Geology of Franklin, Webster, and Nuckolls Counties, Nebraska

GEOLOGICAL SURVEY BULLETIN 1165

Prepared as part of a program of the Department of the Interior for the development of the Missouri River basin

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By ROBERT D. MILLER, RICHARD VAN HORN, ERNEST DOBROVOLNY *and* LAURENCE P. BUCK

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Study of the geology of part of south-central Nebraska, with emphasis on the deposits of Pleistocene age and their engineering characteristics

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CONTENTS

ILLUSTRATIONS

[Plates are in separate volume]

TABLES

GEOLOGY OF FRANKLIN, WEBSTER, AND NUCKOLLS COUNTIES, NEBRASKA

By Robert D. Miller, Richard Van Horn, Ernest Dobrovolny and Laurence P. Buck

ABSTRACT

Franklin, Webster, and Nuckolls Counties cover 1,728 square miles in south-central Nebraska immediately north of the Kansas State line.

Shale and chalk of Late Cretaceous age make up the principal bedrock exposures in the three counties. The Carlile Shale, the oldest formation exposed, is composed of the Blue Hill Shale Member, a dark plastic clayey shale about 80 feet thick, and the overyling Codell Sandstone Member, a soft sandy siltstone only 6 inches thick. The overlying Niobrara Formation is composed of the Fort Hays Limestone Member, a massive limestone and interbedded chalky shale about 40 feet thick, and the Smoky Hill Chalk Member, a gray silty chalk and interbedded chalky shale about 420 feet thick. The uppermost bedrock unit is black plastic clayey Pierre Shale.

Unconformably overlying the Upper Cretaceous rocks is the Ogallala Formation of Pliocene age. It is composed of three units: undifferentiated sand, silt, and clay; quartzite; and mortar beds. The undifferentiated unit consists of well-graded coarse to fine, silty sand; sandy to clayey silt; and silty clay. The sand of the Ogallala is distinguished from overlying Pleistocene deposits by a greater percentage of chert pebbles and calcium carbonate coated pebbles and a smaller percentage of granitic pebbles. The quartzite and mortar beds are lenticular deposits that commonly form ledges on valley sides. The quartzite beds are composed of coarse- to fine-grained sand that is strongly cemented by opaline silica. The mortar beds are sand to sandy silt, moderately well cemented by calcium carbonate.

Sand, silt, volcanic ash, and clay of Pleistocene age unconformably overlie deposits of Cretaceous and Tertiary age. These Pleistocene deposits range in age from Kansan to Wisconsin. Coarse sands of the Grand Island Formation and the underlying Red Cloud Sand and Gravel of Kansan age (which in this report are mapped together) are the oldest Pleistocene deposits exposed in the three counties. They consist principally of crossbedded pebbly coarse sand and a few lenticlar beds of silt and clay. The Sappa Formation of late Kansan and early Yarmouth age at many places overlies the Grand Island. The Sappa consists of three units: the lower silt member, the Pearlette Ash Member, and the upper silt and clay member that locally grades downward into a coarse sand.

Overlying the Sappa Formation is the Crete Formation of Illinoian age. It is a chalky silty colluvium at most places south of the Republican River, but chiefly a coarse sandy alluvium north of the river. The alluvium is similar to the Grand Island Formation; the two can be differentiated only where the Sappa separates them. The Loveland Loess is of Illinoian age. It is a massive, moderate yellowish-brown silt that unconformably overlies the Crete Formation.

Dark-gray humic horizons occur within the Loveland at several localities. A very dark gray-brown soil of Sangamon age is preserved at the top of the loess in most places. Both the soil and the loess are distinctive stratigraphic markers. Overlying the Loveland Loess is yellowish-gray silt of undifferentiated Peorian and Bignell Loesses of Wisconsin age. The older of the two loesses, the Peorian, was deposited during the early part of Wisconsin time; the younger loess, the Bignell, is a later Wisconsin deposit. A well-developed very dark gray-brown soil that may be the Brady Soil of Schultz and Stout (1948, p. 570) separates the two loesses at some places. A high flat surface, referred to in this report as the loess-covered terrace, is prominent along the Republican River. At most places stratified silt in this terrace is overlain by massive Peorian and Bignell Loesses.

Materials of Recent age include two terrace deposits, two dune sand deposits, and alluvium on the flood plains of modern streams. The terraces, consisting of clayey to sandy silt, are flat-topped valley fills bordering streams throughout the area. The dune sand, found only in Franklin County, is fine grained and forms a hummocky terrain. Alluvium, composed of silt and sand, is restricted to the flood plains of the major streams in the area.

The dominant structural feature in the area is the Central Nebraska Basin. Subsidence of the basin in Late Cretaceous and early Tertiary time probably was accompanied by differential warping and minor faulting along its margins.

Deposits in the three counties can be used as construction materials and in the manufacture of ceramic products, tile, brick, whiting, cement, mortar, agricultural lime, rock wool, abrasives, and jewelry. Test wells have been drilled for oil and gas, but no production has been obtained, although several anticlinal structures underlie the area.

Foundation conditions are generally good throughout the three counties; however, bentonite beds in the Pierre Shale and Smoky Hill Chalk Member of the Niobrara Formation can swell and cause shifting of foundations of manmade structures. Loess deposits are potentially hazardous because they tend to settle under heavy loads when saturated with water.

Most of the surficial deposits are fine grained and therefore easily eroded. Loess stands well in vertical cuts, but is rapidly eroded from sloping cuts.

INTRODUCTION

As part of the studies in conjunction with the development of the Missouri River basin, the Nebraska State Department of Roads and Irrigation and the U.S. Geological Survey cooperated in a study of the geology and preparation of an inventory of construction materials of Franklin, Nuckolls, and Webster Counties.

Surficial geology of each of the three counties was mapped at a scale of 1:48,000 (pls. 1, 2, 3). Pleistocene deposits were studied in detail and materials tests were made of more than 250 samples.

INVESTIGATION PROCEDURE

Field mapping was done on aerial photographs borrowed from the U.S. Soil Conservation Service offices in Franklin, Webster, and Nuckoll's Counties. The geology, drainage, and culture were transferred to a base map by means of a vertical sketchmaster.

Geologic investigation was under the general supervision of Ernest Dobrovolny, who also conducted part of the investigation in Webster County. The remainder of the investigation in Webster County was done by R. D. Miller. L. P. Buck conducted the investigation in Nuckolls County, and Richard Van Horn in Franklin County. Most of the fieldwork was done during the years 1948 to 1950. Preparation of this report was delayed by other duties assigned the authors and by the untimely death of Laurence P. Buck in 1957. After a brief visit to the three counties in November 1958, the author completed the report. Van Horn was primarily responsible for the sections on "Introduction," "Geography," "Upper Cretaceous Series," "Pliocene Series," "Recent," "Structure," "Economic geology," "Foundation conditions," and "Erodibility," and Miller for the sections on "Pleistocene Series," and "Geologic history."

ACKNOWLEDGMENTS

The generous assistance and advice by the following persons is acknowledged: E. C. Reed, Director, and V. H. Dreeszen, Assistant Director, Conservation and Survey Division, Nebraska Geological Survey, who gave freely of their time and advice; George Swateck, Materials Engineer, and O. L. Lund, Soils Engineer, Nebraska State Department of Roads and Irrigation, Bureau of Highways, who made available the sample-test information in their files and provided the test results of additional samples collected by the authors; Leonard S. Silvers, Emil J. Polnicky, and A. R. Kuhlman, Work Unit Conservationists, and Ralph Ferebee, Soil Conservation Service, U.S. Department of Agriculture, who helped expedite the work in the counties. Alan C. Pocta acted as field assistant in Franklin County for about 3 weeks during July 1950. The authors gratefully extend their appreciation to the local residents who permitted access to their lands.

GEOGRAPHY

Franklin, Webster, and Nuckolls Counties are in south-central Nebraska along the southern boundary of the State (fig. 1). The area is approximately bounded by lat 40°00′ and 40°21′ N, long 97°50′ and 99°10′ W. The counties comprise 48 townships and cover an area of 1,728 square miles.

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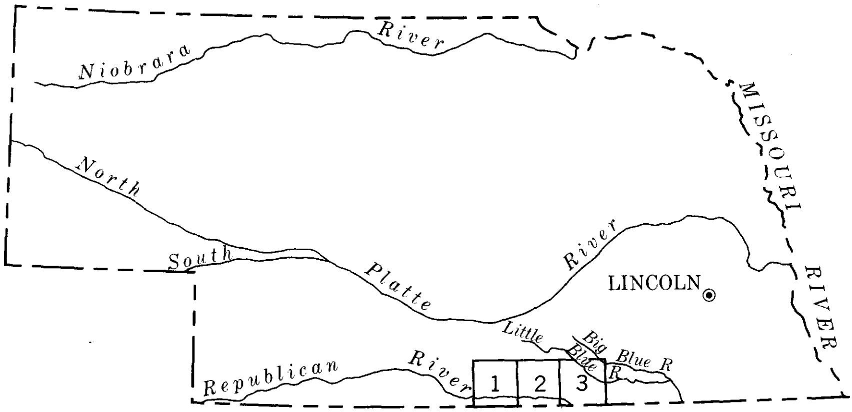


FIGURE 1.—Map of Nebraska showing location of Franklin (1), Webster (2), and Nuckolls (3) Counties.

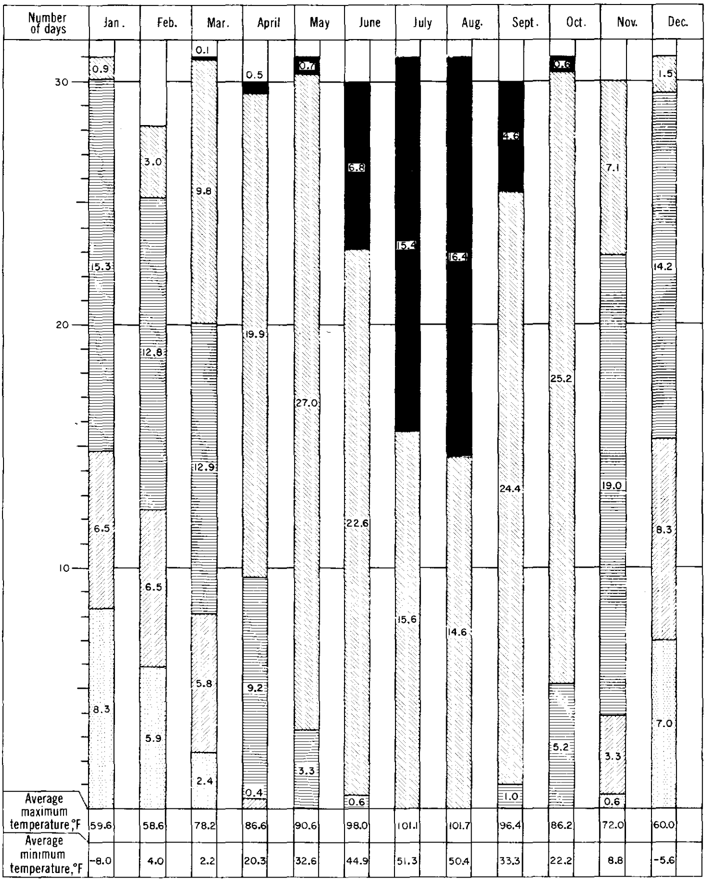
CLIMATE

The climate of the area is characterized by light rainfall, low humidity, hot summers, moderately cold winters, great annual variation in rainfall, and frequent daily or weekly weather changes. Much of the precipitation results from summer thunderstorms of short duration, at times accompanied by high winds and hail. The first killing frost in autumn generally occurs in early October and the last in the spring in early May. The mean annual temperature is about 52° F (fig. 2), and the average annual precipitation is about 23 inches (fig. 3).

PHYSIOGRAPHY

The boundary between the Plains Border section and the High Plains section of the Great Plains physiographic province crosses the northern part of the three counties. The High Plains section is characterized by a moderately rolling, poorly drained surface of low relief. The Plains Border section south of the boundary is characterized by deeply dissected topography of moderate relief. The flat upland surface of the High Plains section slopes eastward about 8 feet per mile; the altitude ranges from 2,250 feet above sea level at the highest point in the northwest corner of Franklin County to 1,750 feet near the northeast corner of Nuckolls County. The valley floor of the Republican River is about 1,950 feet above sea level at the west boundary of Franklin County and 1,500 feet near the east edge of Nuckolls County, a slope of 7 feet per mile.

The Republican and the Little Blue Rivers are the principal streams in the area. The flood plains of both these rivers, as well as those of



Data compiled from Climatological Data for years 1941–50, inclusive, issued by Weather Bureau United States Department of Commerce (U.S. Weather Bureau, 1941–50)

EXPLANATION

Days in which maximum temperature was more than 91°F

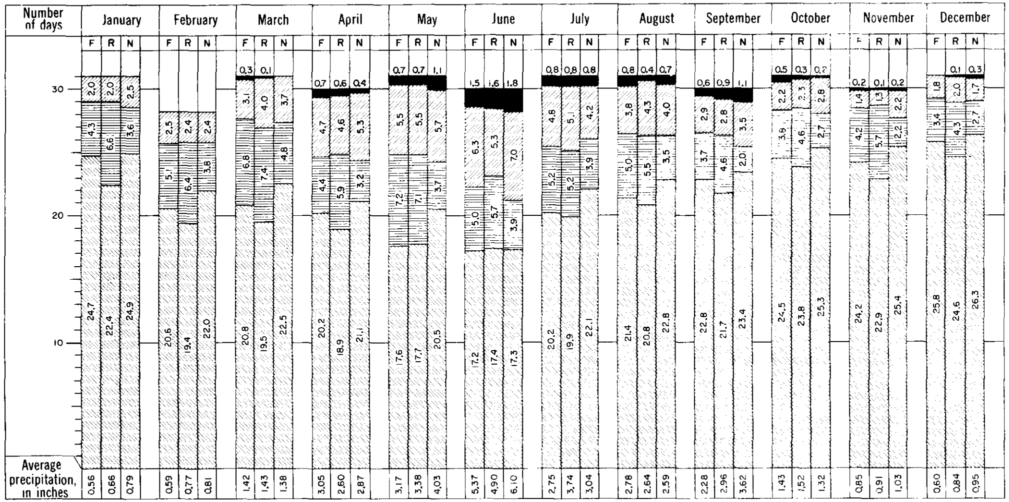
Days in which maximum temperature was between 61°–90°F

Days in which maximum temperature was between 41°–60°F

Days in which maximum temperature was between 33°–40°F

Days in which maximum temperature was less than 32°F

FIGURE 2.—Bar graph showing monthly temperature ranges (in degrees Fahrenheit) at Red Cloud, Nebr.



Data compiled from Climatological Data for years 1941-50, inclusive, issued by Weather Bureau United States Department of Commerce (U.S. Weather Bureau, 1941-50)

EXPLANATION

Days in which precipitation was more than 1 inch

Days in which precipitation was between 0.11 and 1 inch

Days in which precipitation was between a trace and 0.1 inch

Days in which there was no precipitation

F, Franklin; R, Red Cloud; N, Nelson

FIGURE 3.—Chart showing precipitation ranges at Franklin, Red Cloud, and Nelson, Nebr.

their tributaries, are flanked by terraces along the valley walls. The Republican, the larger of the two rivers, flows eastward across the southern part of the area. South of Superior the river bends to the southeast and flows into Kansas. In the three-county area, main tributary streams all enter from the north.

The Little Blue River flows southeast across the northeast corner of Franklin County into Webster County, where it abruptly turns northeast and leaves the county as a relatively small intermittent stream. It reenters the mapped area near the northeast corner of Nuckolls County and flows southeast out of the area. In Nuckolls County the Little Blue River is appreciably larger and flows throughout the year.

GEOLOGY

Bedrock of the area is chiefly shale and chalk of Late Cretaceous age, which crops out near the Republican River. Tertiary and Quaternary deposits of sand, silt, and clay, mostly unconsolidated, overlie the shale and chalk. Most outcrops of the Tertiary deposits are south of the Republican River; the Quaternary deposits mantle the entire area except where stripped by erosion.

Several thousand feet of older sedimentary rock underlie the exposed Upper Cretaceous rocks but are not discussed in this report. In the section on "Structural geology" brief mention is made of the Dakota Sandstone of Cretaceous age that forms a widespread rock layer in the subsurface of all except the southeastern part of Nebraska, and also of the Precambrian basement complex of metamorphic and igneous rocks that underlie the sedimentary rocks of Nebraska.

UPPER CRETACEOUS SERIES

Rocks of Late Cretaceous age exposed in the mapped area in ascending order are: the upper part of the Carlile Shale, the Niobrara Formation, and the lower part of the Pierre Shale. The configuration of the eroded bedrock surface, and the approximate locations of the concealed contacts between the three bedrock units for the area north of the Republican River are shown on plate 4. Similar information was not compiled for the area south of the Republican River because there are so few well records.

The geologic bedrock map (pl. 4) in general conforms with the bedrock map of Keech and Dreeszen (1959, pl. 1). However, their map shows a large buried valley entering northeastern Nuckolls County. Although the subsurface information is scarce in this area, it seems probable that the large valley does not enter Nuckolls County but, instead, extends eastward into a larger buried valley in eastern Clay County.

CARLILE SHALE

Only the upper part of the Carlile Shale is exposed in this area, and outcrops are confined to the sides of tributary valleys in the southern part of Nuckolls County. Well records indicate that the Carlile Shale probably underlies Webster County in the Republican River valley as far west as Guide Rock. Two members of the Carlile, the Blue Hill Shale Member and the overlying Codell Sandstone Member, constitute many of the exposures, but they are not differentiated on the geologic maps. X-ray analyses by A. J. Gude, 3d (written communication, February 13, 1957), of the clay-size fraction of two members of the Carlile Shale indicate that the Blue Hill contains principally a mixed-layered montmorillonite-mica, a minor amount of quartz, and traces of kaolinite and feldspar; the Codell contains principally a mixed-layered montmorillonite-mica, a minor amount of quartz and calcite, and traces of kaolinite.

BLUE HILL SHALE MEMBER

The Blue Hill Shale Member is dark- to light-bluish gray, noncalcareous, plastic, fissile, clayey shale, that in many exposures is stained grayish orange. It weathers to pale yellowish-gray or grayish-brown flakes coated with tiny yellow specks. In many places the upper 6 inches is weathered to a plastic clay. Only the upper 42 feet of the Blue Hill is exposed.

CODELL SANDSTONE MEMBER

The Codell Sandstone Member, about 0.6 foot thick, marks the top of the Carlile Shale. It is a grayish-orange to pale yellowish-brown, noncalcareous, soft, sandy, concretionary siltstone that locally contains fossil shark teeth. At several places the Codell forms a thin hard, very resistant but porous layer. According to Jewell J. Glass (written communication, January 10, 1957) this porous layer seems to be caused by localized accumulations of opal that cement the quartz grains together. This layer is associated with a thin veinlike deposit of pure white gibbsite at one locality.

The Codell Sandstone Member is 4 inches thick in the NE cor. SE¼NE¼ sec. 27, T. 1 N., R. 8 W. (fig. 4). At this place, it is a moderate yellowish-brown siltstone containing *Inoceramus* fragments and shark teeth. The contact between the Codell Member and the overlying Fort Hays Member of the Niobrara Formation is sharp and distinct.

FIGURE 4.—Carlile-Niobrara contact exposed in the NE cor. SE¼NE¼ sec. 27, T. 1 N., R. 8 W. The man is standing on the Blue Hill Shale Member of the Carlile Shale. The base of the 4-inch-thick Codell Sandstone Member of the Carlile Shale is at the bottom of the 6-inch white ruler. The base of the Fort Hays Limestone Member of the Niobrara Formation is 2 inches below the top of the ruler.

NIOBRARA FORMATION

The Niobrara Formation is divided into the Fort Hays Limestone Member and the Smoky Hill Chalk Member, which are not differentiated on the geologic maps.

FORT HAYS LIMESTONE MEMBER

The Fort Hays Limestone Member, about 40 feet thick, overlies the Carlile Shale, and is exposed in Webster and Nuckolls Counties near the Republican River. The limestone is grayish yellow to light brown, massive to thin bedded, and contains scattered small ferruginous concretions. Locally, thin layers of light bluish-gray chalky shale are interbedded with the limestone. The base of the Fort Hays is generally marked by a cliff-forming massive limestone bed 7 to 8 feet thick.

Wilson and Skinner (1937, p. 14, 15, and 124) show that the Fort Hays Limestone Member is composed principally of coccolith fragments and is similar to the Cretaceous chalk deposits of Great Britain. Shells of Foraminifera and the larger *Inoceramus* constitute most of the remaining material in the Fort Hays; ostracodes are also present (Loetterle, 1937). Calcium carbonate constitutes about 75 to 90 percent of the limestone from the Fort Hays (table 9). A typical sequence of rocks is shown in measured section 1.

SMOKY HILL CHALK MEMBER

The Smoky Hill Chalk Member, about 420 feet thick, is exposed in all three counties. The most extensive exposures are south of the Republican River in Franklin and Webster Counties and north of the river in the southern part of Nuckolls County. These exposures are generally along the sides of major valleys and in the bottoms of tributaries. At many places excellent exposures occur in the low cliffs at the margins of the Republican River valley (fig. 5).

The Smoky Hill Chalk Member is light bluish-gray to light olive-gray soft silty chalk that is interbedded with chalky shale and seams of white to dark yellowish-orange bentonite that range from a trace to as much as 3 feet in thickness. In addition, seams of gypsum about 3 inches thick occur at a few places. The chalk and chalky shale weather dark yellowish orange, very pale orange, or light gray, and contain many fossil clams, oysters, and Foraminifera. A. J. Gude, 3d, reports (written communication, February 13, 1957) that a single sample of weathered Smoky Hill is principally calcite but contains minor undifferentiated mixed-layered clay minerals and a trace of quartz. The microscopic remains of coccolith fragments probably make up the bulk of the Smoky Hill.

Foraminifera from several outcrops were identified by A. R. Loeblich, Jr., of the U.S. Geological Survey. (See table 1.) Two species, *Bolivina crenulata* Loetterle and *Loxostoma applinae* (Plummer) (from USGS loc. f 11984) are considered by Loetterle (1937, p. 17) to be good markers for the upper 50 feet of the Niobrara Formation (fig. 5). All outcrops in Franklin County probably are in the upper half of the Smoky Hill. The lower half is exposed in Webster and Nuckolls Counties. The fossil clams and oysters were not identified but appear to be species of *Inoceramus* and *Ostrea*.

At a few places in southeastern Franklin County there are hard zones of yellowish-brown to yellowish-green silicified chalk in the

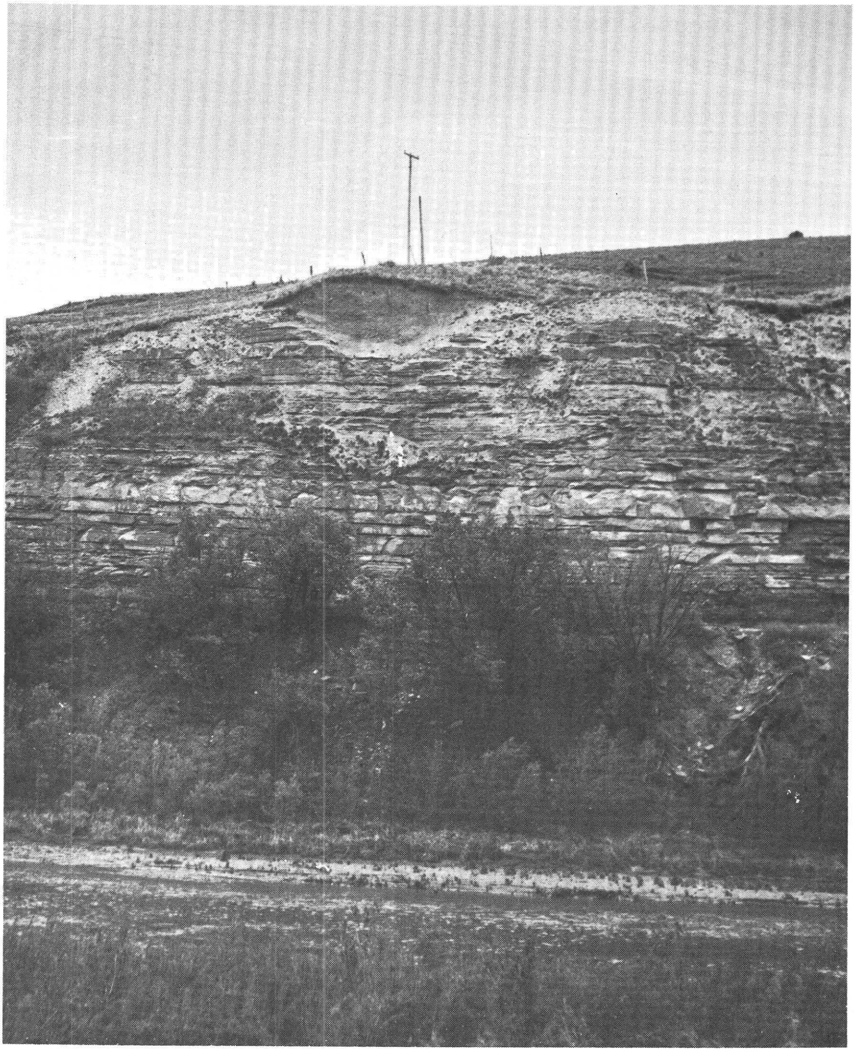


FIGURE 5.—Smoky Hill Chalk Member of the Niobrara Formation exposed at the Bloomington Bridge in the NE¼SW¼ sec. 8, T. 1 N., R. 15 W., at the site of measured section 2. This exposure is Loetterle's locality 35 which he considered to be in the upper part of the Smoky Hill Chalk Member. Note the eroded surface of the Smoky Hill in the center of the photograph, and the reversal of topography reflected in the Peorian and Bignell Loesses.

Smoky Hill. These zones are near the eroded bedrock surface on which the Ogallala Formation was deposited and they probably originated by leaching of silica from volcanic ash beds in the Ogallala Formation and by redeposition of the silica in the Niobrara (Frye and Swineford, 1946, p. 55–60). An abandoned quarry in the SE¼SE¼ sec. 24, T. 1 N., R. 13 W., appears to have been excavated in a large silicified zone in the Smoky Hill Chalk Member. A lens of silicified chalk 3 feet long and half a foot thick is exposed in a roadcut in sec. 22, T. 1 N., R. 15 W., where it is overlain by unsilicified chalk.

Measured section 2 shows a typical sequence of rocks in the Smoky Hill Chalk Member. Samples from this section were examined for microfossils (table 1 USGS fossil locs. f 11987 bed 27, and f 11988 bed 43) and analyzed chemically (table 9, samples 5 and 6).

PIERRE SHALE

The Pierre Shale crops out in a few places in the western part of Franklin County; well-log data indicate that it underlies the Tertiary and Quaternary deposits in northern Franklin and northwestern Web-

TABLE 1.—*Foraminifera of the Smoky Hill Chalk Member of the Niobrara Formation, Franklin County, Nebr.*

[Identified by A. R. Loeblich, Jr.]

Foraminifera	USGS fossil locality [1]					
	[2] f 11983	[3] f 11984	[4] f 11985	[5] f 11987	f 11988	[6] f 11989
	Bed 1			*Bed 27*	*Bed 43*	
Bolivina crenulata Loetterle	×	------	------	------	------	×
Dentalina sp	×	×	------	------	×	×
Eouvigerina sp. aff. *E. americana* Cushman	×	------	------	------	------	------
Globigerina cretacea D'Orbigny	------	×	×	×	×	×
sp	------	×	×	×	------	------
Globorotalia cf. *G. umbilicata* Loetterle	------	×	------	------	------	------
Globotruncana arca (Cushman)	------	×	------	------	------	------
Gümbelina globulifera (Reuss)	------	×	------	------	------	------
globulosa (Ehrenberg)	------	×	------	------	×	------
plummerae Loetterle	------	------	------	×	------	------
sp	------	------	×	------	------	×
Loxostomum applinae (Plummer)	------	×	------	------	------	------
Neobulimina irregularis Cushman and Parker	×	------	------	------	------	------
Nodosaria sp	×	------	------	------	------	------
Planulina cf. *P. kansasensis* Morrow	×	------	------	------	------	------
sp	×	------	------	------	------	------

[1] All samples except from localities f 11985 and f 11988 contained teeth of *Euchodus* sp. (identified by David H. Dunkle of the U.S. National Museum, I. G. Sohn, written communication, April 30, 1951), a fish which had worldwide distribution in the Upper Cretaceous.
[2] Measured section 3 (Pl. 1, sample 74), SE¼SE¼ sec. 15, T. 1 N., R. 16 W.
[3] SW¼SE¼ sec. 24, T. 1 N., R. 15 W.
[4] NW¼SW¼ sec. 27, T. 2 N., R. 13 W.
[5] Measured section 2, unit 27 (Pl. 1, sample 69), NE¼SW¼ sec. 8, T. 1 N., R. 15 W.
[6] NE¼NW¼ sec. 21, T. 1 N., R. 14 W.

ster Counties. The Pierre is chiefly a brownish-gray to black, fissile, noncalcareous, soft, plastic, clayey shale. At places it contains thin seams of bentonite and nodules and rosettes of gypsum. The shale is principally clay-size material but has a few silt-size grains of quartz. Except for a few fish scales, no fossils were found.

The contact between the Pierre Shale and the underlying Smoky Hill Chalk Member of the Niobrara Formation is lithologically sharp. (See measured section 3.) Although no evidence was found for either angular or errosional unconformities, there was certainly an abrupt change in depositional environment from the very calcareous Smoky Hill to the noncalcareous Pierre.

The total thickness of the Pierre Shale deposited in this area is not known; the greatest thickness of Pierre, about 200 feet, is in northwestern Franklin County. Condra and Reed (1943, p. 16 and 17) stated that the Pierre is about 2,000 to 3,000 feet thick in western Nebraska and adjacent states.

PLIOCENE SERIES

OGALLALA FORMATION

Rivers flowing from the Rocky Mountains built an alluvial plain into eastern Kansas and Nebraska in Pliocene time. Interfingering stream gravels, flood-plain sand and silt, and lake silts form the Ogallala Formation of Pliocene age, which unconformably overlies the Cretaceous bedrock. The Ogallala crops out in the bottoms and sides of valleys south of the Republican River in Franklin and Webster Counties. Drill-hole logs (Waite, Reed, and Jones, 1946; Keech and others, 1953 a, b, and c) indicate that it underlies Quaternary deposits north of the Republican River in all three counties. The only outcrop of Ogallala found north of the river is in the middle of sec. 20, T. 2 N., R. 12 W., Webster County. Three units were mapped in the Ogallala Formation: undifferentiated sand, silt, and clay; quartzite; and mortar beds. The quartzite and mortar beds consist of sand and silt that were cemented by secondary accumulations of silica and calcium carbonate, and are exposed only in Franklin County, where they seem to be near and associated with the eroded upper surface of the Ogallala, rather than at any one stratgraphic horizon. Measured section 4 shows the heterogeneity that is typical of this formation.

The only diagnostic fossil found in the Ogallala Formation in the area came from a coarse sand deposit in the SW¼ sec. 27, T. 1 N., R. 11 W. (pl. 2, D–278; table 2, sample 9). It was identified as the third lower molar of a small *Hipparion*-like equid (G. E. Lewis, written communication, June 5, 1959). Lewis stated that this type of fossil horse is characteristic of the "Valentine formation (Lugn, 1939) or lower part of the Ash Hollow formation of the middle part of the Ogallala group of Nebraska." He considers the fossil to be of early Pliocene age.

UNDIFFERENTIATED SAND, SILT, AND CLAY

The undifferentiated material in the Ogallala Formation consists of well-graded coarse to fine silty sand; sandy to clayey silt; and silty clay. The maximum thickness measured in an outcrop was 30 feet, although the unit is much thicker in places.

SAND

The sand is grayish yellow, dark greenish yellow, or moderate yellowish brown. Rounded pebbles contained in the sand are principally chert and quartz but a few consist of a strongly weathered light-colored igneous rock. Comparison of the results of mechanical analysis of the coarse sand from the Ogallala (Miller and others, 1964) with results of similar analyses from near Wray, Colo. (Hill and Tompkin, 1953, table 3) shows a noticeable increase in grain size toward the west, the source direction of the formation.

The coarse sands of the Ogallala and Pleistocene deposits are similar in general appearance, but many of the larger pebbles (greater than 20 mm in diameter) are incrusted with calcium carbonate and seem to be more weathered than pebbles in the Pleistocene deposits. This incrustation gives a collection of Ogallala pebbles a light-gray appearance as opposed to a pale-reddish-brown appearance of thePleistocene pebbles. Lithologically this unit of the Ogallala contains more than 10 percent chert pebbles and a greater variety of colors, including dark brown, dark gray, moderate red, and grayish purple; chert in Pleistocene deposits occurs in amounts of less than 10 percent and is generally dark gray or dark brown. The coarse sand of the Ogallala contains only a few granitic pebbles, whereas the coarse sand in the Pleistocene deposits is composed predominantly of medium- to fine-grained white and pink granitic pebbles. Deposits of both ages contain some mafic igneous rocks, but those in the Ogallala generally are weathered light gray and contain phenocrysts of a dark mafic mineral, whereas in the Pleistocene deposits the igneous rocks are mostly dark gray and have dark phenocrysts.

A study of pebbles from 5 to 20 mm in diameter (table 2) reveals that chert pebbles and lime coatings also are more abundant in the coarse sand of the Ogallala than in coarse sand of Pleistocene age. However, granitic pebbles occur in about equal quantities in both deposits.

The sand-size material of the Ogallala is predominantly quartz, but includes abundant pink and white feldspar. The coarse sand

TABLE 2.—*Lithology of fragments, 5 to 20 mm in diameter, from unconsolidated coarse sand deposits in Franklin, Webster, and Nuckolls Counties, Nebr.*

In percent.: Tr., less than 0.5 percent]

Geologic unit	Location	Sample	Chert	Granite	Feldspar	Quartz	Metamorphic	Quartzite	Igneous	Chalk	Siltstone	$CaCO_3$ nodules	Bone	Unidentified	Total
Crete Formation	SE cor. sec. 19, T. 2 N., R. 12 W	7	1	58	28	8	3	1	------	------	------	------	------	2	101
	NW¼NE¼ sec. 10, T. 1 N., R. 11 W	11	2	32	35	24	2	------	1	3	Tr.	------	------	Tr.	99
	Center sec. 21, T. 2 N., R. 10 W	13	2	54	23	18	------	------	3	------	------	------	------	------	100
	NE¼NW¼ sec. 21, T. 1 N., R. 9 W	15	2	65	15	11	3	3	1	------	1	------	------	------	101
Sappa Formation	Center sec. 21, T. 2 N., R. 10 W	12	------	82	13	3	------	------	------	------	3	------	------	------	101
Grand Island Formation	NW cor. sec. 8, T. 2 N., R. 16 W	1	Tr.	73	13	6	3	2	1	------	1	------	------	------	99
	SE¼ sec. 5, T. 1 N., R. 16 W	2	3	25	31	25	------	------	1	5	Tr.	------	------	10	100
	NW¼ sec. 11, T. 1 N., R. 16 W	3	2	26	25	24	1	------	1	2	1	16	1	4	103
	SW¼SW¼ sec. 27, T. 2 N., R. 15 W	5	2	52	27	14	1	1	Tr.	Tr.	------	------	------	2	99
	NE¼NE¼sec. 32, T. 3 N., R. 13 W	6	1	52	30	11	1	1	2	1	1	------	------	1	101
	NE¼SE¼ sec. 20, T. 2 N., R. 12 W	8	2	43	29	19	4	------	------	------	3	------	------	1	101
	E½ sec. 28, T. 2 N., R. 11 W [1]	10	4	52	22	20	1	1	------	------	1	------	------	------	101
	Center NE¼ sec. 9, T. 2 N., R. 10 W	14	1	53	27	13	1	------	4	------	1	------	------	1	101
	NE¼NE¼ sec. 32, T. 1 N., R. 8 W	16	3	39	30	33	3	------	1	------		------	------	1	100
	NW¼NW¼ sec. 21, T. 1 N., R. 7 W	17	1	56	27	12	2	------	2	------	------	------	------	------	100
	NE¼NW¼ sec. 34, T. 2 N., R. 7 W	18	2	41	40	7	9	------	------	------	1	------	------	------	100
	Sec. 1, T. 4 N., R. 7 W	19	------	50	21	23	------	4	------	------	------	------	------	2	100
	Sec. 12, T. 4 N., R. 7 W	20	2	49	17	26	------	5	------	------	1	------	------	------	100
	Sec. 2, T. 4 N., R. 5 W	21	1	60	15	22	------	1	------	------	------	------	------	2	101
Ogallala Formation	SE¼SE¼ sec. 15, T. 1 N., R. 16 W [2]	4	32	7	16	19	1	7	1	9	3	------	1	5	101
	SW¼ sec. 27, T. 1 N., R. 11 W	9	14	38	24	16	------	5	------	------	------	------	------	3	100

[1] Type locality of Red Cloud Sand and Gravel.
[2] USGS fossil locality f 11983; measured section 3, unit 7.

grains are subrounded and frosted; as the grain size decreases, the percentage of quartz grains increases and the grains become more angular and less frosted.

SILT AND CLAY

The silt beds of the Ogallala Formation are grayish orange, greenish gray, or pale olive, are moderately consolidated, and contain varying amounts of sand and clay. The clay beds are dusky yellowish green to dark yellowish orange. Zones of light-gray calcium carbonate occur at many places. The coarser parts of the silt and clay beds have many sand-size aggregates of silt and clay particles and lesser amounts of angular quartz and feldspar grains. The silt and clay locally occur as thin beds interbedded with sand and gravel, or as thick beds not obviously associated with sand and gravel. The silt and clay is generally parallel bedded in thin layers, but some deposits are massive. Free-swell tests (table 11) show that some of the more clayey material can expand as much as 70 percent. The silt and clay of the Ogallala is distinguishable from silt and clay of Pleistocene age by a lack of columnar jointing, a lighter color due to higher calcium carbonate content, and by stratigraphic relations to other deposits of known age.

QUARTZITE

Quartzite in the Ogallala Formation is an extremely hard, coarse- to fine-grained crossbedded grayish-green rock that forms ledges on the sides of valleys and on projecting shoulders of ridges between valleys. Individual beds within the quartzite range in thickness from 0.2 to 10 feet. The quartzite is composed principally of quartz and feldspar grains well cemented by opaline silica. At many places it contains grayish-green siliceous clay balls. The rock tends to break along tightly closed joints into large angular blocks of irregular shape. When broken, the rock fractures across grains rather than around them. At one place, the quartzite is composed of angular fragments of silicified chalk from the Smoky Hill Chalk Member of the Niobrara Formation. The fragments are as much as 2 inches long and are in a sparse matrix of sand-size grains of quartz and feldspar. The quartzite occurs as large discontinuous, lenticular bodies that generally overlie and lens into uncemented sand of the Ogallala.

The origin of the quartzite is related to leaching and redeposition of siliceous material. Frye and Swineford (1946, p. 56–60) have suggested that the silica cement was carried into the sandy Ogallala by ground water enriched in silica leached from overlying volcanic ash beds of rhyolitic composition. The silica was redeposited in underlying beds of the Ogallala and Niobrara where it replaced calcium carbonate.

MORTAR BEDS

The mortar beds of the Ogallala Formation consists of sand and silt particles of quartz and feldspar, moderately well cemented by calcium carbonate. They are light gray on freshly broken surfaces and medium gray on weathered surfaces. The mortar beds form bold, conspicuous ledges on valley sides and, at places, cap hills. Like the quartzite, the mortar beds seem to be large discontinuous lenticular bodies of little stratigraphic significance that formed by secondary accumulation, in this case of calcium carbonate. At the few places where the two are in contact in Franklin County the mortar beds overlie the quartzite. The greatest observed thickness of the mortar beds is about 15 feet.

PLEISTOCENE SERIES

Pleistocene deposits in this area are all nonglacial. The pre-Wisconsin deposits are of fluvial, lacustrine, colluvial, and eolian origin, whereas the Wisconsin deposits include some alluvium and colluvium but are mostly of eolian origin.

Pleistocene deposits older than early Kansan do not crop out in this area, although Lugn (1935, p. 95) described such deposits from a well near Blue Hill in northern Webster County. Exposed deposits of Pleistocene age in the three counties include the Red Cloud Sand and Gravel, the Grand Island Formation of Kansan age, the Sappa Formation of late Kansan to early Yarmouth age, the Crete Formation of early Illinoian age, the Loveland Loess of Illinoian age, and the Peorian and Bignell Loesses of Wisconsin age.

RED CLOUD SAND AND GRAVEL AND GRAND ISLAND FORMATION

The Grand Island Formation as used in this report encompasses all coarse fluvial sand and deposits of Kansan age. A redefinition and division of the formation by Schultz, Reed, and Lugn (1951, p. 548) into the Red Cloud Sand and Gravel of early Kansan age and the Grand Island Formation of late Kansan age is not used here because the differentiation of the two units had not been adopted by the Geological Survey when the mapping was completed. The type locality of the Red Cloud Sand and Gravel is a gravel pit in the E½ sec. 28, T. 2 N., R. 11 W., near Red Cloud, Webster County.

Within the glaciated region of Nebraska east of the mapped area the Red Cloud Sand and Gravel is overlain by till of Kansan age, which is overlain in turn by the Grand Island Formation of late Kansan age. The Red Cloud was deposited by streams flowing from an advancing glacier, and the Grand Island was deposited by streams flowing from a retreating glacier (Schultz, Reed, and Lugn, 1951, p. 548). In the mapped area, however, Kansan Till is not present and the Red Cloud and Grand Island of Schultz, Reed, and Lugn consist of alluvial coarse sand derived principally from the Rocky Mountains, instead of glaciofluvial outwash from the Kansan ice sheet. Schultz, Reed, and Lugn (1951, p. 548) inferred that, in the Republican River valley, the Grand Island was deposited in valleys cut into the Red Cloud, but this inferred relation could not be verified by the authors.

The Grand Island Formation, a crossbedded fine to coarse sand, crops out along tributaries of the Republican River in a zone that extends about 6 miles north of the river (Pls. 1, 2, and 3). It does not crop out south of the river in Franklin County or in western Webster County.

Topography on the Grand Island Formation is characterized by a dendritic pattern of gullies and ravines radiating out from centrally located channels. Erosion of the coarse sand typically results in moderately steep but sharply defined ribbed walls along the ravines and main channels. Where the Grand Island has not been dissected recently, it is characterized by an upland of low round hills and streams that have gentle gradients.

The Grand Island Formation is generally a light-brown fine to coarse crossbedded sand. Locally, however, the color is light gray or dark yellowish orange. Lenses of silt, pebbly sand, and isolated clay balls are a minor, but characteristic, feature. Pebbles and fragments between 0.5 and 0.187 inch (No. 4 screen) are composed predominantly of feldspar, granite, and quartz. Fragments of chert, siltstone, quartzite, igneous, and metamorphic rocks are minor constituents. Particles larger than a fourth of an inch consist almost entirely of pink feldspar, white feldspar, and granite fragments. Most of the particles are subround, but range in shape from subangular to round.

Table 2 compares samples of the Grand Island with samples collected from other formations. Granite, feldspar, and quartz exceed 75 percent in all samples of Pleistocene age, and only two Pleistocene samples contain less than 85 percent granite, feldspar and quartz. Three samples (table 2, nos. 19, 20, and 21, from the Little Blue River valley in northern Nuckolls County are low in feldspar content (21, 17, 15 percent), whereas the other samples are erratic in feldspar percentage. One other Grand Island sample that contains a very low percentage of feldspar was collected from a railroad cut along the Republican River valley in Franklin County (table 2, sample 1).

Particles smaller than 0.187 inch (No. 4 screen) are composed of quartz, pink feldspar, white feldspar, mica, granite, and black opaque minerals, some of which are attracted by a magnet. A few exposures contain flat tabular fragments of weathered and unweathered chalk from the Niobrara Formation and quartzite from the Ogallala Formation. The quartz grains are generally clear and unfrosted. Fine sand is almost exclusively quartz; other constituents are rare. The particles range in shape from angular to round.

Crossbedding is typical of Grand Island deposits, whether composed of fine or coarse sand. It is particularly well displayed in some vertical faces where etched by the wind (fig. 6). Stringers and layers of fine to coarse gravel are enclosed within the sand.

At the roadcut and borrow pit in sec. 1, T. 4 N., R. 7 W., (fig. 6) the Grand Island is topographically higher than sand exposed beneath the Sappa in the stream valley to the west. The crossbedded sand deposit in continuous, however, with the sand in the stream valley. The Sappa, locally capped by soil, is presumably an alluvial fill deposited in a valley eroded into the Grand Island Formation.

The total thickness of the Grand Island is not known. Its maximum exposed thickness is in the gravel pit 1 mile south of Cowles in Webster County. Here, about 65 feet of coarse sand unconformably

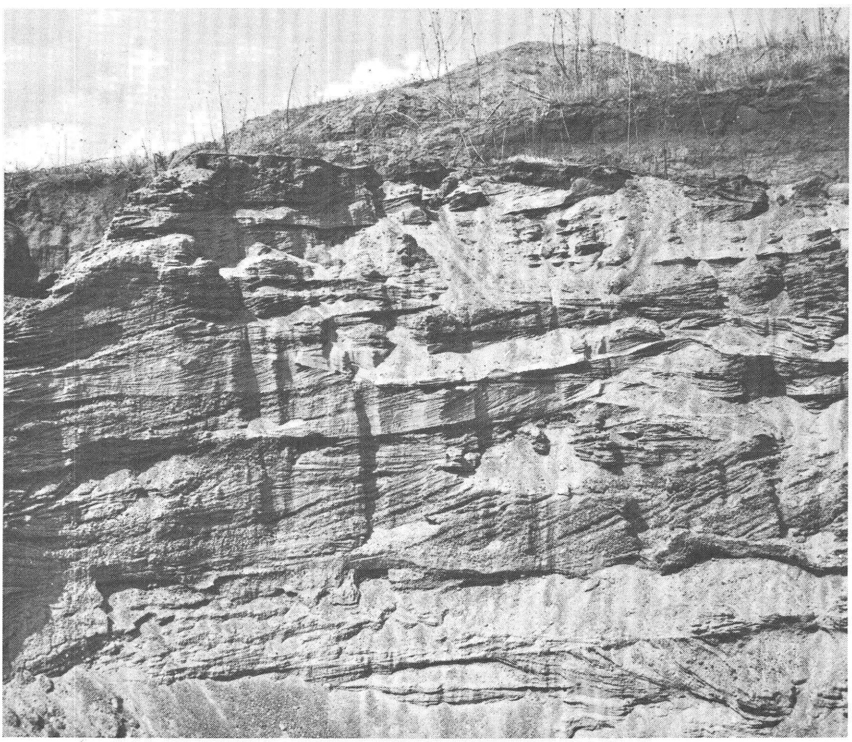


FIGURE 6.—Concave crossbedding in the Grand Island Formation exposed during field studies in 1958 in a borrow pit in the NW¼ sec. 1, T. 4 N., R. 7 W., Nuckolls County. Crossbedding in the sand is more conspicuous here than normally seen elsewhere.

723-429 O—64——4

underlies the Loveland Loess and extends down to the water level in the pit. The sand extends at least an additional 55 feet below the water level (Lugn, 1935, p. 112), for a total thickness of more than 120 feet. Test wells drilled in buried pre-Pleistocene channels north of the Republican River penetrated coarse sand ranging from 39 to 144 feet in thickness (Waite, Reed, and Jones, 1946; Keech and others, 1953a, b, and c), but part of this sand may be older than Grand Island. The maximum thickness is north of Amboy, where a test well intersected 144 feet of coarse sand in the deepest part of a buried channel trending southeast toward the present Republican River (pl. 4).

The Grand Island Formation was derived from rocks in the Rocky Mountains. Eastward-flowing streams deposited alluvium derived from the Rockies over much of the Great Plains in Kansan time. Although the margin of the Kansan ice sheet stood only about 36 miles east of Nuckolls County, near Fairbury in Jefferson County (Lugn, 1935, p. 75), any outwash carried by streams flowing from the glacier in that area was carried southeastward by the Little Blue River, which locally bounds the border of the till sheet. Drill records from Jefferson County (Keech and others, 1953i) seem to indicate that metamorphic fragments are common in coarse sand near the limit of the Kansan glacier. This is not true in the mapped area, however, where the Grand Island contains less than 3 percent metamorphic fragments (table 2).

FOSSILS

No identifiable fossils were found in the Grand Island Formation by the authors. Previous workers have, however, reported vertebrate fossils from outcrops of the formation along the Republican River valley.

Equus (*Equus*) *excelus* (horse), *Mammuthus* (*Parelephas*) *jeffersonii* (mammoth), *Titanotylopus nebrascensis* (giant camel), and *Stegomastodon aftoniae* (mastodont) are reported by Schultz (1934, p. 373, 383, 386, and 388) from the Republican River valley. In 1948, Schultz, Lueninghoener, and Frankforter (p. 36) reported that "*Stegomastodon* (mastodont), *Plesippus* (horse), and *Titanotylopus* (giant camel)" were collected from a gravel pit in the E½ sec. 28, T. 2 N., R. 11 W., which is the type locality of the Red Cloud Sand and Gravel (Schultz, Reed, and Lugn, 1951). Genera collected from the outcrops along the Republican River range in age from Nebraskan to Wisconsin, but faunas containing the restrictive fossils *Plesippus simplicidens* (Cope) (Schultz, Lueninghoener, and Frankforter, 1951, table 1; Hibbard, 1958, p. 6 and 23) and *Titanotylopus* (Schultz, Lueninghoener, and Frankforter, 1951, table 1) are probably Nebraskan to Kansan in age.

AGE AND CORRELATION

Paleontologists recognize fossils of more than one age from the coarse sand regarded as the Grand Island Formation in the mapped area, and agree that the time span of some of the fossils extends back to early Pleistocene time (Schultz, Lueninghoener, and Frankforter, 1951, table 1; Hibbard, 1958, table 1).

The Grand Island Formation in places underlies the Pearlette Ash Member of the Sappa Formation of late Kansan and early Yarmouth age. Thus, the Grand Island of this report is Kansan in age (fig. 7).

SAPPA FORMATION

The Sappa Formation consists of gray to greenish-gray clay and silty clay, tan silt, and white to gray volcanic ash, the Pearlette Ash Member, deposited during the latter part of Kansan alluviation and the early part of the Yarmouth Interglaciation. Sand, fine gravel, and humic-rich silt containing scattered pebbles are locally included within the Sappa. At some places the Sappa is capped by a humic soil formed during the Yarmouth Interglaciation. All silt and ash deposits stratigraphically above the Grand Island Formation and below the Crete Formation, regardless of origin, are mapped in this report as the Sappa Formation.

The name Sappa was first suggested by Reed (1948, p. 1346) and later formally proposed by Condra, Reed, and Gordon (1950, p. 22) to replace the Upland Formation of Lugn (1935, p. 119). At the type locality of the Sappa in Sappa Township, Harlan County, Nebr., the formation consists of an upper silt and clay member that locally grades downward into sand and gravel, the Pearlette Ash Member, and a lower silt member (Reed and Schultz, 1951, pt. 2 p. SWN 3–4). In Franklin, Webster, and Nuckolls Counties, the Pearlette Ash Member is mapped separately, but the upper and lower silt members are not differentiated.

The Sappa Formation is most abundantly exposed north of the Republican River flood plain, although several prominent outcrops occur south of the Republican near the Webster-Nuckolls County boundary. It is discontinuously exposed along major valleys and tributary ravines in the southern half of the map area (pls. 1, 2, and 3).

The thickest deposit of the Sappa Formation, over 40 feet, is in the SW¼NE¼ sec. 14, T. 3 N., R. 6 W. (measured section 6a).

Texture and type of materials constituting the Sappa Formation are related to mode of deposition. Greenish-gray clayey or sandy silt, dark humic sandy silt or clay, and beds of fine to coarse sand are of alluvial and lacustrine origin. The lacustrine Sappa represents deposits in abandoned channels, oxbow lakes, and other small ephemeral pools on the alluvium of the Grand Island Formation. Stratification

<table>
<tr><th colspan="2">Standard time units</th><th>Deposits exposed in Franklin, Webster, and Nuckolls Counties</th></tr>
<tr><td colspan="2">Recent Epoch</td><td>Flood plain alluvium
Dune sand (Qds_2)
Terrace deposits
Dune sand (Qds_1)</td></tr>
<tr><td rowspan="9">Pleistocene Epoch</td><td rowspan="3">Wisconsin Glaciation</td><td>Bignell Loess</td></tr>
<tr><td>Soil</td></tr>
<tr><td>Peorian Loess</td></tr>
<tr><td>Sangamon Interglaciation</td><td>Soil</td></tr>
<tr><td rowspan="2">Illinoian Glaciation</td><td>Loveland Loess</td></tr>
<tr><td>Crete Formation</td></tr>
<tr><td>Yarmouth Interglaciation</td><td>Soil</td></tr>
<tr><td rowspan="2">Kansan Glaciation</td><td>Sappa Formation including the Pearlette Ash Member</td></tr>
<tr><td>Grand Island Formation (mapped with Red Cloud Sand and Gravel)</td></tr>
</table>

FIGURE 7.—Chart comparing Pleistocene and Recent deposits exposed in Franklin, Webster, and Nuckolls Counties, Nebr., with the standard Pleistocene section.

is seldom conspicuous, but where evident it is commonly horizontal or wavy. Massive pinkish clayey or sandy silt in the upland areas of northern Webster and Nuckolls Counties is inferred to be loess. Its topographic position, lack of bedding, and light coloration are indicative of an eolian rather than alluvial origin. The mineral suites in the silt of the Sappa Formation consist of frosted quartz, quartzite, chlorite, pink feldspar, agglomerates of iron and manganese oxides, and unidentified black opaque minerals. At many places shards of volcanic glass compose a small but significant part of silt and clay deposits.

ALLUVIAL AND LACUSTRINE SAPPA

Deposits of alluvial and lacustrine origin are typical of the Sappa Formation. In late Kansan and early Yarmouth times rivers flowing on the Grand Island Formation deposited sandy alluvium, and silty and clayey overbank alluvium, as well as the silty and clayey lacustrine deposits in quiet pools and channels. A humic zone at the top of the Sappa, formed in Yarmouth time, is not widespread, though it is present in all three counties. It is typically exposed in the NW¼SW¼ sec. 19, T. 3 N., R. 13 W., where a 1-foot-thick layer of grayish-brown silt, rich in humus, separates the silt of the overlying Loveland Loess from the clay and silt of the Sappa Formation. The Sappa here overlies about 8 feet of very pale orange coarse sand of the Grand Island Formation.

Clayey silt of the Sappa crops out in Webster County about 20 feet east of the SW cor. sec. 20, T. 2 N., R. 12 W., in a ditch on the north side of the section line road. A brownish clay exposed in a ravine just south of and 20 feet lower than the road is also mapped as Sappa Formation, although it is similar in appearance to clay in the Ogallala Formation exposed three-quarters of a mile away on the east side of Farmers Creek.

Clayey Sappa also is exposed at the type locality of Lugn's Upland Formation just east of State Road 10 in the SW¼NW¼ sec. 18, T. 4 N., R. 14 W. (Lugn, 1935, p. 119–121). The West Branch of Thompson Creek makes a sweeping meander here and has exposed the Sappa beneath Loveland Loess. The section exposed at this locality in November 1958 consisted, in ascending order, of tan, very fine sand or silt, 3 to 4 feet of greenish clay, a humic zone, 5 feet of greenish sand, and 4 feet of greenish clay which contains a second humic zone about 6 inches thick. Sand of the Grand Island Formation described at this locality by Lugn (1935, p. 120) was not seen by the authors.

Coarse alluvium in the Sappa Formation is exposed at a few places in Webster and Nuckolls Counties. A dark-gray to black humic sandy silt bed, 3 feet thick, is exposed beneath crossbedded silt and coarse sand in the center of sec. 21, T. 2 N., R. 10 W., Webster County. This exposure is representative of the coarse alluvium in the Sappa. Three and one-half feet of hard pebbly silt extends from the base of the humic zone to the streambed. The humic zone and underlying pebbly silt are steeply truncated by erosion at the north and south ends of the exposure. A black crust of iron or manganese oxide coats the eroded surface at the south end. A remnant of light-gray silt overlying darker gray silt conformably overlies the humic zone at its north end. The crossbedded silt and coarse sand of the Crete Formation, 15 to 17 feet thick, unconformably overlies the humic zone and gray silt. Peorian and Bignell Loesses overlie the Crete.

LOESS OF THE SAPPA FORMATION

Sappa exposed in the northeastern part of Webster County and in the northwestern part of Nuckolls County closely resembles the Loveland Loess. It consists of light-tan or pale-brown silt that locally is almost white. At places the loess contains layers of silty volcanic ash or scattered glass shards. Outcrops of Sappa in sec. 8, T. 4 N., R. 9 W., erode in angular pinnacles and concave cusps; these errosional features are different from those in the smooth-surfaced Loveland Loess.

Orange loess of the Sappa that contains abundant shards of volcanic glass overlies the alluvial phase in a deep ditch south of the road in the NW¼SE¼ sec. 21, T. 4 N., R. 8 W. (measured section 6, unit 2). Other exposures of the Sappa Formation are listed in table 3.

TABLE 3.—*Location of typical exposures of the Sappa Formation*

Location	*Remarks*
SW¼SE¼ sec. 25, T. 2 N., R. 16 W	Alluvium.
NW¼SW¼ sec. 3, T. 4 N., R. 7 W	Alluvium; volcanic ash layer (RR–58–5).
SW¼NE¼ sec. 34, T. 2 N., R. 7 W	Alluvium; volcanic glass.
NE¼NW¼ sec. 12, T. 4 N., R. 5 W	Alluvium.
NW¼NW¼ sec. 23, T. 3 N., R. 8 W	Loess; volcanic glass.
NW¼NW¼ sec. 36, T. 1 N., R. 13 W	Do.
NE¼NE¼ sec. 28, T. 4 N., R. 8 W	Humic zone (soil of Yarmouth(?) age).
NW¼NW¼ sec. 36, T. 3 N., R. 5 W	Do.
SW¼NE¼ sec. 30, T. 4 N., R. 14 W	Do.
SW¼ sec. 32, T. 3 N., R. 13 W	Pearlette Ash Member.
SE¼SE¼ sec. 19, T. 2 N., R. 12 W	Do.
NW¼ sec. 28, T. 1 N., R. 9 W	Do.
SE¼NE¼ sec. 15, T. 3 N., R. 5 W	Do.

PEARLETTE ASH MEMBER

The Pearlette Ash Member of the Sappa Formation is a widely distributed and distinctive marker bed. It is made up of white to light-gray shards of volcanic glass of rhyolitic composition. At the type locality of the Sappa in Harlan County, Nebr., the deposit consists of four distinct ash layers, each of which perhaps represents a separate ash fall inasmuch as each grades from coarse sand-sized ash at the base to fine at the top.

The type locality of the Sappa Formation was reexamined (measured section 8) by Miller and Van Horn, accompanied by Vincent H. Dreeszen, Nebraska State Geological Survey. Heavy-mineral phenocrysts from samples collected from each bed are characteristic of the phenocrysts of the Pearlette Ash Member elsewhere in south-central Nebraska and Kansas. Phenocrysts of chevkinite (Young and Powers, 1960), ferroaugite, zircon, magnetite, and ilmenite commonly are attached to glass—an association that indicates that these minerals are inherent in the ash. Allanite is reported in the lower parts of the upper two ash beds (measured section 8, samples G–2861 and G–2862). These minerals were identified petrographically by Edward J. Young (written communication, June 16, 1960) who also stated that samples from this exposure of the Pearlette Ash Member indicate that "* * * chevkinite is relatively abundant at the base and disappears completely in the upper half of the member."

Quantitative spectrographic analyses of ash from these four beds indicate that not only is the ash consistent in composition from bed to bed, but also that the ash has a composition similar to the Pearlette Ash Member in Russell and Lincoln Counties, Kans. (table 5, samples G–2861, G–2862, G–2863).

Deposits of the Pearlette Ash Member in the mapped area are as much as several thousand feet long and 18 feet thick, although individual exposures are seldom more than 50 feet long and 5 feet thick. The thickest deposit of ash is exposed in a pit along Elk Creek, Nuckolls County, in the SW¼SE¼ sec. 14, T. 3 N., R. 6 W., where 18 feet of ash (sample C–586) is interbedded with silt of the Sappa Formation.

Fourteen samples from locatities in the three counties were analyzed spectrographically. All samples, except those described below, contained nearly the same amount of boron, gallium, niobium, yttrium, and ytterbium (table 4). Comparison of analyses of samples of the Pearlette Ash Member in Russell and Lincoln Counties, Kans. (table 4, samples G–2874 and G–2875), shows an almost identical composition.

Only one ash deposit exposed in the mapped area does not conform to the analyses characteristic of the Pearlette Ash Member. This deposit is exposed on the east side of a ravine adjacent to a small dam in the NE¼SE¼ sec. 26, T. 3 N., R. 8 W. (fig. 8; measured section 7).

TABLE 4.—*Quantitative spectrographic analyses, in percent by weight,*

[Analyst: P. R. Barnett. Samples were disaggregated and the glass shards were cleaned electromagnet; and analyses were made by general spectographic methods. Reported limits of detection]

Location	USGS sample	Ag	B	Ba	Be	Co	Cr	Cu
Kansas								
Tobin faunule locality, sec. 35, T. 14 S., R. 11 W	G-2874 [1]	<0.00005	<0.001	0.032	0.0006	<0.0001	<0.0001	0.0003
Wilson Valley, sec. 28, T. 13 S., R. 10 W	G-2875 [1]	.00008	<.001	.028	.0006	<.0001	<.0001	.0004
Nebraska								
SW¼SW¼ sec. 12, T. 2 N., R. 20 W. (type section of Sappa Formation)	G-2861 [1]	<0.00005	<0.001	0.017	0.0009	<0.0001	<0.0001	0.0004
Do	G-2862 [1]	<.00005	<.001	.018	.0006	<.0001	<.0001	.0004
Do	G-2863 [1]	<.00005	<.001	.016	.0009	<.0001	<.0001	.0003
Do	G-2864 [1]	<.00005	<.001	.016	.0006	<.0001	<.0001	.0002
NE¼SE¼ sec. 26, T. 3 N., R. 8 W	G-2872 [1]	<.00005	.006	.019	.0003	.0002	.0007	.0050
SE¼SE¼ sec. 15, T. 1 N., R. 16 W	G-2858 [1]	<.00005	<.001	.021	.0007	<.0001	<.0001	.0003
NE¼SW¼ sec. 32, T. 3 N., R. 13 W	G-2857 [1]	<.00005	<.001	.026	.0008	<.0001	<.0001	.0003
SE¼SE¼ sec. 19, T. 2 N., R. 12 W	G-2867 [1]	<.00005	<.001	.030	.0006	<.0001	.0007	.0005
SE¼NE¼NE¼ sec. 36, T. 1 N., R. 9 W	C-584 [2]	----------	.001	.03	.0009	--------	.0002	.0007
NW¼NW¼ sec. 28, T. 1 N., R. 9 W	G-2866 [1]	<.00005	<.001	.024	.0006	<.0001	<.0001	.0002
NW¼SW¼ sec. 26, T. 1 N., R. 9 W	G-2869 [1]	<.00005	<.001	.023	.0010	<.0001	<.0001	.0003
NE¼NW¼ sec. 31, T. 1 N., R. 8 W	C-583 [2]	----------	.001	.03	.001	--------	.0001	.0006
SE¼SE¼ sec. 34, T. 1 N., R. 8 W	C-581 [2]	----------	.0015	.03	.001	--------	.0002	.0008
NE¼SW¼ sec. 32, T. 2 N., R. 7 W	G-2868 [1]	<.00005	<.001	.023	.0007	<.0001	<.0001	.0003
SW¼SW¼ sec. 22, T. 1 N., R. 7 W	C-585 [2]	----------	.0015	.04	.001	--------	.0007	.0015
NW¼SW¼ sec. 3, T. 4 N., R. 7 W	G-2865 [1]	<.00005	<.001	.034	.0004	<.0001	.0004	.0005
NE¼NW¼ sec. 1, T. 1 N., R. 7 W	C-582 [2]	----------	.002	.03	.001	--------	.0003	.002
On section line between secs. 14 and 15, T. 3 N., R. 5 W	G-2870 [1]	<.00005	<.001	.025	.0005	<.0001	<.0001	.0004
SW¼NE¼ sec. 14, T. 3 N., R. 6 W	C-586 [2]	----------	.0015	.04	.0009	--------	.0015	.004

[1] Looked for but not detected: As, Au, Bi, Cd, Ge, In, Pt, Sb, Ta, Th, Tl, U, W, and Zn.
[2] Looked for but not detected: Ag, As, Au, Bi, Cd, Ge, In, Pt, Sb, Sc, Ta, Th, Tl, U, W, and Zn.

The results of quantitative spectrographic analyses, the fluorine and chlorine contents, and heavy-mineral phenocryst determinations of this ash all differ from analyses of the typical Pearlette Ash Member and lead the authors to conclude that this ash bed is not the Pearlette. This conclusion is based on anomalous amounts of boron (high at 0.006 percent by weight), gallium (low at 0.0014 percent), niobium (low at 0.002 percent), tin (low at 0.0006 percent), yttrium (low at 0.002 percent), ytterbium (low at 0.0003 percent), and zirconium (low at 0.010 percent) (table 4, sample G–2872), and the low fluorine and chlorine content (table 5, sample G–2872). Similarly, only one grain of chevkinite—possibly reworked—was found in the heavy-mineral assemblage of this ash.

of glass shards from volcanic ash samples, Nebraska and Kansas

with an ultrasonic transducer; shards were separated from contaminants by use of an
results have an overall accuracy of ±15 percent, except that they are less accurate near

Elements															
Fe	Ga	La	Mn	Mo	Nb	Ni	Pb	Sc	Sn	Sr	Ti	V	Y	Yb	Zr
Kansas															
1.0	0.0024	0.010	0.026	0.0005	0.007	<0.0002	0.004	<0.0005	0.001	<0.001	0.080	<0.0005	0.008	0.0010	0.026
.94	.0024	.010	.024	.0005	.006	<.0002	.004	<.0005	.0014	<.001	.075	<.0005	.008	.0010	.024
Nebraska															
0.93	0.0023	0.014	0.023	0.0003	0.007	<0.0002	0.004	<0.0005	0.001	<0.001	0.082	<0.0005	0.010	0.0010	0.027
.84	.0022	.011	.022	.0005	.005	<.0002	.004	<.0005	.001	<.001	.076	<.0005	.008	.0010	.021
.92	.0023	.010	.024	.0005	.005	<.0002	.005	<.0005	.001	<.001	.074	<.0005	.009	.0010	.020
.91	.0022	.010	.020	.0004	.005	<.0002	.004	<.0005	.001	<.001	.078	<.0005	.008	.0010	.021
.69	.0014	.005	.021	.0005	.002	.0003	.004	.0005	.0006	.004	.069	.0012	.002	.0003	.010
1.0	.0024	.012	.026	.0004	.007	<.0002	.004	<.0005	.001	<.001	.084	<.0005	.009	.0010	.028
1.0	.0026	.012	.026	.0004	.006	<.0002	.005	<.0005	.001	<.001	.079	<.0005	.009	.0010	.026
.94	.0022	.010	.024	.0005	.005	<.0002	.004	<.0005	.001	.002	.080	<.0005	.008	.0009	.018
.9	.0025	.01	.02	.0006	.004	--------	.004	--------	.0007	.002	.06	--------	.008	.0007	.02
1.1	.0024	.012	.028	.0005	.007	<.0002	.004	<.0005	.0009	<.001	.086	<.0005	.010	.0010	.029
1.1	.0024	.015	.028	.0004	.008	<.0002	.004	<.0005	.0009	<.001	.090	<.0005	.010	.0010	.030
1.0	.0025	.01	.02	.0007	.004	--------	.004	--------	.0008	.002	.06	--------	.009	.0008	.02
.9	.0025	.01	.02	.0007	.003	--------	.004	--------	.0008	.002	.05	.0005	.008	.0007	.02
1.0	.0024	.010	.020	.0005	.007	<.0002	.004	<.0005	.0009	<.001	.068	<.0005	.008	.0010	.026
1.0	.002	.01	.015	.0006	.003	<.0002	.003	--------	.0008	.002	.07	.002	.008	.0006	.01
1 0	.0024	.009	.021	.0004	.006	<.0002	.004	<.0005	.001	.002	.098	.0009	.008	.0009	.026
1.0	.002	.01	.02	.0006	.004	--------	.005	--------	.001	.003	.06	.0005	.008	.0007	.02
1.1	.0026	.011	.025	.0005	.007	<.0002	.004	<.0005	.0009	<.001	.081	<.0005	.008	.0010	.029
.9	.002	.01	.01	.0006	.003	--------	.003	--------	.0007	.015	.06	.001	.007	.0006	.02

In the ravine exposure the ash bed unconformably overlies silt and underlies silt that contains tabular fragments of ash. Because the silt and ash are overlain by Loveland Loess, they are thought to be part of the Sappa Formation, despite the fact that the ash apparently is not part of the Pearlette Ash Member. The ashy channel-fill represents what may be a post-Sappa and pre-Loveland alluvium composed of reworked Sappa deposits and, although not typical, is considered part of the Crete Formation of early Illinoian time.

VALIDITY OF THE PEARLETTE ASH MEMBER AS A STRATIGRAPHIC MARKER

The authors believe that results of analyses described above indicate that the Pearlette Ash Member is a valid stratigraphic marker, although some doubt has been expressed by earlier workers. Hibbard

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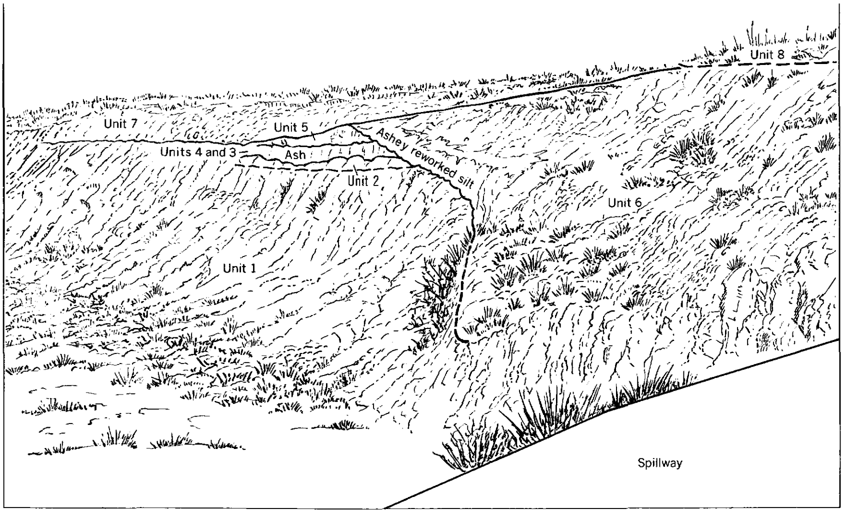

FIGURE 8.—Sketch of deposits adjacent to spillway in the NE¼SE¼ sec. 26, T. 3 N., R. 8 W., showing interpretation of stratigraphic relationship. Numbers refer to those in measured section 7. The ash is overlain by silt that contains tabular fragments of ash (unit 5). The gully was eroded and filled after deposition of this bed. Ash is reworked as a band along sides and bottom of channel.

TABLE 5.—*Chemical analyses, in percent by weight, of the fluorine and chlorine content of glass shards from volcanic ash samples, Nebraska and Kansas*

[Analysts: E. L. Munson and V. C. Smith. Samples were disaggregated and the glass shards were cleaned with an ultrasonic transducer; shards were separated from contaminants by the use of an electromagnet]

Location	USGS sample	F	Cl
Kansas			
Tobin faunule locality, sec. 35, T. 14 S., R. 11 W	G–2874	0. 127	0. 128
Wilson Valley, sec. 28, T. 13 S., R. 10 W	G–2875	. 129	. 123
Nebraska			
SW¼NW¼ sec. 12, T. 2 N., R. 20 W. (type section of Sappa Formation)	G–2861	0. 148	0. 128
Do	G–2862	. 151	. 122
Do	G–2863	. 154	. 124
Do	G–2864	. 141	. 128
NE¼SE¼ sec. 26, T. 3 N., R. 8 W	G–2872	. 052	. 056
SE¼SE¼ sec. 15, T. 1 N., R. 16 W	G–2858	. 130	. 126
NE¼SW¼ sec. 32, T. 3 N., R. 13 W	G–2857	. 134	132
SE¼SE¼ sec. 19, T. 2 N., R. 12 W	G–2867	. 154	. 131
NW¼NW¼ sec. 28, T. 1 N., R. 9 W	G–2866	. 129	. 128
NW¼SW¼ sec. 26, T. 1 N., R. 9 W	G–2869	. 120	. 121
NE¼SW¼ sec. 32, T. 2 N., R. 7 W	G–2868	. 134	. 130
NW¼SW¼ sec. 3, T. 4 N., R. 7 W	G–2865	. 137	. 127
On section line between secs. 14 and 15, T. 3 N., R. 5 W	G–2870	. 126	. 129

(1944, p. 740) thought that differences in contained fossils indicated different ages of volcanic ash in Nebraska and Kansas. Swineford and Frye (1946, p. 29–30), on the basis of minor differences such as index of refraction, shape of glass shards, chemical composition, and distinctive bubbles, suggested the possibility of three ash falls in the Pleistocene. Frye, Swineford, and Leonard (1948) indicated that the Pearlette is an excellent marker bed for correlating Pleistocene deposits, but they made no mention of other Pleistocene ash beds. Analyses of volcanic ash suggest that nearly all of the Pleistocene ash deposits in the three counties are correlative with the Pearlette Member at the type locality of the Sappa Formation.

FOSSILS

Invertebrate and vertebrate fossils are preserved locally in the silt and clay deposits of the Sappa Formation. Mollusks were collected from massive silt and clay in the NW cor. sec. 22, T. 1 N., R. 11 W., Webster County (fig. 9; measured section 9), and identified by Dwight W. Taylor (table 12).

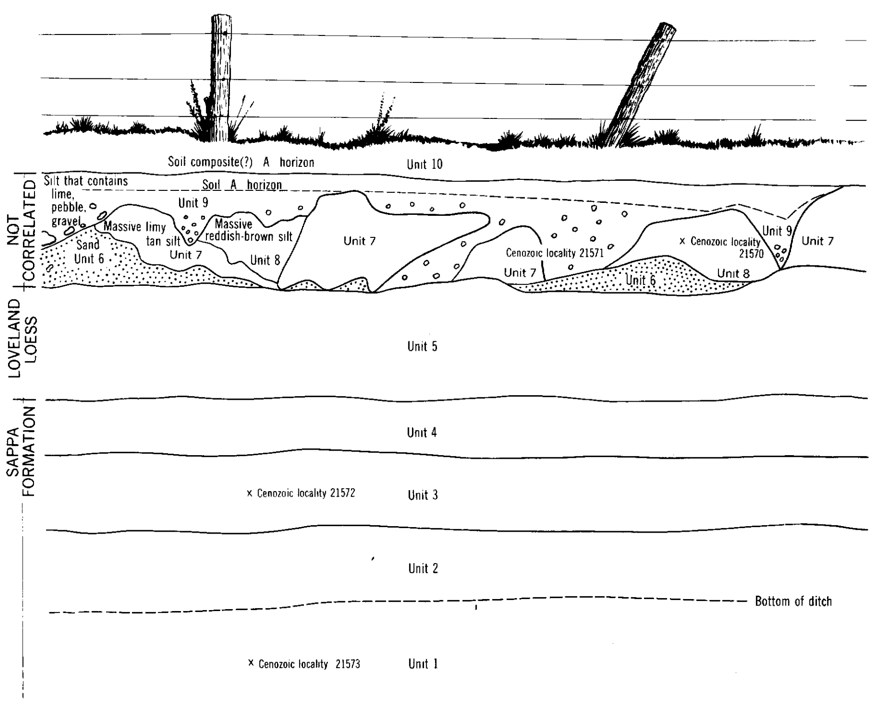

FIGURE 9.—Diagrammatic sketch of deposits in the NW cor. sec. 22, T. 1 N., R. 11 W., Webster County, and interpreted correlations; unit numbers refer to measured section 9, and Cenozoic localities refer to table 6.

According to Taylor the fossil faunas from localities 21572 and 21573 (measured section 9, units 3 and 1) contain northern species and indicate a glacial environment. He suggests an Illinoian or Kansan age for both of these fossil faunas. Because of the clayey consistency and grayish color of these beds a Kansan rather than an Illinoian age was assigned to the deposits. The overlying soil and underlying clay is considered part of the Sappa Formation. Deposits above the Sappa closely resemble the Loveland Loess.

TABLE 6.—*Invertebrate fossils collected from measured section 9, NW cor. sec. 22, T. 1 N., R. 11 W., Webster County, Nebr.*

[Fossils identified by Dwight W. Taylor (written communication, Jan. 15, 1959)]

	Locality, unit			
	21570; 3	21571; 4	21572; 8	21573; 10
Fresh-water clams:				
Pisidium casertanum (Poli)	------	------	×	×
compressum Prime	------	------	×	×
obtusale Pfeiffer	------	×	×	×
Fresh-water snails:				
Stagnicola caperata (Say)	------	------	×	×
Fossaria dalli (Baker)	------	------	×	×
obrussa (Say)	------	------	×	×
Gyraulus circumstriatus (Tryon)	------	------	×	×
parvus (Say)	------	×	×	------
Physa skinneri Taylor	------	------	------	×
Aplexa hypnorum (Linnaeus)	------	------	×	×
Land snails:				
Carychium exiguum (Say)	------	------	×	×
Gastrocopta armifera (Say)	------	×	×	×
cristata (Pilsbry and Vanatta)	×	×	------	------
holzingeri (Sterki)	------	------	×	×
tappaniana (Adams)	------	------	×	×
Pupilla blandi Morse	------	------	×	------
muscorum (Linnaeus)	------	------	×	×
Pupoides albilabris (Adams)	×	×	------	------
Vertigo binneyana Sterki	------	------	×	------
elatior Sterki	------	------	×	------
milium (Gould)	------	×	×	×
ovata Say	------	------	×	×
Vallonia gracilicosta Reinhardt	------	×	×	×
perspectiva Sterki	------	------	×	------
Cionella lubrica (Müller)	------	------	×	------
cf. *Succinea*	------	×	×	×
Oxyloma retusa (Lea)	------	------	------	×
Discus cronkhitei (Newcomb)	------	------	×	×
Punctum minutissimum (Lea)	------	×	×	×
Helicodiscus parallelus (Say)	------	------	×	------
singleyanus (Pilsbry)	×	×	------	------
Euconulus fulvus (Müller)	------	------	×	×
Nesovitrea electrina (Gould)	------	------	×	×
Hawaiia miniscula (Binney)	------	------	×	×
Zonitoides arboreus (Say)	------	------	×	×

Most vertebrate collection localities within the three counties are indefinitely located and the stratigraphic relationships are not clear. One vertebrate-fossil locality, however, is 1½ miles southeast of the town of Angus, in the SW¼SE¼ sec. 33, T. 4 N., R. 6 W., Nuckolls County. Schultz and Tanner (1957, p. 67) reported collecting from an excavation here in the silt of the Sappa Formation the remains of "*Lepus* sp.—Jack Rabbit; *Sylvilagus* sp.—Cottontail; *Cynomys niobraris* Hay—Prairie Dog; *Geomys* sp.—Eastern Pocket Gopher; *Castor* sp.—Beaver; *Ondatra nebrascensis* Hollister—Muskrat; *Microtus?*—Meadow Mouse; *Canis latrans* Say—Coyote; *Mammuthus (Archidiskodon) imperator* (Leidy)—Mammoth; *Equus excelsus* Leidy—Horse; *Mylohyus browni* Gidley—Peccary; *Camelops kansanus* Leidy—Camel; *Odocoileus sheridanus* Frick—Deer; *?Stockoceros* sp.—Four-horned Antelope." They also recovered reptiles, amphibians, birds, and fish, and considered the fauna to be of Yarmouth age.

AGE AND CORRELATION

An age assignment more precise than late Kansan to early Yarmouth is not possible for the Sappa Formation. Different paleontologists have different opinions as to the age of faunas found in the Sappa. Apart from opinions based on the presence of individual species, many inferences of age are influenced by paleoecologic interpretations of both vertebrate and invertebrate faunas. Some paleontologists believe some fossil vertebrate faunas that are considered to be from the Sappa indicate a cold glacial climate, and others believe certain assemblages, also from the Sappa, indicate a warm interglacial climate (Leonard, 1947, p. 1202; 1950, p. 44; Frye, Swineford, and Leonard, 1947, p. 1182; 1948, p. 506; Schultz and Stout, 1948, p. 566; Schultz, Lueninghoener, and Frankforter, 1951, p. 6; Schultz and Tanner, 1955, p. 1612; 1957, p. 78; Hibbard, 1944, p. 740–742; 1949, p. 1421–1426; Taylor, 1954, p. 1; Frye and Leonard, 1952, p. 155–163).

The stratigraphic position of the Sappa, overlying the Grand Island Formation, indicates an age no older than late Kansan. The presence of a widely distributed soil of Yarmouth age in the Great Plains that developed on the upper surface of the Sappa limits the Sappa to an age no younger than Yarmouth. Inasmuch as the formation of this soil must have taken some time, the bulk of the Sappa probably was deposited before late Yarmouth time.

Correlation of clay, silt, or sand deposits as part of the Sappa Formation is based on stratigraphic position or the presence of the Pearlette Ash Member. All gray deposits between the Loveland Loess or Crete Formation and the Grand Island Formation are correlated with the Sappa Formation.

ORIGIN AND CONDITIONS OF DEPOSITION

The Sappa Formation was probably derived either from fine materials carried into the three counties by streams flowing from the northwest or from reworking of the Grand Island Formation. Eolian silt in upland areas probably was derived from flood plains, and volcanic ash was blown into the area from the southwest.

The Sappa accumulated in slack water in oxbow lakes, meander ponds, and pools in abandoned channels; as alluvium along streams; and as loess. In most outcrops of the Sappa along streams and rivers the stratified silt and sand unit is an alluvial-lacustrine deposit. The relative thinness and lenticular shapes of the deposits are compatible with an alluvial origin. Ecological interpretations of the mollusks by Dwight Taylor indicate flood-plain or terrace environments for the deposits in sec. 22, T. 1 N., R. 11 W.

The source of the ash of the Pearlette was probably a volcano or volcanoes southwest of the mapped area. Ash deposits of the Pearlette are widespread in the central Great Plains (Frye, Swineford, and Leonard, 1948), and possibly extend into Utah and Idaho (Powers, Young, and Barnett, 1958). Landes (1928, p. 939) suggested the Capulin group of volcanoes in New Mexico as a possible source of the ash. Swineford (1949, p. 308), however, considers the Valle Grande volcanic area of north-central New Mexico a more probable locality.

The ash of the Pearlette accumulated in quiet ponds or small ephemeral pools. Ash covering the surface was reworked and redeposited in thick accumulations in ponds and lakes. Ash more than 5 feet thick probably represents deposition in larger lakes; ash less than 5 feet thick was deposited in smaller pools. Scattered small pebbles or sand grains, laminations, and sorting within the ash support the hypothesis of water accumulation.

CRETE FORMATION

Pale-orange chalky sand and silt, reddish-brown silty sand, and reddish-brown fine to coarse sand, all primarily deposited as alluvium and colluvium, constitute the Crete Formation.

The Crete includes sand carried into the area by streams flowing from the north and west as well as sand reworked from local deposits of the Grand Island Formation. The authors could not distinguish the Crete from the Grand Island Formation except in the presence of the Sappa Formation. Some of the Grand Island shown on plates 1, 2, and 3, therefore, may include beds in the Crete Formation.

Although the Crete is most abundantly exposed in the southern part of the mapped area, some Crete crops out in the northern part (pls. 1, 2, and 3). Sand crops out both north and south of the Republican

River, but the chalky beds in the Crete are restricted to areas that are near the Ogallala and Niobrara Formations south of the river.

Different types of topography occur on the chalky and sandy phases of the Crete. A microbadland topography has been formed near the mouth of Walnut Creek (fig. 10), where the chalky phase has been eroded into knobs and ridges. This phase typically forms smooth, broad, gentle surfaces along the slopes of valleys above the chalk of the Niobrara Formation. Such surfaces extend almost continuously along Walnut Creek and other large creeks south of the Republican River. These surfaces grade upslope imperceptibly into surfaces underlain by Peorian and Bignell Loesses and downslope into Recent terraces.

Topography on the sandy phase of the Crete is almost identical to that on the Grand Island. It is characterized by a dendritic pattern of gullies and ravines radiating out from centrally located channels. Where modern erosion has not dissected the Crete, low rounded grass-covered hills and gentle slopes are typical.

CHALKY PHASE OF THE CRETE FORMATION

The chalky phase of the Crete Formation is restricted to the slopes of valleys south of the Republican River. It has an overall very pale orange color in most places but locally may be pale yellow, or grayish orange. The color is derived from the many fragments of weathered chalk of the Niobrara, the major constituent of this phase. Particles of quartzite, sandstone, sand, bone fragments, or mortar beds—all from the Ogallala Formation—are minor constituents. The chalky phase is a compact to loose calcareous silt that at places contains enough sand to give it a rough-textured weathered surface. This phase locally contains subround or tabular fragments of chalk from the Niobrara Formation (fig. 11).

A typical example of the chalky phase of the Crete is exposed in a vertical stream cut in the NE¼SE¼ sec. 15, T. 1 N., R. 13 W., Franklin County (fig. 11). It was not mapped because of the small outcrop and vertical exposure. Here the Crete overlies about 18 feet of chalk of the Niobrara and underlies about 12 feet of Peorian and Bignell Loesses. It is very pale orange and is composed of sandy silt interbedded with sand and gravel. The gravel is predominantly rounded pieces of chalk from the Niobrara, some as large as 4 inches in diameter.

Chalky Crete is exposed in a cutbank and grass-covered hillside near the mouth of Walnut Creek, in the NE¼ sec. 8, T. 1 N., R. 12 W., Webster County, where very pale orange color constrasts markedly with the moderate brown of the overlying Loveland Loess (fig. 10).

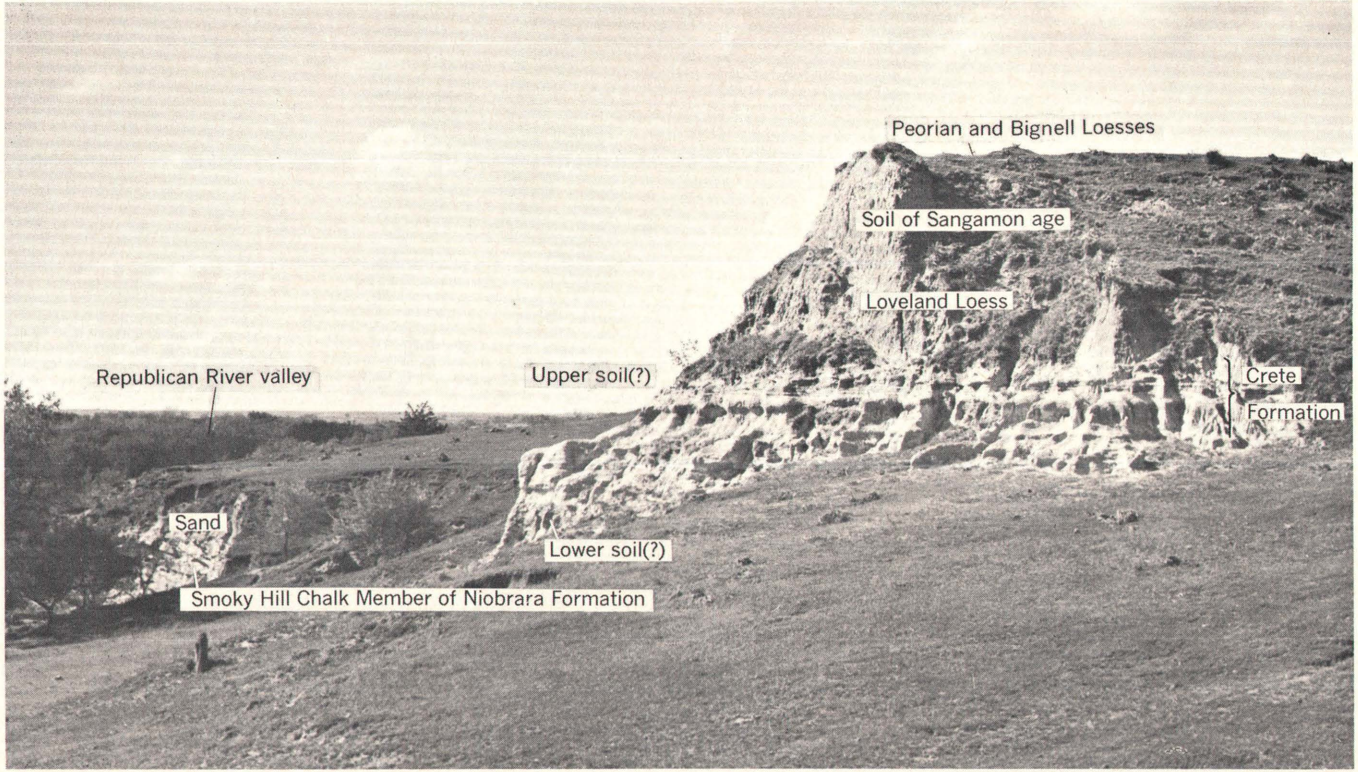

FIGURE 10.—Microbadland topography in the chalky phase of the Crete Formation along Walnut Creek in the NE¼SE¼ sec. 8, T. 1 N., R. 12 W., at the location of measured section 10. The color of the Crete contrasts with the darker brown of the overlying Loveland Loess.

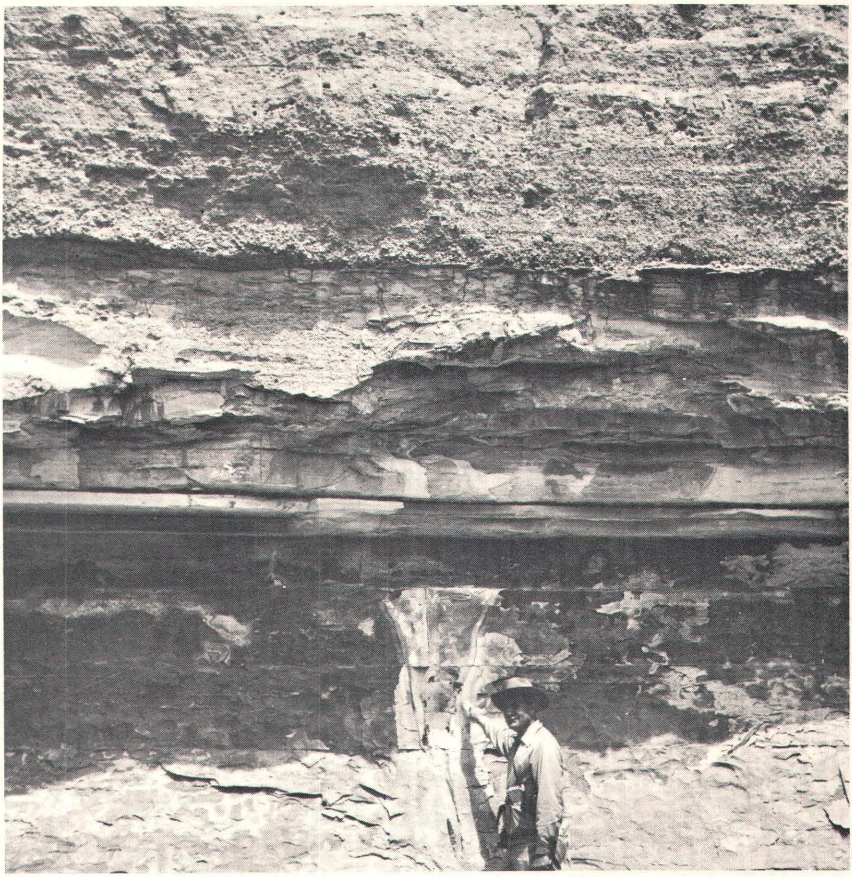

FIGURE 11.—Stratified chalky phase of the Crete Formation composed of reworked fragments of the underlying chalk of the Smoky Hill Chalk Member of the Niobrara Formation, NE¼SE¼ sec. 15, T. 1 N., R. 13 W., Franklin County.

Within the Crete are dark humic zones that may represent soils (measured section 10).

SANDY PHASE OF THE CRETE FORMATION

East of Cedar Creek, south of the Republican River, Webster County, the Crete locally becomes more sandy and is similar to deposits north of the Republican River. This sandy phase is generally gray or reddish brown, poorly sorted, and massive. Granite, feldspar, and quartz grains are the principal constituents. Most of the particles are subround, but they range from subangular to round.

Crete exposed in sec. 16, 20, and 21, T. 1 N., R. 9 W., south of Guide Rock, Webster County, is composed of reddish-brown fine to coarse silty sand that at places near its base grades into the chalky phase.

723-429 O—64——6

This chalky phase lies close to the Niobrara Formation along the valley sides and has the characteristic very pale orange color that can be traced along the valley slopes. Several feet above its contact with the Niobrara Formation, the Crete grades upward into a silty sand that contains very few chalk fragments. This silty sand is persistent over much of the southern part of sec. 16 and the northern part of sec. 21. Stratification is generally obscured; where apparent it is horizontal. Lenses containing pebbles as large as 2 inches in diameter occur throughout the deposit. In this area it contains a slightly higher percentage of granite than other deposits of Crete that were sampled (table 2, sample 15). Vertebrate bones and teeth (*Equus* sp., D–282, D–283, fig. 2) are present in the sand.

North of the Republican River the Crete Formation is generally about 5 feet thick and consists mostly of light-brown clean, moderately sorted, crossbedded fine to coarse sand containing lenses of pebbles, silt, and clay. Locally it is massive and poorly sorted. Quartz, granite, and pink feldspar grains are the principal constituents and igneous, metamorphic, and chert fragments are minor constituents. The quartz generally is clear and unfrosted. Most grains are subround, but range in shape from subangular to round.

Silty sand is exposed over a humic zone on the Sappa Formation in the center of sec. 21, T. 2 N., R. 10 W. This deposit is more than 20 feet thick, much thicker than most Crete found north of the river, and apparently covers all of the central part of sec. 21. Crossbedding is conspicuous in the outcrop. Near the base of the exposure, south of the Sappa outcrop, nearly horizontal layers of coarse sand are overlain by long downward-sweeping concave layers that extend through the lower part of the deposit. Short inclined layers are interbedded with these long laminations. The upper part of the deposit is horizontally bedded and contains bone fragments.

Crete overlies the Sappa Formation along Lost Creek, 5 miles north of Superior, where it is continuous along the west side of the creek for about 1 mile. Ten feet of orange-brown silt of the Sappa, containing volcanic ash shards, underlies about 10 feet of course sand of the Crete. A bed of interest here is a silty humic clayey silt bed that probobly formed during a long period of water saturation of an organic-rich soil. This "gley" [1] soil overlies the sand. Where the gley soil is absent in the NE¼NW¼ sec. 34, a calcium carbonate (caliche) cemented layer 4 inches thick is at the top of the sand. The

[1] "Gley" soil is "a layer of intense reduction * * *. This process involves saturation of the soil with water for long periods in the presence of organic matter" (U.S. Dept. Agriculture, 1951, p. 180).

Crete outcrop extends as far south as U.S. Highway 136 where the Sappa, Crete, Loveland relationships are exposed in the roadcut east of Lost Creek.

Similar stratigraphy is exposed near the Little Blue River in the walls of a steeply eroded ravine in the SW¼ sec. 3, T. 4 N., R. 7 W., Nuckolls County. About 17 feet of light-brown crossbedded sand of the Crete Formation contains clay balls, silt lenses, and iron-stained lenses of fine to coarse sand. The Crete overlies light-gray silt of the Sappa that contains volcanic ash shards.

ORIGIN

The Crete Formation in Franklin, Webster, and Nuckolls Counties is mainly derived from deposits in the immediate vicinity, but locally it includes materials carried by streams flowing into the area from the west and northwest. South of the Republican River the chalky phase of the Crete was derived from weathered chalk of the Niobrara and sand of the Ogallala Formation. It accumulated as alluvial fill along streams tributary to the Republican River. The Crete Formation also covered the lower slopes of these valleys as colluvium. Most of the Crete north of the river likewise accumulated as fill in short tributary streams, or as colluvium on valley slopes. At the same time, alluviation along a few major streams covered older deposits with sand. This sand probably was derived from the Grand Island west and northwest of the area and south of the Platte River. In the three counties, however, most of the Crete mapped probably came from local sources.

FOSSILS

Vertebrate fossils in the Crete were collected at only two localities. Fragments of cheek-teeth of *Equus* sp. (localities D–282, D–283; G. E. Lewis, written communication, June 1, 1959) were collected from sand of the Crete overlying the Sappa in the SW¼ sec. 16, T. 1 N., R. 9 W., and the N½ sec. 21, T. 1 N., R. 9 W. They were regarded by Schultz, Tanner, and Lewis as being post-Kansan in age. The sand and gravel overlying the Sappa in the center of sec. 21, T. 2 N., R. 10 W., contained bone fragments that were identified by G. E. Lewis (loc. D–281, written communication, March 30, 1959) as a small ?camelid of Pleistocene age.

AGE AND CORRELATION

The age of the Crete Formation is generally accepted as being early Illinoian (Condra, Reed, and Gordon, 1947, p. 24–25; 1950, p. 24–25; Shultz and Tanner, 1957, p. 72, fig. 2). Exposures in Franklin, Webster, and Nuckolls Counties show only that the Crete was deposited after the Sappa Formation had been partly eroded and before deposition of the Loveland Loess. The fragmentary *Equus* teeth (post-

Kansan in age) and the overlying Loveland Loess restrict the Crete to an early Illinoian age.

LOVELAND LOESS

The Loveland Loess consists of moderate yellowish-brown clayey to sandy silt, and fine sand, primarily deposited by wind. It is generally massive, but locally has alluvial stratification in the lower part.

The usage in this report follows that of Condra, Reed, and Gordon (1947, p. 25–26), who restricted the Loveland in Nebraska to the massive upland loess. This loess locally contains colluvial and stratified silt and clay in the lower part.

The Loveland Loess is widely exposed in the valley sides along almost every stream in the three counties. The only areas where it does not crop out is in the undissected loess uplands where it is covered by the overlying Peorian and Bignell Loesses.

The Loveland Loess was deposited on an unevenly eroded surface of Pleistocene deposits and bedrock (Lugn, 1935, p. 128, 135). The upper surface of the loess is flat and nearly horizontal beneath terrace surfaces along the Republican and Little Blue Rivers, it is gently undulating in the dissected uplands, and is flat beneath the Peorian and Bignell Loesses in the undissected uplands. Modern erosion of the Loveland Loess produces stepped slopes (Brice, 1958), and steep-walled gullies that end abruptly.

The Loveland is composed of clayey to sandy silt. At a few places the Loveland is predominantly fine sand. A conspicuous very dark brown humic horizon soil of Sangamon age is present at the upper surface at most places. Less well-developed humic zones are found near the base of a few exposures.

Round to subangular frosted quartz grains are the most common constituent of the Loveland Loess. Feldspar and a very few unidentified black opaque minerals are the other main constituents. At places, the silt grains are bound together by calcium carbonate, limonite, or hematite to form sand-size clusters or aggregates. Lenses and channels of coarse sand and calcium carbonate concretions, though rare, occur within the Loveland.

Chemical, spectrographic, and X-ray analyses of two samples suggest that the composition of the Loveland Loess may be consistent from place to place. As would be expected from the quartz and feldspar content of the silt-size particles, silica and alumina are the principal constituents. They constitute more than 84 percent of the loess. Only about 2.35 percent Fe_2O_3 provides the color. The loess also includes the clay minerals montmorillonite and illite.

In most upland exposures the Loveland Loess is massive. Columnar jointing is conspicuous in nearly vertical faces. Near the base of some upland exposures the silt or fine sand is horizontally bedded. In many exposures along the Little Blue and Republican River valleys, or in valley sides adjacent to larger tributary streams, the Loveland is horizontally bedded. A typical section through the Loveland and Peorian and Bignell Loesses was measured in the south embankment of a cut along U.S. Highway 136, in the NW¼NE¼ sec. 5, T. 1 N., R. 7 W., Nuckolls County (measured section 11).

Loveland Loess is exposed in the walls of irrigation canals along the margin of the inner valley of the Republican River. Most exposures are not shown on the geologic map because the canals were constructed after field mapping was completed. The upper surface of the Loveland exposed in the canals can be traced by the continuous dark humic soil of Sangamon age and is paralleled by the modern topography.

SANDY PHASE OF THE LOVELAND LOESS

A sandy phase of the Loveland, which is composed of silty sand, is exposed in several areas in Franklin and Webster Counties. Some deposits are massive, others are stratified. This sandy Loveland is found near broad areas of the Grand Island and Crete Formations, which are probably the source of this sand. Most exposures of the sandy phase of the Loveland are listed in table 7.

CALCAREOUS LOVELAND LOESS

Zones of calcium carbonate concretions that have accumulated locally near the base of the Loveland Loess may easily be confused with concretionary beds of the Ogallala Formation. One such concretionary zone in the Loveland crops out along the irrigation canal half a mile west of Naponee, Franklin County. Here, numerous concretions in the moderate yellowish-brown sandy silt of the Loveland form long tusklike bodies or, at places, an almost continuous mat.

Similar concretionary zones elsewhere in the mapped area are generally easier to recognize as part of the Loveland Loess. These concretionary zones probably formed either at the top of fluctuating ground-water tables or as zones of lime enrichment related to soil development. (See measured section 5.)

Loveland Loess is light buff near the Nebraska-Kansas line in eastern Franklin and western Webster Counties because of the calcium carbonate disseminated throughout the loess. In this area the Loveland Loess may be confused with buff-colored carbonate-enriched silts of the Ogallala Formation. However, they are easily differentiated where in contact with each other, for the Loveland is slightly darker, has less clay, exhibits columnar jointing, and is not as well consolidated as the silt of the Ogallala.

TABLE 7.—*Location of selected areas of the Loveland Loess*

Location	*Remarks*
SE¼SW¼ sec. 16, T. 1 N., R. 16 W	Sandy phase.
SW cor. sec. 22, T. 3 N., R. 15 W	Do.
NW¼SW¼ sec. 28, T. 3 N., R. 15 W	Do.
SE¼SE¼ sec. 29, T. 3 N., R. 15 W	Do.
NE¼NE¼ sec. 13, T. 2 N., R. 15 W	Do.
NW¼NW¼ sec. 18, T. 2 N., R. 14 W	Do.
Secs. 15, 20, 21, T. 3 N., R. 14 W	Do.
NW¼NW¼ sec. 33, T. 2 N., R. 13 W	Do.
SE¼SE¼ sec. 21, T. 3 N., R. 10 W	Do.
NW¼NE¼ sec. 25, T. 3 N., R. 10 W	Do.
NW¼NW¼ sec. 29, T. 3 N., R. 10 W	Do.
SE¼SE¼ sec. 35, T. 3 N., R. 10 W	Do.
NW¼SW¼ sec. 30, T. 3 N., R. 9 W	Do.
NW¼NW¼ sec. 31, T. 3 N., R. 9 W	Do.
Between secs. 19 and 20, T. 2 N., R. 12 W	Concretionary zones.
NW¼ sec. 29, T. 2 N., R. 12 W	Do.
SE¼ sec. 35, T. 2 N., R. 10 W	Do.
SW¼ sec. 36, T. 2 N., R. 10 W	Do.
NE¼ sec. 5, T. 1 N., R. 9 W	Do.
NW¼ sec. 6, T. 1 N., R. 9 W	Do.
SW¼NW¼ sec. 7, T. 2 N., R. 14 W	Humic soil within Loveland.
SE¼ sec. 6, T. 1 N., R. 8 W	Do.
NE¼ sec. 7, T. 1 N., R. 8 W	Do.
N½ sec. 24, T. 3 N., R. 8 W	Do.
SW¼ sec. 29, T. 4 N., R. 6 W	Do.
SE¼NE¼ sec. 27, T. 1 N., R. 7 W	Soil of Sangamon age.
NE¼NW¼ sec. 12, T. 4 N., R. 5 W	Do.

SOILS OF THE LOVELAND LOESS

Dark humic layers—believed to be soil zones—within the Loveland Loess occur in several exposures (table 7). Dark layers are especially conspicuous in cuts along U.S. Highway 136 in western Franklin County. One such humic layer, believed to be a soil, is exposed in a roadcut in sec. 25, T. 2 N., R. 16 W. (measured section 5, unit 14). The humic layer overlies a truncated calcium carbonate-cemented silt, and indicates erosion prior to accumulation of the humic layer. The presence of other humic zones, the general appearance, and the lithology of the deposit indicate that at this place the Loveland accumulated as fine-textured flood-plain alluvium.

A similar light-gray sandy calcareous humic layer, 6 feet thick, is exposed in a roadcut in the SE cor. sec. 28, T. 2 N., R. 16 W. This humic layer is overlain by 10 feet of massive moderate-yellowish-brown silty fine sand and pale-yellowish-brown sandy silt, and is underlain by massive, moderate yellowish-brown slightly clayey silt. Bone fragments from the humic zone were identified as *Equus* sp. by Schultz, Tanner, and Lewis (loc. D–279, G. E. Lewis, written communication, June 6, 1959).

The authors have seen multiple soils within the Loveland Loess during the course of studies in Valley County. The presence of multiple soils elsewhere in the Loveland Loess has been recognized by the Nebraska State Geological Survey and by other workers in the Great Plains (Thorp, Johnson, and Reed, 1951, p. 13–14; Schultz, Lueninghoener, and Frankforter, 1951, p. 6).

SOIL OF SANGAMON AGE

The Loveland Loess is capped by a dark A horizon of the soil of Sangamon age in many exposures. This dark soil is one of the most characteristic and widespread features associated with the Loveland Loess in the central Great Plains. In general, this soil of Sangamon age in the three counties is nearly uniform in appearance. It is most commonly dark yellowish brown when dry, and grayish brown when wet. The humic horizon is firm, friable, porous, and slightly granular; it generally effervesces slightly when treated with dilute hydrochloric acid, and has a pH of 7.5 to 8.0. This calcium carbonate probably has moved down from the overlying calcareous Peorian and Bignell Loesses. It ranges in thickness from 0—where it has been eroded—to more than 5 feet. It is gradational with the underlying oxidized Loveland Loess. Thorp, Johnson, and Reed (1951, p. 12) described the soil of Sangamon age as follows:

> The soils of Sangamonian age are by far the most extensive of all of the strongly developed buried soils of central United States and probably the rest of the country. Throughout their occurrence as far as we know them, the soils are deeply leached and strongly developed in presently humid areas, and leached to lesser depth in drier ones. * * * However, in much of the area of Sangamon soils we find either dark or light coloured A horizons, with reddish-brown or strong-brown B horizons, that indicate good drainage. Much of the so-called 'Loveland soil' (more properly, Sangamon soil) in Loveland loess is of this kind. It was covered by Wisconsin-aged loess and the land was later dissected.
>
> On the Great Plains, it appears from the dark-coloured A horizons and thick, reddish-brown clayey B horizons that the dominant vegetation probably was grass, and that the dominant well-drained soils were Reddish Prairie soils and reddish Chernozems with maximal textural contrasts between A and B horizons.

ORIGIN

Condra, Reed, and Gordon (1950, p. 28) believe the silt in the Loveland Loess was derived from alluvial deposits, dune sand, older Pleistocene deposits, and from the silts of the Ogallala and older Tertiary formations. Condra, Reed, and Gordon stated (p. 39–41) that the color is probably part of a well-developed soil profile on materials weathered in place; this view is now held by most geologists.

Coarsening and thickening of the Loveland Loess from east to west across Nebraska indicate a principal source west and northwest of the mapped area (Lugn, 1935, p. 130). Condra, Reed, and Gordon (1950, p. 42) indicate that the principal source of loess in Nebraska was local valley alluvium from areas north and northwest of the three counties. The Loveland is significantly coarser in Franklin County than is the Loveland in Webster or Nuckolls Counties (fig. 12), and this fact indicates to the authors that much of it was derived from the underlying Crete and Grand Island Formations.

Loveland Loess was transported into the mapped area principally by wind. Included in these "duststorms" was montmorillonite reworked from older deposits. Electrostatic adsorption of the fine clay particles to silt grains is proposed by Beavers (1957, p. 1285) to explain the distribution of montmorillonite throughout entire deposits of loess. Although Beavers is concerned with the Peorian Loess, it seems to the authors that the method is equally applicable to deposition of the Loveland Loess. Such electrostatic adsorption of clay to silt grains may also explain the unstratified nature of most loess deposits (Beavers, 1957, p. 1285). The Loveland accumulated as a

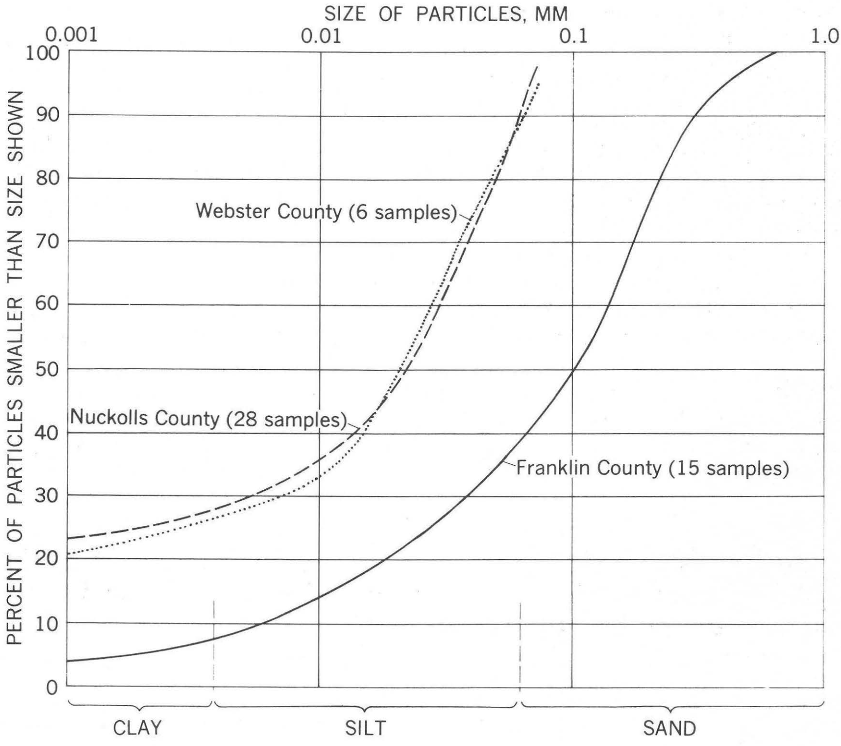

FIGURE 12.—Cumulative curves showing the average size distribution of the Loveland Loess in Franklin, Webster, and Nuckolls Counties.

blanket that reflected the underlying topography of the preexisting surface. Rainwash of hillsides reworked part of the loess into colluvium. Some of the Loveland was reworked by streams and formed stratified alluvium along the major rivers.

AGE AND CORRELATION

For several years, the Loveland was accepted by regional geologists as Sangamon or late Sangamon in age (Lugn, 1935, p. 148–149; Condra, Reed, and Gordon, 1947, p. 20). More recently, the Loveland has been considered as late Illinoian to Sangamon in age (Condra, Reed, and Gordon, 1950, p. 27; Frye and Leonard, 1952, p. 118; Schultz and Tanner, 1957, figs. 2, 7), an assignment with which the present authors agree.

PEORIAN AND BIGNELL LOESSES

The Peorian and Bignell Loesses are nearly identical in appearance and are not differentiated on the accompanying geologic maps. They can be differentiated at a few places by the presence of a conspicuous soil, possibly the Brady Soil of Schultz and Stout (1948, p. 570). The Brady Soil has been described by Thorp, Johnson, and Reed (1951, p. 8–9) as a "chernozemlike soil".[2] The older of the two loesses, the Peorian, was deposited during the early part of Wisconsin time; the overlying Bignell Loess is a later Wisconsin deposit. These two loesses can be differentiated best along the bluffs on the south side of the Republican River in Franklin and Webster Counties, where a dark grayish-brown soil separates them (fig 13). Because these loesses cannot easily be differentiated in most places, they are considered one deposit in this report, the Peorian and Bignell Loesses.

A high flat surface, referred to in this report as the loess-covered terrace, is a prominent feature along the Republican River. A hachure is used on each of the geologic maps to indicate the approximate boundary between this surface and the loess-covered uplands. In most places the surface of the loess-covered terrace is underlain by the Peorian and Bignell Loesses, although stratified alluvial silt generally constitutes the lower part. The Peorian and Bignell Loesses as mapped include these alluvial silt deposits of Wisconsin age along the Republican River.

Peorian and Bignell Loesses cover much of the surface of the three counties; in fact, it is by far the most widely distributed deposit exposed in the area. Most of the hills and the flat upland areas are

[2] Chernozem is a zonal soil having a deep, dark-colored to nearly black surface horizon, rich in organic matter, that grades into lighter colored soils and finally into a layer of lime accumulation (U.S. Dept. Agriculture, 1938).

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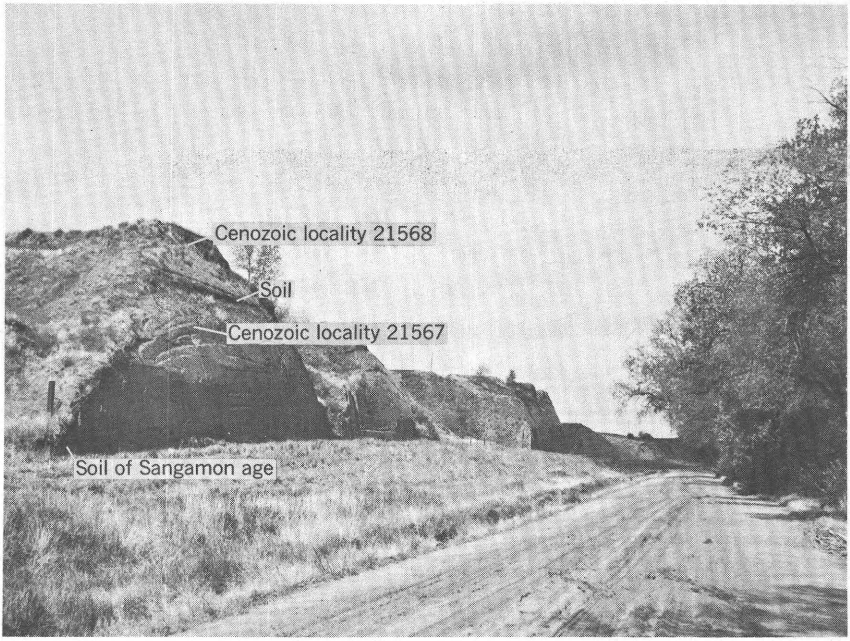

FIGURE 13.—Vertical cuts along the irrigation ditch south of the Republican River, in the SE¼NW¼ sec. 16, T. 1 N., R. 16 W., Franklin County, showing a soil separating two loesses of Wisconsin age. Soil of Sangamon age is in the base of the cut at lower left.

blanketed by this loess. Loess caps the ridges, but in the intervening valleys it has been largely removed by erosion.

Topography formed on this loess varies with locality. Nearly flat undissected loess surfaces reflect the flatness of the deposits beneath the uplands and the loess-covered terrace. Hills and gentle slopes result from moderate erosion, whereas steep-sided ravines characteristically form from severe erosion.

Peorian and Bignell Loesses show little change in physical properties and appearance throughout the three counties. In most exposures the loess is yellowish gray, yellow brown, or grayish orange. It is predominantly a clayey silt, although it contains about 10 percent sand. The loess is coarsest in Franklin County and becomes finer eastward (fig. 14).

Quartz is the principal constituent and feldspar is the second most abundant mineral in the Peorian and Bignell Loesses. A few shards of volcanic ash and fragments of unidentified black opaque minerals are also present. In most exposures, the small grains are bound together by calcium carbonate to form clusters or aggregates. Granules of calcium carbonate are scattered throughout most of the loess.

Chemical, spectrographic, and X-ray analyses of two samples show a consistent composition of the Peorian and Bignell Loesses. As would be expected from the quartz and feldspar content of the loess, silica and alumina are the principal components, constituting about 82 percent. The alumina content in the Peorian and Bignell is higher than in the Loveland, but the silica and the combined silica and alumina is lower in the Peorian and Bignell. The iron oxide (Fe_2O_3) content (2.86 percent) is higher in the Peorian and Bignell than in the Loveland (2.35 percent); this proportion is the reverse of what might be expected from the colors of the two units. It is possible that the iron oxide in the Peorian and Bignell is concentrated in nodules and around root holes but that in the Loveland the oxide is disseminated throughout the deposit. Such a difference in concentration would tend to give the Peorian and Bignell a gray color and the Loveland a brown color.

Montmorillonite is the predominant clay mineral in the Peorian and Bignell Loesses in Kansas, Nebraska, South Dakota, and southwestern

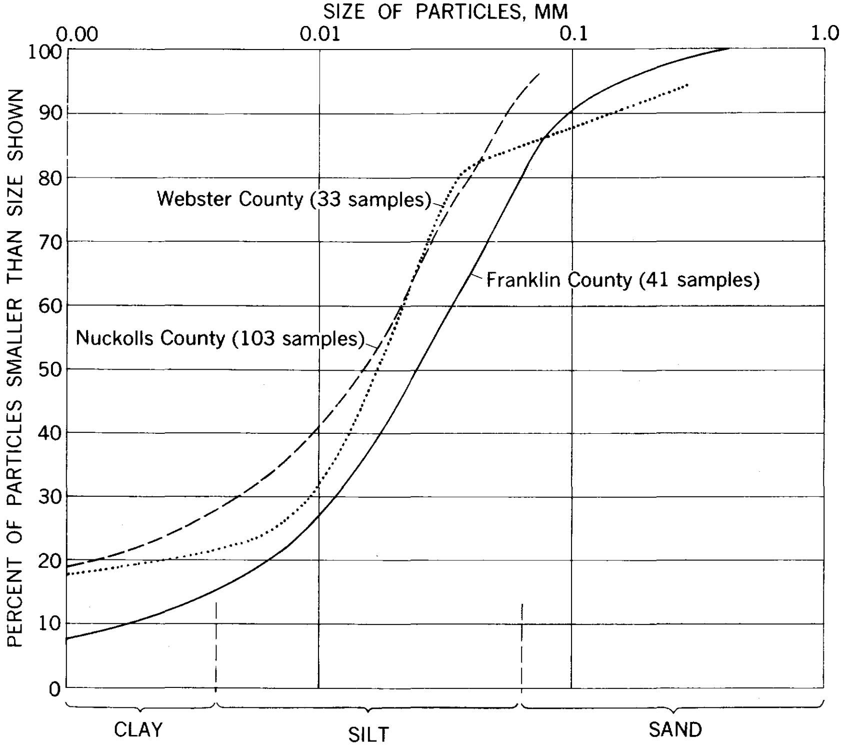

FIGURE 14.—Cumulative curves showing the average size distribution of the Peorian and Bignell Loesses sampled in Franklin, Webster, and Nuckolls Counties.

Iowa (Mielenz, Holland, and King, 1949, p. 1909; Swineford and Frye, 1951, p. 315–316; Davidson and Handy, 1954, p. 197–199; Swineford and Frye, 1955, p. 19, 21). Illite is a minor constituent. Clay mineralogy of the Peorian and Bignell Loesses is similar to that of the Loveland Loess.

Bedding characteristics of the Peorian and Bignell Loesses are almost identical with those of the Loveland Loess. In most upland exposures the Peorian and Bignell Loesses are massive, although locally the silt or fine sand is horizontally bedded near the base of the outcrop. Exposures near the rivers or tributary streams in places show nearly horizontal beds of clayey and sandy silt of alluvial and colluvial origin.

Two features are characteristic of the loess: the tendency to stand in nearly vertical bluffs or cuts (fig. 13), and columnar jointing. Opinions differ as to the cause of the tendency of loess to stand in vertical faces. Bagnold (1937, p. 435) suggested that it is due to true cohesion between grains. He found that particles 0.005 centimeter or smaller in diameter will stand in vertical bluffs and that addition of 0.005-centimeter-size grains to coarser material will allow the coarser deposit to stand in vertical bluffs as well. From 18 to 30 percent of the particles in the Peorian and Bignell Loesses in the three counties is smaller than 0.005 centimeter.

Swineford and Frye (1951, p. 315) and Holtz and Gibbs (1951, p. 15) found that the silt grains are coated with clay materials that form a matrix between grains. Holtz and Gibbs described calcite as being present in distinct silt-size grains, and reported a few silt grains coated with a mixture of calcite and clay. They believe that loess stands in vertical bluffs because the clay and, to a lesser extent, the calcite bond the silt particles together.

Columnar jointing in the Peorian and Bignell Loesses is conspicuous in many exposures. Condra, Reed, and Gordon (1947, p. 33) believe that columnar jointing is related to vertical plant stems and root tubes, rather than being related to the physical properties of the loess. Holland and King (1949, p. 2) and Holtz and Gibbs (1951, p. 15) came to the same conclusion as a result of petrographic studies of loess in the Missouri River basin by the U.S. Bureau of Reclamation.

Detailed descriptions of the Peorian and Bignell Loesses at specific locations are included in some of the measured sections. Some of the better exposures of the Peorian and Bignell Loesses are along irrigation canals, roadcuts, and in the bluffs of the loess-covered terrace next to the Republican River. In many of the exposures a soil separates two loesses believed to be the Peorian and Bignell. More than one soil is preserved at some localities. Thirty feet above the river in the

NW¼SE¼ sec. 26, T. 1 N., R. 8 W., a humic layer, believed to be a middle Wisconsin soil, trends horizontally along the bluff. Three to 8 feet above is a second soil, less well developed. The upper loess is considered to be the Bignell. The age of the higher soil is not known.

The source of the silt in the Peorian and Bignell Loesses in the three counties is probably similar to that of the Loveland Loess; that is, the flood plains of the Platte and Republican Rivers. River flood plains are believed to have contributed considerable amounts of loess throughout the Great Plains (Hutton, 1947, p. 424–426; Swineford and Frye, 1951, p. 306–322; Ulrich and Riecken, 1950, p. 305; Simonson and Hutton, 1954, p. 100).

Loess in Nuckolls County, according to mechanical analyses, is coarsest south of the Republican and Little Blue Rivers (fig. 15). It becomes finer in the area extending from the Republican River northward to a point about 7 miles south of the Little Blue River. It becomes coarser in the area extending from that locality to a point 1 mile north of the Little Blue River, where it becomes finer and is similar to the loess near the north bank of the Republican River.

The Peorian and Bignell Loesses predominantly are eolian, but fossil fresh-water clams and snails indicate that locally the loesses are of fluvial origin (table 8).

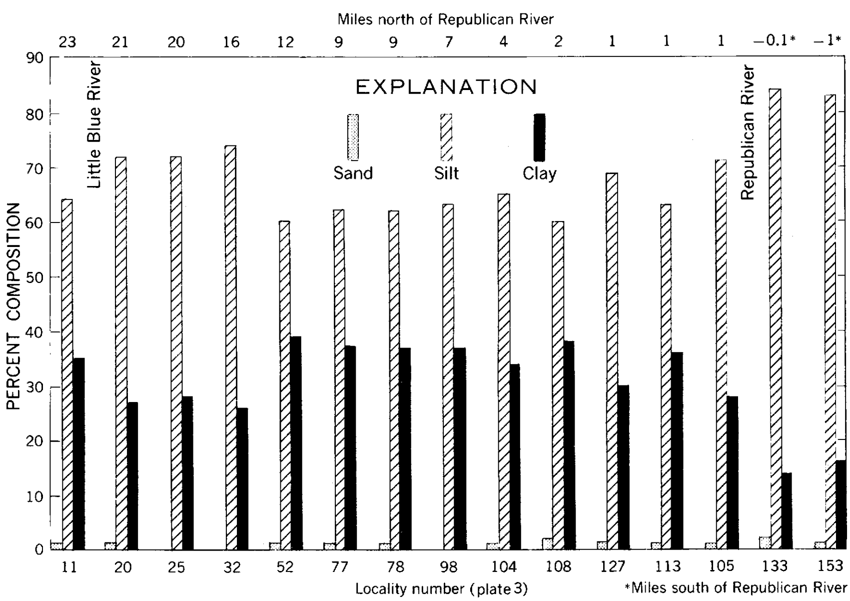

FIGURE 15.—Graph showing the coarsening of the Peorian and Bignell Loesses in the vicinity of the Little Blue and Republican Rivers in central Nuckolls County, Nebr.

TABLE 8.—*Invertebrate fossils of Wisconsin age from Franklin, Webster, and Nuckolls Counties, Nebr.*

[Fossils identified by Dwight W. Taylor (written communication, Dec. 6, 1955; Dec. 26, 1956; Jan. 15, 1959)]

	Location					
	SE¼NW¼ sec. 16, T. 1 N., R. 16 W.		NE¼SW¼ sec. 8, T. 1 N., R. 12 W.	NW¼NE¼ sec, 17, T. 1 N., R. 11 W.	SE¼ sec. 31, T. 1 N., R. 7 W.	NW¼NW¼ sec. 12, T. 1 N., R. 5 W.
	Cenozoic locality					[1] R-101 (no Cenozoic locality)
	21567	21568	21569	19915	19914	
Fresh-water clams:						
Pisidium casertanum (Poli)						X
compressum Prime						X
obtusale Pfeiffer						X
sp			X			
Fresh-water snails:						
Valvata tricarinata (Say)						X
Stagnicola caperata (Say)			X			
sp			X			
Fossaria dalli (Baker)			X			
parva Lea						X
Gyraulus circumstriatus (Tryon)			X			
parvus (Say)						X
Physa anatina Lea						X
Helisoma			X			
Promenetus exacuous (Say)			X			
Aplexa hypnorum (Linnaeus)			X			
Land snails:						
Carychium exiguum (Say)						X
Gastrocopta armifera (Say)				X		
Pupilla blandi (Morse)				X		
muscorum (Linnaeus) [2]		X		X	X	
sp						X
Vertigo binneyana Sterki			X			
gouldi paradoxa Sterki [2]		X		X	X	
modesta (Say)[2]	X	X		X	X	X
ovata Say			X			
Columella alticola (Ingersoll) [2]	X	X			X	
Vallonia gracilicosta Reinhardt [2]	X	X	X	X	X	X
V. perspectiva Sterki			X			X
Cionella lubrica (Müller)						X
cf, *Succinea avara* Say				X		X
cf, *S. ovalis* Say				X		
cf, *S.*	X	X	X		X	
Oxyloma retusa (Lea)						X
Discus cronkhitei (Newcomb)	X	X		X		X
D. shimeki (Pilsbry) [2]	X	X		X	X	
Punctum minutissimum (Lea)	X	X	X	X		
Euconulus fulvus (Müller) [2]		X		X	X	
E. sp						X
Nesovitrea electrina (Gould)	X					X
Hawaiia minuscula (Binney)			X			
Zonitoides arboreus (Say)		X		X		
?*Stenotrema hubrichti* Pilsbry					X	
Snail eggs				X		

[1] Collected from Peorian and Bignell Loesses overlain by Recent terrace deposits.
[2] Found only in Peorian or older loesses (Leonard, 1952, p. 16; Frye and Leonard, 1952, p. 182–183.

The loess-covered terrace along the Republican River is underlain by the Peorian and Bignell Loesses in most places. Stratified alluvial silt generally constitutes the lower part of the terrace deposit, and in some localities it may compose all the deposit. Lenses of subangular to subround fragments of chalk from the Niobrara Formation are scattered throughout the lower part of the alluvial silt.

Silt that composes the loess-covered terrace probably accumulated in several ways. Part of it may have been deposited on the terrace directly from the air as loess that was then in part reworked by streams as alluvium. Other parts may have been colluvium reworked from loess deposited on upland slopes.

A terrace fill, of a probable late Wisconsin age, is correlated with the loess-covered terrace even though the material is not silt. Chalky alluvium of this terrace fill is exposed in the walls of a 20-foot-deep ravine in the NW cor. sec. 16, T. 1 N., R. 12 W., half a mile south of measured section 10. The alluvium is composed entirely of horizontally bedded chalky silt. Pieces of chalk from the Niobrara 3 inches long are common in nearly horizontal layers. The upper surface of the alluvium exposed here merges with the upper terrace surface mapped along Walnut Creek, and with the surface on the chalky Crete Formation above the chalk of the Niobrara Formation high on the valley slopes. This gradational surface is prevalent not only along Walnut Creek, but along most of the other creeks that have broad valleys south of the Republican River in Webster County. It is well preserved southwest of Red Cloud along West Penny, East Penny, and Cedar Creeks.

This chalky alluvium looks almost exactly like the older chalky phase of the Crete, but is probably the alluvium of Wisconsin age reworked from the topographically higher chalky phase of the Crete. Because the chalky phase of the Crete is also colluvium and alluvium reworked from the weathered chalk of the Niobrara, the chalky alluvium is almost identical to it in appearance. Where the Loveland Loess does not overlie the chalky silt, the silt is mapped as the chalky alluvium of Wisconsin age (shown by overprint on pl. 2); where the Loveland does overlie the chalky silt, it is considered to be the chalky phase of the Crete Formation.

Exposures along Cedar Creek in the NW¼ sec. 25, T. 1 N., R. 11 W., indicate that the chalky alluvium of late Wisconsin age underlies the Recent terrace alluvium (fig. 16*A*). A large flat terrace surface 1 mile north is formed on both the chalky alluvium and Recent terrace alluvium (fig. 16*B*). The chalky alluvium exposed in the eastern part of the terrace is stratified and composed principally of chalk fragments, sand, and some pebbles. The terrace alluvium, which occurs nearer the center and along the western part of the terrace, is horizontally stratified tan silt that contains calcium carbonate concretions. These concretions allow the terrace alluvium of Recent age to be confused with the chalky alluvium of late Wisconsin age.

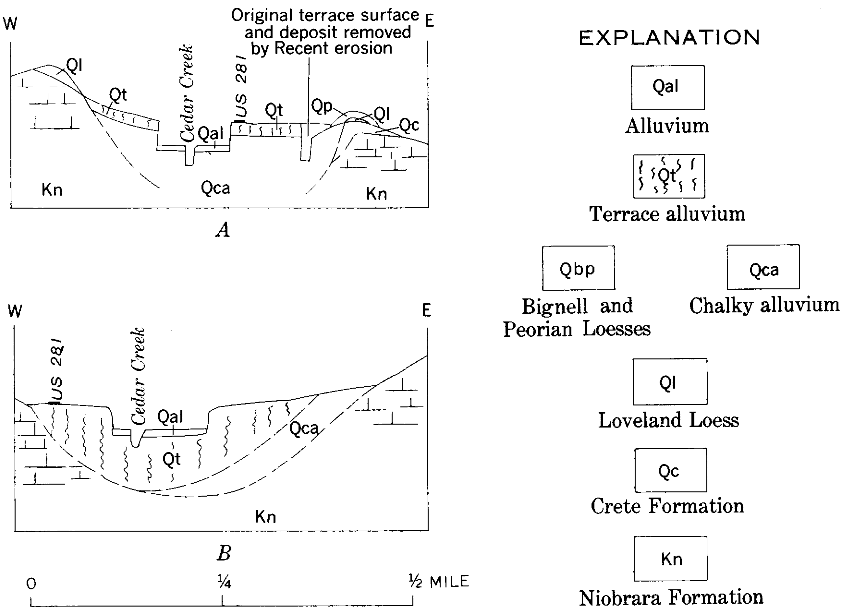

FIGURE 16.—Diagrammatic sketch showing the relationship of the valley-filling chalky alluvium to the overlying terrace alluvium at two locations along Cedar Creek, Webster County; *A*, in the NW¼ sec. 25, T. 1 N., R. 11 W.; *B*, in the NW¼ sec. 24, T. 1 N., R. 11 W.

FOSSILS

Molluscan faunas are preserved throughout much of the unleached silt of the Peorian and Bignell Loesses. Mollusks from samples collected from the loess-covered terrace and from deposits close to major streams were identified by Dwight W. Taylor (written communications, December 6, 1955; December 26, 1956; January 15, 1959) (table 8) who states that the mollusks indicate a Wisconsin age for all samples. Leonard (1952, p. 17) considered that certain forms are indicative of the Peorian Loess of Kansas and are not found in the Bignell. Taylor stated only that two of these forms, *Discus shimeki* and *Columella alticola* are unknown from pre-Wisconsin deposits.

Two fossiliferous horizons were sampled south of the Republican River in the SE¼NW¼ sec. 16, T. 1 N., R. 16 W. (fig. 13; table 8). The first, Cenozoic locality 21567, was in loess 12 feet above a dark soil believed to be Sangamon in age and about 6 feet below a soil believed to be the Brady Soil of Schultz and Stout (1948, p. 570). The second sample, Cenozoic locality 21568, was from loess 14 feet above the first sample and about 6 feet above a soil believed to be the Brady Soil. It should be noted that several of the Peorian forms described by Leonard occur both below and above this soil. This distribution suggests either that the mollusks are not valid stratigraphic markers for separating the Peorian from the Bignell Loesses or that the soil is not the Brady Soil.

AGE AND CORRELATION

The Peorian and Bignell Loesses as mapped include all the silt and loess of Wisconsin age and perhaps some silt and loess of Recent age (fig. 7). From the terrace south of the Republican River in Webster County (at the mouth of Louisa Creek), E. C. Reed, C. B. Schultz, H. Waite, and James Thorp collected soil samples whose radiocarbon dates were placed at 7,809±400 (C–645) and 7,426±600 (C–647) years before the present (Libby, 1955, p. 108). They correlate these sampled deposits with the T–2 terrace fill of Schultz, Lueninghoener, and Frankforter (1951). Radiocarbon dates of material from the T–2 terrace fill from other places in Nebraska are 9,524±450 (C−108a), 8,274±500 (C−470), and 10,493±1,500 (C−471) years before the present (Libby, 1955, p. 107).

Correlation of the loess in the three counties with the type Peorian Loess and Bignell Loesses is based on stratigraphy, depositional characteristics, and fossils. The loess overlies the Loveland and older deposits and contains a buried soil that probably corresponds to the Brady Soil. This soil has not been traced from its type locality; its correlation is based in part on the similarity of development to the Brady at its type locality and in part on its stratigraphic position. Mollusks collected from the loess are a Wisconsin fauna, and most are terrestrial.

RECENT DEPOSITS

Recent deposits include two terrace deposits that are undifferentiated on the geologic maps, two dune-sand deposits, and alluvium deposited on the flood plains of modern streams. The older terrace deposit is tentatively correlated with the older dune sand and with an old alluvium (not shown on the geologic maps) that underlies the flood-plain deposits of the Republican River. These older deposits may be early Recent in age, but there is very little evidence to support this inference. The younger terrace was formed after the older terrace but prior to the deposition of the modern alluvium. The younger dune sand is correlated with the modern flood-plain alluvium—both deposits are forming at the present time.

TERRACE DEPOSITS

Two terrace deposits are mapped as a single unit on the geologic maps (pls. 1, 2, and 3). Both deposits are clayey to sandy silt that form flat-topped valley fills bordering streams throughout the area. The younger terrace deposit seems to contain more sand than the older, and is not as firm. The upper surface of the older terrace deposit is 10 to 15 feet higher than that of the younger terrace. Both terraces have been dissected by erosion, but much of the original physiographic form is still visible. The height of each terrace above the stream is an approximation of the thickness of the terrace deposit. Each deposit will generally be a little thicker than it is high because each terrace deposit extends below stream level at most places.

In Franklin County the terrace deposits are noticeably coarser in the vicinity of outcrops of the Grand Island Formation than elsewhere. The same relationship is probably true for Webster and Nuckolls Counties.

The top of the older terrace deposit generally is from 15 to 40 feet above the modern streams. This range in height reflects the different stream sizes and the distance from the Republican or Little Blue Rivers. The terraces are generally highest along major streams near their mouths and lowest along the smaller streams near the headwaters.

The poorly sorted, clayey to sandy silt of the older terrace is dark brown to gray and is massive to crudely bedded. It tends to weather into blocky fragments. Lenses of pebbly, silty sand are near the base at many places. A weakly developed soil, about 2 feet thick, is at the top of the deposit. The soil, grayish brown, prismatic, and slightly clayey, is underlain by a thin zone containing tiny spots of disseminated calcium carbonate.

The top of the younger terrace deposit is from 5 to 15 feet above the modern streams; the height, like the older terrace, depends on local conditions. At places, streams truncated the older terrace deposits and the younger terrace fill is deposited on the remnants of the older. The younger terrace deposit is similar to the older. A thin dark-brown humic clayey silt is commonly present at the top.

Both terrace deposits are probably of Recent age. The higher deposit is definitely older than the lower and is tentatively assigned to the early part of the Recent Epoch. They both were the result of streams' depositing locally reworked sediments in their valleys. The depths of the old valleys are not known, but probably were not much greater than those of the present valleys.

The soil developed on the older terrace deposit, although weak, is relatively stronger than the soil on the older dune sand deposit discussed in the following section. It would take much more time to develop a soil on the dune sand because of the sand's permeable character. Inasmuch as both of these deposits have weak, although not strictly comparable, soil development, they probably accumulated at about the same time.

A sample from near the middle of a 27-foot-high terrace (older terrace) along Louisa Creek, Webster County, had a radiocarbon date of 4,150±350 years (Libby, 1955, p. 108–109, C–649). The sample was collected in 1949 by E. C. Reed, C. B. Schultz, H. A. Waite, and James Thorp, who believe that the terrace is the T–1 terrace fill of Schultz, Lueninghoener, and Frankforter (1951). Radiocarbon dates of material from the T–1 terrace fill from other places in Nebraska are 2,049±180, 2,675±280, and 3,100±410 years before the present (Libby, 1955). If the date of about 5,000 years, based on the last stabilization of sea level (Frye and Willman, 1960, p. 6), is accepted for the beginning of the Recent, these terraces are Recent in age.

DUNE SAND

Dune sand, found only in Franklin County north of the Republican River, was deposited at two separate times during the Recent Epoch. The principal method of differentiating the two deposits is by the weak soil developed on the older deposit and the lack of soil on the younger. In addition, mechanical analyses (Miller and others, 1964) of these deposits show that the older is slightly finer grained than the younger, but this difference could only be determined in the laboratory. The older deposit does seem to be slightly firmer than the younger; this firmness may be due to the higher silt content and to the soil development on the older deposit. Systematic mapping of the deposits revealed that the older deposits occur only on the gently rolling upland surface and that the younger deposits are confined to the flood plains and terraces of the major streams; consequently, the younger deposits probably were derived from the reworking of alluvium.

The older dune sand deposit is fine to very fine sand composed predominantly of quartz and some feldspar. It is dark yellowish brown when damp and yellowish gray when dry. A good stand of grass covers the gently rolling, hummocky surface of the deposit. At places where the grass cover has been removed, a very complex cross-bedding on a small scale is visible.

The upper 6 to 18 inches of the deposit contains a weakly developed soil profile. The upper 4 to 6 inches consists of a dark yellowish-brown platy silty to sandy humic zone grading downward into 6 to 12 inches of moderate yellowish-brown, slightly humic silty sand.

The older dune sand deposit occurs either as small deposits associated with blowouts (buffalo wallows) or as deposits of variable size not associated with blowouts. The deposits associated with blowouts have a crescentic shape, the horns of the crescent pointing to the north.

The blowout is an undrained depression lying within, and extending slightly north of, the crescent. Blowouts extend 15 to 20 feet below the level of the surrounding plain and are elongated in a southerly direction. The original sides and bottoms of the blowouts are usually obscured by sandy colluvium as much as 6 feet thick. At one place, however, an outcrop on the side of the depression showed dune sand overlying Peorian and Bignell Loesses. The sand deposited along the margin of each blowout extends 10 to 15 feet above the plain at the south end of the blowout and thins northward along the horns of the crescent to merge with the plain. An excellent example of this type of deposit is in sec. 1, T. 3 N., R. 15 W.

The older dune sand deposits not associated with blowouts may be large, such as the three deposits in T. 4 N., Rs. 14 and 15 W., or small, like the one in sec. 19, T. 3 N., R. 15 W. The latter deposit was probably derived from the sandy phase of the Loveland Loess exposed in Center Creek. The large cluster of older dune sand deposits in the T. 4 N., Rs. 14 and 15 W., may have been derived locally, although it seems more probable that this material migrated from the Platte River flood plain about 18 miles to the north. Another large area of older dune sand south of Thompson Creek in T. 2 N., R. 13 W., was derived partly from flood-plain deposits existing at the time the dunes formed and partly from the Grand Island Formation.

The younger dune sand deposit is fine crossbedded loose sand that is predominantly composed of quartz and some feldspar. It is dark yellowish brown when damp and yellowish gray when dry. No soil was found on the dune sand. A sparse grass cover partially stabilizes the uneven, hummocky surface of the deposit. At a few places where there is no grass cover, loose sand is blown from the deposit on windy days and scattered over adjacent dunes and hollows. The dunes range from 5 to 15 feet thick. All the younger dune deposits overlie, and for the most part were reworked from, terrace deposits in the upper parts of larger tributary valleys north of the Republican River.

The stratigraphic position of the older dune sand is not clear. It is younger than the Peorian and Bignell Loesses upon which it lies. The presence of a soil on the older dune sand indicates that the sand was deposited and stabilized prior to deposition of the younger dune sand. This weak soil may be comparable to the weak soil developed on the older terrace deposits. If this is so, the two deposits are nearly contemporaneous.

The younger dune sand overlies the terrace deposits and is not yet entirely stabilized. It is contemporary with the alluvium in the flood plain of the modern streams.

FLOOD-PLAIN ALLUVIUM

The flood-plain alluvium is composed of stream-deposited silt and fine quartz sand; it is yellowish gray or yellowish brown when damp and light gray when dry. At places lenses of coarse sand occur in the finer deposits. Well-log data (Waite, Reed, and Jones, 1946) indicate that the alluvium is as much as 50 feet thick in the Republican River valley and that it contains coarse sand or gravel in the lower part. It is shown on the geologic maps only on the flood plains of the Republican River, of the Little Blue River (Nuckolls County only), and of some of the smaller streams in Webster and Nuckolls Counties. Alluvium also occurs in narrow trenches that many of the larger streams have eroded into the terrace deposits. These deposits are too small to show at the scale of the published maps.

The age of the coarse sand and gravel in the lower part of the flood-plain alluvium in the Republican River valley has not been clearly established. R. C. Cady (written communication, 1940) believed that the coarse sand and gravel is significantly older than the overlying finer alluvium and possibly should be correlated with the older terrace deposits. Similar deposits of sand and gravel are shown by Bradley and Johnson (1957, pl. 38) in the vicinity of McCook, Nebr. (about 90 miles west of Franklin). On the basis of well logs they concluded that the alluvium is overlain by Bignell Loess and underlain by Grand Island Formation and suggested that the alluvium is of late Wisconsin age. E. C. Reed (written communication, May 19, 1959) stated that sand and gravel of late Wisconsin age underlies Bignell Loess at places in Nebraska, including the Republican River area.

STRUCTURAL GEOLOGY

The dominant structural features of the bedrock in this area is the Central Nebraska Basin, a large structural depression in south-central Nebraska and northern Kansas. The axis of the synclinal basin trends sinuously to the northwest and plunges gently in the same direction. Asymmetrical in shape, the basin has an axis that shifts eastward with depth. Its axis is west of Franklin County, as computed from the dip of the contact between the Pierre and Niobrara Formations in western Franklin County, but is near the middle of Franklin County where on the Dakota Sandstone (Merriam, 1957), and underlies the Franklin-Webster County line in the pre-Pennsylvanian rocks (Reed and Svoboda, 1957; Reed and others, 1958). Thus the axial plane of the basin dips northeastward, and the Cretaceous rocks in the three counties are on the northeast limb of the fold.

These Cretaceous rocks dip gently to the northwest in this area. The Pierre and Niobrara contact dips 11 feet per mile to the northwest in western Franklin County and strikes N. 75° E. This determination of dip is based on information from logs of shallow, widely spaced wells (Waite, Reed, and Jones, 1946; Keech and others, 1953 a, b, and c). Similar computations on the top of the Carlile Shale in Nuckolls County indicate a northwest dip of 6 feet per mile and a strike of N. 79° E. The Fort Hays Limestone Member of the Niobrara Formation as based on three deep wells (Condra, Schramm, and Lugn, 1931) in Franklin and Webster Counties, dips 11 feet per mile to the northwest and strikes N. 77° E.

These dips, based on wells that are as much as 24 miles apart, are only in part corroborated by dips taken at individual outcrops. (See pl. 4.) Outcrops show a wide variation in strike, and dips range from horizontal to 16°; beds dipping toward the northwest, however, are most prevalent.

The sinking of the Central Nebraska Basin probably was accompanied by differential warping and minor faulting along the margins of the basin. The main axis of the basin (in pre-Pennsylvanian rocks) divides in northern Franklin County (Reed and others, 1958), one synclinal axis trending northwest and the other north. A minor anticline must lie between the two. Reed and Svoboda (1957) show a structural high on the Precambrian surface extending into central Franklin County from the west.

Structure contours on the top of the Dakota Sandstone in Kansas show three anticlines plunging toward Franklin, Webster, and Nuckolls Counties (Merriam, 1957). The westernmost anticline enters Nebraska 6 miles west of Franklin County, but its northeastward plunge probably brings it into Franklin County just north of Naponee. Oil is produced from this structure in Kansas. The small oil field shown by Reed and others (1958) in T. 1 N., R. 17 W., Harlan County, Nebr., is probably on a continuation of this structure. Another small northeast-plunging anticline (Merriam, 1957) enters Franklin County in T. 1 N., R. 15 W. A third, and very broad, northwest-plunging anticline shown by Merriam enters Webster and Nuckolls Counties. No oil or gas production has been recorded from either of the last two structures.

An anomaly is indicated by a shallow test hole in the NW¼NW¼ sec. 23, T. 3 N., R. 7 W., where the Carlile Shale is apparently 56 feet higher than the Niobrara reported in a well 2½ miles to the northeast, and 30 feet higher than the Niobrara in a well 2 miles to the west. The Carlile may have been displaced by a small anticline or fault.

The only faults large enough to be mapped are in two valleys in sec. 15, T. 1 N., R. 16 W., on the northwest flank of the extension of a small anticline shown by Merriam (1957). Although the fault planes are not exposed, the difference in altitude between adjacent exposures of Pierre Shale and the Smoky Hill Chalk Member of the Niobrara Formation clearly indicates that the Pierre is at least 36 feet lower than the nearby Smoky Hill, which normally underlies the Pierre. This displacement is most obvious in the western valley but also is readily discernible in the eastern valley. Both fault planes appear to be steeply inclined. The vertical displacement is probably not much more than 36 feet. The overlying Ogallala Formation does not seem to be displaced by the faults.

Most of the deformation in this area apparently occurred after the Pierre Shale was deposited but before deposition of the Ogallala. It is probably due to the Laramide Revolution, which began late in the Cretaceous and lasted into the early Tertiary. Merriam and Frye (1954, p. 62) showed that no major folding affected the Tertiary rocks in Kansas, although there was broad uplift during this time.

GEOLOGIC HISTORY

PRE-PLEISTOCENE HISTORY

The geologic history, as revealed by the rocks exposed in the area, is varied but relatively simple. The Carlile Shale of Late Cretaceous age was deposited in a broad shallow sea. Marine conditions continued during the time that the sediments of the Niobrara and Pierre Formations were being deposited.

A great hiatus, representing millions of years, during which the sea retreated from the area, followed deposition of the Pierre Shale. During this time the rocks were gently folded, faulted, and uplifted by the orogeny of the Laramide Revolution. Erosion beveled the west-dipping Cretaceous rocks into a gently undulating plain with long east-sloping valleys. If any sediments were deposited on the Pierre Shale prior to the deposition of the Ogallala Formation, they were completely removed by erosion. Plate 4 shows the general configuration of this surface as slightly modified by post-Ogallala erosion.

In Ogallala time stream gravels, flood-plain deposits, and lake silts constructed a great plain from the Rocky Mountains into eastern Kansas and Nebraska and filled valleys and blanketed ridges in the mapped area. Toward the close of the Pliocene Epoch some of these deposits were cemented by calcium carbonate to form the mortar beds. Later, some beds and zones in the Niobrara Formation were silicified.

At the close of the Pliocene Epoch, erosion removed much of the Ogallala Formation in south-central Nebraska. North of the present valley of the Republican River, many of the pre-Ogallala bedrock ridges were uncovered, and a few of the old valleys were almost denuded of Ogallala sediments. In northwestern Franklin County a plain was formed that sloped gently to the southeast and terminated just below the crestline of the bedrock ridge north of Franklin (pl. 4). East of Franklin County, erosion reexcavated parts of the old valleys.

The features produced by this erosion are entirely different south of the Republican River, where a high east-trending bedrock ridge diverted the eroding streams eastward in Franklin and Webster Counties. This ridge was breached in Nuckolls County where the present Republican River flows southeast into Kansas. The upper part of the Ogallala Formation south of the Republican River probably was removed during this period of erosion, and the general outlines of the modern Republican River basin were established. The flood of Pleistocene deposits from the north and northwest issued into this ancestral Republican River valley.

PLEISTOCENE GEOLOGIC HISTORY

At the beginning of Pleistocene time the appearance of this area was much different from that of today. Broad valleys, eroded into the Cretaceous rocks and partially filled with Tertiary deposits, transected what is now the flat uplands of the three counties. Tributaries joined these valleys and formed a dissected landscape of moderate relief.

The climate became cooler and more humid prior to the Nebraskan Glaciation—the earliest of the Pleistocene glaciations. Exposures in the three counties give little information about Nebraskan time. The Nebraskan glacier itself stopped 60 miles east of Nuckolls County, where the Big Blue River marks the approximate boundary of the glacier (Lugn, 1935, p. 40). Outwash from the ice sheet flowed southwest and south, but probably did not enter the three counties. Debris from the High Plains and the Rocky Mountains, however, was carried into the bedrock valleys, but subsequent erosion, probably during the Aftonian Interglaciation removed most of these deposits. Although these earliest Pleistocene deposits were not recognized in surface exposures, it is quite possible that remnants are preserved in the lower parts of the pre-Pleistocene valleys.

After an extended warm interval, the climate again became cooler and more humid as the Kansan ice sheet advanced into south-central Nebraska to about 30 miles east of Nuckolls County. Most of the debris from the ice sheet was carried south and southeastward into Kansas. Streams flowing from the Rocky Mountains carried coarse sand into the three counties. This Kansas alluviation filled the valleys and covered the bedrock ridges north of the present Republican River valley with a broad, level sand plain.

As streamflow decreased, the alluvial material became finer, and silt and clay of the Sappa Formation was deposited on the flood plains of the rivers. During deposition of the Sappa, volcanic eruptions, possibly in the Valle Grande area of north-central New Mexico, yielded great clouds of fine ash that settled on and covered the surface of the Great Plains. Erosion by water and wind removed most of the ash, but ash that fell or was washed into bodies of standing water was preserved in many places to form the Pearlette Ash Member. The four nearly contemporaneous ash falls at the type section of Sappa Formation may or may not represent separate eruptions. However, the anomalous ash deposit in Nuckolls County does indicate at least two separate eruptions during Sappa deposition.

Erosion was locally active during the accumulation of the Sappa and the Pearlette Ash Member. Subsequently, sand and gravel covered both the volcanic ash and the lower silt of the Sappa in some localities. This erosion and redeposition was followed by alluvial deposition of the upper silt of the Sappa. During the warmer climate of Yarmouth time, soil developed on the Sappa Formation.

As the climate changed to accompany the advance of the Illinoian glacier, streams became larger and entrenched themselves into stabilized channels and removed part of the Kansan deposits. Erosion south of the Republican River in early Illinoian time removed silt and sand of the Ogallala Formation as well as the soft, weathered chalk of the Niobrara Formation. Slope wash and heavily loaded streams redeposited some of this chalk, silt, and sand as the Crete Formation.

North of the Republican River, erosion locally removed or truncated deposits of the silt of the Sappa and ash of the Pearlette Member, while slope wash reworked part of the Grand Island. These sediments also were redeposited as the Crete Formation. In addition, major streams from the northwest and west deposited sand over the Sappa and older deposits and also deposited the Crete south of the Republican River in southwestern Webster County.

Following deposition of the Crete Formation, wind, blowing from the northwest, picked up the clay and silt-size particles from flood-plain, older Pleistocene, Tertiary, and Cretaceous deposits. In most places this material, deposited as the Loveland Loess, formed a blanket over older deposits. Locally, strong winds picked up and redeposited sand along the lee sides of the larger stream valleys. As the Loveland Loess was being deposited in this area, the Illinoian glacier in northeastern Nebraska apparently retreated and readvanced at least once and possibly twice (E. C. Reed, written communication, May 19, 1959). Climatic changes corresponding to fluctuations of the Illinoian glacier permitted humic soils to develop within the Loveland Loess.

The climate of the Sangamon Interglaciation, which followed the deposition of the Loveland Loess, was warmer than the present climate. This interpretation is based on the intensity of development of the soil of Sangamon age in Kansas (Frye and Leonard, 1952, p. 122–123) and on the ecology of vertebrate faunas (Hibbard, 1952, p. 1262; 1955, p. 197–204).

After the Sangamon Interglaciation, the climate again changed. Winds, again from the west and northwest, deposited silt and clay as the Peorian and Bignell Loesses. This loess was probably mixed with silt contributed by secondary sources such as flood-plain alluvium along the Platte and the Republican Rivers. Some of the loess was reworked into alluvium and colluvium and redeposited as part of the loess-covered terrace.

Weathering processes formed soils of varying maturity during each warm period—or interstades—of the Wisconsin Glaciation. After each warm period the climate became cooler and somewhat drier. These alternating cool and warm periods probably correspond to the advances and retreats of the Wisconsin ice sheets.

RECENT GEOLOGIC HISTORY

The transition from the Pleistocene to the Recent was gradual. Loess deposition was for the most part uninterrupted and did not suddenly cease with the end of the Pleistocene. Recent loess accumulated as a thin layer on the older deposits. At this same time Pleistocene deposits were reworked to form the older dune sand and the alluvium of the older terrace deposits.

Erosion during the Recent Epoch cut the older terrace deposit to form steep-sided ravines. Clay, silt, sand, and humus covered the floors of these ravines and gullies. The bottoms of the broad valleys likewise were covered by this deposit to form the alluvium of the younger terrace deposits. In late Recent time, erosion removed much of this deposit but left terraces on both sides of the stream. The younger dune sand and Quaternary alluvium started forming at about this time.

Erosion reexcavated the Recent fill to the level of the modern gully floors; some workers believe it occurred as late as 1880.

ECONOMIC GEOLOGY

Prior to the beginning of the mapping program, the authors believed that each geologic unit would have similar physical characteristics throughout the map area. In general this premise has held true.

The most conspicuous exception is the Loveland Loess, which is much sandier in Franklin County than in Webster or Nuckolls Counties. Although of highly variable texture, the terrace deposits are also sandier in Franklin County. Another deposit of variable texture is the Recent alluvium. The formations that retain similar characteristics throughout the three counties are the Grand Island, Crete (north of the Republican River), Sappa, Pearlette Ash Member of the Sappa, and the Peorian and Bignell. The dune sand deposits of different ages in Franklin County have similar physical properties, although the older is slightly finer grained.

The outcrop areas shown on the geologic maps (pls. 1, 2, and 3) are places where the different formations can be found either at the surface or beneath a few feet of younger material. Most of the deposits are composed of thick tabular horizontal layers that extend indefinitely under the younger materials. Exceptions are the quartzite and mortar beds of the Ogallala Formation and the Pearlette Ash Member of the Sappa Formation; these units are lenticular, and in most places are only a few thousand feet long. It is difficult to predict how far these lenticular formations extend into the hills. The undifferentiated sand, silt, and clay of the Ogallala, the Sappa, and the Crete Formations may be either tabular or lenticular. These variations in size and shape should be kept in mind when prospecting or developing any of these deposits.

CONSTRUCTION MATERIALS

The classification of construction materials used in this report is based on the "Standard Specifications for Highway Construction" (Nebraska Bureau of Highways, 1955, and supplement, 1957), except for riprap, building stone, lightweight aggregate, and clay. These exceptions are based on other systems of classification or on the opinions of the authors of this report. The results of materials tests [1] represent the gross characteristics of the geologic formations involved and may vary significantly within a few feet of the sample location. Additional testing should be done before using materials on the basis of these tables.

CONCRETE AGGREGATE

Aggregate for concrete is composed of fragments of hard, durable minerals or rocks of sand and gravel size that are nearly free from adherent coatings, soft or shaly lumps, and organic or other deleterious material. Potential sources of concrete aggregate are (a) crushed rock from mortar beds and quartzite of the Ogallala Formation and

[1] Tables giving results of the tests have been released to open file and may be inspected and copies obtained for the cost of reproduction at the Survey libraries and at the Nebraska Conservation and Survey Division in Lincoln, Nebr.

the Fort Hays Limestone Member of the Niobrara Formation and (b) coarse sand from the Ogallala, Grand Island, and Crete Formations, and the flood-plain alluvium.

Coarse sand aggregate from the Republican River valley has a reputation of causing deleterious reactions when used with many types of cement (Scholer and Gibson, 1948, p. 1022; Happ, 1948, p. 1329; Scholer and Peyton, 1949, p. 32; Rhoades and Mielenz, 1948, p. 45; Buck, Van Horn, and Young, 1951, p. 17). Several of these authors demonstrated that deleterious reactions are reduced when the coarse fraction of the material is replaced by crushed limestone or some other suitable coarse aggregate. A cooperative study by the Engineering Experiment Station of the Kansas State College and the Portland Cement Association (1946) revealed that deleterious reaction can be partially controlled by using pozzolanic and air-entraining materials.

Rhoades and Mielenz (1948, p. 45) stated that the Republican River aggregate varies from acceptable to slightly deleterious, depending on the absence or presence of small proportions of rhyolite, andesite, chalcedonic or opaline chert, and siliceous limestone. They believe that the coarse-grained granite and potassium feldspar in the aggregate cause much of the deterioration in concrete through: (a) the effect of a low thermal coefficient of expansion, (b) the poor bond with the cement due to impermeable surfaces, and (c) the rigidity of the particles. They point out that the deterioration of concrete made with this aggregate has been controlled by adding 25 to 40 percent by weight of satisfactory coarse aggregate to the mix.

The only materials that fall within the size limits of coarse aggregate are crushed rock from the Fort Hays Limestone Member of the Niobrara Formation and from mortar beds and quartzite of the Ogallala Formation. A single sample from each of these units was subjected to the Los Angeles abrasion test but only the quartzite of the Ogallala qualified for coarse aggregate. It contains an appreciable amount of opaline silica which probably would have a deleterious reaction with portland cement. By locating very coarse beds or by selectively screening gravel from the Ogallala, Grand Island, and Crete Formations and flood-plain alluvium, potential, though possibly deleterious, sources of coarse aggregate could be developed.

The same four units—Ogallala, Grand Island, Crete, and alluvium—are also potential sources of fine aggregate and sand and gravel for concrete. Every deposit should be carefully checked for excessive amounts of material that may have detrimental reactions with portland cement.

MINERAL AGGREGATE

Mineral aggregate consists of clean, hard, durable, and uncoated particles of rock or sand and gravel used for base course, surface course, or armor course. Potential sources of material for mineral aggregate include the Fort Hays Limestone Member of the Niobrara Formation, quartzite, mortar beds, and coarse sand deposits of the Ogallala Formation, Grand Island Formation, Crete Formation, Loveland Loess (sandy phase only), flood-plain alluvium, terrace deposits (coarse phase only), and dune sand.

Crushed rock from the Fort Hays Limestone Member and the quartzite and mortar beds of the Ogallala Formation has a size range suitable for asphaltic concrete. However, the Fort Hays and the mortar bed samples selected for testing showed excessive loss in the Los Angeles abrasion test; the quartzite sample was just within the allowable specification range. Asphalt has a tendency to strip from some kinds of quartzite, and it is possible that it will not adhere to the quartzite of the Ogallala, although this property was not tested.

The Grand Island and Crete Formations (north of the Republican River) and the coarse sand of the Ogallala fall within the allowable size range of coarse sand mineral aggregate. By selective screening or "sweetening," these materials could be made to fit the requirements for coarser aggregate. Sodium sulfate soundness tests (U.S. Bureau of Reclamation, 1946a) on sand from pits north of Naponee and near Cowles show less than 5 percent loss, which is well within the allowable limits. No Los Angeles abrasion test has been reported on these materials.

The flood-plain alluvium, terrace deposits (coarse phase), Loveland Loess (sandy phase), and dune sand are of the proper size range for use as fine or natural sand.

Plummer and Hladik (1948, p. 95–97) indicate the possibility of using ceramic slag made from the loesses of Pleistocene age for road metal and railroad ballast. The Peorian and Bignell and Loveland (silty phase) would be virtually inexhaustible sources of this material.

GRAVEL AND CRUSHED ROCK FOR SURFACING

Gravel and crushed rock for surfacing are durable particles of stone, sand, or crushed rock that may contain a limited amount of clay and silt. The specifications for crushed rock for surfacing (Nebraska Bureau of Highways, 1955, p. 58) state that only limestone is acceptable. The limestone tested from this area exceeds the maximum allowable percentage wear, 45 percent, and is not satisfactory. Except that, as just stated, the specifications mention only limestone, crushed quartzite of the Ogallala Formation meets all the requirements for surfacing. In northern Kansas this quartzite has been used for surfacing.

Coarse sand from the Ogallala, Grand Island, and Crete Formations are all slightly finer than specified, but this deficiency can be easily rectified by controlled screening of the material. Sodium sulfate soundness tests (U.S. Bureau of Reclamation, 1946a) of coarse sand samples from near Naponee and Cowles show 3.2 to 4.7 percent loss after five cycles, which is well within the allowable limits. The flood-plain alluvium is considerably finer than the specifications allow, but coarser deposits may occur at depth.

MINERAL FILLER

Mineral filler is any finely divided inert mineral material that mixes easily with mineral aggregate. Potential sources include sand, silt, and clay of the Ogallala Formation, the Pearlette Ash Member of the Sappa Formation, silt of the Sappa Formation, the Loveland Loess (except the sandy phase in Franklin County), the Peorian and Bignell Loesses, and the finer phase of the terrace deposits.

All samples of the Pearlette Ash Member of the Sappa Formation have the proper size grading and plasticity index for mineral filler. Deposits of the Pearlette are lenticular and at most places are covered by 10 or more feet of overburden within a few yards of the outcrop. The thickness of the deposit appears to change quite radically at most outcrops and can vary from 10 feet to less than 1 foot in a few yards.

The other potential sources of mineral filler are generally more persistent in thickness and continuity, but their physical properties are more variable. In general they fall within the specified size range, but the plasticity index is high. The Peorian and Bignell Loesses and terrace deposits have only 1 to 3 feet of overburden. The terrace deposits contain organic material at some places.

SOIL BINDER

Soil binder consists of fine particles of sand, silt, and clay. Potential sources include the sandy phase of the Loveland Loess, the fine phase of the flood-plain alluvium, parts of the terrace deposits, Peorian and Bignell Loesses, and sand, silt, and clay of the Ogallala Formation. The terrace deposits and the alluvium may contain too much organic material at places to be a good soil binder.

CLAY SURFACING MATERIAL

Clay surfacing material consists of clay, silt, and sand; arenaceous limerock; or calcareous sandstone. Potential sources include sand, silt, and clay of the Ogallala Formation, the Loveland Loess in Franklin County, and the Sappa Formation in Webster County. The mortar beds in the Ogallala Formation may also be suitable for this purpose. Where mixing of different materials is possible, many of the mapped units could be combined into a suitable material.

RIPRAP

Riprap is broken rock used to protect a wall, embankment, or other structure from wave or current action. The rock should be hard and durable. Tests made by the U.S. Bureau of Reclamation (1946a, b; 1947) indicate that the quartzite beds in the Ogallala Formation are suitable for use as riprap. A quartzite quarry in sec. 31, T. 1 N., R. 14 W. (pl. 1, sample 79), Franklin County, was the source of the riprap used in the construction of the Harlan County Dam (just west of Franklin County).

Quartzite deposits in the Ogalla are lenticular in shape, irregularly jointed, and are not uniformly cemented at all places. Prospective deposits should be thoroughly investigated as to size and quality before development.

Frye and others (1949, p. 82) have indicated the possibility of using ceramic slag made from the Sanborn Formation (equivalent of the Peorian and Bignell and Loveland Loesses) for riprap.

LIGHTWEIGHT AGGREGATE

Lightweight aggregate is any material suitable for use as aggregate in producing concrete that weighs less than 120 pounds per cubic foot (Bush, 1951, p. 306). The aggregate should contain a high percentage of enclosed voids and be porous but impermeable. No materials from any of the three counties are known to have been used or tested for lightweight aggregate. Potential sources, after suitable treatment, include the Blue Hill Member of the Carlile Shale and the Pierre Shale, Peorian and Bignell and Loveland Loesses, and the Pearlette Ash Member of the Sappa Formation.

Plummer and Hladik (1948, p. 86) reported that the Blue Hill Member of the Carlile Shale and the Pierre Shale are satisfactory for the production of lightweight aggregate; the Blue Hill Shale Member is especially promising. Their tests also indicate that the loesses of Pleistocene age in Kansas are a potential source of lightweight aggregate. The Loveland and Peorian and Bignell Loesses in Nuckolls, Webster, and Franklin Counties are similar to the deposits in Kansas, and presumably these materials (except for the sandy phase of the Loveland in Franklin County) are satisfactory. Bush (1951, p. 310) has indicated that volcanic ash (pumicite) may be a potential source of lightweight aggregate, although he had no tests to confirm his opinion. Plummer and Hladik (1948) did not test any pure volcanic ash, but they did test a Pleistocene silt that contained 25 percent volcanic ash. Their tests indicate that this material is suitable for the manufacture of lightweight aggregate.

BUILDING STONE

Building stone, as used in this report, includes all natural stone used for ordinary masonry construction. No tests have been made to determine strength or other characteristics of the rock in this area, and the opinions contained in this section of the report are based principally on the observations of the authors. Potential sources of building stone include the Fort Hays Limestone and Smoky Hill Chalk Members of the Niobrara Formation and the quartzite in the Ogallala Formation.

The walls of the Municipal Museum in Franklin are made of quartzite from the Ogallala Formation. The stone blocks are rectangular, but irregular in size and shape and have a rough surface. The stone has a pleasing color, does not stain, is extremely hard, and probably has high compressive strength; it would, however, be difficult to cut blocks of uniform size and shape. Some of the older buildings in the business district of Franklin have large blocks of quartzite in their masonry foundations. No structural defects were noted in any of the buildings. The source of the quartzite is not known, but it was no doubt a quarry in Franklin County.

The Smoky Hill Chalk Member of the Niobrara Formation was used to construct a house in sec. 9, T. 1 N., R. 15 W. The blocks of chalk are rectangular, of even dimensions, and are only slightly iron stained. The yellowish-orange color of the blocks probably would be pleasing to many people. The building, although now abandoned, appeared structurally sound and no defects were seen in the masonry walls. The chalk is easy to quarry and dress to uniform size and shape. It probably does not have sufficient strength for large structures, but should certainly be strong enough for small structures. The location of the quarry used for this house is not known, but it is assumed that the rock was quarried nearby only for this one building.

A silicified zone in the Smoky Hill Chalk Member of the Niobrara Formation in the SE¼SE¼ sec. 24, T. 1 N., R. 13 W., was quarried extensively prior to 1900. In 1951, this quarry was almost completely obliterated by slope wash. Two masonry structures at Riverton were constructed of material from this quarry, the Congregational Church and the center pier of the bridge across the Republican River. A resident of Riverton thought that these had been built between 1875 and 1880. In both structures the blocks seem to have been sawed, and are rectangular, even, and regular in size. The only distress noted is in caps 3 feet long above basement windows on the west side of the church. These long caps are cracked rather badly at places, but not enough to endanger the building. The silicified chalk varies from pale yellowish tan to pale greenish yellow and is stained objectionably. It is interesting to note that the silicified chalk used in the center pier of the bridge shows very little solution, even though it has been partly immersed in water for many years.

No masonry work utilizing the Fort Hays Limestone Member was seen, although this member probably has been used in the area. It has been used quite extensively in Kansas (Jewett and Schoewe, 1942; Runnels and Dubins, 1949; Kulstad and Nixon, 1951). The limestone is easily cut into rectangular, uniformly sized blocks that do not stain if the sparsely distributed iron concretions are wasted.

CLAY

Clay suitable for the manufacture of ceramic slag, tile, and brick exists in large quantities in the area, although it is not being exploited at present. Both the Peorian and Bignell and Loveland Loesses (excluding the sandy phase) are suitable material. Tests performed by the State Geological Survey of Kansas indicate that the Sanborn Formation (equivalent to the Loveland and Peorian and Bignell of this report) can be utilized to make ceramic slag (Plummer and Hladik, 1948, p. 95–97), brick, and hollow tile (Frye and others, 1949, p. 80).

OIL AND GAS

No oil or gas production has been reported from any of the three counties, although several test holes have been drilled. The area lies along the axis of the Central Nebraska Basin (Reed and Svoboda, 1957) and is in a generally unfavorable area for structural traps. A possible anticline underlies the W½ T. 4 N., R. 13 W., between the two synclines shown in Reed and others (1958). Two northeast-plunging anticlines probably occur in T. 2 N., R. 16 W., and in T. 1 N., R. 15 W. (Merriam, 1957), and a rather broad northwest-plunging anticline underlies Nuckolls and eastern Webster Counties. All anticlines are rather minor features. Only the one in T. 2 N., R. 16 W., has produced oil from a small field west of Franklin County. The possibility of stratigraphic traps always exists, but an evaluation of such structures is beyond the scope of this report.

MISCELLANEOUS

Several of the geologic deposits can be used for whiting, cement, mortar, agricultural lime, rock wool, abrasives, and jewelry. The Fort Hays Limestone Member of the Niobrara Formation is satisfactory for whiting, a trade name applied to chalk used for many industrial purposes (Wilson and Skinner, 1937; Jewett and Schoewe, 1942,

p. 126–128). Detailed studies by Runnels and Dubins (1949) show that the Fort Hays is similar in composition and purity to the chalk imported into the United States. Limestone of the Fort Hays is also used to manufacture cement, as at the plant near Superior. Both the Fort Hays Limestone and the Smoky Hill Chalk Members are potential sources of agricultural lime. The Smoky Hill south of Nelson was exploited for agricultural lime. An abandoned lime kiln was seen south of the river from Bloomington, where residents reported that the Smoky Hill was used locally for mortar in early days. Table 9 shows chemical analyses of the Fort Hays and the Smoky Hill.

The Fort Hays, Smoky Hill, and the mortar beds of the Ogallala may be potential sources of rock wool. Tests on similar materials by the State Geological Survey of Kansas (Plummer, 1937 a, b) show that they make rock wool of satisfactory quality.

The volcanic ash (pumicite) of the Pearlette Ash Member of the Sappa Formation has a wide variety of industrial uses which have been enumerated by Jewett and Schoewe (1942, p. 173–174). Table 10 shows chemical analyses of pit-run samples of volcanic ash.

The quartzite in the Ogallala Formation is hard enough to take an excellent polish (Schramm, 1943) and can be made into colorful semiprecious jewelry.

FOUNDATION CONDITIONS

Foundation conditions are generally good in the three counties. No cracks or other forms of distress were seen in any structures in the area. Bentonite beds in the Pierre Shale and Smoky Hill Chalk Member of the Niobrara Formation, although thin, could conceivably damage structures by alternate expansion and contraction related to wetting and drying. The thick deposits of loess are also potentially hazardous to heavy structures because loess has the property of settling under heavy loads when saturated with water. The amount of settling frequently is not the same at all places, and consequently may cause unusual stress in the structure.

Table 11 shows the results of the free-swell test on samples of several formations from Franklin County. Holtz and Gibbs (1954) pointed out that this test is not suitable for exact determinations of swelling capacity, but does indicate the presence of potential swelling clays. Materials that swell more than 100 percent can cause considerable volume change under light loads; in contrast, materials that swell less than 50 percent seldom exhibit appreciable volume change under light loads. Holtz and Gibbs also pointed out that materials having a high plasticity index generally are more expansive than

TABLE 9.—*Rapid rock analyses of the Niobrara Formation*

[Analysts: P. L. D. Elmore, S. D. Botts, and M. D. Mack. The methods used were similar to those described in Shapiro and Brannock (1956). All samples for the analyses were collected by L. P. Buck]

Sample	Laboratory No.	Location: Section	Location: T.	Location: R.	SiO_2	Al_2O_3	Total Fe as Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	H_2O	CO_2	Total S as SO_3	Total	Description of sample
Fort Hays Limestone Member																			
1	149472	SW¼NW¼SW¼ 26	1 N.	8 W.	14.0	2.6	3.4	0.39	43.1	0.14	0.69	0.10	0.23	0.04	1.4	34.1	<0.03	100	
2	149473	SW¼SE¼SE¼ 33	1 N.	8 W.	6.5	2.3	1.1	.30	49.1	.13	.32	.12	.04	.01	1.1	39.0	<.03	100	
3	149474	SE¼SE¼ 6	1 N.	6 W.	4.9	2.0	.58	.38	50.3	.11	.26	.10	.01	.02	1.0	40.1	<.03	100	
Smoky Hill Chalk Member																			
4	149475	NW¼ 36	3 N.	7 W.	10.4	2.9	1.6	0.34	45.7	0.18	0.49	0.15	0.06	0.02	1.6	36.0	<0.03	99	Agricultural lime stockpile.
5	149476	NE¼SW¼ 8	1 N.	15 W.	3.7	1.0	2.6	.17	47.0	.13	.21	.06	.10	.02	3.6	34.5	4.6	[1] 98	Unweathered; from lower part of measured section 2 (pl. 1 sample 69).
6	149477	NE¼SW¼ 8	1 N.	15 W.	4.7	1.6	4.9	.32	48.1	.12	.26	.06	.13	.02	2.0	37.6	.25	100	Weathered; from upper part of measured section 2 (pl. 1 sample 69.)

[1] Sample contains appreciable organic matter.

TABLE 10.—*Rapid chemical analyses, in percent by weight, of pit-run volcanic ash*

[Analysts: P. L. D. Elmore, K. E. White, and S. D. Botts. Samples were analyzed by methods similar to those described by Shapiro and Brannock (1956)]

Laboratory No.	Map unit	Location	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	H_2O	CO_2	Total
148991	Qsp	SE¼ sec. 15, T. 1 N., R. 16 W., Franklin County, Nebr	72.8	12.3	0.7	0.82	0.12	0.71	2.3	6.2	0.14	0.00	0.02	3.7	0.18	100
148992	Qsp	SE¼ sec. 27, T. 3 N., R. 14 W., Franklin County, Nebr	72.3	12.7	.8	.78	.15	.60	2.7	5.6	.14	.00	.02	4.2	.05	100
148990	Qsp	SE¼ sec. 32, T. 3 N., R. 13 W., Franklin County, Nebr	73.0	12.2	.7	.80	.14	.58	2.6	5.8	.12	.00	.03	4.0	.08	100
149002	Qsp	SE¼NE¼NE¼ sec. 36, T. 1 N., R. 9 W., Webster County, Nebr	72.4	12.6	.7	.82	.14	.64	2.6	5.7	.16	.00	.03	4.4	.05	100
149001	Qsp	NW¼ sec. 31, T. 1 N., R. 8 W., Nuckolls County, Nebr	72.9	12.4	.7	.80	.14	.57	2.7	5.8	.13	.00	.03	4.1	.05	100
149003	Qsp	NW¼SW¼ sec. 22, T. 1 N., R. 7 W., Nuckolls County, Nebr	72.0	12.9	1.1	.64	.38	.79	2.1	5.5	.20	.01	.02	4.5	.05	100
149000	Qs	NE¼NE¼ sec. 28, T. 4 N., R. 8 W., Nuckolls County, Nebr	72.4	12.0	2.7	.30	1.2	1.2	1.4	2.7	.54	.09	.04	5.0	.07	100
149004	Qsp	SW¼NE¼ sec. 14, T. 3 N., R. 6 W., Nuckolls County, Nebr	72.5	12.4	1.1	.62	.22	.66	2.6	2.6	.20	.00	.02	4.3	.06	100

Table 11.—*Free-swell tests*

[The procedure followed is outlined in Holtz and Gibbs (1954)]

Sample	Location	Geologic unit	Swell (percent)
1	SE¼SW¼ sec. 29, T. 2 N., R. 13 W.	Sappa Formation	20
2	NW¼NW¼ sec. 36, T. 1 N., R. 13 W.	do	10
3	SW¼SE¼ sec. 25, T. 2 N., R. 16. W.	do	20
4	NW¼SW¼ sec. 21, T. 1 N., R. 14 W.	Silt from the Ogallala Formation.	10
5	NW¼SW¼ sec. 20, T. 1 N., R. 14 W.	Clay from the Ogallala Formation.	50
6 [1]	SE¼SE¼ sec. 15, T. 1 N., R. 16 W.	do	70
7 [2]	do	Pierre Shale	70
8	NW¼SE¼ sec. 33, T. 2 N., R. 16 W.	do	50
9 [3]	SE¼SE¼ sec. 15, T. 1 N., R. 16 W.	Smoky Hill Chalk Member of the Niobrara Formation.	50
10	NE¼NW¼ sec. 21, T. 1 N., R. 14 W.	do	20
11	NW¼SW¼ sec. 27, T. 2 N., R. 13 W.	do	0

[1] Measured section 3, unit 6 (pl. 1, sample locality 82).
[2] Measured section 3, unit 2 (pl. 1, sample locality 82).
[3] Measured section 3, unit 1 (pl. 1, sample locality 82).

those having a low plasticity index. Further testing is advisable on any material that has a plasticity index of 20 or more.

The free-swell tests indicate that the Pierre Shale and the clayey units in the Ogallala Formation are expansive. The single sample from the Smoky Hill Chalk Member of the Niobrara Formation that shows 50 percent swell was collected from a thin shaly weathered layer immediately underlying the Pierre Shale. The sample did not appear to be abnormally clayey. Some very thin unnoticed bentonite beds may have been included in the sample and caused the anomalous swelling. Bentonite beds in the Pierre and Niobrara were not tested but are probably very expansive.

The plasticity indices (Miller and others, 1964) show that the Pierre, the Carlile, and parts of the Ogallala and Sappa have swelling potentialities. At a few places clayey zones in the Crete, the Peorian and Bignell, and the Loveland also have a plasticity index of more than 20. This index generally occurs only in zones of clay enrichment in fossil soils. Only one sample of terrace deposit showed a plasticity index of more than 20.

ERODIBILITY

The fine-grained nature of most of the surficial deposits in this area makes them susceptible to erosion. Loess erodes easily but stands well in vertical cuts (fig. 13). The rapid and deep gullying common in sloping loess cuts can be avoided if the cuts are vertical.

Two types of undercutting in vertical cuts which tends to cause the loess to slump were noticed in this area. The first, and most prevalent, is caused by streams eroding the base of steep banks in loess. The second is caused by cuts which intersect unconsolidated sand underlying loess. The sand has a much lower angle of repose than the loess. In assuming its angle of repose, the sand moves out from under the loess and leaves it unsupported. Undercutting is accentuated if the water table is intersected and springs form in the underlying sand layer.

MEASURED SECTIONS

Rock-color terminology in the following measured sections is from the Rock-Color Chart (Goddard and others, 1948) and the soil-color terminology is from the Munsell Soil Color Charts (Munsell Color Co., 1954).

1.—Part of the Carlile Shale and Niobrara Formation measured in a quarry in the NW¼SW¼ sec. 26, T. 1 N., R. 3 W.

	Thickness (feet)
10. Humus and weathered rock.	
Niobrara Formation:	
Fort Hays Limestone Member (upper part not exposed):	
9. Chalk, weathered	0.5
8. Limestone, chalky, massive	2.0
7. Shale, chalky; interbedded with thin-bedded chalky limestone	1.9
6. Limestone, chalky, massive	2.3
5. Limestone, chalky, massive	6.8
4. Limestone, chalky, massive	5.0
3. Limestone, chalky, thin-bedded	8.0
Total Fort Hays Limestone Member exposed	26.5
Carlile Shale:	
Codell Sandstone Member:	
2. Sandstone, yellowish- to grayish-brown, silty, very fine grained	.6
Total Codell Sandstone Member exposed	.6
Blue Hill Shale Member:	
1. Shale, bluish-black, clayey, plastic, fissile; weathers grayish brown, base covered	4.2
Total Blue Hill Shale Member exposed	4.2

2.—Smoky Hill Chalk Member of the Niobrara Formation measured in a roadcut at the Bloomington Bridge in the NE¼SW¼ sec. 8, T. 1 N., R. 15 W.

[Tr., less than 0.1 foot thick. Pl. 1, sample loc. 76]

	Thickness (feet)
Peorian and Bignell Loesses:	
53. Grass covered, not measured.	
Smoky Hill Chalk Member:	
52. Chalk, mottled pale yellowish-orange and grayish-orange, silty	12.0
51. Bentonite, dusky-yellow	Tr.
50. Chalk, mottled pale yellowish-orange and grayish-orange, silty	11.4
49. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	2.0
48. Bentonite, white; mottled and stained dark yellowish-orange	Tr.
47. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	5.4
46. Bentonite, white; mottled and stained dark yellowish orange	Tr.
45. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	.2
44. Bentonite, white; mottled and stained dark yellowish orange	Tr.
43. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered (table 1, USGS fossil loc. f 11988)	3.7
42. Bentonite, white; mottled and stained dark yellowish orange	Tr.
41. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	1.0
40. Bentonite, white; mottled and stained dark yellowish orange	Tr.
39. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	3.5
38. Bentonite, white; mottled and stained dark yellowish orange	.1
37. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	.2
36. Bentonite, white; mottled and stained dark yellowish orange	Tr.
35. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	1.7
34. Bentonite, white; mottled and stained dark yellowish orange	.3
33. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	1.4
32. Bentonite, white; mottled and stained dark yellowish orange	.3
31. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	2.5
30. Bentonite ,white; mottled and stained dark yellowish orange	.1
29. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	3.1
28. Bentonite, white; mottled and stained dark yellowish orange	.1
27. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered (table 1, USGS fossil loc. f 11987; + pl. 1, sample 76)	1.5
26. Bentonite, white; mottled and stained dark yellowish orange	Tr.
25. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	.7
24. Bentonite, white; mottled and stained dark yellowish orange	Tr.
23. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	.3

2.—Smoky Hill Chalk Member of the Niobrara Formation measured in a roadcut at the Bloomington Bridge in the NE¼ SW¼ sec. 8, T. 1 N., R. 15 W.—Con.

	Thickness (feet)
Smoky Hill Chalk Member—Continued	
22. Bentonite, white; mottled and stained dark yellowish orange	Tr.
21. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	.3
20. Bentonite, white; mottled and stained dark yellowish orange	.2
19. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	.3
18. Bentonite, white; mottled and stained dark yellowish orange	.1
17. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	.5
16. Bentonite, white; mottled and stained dark yellowish orange	.1
15. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	3.2
14. Bentonite, white; mottled and stained dark yellowish orange	Tr.
13. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	1.5
12. Bentonite, white; mottled and stained dark yellowish orange	Tr.
11. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	.8
10. Bentonite, white; mottled and stained dark yellowish orange	.1
9. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	1.0
8. Bentonite, white; mottled and stained dark yellowish orange	.1
7. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	.6
6. Bentonite, white; mottled and stained dark yellowish orange	.1
5. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	.2
4. Bentonite, white; mottled and stained dark yellowish orange	.1
3. Chalk, light bluish-gray, silty, massive to hackly; thin beds obvious where weathered	3.8
2. Concealed by road fill; rubble and debris	17.0
1. Chalk, medium bluish-gray, silty, massive. Chalk is exposed on river bottom and in the south wall of the main channel of the Republican River. Base covered by water	3.0+
Total Smoky Hill Chalk Member exposed	84.5

3.—Section measured in a roadcut in the SE¼SE¼ sec. 15, T. 1 N., R. 16 W., Franklin County

[Pl. 1, sample loc. 81]

	Thickness (feet)
Loveland Loess, not measured.	
Ogallala Formation:	
7. Sand, grayish-yellow-green, coarse; more coarse material and silt at base, becoming sandier toward top; contains a few bone fragments (pl. 1, sample loc. 81, and table 2, sample 4)	11.4
6. Clay, pale olive at base to moderate greenish yellow at top, silty; very light gray calcareous zone halfway down (table 11, sample 6)	5.5

3.—Section measured in a roadcut in the SE¼SE¼ sec. 15, T. 1 N., R. 16 W., Frankin County—Continued

	Thickness (feet)
Ogallala Formation—Continued	
5. Sand, grayish-yellow, fine-grained, silty	.8
4. Sand, pale greenish-yellow, fine-grained, crossbedded; black manganese oxide zone at top	1.5
3. Quartzite, dark yellowish-orange and pale-greenish-yellow, lenticular; thin strong limonite zone at top and base	.2
Total Ogallala Formation exposed	19.4
Pierre Shale:	
2. Shale, brownish-gray, clayey, fissile, noncalcareous; contains many thin bentonite seams; top 0.8 ft strongly limonite stained and weathered (table 11, sample 7)	6.0
Total Pierre Shale exposed	6.0
Niobrara Formation:	
Smoky Hill Chalk Member:	
1. Chalk, light bluish gray at base to dark yellowish orange at top; weathers to the appearance of shale (table 1, USGS fossil loc. f 11983; table 11, sample 9). Exposures in adjacent gullies indicate that at least 50 ft of chalk underlies unit 1	5.0
Total Smoky Hill Chalk Member exposed	5.0

4.—Section measured in the SE¼SW¼ sec. 22, T. 1 N., R. 15 W., on an exposed face of the quarry from which riprap for the Harlan County Dam was taken

[Pl. 1, sample loc. 87]

	Thickness (feet)
Peorian and Bignell Loesses:	
14. Silt, pale yellowish-brown, noncalcareous; top during quarry operation	1.5
Total Peorian and Bignell Loesses exposed	1.5
Loveland Loess:	
13. Silt (soil of Sangamon age), brownish-black, clayey, slightly calcareous; contains white calcareous streaks	1.0
12. Silt (soil of Sangamon age), brownish-black, clayey, noncalcareous	3.0
11. Silt, moderate yellowish brown at top grading down to light brown at base; noncalcareous; basal contact with Crete is irregular	4.0
Total Loveland Loess exposed	8.0
Crete Formation:	
10. Silt, sand, pebbles, cobbles, and boulders, white to very light gray; in heterogeneous mixture; coarse material has calcareous coating, is rounded, and is predominantly quartzite from the Ogallala	2.5
Total Crete Formation exposed	2.5

4.—Section measured in the SE¼SW¼ sec. 22, T. 1 N., R. 15 W., on an exposed face of the quarry from which riprap for the Harlan County Dam was taken—Continued

	Thickness (feet)
Ogallala Formation:	
9. Clay, very pale green to dark yellowish-green, silty	.2
8. Clay, white, very calcareous	1.0
7. Sand, moderate yellowish-brown	2.5
6. Clay, white, very calcareous	.5
5. Sand, moderate yellowish-brown	.5
4. Clay, white, very calcareous	.5
3. Sand, grayish-yellow-green to dark greenish-yellow; basal 2 ft contains dark yellowish-orange clay lentils with bluish-white to white zones	4.0
2. Clay, dusky yellow-green mottled dark yellowish-orange and moderate yelowish-brown	.8
1. Quartzite, grayish-green, indistinctly crossbedded, irregularly fractured; predominantly composed of quartz and pink feldspar and some silicified clay balls; top very irregular (pl. 1, sample 87)	10.0
Total Ogallala Formation exposed	20.0

5.—SW¼SE¼ sec. 25, T. 2 N., R. 16 W.

[Pl. 1, sample loc. 56]

	Thickness (feet)
Modern soil complex:	
20. Silt, yellowish-gray; sandy, humic	1.0–2.0
Total modern soil exposed	2.0
Loveland Loess:	
19. Silt, moderate yellowish-brown, sandy; $CaCO_3$ in stringers and patches; contact with underlying unit 18 abrupt	1.1
18. Silt, dark-gray, humic (buried soil); $CaCO_3$ in closely spaced patches and stringers; upper 8 in. hard; horizontal $CaCO_3$ layer 4 in. thick at base	1.9
17. Silt, dark-gray humic	.5
16. Silt, moderate yellowish-brown (fresh) to white (weathered): contains $CaCO_3$ concretions 1 to 8 in. long and $CaCO_3$ cemented zone 24 in. thick that shows platy partings; base of unit has irregular contact with underlying unit 15, probably because of difference in $CaCO_3$	3.0
15. Silt, moderate yellowish-brown, sandy, hard, compact; upper 10 in. $CaCO_3$ enriched, lighter colored, contains concretions along horizontal layer 10 in. from top; 8-in. layer of silty clay in lower part of unit is hard and compact where dry, breaks in angular fragments; unit forms benchlike break in slope of roadcut	1.6–2.4
14. Silt, moderate yellowish-brown (fresh) to pale yellowish-brown (weathered): humic (buried soil) upper surface slopes downward in eastern part of exposure truncating unit 13	.9

5.—SW¼SE¼ sec. 25, T. 2 N., R. 16 W.—Continued

	Thickness (feet)
Loveland Loess—Continued	
13. Silt, very light gray, hard; $CaCO_3$ cemented; concretionary zone 3 to 4 in. thick extends horizontally across base of unit	2.7
12. Sand, moderate yellowish-brown (fresh) to very pale orange (weathered), fine, silty, hard, compact; 1- to 2-in. thick concretionary layer at base of unit contains coarse sand	1.5
11. Sand, grayish-orange, fine, silty, moderately hard, though less hard than unit 12; $CaCO_3$ content high; upper 4 in. clayey, indistinct horizontal bedding; lower 1.5 ft contains medium sand	3.0
10. Sand, grayish-orange, fine, silty; $CaCO_3$ cemented into discontinuous lenticular layer	.5
9. Sand, grayish-orange, silty, slightly crossbedded; contains rounded pebbles of $CaCO_3$ in vertical alinement; forms gentle slope	3.6
8. Sand yellowish-gray, silty, horizontally bedded; upper surface eroded; forms prominent, nearly vertical face; locally eroded	.0– .9
Total Loveland Loess exposed	20.3–22.0
Sappa Formation:	
7. Silt, pale-olive, massive, blocky; persistent; fills irregularities in underlying unit 6; upper surface very irregular; thickens at east end of exposure but, because unit was eroded (in early Illionian time) from middle part of exposure, sand of unit 9 is in contact with unit 6 on west side of farm access road where lower part of section was measured	.0–5.0
6. Clay, pale-olive (damp), to yellowish-gray (dry), silty; 12 silt lamina 1 mm thick, stained yellowish orange, near middle and upper 0.6 ft.; unit plastic; contains diatoms; dark-gray swirls near base; upper surface undulates beneath unit 7; unit used as datum horizon to continue measurements west of farm access road	1.2
5. Clay, olive-black damp, medium-gray dry, silty; finely laminated (possibly 50 per in.) but no true bedding; lenticular; forms even bed for distance of 300 ft. eastward; pinches out beneath farm access road fill; contains some carbonaceous plant remains; plastic; absent above bone locality (unit 4); may be "gley" soil	.5
4. Silt, light-gray (damp), to very light gray (dry), very fine, calcareous, especially at top of unit; contact with underlying unit 3 distinct, contact with overlying unit 5 less distinct	6–.9
3. Sand light-gray, medium to coarse; lenticular laminations; $CaCO_3$ streaks locally; bottom and top of unit parallel to each other on irregular configuration of surface on underlying unit 2	.5

5.—SW¼SE¼ sec. 25, T. 2 N., R. 16 W.—Continued

	Thickness (feet)
Sappa Formation—Continued	
2. Silt, pale yellowish-green, to pale-gray, sandy; several beds 0.2 ft. thick of silty sand; coherent, massive; (pl. 1, sample 56) upper 2 ft. is hard (dry), breaks in blocks 2 to 8 in. in diameter having minor coatings of $CaCO_3$ on fractures; contains gastropods	6.0
Total Sappa Formation exposed	8.8–14.1
Grand Island Formation:	
1. Sand, light-gray, fine to coarse, crossbedded; loose to slightly coherent; covered in part by slump	5.0
Total Grand Island Formation exposed	5.0

6.—NW¼SE¼ sec. 21, T. 4 N., R. 8 W.

[Pl. 3, sample loc. 26]

	Thickness (feet)
Soil (modern?):	
5. Silt, dark-brown appearing humic	1.0
Total silt exposed	1.0
Loveland Loess:	
4. Silt, moderate-yellowish brown, massive	6.0
Total Loveland Loess exposed	6.0
Sappa Formation:	
3. Silt, grayish-orange, clayey (>15 percent); sample 26 (pl. 3) collected from this unit; forms ledge; contact with unit 4 appears almost gradational	1.0– 2.0
2. Silt, grayish-orange; contains volcanic glass shards; erodes easily	5.0
1. Clay, light-olive; even horizontal surface, slightly unconformable with overlying unit 2 is abrupt and distinct; contact forms vertical bluff; upper 4 ft. appears separate from lower 2 to 3 ft. because of high-water mark	6.0– 7.0
Total Sappa Formation exposed	18.0–20.0

6a.—*SW¼NE¼ sec. 14, T. 3 N., R. 6 W.*

[Pl. 1, sample locs. 36 and C–586. Units 3–7 measured in a volcanic ash quarry, 1 and 2 in a ravine at the west end of the quarry]

	Thickness (feet)
Soil:	
7. Silt, dark-gray, humic (modern soil)	0.5
Total soil exposed	.5
Sappa Formation:	
6. Silt, brown grading downward to light-tan clayey; contains calcareous nodules in lower part	7.0

6a.—*SW¼NE¼ sec. 14, T. 3 N., R. 6 W.*—Continued

	Thickness (feet)
Sappa Formation—Continued	
5. Silt, greenish-gray, clayey, horizontally bedded; contains carbonaceous flecks, coarser grained near base; contains about 12 percent volcanic glass shards	3.4
4. Ash, light-tan, silty; contains 80 percent glass shards	5.7
3. Ash, light-gray, horizontally bedded; gray clay lentils alternating with ash in lower part; floor of pit (pl. 3 samples C–586 and 36, from upper part)	6.0
2. Ash and interbedded clay, light-gray	6.0
1. Clay, gray, silty; base covered	12.0+
Total Sappa Formation exposed	40.1+

7.—*NE¼SE¼ sec. 26, T. 3 N., R. 8 W.*

[Pl. 3, sample locs. 46–49 and G–2872]

	Thickness (feet)
Soil:	
8. Silt, dark-brown, humic	1.0
Total soil exposed	1.0
Peorian and Bignell Loesses:	
7. Silt, grayish-yellow-brown; absent at spillway but present to north	3.4
Total Peorian and Bignell Loesses exposed	3.4
Crete(?) Formation:	
6. Silt, very pale brown; contains 10 to 15 percent ash shards; lower 1.0 ft contains much reworked ash; thickens southward near spillway in channel fill; unconformable with underlying units (pl. 3, sample 46)	2.2-14.0
Total Crete(?) Formation exposed	2.2–14.0
Sappa Formation:	
5. Silt, very pale brown; mixed with platelike fragments of cemented ash; gradational with unit 4; truncated by units 6 and 7	.6–3.0
4. Ash, white, prismatic; contains pumice; massive, bedding absent or obscured; silt size predominant; (table 4, sample G–2872; pl. 3 sample 47)	1.0
3. Ash, white, hard, compact; appears as mortarlike layers; breaks into ½- to 1-in. flat tabular plates; looks like chalk fragments from distance; sharp, slightly undulating unconformable contact with unit 2; truncated by unit 6	.2
2. Silt, light-gray, mottled rust and pink; fine, blocky; no ash; truncated by unit 6; (pl. 3, sample 48)	2.3
1. Silt, very pale brown, thin-bedded; no ash; thins southward where partially eroded prior to fill of unit 6; (pl. 3, sample 49)	4.0–25.0±
Base covered.	
Total Sappa Formation exposed	8.1–31.5±

8.—Type locality of the Sappa Formation SW¼NW¼ sec. 12, T. 2 N., R. 20W., Harlan County

	Thickness (feet)
Sappa Formation:	
Middle sand:	
11. Sand, medium-gray, coarse, crossbedded; contains some reworked 1/16-in. ash balls; irregular contact with underlying unit 10. Upper part not measured	3.0+
Total sand exposed	3.0+
Pearlette Ash Member:	
10. Ash, white, massive; fine at top, coarse at base; heavy-mineral sample G–2861 collected 3 in. above base	2.25
9. Clay, pale-green, bentonitic(?); bed regular and continuous	.02
8. Ash, very light gray, massive, clay-enriched	.33
7. Clay, pale-green, bentonitic(?); bed regular and continuous	.02
6. Ash, very light gray, massive, clay-enriched	.25
5. Ash, white, massive; finer than unit 10, but is graded finer at top, coarser at base; heavy-mineral and ash samples G–2862 collected 3 in. above base	.75
4. Ash, very light gray, massive; clay enriched near top, less clay near base	1.90
3. Ash, white, massive, coarse in lower 1 in. heavy-mineral and ash samples G–2863 collected 3 in. above base	1.33
2. Ash, medium-gray to moderate orange-pink, wavy- to circular-bedded; lower contact irregular; heavy-mineral and ash samples G–2864 collected 3 in. above base	.83
Total Pearlette Ash Member exposed	7.85
Lower silt:	
1. Silt, light olive-gray, sandy	.17
Base covered.	
Total lower silt exposed	.17

9.—NW cor. sec. 22, T. 1 N., R. 11 W.

[Pl. 2, Cenozoic locs. 21570–21573]

	Thickness (feet)
Silt:	
10. Silt, dark-brown to black, humic, hard; upper 0.5 to 0.7 ft less compact than lower 0.7 to 0.9 ft; composite soil	1.2–1.6
9. Silt, light-cream; contains pebble-size gravel derived from Niobrara, fills irregularities on underlying units 6, 7, and 8; gray humic layer (soil?) 0.5 to 1.0 ft thick in upper 1.5 ft	.0–3.0
8. Silt, reddish-brown, massive; conspicuous columnar jointing; eroded upper surface covered by gravel and silt of unit 9; contains mollusks of warm arid climate (pl. 2, Cenozoic loc. 21570)	.0–1.5
7. Silt, light-tan; contains $CaCO_3$, fills channels in sand of unit 5, in places overlies unit 6; stands as remnants or blocks covered by unit 9, or overlain by unit 8; contains mollusks of warm arid climate (pl. 2 Cenozoic loc. 21571)	.0–2.5
Total silt exposed	1.2–8.6

9.—NW cor. sec. 22, T. 1 N., R. 11 W.—Continued

	Thickness (feet)
Sand:	
6. Sand, gray; contains chert and limestone pebbles; upper part eroded and unconformable with units 9, 8, and 7; contact with underlying unit 5 sharp and distinct	.0–1.0
Total sand exposed	.0–1.0
Loveland Loess:	
5. Silt, reddish-brown, massive; semiplastic to plastic when moist; upper contact with unit 6 undulating	4.0–5.0
Total Loveland Loess exposed	4.0–5.0
Sappa Formation:	
4. Silt, dark purple-black; contains carbonaceous matter; horizontally laminated, breaks in platy fragments; contact with unit 5 indistinct; A horizon of soil	.7
3. Clay, gray, horizontally laminated; gradational contact with unit 4; contains cold-climate mollusks (table 6, Cenozoic loc. 21572)	.7
2. Silt, dark-black; contains clay; carbonaceous matter throughout; horizontally laminated, breaks in platy fragments; A horizon of soil	1.6–2.0
1. Clay, greenish-gray; sample collected from auger; not exposed in ditch line; contains mollusks of cold climate (table 6 Cenozoic loc. 21573)	4.0+
Total Sappa Formation exposed	3.0–7.4

10.—NE¼SE¼ sec. 8, T. 1 N., R. 12 W.

	Thickness (feet)
Peorian and Bignell Loesses:	
9. Silt, light-gray, massive; stands vertically; measured from grass cover	10.0
Total Peorian and Bignell Loesses exposed	10.0
Loveland Loess:	
8. Silt, dark yellowish-brown, humic; columnar joints; Sangamon (?) soil	2.0
7. Silt, moderate yellowish-brown, friable; columnar joints; lower part gradational with underlying unit 6	15.0
Total Loveland Loess exposed	17.0
Crete Formation:	
6. Silt, pale yellowish-brown, humic; more compact than underlying unit 5; hard, forms small ledge; upper 6 to 8 in. platy; soil (?)	2.0
5. Silt, very pale orange; contains very little sand; horizontally bedded; stands almost vertically or forms microbadland topography	6.0
4. Silt, dark yellowish-brown, humic; soil (?)	2.0

10.—NE¼SE¼ sec. 8, T. 1 N., R. 12 W.—Continued

	Thickness (feet)
Crete Formation—Continued	
3. Silt, very pale orange; contains fine sand; unit cemented slightly by $CaCO_3$; porous where fresh; contains less sand and more pink feldspar, and the pebbles are smaller and fewer than in unit 2; some weathered shell fragments; horizontally bedded; stands almost vertically	5.0
2. Silt, very pale orange; contains fine sand and a few thin horizontal layers of rounded limestone pebbles as much as 1 in. diameter; quartz sand grains stand out in relief; some pink feldspar grains; horizontally bedded; stands almost vertically	8.5
1. Sand, grayish-orange, fine to medium; predominantly quartz, chalk of the Niobrara Formation, and *Inoceramus* prisms; contains some chert; grains spheroidal to tabular; gravel lenses 5.5 feet above Niobrara, predominantly reworked chalk; forms slope; unconformable over chalk of the Niobrara Formation	17.5
Total Crete Formation exposed	41.0

11.—NW¼NE¼ sec. 5, T. 1 N., R. 7 W.

	Thickness (feet)
Peorian and Bignell Loess:	
5. Silt, very dark gray-brown, humic; A horizon; mostly covered	3.5
4. Silt, pale-yellow; upper 2 in. contains clay, breaks into small (½ to 2 in.) fragments, is darker colored, light olive brown, massive; silt is porous owing to vertical root holes; breaks horizontally; small (⅛ in. diameter by ½ to 1½ in. long) $CaCO_3$ concretions scattered on surface, some have small branches; 3 in. above base pH is 8.0; distinct contact with unit 3	7.0
Total Peorian and Bignell Loesses exposed	10.5
Loveland Loess:	
3. Silt, very dark gray brown, humic; A horizon of Sangamon soil; massive, porous at top owing to root holes; clayey near base; hard, breaks in angular fragments; 3, 6, and 9 in. below top of unit pH is 8.0; gradational contact with underlying unit 2	3.9
2. Silt, reddish-brown, clayey; B horizon; massive; breaks into ½- to 1-in. angular blocks; waxy coating on fresh surfaces of fragments; plastic when wet; gradational with underlying unit 1	2.6
1. Silt, reddish-brown, coarse, massive; porous; breaks into ½- to 3-in. blocks; base covered at ditch line; silt of Sappa Formation exposed at east end of roadcut	1.0
Total Loveland Loess exposed	7.5

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INDEX

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