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Revision of the Classification of the Pleistocene Deposits of Nebraska

BY

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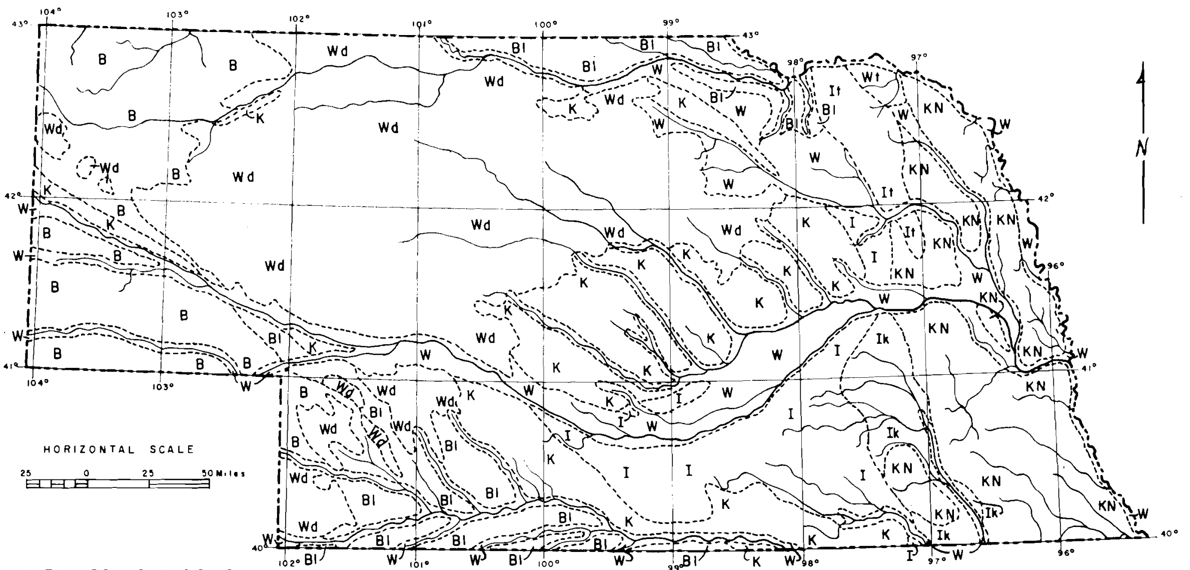
Revision of the Classification of the Pleistocene Deposits of Nebraska

By E. C. Reed and V. H. Dreeszen

The Nebraska Geological Survey has had a long and continued interest in the Pleistocene deposits of the state because of the relationship of these deposits to the soils and agriculture, ground water and well development, and sources of construction materials related to economic development. The first major contribution of the Survey to Pleistocene stratigraphy was that of A. L. Lugn (1935) who established a classification of the periglacial deposits of the state and related these deposits to the glacial stages. G. E. Condra and E. C. Reed (1950) used information acquired during the 1935-1950 period in making important revisions in Lugn's classification. This report is a further revision based on studies made since 1950. It is an effort to reconcile all of the available data and to present a classification which meets the demands of the present knowledge and understanding of these complex deposits. The generalized occurrence of Pleistocene deposits in Nebraska is shown in Figure 1.

The paleontologic and geomorphologic studies of the University of Nebraska State Museum, based on systematic collections referred to stratigraphic horizons, aided by graduate studies in the Department of Geology of the University of Nebraska, have contributed greatly to the present understanding. Participation in field conferences related to the Pleistocene deposits in Nebraska and other states of the Upper Mississippi valley region has been most helpful to those engaged in studying the Nebraska deposits.

Since 1950 there has been continued interest in the Pleistocene deposits and systematic test drilling has expanded into a larger portion of the state (Figure 2), especially in the glaciated eastern part. A careful evaluation of all pertinent data requires certain changes and additions to the earlier Nebraska classification system if all established relationships are to be considered. Moreover, it becomes increasingly essential to be equipped to work with smaller subdivision units of stratigraphic importance if the complex Pleistocene geologic history is to be revealed. Therefore, names are assigned herein to previously unnamed but readily recognizable and extensive depositional units, and previously accepted names are preserved in the concept in which



KEY TO SYMBOLS

W - Wisconsinan terrace deposits (Bignell and Peoria Formations), loess-mantled; also includes Recent alluvium. Wd - Wisconsinan dunesand (Bignell and Peoria Dunesand). Wt - Medial Wisconsinan till (Hartington Till), generally mantled with Late Wisconsinan loess and terrace deposits (Bignell). I - Illinoian terrace deposits (Loveland, Beaver Creek and Grafton Formations), loess-mantled; overlies remnants of Kansan terrace deposits. Ik - Illinoian and Kansan terrace deposits (loess-mantled) above remnants of Early Kansan Till (Nickerson). It - Illinoian Till (Santee and Clarkson Tills), loess-mantled; overlies remnants of older till. KN - Kansan till (Cedar Bluffs and Nickerson Tills), loess-mantled; overlies remnants of Nebraskan tills (Iowa Point and Elk Creek Tills) locally. K - Kansan (Sappa, Walnut Creek and Red Cloud Formations) and Nebraskan (Fullerton and Seward Formations) terrace deposits, loess-mantled. Bl - Loess-mantled bedrock; terrace deposits in channels. B - Bedrock; some thin loess mantle.

Figure 1. Generalized Pleistocene map of Nebraska.

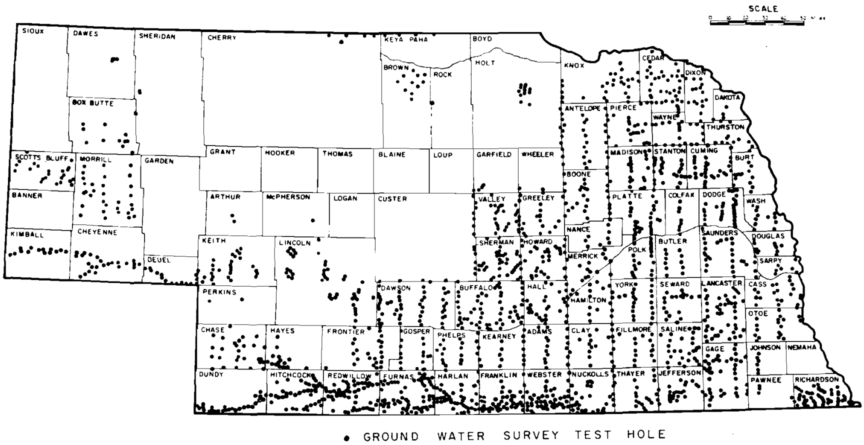


Figure 2. Location of Ground Water Survey test holes.

their use has been established even though the relationships at some of the type localities are questionable. Some previously established unit names are restricted in their present usage from the broader earlier usage. This procedure is believed to be preferable to the substitution of new unit names for established and widely used names because it facilitates comparison of the present classification to the earlier classification. It is not proposed that the names herewith suggested for use in Nebraska be utilized in neighboring states unless there is a need for a more detailed subdivision of units now recognized in those states.

Principles Followed in Classification

The Nebraska Survey has abandoned the use of all names implying time-stratigraphy for rock-stratigraphic units (Figure 3). Thus, Peoria is substituted for Peorian and local names are assigned to tills which previously were known as Nebraskan, Kansan, and Illinoian. The use of Nebraska till for Nebraskan till and Kansas till for Kansan till does not seem to be acceptable in Nebraska because each of these glacial stages is represented by more than one advance and "retreat"[1] of the ice.

The names assigned to stratigraphic units in Nebraska are not necessarily formation names although some of them may be so considered. For example, the Holdrege and Fullerton, Grand Island and Sappa, Crete and Loveland of previous usage, in their fluviatile occurrences, are depositional sequences from coarser textured to finer textured alluvium, and may be regarded as formations in this light, yet

[1] The "retreat" of the ice involves the melting of the ice and not a physical movement of the ice.

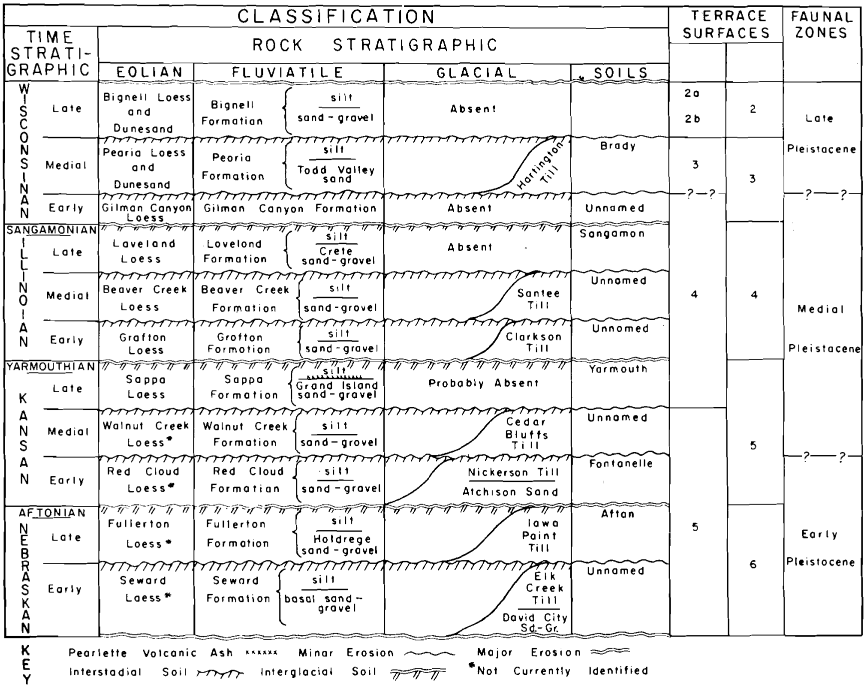


Figure 3. Classification chart of the Pleistocene deposits of Nebraska.

each distinct lithology is truly a mappable unit. Upland phases of depositional sequences are loesses which represent a single lithology and thus a single mappable unit. New names, which have been assigned to additional depositional sequences are applied to the complete depositional sequence although upper silts and lower sands or sands and gravels are generally recognized in the fluviatile occurrences and can be mapped. In the case of previously used names, the same unit names are used for the loessic phases in upland occurrences as were previously used for the fine-textured alluvium in order to facilitate correlation between terrace and upland deposits in the periglacial region.

The general principle, proposed by Lugn (1935), that the advance and retreat of continental glaciations had a controlling effect on the depositional and erosional history of the periglacial region has been substantiated in subsequent investigations and seems to provide a firm basis for correlation between the glacial and periglacial[2] provinces. However, some of the earlier glaciations were much more complex than realized in 1935 and the older classification is no longer adequate.

Four major continental glaciations—the Nebraskan, Kansan, Illi-

[2] Periglacial refers to areas adjacent to but outside of the reaches of glaciation.

noian and Wisconsinan stages—are recognized in the Upper Mississippi River valley region. Each of these glacial stages is separated from the succeeding glacial stage by a period of essential stability under comparatively warm conditions when interglacial soils were developed extensively, followed by a period of extensive major erosion as sea levels were lowered with the growth and advance of continental ice sheets. These events were recorded in the periglacial as well as in the glaciated region by the development of recognizable interglacial soils (Afton, Yarmouth and Sangamon) and by widespread unconformities as active erosion cut deeply into the pre-existing surfaces at the time of glacial advance. The magnitude of the pro-glacial[3] erosion was tremendous, locally removing much or all of the pre-existing deposits and occasionally deepening valleys into the bedrock surface. Under these conditions younger materials were deposited on much older materials and incomplete sequences are the rule rather than the exception. This presents problems in local correlation where easily identifiable key horizons have been removed. Extensive field mapping or extensive test drilling often permits the tracing of materials into areas with more complete sequences, thus establishing the stratigraphic sequence. The similar lithologies of deposits of like origin but different ages further complicates the problem.

In addition to the broad correlation of Pleistocene deposits on the basis of recognizable interglacial soils and major unconformities, the Pleistocene materials in both the periglacial and glaciated regions can be subdivided further on the basis of recognizable interstadial[4] soils and periods of minor, stade erosion. Each partial retreat and readvance of the continental ice sheets within each glacial stage is reflected in separate depositional sequences in the periglacial region. Thus it is believed to be possible to differentiate in the periglacial region two related depositional sequences in the Nebraskan, three in the Kansan, three in the Illinoian, and three in the Wisconsinan which can be related to and correlated with two tills of Nebraskan, two or more tills of Kansan, three tills of Illinoian, and three tills of Wisconsinan age in eastern Nebraska or elsewhere in the northern Mid-continent region. The deposits of the different glaciations of each glacial stage are separated from each other by interstadial soils, developed during periods of essential stability between earlier and later advances of the ice. The interstadial soils were generally developed under cooler conditions than existed during interglacial periods and

[3] The use of the prefix "pro-" refers to events or deposits directly related to the advance of the ice.

[4] Interstadials are periods separating stades or "substages" which are parts of stages.

their development was followed by periods of minor erosion as sea levels were again lowered with readvances of the ice.

Problems Related to Use of Soils in Correlation

One problem in the interpretation of the soils within the Pleistocene sequence involves the evaluation of the soil horizons as interglacial or interstadial and may result in errors of correlation. In this connection, the strength of the soil development is believed to be the most important factor. Pronounced zones of clay enrichment in the "B" horizons of the soils, considerable depth of leaching and great depth of oxidation of the parent material, and significant thicknesses of zones of secondary lime accumulation are believed to be much more important and better indicators of the interglacial nature of the soils than the thickness of the humic or carbonaceous "A" horizon. Some of the thick, dark, friable zones above "B" (clay-enriched) horizons are accumulation zones, unrelated to the development of the underlying part of soil profile.

The environment of the site also exerts a considerable influence on the type of soil development that may result during both interglacial and interstadial times. If the site was well-drained at the time of soil development, greater depth of oxidation and leaching may be expected resulting in a "reddish prairie" type of soil, whereas "Wiesenbodens" tend to be developed in poorly drained environments.

Use of Pearlette Volcanic Ash Horizon in Correlation

The widespread distribution of the Pearlette Volcanic Ash horizon in Nebraska and surrounding states is of great assistance in the correlation of the Pleistocene deposits. The Pearlette Volcanic Ash, varying in thickness from a few inches to 18 feet or more, is recognized as a persistent horizon in the Sappa Formation which is believed to be of Late Kansan age. The volcanic ash is readily identified in the field in exposures where it occurs as a comparatively pure bed, and can be identified in other localities by microscopic examination of silt samples that contain ash shards intermixed with silts.

The Pearlette Volcanic Ash bed was intensively studied by Swineford and Frye (1946) and found to be distinct from the volcanic ash beds of Tertiary age on the basis of refractive index and other characteristics. Young and Powers (1960) initiated more intensive petrographic studies of the Pearlette and reported on the presence of chevkinite. Miller, Van Horn, Dobrovolny and Buck (1964, pp. 24–29) compared the Pleistocene volcanic ash deposits of Franklin, Webster and Nuckolls counties in Nebraska with the Pearlette Volcanic Ash at two localities in Kansas and with the volcanic ash at the type local-

Formation	State	Legal Description Location	USGS Laboratory Number	Ag	B	Ba	Be	Co	Cr	Cu	Fe	Ga	La	Mn	Mo	Nb	Ni	Pb	Sc	Sn	Sr	Ti	V	Y	Yb	Zr
Pearlette Bed of Sappo	Kansas	35-14S-11W	G2874°′	<.00005	<.001	.032	.0006	<.0001	<.0001	.0003	1.00	.0024	.010	.026	.0005	.007	<.0002	.004	<.0005	.0010	<.001	.080	<.0005	.008	.0010	.026
	"	28-13S-10W	G2875°′	.00008	<.001	.028	.0006	<.0001	<.0001	.0004	.94	.0024	.010	.024	.0005	.006	<.0002	.004	<.0005	.0014	<.001	.075	<.0005	.008	.0010	.024
	Colorado	28-3S-70W	G2860	<.00005	<.001	.032	.0007	<.0001	<.0001	.0004	1.10	.0024	.013	.026	.0005	.007	<.0002	.004	<.0005	.0010	<.001	.087	<.0005	.009	.0010	.030
	Nebraska	15-1N-16W	G2858°	<.00005	<.001	.021	.0007	<.0001	<.0001	.0003	1.00	.0024	.012	.026	.0004	.007	<.0002	.004	<.0005	.0010	<.001	.084	<.0005	.009	.0010	.028
	"	28-1N-9W	G2866°	<.00005	<.001	.024	.0006	<.0001	<.0001	.0002	1.10	.0024	.012	.028	.0005	.007	<.0002	.004	<.0005	.0009	<.001	.086	<.0005	.010	.0010	.029
	"	26-1N-9W	G2869°	<.00005	<.001	.023	.0010	<.0001	<.0001	.0003	1.10	.0024	.015	.028	.0004	.008	<.0002	.004	<.0005	.0009	<.001	.090	<.0005	.010	.0010	.030
	"	12-2N-20W	G2861°′	<.00005	<.001	.017	.0009	<.0001	<.0001	.0004	.93	.0023	.014	.023	.0003	.007	<.0002	.004	<.0005	.0010	<.001	.082	<.0005	.010	.0010	.027
	"	"	G2862°′	<.00005	<.001	.018	.0006	<.0001	<.0001	.0004	.84	.0022	.011	.022	.0005	.005	<.0002	.004	<.0005	.0010	<.001	.076	<.0005	.008	.0010	.021
	"	"	G2863°′	<.00005	<.001	.016	.0009	<.0001	<.0001	.0003	.92	.0023	.010	.024	.0005	.005	<.0002	.005	<.0005	.0010	<.001	.074	<.0005	.009	.0010	.020
	"	"	G2864°′	<.00005	<.001	.016	.0006	<.0001	<.0001	.0002	.91	.0022	.010	.020	.0004	.005	<.0002	.004	<.0005	.0010	<.001	.078	<.0005	.008	.0010	.021
	"	19-2N-12W	G2867°	<.00005	<.001	.030	.0006	<.0001	.0007	.0005	.94	.0022	.010	.024	.0005	.005	<.0002	.004	<.0005	.0010	.002	.080	<.0005	.008	.0009	.018
	"	32-2N-7W	G2868°	<.00005	<.001	.023	.0007	<.0001	<.0001	.0003	1.00	.0024	.010	.020	.0005	.007	<.0002	.004	<.0005	.0009	<.001	.068	<.0005	.008	.0010	.026
	"	32-3N-13W	G2857°	<.00005	<.001	.026	.0008	<.0001	<.0001	.0003	1.00	.0026	.012	.026	.0004	.006	<.0002	.005	<.0005	.0010	<.001	.079	<.0005	.009	.0010	.026
	"	14,15-3N-5W	G2870°	<.00005	<.001	.025	.0005	<.0001	<.0001	.0004	1.10	.0026	.011	.025	.0005	.007	<.0002	.004	<.0005	.0009	<.001	.081	<.0005	.008	.0010	.029
	"	3-4N-7E	G2865°	<.00005	<.001	.034	.0004	<.0001	.0004	.0005	1.00	.0024	.009	.021	.0004	.006	<.0002	.004	<.0005	.0010	.002	.098	.0009	.008	.0009	.026
	"	17-9N-1E	G2855	<.00005	<.001	.028	.0008	<.0001	.0002	.0003	1.00	.0023	.016	.028	.0003	.009	<.0002	.004	<.0005	.0009	<.001	.083	<.0005	.011	.0010	.034
	"	26-9N-2E	G2856	<.00005	<.001	.022	.0006	.0001	.0002	.0004	1.10	.0023	.011	.026	.0004	.007	<.0002	.004	<.0005	.0010	<.001	.084	<.0005	.009	.0009	.026
	"	8-10N-26W	G2853	<.00005	<.001	.021	.0009	.0001	<.0001	.0003	1.20	.0026	.014	.030	.0004	.007	<.0002	.004	<.0005	.0008	<.001	.084	<.0005	.009	.0009	.028
	"	9-16N-13E	E2079′	N. D.	.002	.024	.0010	<.0001	.0002	.0006	1.20	.0024	.012	.029	.0006	.006	N. D.	.004	?	.0010	.0014	.082	N. D.	.010	.0009	.029
	"	25-17N-13W	G2873	<.00005	<.001	.033	.0005	<.0001	.0001	.0006	1.00	.0028	.011	.026	.0005	.005	<.0002	.005	<.0005	.0010	<.001	.072	<.0005	.008	.0010	.026
	Iowa	5-81N-45W	G2852′	<.00005	<.001	.025	.0006	.0002	.0003	.0005	.92	.0022	.008	.022	.0004	.007	<.0002	.004	<.0005	.0010	.001	.083	<.0005	.008	.0010	.023
	Nebraska	11-29N-1E	G2854	<.00005	<.001	.013	.0009	.0002	.0001	.0004	.93	.0022	.010	.026	.0004	.007	<.0002	.004	<.0005	.0008	<.001	.074	<.0005	.010	.0010	.021
Fullerton ?	"	26-3N-8W	G2872°	<.00005	.006	.019	.0003	.0002	.0007	.0050	.69	.0014	.005	.021	.0005	.002	.0003	.004	.0005	.0006	.004	.069	.0012	.002	.0003	.010
Ogallala	Kansas	25-2S-22W	G2859	<.00005	<.001	.074	.0005	<.0001	<.0001	.0007	1.20	.0018	.010	.023	.0004	.004	<.0002	.004	.0006	.0010	.002	.140	.0015	.006	.0008	.039
"	Nebraska	25-32N-22W	G2871	<.00005	<.001	.120	.0006	<.0001	<.0001	.0005	1.20	.0018	.011	.024	.0003	.004	<.0002	.004	.0006	.0009	.005	.150	.0016	.007	.0008	.038

All results in percent by weight of glass shards, cleaned with ultrasonic transducer and separated from contaminants by use of electromagnet; analyses by general spectographic methods. Reported results have accuracy of ± 15 percent except near limits of detection where accuracy is less.

Looked for but not detected: As, Au, Bi, Cd, Ge, In, Pt, Sb, Ta, Th, Tl, U, W, and Zn.

N. D. – Looked for but not detected.

U. S. G. S. Laboratory Numbers

° After U.S.G.S. Bulletin 1165, Table 4, pp 26, 27

′ After U.S.G.S. Professional Paper 472, Table 3, p. 31

Remainder reported by Robert D. Miller, personal communication, 3-24-65, from U.S.G.S., Geochemistry & Petrology Branch Report IDS 474, 7-19-60

KEY TO MAP SYMBOLS

× Pearlette

• Probably Pleistocene, probably not Pearlette

△ Pliocene - Ogallala formation

G2859 Indicates U. S. G. S. Laboratory Serial Numbers

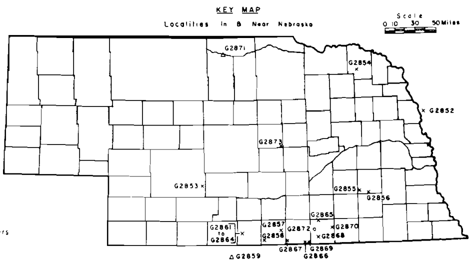


Figure 4. Spectrographic analyses of trace elements in volcanic ash beds.

ity of the Sappa Formation in Harlan County, Nebraska, on the basis of quantitative spectrographic analyses of trace elements. Miller (1964, p. 31) reported on the trace elements in volcanic ash from a locality north of Omaha and from the Harrison-Monona County line section along the east side of the Little Sioux River valley in northwestern Iowa; he (personal communication, March 24, 1965) also has furnished similar analyses from exposures of the Pearlette at other localities in Nebraska. All of these studies confirm the correlation of the Pearlette Volcanic Ash horizon throughout Nebraska and Kansas (Figure 4).

The occurrence of the Yarmouth Soil above the Pearlette Volcanic Ash, where not removed by post-Yarmouthian erosion, and the presence of Medial Kansan till or older deposits below the Pearlette Volcanic Ash results in our placement of the Pearlette Volcanic Ash and the Sappa Formation in the Late Kansan, although some Pleistocene geologists and paleontologists regard it as Early Yarmouthian. This variation in concept will be discussed later.

Whether or not the Pearlette Volcanic Ash represents a single ash fall from a single source or a series of ash falls from the same or different sources is comparatively unimportant because this period of ash accumulation must represent a relatively short period of volcanic activity elsewhere and thus a comparative moment in geologic time. For a long period of time it was our opinion that there was a single volcanic ash bed in the Pleistocene sequence. However, volcanic ash has been noted in the samples from two test holes at a level below a till correlated as Early Kansan and one or two exposures of volcanic ash in Nebraska do not seem to duplicate the petrographic characteristics of the Pearlette. Therefore, it appears that there may have been an earlier ash fall in the Pleistocene, possibly of Late Nebraskan age, which is imperfectly and rarely preserved.

The Pearlette Volcanic Ash in Nebraska and Kansas appears to be within the silt member of the Sappa Formation, but some occurrences farther to the west appear to be in sands and gravels which seem to correlate with the underlying Grand Island sand and gravel member of the Sappa. If the ash fall is a true time line, as we believe, it could well occur in more than one lithologic entity because mappable units established as lithologic entities can and do transgress time lines.

There are some apparently anomalous occurrences of the Pearlette Volcanic Ash, so far as the relation to valley elevations is concerned. The lower level occurrences are associated with fluviatile silts of the Sappa while the anomalous higher level occurrences of the Pearlette seem to be associated with eolian silts or loess which we classify as Sappa Loess. These may rest on older deposits which were uplands during Late Kansan time.

Interpretation of Topographic Features Related to Glaciation

The availability of more detailed topographic maps in Nebraska and adjoining states, especially the 1:250,000 topographic maps, makes it possible to study the regional geomorphology of the glaciated region of eastern Nebraska and these studies have facilitated the classification of the Kansan and early Illinoian glaciations, especially when these features are studied in relation to test hole records which penetrate all of the Pleistocene deposits. Even though this region is generally loess-mantled, the topography clearly reflects morainic ridges which often form drainage divides and result in some peculiar drainage trends as the divide areas are approached (see Figures 5A and 5B). Some of these features have been recognized as "lateral moraines" by earlier workers including Lugn (1935).

The topographic features shown in Figures 5A and 5B indicate that the Missouri River, above Kansas City, is located in the central lowland of a semi-elliptical morainic system which exhibits the same general configuration as the James River valley in South Dakota (Flint, 1955) except that the moraine-divides are generally developed on tills of Kansan and Illinoian age instead of on Wisconsinan till as in South Dakota. The earliest advance of the Kansan ice certainly extended farther west and south in Nebraska and northeastern Kansas. It is marked by the topographic divide between the Big and Little Blue River valleys near the Kansas-Nebraska state line (labeled Nickerson in Figure 5A) but its north-northwest extension in Nebraska is obscured because the Early Kansan till is mantled by terrace deposits of Medial Kansan, Late Kansan and Illinoian age.

The Kansan ice sheet apparently "retreated" from Nebraska during the first Kansan interstadial period when the Fontanelle interstadial soil developed on the Early Kansan (Nickerson) till. The second advance of the Kansan ice sheet developed a moraine-controlled divide between the Big Blue River drainage and the Missouri River system above Kansas City and this divide (labeled Cedar Bluffs in Figure 5A) can be traced across southeastern Nebraska and into northeastern Kansas although it is breached by the Platte River valley which developed largely in Wisconsinan time.

A third moraine-controlled divide (Clarkson moraine, Figure 5A) parallels and lies east of the second one (Cedar Bluffs) between the Platte and Elkhorn River valleys where three tills younger than Aftonian can be identified in drilling (Figure 6). The till in the third moraine is tentatively placed in the Early Illinoian.

A fourth moraine-controlled divide (Santee moraine, Figure 5A) is prominent in the northeastern part of the state, north of the Elkhorn valley. This divide is developed on till (Santee) which is post-Pearlette Volcanic Ash and pre-Sangamonian in age and is there classified as Illinoian, probably Medial Illinoian. The current classification of the deposits of Pleistocene age in Nebraska is illustrated in Figure 3.

Terrace Deposits, Terrace Surfaces and Loess-Mantled Terraces

There is some confusion in the utilization of the term terrace in Nebraska that should be clarified. Terrace deposits are sediments of fluviatile origin that have been dissected by later drainages and remain as valley-side remnants of the alluvial deposits that filled the pre-existing valleys. In many cases the terrace deposits were mantled by younger loess or dunesand blown up from lower-lying valleys and by colluvium moved down from higher side-slopes. The present surface is identifiable and generally reflects the older surface on which the mantle accumulated but the present surface may not parallel the

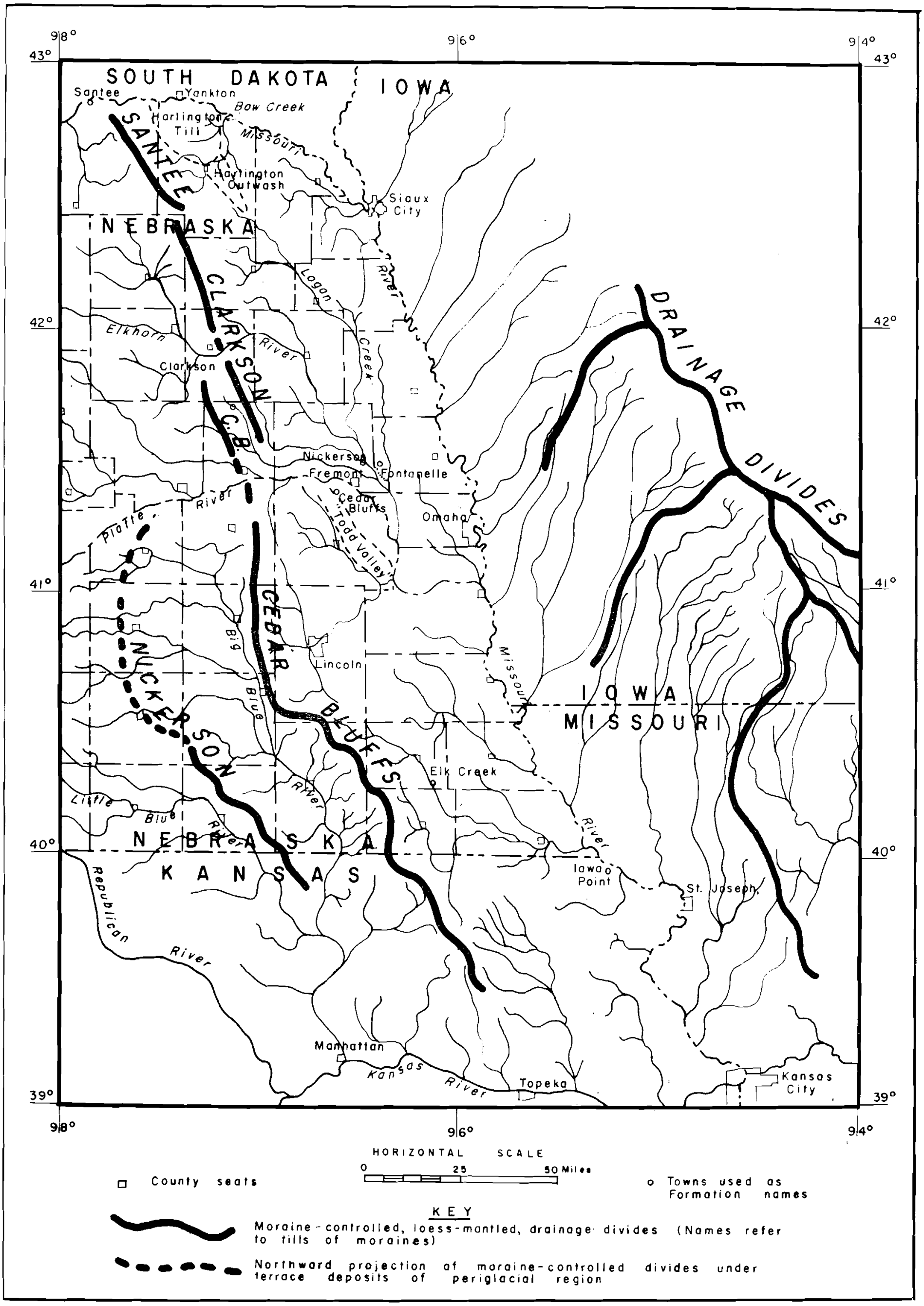


Figure 5A. Drainage pattern and moraine-controlled drainage divides in eastern Nebraska and adjoining areas.

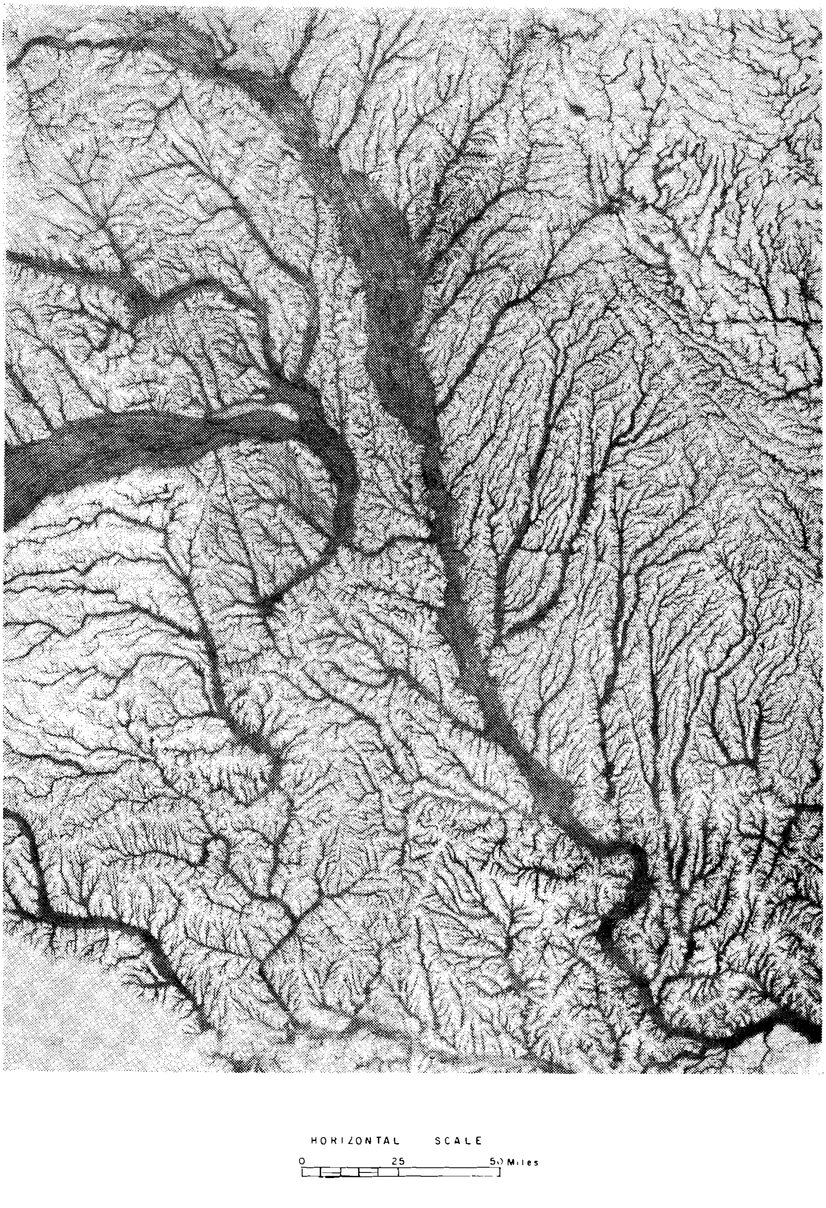
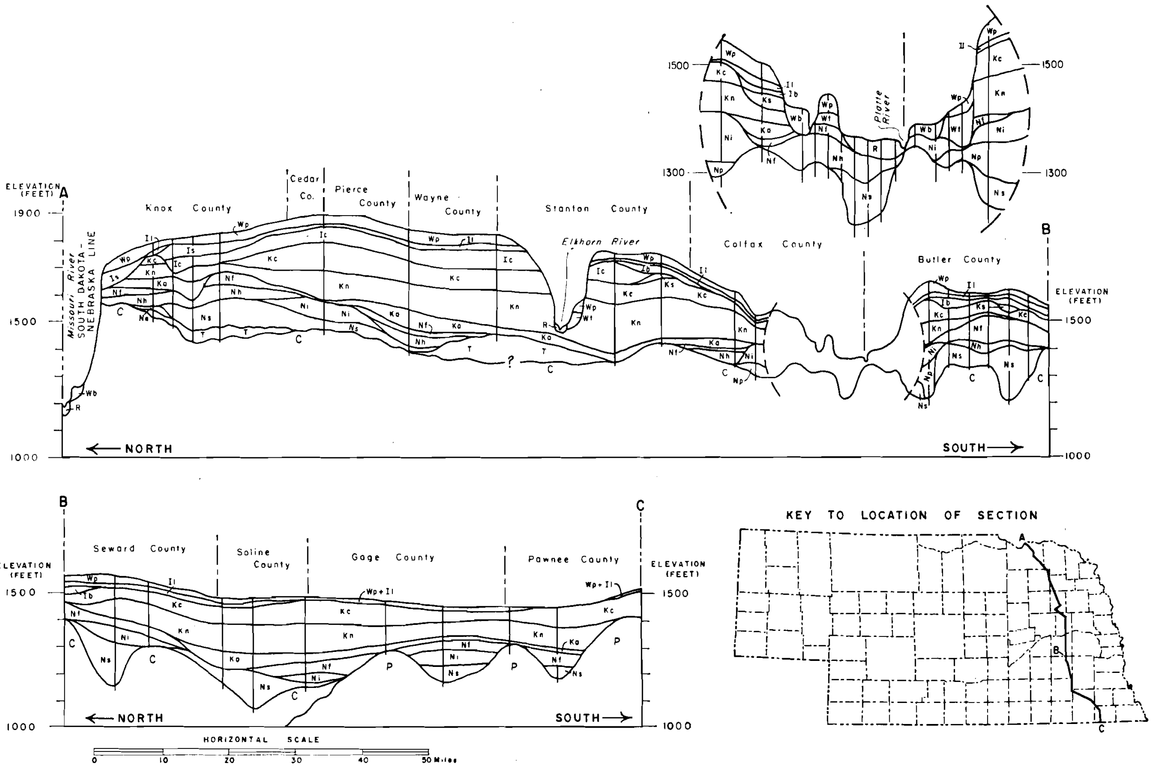


Figure 5B. Relief map of eastern Nebraska and adjoining area based on U. S. Geological Survey 1:250,000 scale topographic maps.



KEY TO SYMBOLS

Wb - Bignell Formation   Wp - Peoria Loess (including Gilmon Canyon) in upland, Peoria Formation in terraces   Wt - Todd Valley sand member of Peoria Formation   Il - Loveland Formation   Ib - Beaver Creek Formation   Is - Santee Till   Ic - Clarkson Till   Ks - Sappa Formation   Kc - Cedar Bluffs Till   Kn - Nickerson Till   Ka - Atchison Formation   Nf - Fullerton Formation   Nh - Holdrege member, Fullerton Fm.   Ni - Iowa Point Till   Np - Pro-Iowa Point sand & gravel   Ns - Seward Form.   Ne - Elk Point Till   W - Wisconsinan   I - Illinoian   K - Kansan   N - Nebraskan   R - Recent Alluvium

Vertical lines indicate test hole locations.   Bedrock: T - Tertiary   C - Cretaceous   P - Pennsylvanian

Figure 6. North to south geologic profile section across eastern Nebraska showing relationship of tills and associated deposits.

top of the older terrace deposits. Thus the mantled terrace surfaces tend to slope both down-valley and away from the upland margins. When the present stream has meandered close to the upland margin the height of the mantled surface above the flood plain is greater than it is when the present stream is located midway between the upland margins even though the top of the valley alluvium may occur at a constant level across the valley. As a result, mantled terrace surfaces cannot be identified accurately on the basis of intervals above flood plains but they can be identified, in many cases, if gully erosion has exposed the underlying terrace deposits and if these deposits are diagnostic, either lithologically or paleontologically.

Some loess-mantled terrace surfaces have been modified by erosion, especially where they occur high on valley sides. In other cases, especially in western Nebraska, many of the terrace surfaces have not been loess-mantled but the deposits tend to be eroded and may not now represent all of the original terrace deposits.

Schultz and Stout (1945) and Schultz, Lueninghoener and Frankforter (1951) have reported on extensive studies of the terrace deposits of the state and the related surfaces which they have numbered from 1 to 5 from youngest to oldest and from lowest to highest in respect to present flood plains. In addition, they have recognized two components of the second surface and designate the younger of the two as 2a and the older as 2b. A radiocarbon date of 2,147 ± 150 years before present for the terrace deposits of their T-1 surface identifies these deposits as Recent (Schultz, Lueninghoener and Frankforter, 1951). Therefore, they recognize four separate levels in the Pleistocene with a "complex" related to the youngest Pleistocene surface (T-2) and correlate the terrace deposits under their T-5 level as Nebraskan to Early Kansan, the terrace deposits under their T-4 level as Late Kansan to Illinoian, the terrace deposits under their T-3 level as "late Iowan" (Early Wisconsinan), the terrace deposits under their 2a surface as "late Cary" and those under the T-1 surface as "late Mankato."

We believe that there is good evidence for *six* general associations of terrace deposits in Nebraska including the Recent one (T-1) and would add the additional one within the Schultz *et al* T-4 level. This is based on the fact that a distinct Late Kansan surface occurs at a higher level than a Late Illinoian surface in much of the glaciated portion of Nebraska although the Late Kansan terrace deposits underlie Illinoian terrace deposits to the west of the till border.

We are proposing herewith six general fills above the flood plains of Nebraska, including the T-1 (Recent) terrace fill, realizing that several of them may be complex. The oldest terrace fill (our T-6) is correlated with the Nebraskan but may include earliest Kansan. The

T-5 deposit are correlated with the tills of Kansan age and locally contain Early, Medial and Late Kansan sequences. The T-4 deposits are correlated with the Illinoian and locally are represented by Early, Medial and Late Illinoian sequences. The T-3 deposits (Todd Valley sand) are believed to be Medial Wisconsinan (Tazewell and Cary of earlier classifications), and the T-2 deposits are correlated with the Late Wisconsinan (Valderan).

Furthermore, we believe that the separate terrace deposits of westernmost Nebraska tend to occur at progressively lower levels in terms of age with T-6 being the highest and T-1 the lowest with some levels being nearly or completely removed by the erosion that preceded the next younger alluviation. The sequence in east-central Nebraska differs from that of western Nebraska in that the T-6 deposits occur at the lowest level and the T-5 and T-4 deposits tend to occur at progressively higher levels. In the glaciated region of easternmost Nebraska the T-5 deposits are at a slightly higher level than the T-4 deposits. Throughout all of the state the T-3, T-2 and T-1 deposits generally occur along the present valleys at progressively lower levels, below the level of the T-4 deposits. Some of the present river valleys are only partially superimposed on older valleys and therefore do not have representatives of all terrace deposits.

In connection with the change in relative elevations of terrace deposit sequences from western Nebraska it appears that there may have been some tilting of the general land surfaces during the pre-Wisconsinan Pleistocene. It is suggested that this tilting may have resulted from the over-loading of the land surface as a result of the thick accumulation of ice during Nebraskan, Kansan and Illinoian time. Certainly there is good evidence of eastward tilting down the North Platte and Platte River valleys across Nebraska and fairly good evidence of northeastward tilting in south-central and southwestern Nebraska.

Pleistocene Correlation and the Glacial-Interglacial Concept

Many differences of opinion regarding Pleistocene correlations result from the almost-futile effort to classify deposits as glacial or interglacial. Paleontologists report that certain faunas are glacial because the fossils are colder-climate forms and that other deposits are interglacial because the fossils are warmer-climate forms. However, it seems probable that many northern forms were driven southward during the advance of a continental ice sheet and that many southern forms advanced rapidly northward during the retreat of a continental ice sheet. It also seems probable that the advance and retreat of a continental ice sheet over many miles may have exerted a more profound change in the animal life of an area than may have resulted during a period of relatively stabilized conditions when soil surfaces were being developed, unless a very long time is represented by the period of soil development.

All deposits of the Pleistocene that are not till may be regarded by some as interglacial whereas others would place only the periods of soil development in the interglacial. We would tend to favor the second extreme largely in the hope that a glacial-interglacial subdivision in classification be abandoned as a satisfactory basis for the classification of the Pleistocene. Moreover, some periglacial deposits may have been deposited far from the glaciated areas and thus located in a different climate belt. A more satisfactory and less controversial classification of the Pleistocene is a broad division into four stages, each of which began with a period of erosion initiated by the lowering of sea levels as the result of tying up more water in the ice of continental glaciers, continuing through the periods of glacial advance and retreat, and ending with the period of stabilized conditions and extensive soil formation under comparatively warm conditions. Each of the major stages can be further subdivided into stades on the same basis. Then, and only then, do we have a true basis for a time-stratigraphic classification of Pleistocene deposits.

Mechanics of Till Accumulation

The distribution and thickness of till sheets in the glaciated portion of eastern Nebraska, as well as in other parts of the country, raise some questions concerning the mechanics of till deposition. Certainly the thickness of the deposited till is not relative to the thickness of the ice sheet. It would appear that there is a strong tendency to "squeeze" the debris incorporated in the advancing ice out to or near the margins of the ice sheet where the pressures developed by the ice are relieved because of thinner ice and lesser loads. Certainly some rock detritus is moved ahead of the ice. The result is a thick, marginal, lateral-moraine deposit, a somewhat thinner end-moraine deposit, and a very thin ground-moraine deposit which tends to occur within the internal depression of the glaciation and may include recessional moraines. Under these conditions the ground-moraine deposits are very vulnerable to later erosion and are often subject to complete removal by a readvance of a younger ice sheet which tends to form and move down the internal depression of the previous glaciation. As a result, all of the ground-moraine deposits related to comparatively thick lateral-moraine deposits may be missing from the internal depression where the ice thickness may have been the greatest. This adds greatly to the problems of identifying and tracing separate till sheets into the interior depression.

Importance of Erosion During the Pleistocene

Although maximum thicknesses of the Pleistocene deposits reach impressive figures when added together, it must be realized that much more material was removed by erosion during the Pleistocene than was deposited. In broad areas all of the deposits of a major glaciation were removed prior to the accumulation of the deposits of the next younger glaciation and in many parts of Nebraska erosion with little or no deposition continued throughout most of the Pleistocene. Under these conditions it is remarkable that representatives of most, if not all of the deposits of the Pleistocene have been preserved.

Loess Accumulation

There are two viewpoints in connection with the conditions under which loess deposits are formed which vary greatly. The one concludes that silt-size particles are more readily available under extremely dry conditions when the vegetative cover has died out and no longer protects the land surface. There is no question but that dust storms are common during drouths but it seems doubtful that significant deposits of wind-blown dust accumulated and were preserved under these conditions in Nebraska. The alternative theory, advanced and defended by Kirk Bryan (1945), proposes that loess accumulation occurs under generally moist or subhumid conditions, often derived from glacial outwash valleys when flood-plains are kept free from effective vegetative cover as a result of the periodic discharge of ice-melt water. The dust is blown up from the outwash valleys and accumulates on an upper surface that is grass-covered and thus permitted to lodge and accumulate in significant thicknesses. Certainly much of the loess in eastern Nebraska could have accumulated in this manner and tends to thicken and coarsen toward the valley source.

Lugn (1960) reaffirms his "desert" explanation of most of the loess of Nebraska and designates the Sand Hills region of the state as the primary source area, although suggesting that some contribution has come from the river flood plains and infers that the finer materials of the Tertiary Ogallala Formation were the direct source of the loess with the coarser material remaining in the source area as a lag concentrate to mantle the Ogallala Formation as dunesand.

We agree with Lugn that the Sand Hills region of Nebraska is an important source area for the loess which was deposited on the Plains surface to the southeast but do not agree with his implication that the eolian silt was blown *directly* out of the Ogallala Formation or that desert conditions necessarily existed at the time of accumulation. The presence of the remains of snail shells extensively in the loess deposits certainly does not confirm "desert" or very arid conditions. Moreover, the presence of replaced rootlets throughout the loess deposits indicates that the upland surfaces, which were sites of loess accumulation, had a grass cover during the period of accumulation—a condition that encouraged the accretion of dust on this surface. It seems unlikely that desert conditions could have prevailed in the source area while non-desert conditions were common in the accumulation area farther to the south and southeast. In addition, it seems improbable that the Ogallala Formation was a direct source of loess because the lag concentrate sand mantle would have covered the source material quickly and eliminated the availability of a continuing source of material.

There is no question that the bedrock formation under the Sand Hills region is the Ogallala Formation. However, other extensive areas of the Ogallala Formation in southwestern Nebraska and western Kansas were not important source areas for loess. Therefore, the Sand Hills region must have had a different pre-Wisconsinan Pleistocene history than the other Ogallala bedrock areas in order to prepare it for the role of a loess source area.

Extensive and systematic test drilling has not been completed in the Sand Hills region of Nebraska to date (Figure 2). However, there is good though incomplete evidence that the Ogallala bedrock of the Sand Hills region was eroded into a hill and valley topography during the pre-Wisconsinan Pleistocene and that valleys, cut into the Ogallala bedrock, were filled with fluviatile deposits with an upward succession of coarse to fine clastic sediments. The silt fraction of these pre-Wisconsinan Pleistocene deposits was available to be blown out to the southeast and the coarser sand was blown up to accumulate as transverse dune sand ridges which migrated southeastward to mantle and obscure the pre-existing surfaces and to almost obliterate the pre-existing drainage pattern of the region. Thus we propose that the Ogallala bedrock was eroded and the erosional debris was deposited as water-sorted alluvium in valleys during the pre-Wisconsinan Pleistocene. This alluvium was then the source for the dunesand and loess deposits of the Medial and Late Wisconsinan.

There are two requisites for significant loess accumulation—a deflation area, or a continuing source area for silt, and an inflation area, or a continuing area favorable to dust accumulation. The deflation area does not need to be huge if its supply of silt is continually replenished by the water erosion of silty upland margins. It seems most probable that Pleistocene streams tended to flow eastward and southeastward during much of the Pleistocene but that their lower courses were shifted eastward and even northeastward as the headward erosion of the Lower Platte valley in Medial Wisconsinan time captured much of this drainage system. Strong wind systems from the northwest must have had an uninterrupted sweep down the southeast-trending valleys. However, the finer silt fraction was blown up and out of these valleys southeastward in the lower courses of the valleys where drainage trends shifted eastward and northeastward.

Type Localities and Unit Names

The present classification of the Pleistocene in Nebraska (Figure 3) has evolved over a considerable period of time as new information was added and studied and the classification became increasingly complicated. The monumental work of Lugn (1935) and the additions and revisions of Condra and Reed (1950) have been important contributions but are now inadequate. Many unit names have become well established in usage and have been applied, to some degree, in adjoining states. Although most of these established names have been preserved in the classification presented herewith it has been necessary to restrict the concept and usage of some "formation" names and to recognize that a number of type localities were established at localities where stratigraphic relationships cannot be demonstrated to our present satisfaction or where other correlations of the deposits involved seem more probable and defensible.

Many of these names have become so well established that it would be difficult to discard them now and substitute new names and still preserve some tie with the past. Therefore, we are suggesting substitute type localities for these "formation" names herein at locations where, in our opinion, stratigraphic relationships can be more clearly demonstrated. We believe that the type localities of the Holdrege, Fullerton, Red Cloud, and Grand Island "formations" are at locations where precise stratigraphic relationships are moderately to highly questionable.

The type Holdrege was established by Lugn (1935, pp. 92, 93) in a well drilled as a test for oil and gas and the interval included is now believed to be a part of the Ogallala Formation of Pliocene age. The type locality of the Fullerton was established by Lugn (1935, p. 83) in exposures northwest of Fullerton which may or may not be at the top of the Late Nebraskan deposits. The absence of any vestige of an Aftonian Soil horizon at the top of Lugn's type locality Fullerton and the distance of the locality from glaciated areas precludes its more positive designation as Late Nebraskan.

The type locality of the Red Cloud was established by Schultz, Reed and Lugn (1951) at a location where it occurs above chalk of Cretaceous age and below thin silts believed to be Sappa with unconformable relationships at both top and base. Thus, stratigraphically, all that is known about this locality is that it is post-Cretaceous and pre-Late Kansan. The vertebrates from this locality bear certain affinities to the "Broadwater" fauna (Schultz and Stout, 1945) of Nebraskan age and closer affinities to the fauna from gravels below till of Early Kansan age in gravel pits located northwest of Wisner (Frankforter, 1950). At the time of the designation of the Red Cloud as a formation the gravels northwest of Wisner were believed to be pro-Kansan but more recent studies indicate that they may be in the Holdrege sand and gravel member of the Fullerton Formation of Late Nebraskan age. Thus, the Red Cloud type locality gravels may be Late Nebraskan and not Early Kansan.

The type locality of the Grand Island was established by Lugn (1935) in exposures about 5 miles southeast of Grand Island south of the Platte River valley. Our regional test drilling, as well as more recent studies of this exposed section, indicates that the deposits assigned to the Grand Island are more probably Middle Illinoian and not Late Kansan in age. Likewise, some of the type localities that we are herein designating may be disproved in the future or need to be replaced for other reasons.

Configuration and Nature of Bedrock Surface Below the Pleistocene Deposits

The Tertiary, Cretaceous, Permian and Pennsylvanian bedrock materials were extensively eroded before they were mantled with the Pleistocene deposits. The configuration of the top of the pre-Pleistocene bedrock is shown in Figure 7. The Pennsylvanian and Permian rocks consist of a succession of marine limestones interbedded with shales, sandy shales, and (rarely) fine-grained sandstones (Condra and Reed, 1959). They were extensively tilted prior to the deposition of the Cretaceous rocks and tend to dip to the west and southwest in the western part of their subcrop area and to the southeast and east in the eastern part. There is a tendency to develop rock benches in the thicker limestone zones and side slopes and valleys in the thicker and less-resistant shales.

The Cretaceous formations were deposited on the eroded surface of the Pennsylvanian and Permian limestones and shales and dip generally northwestward in southeastern and eastern Nebraska with a less pronounced southwestward dip in northeastern Nebraska. The basal material of Cretaceous age in the Cretaceous subcrop area is the Dakota Group of sandstones and shales, which is believed to be late Lower Cretaceous to early Upper Cretaceous in age. The Dakota Group deposits form a comparatively wide northeast-southwest trending band immediately northwest of the Pennsylvanian-Permian subcrop area; they also form the outcropping bedrock along a narrow band in extreme northeastern Nebraska. Maximum thicknesses of the Dakota are in the neighborhood of 400 feet. The Dakota tends to consist of a lower sandstone zone which is generally overlapped eastward

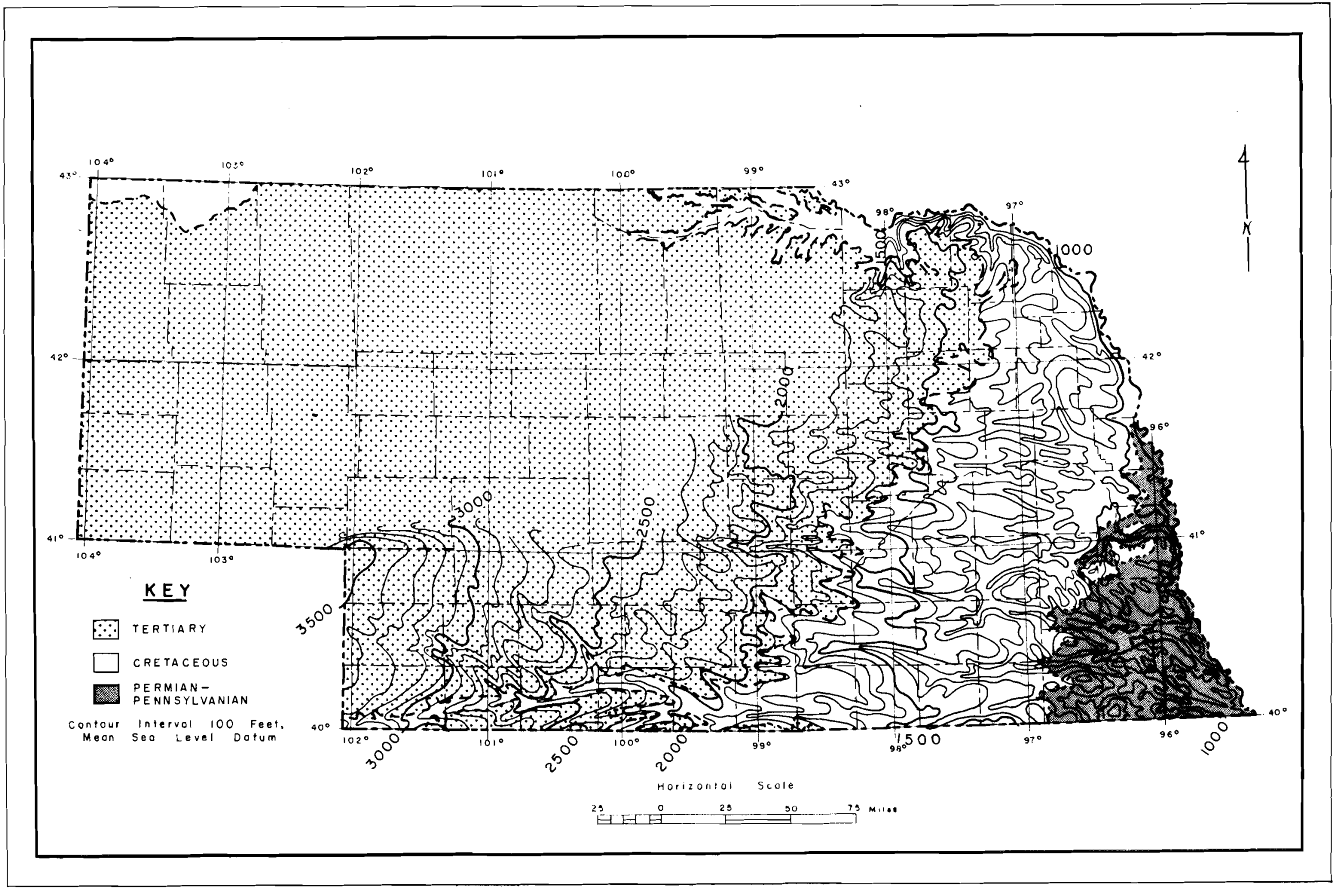


Figure 7. Generalized topographic map of the bedrock surface in Nebraska showing geologic age of bedrock materials.

by a middle shale and upper sandstone zone. In many localities the upper sandstone may be replaced by a clay-shale facies which tends to be light gray or red-varicolored. The Graneros Shale (typically about 50 feet thick) and the Greenhorn Limestone (about 30 feet thick) occur above the Dakota Sandstone in succession on the next higher slopes of the bedrock surface. The Greenhorn is overlain by 170 to 220 feet of Carlile Shale and 200 feet or more of the Niobrara Chalk with some Pierre Shale occurring below the Pleistocene in the western part of the Cretaceous subcrop area of northeast Nebraska as well as in some other parts of the state.

The nature of the Cretaceous bedrock exerted considerable control on the pre-Pleistocene surface developed on it. There is a strong tendency to develop wider valleys and gentler slopes on the thicker shale zones with "water-gaps" and dip slopes on the Greenhorn Limestone and narrower valleys through the Niobrara Chalk terrane. The Cretaceous rocks are largely of marine origin and were extensively eroded and truncated to a generally east-southeastward sloping surface before they were covered with Pliocene deposits.

The Pliocene Ogallala Formation, of continental origin and with a maximum thickness of about 400 feet, was deposited on the eastward sloping surface of eroded Cretaceous rocks but was largely removed from the southeastern part of the area by post-Pliocene erosion. The sub-Pleistocene surface, developed on the bedrock materials, has considerable hill and valley relief with valleys tending to trend southeastward and eastward across southeastern Nebraska. The drainage pattern is somewhat complex because not all of the valleys were developed in post-Pliocene to early Pleistocene time and some valleys were cut below the lower surfaces at several times during the Pleistocene.

STRATIGRAPHY AND GEOMORPHOLOGY OF THE PLEISTOCENE DEPOSITS

General Introduction

The deposits referred to the Pleistocene in Nebraska are divided into four parts related to the four glacial stages recognized in the northern Midcontinent region of the United States, namely the Nebraskan (oldest), Kansan, Illinoian and Wisconsinan (youngest). Each of these glacial stages is complex and made up of more than a single, simple advance and retreat of a continental ice sheet. There is good evidence that at least three of the glacial stages are tripartate and that they consist of early, medial and late stades which can be recognized and separated, at least in the attenuated margins of the glaciated areas. It is presumed that early medial and late stades may not be clearly differentiated in areas far from glaciated regions and less affected by the stade advances and retreats.

Each glacial stage is separated from the succeeding and younger glacial stage by a probably-long period of relatively stable conditions when interglacial soils were developed on the then-existing land surface under comparatively warm climatic conditions. This period of interglacial soil development was followed by a period of strong pro-glacial erosion when sea levels lowered as a result of "tying up" more and more water into continental ice sheets and increasing the gradients of valley systems, or when similar effects were caused by crustal movement. Also, advancing ice sheets probably blocked drainageways, thus creating catchment basins for fluviatile sediments. These concepts form the basis for the four-fold division of the Pleistocene deposits which is used in this report.

A further complication to a simple classification of the Pleistocene deposits is introduced when it becomes apparent that each of the four glacial stages was complex to the degree that partial retreats and readvances of the continental ice sheets resulted in events similar to but of lesser magnitude than the events which permit the division of the Pleistocene deposits into four divisions or stages. The result is that the deposits of most of the glacial stages may be subdivided into early, medial and late stades on the basis of interstadial soils and minor erosion. The accuracy of correlations is dependent upon the ability of the stratigrapher to recognize soils as either interglacial or interstadial in nature and to recognize erosional unconformities as of major or minor significance.

Glacial deposition consisted of (1) pro-glacial fluviatile deposits filling channels or depressions in the pre-existing surface ahead of the advancing ice (the pro-till deposits), and (2) tills that are boulder clay deposits which were either deposited by the ice as it advanced or accumulated on the surface as the ice retreated. The thickest till tended to accumulate at or near the margins of the ice sheets.

Periglacial deposition during the Pleistocene in Nebraska clearly reflects the pulsations of glacial advance and retreat, and the periglacial deposits can be separated into deposits of fluviatile and eolian origin. The fluviatile deposits generally occur in valleys and basins, outside of the reaches of glaciation, that probably tended to be eroded throughout glacial advance when valley gradients were maximum and probably tended to be alluviated during glacial retreat when valley gradients were progressively reduced. Thus there are sequences of fluviatile deposits grading upward from coarse clastics to fine clastics which are herein regarded as formations with sand and gravel members in the lower part and silt members in the upper part.

In addition to the fluviatile deposits of the valleys and basins, there were extensive upland areas mantled by eolian deposits (both loess and dunesand) blown up from lower levels to accumulate on higher surfaces and generally believed to be contemporaneous with the fluviatile deposits of the valleys and basins. The same names are applied to both the eolian and fluviatile formations because their contemporaneity seems to be fairly well established. Rock-stratigraphic names are applied to the tills and to some of the pro-glacial deposits. The stratigraphic units of the Pleistocene deposits, as illustrated in Figure 3, are discussed in succession, from oldest to youngest.

Nebraskan Stage Deposits

Deposits of Nebraskan age are less well known than those of later glacial stages because they tend to be more deeply buried by younger deposits and because various periods of major and minor erosion tended to remove a large proportion of these deposits. The Nebraskan stage is the only glacial stage where a tripartate division is not recognized. However, the deposits of Nebraskan age can be divided into Early and Late Nebraskan deposits which are separated by an erosion period which may have been of somewhat greater intensity than the erosion periods that separated the various stades of the later glaciations.

Early Nebraskan Deposits

The oldest known till in Nebraska is the *Elk Creek Till* (new name) which rests upon the Pennsylvanian limestone and shale bedrock and is well exposed at places along the west side of the North Fork Big Nemaha River valley in northeastern Pawnee County between Elk Creek and Table Rock. The type locality is located in the N.W. ¼ of the S.W. ¼ of Section 1, T. 3 N., R. 11 E., Pawnee County and its relationship to younger deposits of Pleistocene age are shown in Columnar Section 1 (Appendix).

The Elk Creek Till is about ten feet thick at the type locality but thicknesses of 50 feet or more are known in test hole records in southeastern Nebraska and a pro-glacial sand and gravel (*David City*) occurs in some localities below the Elk Creek Till. The Elk Creek Till is medium gray to brownish-gray mottled in color; it seems to have greater induration and higher bulk density than many of the younger tills, and includes pebbles and fragments reworked from the Pennsylvanian limestones and shales. Hydrochloric acid treatment and textural analyses of the residue of a sample of the Elk Creek Till gave the following results:

Acid Soluble	12.09%
Silt and clay	79.50%
1/16–1/8 mm.	1.23%
1/8 –1/4 mm.	2.47%
1/4 –1/2 mm.	2.67%
1/2 – 1 mm.	1.33%
1 – 2 mm.	.53%
Over 2 mm.	.18%
	100.00%

About 60 feet of Late Nebraskan silts rest upon the eroded top of the Elk Creek Till at the type locality and there is at least five feet of relief on the top of the till.

The periglacial equivalent of the Elk Creek Till is the *Seward Formation* (Condra and Reed, 1950, p. 15, 16) which occurs extensively as erosion remnants below Late Nebraskan deposits west of the till border. Condra and Reed suggested that this formation was probably a fine-textured eastern equivalent of the Ogallala Formation of Pliocene age because they were unaware of the two-fold nature of the Nebraskan deposits. More recent detailed studies of test hole records indicate that the Seward Formation is post-Ogallala in age and it is therefore assigned to the Early Nebraskan and is believed to have been deposited as the Elk Creek ice sheet retreated. It consists of silts and fine sands, in part poorly sorted, which have developed strong brown coloration in the upper part and includes a basal gravel zone in local areas, generally composed of Cretaceous bedrock pebbles and cobbles.

Comparatively recent surficial mapping and Pleistocene studies by Carroll Goll (1961) have resulted in the location of an outcrop of the Seward Formation along the Middle Oak Creek drainage in northeastern Seward County which we believe can be demonstrated stratigraphically to be early Nebraskan in age and referable to the Seward Formation. Therefore, we are herewith designating this locality (N. ½, N.W. ¼ of Sec. 26, T. 12 N., R. 4 E., Seward County) as the type locality of the Seward Formation. The Seward Formation aggregates only about 12.5 feet in thickness at this location (see Columnar Section 2, Appendix). Subsurface thicknesses of more than 100 feet have been drilled farther to the west and southwest.

The Seward Formation was extensively eroded prior to the deposition of the Late Nebraskan deposits. In southeastern Nebraska it occurs below Late Nebraskan fluviatile deposits as well as below till of Late Nebraskan age (Iowa Point).

Late Nebraskan Deposits

Till of Late Nebraskan age has been penetrated in test drilling at a number of locations in southeastern Nebraska occurring below the Afton Soil and resting upon the Seward Formation. However, a stratigraphically documented outcrop of this till in Nebraska has not been located to date. Therefore, we are designating a locality in northeastern Kansas, reported by Frye and Leonard (1949, pp. 887, 888) and classified as "Nebraska till," as the type locality of the Late Nebraskan till and are herewith applying the rock-stratigraphic name of *Iowa Point Till* (new name) to this deposit. The location of the type locality is in the N.E. ¼ of the S.E. ¼ of Section 6, T. 2 S., R. 20 E., Doniphan County, Kansas, about two miles southeast of Iowa Point, Kansas.

Frye and Leonard record 7 feet of till at the Iowa Point locality which they describe as follows: "Till; matrix of clay and silt with pebbles and cobbles of limestone, igneous rocks and a few of pink quartzite. Irregular masses of sand and gravel incorporated in till. At top is a well-developed post-Nebraskan pre-Kansan soil profile characterized by a black to dark gray upper zone about 2 feet thick, leached of $CaCO_3$ and lacking limestone pebbles but containing quartzite pebbles and a few igneous rock pebbles. The upper zone grades downward into a medium gray to light brown leached and oxidized zone which in turn grades downward into gray calcareous till."

The development of the Afton Soil directly at the top of the Iowa Point Till at the northeast Kansas locality and on an apparently flat and uneroded surface indicates that the Afton Soil is much more closely related to the Iowa Point Till than to the Elk Creek Till. At the type section of the Elk Creek Till, the Afton Soil is developed at the top of thick Late Nebraskan silts (Fullerton) which mantle the extensively eroded Elk Creek Till.

The periglacial equivalent of the Iowa Point Till is the *Fullerton Formation*. Lugn (1935, p. 83) applied the name Fullerton to silts exposed along the south side of the Cedar Creek valley (about one mile northwest of Fullerton in Nance County) which occur below sands and gravels which he correlated with the Grand Island and above sands and gravels which he classified as Holdrege. In addition, he classified Fullerton and Holdrege as Nebraskan and these "formation" names became firmly established in this sense and have been applied throughout Nebraska and adjacent states. The precise stratigraphic position of the silt layer exposed northwest of Fullerton is not clearly demonstrable and therefore may be questionable, especially in relation to the more complex current classification.

Moreover, the classification of Lugn and also that of Condra and Reed (1950) recognized the Fullerton and Holdrege as formations. Rather than introduce a new formation name for this depositional unit, we are continuing the name Fullerton in a formational sense to include the upper silt member (the Fullerton of earlier reports) and the *Holdrege sand and gravel member*. In addition, we are designating a substitute type locality for the *Fullerton Formation* at a location in Lancaster County 2¾ miles west of Raymond along the west line of the N.W. ¼, S.W. ¼ of Section 2, T. 11 N., R. 5 E. (Columnar Section 3, Appendix), and in Ground Water Survey Test Hole A15-1-24aaa (N.E. corner Sec. 24, T. 5 N., R. 1 E., Butler County) between the depths of 150 and 290 feet (Columnar Section 4, Appendix). The upper silt member is 78 feet thick in this test hole record and rests above 62 feet of sand and gravel which is herein designated as a substitute type locality for the Holdrege sand and gravel member of the Fullerton Formation.

The type locality, designated by Lugn (1935), for the Holdrege sand and gravel (an oil and gas test well near Holdrege in Phelps County) seems to be of questionable correlation and may be Pliocene and not Pleistocene in age.

Afton Soil and pro-Kansan Erosion

The Nebraskan stage, including both glacial and interglacial time, was culminated by a comparatively long period of essentially stable conditions when the *Afton Soil* was developed on the then-existing land surface. Where preserved in its entirety, the Afton Soil is a well-developed soil which tends to be a "Wiesenboden" if developed on a poorly drained surface and a "Reddish-brown Chernozem" where developed on a well-drained surface. Often the soil exhibits a comparatively thick zone of clay enrichment in the "B" horizon. Considerable depth of oxidation of the parent materials is evident when developed under well-drained conditions.

The Afton Soil is an important "key" bed of the Pleistocene and is extensively used in the classification of deposits in sequence with it. Unfortunately, this soil horizon has been truncated or completely removed by pro-Kansan or later erosion in many exposures.

The Kansan stage began when climatic conditions changed sufficiently to result in the accumulation and "build up" of a continental ice sheet in post-Aftonian time. Sea levels were progressively lowering, valley gradients were progressively increasing and erosion was dominant as the ice sheet enlarged and advanced. As a result the Afton Soil and the deposits below were extensively eroded and all of the deposits of Nebraskan age were removed in some places. The topographic relief on the pre-Kansan surface, as indicated by test drilling records, is considerable (Figure 6).

Kansan Stage Deposits

At least two tills of Kansan age are recognized and can be differtiated in the glaciated part of eastern Nebraska and three depositional sequences (Figure 9) can be differentiated in the periglacial region of the state. Thus there is a sound basis for a subdivision of the Kansan stage into Early, Medial and Late Kansan stades. The Kansan deposits are separated from the Nebraskan deposits by the period of interglacial soil development resulting in the Afton Soil and a period of major erosion during pro-Kansan time. The stades are separated from each other by interstadial soils and periods of minor pro-glacial erosion developed during the readvances of the ice.

The Early Kansan glaciation reached farther west and southwest in Nebraska than any other glaciation and formed a moraine ridge which controlled the divide between the Little Blue and Big Blue River valleys in Jefferson County. The western limit of Early Kansan glaciation can be projected northward into Fillmore, York and Polk counties where it is buried by fluviatile deposits of later Kansan and Illinoian age (Figurse 5A, 5B). The Medial Kansan till formed a moraine at or near its western and southwestern limit which controlled the divide between the Big Blue River drainage and the drainage to the Missouri River in the southern half of eastern Nebraska (south of the Platte River valley). A third moraine-controlled divide occurs east of the Medial Kansan divide between the Platte and Elkhorn valleys and apparently continues north of the Elkhorn River valley into northeastern Nebraska, but the youngest till in this divide is tentatively assigned to the Early Illinoian because of the strong weathering profile on the Medial Kansan till below it. The presence of three depositional sequences in the Kansan of the periglacial sequence strongly suggests that there may have been a late advance of the Kansan ice that probably did not reach Nebraska or has not been recognized to date.

Early Kansan Deposits

The oldest till of the Kansan stage in Nebraska is the *Nickerson Till* (new name) and the type locality is designated as a road cut on the east side of the Elkhorn River valley, one-half mile north and two miles east of Nickerson, in the S.E. ¼ of the S.W. ¼ of Section 8, T. 18 N., R. 9 E., Washington County. A description of this locality is included herewith as Columnar Section 5 (Appendix). However, a greater thickness of the Nickerson Till is exposed in the bluffs on the southwest side of the Platte River valley, one and one-half miles southwest of Fremont near the S.W. corner of Section 27, T. 17 N., R. 8 E., Saunders County, where about 50 feet of Nickerson Till occurs above valley level (Columnar Section 6, Appendix).

Lugn (1935) classified this till as Nebraskan on the basis of a soil development at its top which he believed to be the Afton Soil. However, test drilling in this vicinity indicates that the Fullerton Formation silts occur at levels below this till in this vicinity and a close study of the soil horizon at the top of this till, herein called the Fontanelle Soil, indicates that it is probably an interstadial and not an interglacial soil.

Laboratory analyses of samples from the exposures of Nickerson Till and Fontanelle Soil southwest of Fremont, involving hydrochloric acid treatment and textural analyses of the residues, gave the following results:

Fontanelle Soil (1-2 feet thick)

Acid Soluble	2.61%
Silt and clay	88.64%
1/16–1/8 mm.	2.89%
1/8 –1/4 mm.	3.02%
1/4 –1/2 mm.	1.80%
1/2 – 1 mm.	.89%
1 – 2 mm.	.15%
	100.00%

Upper Part Nickerson Till

Acid Soluble	9.47%
Silt and clay	63.82%
1/16–1/8 mm.	6.70%
1/8 –1/4 mm.	9.03%
1/4 –1/2 mm.	6.24%
1/2 – 1 mm.	2.37%
1 – 2 mm.	1.05%
2 – 4 mm.	1.32%
	100.00%

Three foot sand, 33 feet below top

Acid Soluble	Not determined
1/16–1/8 mm.	1.41%
1/8 –1/4 mm.	42.51%
1/4 –1/2 mm.	46.92%
1/2 – 1 mm.	7.60%
1 – 2 mm.	.83%
2 – 4 mm.	.73%
	100.00%

Till below sand

Acid Soluble	10.67%
Silt and clay	67.00%
1/16–1/8 mm.	4.83%
1/8 –1/4 mm.	6.94%
1/4 –1/2 mm.	6.50%
1/2 – 1 mm.	2.78%
1 – 2 mm.	.93%
2 – 4 mm.	.35%

A pro-Nickerson sand with some gravel occurs very extensively in southeastern Nebraska and northeastern Kansas, especially in channels eroded into the Nebraskan age deposits. Frye and Leonard (1952) applied the name *Atchison Formation* to this sand and we are continuing the use of this name in the Nebraska classification.

The equivalent of the Early Kansan glacial deposits in the periglacial region of Nebraska is the *Red Cloud Formation* (Schultz, Reed and Lugn, 1951). However, there is considerable doubt as to the validity of the type locality as defined by Schultz, Reed and Lugn. At this locality the sands and gravels named Red Cloud rest unconformably upon Cretaceous Chalk bedrock, and are unconformably overlain by silts which are probably Late Kansan. Geomorphologically, these deposits seem to be more probably Late Nebraskan and not Early Kansan. However, the name Red Cloud has been widely used as a name for the Early Kansan fluviatile deposits elsewhere in Nebraska and is herein continued in this connotation.

Schultz, Reed and Lugn placed the exposures near Red Cloud in the Early Kansan in 1951 because the vertebrate fauna was very similar to the vertebrate fauna studied by Frankforter (1950) from sand and gravel pits northwest of Wisner in Cuming County which occur below the Nickerson Till. A careful study of the test hole records in the vicinity of the gravel pits near Wisner indicates that the Atchison Formation is channeled into the Holdrege sand and gravel member of the Fullerton Formation in this vicinity and it is believed that Frankforter's fauna more probably came from the Holdrege member of the Fullerton Formation than from the pro-Kansan sands (Figure 8). Certainly the fauna is an Early Pleistocene fauna with considerable affinity to the "Broadwater fauna" which is believed to be Nebraskan in age.

In view of the problems related to the original type locality of the Red Cloud Formation, we are herein designating a test hole located in the S.E. ¼, S.E. ¼, S.E. ¼ of Section 1, T. 7 N., R. 5 W., Clay County, as a substitute type locality for the Red Cloud Formation and the description of the formation is included in Columnar Section 7 of the

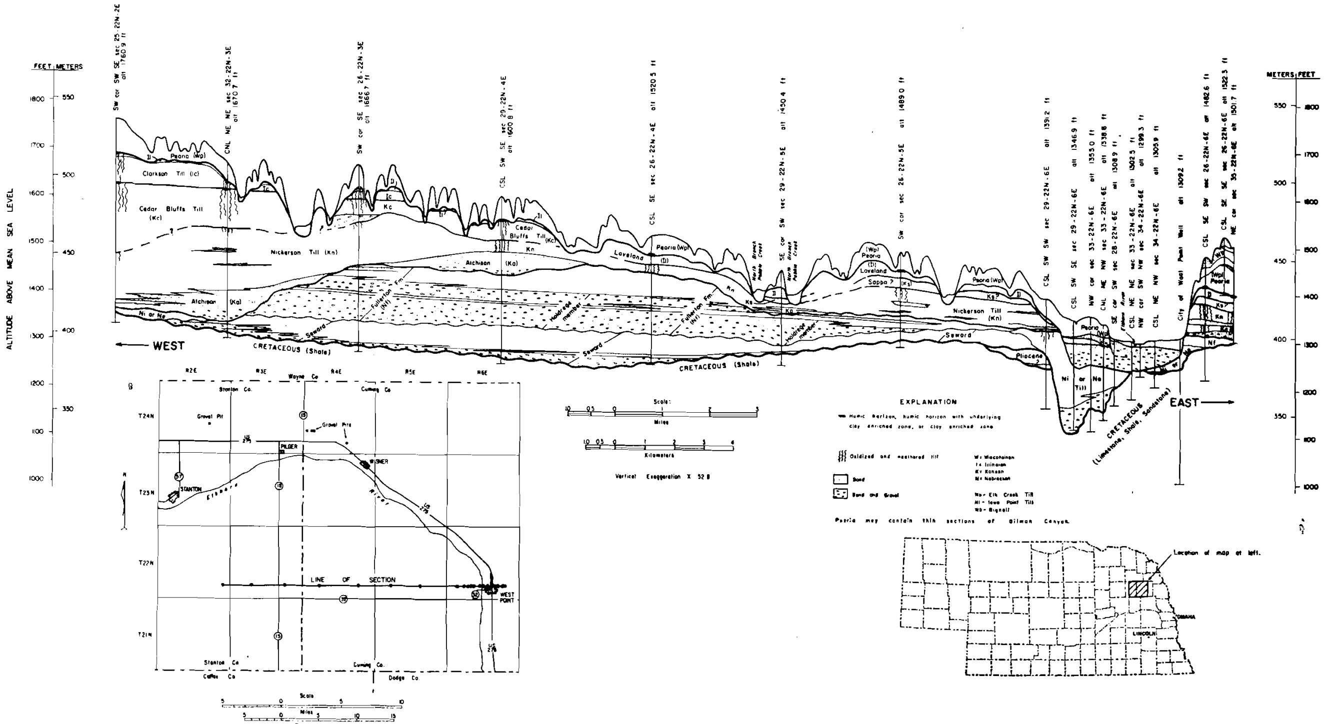


Figure 8. West to east geologic profile section across eastern Stanton County and Cuming County to east side of Elkhorn Valley.

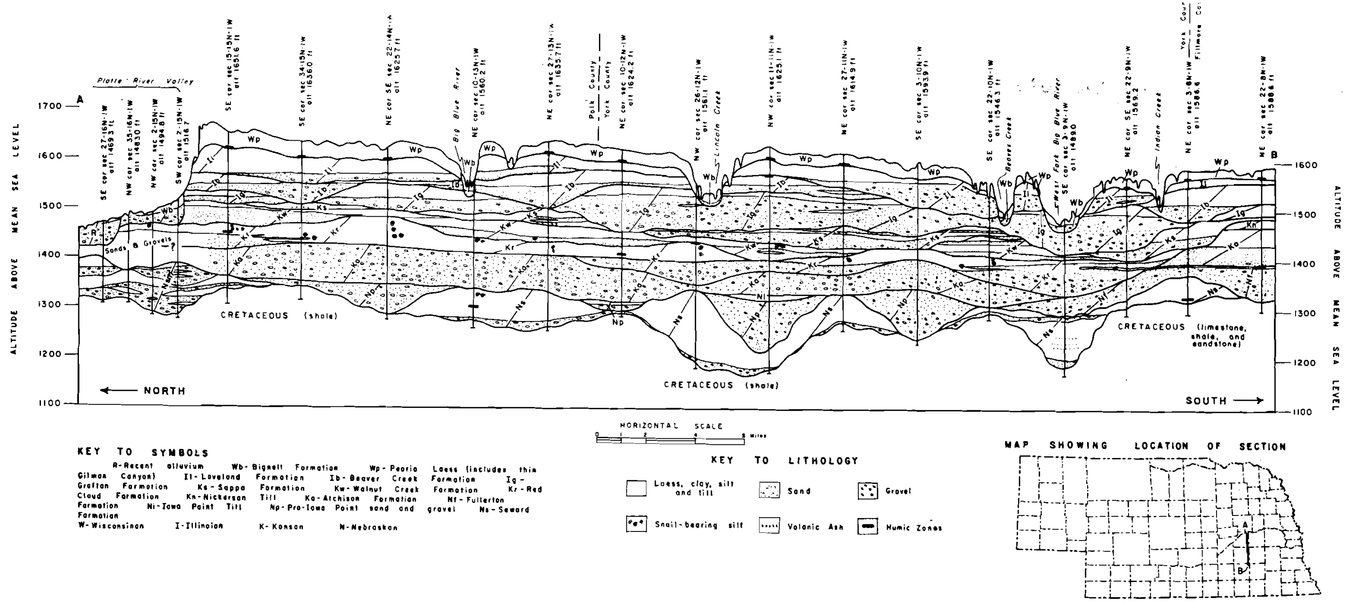


Figure 9. North to south geologic profile section in Eastern Polk and York counties showing relationship of Kansan and Illinoian depositional sequences.

Appendix. The subsurface relationships of the Red Cloud Formation are shown in Figure 9. Typically the Red Cloud Formation consists of an alluvial sequence grading upward from sand and gravel into silt. It is believed to have been deposited at the time of the retreat of the Nickerson ice sheet and therefore it is believed to be somewhat younger than the Atchison Formation.

Medial Kansan Deposits

The *Cedar Bluffs Till* (new name) is classified as Medial Kansan in the glaciated part of eastern Nebraska. This till is well represented in a prominent drainage divide between the Big Blue River and Missouri River drainages in southeastern Nebraska where it forms a prominent lateral moraine which Lugn (1935) recognized as the lateral moraine of the Kansan. However, a multiple Kansan glaciation was not considered as a possibility when his studies were made.

The type locality of the Cedar Bluffs Till is located in the bluffs on the southwest side of the Platte River Valley below the Boy Scout Camp Cedars, about 3 miles northeast of the town of Cedar Bluffs, in the S.W. ¼, N.E. ¼, N.W. ¼ of Section 24, T. 17 N., R. 7 E., Saunders County. The description of the till at this locality is included in Columnar Section 8 of the Appendix.

The Cedar Bluffs Till, at the type locality, is about 17.5 feet in thickness and occurs above the Fontanelle Soil, developed at the top of the Nickerson Till. Locally a strong zone of secondary lime enrichment occurs at its top which is believed to represent the Yarmouth Soil. The Cedar Bluffs Till is not significantly leached in its upper part at the type locality but it is rather deeply oxidized and tends to have more of a brownish-yellow color than the Nickerson Till. The Cedar Bluffs Till in many test holes, where it is thicker than at the type locality, may grade downward from strongly oxidized till into comparatively unoxidized till which rests upon an interstadial soil, developed on the Nickerson, or occurs above a thin zone of oxidized till developed in the upper part of the Nickerson.

Laboratory analyses of samples from the Yarmouth Soil secondary lime accumulation zone at the type locality of the Cedar Bluffs Till and from the Cedar Bluffs Till exposure southwest of Fremont (Columnar Section 8) gave the following results (page 33) when textural analyses were made of the residue remaining after treatment with hydrochloric acid.

The fluviatile equivalent of the Cedar Bluffs Till in the periglacial region is the *Walnut Creek Formation* (new name) with the type locality located on the west side of the Walnut Creek valley in the E. ½, S.W. ¼, N.E. ¼ of Section 7, T. 9 N., R. 2 E., Seward County. The details of the formation as exposed at this locality are included

Yarmouth Soil

Acid Soluble	34.14%
Silt and clay	38.96%
1/16–1/8 mm.	5.30%
1/8 –1/4 mm.	8.87%
1/4 –1/2 mm.	6.98%
1/2 – 1 mm.	3.12%
1 – 2 mm.	1.37%
2 – 4 mm.	1.26%
	100.00%

Cedar Bluffs Till

Acid Soluble	16.13%
Silt and clay	64.12%
1/16–1/8 mm.	4.67%
1/8 –1/4 mm.	5.86%
1/4 –1/2 mm.	4.77%
1/2 – 1 mm.	2.05%
1 – 2 mm.	.87%
2 – 4 mm.	1.53%
	100.00%

in Columnar Section 9 (Appendix). A second locality in Seward County, on the southwest side of the West Fork Big Blue River valley, near the center of Section 26, T. 9 N., R. 2 E., Seward County, shows a better development of the overlying Sappa Formation and a more complete interstadial soil between the Walnut Creek Formation below and the Sappa Formation above and is included as Columnar Section 10 in the Appendix. This locality may be regarded as a substitute type locality for the Grand Island member of the Sappa.

The Walnut Creek Formation consists of an alluvial sequence grading upward from coarse to fine clastics that is believed to have been deposited during the retreat of the Cedar Bluffs ice in Medial Kansan time. The humic soil, developed at the top of the Walnut Creek Formation is regolithic in nature and has little or no clay-enriched zone related to it. Thus it is classed as an interstadial and not an interglacial soil. Undoubtedly there were eolian equivalents to the Walnut Creek Formation deposited in the uplands during Medial Kansan time but we know of no localities where a Walnut Creek Loess has been preserved and can be documented.

Late Kansan Deposits

The Cedar Bluffs Till is overlain by the Clarkson Till in northeastern Nebraska between the Platte and Elkhorn River valleys.

Although the Clarkson Till could be of Late Kansan age, it is believed to be of Early Illinoian age because of the presence of a thick zone of oxidation on the underlying Cedar Bluffs Till. Therefore, in this report the Clarkson Till is tentatively classified as Early Illinoian and not Late Kansan. However, there are three alluvial sequences in the periglacial region of Nebraska that are of Kansan age (Figure 9) and it seems essential to hypothesize that the Kansan ice did advance and retreat three times even though we cannot document the last episode with a till in Nebraska. The Clarkson Till will be discussed in more detail later in this report.

The fluviatile deposits of Late Kansan age in the periglacial region of Nebraska are represented by the *Sappa Formation* (Condra and Reed, 1950) which consists of the *Grand Island sand and gravel member* in its lower part, grading upward into silts of greenish-gray color which include the Pearlette Volcanic Ash bed. The name Sappa Formation was restricted to the fine-textured upper part of the present formation by Condra and Reed (1950) but we believe it is more satisfactory to reserve the rank of formation for the complete depositional unit. The type locality of the Sappa Formation (revised usage) is in Sappa Township, Harlan County, 4½ miles west and 1½ miles north of Orleans, near the site of a long-abandoned volcanic ash "mine" of the Cudahy Packing Company in the W. ½, S.W. ¼, S.E. ¼, N.E. ¼ of Section 11, T. 2 N., R. 20 W., in drainages which flow eastward and northeastward to the Republican River valley (Columnar Section 11, Appendix).

The significance of the Pearlette Volcanic Ash bed as a "time line" and effective key bed for stratigraphic use in the Pleistocene of Nebraska and adjoining states has been discussed earlier in this report. However, the volcanic ash may occur well up or well down in the upper silt member of the Sappa Formation and locally may be in the lower Grand Island sand and gravel member of the formation.

Close study of the Sappa and overlying deposits in the periglacial region of Nebraska indicates that exposures of some greenish-gray silts that are of Early or Medial Illinoian age have been confused with the Sappa Formation at many locations including Lugn's type locality of the Grand Island (Lugn, 1935). Therefore, the correlation of greenish-gray silts lacking a Pearlette Volcanic Ash bed or without scattered shards of volcanic ash in the silts with the Sappa Formation is very questionable unless the silts can be traced into volcanic ash-bearing silts. Microscopic examination of samples from many occurrences of silt without visible beds of relatively pure volcanic ash do indicate the presence of volcanic ash shards in the silts and thus permit the identification of the Sappa Formation over a far wider area than would be possible otherwise. In some occurrences, the shards may be reworked into younger deposits.

The *Sappa Loess* was deposited in the uplands contemporaneous with the fluviatile occurrences of the Sappa Formation and may be recognized because of the presence of volcanic ash shards in the loess. An exposure of shard-bearing Sappa Loess (or silt) occurs above eroded Cedar Bluffs Till in a road cut south of Prague in northwestern Saunders County (N.E., S.E., S.E., Sec. 2, T. 15 N., R. 5 E.), thus establishing a post-Cedar Bluffs till age for the Sappa.

Many exposures of the Sappa Formation in Nebraska have a truncated and eroded top as a result of pro-Illinoian or later erosion and the evidences of the Yarmouth Soil are missing. However, the Yarmouth Soil is well developed at the top of the Sappa at several localities in Nebraska and at a number of places in Kansas and its classification as Late Kansan seems to be definite. Some have classified it as interglacial (Yarmouthian) and not as a part of the Kansan stage of glaciation but differences of opinion regarding the criteria for separating glacial and interglacial deposits are so great that it seems advisable to make no attempt to separate deposits into glacial and interglacial parts.

Yarmouth Soil and pro-Illinoian Erosion

The close of the Kansan stage was marked by a comparatively long period of relatively stable conditions with relatively warm climate when the *Yarmouth Soil* developed on the deposits which formed the land surface. The nature of the Yarmouth Soil varies regionally as do the modern soils but it is a well developed soil either typified by a comparatively thick B-horizon of clay enrichment or a comparatively thick zone of lime accumulation or both. In some localities, where the lime accumulation zone is very thick, it may involve the addition of lime during Sangamonian as well as Yarmouthian time.

Certainly there was extensive major erosion of the Yarmouth Soil and older deposits as the Illinoian ice sheet formed and advanced. The result is that the Yarmouth Soil has been truncated or completely removed in many exposures. This situation, of course, presents problems of correlation.

Illinoian Stage Deposits

It has been recognized for some time that there is more than one alluvial depositional sequence between the Yarmouth and Sangamon soils or between the Pearlette Volcanic Ash bed and the Sangamon Soil in the periglacial region of Nebraska and a multiple Illinoian was strongly suggested. The recognition and differentiation of three tills of Early, Medial and Late Illinoian age in Illinois further strength-

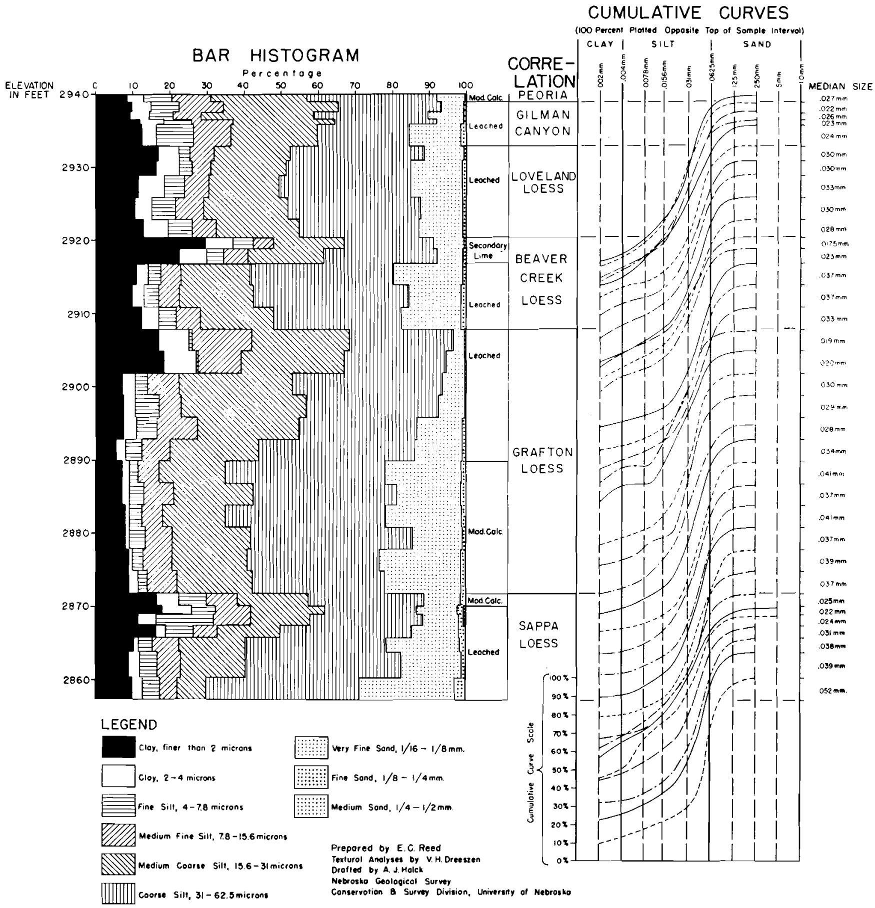


Figure 10. Textural analyses of samples from Loveland, Beaver Creek, Grafton and upper Sappa Formations at Buzzard's Roost locality (Columnar Section 18, Appendix).

ened this conclusion. Condra and Reed (1950) recognized one till of Illinoian age in northeastern Nebraska which was later tentatively correlated as Early Illinoian. However, this till does not seem to be the earliest Illinoian because of the absence of more than one depositional sequence above it and we are proposing herewith that the Illinoian till that Condra and Reed recognized in northeast Nebraska is Medial and not Early Illinoian.

It seems probable that an Early Illinoian till as well as a Medial Illinoian till may have reached into Nebraska. Certainly a till can be differentiated in eastern Nebraska that is younger than the Medial Kansan till (Cedar Bluffs) and older than the till identified by Condra and Reed as Illinoian. Completely adequate proof that this till is Early Illinoian and not Late Kansan is not immediately at hand but the

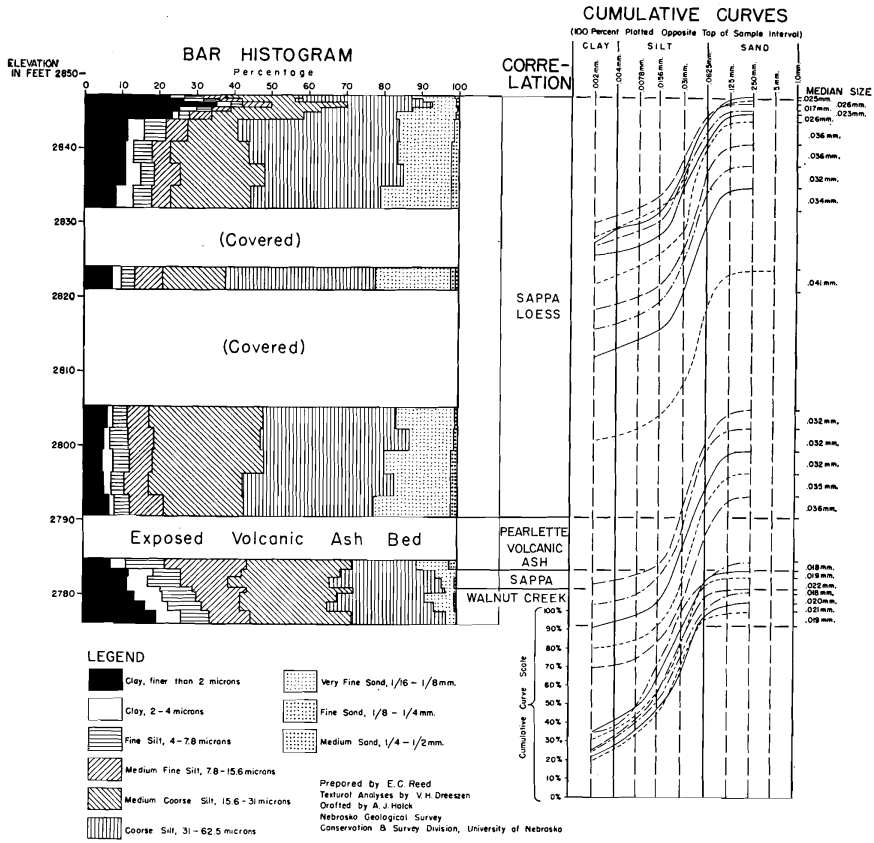


Figure 11. Textural analyses of samples from the Sappa Formation at Gilman Canyon locality (Columnar Section 19, Appendix).

preponderance of stratigraphic evidence favors an Early Illinoian classification.

Early Illinoian Deposits

The *Clarkson Till* (new name) occurs above eroded and oxidized Cedar Bluffs Till in northeastern Nebrska, north of the Platte River valley. The moraine of the Clarkson Till is reflected in a prominent, north-south ridge which is located 8 miles east of the northward extension of the Cedar Bluffs moraine (see Figures 5A and 5B). No exposures of this till are known at the present time so the type locality is designated in Ground Water Survey Test Hole A22-2-25dc which was drilled in the S.W. corner of the S.E. ¼ of Section 25, T. 22 N., R. 2 E., Stanton County, 8 miles north and ½ mile west of Clarkson, and the description of the type section is given in Columnar Section 12 in the Appendix. Its relationship to older and younger formations of Pleistocene age is shown in Figures 6 and 8.

The fluviatile equivalent of the Clarkson Till is believed to be the *Grafton Formation* (new name) which is an alluvial depositional sequence grading from coarse clastics below, upward into greenish-gray silts. The type locality is designated as the N. ½, S.W. ¼, S.W. ¼, S.W. ¼ of Section 6, T. 8 N., R. 3 W., Fillmore County (3½ miles north of Grafton, in a cut bank along the southwest side of the West Fork Big Blue River valley) where a meander of the stream has eroded into the upland margin which is a loess-mantled plain developed above fluviatile deposits of Illinoian age. The deposits exposed at this locality are described in Columnar Section 13 (Appendix). The uppermost deposits in this area are more clearly shown in an erosion ditch located two miles south and 4.7 miles west of this type locality in the S.W. ¼, S.E. ¼, S.W. ¼ of Section 17, T. 8 N., R. 4 W., about 0.6 mile west of old Lyman Station on the Stromsburg and Alma Branch of the C. B. & Q. Railroad.

The Grafton Formation was deposited in channels eroded into the Sappa Formation of Late Kansan age and older deposits in this region and it is believed that these sediments were deposited during the retreat of the Clarkson ice sheet. Because of the greenish-gray color of the upper silts of the Grafton, it has been confused with the Sappa Formation at a number of localities. The upland eolian equivalent of the Grafton Formation is the *Grafton Loess* which can be differentiated at Buzzard's Roost (Columnar Section 18) in southeastern Lincoln County. An interstadial soil may occur at the top of the Grafton but it has been removed in many places by the pro-Medial Illinoian erosion. There is a good possibility that the deposits that Thorp, Johnson and Reed (1951) tentatively assigned to the Sappa in the Yankee Hill Brick Yard section and that Schultz and Tanner (1957) referred to the Sappa at the Bartek Farm in Saunders County as well as at other localities in the state, represent the Grafton and not the Sappa. This, of course, raises the question as to whether or not certain faunas, referred to the Sappa silts and Grand Island sand and gravel are Late Kansan to Yarmouthian or may be Early Illinoian. Additional studies are needed in order to solve these problems.

Apparently snail faunas from some exposures of the Grafton Formation in Nebraska are very similar to those believed by Leonard (1950) to be limited to the Sappa Formation. However, Condra and Reed (1950) undoubtedly contributed to this confusion by including some sediments of possibly Early Illinoian age with the Sappa Formation at its type locality.

Medial Illinoian Deposits

Condra and Reed (1950) recognized a till in northeastern Nebraska which they classified as Illinoian because of its occurrence above the

Pearlette Volcanic Ash bed of the Sappa Formation and because it exhibited "weathering characteristics" intermediate between those of the Kansan and Wisconsinan tills. More recently one locality has been found where the Sangamon Soil has been preserved above this Illinoian till, possibly developed in a thin representative of the Late Illinoian Loveland Formation. This till is herein assigned to the Medial Illinoian and the type locality is designated in a road cut, 3 miles southeast of Santee in the S.E. ¼, S.E. ¼, N.W. ¼ of Section 29, T. 33 N., R. 4 W., Knox County. This till is herein called the *Santee Till* (new name) and the type locality is described in Columnar Section 14 (Appendix). It forms a moraine which trends from the type locality southeastward to west of Coleridge and the exposure where the Sangamon Soil is developed above it or in its upper part is at the Sunny Hill School in the N.E. corner of Section 35, T. 30 N., R. 1 W., Cedar County. The Sunny Hill School exposure is described in Columnar Section 15 (Appendix).

The Santee Till, at its type locality and at Sunny Hill School, rests upon the Fullerton Formation of Late Nebraskan age, with great unconformity but the till at both of these localities can be traced eastward and southeastward to localities where the till rests on the Sappa Formation including the Pearlette Volcanic Ash bed. Thus it is established as post-Sappa and pre-Sangamonian in age. More studies are needed to establish the exact relationships between the Santee Till and the Clarkson Till but the Santee is definitely younger than the Clarkson and it is believed that the two tills are separated by an interstadial soil where they occur in sequence.

The assignment of the Clarkson and Santee tills to Early and Medial Illinoian is tentative at this time, as discussed earlier.

Laboratory studies of successive samples of Santee Till from the type locality gave the following results with acid treatment and textural analyses of the residues:

	Acid soluble	Silt and clay	1/16–1/8 mm.	1/8–1/4 mm.	1/4–1/2 mm.	1/2–1 mm.	1–2 mm.	2–4 mm.
Top— Sample 1	15.17%	63.47%	4.21%	7.83%	5.93%	2.40%	.84%	.15%
2	14.66%	63.80%	4.93%	8.13%	5.60%	1.84%	.78%	.26%
3	15.46%	62.35%	4.79%	7.63%	5.93%	2.23%	.74%	.87%
4	14.08%	65.15%	4.75%	6.77%	5.52%	2.20%	.89%	.64%
5	12.90%	64.73%	4.54%	6.65%	6.39%	2.95%	1.41%	.43%
6	10.48%	65.65%	4.79%	6.71%	6.45%	2.95%	1.30%	1.67%
Bottom— Sample 7	11.83%	63.33%	6.05%	6.77%	6.85%	3.21%	1.23%	.73%
Fullerton Formation	12.47%	86.44%	.70%	.33%	.05%	.01%	00	00

NOTE: Each till sample represents 5.5 feet; Fullerton sample from Upper 5 feet.

The periglacial fluviatile equivalent of the Santee Till is believed to be the *Beaver Creek Formation* (new name) with a type locality in cut banks on the northeast side of the Beaver Creek valley in the N.E. ¼, S.E. ¼, N.E. ¼ of Section 25, T. 10 N., R. 1 W., York County. The measured section at the type locality is Columnar Section 16 in the Appendix. This interesting exposure was brought to the attention of the authors by Carroll Goll, in connection with his graduate studies.

The upland eolian equivalent of the Beaver Creek Formation is the *Beaver Creek Loess* which is identified at Buzzard's Roost (Columnar Section 18) as well as at a number of other localities in Nebraska.

Late Illinoian Deposits

No till of Late Illinoian age has been identified in Nebraska but a Late Illinoian formation is recognized in the periglacial region and we are herewith restricting the Nebraska use of the older name *Loveland Formation* to deposits of this age and classify the underlying sands and gravel (named Crete by Condra and Reed, 1950) as the Crete sand and gravel member of the Loveland Formation.

Condra and Reed (1950, p. 25) included a columnar section at the Crete type locality which is reclassified in Columnar Section 17 of the Appendix to correspond to the revised classification used in this report.

Although the Loveland Formation is the Late Illinoian depositional sequence in the periglacial region, it seems to be eolian under the higher flat levels of the loess-mantled Illinoian terraces and the fluviatile sequences, involving the Crete sand and gravel, occur under slightly lower levels of the plains.

Sangamon Soil and pro-Wisconsinan Erosion

The *Sangamon Soil* is widely recognized throughout Nebraska and in adjoining states because of the strong reddish-brown color of the parent material and because of the marked clay enrichment of the B-horizon. It developed on the then-present land surface during the period of warm climate and stabilized conditions that separated the Illinoian and Wisconsinan glacial stages.

The comparatively thick zone of humic silt occurring above the B-horizon of the Sangamon Soil has long been regarded as the A-horizon of the Sangamon Soil, although many workers regarded this development as a "double" soil development. John A. Elder, Pedologist in charge of Soil Survey investigations for the Conservation and Survey Division, and the junior author have studied this horizon in considerable detail, and John Elder concludes, "The explanation advanced for the Gilman Canyon increment seems well founded. The dark colored humus-enriched horizon, 1½ to 4 feet thick, overlying the reddish-brown Loveland Formation has been regarded by some workers as the A-horizon of the Sangamon Soil. The lower part of the horizon grades to a clay-enriched soil which grades gradually to unweathered material. A carbonate-enriched horizon is a feature of the slightly altered zone below the horizon of clay enrichment.

"This sequence of horizons establishes beyond doubt that a well developed soil was present on this landscape. That this soil developed an A-horizon of such great thickness is most unlikely. Grassland soils are well known for their thick, dark A-horizons, but the dark, humus-enriched horizon seldom exceeds 12 inches unless loess is being slowly accumulated or a thin mantle of loess is deposited and darkened by continuing soil formation. It is well documented that there is an overly thick A-horizon on the soil in the present landscape where a thin mantle of Bignell Loess overlies the Brady Soil, also that accumulations of 'dust' from central Nebraska river valleys are giving rise to overly thick A-horizons in the modern soils on stream terraces and on the adjacent uplands.

"Very thin blankets of Early Wisconsinan Loess draped over the Illinoian landscape would produce what appears to be a thick A-horizon of the Sangamon Soil. The greater part of this darkened horizon would not be contemporary with the Sangamon Soil. Parts of it might well be contemporaneous with the loess deposits of Early Wisconsinan age."

Therefore, we are removing the accumulation deposit of humic material from the Sangamon Soil and believe it to be post-Sangamonian and probably of Early Wisconsinan age. Many of the so-called "Citellus Zone" fossils of the vertebrate paleontologists have been collected from this accumulation zone and we would refer them to Early Wisconsinan and not to the Sangamonian. Efforts are now being made to secure a radio-carbon dating of this horizon and it is believed that the carbon in this zone may be datable by radio-carbon methods and therefore younger than Sangamonian.

An extensive period of major erosion was initiated with the beginning of Wisconsinan glaciation. This resulted in progressive deepening and narrowing of most of the present valley systems in the state.

Wisconsinan Stage Deposits

The Wisconsinan deposits in Nebraska may be divided into Early, Medial and Late in the periglacial region, although the deposits of Early Wisconsinan age seem to be poorly represented. A single till of Wisconsinan age is present in the vicinity of Hartington in extreme northeastern Nebraska and it appears to be of Medial Wisconsinan age and is apparently equivalent to the Tazewell or Tazewell and Cary tills as mapped in adjoining South Dakota (Flint, 1955). Thus there is one Wisconsinan till (probably Medial) and three depositional sequences (probably Early, Medial and Late Wisconsinan) in Nebraska.

Early Wisconsinan Deposits

No till of Early Wisconsinan age is recognized in Nebraska but the "Iowan till" is probably Early Wisconsinan, at least in some Iowa localities where it has been mapped. This is at some distance from Nebraska so it is not unusual that we have a comparatively thin equivalent to this Early Wisconsinan in Nebraska.

The depositional unit in Nebraska that is referred to the Early Wisconsinan is the *Gilman Canyon Formation* (new name). The type locality of the Gilman Canyon is in the west fork of Gilman Canyon in the Buzzard's Roost section which has been studied in considerable detail (Figure 10) and is described in Columnar Section 18 (Appendix). Important exposures at stratigraphically lower levels that involve the Sappa Formation, including the Pearlette Volcanic Ash bed, have been measured and studied (see Figure 11) in exposures farther east in the west fork of Gilman Canyon and are described in Columnar Section 19 (Appendix).

The top of the Gilman Canyon Formation is placed at a "weak" soil horizon that is believed to represent the *Farmdale Interstadial Soil* and marks the contact between the Early and Medial Wisconsinan deposits.

Medial Wisconsinan Deposits

Till that is believed to represent a deposit of Medial Wisconsinan age is differentiated in the vicinity of Hartington in Cedar County. This is the *Hartington Till* and the type locality is designated as Ground Water Survey test hole A31-1-13ccc drilled near the Tip-Top School, two miles north of Hartington (271 ft. E. of S.W. corner of Sec. 13, T. 31 N., R. 1 E., Cedar County). The record of this test hole is included in the Appendix and is designated Columnar Section 20.

Condra and Reed (1950) recognized this till as Wisconsinan but correlated it with the "Iowan till" of Early Wisconsinan. It now seems improbable that this till is as old as the Iowan because it appears that this glaciation crossed the Missouri River into Nebraska from the north where Medial Wisconsinan till has been differentiated by Flint (1955) and Simpson (1960), and no "Iowan till" is recognized.

The fluviatile deposits in the periglacial region that are believed to be equivalent to the Hartington Till are designated as the *Peoria Formation* including a basal sand (Todd Valley sand of Lugn, 1935) grading upward into silts. The Todd Valley sand, given formational rank by Lugn, is herewith classified as a member of the Peoria Formation and no name is applied to the upper silts of the depositional sequence.

The upland equivalent of the Peoria Formation is the *Peoria Loess* (Peorian of earlier usage) and the most extensive dunesand deposits of the Sand Hills region are classified as *Peoria Dunesand* (see Columnar Section 21, Appendix).

The Peoria Formation occurs as terrace deposits under comparatively high levels along valley sides which are generally lower than the terraces developed on Illinoian sequences and are more restricted in areal extent. The Peoria Loess occurs as an eolian mantle over much of upland area of central and eastern Nebraska and blankets the terrace deposits of Illinoian and older ages. It thickens and coarsens in the direction of the Sand Hills and also thickens and coarsens near the Missouri River valley and adjacent to outwash outlets related to the Hartington Till (see Figures 5A and 5B). The *Brady Interstadial Soil* (Schultz and Sout, 1945) was developed at the top of the Peoria Formation, Peoria Loess and Peoria Dunesand, but this soil cannot be satisfactorily separated from the modern soil in much of the higher upland. A radiocarbon date of 9,160 ± 250 years has been determined from carbon removed from the A-horizon of the Brady Soil at its type locality but it is apparent that this soil may be contaminated to some degree by the roots of more recent plants. Also, radiocarbon dates varying from 12,500 ± 400 to 12,700 ± 300 years have been reported from snail shells collected by A. B. Leonard from loess above the Brady Soil in northeastern Kansas. Therefore, a compromise consensus date for the Brady Soil is somewhere near that of the Two Creeks Forest Bed and is the basis for our placement of the post-Brady deposits in the Late Wisconsinan (Valderan).

Late Wisconsinan Deposits

No till of Late Wisconsinan age is recognized in Nebraska but fluviatile and eolian deposits of post-Brady Soil age are developed in the upland margins and under prominent terrace levels throughout Nebraska which occur below the level of the Medial Wisconsinan deposits and above Recent terrace levels. The fluviatile deposits of Late Wisconsinan age are classified as the *Bignell Formation*, the finer-textured eolian equivalents are named the *Bignell Loess*, and the Late Wisconsinan coarser-textured eolian deposits are called *Bignell Dunesand*. The type locality of the Bignell was established by Schultz and Stout (1945) at a location in the upland margin south of Bignell in the N.E. ¼ of Section 3, T. 12 N., R. 29 W., Lincoln County, where it is represented by some 12 feet of loess.

THE SAND HILLS REGION

The Sand Hills region of Nebraska is the most extensive area of stabilized sand dunes in the country and therefore merits special consideration in any discussion of the Pleistocene of the state. It comprises more than 22,000 square miles and includes a principal area in north-central Nebraska and some smaller outlying areas to the west and southwest (see Figure 1).

This region, in spite of its size, is one of the least understood parts of the state and is also an area that has been less thoroughly investigated because it involves a type of land that is currently utilized about as advantageously as it could be, and also because it is not an area where the development of necessary ground water supplies is a particular problem at the present time. Therefore, ground water survey test drilling has not been accomplished in much of this region to date (see Figure 2), even though systematic test drilling will be required to determine accurately the complete Pleistocene history of the region.

A. L. Lugn (1935) made some studies of the Sand Hills region and recognized this area as an important source of loess during Wisconsinan time. He also suggested that the area probably had a complex pre-dunesand Pleistocene history with a hill and valley topography eroded into the underlying Tertiary (Pliocene) bedrock of the Ogallala Formation and implied, to some degree, that the dunesand and loess may have been blown out of the Ogallala Formation directly before being reworked into fluviatile sediments during earlier Pleistocene time. He classified the dunesand as the "Sand Hills Formation" and regarded it as an equivalent of the "Peorian Loess" in eastern and southeastern Nebraska. We agree, in large part, with most of Lugn's conclusions regarding the Sand Hills region but do not agree with the implication that any significant amounts of dunesand or loess were blown directly out of the Ogallala Formation.

An intensive photo-interpretation and field examination study of the Nebraska Sand Hills has been completed by H. T. U. Smith and the dune features, as a result of Smith's studies, were included in the Eolian Map of the United States (Thorp and Smith, 1952). A more detailed report of these studies is now in press, according to a personal communication from Smith and it is hoped that this publication will provide additional data. Smith recognized an older generation of transverse dune ridges (some as much as 300 feet in height) and a second generation of dunesand formation, mostly in the form of longitudinal dunes. He also noted a number of localities where a younger dunesand was separated from an older dunesand by a soil horizon. We correlate the older dunesand with the Peoria Loess of Medial

Wisconsinan age and apply the name Peoria Dunesand to these deposits. The younger dunesand is herein regarded as equivalent to the Bignell Loess of Late Wisconsinan age and the name Bignell Dunesand is applied to it. The soil between the younger and older dunesands is classified as the Brady Interstadial Soil.

The deposits of Pleistocene age in the Sand Hills region which underlie the Peoria Dunesand (Columnar Section 21, Appendix) seem to be generally coarser textured than their equivalents southeastward, probably because they were deposited closer to the headwaters of the Early and Medial Pleistocene drainages and had an abundant source of coarser clastics in the Ogallala Formation which was the only available bedrock material.

It appears probable that the dunesands deposits of the Sand Hills region mantle Illinoian as well as Kansan terrace deposits. The earlier drainage patterns have been obscured by the "advance" of the dunes and the result is many closed, drained basins where water table lakes now occur. Many valley trends were probably eastward and southeastward throughout much of pre-Wisconsinan Pleistocene time with some shifting of their down-valley trends to the more easterly directions in Early and Medial Wisconsinan time. The present Platte River valley which marks the south and southeast edge of the main Sand Hills region appears to have been developed in Late Wisconsinan time.

GENERAL CONCLUSIONS

The revised classification of the Pleistocene deposits of Nebraska appears to meet the present demands of our current knowledge of these deposits in the state. However, it is probable that further studies will result in some changes in classification in the future and many local occurrences of deposits may be subject to correlation revision as more detailed data are available. It has been impossible to include all of the detailed records which have influenced the development of the classification presented herewith, but most of the more significant data have been included.

The older Pleistocene deposits are exposed at fewer locations than the younger deposits and therefore are less available for detailed examination. As a result, much of the earlier Pleistocene record must be learned from a careful examination and interpretation of samples from test holes which penetrate these deposits. Our cooperative ground water survey test drilling program has developed superior methods of sampling and logging relatively unconsolidated deposits, yet some thin intervals cannot be sampled in enough detail to secure all of the changes in character of the deposits that may be desirable for the most complete and detailed interpretation of the deposits. However, much detail can be secured when the drilling record is supplemented with a careful microscopic examination of samples. The lack of detailed, modern, topographic maps, especially in northeastern Nebraska, is a handicap in the detailed study of the Pleistocene deposits, especially in relation to the geomorphology.

Microscopic examination of samples from both outcropping exposures and test holes often provides essential information not apparent from the customary field examination and description. Volcanic ash shards have been identified at a number of localities where their presence is not apparent from a more cursory examination of materials. Textural analyses of samples collected from exposures often reveal zones of clay-enrichment that may be overlooked. The careful use of Munsell color coordinates in description of colors is most helpful in locating formation boundaries, especially in central and western Nebraska where color distinctions are less apparent.

There is a great advantage in the precise location of detailed exposures and test hole records, both horizontally and vertically. Therefore, we have included elevations determined carefully with controlled altimeter traverses from Coast and Geodetic Survey bench marks where instrumental levels are not available. The altimeter elevations are generally accurate to one or two feet.

There are yet some problems in establishing the exact relationships of the Cedar Bluffs, Clarkson and Santee Tills to each other because of the lack of enough subsurface records for study where they occur in succession. However, we believe that they are properly correlated but need more records for study where the interglacial and interstadial soils between them are more completely preserved.

There are difficulties in tracing some of the till formations eastward from their moraines toward and into the region immediately west of the Missouri River valley. Part of these difficulties are related to the test hole drilling pattern designed primarily to locate east-west trending buried valleys which may be sources of larger ground water supplies. More east-west, test-drilled profiles with a closer spacing of test holes and more detailed studies of the samples of some of the test holes already drilled are needed to more completely prove correlations projected eastward. Likewise, more systematic test drilling is needed in and near the Sand Hills region of the state.

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APPENDIX

Columnar Section 1

Composite section at the type locality of the Elk Creek Till and in vicinity (measured by V. H. Dreeszen, E. C. Reed, and J. A. Elder).

Location: S.E. 1/4 of Section 26, T. 4 N., R. 11 E., Johnson County, and west line of Section 1 and east line of Section 13, both in T. 3 N., R. 11 E., Pawnee County.

	Thickness
Wisconsinan:	
Peoria Loess	0-5 feet
Illinoian:	
Loveland Formation: 0-2 feet in uplands; terrace sequence (S.E. corner Sec. 26, T. 4 N., R. 11 E.) about 24 feet:	
a. Silt, with colluvial sand near side slopes, reddish-brown in upper part, olive gray in lower part (elevation at base 1079 feet)	about 21 feet
b. Crete sand and gravel member	3 feet or more
Late Kansan:	
Sappa Formation (absent in uplands): terrace sequence (S.W., S.E., Sec. 26, T. 4 N., R. 11 E.) about 15 feet:	
a. Silt member:	
1. Silty clay, medium brown, Yarmouth Soil developed in upper part	2-3 feet
2. Silt, pinkish-brown	1 foot
3. Pearlette Volcanic Ash bed, light gray, part altered, elevation at top 1153 feet	2 feet 1 inch
4. Clay, very light olive gray	2 feet
5. Silty clay to very sandy clay, very light gray	about 5 feet
b. Grand Island sand and gravel member; channeled into Elk Creek Till	2-3 feet
Early Kansan:	
Nickerson Till: gray to brownish boulder clay, generally calcareous, oxidized, thickness measured in S.E. 1/4 of Sec. 13, T. 3 N., R. 11 E.	65 feet
Atchison Formation: Sand, brownish-gray, medium-grained; occurs in channels cut into Fullerton silts; measured in S.W. 1/4 of Sec. 1, T. 3 N., R. 11 E.	10 feet
Late Nebraskan:	
Fullerton Formation: Silt and clay, medium to light gray, common zones of ferruginous to calcareous concretions; dark brown-gray Afton Soil developed in upper part, lower part grades to very fine gray sand with uneven erosional contact at base; measured in S.W. 1/4 of Sec. 1, and S.E. 1/4 of Sec. 13, T. 3 N., R. 11 E.	about 66 feet
Early Nebraskan:	
Elk Creek Till: Boulder clay, medium gray to brownish, oxidized, calcareous, top eroded; elevation of top along west line of Sec. 1, T. 3 N., R. 11 E. (type locality) is 1118 feet; elevation of top in S.W., S.E., Sec. 26, T. 4 N., R. 11 E. is 1136 feet; measured in N.W., S.W., of Sec. 1, T. 3 N., R. 11 E.	5-15 feet
Pennsylvanian Limestones and Shales, contact obscured.	

Columnar Section 2

Type Locality Seward Formation (measured by Carroll Goll, E. C. Reed and V. H. Dreeszen).

Location: Cut bank, southwest side of Middle Oak Creek valley, in the north half of the N.W. ¼ of Section 26, T. 12 N., R. 4 E., Seward County (elevation at top of measured section about 1440 feet).

	Thickness
Medial Wisconsinan:	
Peoria Loess, exposed in surrounding upland	about 15 feet
Late Illinoian:	
Loveland Formation: Sandy silt, reddish-brown, grading down to sand and gravel, poorly exposed	about 5 feet
Late Nebraskan:	
Fullerton Formation: Silt and very fine sand, light gray to light brown, laminated, in part cross-bedded, sharp contact at base	about 40 feet
Early Nebraskan:	
Seward Formation, 12 feet:	
a. Soil, dark gray to black, leached, common limonitic concretions	5 feet 6 inches
b. Silt, light gray to white, very calcareous, laminated, some snail shells	2 feet to 2 feet 6 inches
c. Soil, dark gray to black, slightly calcareous	1 foot 8 inches
d. Silt, light gray to white, very calcareous	about 1 foot
e. Silt and clay with bedrock fragments and pebbles, buff-colored, limonitic	1 foot 6 inches

Cretaceous: About 1 foot 7 inches of Graneros Shale and 3 feet 6 inches to 5 feet 6 inches of Dakota Group sandy shale with concretionary ironstone beds exposed above creek level.

Columnar Section 3

Substitute Type Locality of Fullerton Formation in road cut 2¾ miles west and ½ mile south of Raymond (measured by L. W. Stoesz [1949], E. C. Reed and V. H. Dreeszen).

Location: Middle of west line of N.W. ¼ of S.W. ¼ of Section 2, T. 11 N., R. 5 E., Lancaster County (elevation top of section about 1330 feet).

	Thickness
Late Nebraskan:	
Fullerton Formation, eroded at top, 18 feet 6 inches:	
a. Clayey silt to silty clay, brownish-gray to buff, moderately calcareous (lime enrichment related to Afton Soil development)	2 feet
b. Clayey silt, brownish-gray to buff, moderately to very calcareous (lime enrichment related to Afton Soil development)	7 inches
c. Silt, slightly clayey, medium dark brownish-gray to yellowish, lenticular, slightly calcareous; some limy concretions	1 foot 8 inches
d. Silt, brownish-gray to yellowish, slightly to moderately calcareous; thin lenses of fine-grained, light gray sand in lower part; some limy concretions in upper part	1 foot 1 inch
e. Sand, light gray, fine-grained, slightly calcareous; many rodent burrows; laminated and banded in lower part	3 feet 10 inches
f. Sand, light gray, fine-grained, moderately calcareous, fairly common limy, concretionary zones; light buff-colored in upper and lower parts	9 feet 4 inches

Early Nebraskan (?):
Seward (?) Formation: Silty clay, brownish-gray, slightly sandy; thin lens of fine sand in upper part; middle and lower parts concretionary, moderately calcareous — 2 feet 6 inches +

Note: The above section was described and sampled by L. W. Stoesz (1949) in connection with graduate studies at the University of Nebraska; the sand member of the Fullerton Formation here may be a fine-textured equivalent of the Holdrege sand and gravel member of channel areas.

Columnar Section 4

Substitute Type Locality of Holdrege sand and gravel member of Fullerton Formation; Ground Water Survey Test Hole A15-1-24aaa (described by V. H. Dreeszen and M. P. Carlson).

Location: 82 feet west and 9 feet south of northeast corner of Section 24, T. 15 N., R. 1 E., Butler County (elevation of ground level, 1633 feet).

	Thickness
Medial Wisconsinan:	
Peoria Loess: Silt, yellowish-gray to buff, moderately clayey and brownish in upper 4 feet, slightly calcareous below, some snail shells	31.5 feet
Early Wisconsinan:	
Gilman Canyon Formation: Silt, dark brown-gray, soil-like, slightly to moderately clayey	2.5 feet
Late Illinoian:	
Loveland Formation, 41 feet:	
a. Silt, medium brown-gray, moderately to very clayey in upper 16.5 feet; light brown and progressively more sandy downward in lower 14.5 feet	31 feet
b. Crete sand member: sand, slightly silty in upper part, fine to medium-grained with some coarse sand in middle and lower parts	10 feet
Medial Illinoian:	
Beaver Creek Formation:	
a. Silt, light brown, moderately sandy	1 foot
b. Sand, fine to coarse-grained	1.5 feet
Early Illinoian:	
Grafton Formation, 19.5 feet:	
a. Silt, light brown-gray, slightly to moderately clayey, more sandy at base	5.5 feet
b. Sand, very fine to medium-grained with some coarse sand in upper 3 feet; sand, fine, to coarse gravel with common fine-grained gravel in lower 11 feet	14 feet
Late Kansan	
Sappa (?) Formation: silt, light yellowish-gray, slightly to moderately clayey	10 feet
Medial Kansan:	
Walnut Creek Formation, 28 feet:	
a. Silty clay and clayey silt, very light gray; some limy nodules 3 feet below top	9 feet
b. Sand, fine-grained and part silty in upper 8 feet; sand, fine to coarse-grained in middle 6 feet; fine to medium with some coarse sand in lower 5 feet	19 feet
Early Kansan:	
Nickerson Till: Boulder clay, silty to sandy to pebbly, light brownish-yellow in upper 7 feet, medium gray to brownish below	15 feet

Late Nebraskan:
Fullerton Formation, 140.3 feet:
a. Upper silt member: Silt, medium brown to brownish-gray; moderately clayey in upper 8 feet; moderately to very sandy in lower 11 feet — 78 feet
b. Holdrege sand and gravel member: grades from very fine to very coarse sand in upper 7 feet to sand and gravel (medium sand to medium gravel) in lower 55.3 feet with a thin silt separation 34.6 feet above the base — 62.3 feet

Lower Nebraskan:
Seward Formation: Silt and clay, light gray to dark gray; contains a 23 foot zone of sand with some gravel 14.7 feet below top and in lower 2.5 feet (limestone pebbles); prominent 8 foot zone of dark gray to black silty clay 41.7 feet below top — 58.7 feet

Cretaceous: Lower Carlile Shale, Greenhorn Limestone and upper Graneros Shale; 51 feet drilled to total depth of 400 feet.

Columnar Section 5

Type Locality of Nickerson Till and Fontanelle Soil (described by E. C. Reed, V. H. Dreeszen, J. A. Elder, and Gilbert Lueninghoener).

Location: In road cuts north side Nebraska Highway 91, ½ mile north and 2 miles east of Nickerson, ¼ mile north and ½ mile west of Fontanelle, in the S.E. ¼ of the S.W. ¼ of Section 8, T. 18 N., R. 9 E., Washington County.

Thickness

Medial Wisconsinan:
Peoria Loess: Silt, light brownish-gray (probably 20 feet or more in upland farther east), thickness exposed in cut — 6 feet 6 inches

Early Wisconsinan:
Gilman Canyon Formation: Silt, dark brown-gray, soil-like, humic — 1 foot 6 inches

Late Illinoian:
Loveland Formation: Silt, reddish-brown, clayey, sandy throughout, with a 6 inch to 8 inch cobble zone at base (many quartzite cobbles) — 6 feet

Medial Kansan:
Cedar Bluffs Till: Boulder clay, yellow-brown to brown-gray, oxidized, calcareous, more than 15 feet thick farther east, thickness exposed in cut — 7 feet 6 inches

Early Kansan:
Nickerson Till, 15 feet 3 inches exposed:
a. Fontanelle Soil: Silty clay, dark brown to chocolate colored, secondarily lime-enriched, slightly sandy; elevation at top about 1220 feet (top essentially level) — 2 feet 9 inches
b. Boulder clay, medium gray to yellowish, becoming medium dark gray in lower part; zone of secondary lime accumulation in upper foot — 12 feet +

Note: Immediately west of above exposure is a Late Wisconsinan terrace fill with 27 feet of silts exposed and top of surface about 40 feet above flood plain of Elkhorn River; some evidence of older fill in eastern part; this is probably the Terrace 2 complex of Schultz *et al.* (1951).

Columnar Section 6

Fremont Bluff Section (Gas Pipe-Line Section of Lueninghoener, 1947) (described by E. C. Reed, V. H. Dreeszen and J. A. Elder)

Location: Two miles southwest of Fremont in bluffs southwest of Platte River valley, in southwest corner of Section 27, T. 17 N., R. 8 E., Saunders County (elevation at top, 1320 feet).

	Thickness
Medial and Late (?) Wisconsinan:	
Peoria and Bignell (?) Loess: Silt, light brownish-gray to buff, about 15 feet exposed in cut, thickness to upland level	40 feet +
Early Wisconsinan:	
Gilman Canyon Formation: Silt, dark brownish-gray, soil-like, humic	about 1 foot
Late Illinoian:	
Loveland Formation: Silt and some sand, reddish-brown	0-6 feet
Medial Kansan:	
Cedar Bluffs Till: Boulder clay, brownish-yellow, mottled with light gray, silty to pebbly; up to 35 feet in thickness farther east where a zone of lime concretions is developed in upper 8 feet; top eroded at pipe line	0-10 feet
Early Kansan:	
Nickerson Till, about 50 feet:	
a. Fontanelle Soil, brownish-gray to chocolate colored, leached except for some secondary lime, fairly common fine to coarse sand including rare pebbles; upper surface nearly level; elevation at top 1260 feet	0-2 feet
b. Upper till zone, light gray to yellowish, calcareous, silty to sandy to pebbly; secondary lime accumulation at top	33 feet
c. Sand, gray to brownish, medium-grained	3 feet
d. Lower till zone, medium dark gray, calcareous, silty to sandy and pebbly; exposed above river level	about 12 feet

Note: Lugn (1935) and Lueninghoener (1947) classified the Cedar Bluffs Till as Kansan and the Nickerson Till as Nebraskan and called the Fontanelle Soil a "gumbotil."

Columnar Section 7

Substitute Type Locality for the Red Cloud Formation, Ground Water Survey Test Hole 7-5-1ddd (described by V. H. Dreeszen and F. A. Smith).

Location: 111 feet north and 9 feet west of southeast corner of Section 1, T. 7 N., R. 5 W., Clay County (elevation of ground level, 1726 feet).

	Thickness
Medial Wisconsinan:	
Peoria Loess, light brown in color to 4.8 feet below top, light brownish-gray to yellowish in next 11.7 feet, lower 2.2 feet light brown; modern soil at top; generally noncalcareous	18.7 feet
Early Wisconsinan:	
Gilman Canyon Formation: Silt, dark brown-gray, soil-like, humic	2.8 feet
Late Illinoian:	
Loveland Formation: Silt, moderately clayey at top to moderately sandy at base, noncalcareous, medium brown to reddish	7.2 feet
Medial Illinoian:	
Beaver Creek Formation, 21.3 feet:	
a. Silt, very clayey in upper 5.6 feet, less clayey and moderately sandy below, noncalcareous, reddish-brown at top to brown and light brown-gray below	16.1 feet
b. Sand, light gray, very fine to very coarse	5.2 feet
Early Illinoian:	
Grafton Formation, 53 feet:	
a. Silt, light gray, moderately clayey in upper 1.5 feet, sandy silt in lower 1.5 feet with coarse sand lens in middle part	4 feet

b. Upper 16 feet is sand, very fine to coarse with some gravel in lower part; middle 25 feet is gravelly sand with a ten foot zone of sandy gravel 5 feet above the base; lower 8 feet is sand, fine to coarse, light gray — 49 feet

Late Kansan:

Sappa (?) Formation: upper 2 feet is medium dark gray, clayey silt, peaty, noncalcareous; lower ten feet is light gray silt, in part sandy, calcareous with snails in upper 4 feet — 12 feet

Medial Kansan:

Walnut Creek Formation, 27 feet:

a. Silt, dark brown-gray, sandy, noncalcareous with a 3½ foot zone of gravelly sand (quartz and dark silicates) one foot above base — 8.5 feet

b. Gravelly sand (common pink feldspars) — 18.5 feet

Early Kansan:

Red Cloud Formation, 84 feet:

a. Sand, fine to very coarse with thin clay layers — 18 feet

b. Gravelly sand with a 4 foot layer of silty sand 38 feet above base; lower 21 feet is finer textured — 66 feet

Late Nebraskan:

Fullerton Formation: Slightly clayey silt, slightly calcareous; light brown in upper 24 feet (very clayey in lower 7.5 feet with limy nodular zones); light gray to brownish in lower 18 feet — 42 feet

Early Nebraskan:

Seward Formation, 61.7 feet:

a. Moderately clayey silt, light to medium brown in upper 22 feet, light brown-gray below; 6.5 foot zone of limy nodules 3 feet below top; only slightly calcareous in upper 3 feet; sandy in lower 10 feet — 52.2 feet

b. Sand and gravel: grades from a gravelly sand with limestone and chalk pebbles in upper 4.8 feet to a somewhat coarser gravelly sand in lower part — 9.5 feet

Cretaceous: Carlile Shale, 20.3 feet drilled to total depth of 350 feet.

Columnar Section 8

Type Locality of Cedar Bluffs Till (measured and described by V. H. Dreeszen, E. C. Reed and V. L. Souders).

Location: 3 miles north and 2 miles east of Cedar Bluffs, in bluffs south side of Platte River valley below Boy Scouts of America Camp Cedars, S.W. ¼ of N.E. ¼ of N.W. ¼ of Section 24, T. 17 N., R. 7 E., Saunders County.

Thickness

Medial Wisconsinan:

Peoria Loess, light brownish-gray, channeled into formations below — 2-10 feet

Late Illinoian:

Loveland Formation: clayey silt, reddish-brown, part sandy, top eroded, channeled into Cedar Bluffs Till below — 2–5 feet

Medial Kansan:

Cedar Bluffs Till: Upper four feet, where uneroded, is lime-enriched zone (34 percent acid soluble) probably representing both Yarmouth Soil lime enrichment plus Sangamon Soil lime enrichment (residue after acid treatment is 59 percent silt and clay and 41 percent fine to very coarse sand and very fine gravel); next below is calcareous boulder clay; yellow-brown, light brown and light gray mottled in upper 10 feet; lower part largely light gray and light brown-gray with some yellowish-brown; silty to sandy with rare pebbles; lower 9 inches includes incorporated fragments of Fontanelle Soil and sandy silt blocks 17-26 feet

Early Kansan:

Nickerson Till (Top about 50 feet above river level):

Fontanelle Soil: Silty clay, dark gray, humic, leached with rare secondary lime, upper surface relatively level, in upper 8 inches; next lower one foot 8 inches is partially leached, light brown-gray, oxidized till; next lower 7 inches is secondarily lime-enriched zone; next lower 4 feet is light brown gray to yellowish till with more common limestone pebbles; lowest 13 feet exposed is gray, calcareous till with some light brown-gray mottling 19 feet 11 inches +

Note: Scattered outcrops of dark gray till in lower covered slope (30 feet).

Columnar Section 9

Type Locality of Walnut Creek Formation (described by V. H. Dreeszen).

Location: In cut bank on west side of Walnut Creek valley, in the northeast corner of the S.E. ¼ and the southwest corner of the N.E. ¼ of the S.W. ¼ of the N.E. ¼ of Section 7, T. 9 N., R. 2 E., Seward County.

Thickness

Late Illinoian:

Loveland Formation: Crete member gravelly sand 5 feet +

Late Kansan:

Sappa Formation: Silt, very light yellowish-gray; moderately to very clayey in upper 8 feet; next lower 10 feet contains fairly common shards of volcanic ash; lowest 4 inches is light gray to white volcanic ash (Pearlette) 18 feet 4 inches

Medial Kansan:

Walnut Creek Formation, 23 feet 10 inches exposed:

a. Upper 3 feet is very light brownish-gray, slightly clayey silt except for top 4 inches which is dark grayish-brown; contains diatoms; lower 3 feet 7 inches is light yellowish-gray, moderately to very sandy silt with a 10 inch bed of silty sand 5 inches above base 6 feet 7 inches
b. Sand, very fine to medium-grained and part silty in upper 9 feet 3 inches; lower 8 feet is sand, very fine to coarse-grained with rare grains of gravel and some clay pebbles, base not exposed 17 feet 3 inches +

Note: Interval classed as Loveland in doubt.

Columnar Section 10

Dam No. 7 Locality on West Fork Blue River valley (measured and described by E. C. Reed).

Location: In drainages on southwest side of valley above abandoned dam, near center of Section 26, T. 9 N., R. 2 E., Seward County. (Elevation top of section about 1480 feet.)

Thickness

Medial Wisconsinan:

Peoria Loess, light brownish-gray to buff, lower contact covered 8 feet or less

Late Illinoian:

Loveland Formation, 9 feet 4 inches or more:

a. Silt, sandy, pinkish-brown, top covered 4 feet or +
b. Crete sand and gravel member, gray to reddish-brown; upper 3 feet 7 inches largely sand with scattered gravel; lower 1 foot 9 inches is sand and gravel 5 feet 4 inches

Medial Illinoian (?):
Beaver Creek (?) Formation: Sand, grayish-brown, with some gravel — 1 foot 9 inches

Late Kansan:
Sappa Formation, 20 feet 11 inches to 22 feet 10 inches:
a. Silt, gray to brownish-gray with a 5 inch sand bed 2 feet 8 inches below top — 14 feet 8 inches
b. Pearlette Volcanic Ash bed, light gray to white, massive; impure in upper part; lower 3 inches laminated — 6 feet 3 inches to 8 feet 2 inches

Medial Kansan:
Walnut Creek Formation, 6 feet 4 inches or more:
a. Silt, light gray to light greenish-gray; upper foot dark gray and humic; lower 1 foot 4 inches sandy — 3 feet 4 inches
b. Sand, gray, fine-grained at top, becomes coarser downward, base not exposed — 3 feet or +

Columnar Section 11

Type Location of Sappa Formation, ravines southwest of Republican River valley, Sappa Township (measured by E. C. Reed).

Location: N.W. ¼ of N.W. ¼ of S.E. ¼ of Section 11, T. 2 N., R. 20 W., Harlan County.

Thickness

Medial Wisconsinan:
Peoria Loess, gray to light brownish-gray, poorly exposed — about 25 feet

Early Wisconsinan:
Gilman Canyon Formation: Silt, dark gray, humic, soil-like; probably accumulation zone — 2 feet

Late Illinoian:
Loveland Formation, 12 feet 6 inches:
a. Silty sand, reddish-brown, upper part clayey, becoming more sandy downward — 8 feet 6 inches
b. Crete sand and gravel member: sand, fine-grained in upper part, gravelly in lower two and one-half feet — 4 feet

Lower Illinoian (?)
Grafton (?) Formation, 17 feet 3 inches to 18 feet 6 inches:
a. Silt, light gray to greenish-gray, indurated in upper foot, middle part clayey, massive in lower 2 feet 6 inches — 5 feet 9 inches
b. Silty sand to sandy silt, light greenish-gray, massive to laminated in upper third, laminated in middle third, massive in lower third — 4 feet 6 inches
c. Sand, gray, silty, light greenish-gray, laminated to current-bedded in upper 2 feet 4 inches; lower 4 feet 6 inches to 5 feet 9 inches is medium to very coarse-grained with some gravel in lower part, laminated to cross-bedded, uneven erosional base — 6 feet 10 inches to 8 feet 1 inch

Late Kansan:
Sappa Formation, 7 feet 6 inches to 20 feet 6 inches:
a. Pearlette Volcanic Ash bed: white, massive, with 2 to 4 inch clayey ash seam 1 foot 9 inches to 3 feet (where uneroded) below top, laminated in lower 7 to 9 inches — 4 feet 6 inches to 6 feet 1 inch
b. Silt, very sandy, greenish-gray — 9 inches
c. Grand Island sand member: Sand, light gray to light greenish-gray, fine-grained, laminated to massive in upper 1 foot 9 inches; sand, gray, medium to fine-grained, massive

in lower 6 inches (12 feet exposed nearby) 2 feet 3 inches to 13 feet 9 inches

Note: This is Reed's type locality of the Sappa. In 1950, Reed included Grafton (?) Formation above as the upper member of the Sappa. We tentatively classify this depositional unit as Grafton because of its unconformable relationship to the Pearlette Volcanic Ash bed and underlying sediments. This unit may be either the Beaver Creek Formation or the Grafton. Some may choose to include it with the Sappa.

Columnar Section 12

Type Locality of Clarkson Till, Ground Water Survey Test Hole A22-2-25dcc, 8 miles north and ½ mile west of Clarkson (described by F. A. Smith, V. L. Souders and V. H. Dreeszen).

Location: 44 feet east and 5 feet north of center of south line of Section 25, T. 22 N., R. 2 E., Stanton County (elevation of ground level about 1760 feet).

	Thickness
Medial Wisconsinan:	
Peoria Loess: Silt, brownish-gray to olive brown, slightly clayey, slightly to moderately calcareous except in upper 12 feet which is leached and may include some Bignell Loess	59 feet
Early Wisconsinan:	
Gilman Canyon Formation: Silt, medium gray, noncalcareous in upper 9 feet, becoming darker downward; very dark brownish-gray to black and carbonaceous in lower 2 feet (weak Farmdale (?) Soil at top)	11 feet
Late Illinoian:	
Loveland Formation: Silt, moderately to very clayey (Sangamon Soil developed in upper part), medium dark brownish-gray, noncalcareous, sandy to gravelly at base	7.4 feet
Early Illinoian:	
Clarkson Till: Boulder clay, silty to sandy and pebbly, yellowish-brown to olive gray mottled in upper 37.6 feet, olive gray to brownish in lower 20 feet; moderately calcareous except for upper 2.6 feet which is noncalcareous, very clayey and brownish in color (probably interstadial soil); gravelly in lower foot	57.6 feet
Kansan, undifferentiated:	
Cedar Bluffs and Nickerson Tills undifferentiated: upper 8 feet is Yarmouth Soil developed in a moderately silty clay that is leached except for secondary lime areas and nodules; remainder is a heterogeneous, silty to sandy to pebbly, moderately calcareous boulder clay, strongly oxidized to a yellowish-brown color in upper 57 feet, lower part medium dark gray; a one-foot fine sand lens 8.3 feet above base; electric log indicates change in spontaneous potential 106 feet above base which may be contact between unoxidized Cedar Bluffs and unoxidized Nickerson Till	252.2 feet
Atchison Formation: Sand, medium gray, very fine to medium grained, slightly calcareous	9.3 feet
Nebraskan:	
Iowa Point or Elk Creek Till: medium dark gray, silty to sandy to pebbly, boulder clay, slightly calcareous, medium gray	11.5 feet
Cretaceous: Carlile Shale, thickness drilled to total depth of 430 feet	22 feet

Columnar Section 13

Composite section measured at type locality of Grafton Formation and vicinity (measured by V. H. Dreeszen, E. C. Reed and J. A. Elder).

Location: S.W. ¼, S.W. ¼, S.W. ¼ of Section 6, T. 8 N., R. 3 W., Fillmore County, in cut bank on southwest side of West Fork Big Blue River valley (details of Wisconsinan and Late Illinoian described in S.W., S.E., S.W., of Section 17, T. 8 N., R. 4 W., Fillmore County, in ditch eroded around east side of farm dam).

	Thickness
Medial Wisconsinan:	
Peoria Loess, gray to brownish-gray, caps upland surface, modern soil developed at top	16 feet 6 inches
Early Wisconsinan:	
Gilman Canyon Formation: Silt, dark gray, humic, soil-like, probably an accumulation deposit on Sangamon Soil surface	3 feet
Late Illinoian:	
Loveland Formation: Loess or silt, reddish-brown, clayey, Sangamon Soil developed in upper part; locally includes dark gray, clayey, snail-bearing silts in lower foot where deposited in depressions	14 feet
Medial Illinoian:	
Beaver Creek Formation, 10 feet or more:	
a. Silt, brownish-gray, clayey, secondarily lime-enriched, forms more resistant bed; elevation at top in 6-8N-3W is 1637 feet, and in 17-8N-4W is 1665 feet	3 feet
b. Sand, grading downward to sand and gravel, brownish-gray to gray; channeled into underlying Grafton	7 feet or +
Early Illinoian:	
Grafton Formation, about 70 feet:	
a. Silt, greenish-gray to gray, clayey in upper part, progressively more sandy in middle and lower part	15 feet
b. Sand, light gray, fine-textured in upper part, becomes coarser-grained downward grading into sands and gravels; upper 3 feet exposed above 10 foot covered slope in 6-8N-3W, middle and lower parts from test hole records in surrounding area	55 feet

Columnar Section 14

Type Locality of Santee Till (measured by E. C. Reed).

Location: In road cut 3 miles southeast of Santee, S.E. ¼ of S.E. ¼ of N.W. ¼ of Section 29, T. 33 N., R. 4 W., Knox County.

	Thickness
Medial Wisconsinan:	
Peoria Loess, light brownish-gray to buff	5 feet or +
Medial Illinoian:	
Santee Till: Boulder clay, medium dark gray, calcareous throughout, top eroded, a slightly sandy to pebbly clay till with fairly common granitic pebbles; cracks developed throughout till that are oxidized to depths of about ¼ inch (elevation at top about 1600 feet)	38 feet 6 inches to 40 feet
Late Nebraskan:	
Fullerton Formation, about 20 feet or more:	
a. Silt, brownish-gray, bedded, upper part clayey, becomes more sandy downward	about 10 feet
b. Sand, grading down to sand and gravel, poorly exposed	10 feet or more

Tertiary and Cretaceous (Pierre Shale and Niobrara Chalk) exposed in lower slopes.

Note: 2 miles east-southeast of this locality the Santee Till rests on greenish-gray volcanic ash-bearing silts of the Sappa Formation (Todd, 1898, p. 70).

Columnar Section 15

Sunny Hill Exposures (measured and described by E. C. Reed, J. A. Elder and V. H. Dreeszen).

Location: In road cut at east side of Sunny Hill School (near northeast corner of Section 35, T. 30 N., R. 1 W., Cedar County) and extending northward to the west line of the S.W. 1/4 of the S.W. 1/4 of Section 25, T. 30 N., R. 1 W., Cedar County (elevation at top of exposure about 1700 feet).

	Thickness
Medial Wisconsinan:	
Peoria Loess: Modern soil development in upper 2 feet 4 inches (silty clay loam) with a "weak" B zone development in lower part; next lower 1 foot ten inches is silt, olive brown, massive, with yellowish-brown iron stains, strongly calcareous in upper part to weakly calcareous below with some secondary lime; lowest 1 foot 2 inches is silt, light olive brown, massive, weakly calcareous	5 feet 8 inches
Early Wisconsinan (?):	
Gilman Canyon Formation (?): Silt, light olive brown, noncalcareous; includes chunks of underlying soil apparently moved up or in by solifluction or ice action	10 inches
Medial Illinoian:	
Santee Till with Sangamon Soil development, 51 feet:	
a. Sangamon Soil developed on Santee Till: upper 9 inches (A-horizon) is silty clay loam, very dark brown, medium platy structure, with fine, reddish-brown mottles, noncalcareous except for trace of secondary lime; next lower 1 foot 1 inch (upper B-horizon) is clay loam, dark brown, with a few sand grains and occasional pebbles and some till which appears to be reworked; next lower 11 inches (lower B-horizon) is clay loam till, dark brown, noncalcareous except for trace of secondary lime, transitional to till below	2 feet 9 inches
b. Till, brown to grayish-brown, clayey, noncalcareous except for secondary lime, many light gray lime concretions in lower 8 inches	2 feet 10 inches
c. Till, medium dark gray, clayey, calcareous throughout, unoxidized except along cracks in till, common light gray lime concretions in upper part	45 feet 5 inches
Late Nebraskan:	
Fullerton Formation: Silt and silty clay with some sandy zones, brownish-gray, leached in upper part	22 feet exposed

Note: It is believed that the upper 1 foot 10 inches of the interval described under Santee Till may be a Sangamon Soil development in the Late Illinoian Loveland Formation. However, the soil development extends into the Santee Till below, making easy separation difficult. A test hole (Ground Water Survey Test Hole 30-1-36ddd) drilled at a location one mile east and one mile south of the Sunny Hill School, with a ground level elevation of 1706 feet penetrated 6.5 feet of Peoria Loess, 39.9 feet of Santee Till, 40.6 feet of the silt member of the Fullerton Formation, 67 feet of the Holdrege sand member of the Fullerton Formation and 26 feet of Seward Formation silts resting on 104.5 feet of Pliocene above 42.5 feet of Cretaceous Shale. 33 feet of Cretaceous Niobrara Chalk was drilled below the Pierre Shale to a total depth of 350 feet.

Columnar Section 16

Type Locality Beaver Creek Formation, York-Seward County Line Section (described by V. H. Dreeszen).

Location: N.E. ¼, S.E. ¼, N.E. ¼ Sec. 25, T. 10 N., R. 1 W. (elevation at top of Loveland about 1545 feet).

	Thickness
Medial Wisconsinan:	
Peoria Formation: Silt, slightly clayey, noncalcareous, very light yellowish-brown (between 10YR and 2.5Y 6/4); contains rare sand grains, common root holes, and a few small iron-stained spots; angular fragments of underlying Loveland Formation incorporated in lower few inches	1 foot
Illinoian:	
Loveland Formation:	
a. Silt member, 4 feet 9 inches:	
1. Clay, silty and moderately sandy, medium brown (7.5YR 5/4), sand grades from very fine to very coarse; dry sample breaks into angular to a few rounded aggregates; coarse silt and very fine sand coat the surface in some cracks	1 foot
2. As above, more sandy in lower 8 inches, lesser tendency to break into aggregates, some clay and iron-manganese films in cracks and in root holes	1 foot
3. Clay, silty, very sandy, light brown (7.5YR 6/4), sand is very fine to medium with a few coarse to very coarse grains, some root holes have a very thin coating of calcium carbonate, a few have a clay coating	1 foot
4. Silt, very clayey and moderately sandy, light brown (7.5YR 6/4), sand is very fine to medium with a few coarse to very coarse sand grains, rare gravel grains, root holes rare with a thin clay film and trace of calcium carbonate	1 foot
5. As above, grades to very sandy, limy coating and partial filling of root holes more common	9 inches
b. Crete member, 2 feet:	
1. Sand, slightly gravelly, sand grades from very fine to coarse with some very coarse, about 5 to 10 per cent gravel, light brown; slightly clayey in part, most grains are slightly stained with yellowish-brown pigment, a few are dark stained with a coating of iron-manganese	1 foot
2. Sand, slightly gravelly, sand grades from fine to very coarse, about 15 percent fine gravel with rare medium to coarse gravel grains, each grain is stained with a thin dark brown coat of iron-oxide and/or clay, in part weakly cemented	1 foot
Beaver Creek Formation, 19 feet 4 inches:	
a. Silt, very clayey, very slightly sandy; contains very fine to fine sand, mottled very light gray and very light brown, a few dark brown and yellowish-brown stained areas, a few root holes, a few of which have thin film of clay or iron oxide, a few small irregular bodies of waxy, very light gray or light brown clay	1 foot 2 inches
b. As above, but principally very light gray with some very light brown, contains slightly more sand with a trace of medium sand	1 foot
c. Silt, very clayey, slightly sandy, contains very fine to fine with a trace of medium sand, light gray (5Y 7/2), a few root	

holes with either yellowish-brown clay or iron oxide film or with filling of dark iron oxide 1 foot 6 inches

d. Silt, very clayey, light medium gray (10YR 5.5/1), with some mottled light gray, contains a few sand grains and rare root holes with thin yellowish-brown film 1 foot 6 inches

e. Silt, moderately, in parts very clayey, mottled very light brown-gray, very light gray and light yellow, contains some very fine to fine sand, some dark stain, rare root holes 6 inches

f. Silt, moderately, in part very clayey, slightly sandy, contains very fine to fine sand, very light yellowish-gray (5Y 7/2 and 8/2), common root holes with dark film or partially filled with dense clay and oxide 3 feet

g. Silt, moderately clayey, moderately sandy, contains very fine to fine sand with a trace of medium sand, very light yellowish-gray (5Y 8/2), a few root holes with dark coating 4 feet 6 inches

h. Sand, slightly silty, in part slightly clayey, sand is very fine to medium, silt is very coarse, contains coarse sand grains, very light yellowish-gray (5Y 7/2) with some 5Y 7/3 and 6/3 stain 2 feet 9 inches

i. Sand, very fine to coarse, contains some coarse silt (2.5Y 7/3) light yellowish-gray, grains slightly stained with yellowish-brown oxide 7 inches

j. Sand, slightly silty, sand is very fine to fine with a trace of medium sand, silt is coarse-grained, very light yellowish-gray (5Y 7/2) 2 feet 10 inches

Grafton Formation, 11 feet 10 inches:

a. Silt, very clayey, very light olive to greenish-gray (about 7.5Y 8/2), contains rare root holes and a few fine to coarse sand grains, slightly sandy in lower one foot 2 feet 10 inches

b. Sandy clay, gravelly sand, and sandy silt, interbedded, very light olive gray 1 foot

c. Sand, slightly gravelly, fine to very coarse sand with about 15 percent fine gravel, very light olive gray color to white, quartz with common light colored feldspar; contains bone fragments 3 feet

d. As above, moderately gravelly, about 25 percent gravel, much coarse to very coarse sand 3 feet

e. Sand, very fine to medium, some coarse sand and a trace of very coarse sand and gravel 2 feet

Note: Base of sampled section is 32 feet above Beaver Creek level, sand and gravelly sand intermittently exposed to about 12 feet above Beaver Creek; Munsell color coordinates included in parentheses; interval correlated as Grafton Formation may also be a part of the Beaver Creek but it appears to represent a pre-Beaver Creek depositional sequence.

Columnar Section 17

Type Locality of Crete sand and gravel (after Condra and Reed, 1950, p. 25; revised by E. C. Reed).

Location: One mile west of Crete, ¼ mile south and ⅛ mile west of northeast corner of Section 32, T. 8 N., R. 4 E.

Thickness

Medial Wisconsinan:

Peoria Loess, light brownish-gray to buff in upper part, medium light gray in middle, light gray to brownish and iron-stained in lower part; modern soil developed in upper part; many small lime concretions throughout 11 feet

Early Wisconsinan:

Gilman Canyon Formation: Silt, dark brown-gray to dark gray, humic, scattered sand grains — 1 foot 6 inches

Late Illinoian:

Loveland Formation, 15 feet 10 inches to 16 feet 6 inches:

a. Silt, reddish-brown, very clayey in upper part, progressively more sandy downward — 7 feet

b. Crete sand and gravel member: upper part light pinkish-brown, lower part light brownish-gray; upper part is fine to medium sand with rare fine gravel, grades downward to sand, medium to coarse grained with fairly common fine to medium gravel; lower 1 to 2 inches iron-stained — 8 feet 10 inches to 9 feet 6 inches

Medial or Early Illinoian:

Beaver Creek or Grafton Formation: Silt, light greenish-gray, slightly clayey, massive — 2 feet exposed

Note: Above section measured under a level slightly below the upland flats farther west; the sand and gravel member of the Loveland seems to be absent 500 feet farther to the west where the Loveland Formation silts rest unconformably upon a silt grading downward to sand (probably Beaver Creek), underlain by a second silt with a weak, dark colored soil development at its top (probably Grafton).

Columnar Section 18

Buzzard's Roost Exposures, Type Locality of Gilman Canyon Formation (measured and described by E. C. Reed, W. M. Johnson and V. H. Dreeszen).

Location: In road cut extending from the center of the S.W. ¼ of the S.E. ¼ of Section 8 to the S.W. ¼ of the S.W. ¼ of the S.E. ¼ of Section 7, T. 10 N., R. 26 W., Lincoln County; top of section at Buzzard's Roost with an elevation of about 3040 feet and base of section in headwaters of west branch of Gilman Canyon at elevation of 2858 feet.

Thickness

Medial Wisconsinan:

Peoria Loess: Silt, light brownish, coarse-textured (generally 10 to 30 percent sand), snail-bearing, middle and upper parts poorly exposed, moderately calcareous — 83 feet or +

Early Wisconsinan:

Gilman Canyon Formation: Upper 12 inches is medium dark gray, slightly humic, silt; middle 1 foot 1 inch is light brownish-gray silt; basal 3 feet 8 inches is dark brownish-gray, humic, soil-like silt; entire thickness is noncalcareous — 5 feet 9 inches

Late Illinoian:

Loveland Loess, brownish-gray to slightly reddish, clay-enriched in upper five feet, noncalcareous, elevation at top is 2933 feet — 12 feet 6 inches

Beaver Creek Loess, brownish-gray to slightly reddish, clay-enriched in upper 3 feet 6 inches, secondary lime in upper 3 feet 6 inches, noncalcareous below — 12 feet 6 inches

Grafton Loess, brownish-gray to slightly reddish; clay-enriched in upper 5 to 6 feet (a thin upper clayey zone and a thick lower clayey zone separated by a less clayey zone); noncalcareous in upper 18 feet, moderately calcareous in lower 18 feet — 36 feet

Late Kansan:

Sappa Loess, 14 feet 7 inches exposed:

a. Yarmouth Soil development: Upper 1 foot 9 inches (A-horizon) is medium brownish-gray, moderately clayey silt; next lower 1 foot 2 inches (B21-horizon) is medium dark brownish-gray, moderately clayey silt; next lower 1 foot 5 inches

(B22-horizon) is colored as above but less clayey; lowest 1 foot 8 inches (C-1 horizon) is colored as above but is moderately clayey; elevation at top is 2872 feet 6 feet

b. Silt, sandy, medium to lighter brownish-gray, massive 8 feet 7 inches exposed

Note: Textural analyses of the lower 82 feet of the section described above are illustrated in Figure 10 (p. 36).

Columnar Section 19

Gilman Canyon Exposures (measured and described by E. C. Reed, W. M. Johnson and V. H. Dreeszen).

Location: In south tributary to west fork of Gilman Canyon, about 2 miles east of Buzzard's Roost, near the center of the N.W. ¼ of the N.E. ¼ of Section 17, T. 10 N., R. 26 W., Lincoln County (elevation at top of measured section is 2847 feet).

Thickness

Late Kansan:

Sappa Formation, 66 feet 3 inches:

a. Yarmouth Soil development in upper part: upper 6 inches (B-21 horizon) is silty clay, brownish-gray to slightly yellowish; next lower 5½ inches (B-22 horizon) is colored as above but slightly more clayey; next lower 9½ inches (BCA-1-horizon) is slightly silty clay, light brownish-gray; lowest 8 inches is silty clay, light brownish-gray 2 feet 5 inches

b. Silt, moderately sandy, slightly to moderately clayey, brownish-gray to light brown-gray; middle part largely covered; common ash shards in lower 15 feet; wavy contact at base 54 feet 6 inches

c. Pearlette Volcanic Ash bed; light gray to white ash, massive; 5 feet 9 inches exposed, 1 foot 2 inches augered 6 feet 11 inches

d. Silt, slightly sandy, medium brownish-gray; some volcanic ash shards (augered) 2 feet 4 inches

Medial Kansan:

Walnut Creek Formation: Silt, slightly sandy, slightly to moderately clayey; medium to dark gray with common small iron concretions in upper 2 feet 1 inch; lower part medium brownish-gray and moderately clayey; thickness augered 5 feet 2 inches

Note: The soil development in the upper part of the Walnut Creek is interpreted as interstadial in character. The Yarmouth Soil and the two interstadial soils of the Illinoian can be traced intermittently down Gilman Canyon between the Buzzard's Roost exposures (Columnar Section 18) and the locality described above and lower eastward in elevation at about the same rate as the upland surface. Textural analyses of samples from these exposures are illustrated in Figure 11 (p. 37).

Columnar Section 20

Type Locality of Hartington Till, Ground Water Survey Test Hole A31-1-13ccc record (described by V. H. Dreeszen and F. A. Smith).

Location: 271 feet east and 9 feet north of southwest corner of section 13, T. 31 N., R. 1 E., Cedar County; near Tip-Top School, 2 miles north of Hartington; ground level elevation at test hole site, 1534 feet.

Thickness

Late Wisconsinan:

Bignell Formation:

a. Upper silt member: Silt, brownish-gray in upper part grading to olive gray below, grades from moderately clayey in upper part to very sandy near base, moderately calcareous in lower ten feet — 14.8 feet

b. Lower sand and gravel member: Sand and gravel, grades from fine sand to medium gravel, common limestone grains — 2.7 feet

Medial Wisconsinan:

Hartington Till: Boulder clay, yellowish-brown to olive gray in upper part grading to medium dark gray in lower part, silty to sandy and pebbly, moderately calcareous throughout; includes a 0.2 foot thick sandy silt separation or block 14.7 feet below top — 20.8 feet

Late Kansan:

Sappa Formation: Silt, light olive gray, upper part is a clayey silt, lower part grades to sandy silt, common snail fauna throughout, some concretionary limy zones — 4.8 feet

Early Kansan:

Nickerson Till: Boulder clay, silty to sandy to pebbly, moderately calcareous throughout, medium brownish-gray in upper part, medium dark gray in middle and lower part — 32.3 feet

Atchison Formation:

a. Upper silt and clay, medium gray, moderately calcareous, rare snails in upper part — 5.7 feet

b. Sand, upper two feet very fine-grained, middle 15.4 feet very fine to very coarse-grained with some fine gravel, lower 14.3 feet very fine to medium grained; slightly calcareous throughout — 42 feet

Late Nebraskan:

Fullerton Formation:

a. Upper silt, yellowish-gray, moderately clayey, moderately calcareous — 9.8 feet

b. Holdrege sand member: Sand, very fine to very coarse with a little fine gravel at base, includes a silt separation — 15.6 feet

Early Nebraskan:

Seward Formation: Silt and clay, olive gray, upper part dark brown-gray, moderately calcareous — 8.1 feet

Cretaceous: Niobrara Chalk, some bentonite seams — 22 feet or +

Note: Correlation of pre-Hartington Till deposits subject to revision.

Columnar Section 21

In ravines on north side of Dismal River, south of Mullen, west of old bridge (measured by E. C. Reed and James Thorp).

Location: S.W. ¼ of N.E. ¼ of N.E. ¼ of Section 29, T. 22 N., R. 32 W., Hooker County.

Thickness

Medial Wisconsinan:

Peoria Dunesand: Sand, brownish-gray, slightly clayey, 15 feet exposed in ravine, probable thickness in transverse dune ridge ½ mile north — about 140 feet

Illinoian or Early Wisconsinan:

Either Gilman Canyon Formation or A-horizon of Sangamon Soil; dark gray to black, humic — 6 inches

Illinoian:

Loveland Formation:

a. Diatomaceous clay, light gray to white; elevation at top 3180 feet — 2–3 feet

b. Sand, light gray, medium-grained, stratified — 33 feet

Beaver Creek (?) Formation:

a. Clay, light greenish-gray, silty; may represent a truncated interstadial soil — 2–3 feet

b. Interstratified sandy silts and silty sands grading downward into sands and gravels 62 feet or +

Note: The correlation of the lower two units described above is tentative; these deposits were formerly classified as the Sappa Formation; it seems more probable that they are a part of an Illinoian terrace sequence. Locally a still younger dunesand, the Bignell Dunesand, occurs above the Peoria Dunesand and a soil horizon marks the contact.