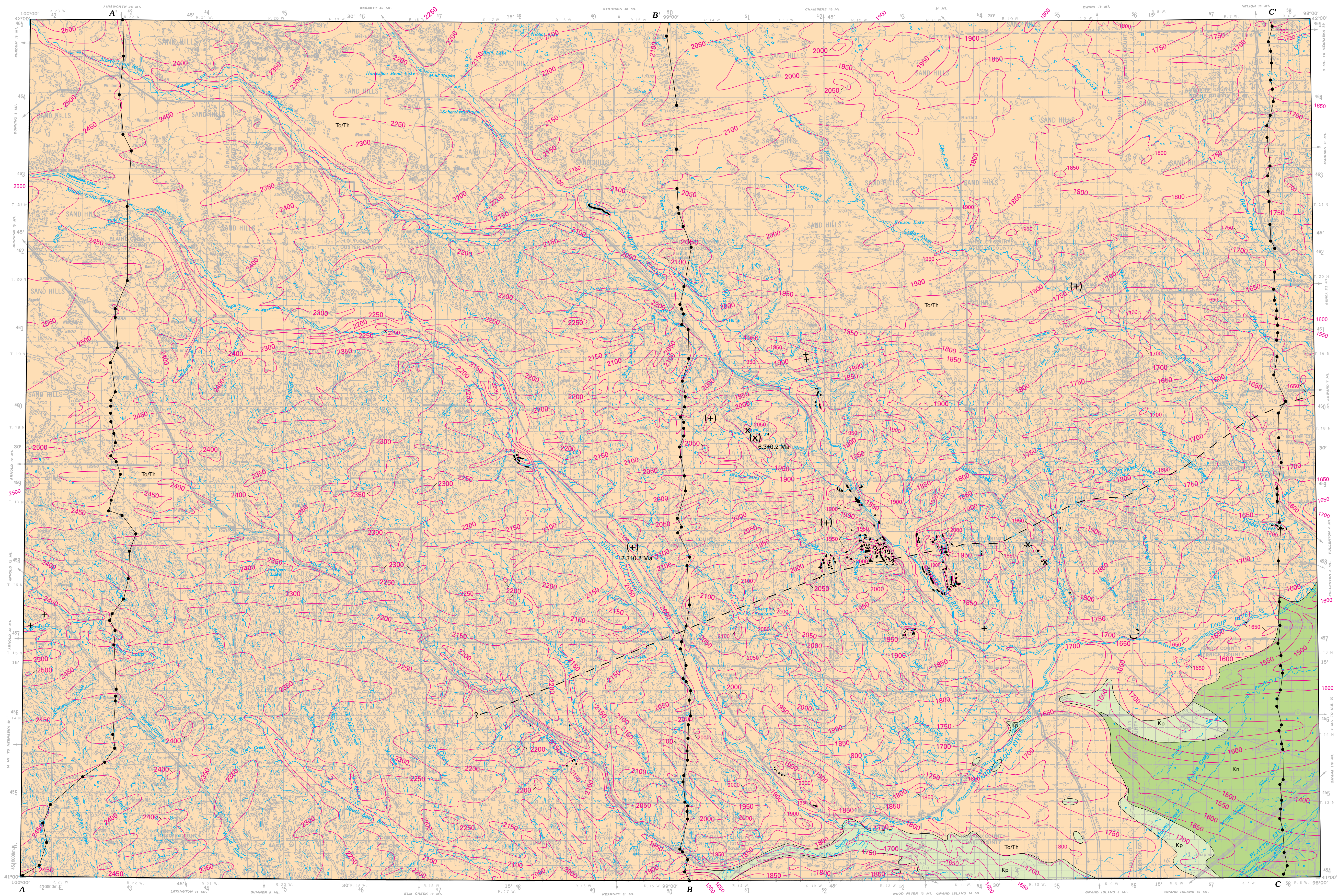
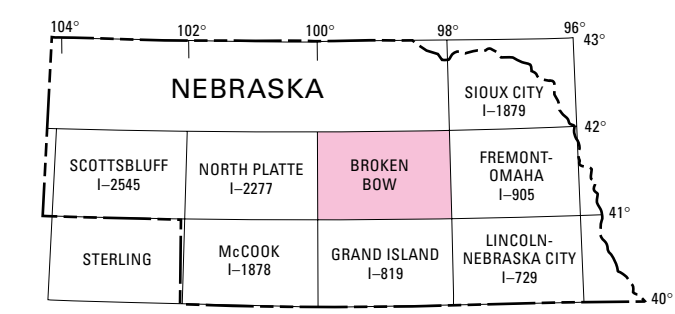
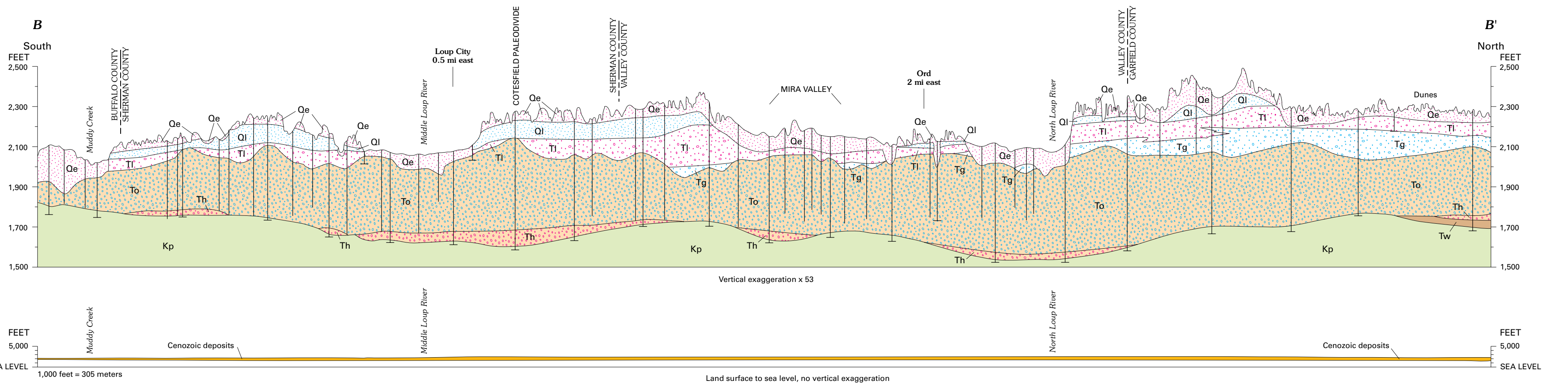
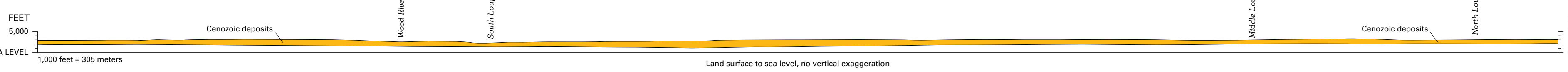
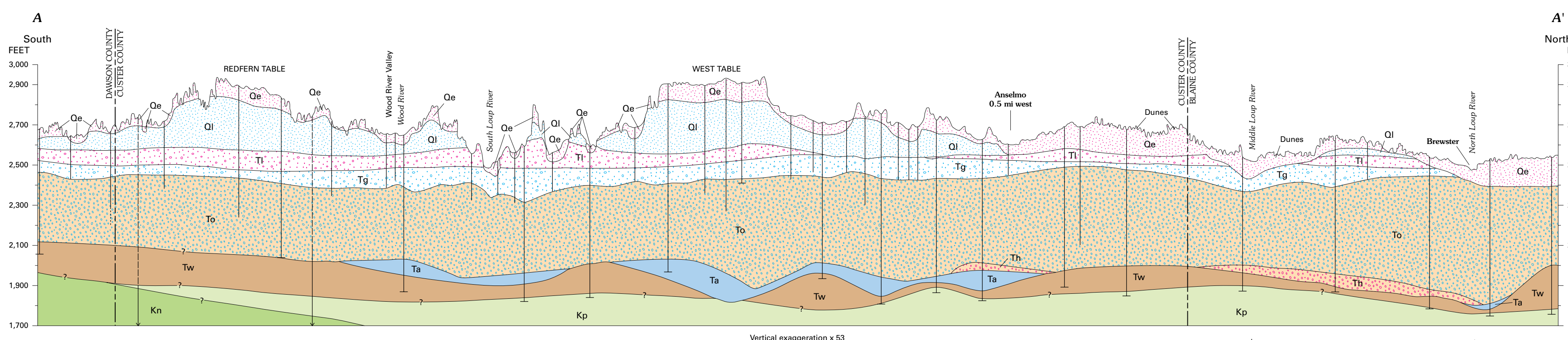




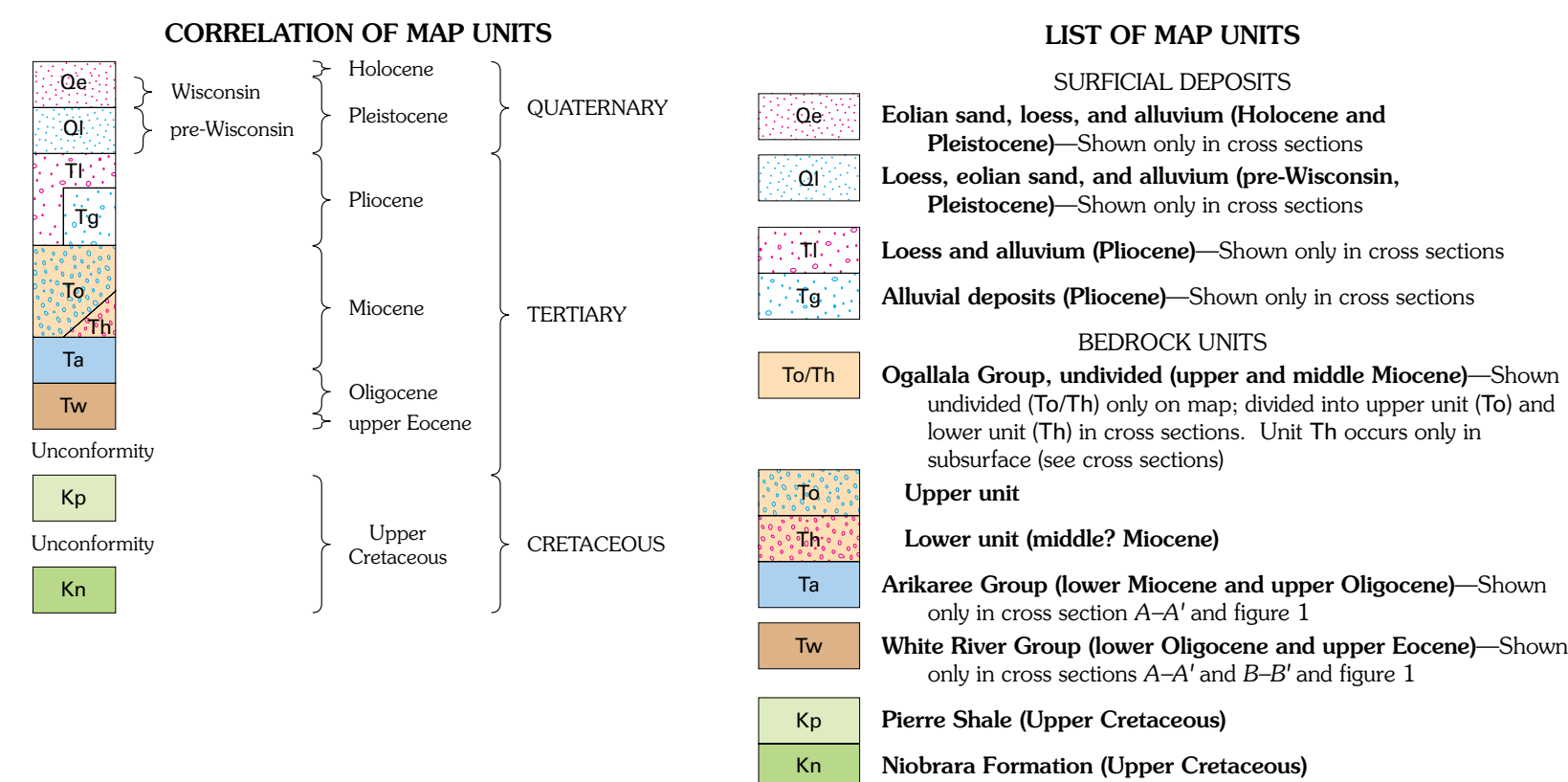
Base from U.S. Geological Survey, 1956, revised 1971.
Transverse Mercator projection.
10,000 meter Universal Transverse Mercator grid, zone 14.
1927 North American datum

Geology mapped 1987 to 1988
Geologic map digitized by Tina North Mapping
Cross sections and illustrations drafted by Springfield and Springfield
Editing and layout by Alessandro J. Donath
Manuscript approved for publication April 21, 2000

CONTOUR INTERVAL 100 FEET
NATIONAL GEOLOGIC VERTICAL DATUM OF 1929



INDEX SHOWING LOCATION OF BROKEN BOW QUADRANGLE
AND OTHER 1° x 2° GEOLOGIC QUADRANGLES
PUBLISHED BY THE U.S. GEOLOGICAL SURVEY



Bedrock outcrop
Contact
Structure contour drawn on top of bedrock—Altitude above sea level.
Contour interval 50 ft
Line of cross section—Solid circle is test-hole location
Cotestified paleokhnde—Queried where location uncertain

Volcanic ash bed—All are of probable
Platocene age except for one having
a fusion-track age of 2.34±0.2 Ma
(Pliocene). Parentheses indicate ash
bed is covered by slope wash or water
X
Volcanic ash bed in Ogallala Group—
Bed at one locality has fusion-track
age of 6.34±0.2 Ma (Miocene).
Parentheses indicate ash bed is
covered

**Test hole with detailed samples and, in
most cases, an electric log**
Irrigation or other water well with
driller's log
Oil and gas test with electric log—
Dashed line represents cased area
with no log. Arrow indicates test
extends deeper than base of section

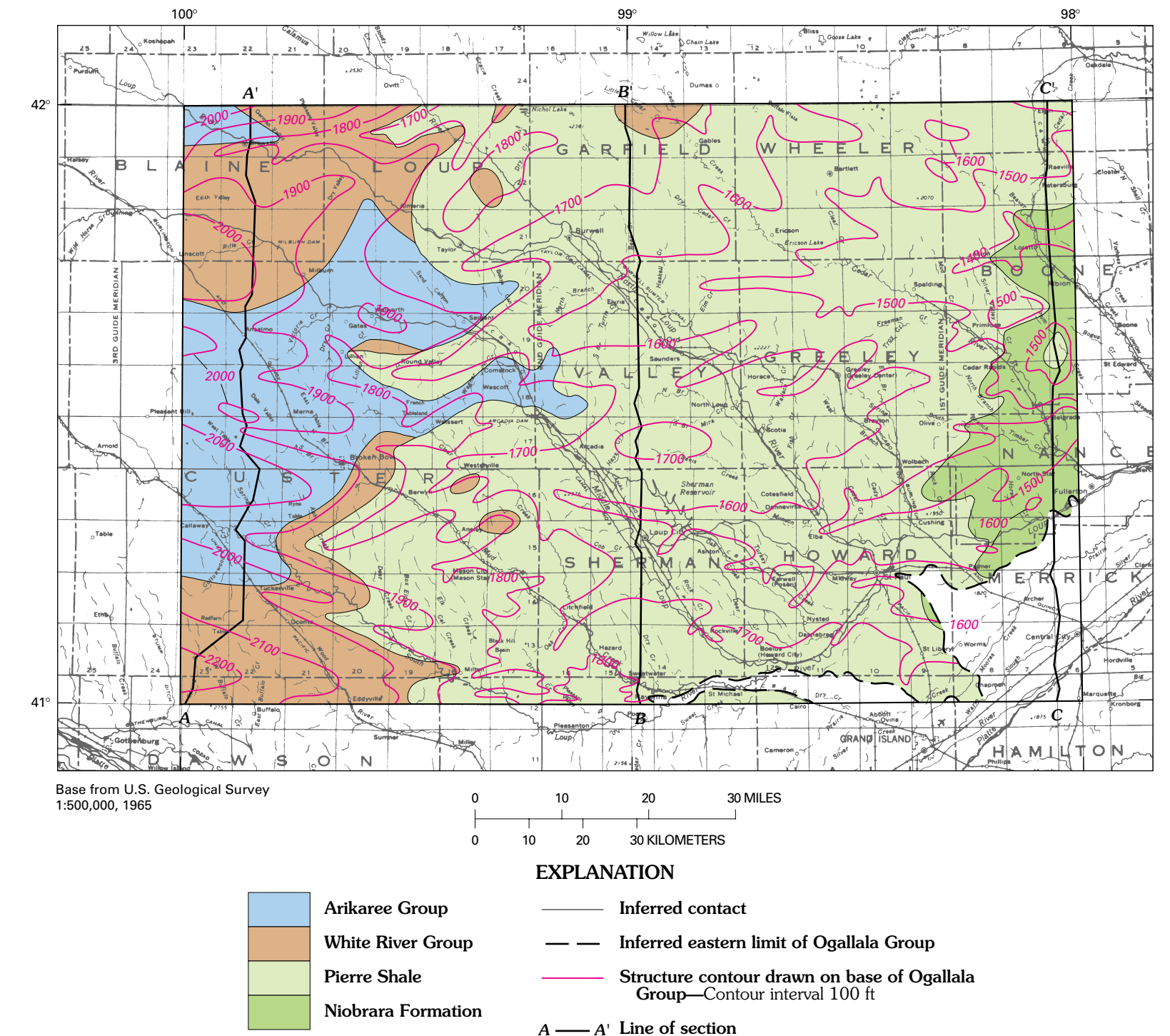
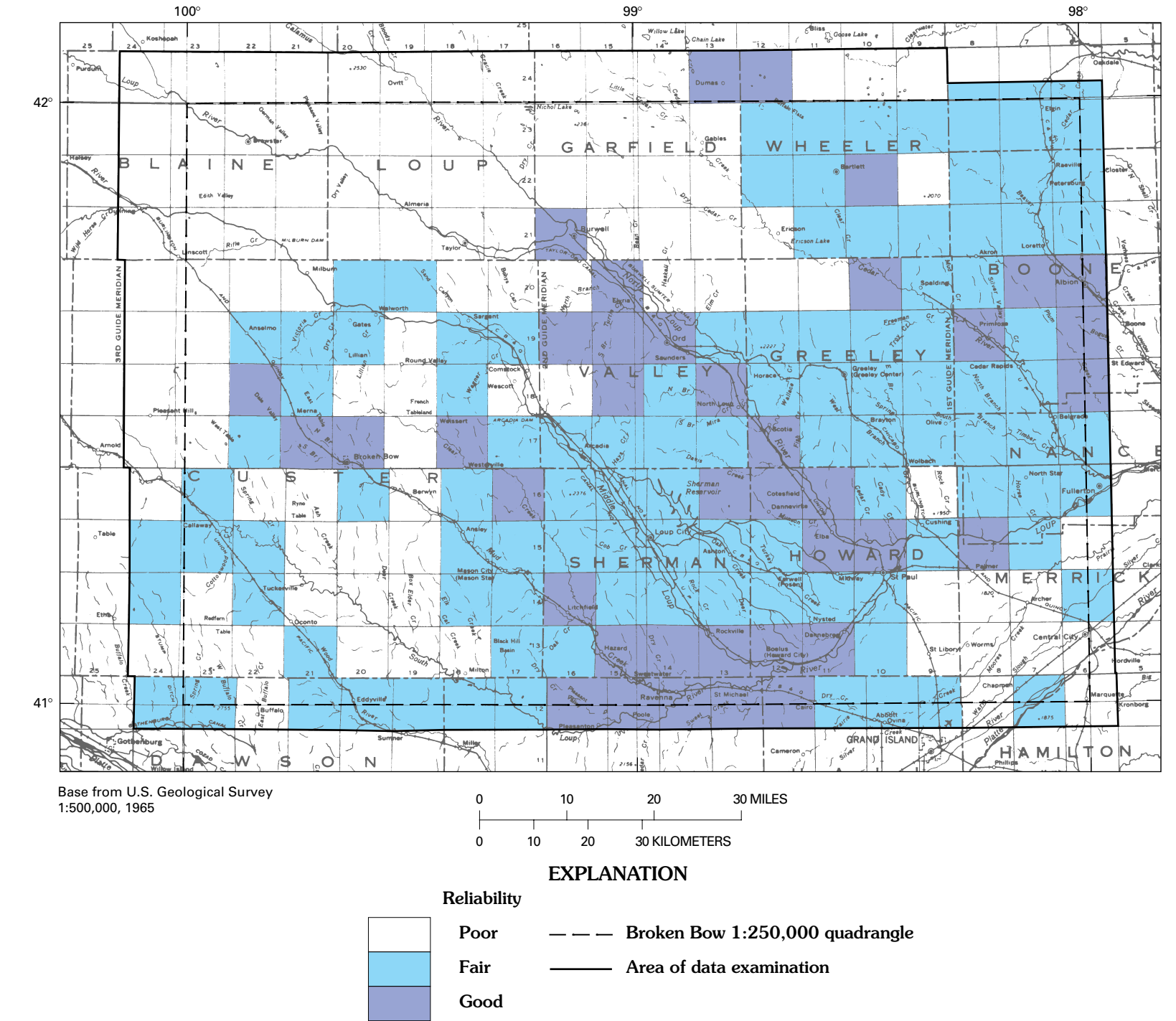


Figure 1. Configuration of the base of the Ogallala Group and distribution of subjacent bedrock units

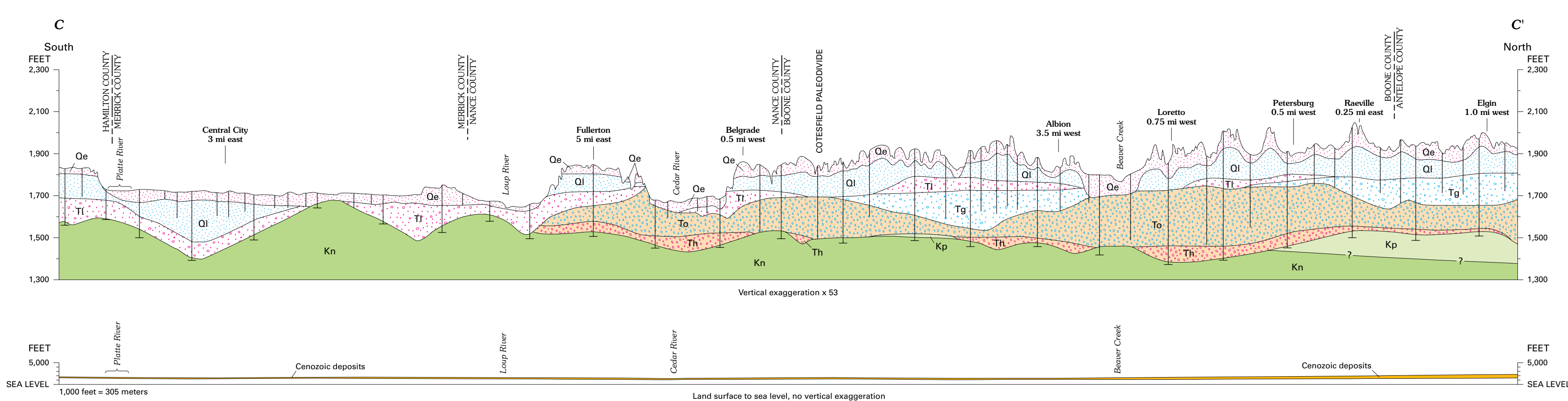


RELIABILITY DIAGRAM OF DATA USED IN PREPARING STRUCTURE CONTOURS DRAWN ON TOP OF BEDROCK

DISCUSSION OF RELIABILITY DIAGRAM

Quality and quantity of basic data, geographic distribution of those data, and complexity of the geology are the principal factors that determine reliability. Good data consisted of observed outcrops (about 140 individual outcrops or clusters of outcrops) and logs of test wells complete with detailed rotary samples, commonly supplemented by electric logs, or cores (about 510); data of intermediate quality included electric logs of test holes or wells, some of which had driller's logs (about 120). Driller's logs of registered irrigation, municipal, stock, and domestic wells plus some driller's logs of miscellaneous test holes and wells provided most of the data (more than 5,300) for this report. Subsurface control averaged about two data points per 3 mi².

Diagram was derived as follows: acceptable driller's log rated one point, good electric log or log with professional geological oversight (some government and oil company logs), two points; core hole or test hole with detailed samples (often in conjunction with electric log), three points. Points per township ranged from none for two townships in northwest part of quadrangle to 73 in one township at east-central edge of map. Twenty or fewer points per township are considered to indicate very poor to poor reliability; 21–50 points, fair; and more than 50, good. Classification values were plotted and map adjusted for bedrock outcrops, distribution of data, and geological complexity.



GEOLOGIC MAPS AND CROSS SECTIONS SHOWING CONFIGURATIONS OF BEDROCK SURFACES, BROKEN BOW 1° x 2° QUADRANGLE, EAST-CENTRAL NEBRASKA

By
V.L. Souders, Nebraska Geological Survey
2000

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ISBN 1-607-74130-5
9 781607 741305

Geologic maps and cross sections showing configurations of bedrock surfaces, Broken Bow 1° x 2° quadrangle, east-central Nebraska

By V.L. Souders, Nebraska Geological Survey

Prepared in cooperation with the Conservation and Survey Division,
Institute of Agriculture and Natural Resources, University of Nebraska—Lincoln

Pamphlet to accompany

Geologic Investigations Series I-2725

Version 1.0



North side of the Elba Cut, Fullerton Canal, 3 mi east of Elba, Nebr., described and illustrated by May and others (1995). Lighter colored upper unit is late Wisconsin Peoria Loess, which unconformably overlies Gilman Canyon Formation (both in unit Qe). Loesses of unit Ql are in middle third of section. Loesses of unit Tl (Pliocene Fullerton Formation) are exposed from the canal road up to the first prominent paleosol. Photograph by R.F. Diffendal, Jr., Nebraska Geological Survey.

2000

U.S. Department of the Interior
U.S. Geological Survey

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qe Eolian sand, loess, and alluvium (Holocene and Pleistocene)—Shown only in cross sections.

Dune and sheet sands (mostly Holocene): Sand, very fine to medium, well sorted, mostly pale brown to light brownish gray. Dunes may reach a height of 150 ft in northwest part of map area.

Loess, mostly Peoria Loess (late Wisconsin): Silt, uniform, locally slightly clayey or sandy, pale yellow and light yellowish brown to pale brown; also light brownish gray to light gray locally. Reaches thickness of nearly 120 ft beneath tablelands (mesa-like uplands) in west and southwest parts of map area (cross section A–A') and about 100 ft on early to middle Wisconsin age terraces on south side of Middle Loup River in T. 19 N., R. 20 W. and T. 20 N., R. 22 W.; locally, on some high terraces and eroded uplands, Peoria Loess is mantled by dune sand. Thick paleosols and thin loess accumulations of early to middle Wisconsin age (Gilman Canyon Formation of Reed and Dreeszen, 1965) are present in many places beneath Peoria-capped uplands and hills throughout loess-covered regions; Holocene loess deposits inconsequential in thickness and areal extent in comparison to Peoria Loess.

Alluvial deposits beneath floodplains and terraces associated with present drainage: Sand, fine to very coarse, poorly sorted, pale brown to dark gray; some gravel, fine to coarse, with variable composition but mostly with clasts of granite, quartz, quartzite, gneiss, and calcrete, chalk, or shale derived from local bedrock; silt and clay, locally sandy and gravelly, pale brown to dark gray. As many as five levels of Holocene terrace surfaces and at least three terrace fills possibly present along modern drainageways (May and others, 1995) with two additional Wisconsin terrace fills identified in Loup River system (May and others, 1995; this report); alluvium of different terrace fills is similar in character and difficult to distinguish from each other based on drill cuttings or isolated outcrops; alluvium of Holocene age appears to consist of higher percentage of finer grained deposits than Wisconsin fills. Maximum thickness of Holocene alluvium probably less than 100 ft. Late Wisconsin alluvial fill (Peoria equivalent) and capping sheet sands and loesses are about 220 ft thick in South Loup Valley (south end of cross section B–B') but this thickness may include older Wisconsin and (or) pre-Wisconsin Pleistocene deposits in lower part. Early to middle Wisconsin alluvial deposits (Gilman Canyon Formation) about 265 ft thick present beneath high terrace south of Middle Loup River in T. 19 N., R. 20 W., where they are capped by 70–100 ft of Peoria Loess; combined thickness of these early to middle Wisconsin deposits is 360 ft.

Ql Loess, eolian sand, and alluvium (pre-Wisconsin, Pleistocene)—Shown only in cross sections.

Undifferentiated eolian deposits of possible Pleistocene age but older than the Wisconsin: Clayey silt, silty clay, and sandy silt, pale brown, brown, olive, and gray; generally more clayey in east part of map area and sandier to west; in west and northwest parts, interbedded with silty sand and sand, very fine to medium, well sorted, mostly light gray; sequence of silt and sand, which probably includes minor alluvial material. Reaches thickness of about 250 ft beneath tablelands in west (cross section A–A'), however, deposits are difficult to distinguish from underlying Pliocene eolian deposits.

Individual loess units are generally less than 40 ft thick and weak paleosols are present in many places.

Alluvium: Sand, fine to very coarse, gravelly sand (fine to medium gravel), silty sand, silt, and clay, mostly gray and olive gray. An alluvial fill in southeast part of map area is about 200 ft thick (near south end of cross section C–C') and includes argillic paleosols, fine- to coarse-grained sediments, and a volcanic ash bed; gravels in this fill are less arkosic than the Holocene, Wisconsin, or Pliocene

gravels and have many clasts of quartz and dark silicates; some minor alluvial fills contain considerable granite, quartzite, and gneiss clasts. Volcanic ash deposits of undetermined source and date are exposed or were encountered in test holes in several localities, and ash was once mined east of Ord (sec. 26, T. 19 N., R. 13 W.) and west of Callaway (sec. 8, T. 15 N., R. 23 W.); volcanic ash at the former mine and in well-exposed Elba cut on Fullerton Canal (sec. 6, T. 15 N., R. 10 W.; May and others, 1995) occurs in minor alluvial deposits; maximum ash thickness at old Callaway mine probably was about 15 ft

Tl

Loess and alluvium (Pliocene)—Shown only in cross sections.

Loess: Silt, locally clayey and sandy, pink to very pale brown (nearly white on weathered outcrop), brown, and light brownish gray; contains irregular lime concretions a few inches to nearly 2 ft long locally, which are in places slightly indurated; remnants of several paleosols, including enriched clay horizons and concretions, at many localities. Loess deposits are of Fullerton Formation [originally considered of Pleistocene age, now classified as Pliocene (May and others, 1995)] and older Pliocene clay and silt deposits.

Alluvium: Lower part of alluvium in paleovalleys in south-central and south-east parts of map area consists of fine-grained alluvial deposits that are gray to olive gray, more clayey, sandy, and, at some test hole sites, gravelly; upper part becomes increasingly coarser grained (more coarse silt to medium sand) to north and northwest and has fewer concretions; in northwest part of quadrangle, alluvium is mostly interbedded with fine sand and gray in color.

Total thickness of unit may be about 240 ft south of Mira Valley (central part of cross section B–B') but thickness difficult to determine because upper part of unit resembles overlying Pleistocene deposits and lower part, in this locality, probably includes 20 ft or more of unit Tg. Volcanic ash, formerly exposed in sec. 5, T. 16 N., R. 15 W. (Arcadia Canal ash, Boellstorff, 1978a, p. 69), was fission-track dated at 2.3 ± 0.2 Ma. Volcanic ash beds were encountered in loess of Fullerton Formation in at least three test holes in southeast part of map area. Base is difficult to pick in drill holes where unit Tl overlies similar lithologies of unit To

Tg

Alluvial deposits (Pliocene)—Shown only in cross sections.

Gravel, sand, and lesser amounts of sandy silt, silt, and clay; principal gravel components are granite, quartzite, quartz, and gneiss, but clasts of sedimentary rock (including chert and jasper), dark silicates (igneous and metamorphic rocks), and acidic volcanic rock present in minor amounts; clasts of local bedrock rare. Gravel composition indicates sources in southeastern Wyoming and north-central Colorado. Fine-grained deposits range from well-sorted silt to very poorly sorted gravelly clay; colors are pale brown, brown, light brownish gray, gray, and olive; lime concretions occur in fine-grained deposits in places but not as common as in upper part of unit Tl. Deposits equivalent in age to Broadwater Formation and related beds of Schultz and Stout (1945, 1948) and Swinehart and Diffendal (1989, 1995, 1997) in western Nebraska and Nebraska Sand Hills, to Long Pine Formation gravel and related alluvial fills of Skinner and Hibbard (1972) in north-central Nebraska, and to H₃ hydrologic unit of Lawton and Hiergesell (1988) in Garfield and Wheeler Counties; in concept, may be equivalent to Holdrege Formation as redefined by Reed and Dreeszen (1965) (which is of probable Pliocene age) in central and eastern Nebraska (Holdrege Formation of Lugn, 1935, and Lugn and Wenzel, 1938, probably is younger than unit Tg). Maximum reported thickness about 200 ft in a paleochannel fill penetrated in irrigation well southwest of Broken Bow in Custer County (sec. 35, T. 16 N., R. 21 W.); unit is 170 ft thick in the same paleochannel elsewhere as well as at several sites in Wheeler and Boone Counties in northeast part of quadrangle.

Unit is part of a complex fluvial sequence—containing at least three gravel units at some localities—that was deposited north of a major Pliocene paleo-drainage divide (Cotesfield paleodivide—named in this report). This paleodivide extends from present-day southern Custer County northeastward across the mapped area into northwestern Nance and southern Boone Counties; the

paleodivide is an identifiable feature in the subsurface in many places over much of the area and elsewhere it is marked by bedrock outcrops, especially in northeastern Sherman and northern Howard Counties in the vicinity of Cotesfield (T. 16–17 N., R. 11–12 W.). Base is difficult to pick in drill holes where unit Tg overlies similar lithologies of unit To

BEDROCK UNITS

To/Th	Ogallala Group, undivided (upper and middle Miocene)—Shown undivided (To/Th) only on map; divided into upper unit (To) and lower unit (Th) in cross sections. Unit Th occurs only in subsurface (see cross sections). Thick group that probably cannot be subdivided consistently on the basis of subsurface data. Predominantly fluvial deposits subdivided into two general units: principal upper unit, probably equivalent to Ash Hollow Formation and most of Valentine Formation (Swinehart and others, 1985); and minor fine-grained lower unit, probably equivalent to lower part of Valentine or to one or more formations of lower part of Ogallala Group (Swinehart and others, 1985) in western Nebraska (Olcott, Sheep Creek, Box Butte, and Runningwater Formations). In subsurface in central Nebraska, lower unit of Ogallala locally resembles Box Butte Formation lithologically, but elsewhere it resembles other formations of middle and lower Ogallala Group. Maximum thickness of Ogallala Group about 700 ft southwest of Brewster in Blaine County (T. 22–23 N., R. 22–23 W.). Group thins from west to east due to erosion and less deposition
To	Upper unit—Clay, silt, siltstone, sand, sandstone, pebbly sandstone, and gravelly sand; many sand and sandstone beds of well-sorted, very fine to fine and fine to medium sand, but gravelly and silty to clayey beds, generally poorly sorted; light gray, light olive gray, pale olive and pale yellow, but locally light brown and yellowish brown in upper part. Unit ranges from unconsolidated to well consolidated; principal cement is calcium carbonate but silica cement locally; some calccrete locally; siliceous root casts common to abundant; lacustrine limestone present locally and was mined for local building stone (sec. 16, T. 17 N., R. 12 W., southwestern Greeley County near Scotia). Volcanic ash scattered throughout unit and crops out at a few places; shards from an ash bed from one location (sec. 24, T. 18 N., R. 14 W., eastern Valley County) have fission-track age of 6.3 ± 0.2 Ma (late Miocene) (Boellstorff, 1978b, p. 46; 1976, p. 63). Maximum thickness of upper unit about 600 ft near Brewster, Blaine County. Electric logs and drill cuttings from test holes indicate upper unit of Ogallala Group generally consists of fining-upward depositional sequences in all or much of unit, but locally the sequences are not apparent; in places where unit is more than 500 ft thick it contains as many as six fining-upward sequences that range in thickness from 50 to 230 ft, but most are from 50 to 130 ft; difficulties in distinguishing unit To from overlying Pliocene unit occurred in several places, especially where unit Tl deposits overlay fine-grained unit To and only driller's logs of irrigation wells are available for interpretation; problems also were encountered in south-central and southwestern Custer County, along the Loup River northeast of St. Paul in Howard County, in western Boone County, and in parts of Wheeler County where gravelly sands in Ogallala Group were in close association with units Tg and Tl
Th	Lower unit (middle? Miocene)—Probably two lithologic phases. Dominant phase consists of silt, clayey silt, and clay, which is sandy locally; light gray, pale olive, pale yellow, and yellowish brown; contains scattered calcareous concretions and concretion zones; locally, thin beds of poorly sorted fine to coarse sand. Less common phase consists of light-brown sandy silt; sand is very fine to medium; fairly well sorted. Unit includes angular clasts of older bedrock units at base at some localities. Volcanic glass shards may be present in some samples, but not abundant enough to be easily identified when viewed with a x30 binocular microscope. Maximum thickness about 120 ft in Nance County north of Loup River (for example in T. 16 N., R. 7 W.).

Tentative identification of unit Th based on microscopic examination of drill cuttings, electric logs, and comparison of data to those reported from probable equivalent formations (Valentine through Runningwater Formations) in western Nebraska (Swinehart and others, 1985; Souders, 1981; Souders and others, 1980)

Ta **Arikaree Group (lower Miocene and upper Oligocene)**—Shown only in cross section A–A' and fig. 1.

Siltstone, sandy; locally grades to silty sandstone. Sand is very fine to fine, pale brown, brown, light brownish gray, and light gray; some calcareous zones; present only in subsurface of western part of map area at depths of 500–1,000 ft. Rocks are volcanoclastic and contain volcanic ash beds locally; glass shards readily apparent in most samples under a x30 binocular microscope. Maximum thickness about 160 ft at west-central edge of map area.

Locally difficult to distinguish from unit Th in places and from underlying unit Tw. Lithology of drill cuttings and electric log characteristics indicate that Arikaree Group beds are possibly equivalent to the upper beds of Harrison Formation and to the Monroe Creek and Harrison Formations (Swinehart and others, 1985; Souders, 1981; Souders and others, 1980)

Tw **White River Group (lower Oligocene and upper Eocene)**—Shown only in cross sections A–A' and B–B' and fig. 1.

Siltstone, locally sandy, silty sandstone, claystone, and, in northwest part of map area, minor amounts of sandstone at or near base; light brown, light olive gray, and pale yellow with lesser amounts of brown, pinkish gray, and pale red. Sand of silty sandstone beds is mostly very fine; basal sand beds are fine to very coarse and contain some gravel, sand mostly quartz but some chert; gravel is mostly lithic clasts. Unit is present only in subsurface in western and northern parts of map area at depths of 500–1,000 ft. High content of volcanoclastic sediments and volcanic ash beds in some localities; glass shards not readily apparent with a x30 binocular microscope because drill samples are too fine grained, but on a wet slide under petrographic microscope volcanoclastic fragments are evident. Maximum thickness about 240 ft near northwest corner.

Unit composed of Brule and Chadron Formations of White River Group (Tedford and others, 1996; Terry and others, 1995; Swinehart and others, 1985); these formations can be identified at some localities by studying drill cuttings and electric logs; electric log characteristics are similar to those of Brule and Chadron Formations in western Nebraska (Souders, 1986); at other localities where both drill samples and electric logs are not available, White River beds are difficult to distinguish from overlying Arikaree beds. So, identification of the two units and the position of the contact between them are tenuous. Sand beds at or near base of Chadron Formation occurred in two test holes in Blaine County north of Brewster (T. 22 N., R. 21–22 W.), in two test holes and one oil and gas test southeast of that community in Blaine and Loup Counties (T. 22–23 N., R. 21 W., and T. 22 N., R. 19 W.), and in one test hole east of Broken Bow in Custer County (T. 17 N., R. 19 W.). Sand beds included some clayey zones and ranged from less than 10 ft to about 25 ft thick. White River Group unconformably overlies Pierre Shale

Kp **Pierre Shale (Upper Cretaceous)**—Silty shale, clay shale, and claystone, calcareous shale, and a few thin limestone beds, all of marine origin; mostly gray and dark gray; present in subsurface at depths as shallow as 50–60 ft in parts of Platte Valley in Hall County in southeast part of map area, and at about 1,100 ft beneath tablelands in west part; unit completely removed from southwest corner of quadrangle by post-Pierre pre-White River erosion (see cross section A–A') and from southeastern and east-central parts by post-Pierre pre-Ogallala erosion. No complete section of Pierre Shale is present in map area and maximum thickness is 550–600 ft near north-central edge of quadrangle.

Upper part of Pierre is calcareous when thickness of Pierre exceeds about 250 ft. Uppermost part, which is 1 ft to as much as 35 ft thick, is oxidized and weathered except where paleochannels containing thick Quaternary and Tertiary

fills cut deeply into unit; color of weathered zone mostly yellowish brown, brownish gray, olive gray, and light gray. Lowermost 50 ft of Pierre difficult to recognize across map area; data from the few available electric logs of oil and gas test wells indicate that relationship of Pierre and underlying Niobrara Formation is complex and unconformable, a situation that has been noted elsewhere in Nebraska (DeGraw, 1975; Souders and Miguez, 1990)

Kn

Niobrara Formation (Upper Cretaceous)—Chalk, shaly limestone, and calcareous shale, locally sandy in basal part; mostly light gray to gray. Apparently does not crop out in map area but is exposed on south bank of Loup River 1,900 ft east of east edge of quadrangle; present at a depth of about 30 ft in parts of Platte-Loup Valleys in southeast part of map area but at depth of 1,300 ft or more beneath western tablelands; underlies entire quadrangle but upper part removed by post-Pierre pre-White River erosion in southwest corner (see cross section A–A') and by post-Pierre pre-Ogallala erosion in southeast and east-central parts (see fig. 1). Upper few feet to as much as 35 ft of Niobrara is weathered yellow and pale yellow beneath beds of Ogallala Group and younger deposits. Minimum thickness of about 200 ft probably beneath a Pliocene paleochannel near Central City (T. 13 N., R. 6 W.) near southeast corner of map area; maximum thickness probably 450–500 ft immediately west of Niobrara-Pierre contact in northwest part of Merrick County (T. 15 N., R. 8 W.) (fig. 1) and southwest corner of Merrick County (T. 12 N., R. 8 W.), and near southeast corner of quadrangle (T. 12 N., R. 6 W.)

DISCUSSION

Sod-stabilized sand hills cover the northwest and north parts of the Broken Bow 1°x2° quadrangle, east-central Nebraska. Southeast of these hills stretches a broad belt of loess-mantled tablelands and hills; the loess hills form a northeast-trending belt across the region, which is the dominant element in the landscape of the quadrangle. Some of the thickest loess deposits of North America occur here. In the southeast corner of the quadrangle is the 20- to 25-mi-wide valley of the Loup River–Platte River system. The Platte valley has a broad floodplain and broad Holocene terraces, whereas in the Loup River system floodplain and Holocene terraces are narrow but there is a broad Wisconsin-age terrace. Both rivers, having made their big bends, flow northeastward parallel to each other at the margins of this wide valley. The Loup River is more deeply entrenched than the Platte, which has a steeper gradient above its junction with the Loup east of the quadrangle.

Most of the Loup drainage apparently attained its present configuration since early to middle Wisconsin time. These streams eroded through the overburden into bedrock in several reaches, with especially long stretches being incised into bedrock in the valleys of the Middle Loup and North Loup Rivers. Wisconsin-age terraces border the streams of the Loup system throughout much of the area and are evidence that the drainage system was established at that time. In 1994, David May (University of

Northern Iowa) and I sampled a humic horizon in terrace-fill deposits on the north side of the Loup River near Cushing (SW1/4NE1/4 sec. 5, T. 15 N., R. 9 W.). This sample from a fresh canal cut had a radiocarbon age of $38,760 \pm 2,080$ yr B.P. (Tx-8248), which indicated the terrace deposits at this site were middle Wisconsin in age (Gilman Canyon Formation). This age is also compatible with the apparent age of the Todd Valley terrace fill in the Platte Valley in Saunders County approximately 70 mi east of the map area (May and others, 1995). Those authors confirmed the presence of a younger Wisconsin terrace (Peoria Loess equivalent) in the South Loup system. This terrace, located on the southeast side of the South and Middle Loup Rivers, is along the Loup River across from the Cushing site. The South Loup River system appears to have pirated the headwaters of the Wood River near Callaway in the southwest part of the quadrangle (Hicks, 1892a, b), possibly during the middle Wisconsin. High terraces of early to middle Wisconsin age are most common northwest of the Cotesfield paleodivide. They border the modern streams in many places, are high-lying abandoned valleys in parts of Boone, Greeley, Valley, and Custer Counties, and appear to be the surface on which the dunes of the Sand Hills were deposited throughout most of the northwest and north-central part of the quadrangle. Terraces of late Wisconsin age may be present in areas other than the South Loup Valley, but they have not been recognized. Holocene terraces are

confined to the Wisconsin-age valleys and are most extensive along the Platte River in the southeast part.

No Wisconsin-age terrace has been identified in the Platte River Valley in the Broken Bow quadrangle, but middle Wisconsin terraces (Gilman Canyon Formation) are present on both sides of the Platte River in the big bend of the river west of Grand Island (Jensen site of May and Holen, 1994; May and Souders, 1988; Souders and Dreeszen, 1991). For a long period prior to the Wisconsin, the Platte River system draining the Rocky Mountains discharged southeast through the Big and Little Blue Basins of Nebraska (Reed and Dreeszen, 1965), which are part of the present Kansas River system, because eastward drainage was blocked by glacial ice and debris. The precise time when the lower Platte was diverted to its present course is not yet known. Stream profiles indicate that the Elkhorn River-Loup River systems are the parent streams of the modern lower Platte drainage area and the capture of the upper Platte apparently was during the Wisconsin, possibly just prior to deposition of the Peoria Loess.

Pre-Wisconsin Pleistocene drainage systems in the Broken Bow quadrangle seem to have eroded to bedrock only in local areas. Most of the thick pre-Wisconsin alluvial deposits occur south of the Cotesfield paleodivide (see discussion of unit Tg) and seem to coincide with deep Pliocene-age paleovalleys for at least part of their reaches. One of the pre-Wisconsin alluvial systems coincides with the modern South Loup Valley but trends east-southeast out of the quadrangle instead of following the northeast-draining South Loup River. A small, high-standing, coarse-grained fill of pre-Wisconsin age trends east-northeast along the Cotesfield paleodivide in northern Sherman County and northwest Howard County. Somewhat similar coarse-grained fills are present in some test holes south of the paleodivide, but the complex stratigraphy and paleogeography of the pre-Wisconsin Pleistocene deposits are not worked out except to note that the older drainage trends did not conform to modern ones.

Erosion prior to deposition of earliest Pliocene sediments, as well as during the Pliocene, sculpted the bedrock surface throughout most of the quadrangle. North of the Cotesfield paleodivide the drainage direction was east-northeast and coarse sediments of Rocky Mountain origin are common. Several cycles of erosion and deposition occurred in the map area during the Pliocene (see Lawton and Hiergesell,

1988, p. 34–36, for examples of two different Pliocene paleovalley systems).

South of the paleodivide, paleochannels trend east-southeast. Only small amounts of coarse-grained clastics occur at the base of the channels, and these clastics appear to be locally derived. Some deep paleovalleys occur in this part of the quadrangle (see cross-section C–C') and are filled with thick deposits of fine-grained fluvial sediments, mostly silt and clay, and loess.

The configuration of the base of the Ogallala Group (fig. 1) indicates that initial deposition of these sediments was in broad valleys trending east or east-northeast. There was no major drainage divide in this area as there was in Pliocene time. The direction of deposition throughout Ogallala time presumably was from west to east following the slope of the Ogallala valleys.

The transport directions of the Arikaree and White River deposits are difficult to determine because of few deep test holes and the problems of identifying these units. Available evidence does indicate that a belt of thick Arikaree-type sediments extends east across the west-central part of the quadrangle. These deposits probably are in an eastward continuation of the major Arikaree paleovalley in southern Box Butte County in western Nebraska (Souders and others, 1980). The paleovalley was also encountered in the subsurface of the central Sand Hills (Swinehart and others, 1985; Swinehart and Diffendal, 1989).

Shifts in drainage direction during the Cenozoic indicate important tectonic and (or) climatic events. The Broken Bow quadrangle lies at the southern end of the Central Nebraska Basin as defined by structural maps showing the configuration of Cretaceous rocks. The Chadron-Cambridge arch on the west flank of the basin occurs near the southwest corner of the quadrangle, and Cretaceous rocks are structurally higher to the south and east than within the quadrangle. From the Late Cretaceous to early Tertiary there was movement primarily along the Chadron-Cambridge arch and probably also along the other basin margins (DeGraw, 1977, preliminary maps).

The apparent switch from northward to eastward drainage from early White River to early Arikaree time indicates some tectonic activity in the region during the Oligocene. The complex stratigraphy of the Ogallala Group has not been deciphered within the quadrangle, so stratigraphic evidence is not available to determine possible tectonism during the Miocene.

The large influx of coarse deposits from the Rocky Mountains in the Pliocene documents

mountain building to the west in late Miocene to early Pliocene time (Swinehart and others, 1985). The erosion of deep valleys in the southeast part of the quadrangle indicates the southern region was an active area of erosion at about the same time. These large paleovalleys in the south part of the quadrangle presently lie at lower altitudes than the regional paleovalleys in the north in which gravel was deposited. If the southern valleys had been lower lying at the time the gravels were laid down, then it would seem that the major regional drainage should have been to the southeast. Cross section C–C' shows that the top of the coarse deposits apparently dips to the south. The southern valleys containing nongravelly fills, then, probably were part of a landscape that lay higher in relation to the northern valleys during the Pliocene, and the north part of C–C' has warped upward relative to the south since the time of gravel deposition.

Maps of Pliocene gravel deposits (for example, Swinehart and Diffendal, 1989; Lawton and Hiergesell, 1988; and preliminary maps by this author) indicate that the major gravel bodies currently do not trend perpendicular to the regional slope but at a slight angle to it. An upward tilting of about 200 ft or more from the Cotesfield paleodivide to the northwest corner of the quadrangle during the late Pliocene and Quaternary could account for this angle and also could account for the low-altitude paleovalleys in the southeast.

No thick, lower Pleistocene coarse-grained clastic deposits of Rocky Mountain origin are present in the Broken Bow quadrangle. These deposits are present, however, south of the quadrangle and south of the modern Platte River (Reed and Dreeszen, 1965). A wholesale change in the position of major drainage systems in the map area and in south-central Nebraska (Swinehart and others, 1994) possibly coincided with the advance of glacial ice into what is now eastern Nebraska, crustal depression or other changes due to ice loading, and tectonic upwarping toward the northwest.

Widespread and deep erosion in the area in early to middle Wisconsin time (75,000 to about 50,000 yr B.P.), renewed and vigorous erosion at the end of Gilman Canyon time (19,000–20,000 yr B.P.; referred to as “diastrophism” by Lugen, 1935), and the pronounced erosion at the beginning of the Holocene (about 10,000 yr B.P.) probably were due mostly to changes in climate, but episodes of upwarping also may have played a role. Some indirect evidence for late Quaternary neotectonism includes: parallelism of the Loup River drainages; captures of the upper

Wood River and the lower Platte River during that period; greatest depth of late Quaternary stream valley erosion in the northwest, a fact consistent with other indications of upwarping to the northwest earlier in the Quaternary; presence of high-lying Wisconsin terraces, abandoned valleys, and parks (nearly circular valleys, often with drainages opposite to that of the regional grain) within the quadrangle, most commonly northwest of the Cotesfield paleodivide; and the flow of the lower Platte River, diverted in late Quaternary into its modern course, nearly along the strike of the buried Niobrara Formation where this formation marks the southeastern edge of the Central Nebraska Basin.

Earthquakes provide more direct evidence of neotectonism in the map area. Six earthquakes occurred within the quadrangle from 1927 to 1990 (Burchett, 1990, and oral commun., 1998). Intensity of the earthquakes, as rated by the Modified Mercalli scale, ranged from II to V with four of the six being rated IV or V (the higher the Roman numeral, the greater the intensity as felt by humans). Epicenters of three of the earthquakes rated IV were located in the North Loup Valley in Valley, Greeley, and Howard Counties and the epicenter of a fourth earthquake, rated II, was located west of the river valley along the Cotesfield paleodivide. The epicenter of the most intense earthquake was in the Middle Loup Valley west of the seismic activity in the North Loup Valley. Microearthquakes, or small earthquakes that cannot be felt by humans, also occur within the quadrangle. About 15 microearthquakes took place in the map area from 1977 to 1989 (Burchett, 1990); seven of them were clustered along the North Loup Valley or the Cotesfield paleodivide in Valley, Greeley, Howard, and Sherman Counties. Although these earthquakes indicate the possibility of neotectonism, none of them was a major event and no concrete evidence of Quaternary faulting has been verified in the map area. Prolonged erosion in the northern and northwestern parts of the quadrangle during the early to middle Wisconsin created linear relations in some localities between the old uplands and the lower-lying eroded lands, all of which were later mantled by loess or sand. Crone and others (1996) and Machette and others (1998) demonstrated that one such prominent lineament was not the result of faulting.

A general tilting upward to the northwest at different times after the deposition of the Pliocene gravels would imply that the Arikaree and Ogallala paleovalleys had lower gradients than the maps in this report depict. The

northward gradient of the basal White River deposits would have been greater.

The late Quaternary erosional/depositional episodes, along with different climatic and vegetative conditions, created landscapes in the quadrangle unlike the modern one. For instance, in the Middle Loup Valley west of Sargent (T. 19 N., R. 20 W.) the general level of the loess-mantled hills south of the valley is about 300 ft higher than the river. Wood retrieved from a depth of 65–70 feet in Test Hole 12-A-66 (NW1/4NE1/4 sec. 13, T. 19 N., R. 20 W.) has a radiocarbon age of $8,530 \pm 60$ yr B.P. (Beta 60048). The wood was about 45 ft above the base of Holocene deposits. The relief from the loess-capped hilltops to the stream at the beginning of the Holocene was about 400 ft. At the other extreme, before the erosional episode prior to the deposition of the Peoria Loess (at about 20,000 yr B.P.), the relief from the stream to the top of the undraped hills was only about 110–150 ft, and bluffs or other features lacking vegetation would have been reddish-hued rather than the present tan.

One landscape feature of the loess-mantled part of the Broken Bow quadrangle was noted early in the settlement of the region (Hicks, 1891) and deserves a final comment. Oval depressions, ranging from a few acres to more than 1,000 acres in area, occur in abundance on the tablelands and tableland remnants and in lesser numbers on the high-terrace surfaces. The long axes of the depressions trend northeast and the depths range from a few feet to nearly 100 ft. A ridge of loess is sometimes present on the south-southeast side of the depressions. A few of these depressions, observed on 7.5-minute topographic maps by the unwary, may suggest meteorite impact craters, but shape alone is not proof of impact origin. The Conservation and Survey Division, University of Nebraska–Lincoln, drilled four test holes in one prominent depression (sec. 9, T. 17 N., R. 23 W.) in April 1998 (J.B. Swinehart, oral commun., 1998). The test holes ranged from 140 to 360 ft deep. Analyses of the data from these test holes, from the log of a 468-ft-deep irrigation well within the depression, and from the log of a 470-ft-deep domestic well on the south edge of the depression showed that the Peoria Loess uniformly mantled this feature, the pre-Wisconsin deposits beneath the depression were undisturbed, and the stratigraphy beneath the depression and along its boundary conformed in altitude and attitude to that of the surrounding area as known from other test holes and logs of wells. Samples and electric logs of the four test holes showed no evidence of impact phenomena

such as brecciation and melt rock. The numerous depressions are restricted to landscapes that were in existence about 20,000 yr B.P. and which have since been mantled with the Peoria Loess. Origins of the depressions are poorly understood and, except for having a much thicker loess cover, the one drilled in this quadrangle resembles those studied by Kuzila (1988) and Krueger (1986) on the loess-mantled plain of south-central Nebraska.

PREVIOUS WORK AND ACKNOWLEDGMENTS

The surface and subsurface mapping of this quadrangle benefitted from the efforts of previous workers—soil scientists, geologists, and hydrologists. Bedrock and geologic maps of adjoining $1^\circ \times 2^\circ$ quadrangles by Burchett and others (1975), Diffendal (1991), and Dreeszen and others (1973) outlined some of the bedrock setting. An open-file geologic report by Miller (1951) was useful in some localities. Some of the rock outcrops, gravel deposits, and other surface features are shown on soils maps by Mahnke and others (1974), Shurtliff and others (1988), Wahl and others (1990), Williard and others (1960), Wilson and others (1993), Wilson and others (1982), and Wilson and others (1985).

Brice (1964) presented a broad view of the Loup River system and Bentall (1971) provided comprehensive information about the geology, hydrology, and drainages of the Elkhorn River basin, which occupies the extreme northeast corner of the map area. Information about stratigraphy and the configuration of the bedrock surface occurs in several reports about ground water resources. Some of these include the following: Hyland and Keech (1964), Keech (1962), Keech and Dreeszen (1964), Schreurs (1956), Sniegocki (1955, 1959), and Souders and Shaffer (1969).

James Swinehart (Conservation and Survey Division) helped evaluate some drill cuttings and electric logs to distinguish various Tertiary units. Final identifications, and any errors, are mine. Swinehart also spent time in the field discussing geologic interpretations. Larry Cast, geologist formerly with the U.S. Bureau of Reclamation, pointed out exposed stratigraphic units in canal cuts, provided drill records, measured sections, and photographs of fresh cuts, and freely shared his knowledge of the area. Francis Belohlavy (Conservation and Survey Division), soil scientist with broad experience in the region, led me to geologic sites and helped sample some gravel deposits. David May

(University of Northern Iowa) shared his knowledge of late Quaternary landscapes on several field trips. Jeffrey Gottula (Nebraska Department of Environmental Quality) helped measure and sample sections. H.M. DeGraw (formerly of the Conservation and Survey Division) furnished draft maps of Cretaceous units and geologic structures. R.F. Diffendal, Jr., (Conservation and Survey Division) aided with references, advised the author on pre-publication techniques for this map, and saw the project through to completion. Jerry Leach (Conservation and Survey Division) helped in the field and he and Ann Mack (Conservation and Survey Division) produced work maps. I thank Ron Wolfe and the staff of Twin Loups Irrigation and Reclamation District for allowing me to study exposures in canal cuts and showing an interest in my work. I am also grateful to the many landowners who allowed me to tramp their fields and pastures.

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