3A) is strongly suggestive of soil caliche accumulation. As some of these "caliche" zones are separated by only a few feet of noncalcareous silty sand, it is judged that, locally, increments of sedimentation 6 feet thick or thicker accumulated rapidly and were preceded and followed by periods of surface stability sufficiently long to permit the development of deep, mature lime-accumulating soils containing caliche zones several feet thick. This type of calcareous material was used as a natural mortar for sod houses by the earliest settlers of the region; this use led to the early application of the term "Mortar beds" to the Ogallala formation.

This mode of origin cannot be called upon to account for all the calcareous cement and carbonate rock of the Ash Hollow. There are at least two other general classes of calcareous beds in the member, namely, fresh-water limestones or marls, and sands and gravels cemented by the action of groundwater, in addition to nodules and tubules scattered throughout.

Fresh-water limestones are quantitatively rare and have been studied most in Norton County. Their abundant contained diatoms and locally abundant fossil snails or snail molds leave little doubt that they accumulated in relatively shallow ponds of quiet water. In some places they contain a significant quantity of volcanic ash shards and an open network of opal.

Lenticular bodies of sand and gravel, many of them crossbedded, hence judged to be stream-channel deposits (Pl. 3B, C), have been observed at virtually all stratigraphic positions in the member. They are more common in the upper half of the member but are not everywhere present, even in the upper part. These lentils are generally the coarsest materials in the section. They are firmly cemented with calcium carbonate and form prominent bluffs. As they commonly lack association with reddish noncalcareous B horizons, they are interpreted as being the result of cementation below water-table, although the calcium carbonate may have been concentrated as a result of surface conditions.

A prominent constituent of the cement in the Ash Hollow, although less important quantitatively than the calcium carbonate, is opal. The silica may have been derived from volcanic ash lentils, from weathering of feldspathic sand, or locally from accumulations of diatoms. It is widely distributed through the cemented zones of the member as open "sponge-work" and as minute tubules. Some of the unusual weathering effects in Ogallala rocks may have been influenced by this small increment of opal cement.

The internal stratigraphy of the member is relatively simple and nondescript. In natural exposures the caliche and cemented zones simulate bedding, but such false beds are not traceable for more than a few hundred yards at most. Stratigraphic placement within the member cannot be made on the basis of general lithology alone, and stratigraphic sequence can be used for this purpose only at localities where there is exposed an exceptionally thick series of deposits. Molluscan faunas are known from several stratigraphic positions within the member, but their geographic distribution is not adequate to permit their general use for local detailed work. In study of the internal stratigraphy of the Ash Hollow, five distinctive named volcanic ash falls and abundant fossil plant material have been the most useful features. Assemblages of fossil seeds, which allow subdivision of the Ash Hollow into lower, middle, and upper portions, are discussed in detail elsewhere in this report (see also, Fig. 3, 5).

Kimball Member

The Kimball member is the uppermost and thinnest of the three subdivisions of the Ogallala formation. Isolated remnants of the uppermost beds of the member (particularly the "Algal limestone") on the Cretaceous uplands of Russell, Lincoln, Osborne, Mitchell, Jewell, and Cloud Counties give this member by far the most widespread geographic distribution, but complete sections of Kimball member resting on Ash Hollow beds and capped by "Algal limestone" are exposed in only a few counties. The member is known primarily from its exposures in the south valley wall of Smoky Hill River valley in Wallace County and eastward (note measured sections), and in Sherman, Cheyenne, and Rawlins Counties. Elsewhere in northern Kansas a full span of Kimball is present locally (e.g., measured section, Logan County; northwest of Brewster, Thomas County; southwest of

Lenora, Norton County), but the member is generally absent or represented by its lower part only (e.g., Almena section, Norton County).

Although the distribution of the member is now greatly reduced, it is judged that the Kimball was deposited over a larger area than any other part of the Ogallala formation. Its original extent is reconstructed from scattered erosional remnants of the member; some rest on Ash Hollow deposits, but more consist of "Algal limestone" resting on a sequence of a few feet of predominantly local silt, sand, and gravel, which in turn rests on Cretaceous rocks. Remnants of the Kimball member are known to occur in 31 counties in the northern half of Kansas, and have been observed in every county westward from Jewell, Osborne, Lincoln, and Ellsworth. The Kimball was the culmination of Ogallala alluviation, and overlapped most if not all of the former bedrock divides. Its surface extended as a vast coalescent plain of regional alluviation. During Kimball deposition the former bedrock valleys were no longer effective in controlling the position or direction of flow of major streams, which became free to shift in response to load, volume, and gradient. Such an environment eliminated formerly important local factors of control and thus the Kimball has a greater degree of uniformity, both in lithology and thickness, than the lower members throughout its extent from west-central Nebraska to west-central Kansas.

The stratigraphic span of the Kimball is more distinct and more easily determined than that of either of the other two members. Its top is the stratigraphic top of the formation, marked at many places by the "Algal limestone", and where lentils of Sidney gravel are present the base of the member can be drawn at the base of the gravels. The base of the member can be drawn fairly closely on the basis of plant fossils and fossil molluscan assemblages. The occurrence of the fossil plants *Prolithospermum johnsoni*, *Berrichloa minuta*, and *B. maxima* in the same assemblage is an accurate guide to the Kimball member. Fossil molluscan assemblages that contain *Promenetus blancoensis* and *Lymnaea macella*, but lack such species as *Helisoma valens*, *H. goodrichi*, *Pseudosuccinea columella*, and of course all characteristic Valentine species, characterize Kimball deposits. Molluscan faunal assemblages and fossil seed floras are as well defined across the Ash Hollow-Kimball boundary as they are across the Valentine-Ash Hollow boundary.

The Kimball member in northern Kansas, where a full section is present resting on Ash Hollow beds, has an average thickness of about 30 feet, but the measured sections included here show a range from 44 feet (Cheyenne County) to less than 25 feet (Ellis and Wallace Counties). In the belt of Greenhorn limestone (Cretaceous) outcrop in north-central Kansas, as little as 2½ feet of Kimball, including the "Algal limestone" at the top, rests directly on bedrock.

Except for the basal Sidney gravel lentils, the Kimball member is predominantly fine textured and richly calcareous. Feldspathic medium to fine sands and silts predominate. In zones where the calcium carbonate content is low, these beds are reddish tan to red brown, but the calcareous material commonly masks the hues of red, giving the entire member an ash-gray color. The calcium carbonate content of the member commonly increases upward, the upper one-half to one-third of the member consisting of impure, relatively soft limestone locally capped by the "Algal limestone" bed. In many exposures this upper silty, sandy limestone shows a platy structure in the upper part, grading downward through a somewhat massive zone into a prismatic to nodular zone 8 to 10 feet below the top. This downward gradation of structure is well illustrated in the exposures south of Dighton, Lane County, shown in Plate 2A.

Opaline chert is characteristically associated with the Kimball member, but has an erratic geographic distribution. In northern Kansas it has its maximum development in the Kimball in the exposures along the south side of Little Beaver Creek, south of McDonald, Rawlins County. In this area the silicified zone is as much as 12 feet thick and extensive (Frye and Swineford, 1946). Generally, silicification of the Kimball member is less extensive and less uniform. In the measured sections in Cheyenne and Wallace Counties, silicification is restricted to thin zones of opal (including minor quantities of chert) distributed discontinuously through the member; at other localities silica is present as an open spongework throughout the deposit. Chemical analysis (Frye and Swineford, 1946) shows that even in the thick, massive Rawlins County deposit silica constitutes only slightly more than half of the rock and that calcium carbonate is an important constituent.

The opal and chert of the Kimball member are judged to be secondary replacements of the calcium carbonate, although the source of the silica is not known. Volcanic ash deposited directly upon the surface of the formation is a possible source, or silicates may have become available from the weathering of feldspathic sand and silt in the upper part of the Kimball. In contrast to the opal-cemented sands and gravels of the Valentine member, the color, type of replacement, association of clay minerals, and stratigraphic relations all suggest that the opal of the Kimball member was deposited by downward-percolating waters in the vadose zone, but derived from a source on or near the alluvial surface at the top of the formation, rather than from contained volcanic ash lentils by groundwater circulation.

The top of the Kimball member—and of the Ogallala formation—is marked at many places by the "Algal limestone" bed. As has been pointed out, the origin of this bed has been a subject of debate since it was described by Elias in 1931. It is a hard, generally fractured, irregular limestone that ranges in thickness from less than 1 foot to about 3 feet. It is marked by concentric wavy laminae and pisolitic structures generally showing an alternation of pinkish-tan and gray colors; it contains grains of quartz and feldspar and locally granitic and other igneous pebbles; its upper surface is generally pitted and uneven where exposed; and Elias (1931) has described the fossil alga *Chlorellopsis bradleyi* as occurring within it. In strong contrast to the freshwater limestones or marls that occur from the lower part of the Kimball member downward into the Valentine member, it has never yielded remains or indications of fossil mollusks or of diatoms. In some exposures it has a sharp contact at the base, but in others (Pl. 2A) it seems to be gradational with the platy impure limestones below it. The general appearance and lithology of the bed is the same where it caps a section of 250 feet of Ogallala deposits and where it is separated from Cretaceous sediments by less than 5 feet of locally derived clastic material. There is no other bed within the Cenozoic sediments of northern Kansas that even approximately resembles the "Algal limestone" in appearance.

Whatever its origin may have been, it seems undeniable that this bed is genetically related to the surface of the plain of alluviation that marked the end of Ogallala deposition in the region, and that the plain on which it formed maintained surface stability for a significant interval of time. The described presence of a fossil alga is seemingly the only line of evidence that demands formation of the bed in a body of water; whereas the general relations to the other Kimball sediments below, lack of other organic remains, encrusting relationship over the undulating Cretaceous uplands of north-central Kansas, and the secondary solution effects might be explained as phenomena produced by weathering on a relatively stable surface during a long interval of time.

In northern Kansas the post-Ogallala history includes a long interval of surface exposure of the remnants of the alluvial plain surface that is the top of the Ogallala. Throughout the region this surface marks the end of upward accumulation of alluvial deposits, and where Pleistocene materials rest upon it they are loess or locally dune sand. Stream-laid Pleistocene deposits of the region are all confined to terrace or valley flat positions and were formed after dissection of the Ogallala plain had begun. Furthermore, none of the eolian Pleistocene deposits found resting on the stratigraphic upper surface of the formation are older than Illinoian and most are of Wisconsinan age. The dissection of the Ogallala surface by major streams probably began in Nebraskan time, but large areas (e.g., Sherman County) are still virtually unmodified by erosion. Thus, the surface of the alluvial plain that marked the end of Ogallala deposition existed under conditions of erosional-depositional equilibrium for a relatively long interval of time, affected only by surficial processes of weathering.

Summary

The Ogallala formation consists of fluviatile, late Tertiary (Neogene) deposits that underlie the surface that forms the High Plains. Ranging up to 300 feet in thickness, these deposits extend from Texas to South Dakota in a broad belt several hundred miles wide. Contrary to prevalent concepts, the Ogallala was not deposited as a series of broad, overlapping fans from the source in the Front Range of the Rocky Mountains; rather, alluviation from source areas in the Rocky Mountains was controlled by relatively broad and shallow, eastward-trending erosional valleys cut in Cretaceous bedrock.

Three members are recognized in the Ogallala formation in northwestern Kansas, the region to which this report is restricted. Each of these members has been correlated with type sections in Nebraska on the basis of data derived from lithologic comparisons, petrographically distinctive volcanic ash beds, and characteristic assemblages of fossil plant remains. In addition to these sources

of comparative data, fossil molluscan faunules, previously undescribed anywhere in the Ogallala, have been utilized in correlations within northwestern Kansas. Assemblages of fossil vertebrates, although recognized as important in referring parts of the Ogallala formation in northwestern Kansas to the standard time scale, have not been utilized for correlations within the region under study, because of the localized geographical and stratigraphical occurrence of these faunas.

The Valentine member, the first to be deposited in northwestern Kansas, was confined entirely to valleys cut in Cretaceous bedrock, where it was subsequently buried by Ash Hollow and Kimball sediments. The Kansas outcrops are correlated with the type of the Valentine in Nebraska on the basis of petrographically similar volcanic ash together with other lithologic similarities, the presence within the rocks of the fossil grass seed, *Stipidium commune*, regarded as diagnostic of this segment of the Ogallala, and by the occurrence of a distinctive fossil molluscan assemblage. In general, the Valentine is composed of medium to fine, greenish to pale-tan sands, silt, and clay, bentonite, and lentils of volcanic ash, opal-cemented sand and gravel, and soft, diatomaceous marls, which in places contain external molds of gastropods. Because of its deposition in the bottom of bedrock valleys below subsequently deposited Ash Hollow and Kimball sediments, the Valentine is poorly and locally exposed. Its geographic extent in Kansas is known from subsurface data.

The Ash Hollow member overlies the Valentine, overlapping laterally the gentle slopes of bedrock valleys in which it was deposited, and in many places transgressing former divides. The Ash Hollow is lithologically heterogeneous, being composed of a disorderly assemblage of stratified and massive beds, composed of gray and pink to reddish-brown sand, silt, gravel, and clay, together with many lentils of volcanic ash and fossiliferous limestone and marl. In general this member is composed of coarser clastics than is the Valentine. The Ash Hollow is richly fossiliferous. It contains all the best-known fossil vertebrate assemblages occurring in the Ogallala of northwestern Kansas, previously referred to in this report, a series of distinctive assemblages of fossil seeds comprising three floral zones, and distinctive though local fossil molluscan faunules. Of the three members of the Ogallala formation, the Ash Hollow is the most conspicuously exposed at the surface in northwestern Kansas. This phenomenon is related to the facts that the Ash Hollow overlies the Valentine, which it generally completely covers; the overlying Kimball, which is generally thin, has been seriously attacked by, and locally completely removed by erosion; other overlying resistant beds to protect the Ash Hollow from erosion are almost completely lacking; and cementation by calcium carbonate and dispersed opal has produced many relatively resistant beds, which stand out conspicuously as bluffs or ledges wherever the Ash Hollow has been dissected.

The Kimball member, although averaging scarcely more than 20 feet in thickness, is the most widely distributed member of the Ogallala formation. At the time of its deposition, not only were the Cretaceous bedrock valleys filled, but most major divides had been transgressed by the Ash Hollow, so that the local factors that formerly controlled alluviation were no longer operative. Kimball sediments spread as a broad sheet over the underlying Ash Hollow without confinement to valleys, a distribution that tends to give a misleading impression of the volume of sediments contained within it. Locally, coarse gravel forms the base of the Kimball, but most of the sediments are gray, fine to medium sand, silt, and some clay, all heavily infiltrated with calcium carbonate, and capped by a layer of dense, nodular pinkish to grayish-pink or white limestone ranging from 6 inches to 3 feet in thickness. This limestone has been called the "Algal limestone" because of a fossil alga reported to occur within it; it is otherwise nonfossiliferous, and does not even contain diatoms, which should occur with other algae. The "Algal limestone" is an important stratigraphic marker, whatever its origin, because there is no doubt that it occurs at the stratigraphic top of the Kimball member and of the Ogallala formation.

Ten petrographically distinctive volcanic ash lentils have been described from the Ogallala formation in northwestern Kansas; six of them, because of their distinctive petrographic character, stratigraphic significance, and relatively wide distribution, have been given formal bed names; four other ash falls known to occur in this area have little stratigraphic significance and have not been named. The Valentine contains the *Calvert* bed, correlated with an altered volcanic ash in the type section of the Valentine; the other nine volcanic ash falls occur in the Ash Hollow. The *Rawlins* bed has been correlated with volcanic ash in the type section of the Ash Hollow in Nebraska; the *Fort Wallace, Dellvale, Reager,* and *Reamsville* beds have been used, together with other data, in correlations within the Ash Hollow in northwestern Kansas.

Fossil molluscan assemblages are known from eight stratigraphically important localities in the Ogallala of northwestern Kansas; these are distributed through Valentine, Ash Hollow, and Kimball rocks. The molluscan faunas undergo gradual progressive changes without marked faunal discordances, but faunal characteristics vary sufficiently with vertical distribution of molluscan assemblages to allow recognition of Valentine, Ash Hollow, and Kimball members.

Fossil seeds, widely dispersed geographically and abundantly represented in stratigraphically variable populations, are without question the most important stratigraphic tool among the several kinds of organic remains preserved in the Ogallala. Fossil floras, based on fossilized hulls of grasses, and nutlets and fruits of various herbs and a single tree, are listed from 27 stratigraphically significant localities in the Ogallala formation of northwestern Kansas. Assemblages of fossil plant remains permit positive identification of Valentine, Ash Hollow, and Kimball members, and make it possible to subdivide the Ash Hollow member into lower, middle, and upper stratigraphic units.

MEASURED SECTIONS

Section measured in the SW¼ NW¼ sec. 2, T. 2 S., R. 40 W., Cheyenne County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
11. Moss agate in nodular zone, produces minor bench on slope	1
10. Sand, some silt and gravel, partly covered	5
9. Silt and some sand cemented to resemble limestone, platy	1
8. Sand and silt, compact but uncemented, locally contains some clay, reddish-brown	4
7. Silt and sand and a small amount of calcium carbonate cement, gray	1
6. Sand and silt, compact but not cemented, reddish-brown	3
5. Sand and some gravel, well cemented, buff, weathers to botryoidal surface; contains the following fossil seeds: *Berrichloa maxima, Biorbia fossilia, Celtis willistoni*	5
4. Sand, some silty zones, loose, partly covered	8
3. Sand and gravel, cross bedded, cemented	6
2. Sand, some gravel, loose, reddish-tan	2
1. Pierre shale exposed along lower parts of canyon; a thin gray weathered zone at top	
Total Ogallala measured	36

Section measured in the NW¼ NW¼ sec. 22, T. 1 S., R. 42 W., Cheyenne County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
7. "Algal limestone", pinkish-tan, with well developed pisolitic structure. Caps local topography	2.5
6. Silt and fine sand, densely cemented	3
5. Silt, sand, and gravel, poorly sorted, loosely cemented; contains abundant nodules and stringers of caliche	15.5
4. Sand, coarse, and gravel, heavily impregnated with dense caliche, locally nodular. (This zone is probably a heavy soil caliche.)	3
3. Gravel and coarse sand, loose tan to gray; contains pebbles to 4 inches in diameter	20.5
Ash Hollow member (?)	
2. Sand, coarse, and gravel, containing pebbles to 2 inches in diameter, locally cross-bedded, finer in upper part, densely cemented	8
1. Sand, coarse, and gravel, containing pebbles to 2 inches in diameter and cobbles of Pierre shale, poorly sorted, rusty-tan; locally as much as half the volume consists of reworked Pierre shale. This bed rests on weathered Pierre shale that contains a zone of caliche nodules in the uppermost 1 foot	8
Total thickness of Ogallala	60.5

Section measured in the NW¼ NE¼ sec. 34, T. 1 S., R. 27 W., Decatur County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
6. Sand, medium to fine, tan, cemented locally; contains the following fossil seeds: *Stipidium elongatum, S. aristatum, Celtis willistoni, Biorbia fossilia*	8
5. Sand, medium, containing a few pebbles, tan, cemented; clay balls common in lower part; contains the following fossil seeds: *Berrichloa glabra, Biorbia fossilia, Stipidium nebraskense, S. tubus, Berrichloa conica*	13
4. Sand, medium to fine, silty in upper part, loose to irregularly cemented, massive	9
3. Sand, medium, containing a few large pebbles and clay balls to 4 inches in diameter; massive, contains thin, irregular, contorted lenses of fine-grained, hard limestone	8.5
2. Sand, medium, massive, loose to irregularly cemented, tan	16
1. Sand, medium, containing a few coarse quartz grains, cemented. Contains *Krynitzkia coroniformis*	8
Total Ogallala measured	62.5

Cedar Bluff section, measured on south side of Beaver Creek valley in the NE¼ SE¼ sec. 10, T. 1 S., R. 29 W., Decatur County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
9. Sand, fine to coarse, well to irregularly cemented, massive; calcium carbonate nodules in lower part; forms steep bluff of valley side. Contains *Celtis willistoni*	17
8. Sand, fine to medium, lenticularly cemented	3
7. Sand, medium, tan, cemented throughout	1
6. Sand, medium, tan, loose	3.5
5. Sand and silt, loosely but uniformly cemented, pale greenish-gray	6
4. Sand and some gravel, compact but not cemented, gray to greenish-gray, interbedded with clayey zones in upper part	11
3. Covered slope	2
2. Sand, fine, some silt, thick-bedded to blocky, calcareous, tan to gray-tan	2.5
1. Sand, fine, and silt, massive, uncemented, pinkish-tan	4
Total Ogallala measured	50

Section measured in the SW¼ NW¼ sec. 24, T. 3 S., R. 30 W., Decatur County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
5. Sand, some silty zones, irregularly and lenticularly cemented, partly covered	14
4. Sand, medium to coarse, yellowish-gray to light-gray, well cemented except for uncemented lentils; contains the following fossil seeds: *Biorbia fossilia, Celtis willistoni*	12
3. Sand, some silt, lenticular zones loosely cemented, pale greenish-gray. Seeds in lenticular masses near the top include the following: *Biorbia fossilia, Stipidium grande*	6
2. Sand, medium to coarse, well cemented, sparse seed flora contains the following: *Biorbia fossilia, Celtis willistoni, Krynitzkia auriculata*	2
1. Silt and sand, fine to medium, irregularly and lenticularly cemented, gray, greenish-gray, and pinkish-tan	16
Total Ogallala measured	50

Section measured in the SE¼ SW¼ sec. 8, T. 4 S., R. 29 W., Decatur County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
5. Sand, fine to medium, tan to gray, irregularly cemented; contains fossil seeds of *Biorbia fossilia*	5
4. Sand, fine to medium, tan to gray, uniformly well cemented; contains fossil seeds of *Biorbia fossilia, Stipidium aristatum, S. variegatum*	5
3. Volcanic ash, *Reamsville* bed, becomes sandy and impure upward, massive to locally laminated, blue-gray to gray, lower 3 feet loosely cemented, top well cemented; contains calcareous tubules and nodules throughout	9
2. Sand, medium to fine, some silt, loosely cemented, tan	1.5
1. Sand, coarse, loose, partly covered	7.8
Total Ogallala measured	28.3

Section measured in center W. line, sec. 3, T. 12 S., R. 20 W., Ellis County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
8. "Algal limestone"	2
7. Sand, contains reddish-brown silt in lower part, and a few scattered pebbles, densely cemented, gray to tan. The following fossil seeds occur sparsely in lower part: *Celtis willistoni, Panicum elegans, Berrichloa maxima*	23
Ash Hollow and Valentine members, undifferentiated	
6. Sand, fine, well sorted, massive, tan, loosely cemented, contains scattered nodules of caliche	9
5. Limestone, soft, porous, contains some silt and fine sand, grayish-white. Locally contains abundant fresh water gastropod fossils as casts, molds, or entire shells: *Helisoma valens, H. antrosum, H. goodrichi, Physa hawni, Lymnaea lavernensis, Pupoides albilabris, Pseudosuccinea columella, Calipyrgula hibbardi*	2
4. Limestone, and small amount of sand, grayish-white, indurated	5
3. Sand, medium to coarse, loose	5
2. Sand, fine, silt, and some clay, massive, greenish-gray; heavy nodular caliche in upper 5 feet	10
1. Sand, locally silt, containing local lenticular bodies of unctuous green clay, massive, reddish-brown, uncemented; irregular streaks of caliche. Ogallala rests on Niobrara formation	45
Total thickness of Ogallala	101

Section measured in the SE¼ SE¼ sec. 15, T. 13 S., R. 30 W., Gove County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
8. Silt, fine sand, and gravel, finer in upper part, uniformly cemented; well developed platy structure in upper part	2
7. Sand, silt, and gravel, uncemented but mottled with caliche, tan	7
Ash Hollow member	
6. Sand, fine, silt and pebbles, contains abundant mica flakes, loosely cemented; platy structure at top	4
5. Sand, coarse, and gravel, grading upward into silt, fine sand, and clay at top, tan to ash-gray	14.5
4. Silt, some pebbles, soft cement throughout, white to cream-color	4
3. Silt, sand, gravel, and pebbles, poorly sorted, weakly cemented, gray to brick-red	2
2. Sand, coarse, and gravel, massive, poorly sorted, well cemented, weathers to honeycomb surface	5
1. Sand, coarse, and gravel, thin-bedded to cross-bedded, irregularly cemented, contains pebbles of Niobrara chalk and rests on weathered Niobrara chalk	5.5
Total Ogallala measured	44

Section measured in the NE¼ NE¼ sec. 2, T. 7 S., R. 24 W., Graham County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
9. Silt, sand, clay, and fine gravel, irregularly cemented	3
8. Sand and silt, interbedded, cemented in thin crenulate zones, contains volcanic ash shards, gray to gray-tan	5
7. Clay, silty, thin caliche band at top, mottled reddish-brown and greenish-gray	2.5
6. Sand, medium, well sorted, micaceous, massive, gray	1.5
5. Silt, thinly laminated to cross-bedded in thin zones	1.5
4. Sand, medium, some silt and pebbles, massive, compact, rusty-brown to gray	3
3. Clay, bentonitic, and silt, reddish-brown; caliche nodules in upper part	3
2. Sand, fine, compact, gray	1.5
1. Sand and silt, massive, pinkish-tan	3.5
Total Ogallala measured	24.5

Section measured in the SE¼ NE¼ sec. 8, T. 17 S., R. 27 W., Lane County, Kansas

	Thickness, feet
Tertiary—Pliocene	
Ogallala formation—Kimball member	
11. Limestone, sandy, dense, platy, pinkish-gray	3
10. Silt and sand, fine, densely and uniformly cemented	5
9. Sand, medium to coarse, loose, tan to rusty	9
8. Sand, fine, and silt, some coarse sand, compact; reddish to pale olive-gray, nodules and stringers of caliche in upper part	6
7. Sand, medium, uniformly well cemented, ash-gray	1.5
6. Sand, coarse, and gravel, uniformly cemented; contains *Celtis willistoni*	8.5
Ash Hollow member	
5. Sand, well cemented, platy, gray	.5
4. Sand, fine to medium, and silt, compact; mottling and lentils of cement; brick-red; contains the fossil seed *Biorbia fossilia*	7
3. Sand, loosely and irregularly cemented, pale-gray to tan; contains the fossil seed *Biorbia fossilia*	2
2. Sand and gravel, loose, tan	1.5
1. Sand, coarse, and gravel, cemented. The base of this bed is a few feet above the contact of Ogallala on Niobrara formation	2.5
Total Ogallala measured	46.5

Section measured in the SW¼ SW¼ sec. 19, T. 18 S., R. 28 W., Lane County, Kansas

	Thickness, feet
Tertiary—Pliocene	
Ogallala formation—Kimball member	
3. "Algal limestone", dense, irregular limestone, containing scattered sand grains, gray, with pink crenulated and pisolitic structures	2
2. Limestone, silt, and fine sand, indurated, nodular structure in lower part, well developed platy structure in upper part, white, streaks of tan and brown	21
1. Silt and sand, very fine, uniformly cemented, light-gray	2.5
Total Ogallala measured	25.5

Section measured in the NE¼ NE¼ sec. 23, T. 12 S., R. 32 W., Logan County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
9. Silt and caliche, indurated, platy structure prominently developed in upper part, whitish to cream-color, a few pinkish-tan lentils; a thin layer at the top resembles "Algal limestone"	7
8. Gravel, sand, and silt, well cemented, ash-gray	6.5
7. Silt and very fine sand, well cemented, whitish to cream-color	3.5
6. Sand, fine to medium, containing scattered pebbles, well but irregularly cemented, weathers to honeycomb surface; contains fossil seeds of *Celtis willistoni* in clumps	6.5
5. Sand, fine to medium, weakly cemented, tan to brown; contains tubules and nodules of caliche and fossil seeds of *Celtis willistoni, Biorbia fossilia*	5
Ash Hollow member	
4. Sand, medium, uniform, well cemented	.5
3. Sand, silt, and fine gravel, massive, loosely cemented, tan to buff	10.5
2. Sand, fine to medium, some silt, tan; contains irregular cemented zones	4.5
1. Sand and coarse gravel, cross-bedded to massive, cemented. Base of section at level of floodplain in Hackberry Creek	11.5
Total Ogallala measured	55.5

Section measured in the SW¼ sec. 1, T. 16 S., R. 21 W., Ness County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
6. Silt, densely cemented, pale-gray to pinkish-gray, contains irregular opalized nodules	3
5. Sand and silt, loosely cemented, pinkish-tan, partly covered. At this stratigraphic position in the NW¼ SW¼ sec. 21, T. 15 S., R. 21 W., Trego County, the following fossil seeds were collected: *Berrichloa conica, B. tuberculata, Biorbia fossilia, Celtis willistoni*	2.5
4. Sand, fine to coarse, some pebbles, cemented; weathers to smooth convex surfaces	7.5
3. Covered	7
Valentine member (?)	
2. Conglomerate, densely cemented with opal; the opaline matrix has distinct green color and is lenticular in distribution	10
1. Gravel and cobbles of Cretaceous Niobrara chalk to 1 foot in diameter, in matrix of clay and chalk sand. Base rests on Niobrara chalk	3
Total Ogallala measured	33

Edmond section, measured in the SW¼ SW¼ sec. 19, and NW¼ sec. 30, T. 5 S., R. 22 W., Norton County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
16. Sand and gravel, irregularly cemented, dense zone at top	6
15. Sand, medium, irregularly cemented; contains the following fossil seeds: *Biorbia fossilia, Celtis willistoni, Stipidium variegatum*	4.5
14. Sand, medium, densely cemented, gray; contains the following fossil seeds: *Biorbia fossilia, Celtis willistoni, S. variegatum*	4
13. Sand, compact but uncemented, greenish-gray	8
12. Sand, fine to medium, densely cemented, gray to greenish-gray	3.5
11. Sand, fine to medium, compact to loosely cemented, greenish-gray	8
10. Sand, well cemented, ash-gray; contains tubules of hard caliche and the following fossil seeds: *Berrichloa tuberculata, Biorbia fossilia*	2
9. Sand, medium, uncemented but contains stringers and tubules of caliche, gray	5
8. Sand, fine to medium, densely cemented, gray	2
7. Sand and silt, contains some clay in middle and mottling of caliche throughout, red, olive-brown to gray; weakly cemented in upper part	19
6. Sand, medium, and silt, compact to loose; some cementation at top	5
5. Sand, some silt, loose to compact; mottling of caliche, cemented zone at top, ash-gray. Contains *Krynitzkia coroniformis*	15
4. Silt, sand, and clay, loosely and uniformly cemented; some thin plates of caliche	2
3. Sand, medium to coarse, loosely and irregularly cemented, but dense zone at top, tan to gray; contains *Celtis willistoni* in large local aggregations	7
Valentine member	
2. Sand and fine gravel, loosely and irregularly cemented, tan. Contains *Berrichloa sp.* [fragments], *Stipidium commune*	5
1. Sand, fine to medium, massive, loose, some very small caliche tubules, ash-gray, pale greenish-gray to tan in the upper part. Contains *Stipidium commune*. Base rests on Niobrara chalk, which is locally irregularly silicified in the upper few feet	29
Total Ogallala measured	125

Almena section, measured in the W½ sec. 16, T. 2 S., R. 21 W., Norton County, Kansas. (Modified from Frye and A. R. Leonard, 1949, p. 36-37)

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
23. Limestone, soft, silty, porous, pale cream-color; contains abundant molds of snails (*Vertigo ovata, Lymnaea macella, Promenetus blancoensis, Pupoides albilabris, Helisoma antrosum*), and ostracodes and diatoms	3

Ash Hollow member	
22. Sand and silt, partly covered, cemented zone exposed about midway	35
21. Sand, silty, fine to medium, loosely cemented with calcium carbonate to form irregular bench; contains *Biorbia fossilia, Berrichloa glabra, B. conica,* and *Celtis willistoni*	6.4
20. Partly covered silt and sand, unconsolidated, buff	32
19. Sand, coarse to fine, and some silt; cemented with calcium carbonate	1
18. Sand, fine to medium, buff, some calcium carbonate cement distributed irregularly. *Berrichloa amphoralis, Biorbia fossilia, Stipidium variegatum*	5
17. Volcanic ash, *Dellvale* bed, sandy at base (becomes impure farther south); upper part locally cemented with calcium carbonate	6.5
16. Silt and sand cemented with calcium carbonate, roughly bedded; contains *Berrichloa conica, Biorbia fossilia, Krynitzkia coroniformis*	6.5
15. Partly covered, calcareous silt, clay, and sand, greenish-gray in upper and lower parts, middle part buff silt and very fine sand containing concretions	20
14. Silt, sand, and calcium carbonate, indurated, gray; contains abundant shards of volcanic glass, classed as *Rawlins* ash bed, and diatoms. In adjacent quarry to east contains abundant molds of fossil snails *(Vertigo ovata, Pupoides albilabris, Physa anatina, P. hawni, Helisoma antrosum, Pseudosuccinea columella)*	4
13. Sandy silt, buff, locally unevenly cemented with calcium carbonate	.7
12. Silt, sand, and calcium carbonate, massive, light greenish-buff	6.9
11. Sand, fine to medium, pale greenish-tan	3.7
10. Silt, sand, and clay, greenish-brown; calcium carbonate in irregular nodules in a noncalcareous matrix	3
Valentine member	
9. Silt, clay, and sand, greenish-brown	1.8
8. Sand and some gravel	3
7. Sand, clay, and silt, greenish-brown; contains abundant fragments of fossil vertebrates	2.5
6. Sand, medium, poorly sorted, uncemented, brown	3
5. Partly covered, silt and sand	4
4. Limestone, soft, silty, porous, gray; contains abundant molds of fossil snails *(Physa hawni, Pseudosuccinea columella, Helisoma goodrichi, Helisoma valens, Calipyrgula hibbardi, C. senta, Lymnaea lavernensis)* and diatoms	1
3. Sand and silt, calcareous throughout, irregularly bedded, gray to pink; upper part indurated, contains a few molds of fossil snail shells	3.2
2. Silt, some clay and fine sand, massive, gray to gray-green; contains *Stipidium commune*	5.5
1. Sand, fine, and silt, some clay and coarse sand, calcareous throughout, massive to irregularly bedded, gray. Covered in basal part to level of C.R.I. & P.R.R. tracks on the level of the Almena terrace of Prairie Dog Creek valley	5.3
Total Ogallala measured	163

Section measured in the NW¼ NW¼ sec. 2, T. 4 S., R. 24 W., Norton County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
8. Sand, silty, cemented with calcium carbonate, pinkish-gray	.8
7. Silt, fine sand, and clay, loose, tan to brown	1
6. Volcanic ash, *Dellvale* bed, exceptionally coarse at the base, becoming finer and impure upward, thin-bedded, irregularly cemented in upper part, light-gray	9.7
5. Sand, fine, and silt, irregular cemented areas, pale greenish-gray, abundant seeds of *Celtis willistoni*, and less-abundant seeds of *Biorbia fossilia*	2.5
4. Silt, some clay and sand, nodules of pebble size, nodular discontinuous cement at top, gray	2.5
3. Silt, sand, fine to medium, and pebbles of marl, pale greenish-gray	.5
2. Marl, soft, yellowish-green, contains a few molds of gastropods *(Vertigo ovata, Physa hawni, Helisoma antrosum, H. goodrichi, H. valens, Pseudosuccinea columella)* and bones of small vertebrates	1
1. Sand, fine to coarse, some gravel, yellow, tan, greenish-yellow, and gray, mottled and streaked, lenticularly cemented to form ledges; contains abundant seeds of *Biorbia fossilia* and *Berrichloa amphoralis*	15
Total Ogallala measured	33

Section measured in center N line, sec. 36, T. 2 S., R. 25 W., Norton County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
5. Sand, medium to coarse, a few pebbles, tightly cemented	2.5
4. Sand, fine, and silt, some pebbles, light-tan to cream-buff, soft caliche, not well cemented; a thin zone of diatomaceous marl in middle; the following fossil seeds in the upper part: *Biorbia fossilia, Celtis willistoni*	6
3. Volcanic ash, unnamed bed, dove-gray when damp but light-gray with a slight bluish cast when dry; sharp contact at base but gradational at top	3
2. Sand, silt, and some gravel including pebbles of caliche and clay balls, tubules and some cement, light-tan to gray-tan at base grading upward to pale greenish-gray; contains the following fossil seeds: *Berrichloa conica, B. amphoralis, Biorbia fossilia, Stipidium variegatum, Celtis willistoni*	7.5
1. Silt, fine, sand, and caliche, in alternating irregular zones, gray to light-tan; the cemented zones give the appearance of relatively uniform bedding	5
Total Ogallala measured	24

New Almelo section, measured in center E. line, sec. 34, T. 5 S., R. 25 W., Norton County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
8. Limestone, silty and sandy, soft, gray	5
7. Limestone, containing a small amount of silt and fine sand, tough, light-gray; contains abundant molds of fossil snails (*Pupoides albilabris, Physa anatina, Helisoma antrosum, H. valens, Pseudosuccinea columella*)	2.5
6. Caliche, silty, white, soft, and a small amount of silt and sand	.8
5. Sand, silt, and gravel, irregularly cemented, gray to dirty-gray. Contains *Biorbia fossilia, Berrichloa amphoralis, Celtis willistoni*	6
4. Sand, massive, pale greenish-gray	3.5
3. Sand and gravel, masses and thin lenses of caliche, clay balls, locally some cement, pale greenish-gray	3.5
2. Sand, coarse, predominately quartz but contains pebbles of Cretaceous chalk, massive, uniform, dark-green at base becoming pale gray-green upward	15
1. Sand, coarse, and gravel; 75 percent of the pebbles Cretaceous chalk to 3½ inches in diameter; greenish-tan	2
Total Ogallala measured	38.3

Section measured in the NW¼ NE¼ sec. 30, T. 1 S., R. 19 W., Phillips County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
9. Sand, fine to coarse, a few pebbles, irregularly cemented throughout with calcium carbonate	7
8. Silt, fine sand, and clay, uncemented, mottled gray-brown and green	6
7. Clay, silty, some fine sand, tan to gray-greenish tan	5
6. Silt and fine sand, some mica flakes and ash shards, laminated, tan, mottled with greenish-gray. Contains *Biorbia fossilia, Celtis willistoni, Krynitzkia coroniformis, Stipidium elongatum, S. grande*	1.5
5. Silt, bentonitic clay, and fine sand, interbedded, tan to greenish-tan	8
4. Marl and volcanic ash containing diatoms and abundant molds of snails (*Vertigo ovata, Pupoides albilabris, Physa anatina, Helisoma antrosum, H. valens, Pseudosuccinea columella*); whitish to cream-color	2.5
3. Volcanic ash, *Rawlins* bed, clean and fresh, uncemented, blue-gray	1
2. Sand, some zones of silt and bentonitic clay, locally loosely cemented with calcium carbonate, greenish-gray	3
1. Covered interval from bridge (culvert) floor	4
Total thickness of section	38

Section measured in the SW¼ SE¼ sec. 2, T. 3 S., R. 33 W., Rawlins County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
11. Sand, fine to medium, tan to gray, irregularly cemented to form weak ledge	2
10. Silt and sand, some clay, gray to tan, locally cemented in streaks and lentils	6
9. Sand, fine, lentils of silt, loose, gray to tan; contains following fossil seeds: *Celtis willistoni, Biorbia fossilia, Stipidium elongatum*	.5
8. Sand and silt, some gravel, massive, lentils of cemented silt, white, matrix generally brick-red	2.7
7. Silt, clay, and sand, fine, blocky to massive, tan to brown	3.5
6. Sand, medium to coarse, and gravel, well to irregularly cemented, except for local lentils of uncemented sand and gravel; contains the following fossil seeds: *Biorbia fossilia, Stipidium elongatum*	18
5. Marl and fine sand, well cemented, off-white to cream-color	1.5
4. Sand, fine to medium, cemented, tan to yellowish, locally contains gravel and coarse sand; contains abundant fossil seeds: *Biorbia fossilia, Berrichloa amphoralis, Stipidium variegatum*	5
3. Sand and gravel, contains pebbles of maximum diameter greater than 1 inch, and a few cemented lentils of sandy silt	15
2. Volcanic ash, *Reamsville* bed, contains some fine sand, steel-gray to gray-tan at top. (Farther south the ash zone is 18 feet thick. The basal 8 feet is relatively pure ash and is a separate lens classed as the *Reager* bed.)	6
1. Sand and gravel, loose, partly covered. The base of the section is approximately at the level of the Pierre shale contact in adjacent canyons	23
Total Ogallala measured	83.2

Section measured in the SE¼ SE¼ sec. 20, T. 5 S., R. 36 W., Rawlins County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
7. Sand, coarse, and gravel; quartz pebbles to 2 inches in diameter; loose, tan; top 1 foot cemented	18
6. Sand and gravel, cemented, interbedded with thin zones of pink silty sand	1
5. Sand, fine to medium, loose, some silt	14
4. Sand, coarse, some gravel, cemented	1.5
3. Sand, fine to medium, some silt, tan; contains *Berrichloa amphoralis, B. glabra, Celtis willistoni*	12
2. Volcanic ash, *Rawlins* bed, light bluish-gray; locally cemented, contaminated with fine sand, and interbedded with fine to medium, tan sand	1
1. Sand, fine to medium, weakly cemented in middle, tan; contains *Celtis willistoni*	11
Total Ogallala measured	58.5

Section measured in the SE¼ SE¼ sec. 13, and the NE¼ NE¼ sec. 24, T. 3 S., R. 35 W., Rawlins County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
12. Gravel, some sand, locally cemented	5
11. Sand and gravel, coarse, contains pebbles to 2 inches in diameter; cemented lentils scattered throughout	14
Ash Hollow member	
10. Sand, coarse, and gravel, poorly sorted, locally and irregularly cemented	5
9. Sand and silt, compact but not cemented, tan to brown	10
8. Sand, fine, and silt, densely cemented, interstratified with loose gray fine sand and silt	1
7. Sand, fine to medium, and silt, loose, reddish-tan to brown	8
6. Sand, medium to coarse, generally well cemented; contains *Celtis willistoni* and *Biorbia fossilia*	5
5. Sand and silt, some clay, generally uncemented but contains cobbles and nodules of cemented material; marly zones at intervals of a few feet	11
4. Sand, medium, and silt, irregularly cemented	5
3. Sand and silt, some gravel, unconsolidated, tan	12
2. Sand, medium to coarse, irregularly cemented; in lower 1 foot contains the following fossil seeds: *Biorbia fossilia*, *Celtis willistoni*, *Stipidium elongatum*	9
1. Sand, fine to medium, and silt, uncemented but containing pipes and stringers of caliche, massive, brown to tan	6
Total Ogallala measured	91

Section measured at center W line SW¼ sec. 4, T. 4 S., R. 34 W., Rawlins County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
10. Sand, some pebbles, incompletely cemented; the following fossil seeds were collected: *Berrichloa amphoralis*, *Panicum elegans*, *Stipidium tubus*, *Celtis willistoni*	5
9. Sand, fine to coarse, some gravel, poorly sorted, irregularly cemented	11
8. Sand, some gravel, gray to tan, cemented in local lentils; a thin, densely cemented zone of silt and fine sand at top	4.5
7. Sand, fine to coarse, some gravel, uniformly well cemented; the following fossil seeds were collected: *Biorbia fossilia*, *Stipidium aristatum*, *S. variegatum*, *Berrichloa amphoralis*	6
6. Sand, fine to coarse, irregularly cemented, contains pipes and stringers of calcium carbonate; uncemented portion is pinkish-buff; weathers to honeycomb surface	4.5
5. Sand, medium to coarse, and gravel, pebbles to 1 inch in diameter, irregularly cemented; contains *Panicum elegans*	6
4. Sand and silt, unconsolidated	22
3. Marl, silty and sandy, indurated, cream-color	1
2. Volcanic ash, *Rawlins* bed, basal 2 feet is pure ash, fine, light-gray, upper 1½ feet interbedded with fine to medium sand	3.5
1. Sand, fine, silt, and clay; thin-bedded, uncemented, pale yellowish-green to tan; contains thin zones of silt and clay near top and discontinuous streaks of caliche throughout	10
Total Ogallala measured	73.5

Scott County State Lake section, measured in the SE¼ SE¼ sec. 2, and N½ sec. 11, T. 16 S., R. 33 W., Scott County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
16. Sand, silt, and pebbles, predominantly silt in upper part, uniformly loosely cemented, but upper part showing platy structure and harder	13
15. Sand and gravel, reddish-tan, uncemented, some silt in upper part	13
Ash Hollow member	
14. Silt and fine sand, densely cemented, gray to white; a few lentils of uncemented fine red sand and silt	18
13. Clay, silt, and pebbles, compact, prismatic structure, whitish, red and tan	1
12. Silt, densely cemented, contains nodular opalized areas in lower few feet and a few lentils of red sand	6.5
11. Sand, fine, and silt, some pebbles and nodules of caliche, red, compact	4
10. Sand and silt, cemented and indurated, contains intraformational conglomerate in lower portion and platy zone at top	13.5
9. Sand and silt, uncemented, gray to brown; has the appearance of a sandy, pebbly loam	1.5
8. Sand, fine, silt, and pebbles, uncemented at base but stringers and plates of caliche irregularly developed in upper part, brick-red, weathers to a honeycomb surface; beds 8 and 9 constitute a fossil soil profile	4.5
7. Sand, fine gravel, and silt, poorly sorted, massive, cemented, ash-gray to tan	2
6. Sand, fine to coarse, and fine gravel, cross-bedded, irregularly cemented, tan to yellowish-tan	13
5. Sand, medium to coarse, compacted, massive at base to cross-bedded at top, tan to brick-red; contains irregular nodules and cobbles of caliche	5.5
4. Sand, fine to medium silt, and fine gravel, poorly sorted, massive, uniformly but weakly cemented, tan to brown; contains the following fossil seeds: *Berrichloa tuberculata, Biorbia fossilia, Celtis willistoni*	6.5
3. Sand and gravel, fine to coarse, cross-bedded to evenly bedded, weakly cemented lentils in middle and in upper part, local variations in texture; locally contains thin cream-colored marl bed at top	36
2. Silt, sand, and clay, massive, uncemented, brown	8
Valentine member (?)	
1. Clay, bentonitic, massive, containing a few scattered sand grains, tan to olive-brown. This bed rests on weathered Niobrara chalky shale	8.5
Total Ogallala measured	154.5

Section measured in center W. line of the SW¼ sec. 7, T. 8 S., R. 26 W., Sheridan County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
11. Sand and silt, locally irregularly cemented, red to pinkish-gray	6
10. Sand, irregularly cemented, gray to tan	1.5
9. Sand, fine, and silt, massive, compact, uncemented, red at base to gray at top	8.5
8. Gravel and sand, cross-bedded, cemented, gray	5
7. Sand, silt, and soft caliche, pinkish-tan to pinkish-gray, nodules of hard caliche	15
6. Sand, gravel, and silt, gray cement distributed in honeycomb pattern around red-brown areas; platy structure at top; in lower half contains the following fossil seeds: *Berrichloa conica, Biorbia fossilia, Celtis willistoni*	10
5. Sand, some gravel and silt, lenticularly cemented in upper part; upper part contains the following fossil seeds: *Berrichloa amphoralis, B. tuberculata, Biorbia fossilia, Celtis willistoni*	12
4. Sand and silt, well cemented, gray	2.5
3. Sand, some gravel and silt, loose, gray to tan	7.5
2. Sand and silt, massive, weakly cemented, gray to tan	4
1. Sand, some silt, loose, gray to tan. Base of bed a few feet above Niobrara chalk	3
Total Ogallala measured	75

Section measured in center W. line of the SW¼ sec. 32, T. 1 S., R. 14 W., Smith County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
6. Sand, fine to medium, loosely cemented throughout; hard nodules of caliche, gray	7
5. Volcanic ash, *Reamsville* bed, partly cemented and locally interbedded with tan sand, sharp contact at base but gradational at top, light bluish-gray; contains the following fossil seeds: *Berrichloa glabra, Celtis willistoni, Biorbia fossilia, Stipidium tubus*	3
4. Sand, medium to fine, loosely cemented, a few nodules and stringers of caliche, massive, gray to gray-tan	5
3. Sand, fine to medium, cemented in irregular zones, pale greenish-gray to tan; contains the following fossil seeds: *Biorbia fossilia, Stipidium variegatum, Berrichloa amphoralis, B. tuberculata*	6
2. Sand, fine to medium, some calcareous clay balls and tubules, uncemented, pink, tan, and greenish-gray, mottled	5
1. Partly covered; sand, fine to medium, greenish-gray, pinkish-tan, and zones of caliche. Exposures in adjacent canyons indicate that the top of the Niobrara chalk is at the approximate base of this bed	50
Total Ogallala measured	76

Section measured in the SE¼ sec. 16, T. 11 S., R. 25 W., Trego County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
7. Sand and silt permeated with soft caliche, red to gray-tan	2.5
6. Sand, micaceous, locally densely cemented	2
5. Sand, some gravel and silt, loose, tan	6
4. Silt and very fine sand, compact, local irregular cemented zones	1.5
3. Sand and some silt, massive, uncemented, red	4
2. Sand and silt, massive to irregular thick-bedded, irregularly cemented, nodules and stringers of caliche and platy structure in upper part, gray; local zone in middle has superficial appearance of limestone conglomerate; in lower half the following fossil seeds were collected: *Celtis willistoni, Biorbia fossilia, Berrichloa amphoralis, B. tuberculata, B. conica*	15
1. Sand and gravel, grading to sand and silt in upper part, massive, uncemented, tan to brick-red, lower part partly covered; base of this bed rests on Niobrara chalk exposed in creek bank	41
Total Ogallala measured	72

Section measured in the W½ SW¼ sec. 7, T. 14 S., R. 38 W., Wallace County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
14. "Algal limestone", gray, pinkish crenulations	1
13. Caliche, silt, fine sand, and a few pebbles, gray to ash-gray, contains dispersed opalized nodules particularly in the lower 4 feet, none in uppermost 6 feet, distinct platy structure in uppermost 6 to 8 feet	18
12. Sand, fine to coarse, compacted but not cemented, red; irregular pipy and platy calcareous concretions; contains fossil seeds of *Celtis willistoni, Berrichloa maxima, Prolithospermum johnsoni*	8.5
Ash Hollow member	
11. Sand and coarse gravel grading upward to medium to coarse sand, poorly stratified, gray at base to pinkish-tan at top, uniformly and lenticularly cemented, platy caliche zone in top 1.5 feet; contains the following fossil seeds: *Berrichloa amphoralis, B. conica, Biorbia fossilia, Celtis willistoni*	14
10. Sand and gravel, irregularly cemented, dense caliche zone at top; contains the following fossil seeds: *Berrichloa amphoralis, B. glabra, B. conica, Celtis willistoni, Stipidium elongatum, Biorbia fossilia*	5.5
9. Sand, fine to medium, and silt, red; horizontal zones of dense caliche separated by uncemented red zones	5
8. Gravel and sand, silty in upper part, pinkish-tan to tan, irregularly cemented, a zone of dense cement at top	11
7. Sand, fine to medium, and silt, poorly sorted, massive to thin-bedded, gray to tan; contains volcanic ash shards and irregular plates of caliche at top	1.5

6. Volcanic ash, *Fort Wallace* bed, some silt and sand, thin but irregularly bedded, ash-gray, cemented in thin platy lentils	1.5
5. Gravel, sand, and silt, irregularly interbedded, coarser at base becoming finer upward, gray, streaks of brown and pink; tightly cemented in platy zones separated by uncemented zones	4.5
4. Sand, silt, clay, and gravel, poorly sorted, massive and blocky, uncemented, brown; contains a few nodules and stringers of caliche in upper part	3.5
3. Sand and silt, some pebbles, massive, pinkish-tan to tan, gray zone at top; contains caliche in scattered nodules in lower part grading upward to heavy caliche	7.5
2. Sand, silt, and gravel, massive, pinkish-tan; contains disseminated soft caliche	9
1. Sand, gravel, and silt, a few coarse pebbles in base, pinkish-tan; caliche nodules disseminated throughout; sharp basal contact on Pierre shale, 15 feet of Pierre exposed below base of the Ogallala	4.5
Total Ogallala measured	95

Section measured in the NE¼ NE¼ sec. 3, T. 12 S., R. 42 W., Wallace County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
13. Sand, fine to coarse, in a caliche matrix	3
12. Sand, silt, and gravel, poorly sorted, compact but uncemented, pink-brown	3
11. Sand, coarse, and gravel, irregularly cemented to loose, contains irregular pipy concretions	9
10. Sand, fine, and silt, massive, poorly sorted, contains pebbles, gray; densely cemented thin zones of silt at top	14
9. Sand, medium, uncemented but containing platy caliche, red-brown	6
8. Sand, gravel, and silt, locally loosely cemented, gray; contains the following fossil seeds: *Celtis willistoni, Biorbia fossilia, Stipidium nebraskense, Krynitzkia auriculata*	6
7. Silt, calcareous and indurated, nodular discontinuous opalized zones, gray	1
6. Sand, fine, and gravel, interbedded and cross-bedded, locally contains calcareous tubules and plates	1.5
5. Silt and fine sand, interbedded and cross-bedded, gray, tan, and green	0.5
4. Sand, medium to coarse, and gravel, thin-bedded to cross-bedded, tan, streaks of brown	2.5
3. Sand, fine, and silt, thin-bedded, ash-gray	1
2. Silt and fine sand, thin-bedded and interbedded with fine to coarse sand, gray streaked with tan and brown	1.5
1. Sand, some gravel, massive, loose, pinkish	4
Total Ogallala measured	53

Section measured in center W. line of the NW¼ sec. 35, T. 14 S., R. 42 W., Wallace County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
6. "Algal limestone", indurated, showing typical pisolitic structure, gray and pink	2
5. Caliche, some silt, sand, and pebbles, massive, grading upward to a platy structure, ash-gray	7
4. Sand, fine to medium, and silt, irregularly and locally cemented, pinkish-tan	5
3. Sand, fine to medium, loosely cemented throughout	1
2. Silt and clay, some sand and gravel, compact but uncemented, containing stringers and lentils of caliche, pinkish-tan to brown; contains *Celtis willistoni*, *Berrichloa maxima*	3
1. Silt, some sand and gravel, gray-tan to pale greenish-tan	3.5
Total Ogallala measured	21.5

Section measured in the SE¼ sec. 11, T. 13 S., R. 42 W., Wallace County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
10. "Algal limestone"	0.5
9. Caliche, silt, fine sand, and a few pebbles, gray to ash-gray, distinctly platy structure throughout	9
8. Sand, fine, some coarse sand and pebbles, massive, densely cemented with calcium carbonate, gray	13
Ash Hollow member	
7. Silt, fine sand, and clay, loose, massive to thin-bedded, greenish-gray to brown; contains nodules of caliche and small cemented lenses	11
6. Sand, pebbles of quartz and caliche, and cobbles of red silt, loosely cemented throughout; contains *Celtis willistoni*	10
5. Silt and fine sand, well sorted in thin beds, some cross-bedded zones; weathered volcanic ash shards abundant in basal part; discontinuous caliche zone at top	10
4. Sand, medium, some fine gravel, massive, gray, densely cemented; contains *Celtis willistoni*	7
3. Sand, fine to medium, loosely cemented, gray to pinkish-tan	4
2. Sand and gravel, brown to tan, densely cemented, contains the following fossil seeds: *Berrichloa amphoralis*, *B. tuberculata*, *Biorbia fossilia*, *Krynitzkia auriculata*, *Stipidium intermedium*, *S. variegatum*	8
1. Silt and sand, loose, local cemented lenses, pinkish to reddish-brown. The Ogallala rests on Pierre shale	26
Total Ogallala measured	98.5

Section measured in the SE¼ SE¼ SE¼ sec. 8, T. 14 S., R. 38 W., Wallace County, Kansas

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
14. "Algal limestone" at top of covered interval	7
13. Silt and sand, irregularly well cemented, irregular zone of opal cement in basal 1.5 feet	10
12. Sand, fine to coarse, silt, and a few pebbles, uniformly cemented, gray, tan, and brick-red	5
11. Cherty limestone, gray	1
10. Silt, some sand and pebbles, tightly cemented	5
9. Opalized limestone, nodular, discontinuous, gray	1
Ash Hollow member	
8. Sand, fine to medium, and silt, uncemented, reddish-tan	3
7. Sand, fine to medium, and pebbles, poorly sorted, well cemented, tan to cream-color	7
6. Sand, fine to medium, some pebbles, irregularly and locally cemented, tan	8
5. Sand and silt, irregularly cemented, pinkish-tan	2.5
4. Sand, coarse, and gravel, irregularly cemented	4
3. Partly covered silt, sand, and pebbles	24
2. Volcanic ash, *Rawlins* bed, interbedded with silt in upper part, gray	3
1. Covered from top of Pierre shale	7
Total Ogallala measured	87.5

Type locality, Ash Hollow member, Ogallala formation. Measured in Ash Hollow, southeast of Lewellen, Nebraska.

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimball member	
23. Gravel, sand, and cobbles, maximum diameter 4 inches; contains pebbles and cobbles of reworked material from bed 22 (Sidney gravel formation of Lugn, 1935)	8.5
Ash Hollow member (Formation of Nebraska classification, Lugn, 1935)	
22. Sand, fine to medium, silty, gray to whitish, cemented with calcium carbonate at base grading upward to less well cemented, siltier	18.5
21. Sand, fine, uniform, gray, massive; irregularly cemented; contains a few zones of pink sandy silt; uppermost 2 feet is noncalcareous sandy silt	26
20. Silt, fine sand, and locally clay, tan to brown, noncalcareous, a few streaks of lime; contains laminae of noncalcareous white silt in lower part	12
19. Marl, indurated, massive, white	1
18. Sand, medium to coarse, loose, tan to gray	6.5
17. Sand and gravel, becoming finer upward; well cemented near top and bottom	10
16. Silt, fine sand, and gravel in lower part grading upward into uniform sand, tan to gray-tan, lenticularly cemented, silt and clay zones commonly below the cemented lentils	53
15. Silt, massive, noncalcareous, pinkish-brown to gray-brown, becoming darker upward. Resembles A and B horizons of a soil	1

14. Sand, fine, massive, well sorted, grayish-tan, calcareous	5
13. Sand, fine, grading upward into coarser sand and some gravel, 0.5 foot silty clay at top, buff to pinkish-brown, cemented in lower part; thin lentils of fine sand and silt throughout	18
12. Silt and fine sand, gray, tan, and pinkish-brown, lenticularly cemented, joints in upper part filled with calcium carbonate	23
11. Volcanic ash (*Rawlins* bed), silt, and fine sand, gray; lower part relatively pure ash	4
10. Partly covered sand and gravel	23
9. Sand, fine to medium, gray to tan, indurated, calcium carbonate cement	14
8. Silt and fine sand, becoming coarser upward, gray, tan, and tan-white, generally uncemented, but scattered lentils indurated	21.5
7. Sand, containing a few pebbles of pink quartz, gray to tan, well cemented	2
(? Valentine member ?)	
6. Sand, fine, containing silt in upper part, platy, gray, well cemented in basal part, stringers and concretions of lime throughout	7.5
5. Sand, fine, containing abundant cobbles and pebbles of calcium carbonate cemented sand and silt; upper part indurated throughout	4
4. Sand, fine, gray, calcareous; contains discontinuous indurated zones	22
3. Sand, silty, massive, gray, uncemented	1.5
2. Sand, fine, silty, massive, calcareous, gray, well cemented in discontinuous zones; conglomeritic in upper part	15.5
1. Covered slope from bed of creek. (Judged on the basis of exposures a short distance to the north, the top of the Brule formation is at or somewhat below the level of the creek channel at this point.)	8
Total section measured	305.5

REFERENCES

ASHLEY, G. H., and others (1933) Classification and nomenclature of rock units: Geol. Soc. America Bull., v. 44, p. 423-459.

ATWOOD, W. W., and ATWOOD, W. W., JR. (1948) Tertiary-Pleistocene transition at the east margin of the Rocky Mountains: Geol. Soc. America Bull., v. 59, p. 605-608.

BARBOUR, E. H., and COOK, H. J. (1917) Skull of AELURODON PLATYRHINUS, sp. nov.: Nebraska Geol. Survey Bull., v. 7, pt. 19, p. 173-180.

BRETZ, J H., and HORBERG, LELAND (1949) Caliche in southeastern New Mexico: Jour. Geology, v. 57, p. 491-511.

BYRNE, F. E., BECK, H. V., and BEARMAN, C. H. (1949) Construction materials in Norton County, Kansas: U. S. Geol. Survey Circ. 24, p. 1-16.

COLBERT, E. H. (1938) Remarks on the use of the name "Valentine": Am. Jour. Sci., 5th ser., v. 36, p. 212-214.

COOK, H. J. (1922) Two new Bunomastodonts from Colorado: Colorado Mus. Nat. History Proc., v. 4, no. 1, 15 p.

———(1922a) A Pliocene fauna from Yuma County, Colorado, with notes on the closely related Snake Creek beds, from Nebraska: Colorado Mus. Nat. History Proc., v. 4, no. 2, 29 p.

———(1927) A new Rhinoceros of the genus *Teleoceras* from Colorado: Colorado Mus. Nat. History Proc., v. 7, no. 1, 2 p.

———(1930) New Rhinoceroses from the Pliocene of Colorado and Nebraska: Colorado Mus. Nat. History Proc., v. 9, no. 4, pp. 44-51.

———and COOK, M. C. (1933) Faunal lists of the Tertiary vertebrata of Nebraska and adjacent areas; with Preface by George Evert Condra: Nebraska Geol. Survey Paper 5, 58 p.

DARTON, N. H. (1899) Preliminary report on the geology and water resources of Nebraska west of the One Hundred and Third Meridian: U. S. Geol. Survey. 19th Ann. Rept., pt. 4, Hydrology, p. 719-785.

———(1905) Preliminary report on the underground-water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, p. 1-433.

———(1920) U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin folio, (no. 212) 10 p.

ELIAS, M. K. (1931) The geology of Wallace County, Kansas: Kansas Geol. Survey Bull. 18, p. 1-254.

———(1937) Geology of Rawlins and Decatur Counties, with special reference to water resources: Kansas Geol. Survey Min. Resources Circ. 7, p. 1-25.

———(1942) Tertiary prairie grasses and other herbs from the High Plains: Geol. Soc. America, Special Paper 41, p. 1-176.

———(1948) Ogallala and post-Ogallala sediments: Geol. Soc. America Bull., v. 59, p. 609-612.

ENGLEMANN, HENRY (1876) Appendix I. Report on the geology of the country between Fort Leavenworth, Kansas, and the Sierra Nevada, near Carson Valley; p. 243-335, *in* Simpson, J. H., Report of explorations across the Great Basin of the Territory of Utah for a direct wagon-route from Camp Floyd to Genoa, in Carson Valley, in 1859, Washington, G. P. O., p. 1-518.

FRICK, CHILDS (1937) Horned ruminants of North America: Am. Mus. Nat. History Bull., v. 69, 669 p.

FRYE, J. C. (1945) Geology and ground-water resources of Thomas County, Kansas: Kansas Geol. Survey Bull. 59, p. 1-110.

———(1945a) Valley erosion since Pliocene "Algal limestone" deposition in central Kansas: Kansas Geol. Survey Bull. 60, pt. 3, p. 85-100.

———(1948) Pliocene-Pleistocene boundary in the Great Plains—evidence and problems: Geol. Soc. America Bull., v. 59, p. 598-604.

———(1955) Erosional history of the Flint Hills: Kansas Acad. Sci. Trans., v. 58, p. 79-86.

———and LEONARD, A. B. (1952) Pleistocene geology of Kansas: Kansas Geol. Survey Bull. 99, p. 1-230.
———and LEONARD A. R. (1949) Geology and ground-water resources of Norton County and northwestern Phillips County, Kansas: Kansas Geol. Survey Bull. 81, p. 1-144.
———and SWINEFORD, ADA (1946) Silicified rock in the Ogallala formation: Kansas Geol. Survey Bull. 64, pt. 2, p. 33-76.
———SWINEFORD, ADA, and LEONARD, A. B. (1948) Correlation of Pleistocene deposits of the central Great Plains with the glacial section: Jour. Geology, v. 56, p. 501-525.
GILBERT, G. K. (1896) The underground water of the Arkansas valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, p. 551-601.
HAWN, F. (1866) Report of Major F. Hawn; *in* Swallow, G. C., Kansas Geol. Survey Prelim. Rept., p. 95-112.
HAWORTH, ERASMUS (1897) Physical properties of the Tertiary: Kansas Univ. Geol. Survey, v. 2, p. 247-284.
HAY, ROBERT (1885) Preliminary report on the geology of Norton County, Kansas: Kansas Acad. Sci. Trans., v. 9, p. 17-24.
HESSE, C. J. (1935) A vertebrate fauna from the type locality of the Ogallala formation: Kansas Univ. Sci. Bull., v. 22, no. 5, p. 79-117.
HIBBARD, C. W. (1934) Two new genera of Felidae from the middle Pliocene of Kansas: Kansas Acad. Sci. Trans., v. 37, p. 239-255.
———(1939) Notes on additional fauna of Edson quarry of the Middle Pliocene of Kansas: Kansas Acad. Sci. Trans., v. 42, p. 457-461.
———(1952) Vertebrate fossils from Late Cenozoic deposits of central Kansas: Kansas Univ. Paleontological Contributions; Vertebrata, Art. 2, p. 1-14.
JOHNSON, F. W. (1935) The status of the name "Valentine" in Tertiary geology and paleontology: Am. Jour. Sci., 5th ser. v. 31, p. 467-475.
———(1938) Further comments on the usage of "Valentine": Am. Jour. Sci., 5th ser., v. 36, p. 215-219.
JOHNSON, W. D. (1901) The High Plains and their utilization: U. S. Geol. Survey 21st Ann. Rept., pt. 4, p. 601-741.
KING, CLARENCE (1878) Systematic geology: U. S. Geol. Expl. 40th Par. Rept., v. 1, 803 p.
LANDES, K. K., and KEROHER, R. P. (1942) Mineral resources of Phillips County: Kansas Geol. Survey Bull. 41, pt. 8, p. 277-312.
LEONARD, A. B., and FRANZEN, D. S. (1944) Mollusca of the Laverne formation (lower Pliocene) of Beaver County, Oklahoma: Kansas Univ. Sci. Bull., v. 30, pt. 1, p. 15-39.
LEWIS, G. E. (1938) Commentary on McGrew and Meade's paper: Am. Jour. Sci., 5th ser., v. 36, p. 208-211.
LUGN, A. L. (1938) The Nebraska State Geological Survey and the "Valentine Problem": Am. Jour. Sci., 5th ser., v. 36, p. 220-227.
———(1939) Classification of the Tertiary System in Nebraska: Geol. Soc. America Bull., v. 50, p. 1245-1276.
McGREW, P. O., and MEADE, G. E. (1938) The bearing of the Valentine area in continental Miocene-Pliocene correlation: Am. Jour. Sci., 5th ser., v. 36, p. 197-207.
MEEK, F. B., and HAYDEN, F. V. (1862). Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska, by the exploring expedition under the command of Capt. Wm. F. Raynolds, U. S. Top. Engrs.; with some remarks on the rocks from which they were obtained; Acad. Nat. Sci. Philadelphia Proc. 1861, p. 415-447.
MERRIAM, D. F., and FRYE, J. C. (1954) Additional studies of the Cenozoic of western Kansas: Kansas Geol. Survey Bull. 109, pt. 4, p. 49-64.
MOORE, R. C., FRYE, J. C., and JEWETT, J. M. (1944) Tabular description of outcropping rocks in Kansas: Kansas Geol. Survey Bull. 52, pt. 4, p. 137-212.

MOORE, R. C., and others (1951) The Kansas rock column: Kansas Geol. Survey Bull. 89, p. 1-132.

OSBORN, H. F. (1909) Cenozoic mammal horizons of western North America: U. S. Geol. Survey Bull. 361, 138 p.

PRESCOTT, G. C., JR. (1951) Geology and ground-water resources of Lane County, Kansas: Kansas Geol. Survey Bull. 93, 126 p.

———(1953) Geology and ground-water resources of Cheyenne County, Kansas: Kansas Geol. Survey Bull. 100, 106 p.

———(1953a) Geology and ground-water resources of Sherman County, Kansas: Kansas Geol. Survey Bull. 105, 130 p.

PRICE, W. A., ELIAS, M. K., and FRYE, J. C. (1946) Algal reefs in the cap rock of Ogallala formation on Llano Estacado plateau, New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 1742-1746.

SIMPSON, G. G. (1933) Glossary and correlation charts of North American Tertiary mammal-bearing formations: Am. Mus. Nat. History Bull., v. 67, art. 3, p. 79-121.

SMITH, H. T. U. (1940) Geologic studies in southwestern Kansas: Kansas Geol. Survey Bull. 34, p. 1-240.

STIRTON, R. A. (1936) Succession of North American continental Pliocene mammalian faunas: Am. Jour. Sci., 5th ser., v. 32, p. 161-206.

———(1944) Comments on the relationships of the Cervoid family Palaeomerycidae: Am. Jour. Sci., v. 242, p. 633-655.

———and MCGREW, P. O. (1935) A preliminary notice on the Miocene and Pliocene mammalian faunas near Valentine, Nebraska: Am. Jour. Sci., 5th ser., v. 29, p. 125-132.

SWINEFORD, ADA, and FRYE, J. C. (1946) Petrographic comparison of Pliocene and Pleistocene volcanic ash from western Kansas: Kansas Geol. Survey Bull. 64, pt. 1, p. 1-32.

———FRYE, J. C., and LEONARD, A. B. (1955) Petrography of the late Tertiary volcanic ash falls in the central Great Plains: Jour. Sedimentary Petrology, v. 25, p. 243-261.

THORPE, M. R. (1922) Some Tertiary carnivora in the Marsh collection, with descriptions of new forms: Am. Jour. Sci., 5th ser., v. 3, p. 423-455.

WAITE, H. A. (1947) Geology and ground-water resources of Scott County, Kansas: Kansas Geol. Survey Bull. 66, 216 p.

WILLIAMS, C. C., and LOHMAN, S. W. (1949) Geology and ground-water resources of a part of south-central Kansas: Kansas Geol. Survey Bull. 79, p. 1-455.

WILMARTH, G. M. (1938) Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, pt. 1, p. 1-1244; pt. 2, p. 1245-2396.

WOOD, H. E., and others (1941) Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, p. 1-48.

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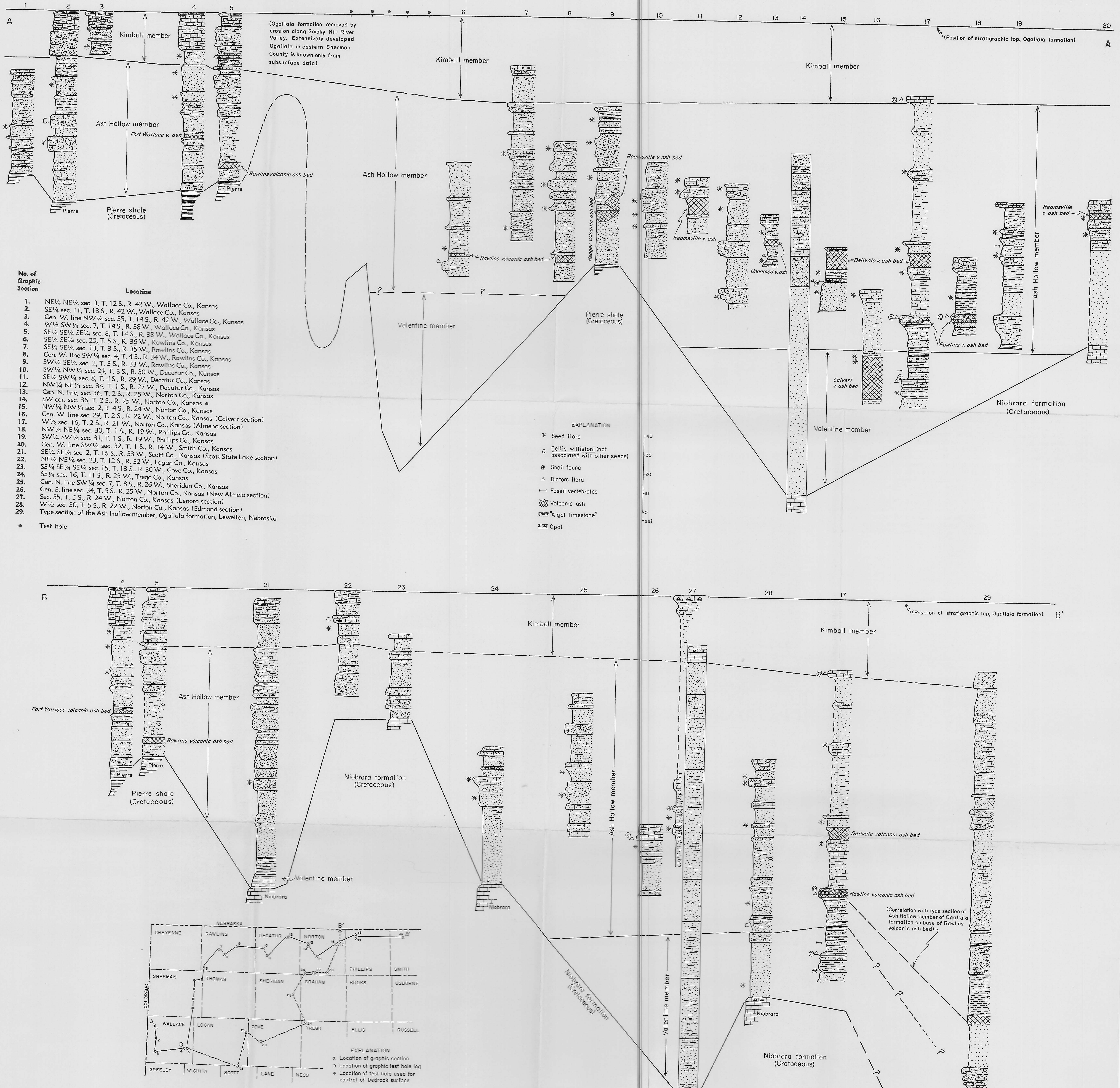

State Geological Survey of Kansas
Bulletin 118, Plate I

Correlated Measured Sections of the Ogallala Formation in Northern Kansas

by John C. Frye, A. Byron Leonard, and Ada Swineford, 1956