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Cenozoic Geology of the North Platte River Valley, Morrill and Garden counties, Nebraska

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CENOZOIC GEOLOGY OF THE NORTH PLATTE RIVER VALLEY, MORRILL AND GARDEN COUNTIES, NEBRASKA

by

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Under the Supervision of Dr. John D. Boellstorff,

and Dr. Michael R. Voorhies

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"Let the stones speak with tongues
that talk all tongues."

Dylan Thomas

"A man is a small thing and the night
is very large and full of wonders."

King Karnos

"There is no record of a Spanish Mackeral
attacking a human... off the Natal coast..."

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ABSTRACT

Mapping of the Cenozoic deposits (Oligocene through Recent) on the north side of the North Platte River Valley near Broadwater and Lisco Nebraska was combined with analysis of drill-hole records and mineralogical and textural data. The stratigraphic framework thus established permits a reevaluation of earlier concepts regarding these deposits.

The Whitney Member of the Brule Formation (Oligocene), the oldest deposit exposed in the area, is an eolian, loess-like siltstone consisting of a lower clayey facies and an upper sandy facies. Vitric, crystal, and lithic volcaniclastic material--probably derived from distant western ash flow eruptions--makes up a minimum of 75 percent of both facies.

The Arikaree Group (Late Oligocene-Early Miocene) overlies the Whitney Member and is divided into two units. The lower is the Gering Formation, which primarily is a fluvial volcaniclastic silty sand containing local accumulations of pumice pebbles derived from North Park, Colorado. Overlying it is a sequence of massive, volcaniclastic fine-grained sands--the Harrison-Monroe Creek formations, undifferentiated. This upper unit, like the Whitney, is primarily an eolian, loess-like deposit but contains a greater proportion of epiclastic material.

A hiatus representing about 10 million years duration separates the Arikaree Group from the overlying Pussy Springs channel complex (informal name) of the Ash Hollow Formation (Late Miocene). The arkosic, poorly sorted silty and pebbly sands of the Pussy Springs unit resulted from the rapid filling of deep and narrow "arroyos" cut through the Arikaree Group and almost 200 feet into the Whitney Member. The remainder of the Ash Hollow Formation consists of sand and gravel, silty sand, mudstone, caliche, and siliceous root cast horizons representing fluvial, lacustrine, and pedogenic deposits. Acidic volcanic clasts suggest a Colorado Front Range source.

A hiatus representing several million years separates the Ash Hollow Formation from the Broadwater Formation (Pliocene-Early Pleistocene), an extensive sand and gravel containing several lenticular fine-grained units (including diatomites) that contain Blancan fossils. The Broadwater was deposited in a large east-trending paleovalley. Anorthosite and mafic igneous clasts indicate that the Laramie Mountains were a primary source of sediments. A series of isolated deposits of very coarse gravel and sand, some filling deep narrow channels and containing clast types similar to the Broadwater Formation, are interpreted to represent the basal fill of the Broadwater paleovalley.

INTRODUCTION

A series of Cenozoic fluvial, eolian, and lacustrine sedimentary deposits are exposed along the north side of the North Platte River Valley in the vicinity of Broadwater and Lisco, Nebraska (Fig. 1). These deposits are part of an extensive sequence of Oligocene and younger deposits that extend from the Laramie and Front ranges eastward 400 miles or more onto the High Plains. The stratigraphy and age relationships of this sequence in the North Platte River Valley and adjacent areas have been the subject of study by stratigraphers and paleontologists since the late 1800s (Breyer 1975; Darton 1899, 1903a and b; Elias 1942, Lugn 1939, McGrew 1963, Schlaikjer 1935, Schultz and Stout 1955, 1961; Skinner and others 1977; Vondra 1962; Vondra and others 1969). Since the 1950s a considerable amount of information on subsurface stratigraphy has been obtained from Conservation and Survey Division test hole drilling programs, oil and gas tests, and irrigation wells (DeGraw 1969; Smith and Souders 1975; Souders, Smith, and Swinehart, in press). The subdivisions and lithostratigraphic boundaries established from subsurface data have not always matched those determined from surface data.

In addition to stratigraphic and biostratigraphic studies, sedimentologic and paleoecologic studies have suggested that much of the Tertiary sediments were deposited in environments similar to the present-day braided stream, semi-arid prairie grassland environment. (Bart 1975,

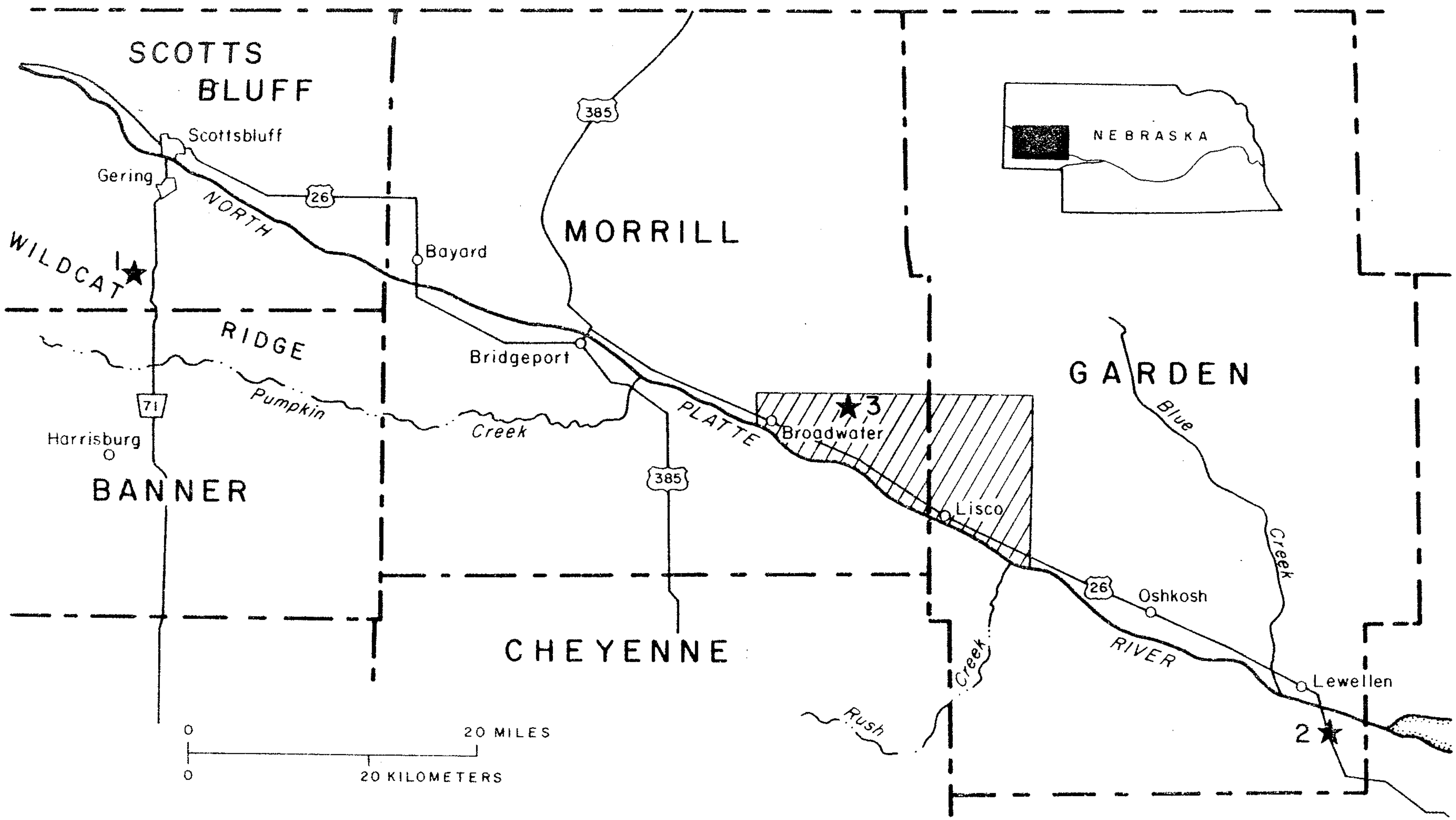


Figure 1. Location of study area (shaded). Numbered stars identify the following: (1) type section of Gering Formation (Vondra, Schultz and Stout 1969): (2) type locality of the Ash Hollow Formation (Lugn 1934; Stout et al., 1971) (3) type section of the Broadwater Formation (Schultz and Stout 1945, 1948).

Blodgett 1974, Elias 1942, Stanley and Fagerstrom 1974, Schultz and Falkenbach 1968). Petrologic studies have established that the major difference between past and present environments is the large amount of volcanic debris blown into the area from the west. Sediments of the White River and Arikaree groups are dominated by eolian deposits (Bart 1974, Denson 1969; Souders, Smith, and Swinehart, in press; Stanley 1976, Swinehart 1977). These studies have indicated that it is possible to discriminate between various stratigraphic units in the Cenozoic on the basis of mineralogy.

Stanley (1971) and Stanley and Wayne (1972) have shown the potential usefulness of pebble types and maximum pebble size data in differentiating late Cenozoic age gravel deposits in Nebraska.

The type section of the Broadwater Formation is located just east of Broadwater (Fig. 1) and most studies in this area have been directed at the Broadwater Formation and the large number of fossil mammals quarried from it (Schultz and Stout 1975, 1948; Stout 1965). Schultz and Stout have considered the contact between the Broadwater and the underlying Ogallala Group, specifically their "Kimball Formation," to represent the Pliocene-Pleistocene boundary in the High Plains.

However, Boellstorff (1978) presented data to suggest that about a 4-million-year hiatus exists between the Broadwater Formation and the youngest Ogallala Group deposits in western Nebraska. Breyer (1975) suggested that a series of isolated coarse gravel-filled channels, cut more then

200 feet below the base of the Broadwater Formation at its type section, represented the basal phase of the Broadwater Formation. There has also been disagreement as to whether the dispersal pattern of Broadwater sediments was to the southeast (Stout 1965) or to the east and northeast (Stanley and Wayne 1972).

Another area of controversy in the Broadwater-Lisco area is the relationship of the lowest Arikaree Group unit, the Gering Formation, to the highest White River Group unit, the Whitney Member of the Brule Formation. In the Wildcat Ridge, Vondra (1963) and Vondra, Schultz, and Stout (1969) included a sequence of sandy siltstone and silty sandstone, up to 100 feet thick, within the Gering Formation. Vondra (1963) interpreted this sequence as a "distant floodplain" facies of the Gering. Darton's (1899) descriptions and geologic sections indicate he included these "floodplain deposits" within the Brule. He further indicated, however, at some points along Wildcat Ridge the Gering may be represented by clayey members not distinguishable from the Brule (Darton 1899, p. 747).

Previous mapping (Burchett 1969; Lugn 1939) and my own field reconnaissance indicated the easternmost Arikaree exposures in the North Platte Valley occur between Lisco and Broadwater. I felt this area could possibly provide additional data to help understand and resolve the Gering "floodplain" problem.

In addition to the problems outlined above, discussions with Morris Skinner of the American Museum of Natural History and Mike Voorhies and T. Mylan Stout of the Nebraska State Museum indicated a complex series of channel-form deposits are present in the Ogallala Group of the Broadwater-Lisco area. Vertebrate fossils have been collected from these channels for a number of years but studies have not been made on the sediments.

With the above factors in mind, the main purpose for this study is to reevaluate the stratigraphic and geologic framework of the area by integrating surface mapping, subsurface information, petrologic and sedimentologic data, and faunal evidence (Fig. 2).

METHODS OF INVESTIGATION

Field Methods

Field mapping was done in 1978 on 1:24,000 scale 7 1/2 minute topographic maps (Plate 1); selected areas were also mapped on 1:12,000 (SCS, 1976) scale aerial photographs. In addition, 1:20,000 (USDA, 1961) and 1:40,000 (SCS, 1976) scale aerial photographs were used as mapping aids.

Sections were measured at significant exposures, particularly in the eastern part of the area (Plate 2, Appendix A). Colors indicated were made on comparison of wetted samples and the Geological Society of America Rock

Series	North American Mammal Ages	Stratigraphic sequence in study area: Group	Stratigraphic sequence in study area: Formation or other unit
Pleistocene			
	2		
Pliocene	Blancan		Broadwater Formation
			? ?
			Coarse gravel
	4.5		
5			
	Hemphillian		
			Ash Hollow Formation
	9	Ogallala	
	Clarendonian		Pussy Springs
	11		
Miocene	Barstovian		
	16		
	Hemingfordian		
	20		
			Harrison-Monroe Creek formations, undifferentiated
24	Arikareean	Arikaree	
			Gering Formation
Oligocene			
	29		
	Whitneyan	White River	Whitney Member

Figure 2. Stratigraphic chart of Cenozoic deposits in study area. Correlations of North American Mammal Ages and Cenozoic Series taken from Tedford and others (1979) and Van Couvering (1978). Dates are in millions of years.

Color Chart (Goddard and others 1970). Most of the samples for mineralogic analyses (6 inch channel samples) were collected during the course of section measuring.

The maximum clast size was determined in the field at 15 localities (Appendix B) by measuring the diameter of the intermediate (B) and long (A) axes of the clasts having the largest intermediate axis diameter found in an area of generally less than 20 acres for each locality. The ten clasts having the largest intermediate axis diameter were used in computing the average intermediate and long axis clast size at each locality. This technique is similar to sieving which essentially discriminates on the intermediate axis diamter.

Thirteen pebble samples for making pebble type analyses were obtained by shoveling sediment from about a 30 x 30 square foot area of surface exposure into nested 16 mm and 32 mm sieves. Enough sediment was sieved so that at least 300 pebbles were obtained. Pebble lithology for 10 of these samples was determined in the laboratory. For the remaining 3 samples only anorthosite and non-anorthosite pebbles were counted. The following categories of pebbles were counted:

(1) Pink granite and feldspar--includes graphic granite

(2) Grey granite and feldspar--mostly granodiorite

(3) Quartz

(4) Quartzite--sometimes difficult to distinguish from milky quartz

(5) Anorthosite--generally greenish-black to medium bluish-grey with elongate plagioclase crystals, often weathered to a yellowish grey around the crystal edges.

(6) Mafic plutonic--includes gabbros and diorites

(7) Acidic volcanic--primarily reddish, purplish, and grey rhyolitic ash flow tuffs, but probably includes some dacites and andesites

(8) Gneiss

(9) Schists and phyllite--mostly dark-colored and foliated

(10) Aphanite--dark, dense, very fine grained, homogeneous rocks

(11) Chert

(12) Sandstone, siltstone

(13) Other

Vertebrate fossils collected during the course of field mapping were documented as to location, elevation, and stratigraphic position (Appendix D). They were deposited in the University of Nebraska State Museum research collection.

Subsurface Data

Subsurface data including written well logs, cuttings, and electric logs were analyzed for 36 irrigation wells, 6 Conservation and Survey Division test holes, and 1 oil well test (Pl. 2 and 3).

Laboratory Methods

Previous petrographic studies (Swinehart 1977, and Souders, Smith, and Swinehart, in press) indicate that in Box Butte County and central Sioux County mineralogic composition can be useful to characterize and differentiate various Tertiary rock units that appeared to be very similar in hand specimen. It is known that the mineralogy of clastic sedimentary rocks is partially controlled by their grain size distribution (Pettijohn, Potter, and Siever 1972, p. 55). I therefore selected one size, very fine sand (0.062 to 0.125 mm, 3 to 4ϕ), in an attempt to reduce this influence as I wanted to compare sediments with different grain size distributions. It is also a convenient one to use in making grain mounts and is a size in common to both sandstones and siltstones of the Tertiary sequence of western Nebraska.

Most sand and silt grains in the Tertiary sequence of Nebraska have clay rims that make petrographic identification difficult (Fig. 3 and 4). The following procedure was used to remove these rims and to prepare the samples for petrographic analysis:

(1) Gently crush sample with rolling pin

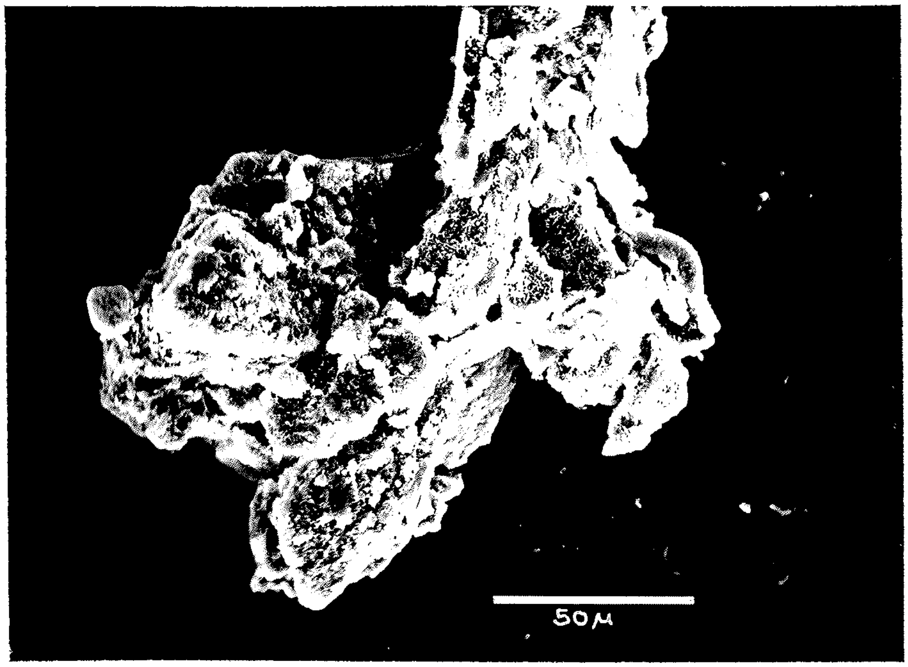
(2) Place about 50 grams in nested ASTM 35-60-120-240 mesh sieves plus pan

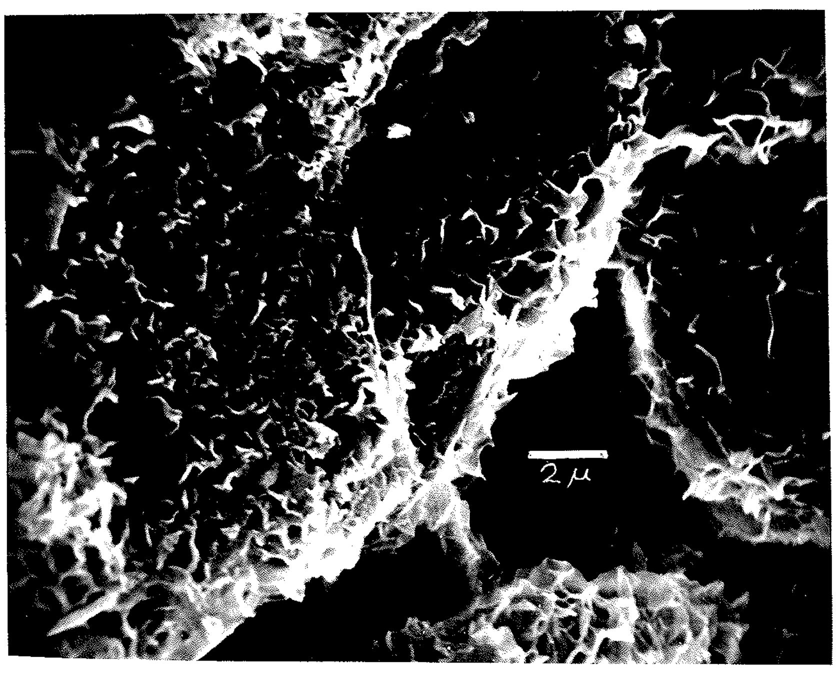
(3) Sieve for 10 minutes in Ro-tap

(4) Weigh sieved fractions and place in envelopes

Figure 3. Scanning electron micrograph of uncleaned glass shard from sample LJ78-89 (Whitney Member, Appendix A). Note the many small aggregates adhering to the shard. Sample was sieved for 10 minutes. Enlargement of 525 diameters.

Figure 4. Scanning electron micrograph of central part of glass shard of Fig. 3. Note thin, boxwork-like nature of the clay mineral (smectite group?) growing from the surface of the shard. Enlargement of 5250 diameters.


50μ


2μ

(5) Place 1-2 gm sample of very fine sand fraction in beaker and add 10 percent HCl (hydrochloric acid) until effervescence ceases.

(6) Fill beaker with water and decant--repeat

(7) Add 20 ml of 3 percent HF (hydrofluoric acid) and gently agitate for 20 sec.

(8) Fill beaker with water and decant--repeat

(9) Rinse sample with acetone and dry in oven (150° C)

(10) Hand sieve over 0.062-0.125 mm sieve for 1 minute.

(11) Make a grain mount of sample using Lakeside 70. This procedure is usually sufficient to remove most of the clay coatings and aggregates adhering to the grains (Fig. 5) and greatly facilitates grain identification.

The grain mounts were examined with a petrographic microscope and 300 grains per slide were counted using a line count technique. The grains were classified into the following categories:

(1) Glass shards--less than 10 percent non-glass

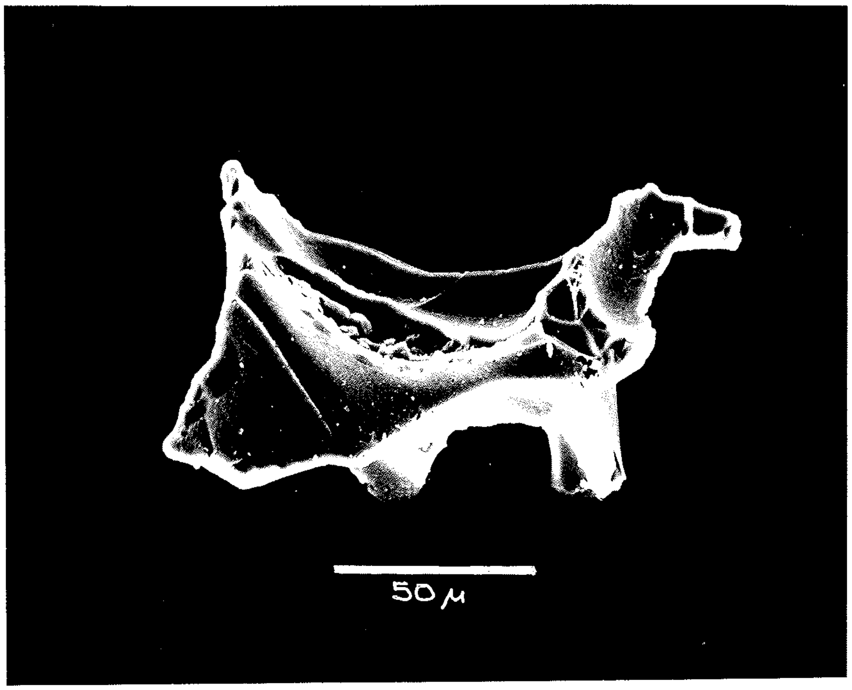
(2) Plutonic quartz--quartz with undulatory extinction, inclusions, polycrystalline quartz, iron oxide stains, or overgrowths.

(3) Volcanic quartz--clear, no inclusions, no undulatory extinction

(4) Plagioclase

(5) Potassium feldspar--includes microcline, orthoclase, and sanidine

Figure 5. Scanning electron micrographs of two glass shards from sample LJ78-89 (Whitney Member, Appendix A) after cleaning in 10 percent HCl and 3 percent HF. Compare with glass shard in Fig. 3. Enlargement of 525 diameters.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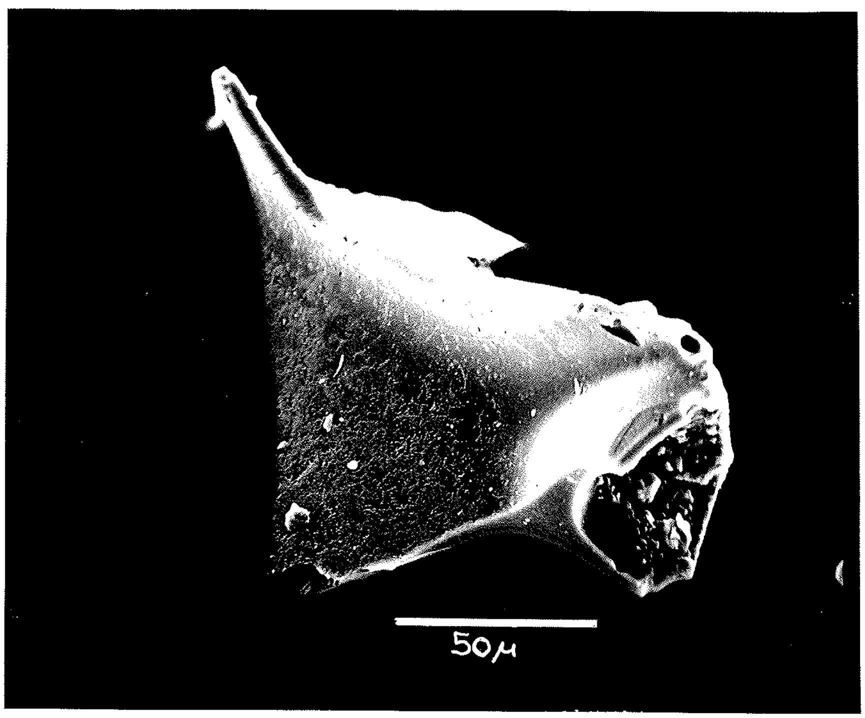
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(6) Acidic volcanic rock fragments--grains with glassy matrix and greater than 10 percent crystal phenocrysts

(7) Heavy minerals--includes opaque and non opaque minerals, amphibole, pyroxene, zircon, apatite, garnet, and biotite

(8) Others--all other grains

The frequency of glass rims was tallied in categories 3, 4, and 7.

STRATIGRAPHY

The Cenozoic sediments exposed in the study area (Fig. 1) range in age from Oligocene to recent (Fig. 2). Seven lithostratigraphic units are recognized and mapped (Pl. 1, Fig. 6 and 7). They are in order of superposition: Whitney Member, Brule Formation; Gering Formation; Harrison-Monroe Creek formations, undifferentiated; Pussy Springs channel complex, an informal unit at the base of the Ash Hollow Formation; Ash Hollow Formation; the Broadwater Formation; the coarse gravel unit, an unnamed unit of uncertain stratigraphic position interpreted to be a basal phase of the Broadwater Formation. Two additional, essentially materials units, younger than the Broadwater Formation were mapped; an alluvium-colluvium unit, undifferentiated; and a dune sand category which includes sandy silts (loess).

Lithologies in the seven lithostratigraphic units range from clayey siltstone to coarse gravel and include limestones, diatomites and volcanic ash beds. These deposits

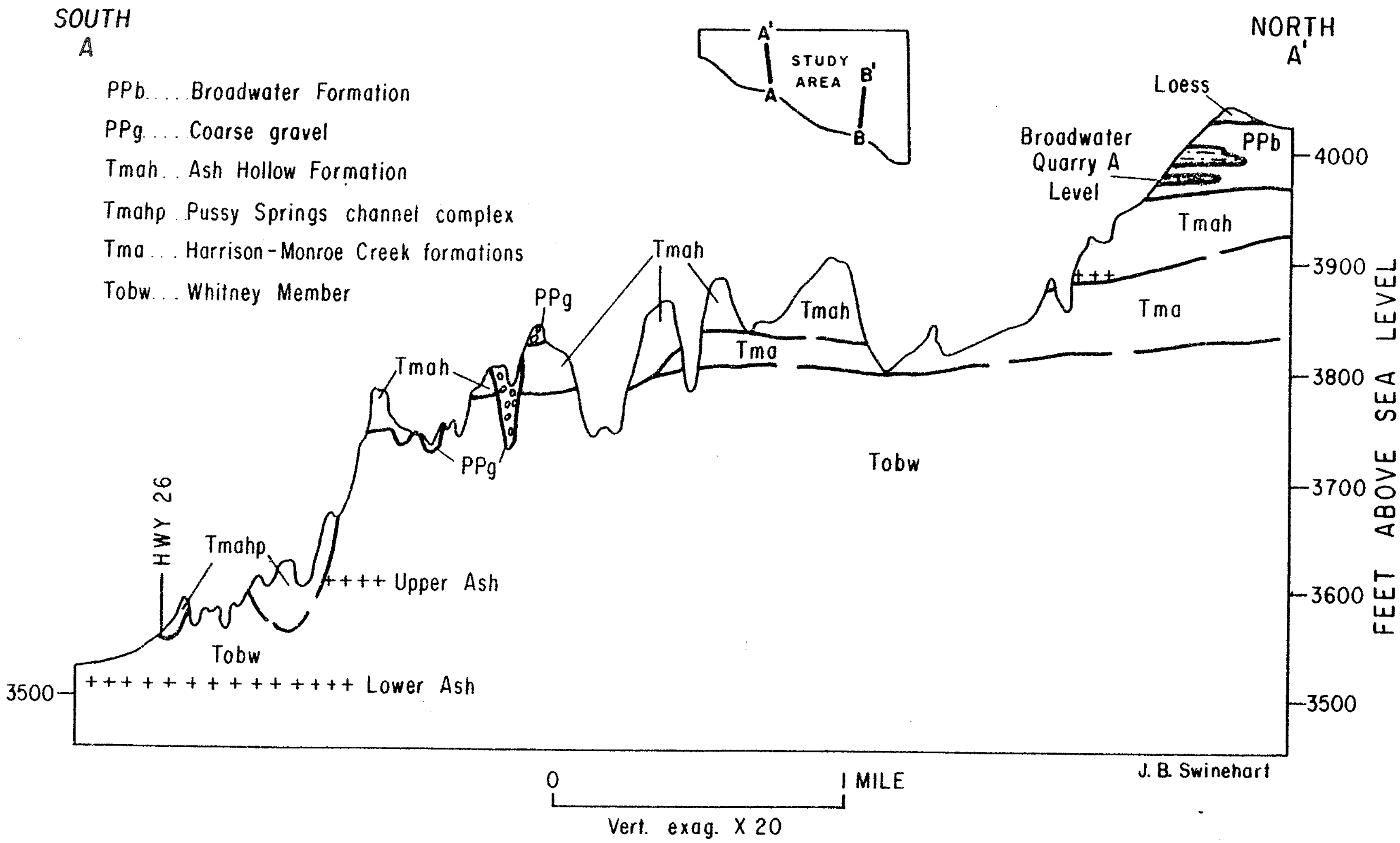


Figure 6. Geologic section A-A'. Lower ash of Whitney member was projected from Conservation and Survey Division test hole 25-A-53, 0.75 mile west of section.

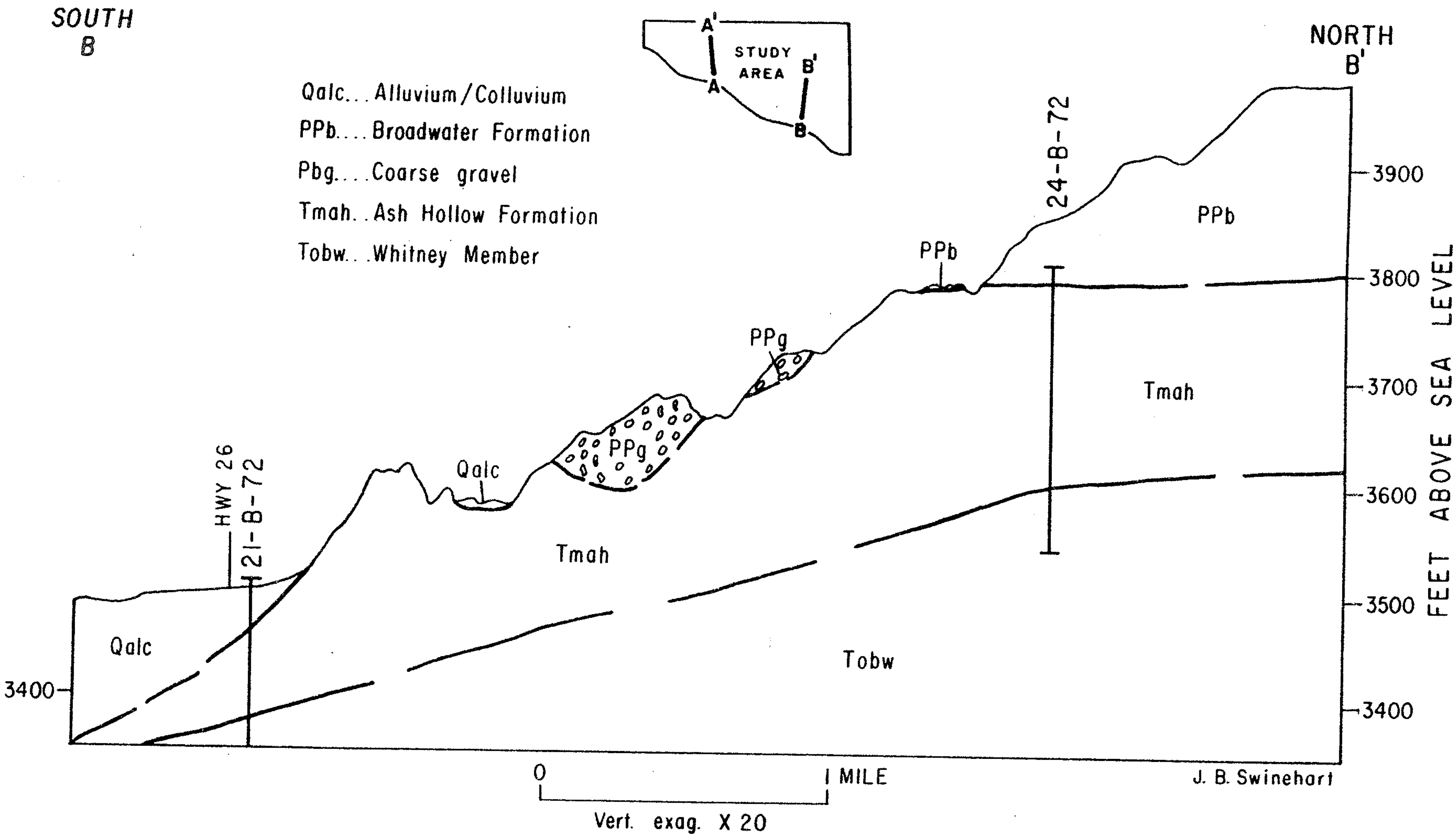


Figure 7. Geologic section B-B'. Conservation and Survey Division test holes 12-B-72 and 24-B-72 were projected onto the section.

represent a rather wide variety of continental depositional environments.

Hiatuses shown in Figure 2 are intended to be schematic and they serve to emphasize the gap in time between Arikaree Group and Ogallala Group sediments in the study area.

Whitney Member, Brule Formation

The Brule Formation was named by Darton (1899, p. 736). Schultz and Stout (1938) defined the Whitney as the upper member of the Brule Formation at Darton's "Round Top to Adelia" section (secs. 21 and 20, T. 33 N., R. 53 W.) northwest of Crawford, Nebraska. They described the Whitney as a massive, buff, silty loess, with a maximum thickness of about 480 feet. Two prominent ash beds, the Lower and Upper Ash (Schultz and Stout 1955, p. 45), were used to subdivide the Whitney and to correlate it with a similar sequence along the North Platte River Valley. DeGraw (1969 and unpublished open file maps) has correlated the Lower and Upper Whitney Ashes throughout much of the southern panhandle of Nebraska. The only other lithology occurring in the Whitney is channel-form sandstone typical of the interval below the Lower Ash in the North Platte River Valley.

Darton (1899, p. 755) described the Brule as consisting "mainly of massive clay or a mixture of fine sand and clay of pale flesh color." In the North Platte River Valley Darton noted the presence of an upper sandy zone in the Brule. It is clear that Darton did not intend to include this sandy uppermost Brule in either the Gering or Arikaree Formations. Although he does remark that in some areas the Gering may possibly be represented "...by clayey members which are not distinguishable from the Brule clay..." (Darton 189, p. 747).

Vondra (1963), and Vondra, Schultz, and Stout (1969) correlated the upper and lower ash beds of the Whitney in the North Platte River Valley but included Darton's upper sandy Brule in their Gering Formation. For example at his Castle Rock section, Darton's (1899, Pl. C) illustration seems unambiguous as he shows a gradation from pink clays to sandy clays taking place within the upper 100 feet of the Brule Clay. Vondra, Schultz, and Stout (1965, Fig. 2) include the upper 19 feet of this unit in the Gering Formation.

Morris Skinner and Richard Tedford of the American Museum of Natural History recognized an upper sandy zone above the Upper Whitney Ash and included it in the Whitney Member of the Brule Formation (written communication, 1978).

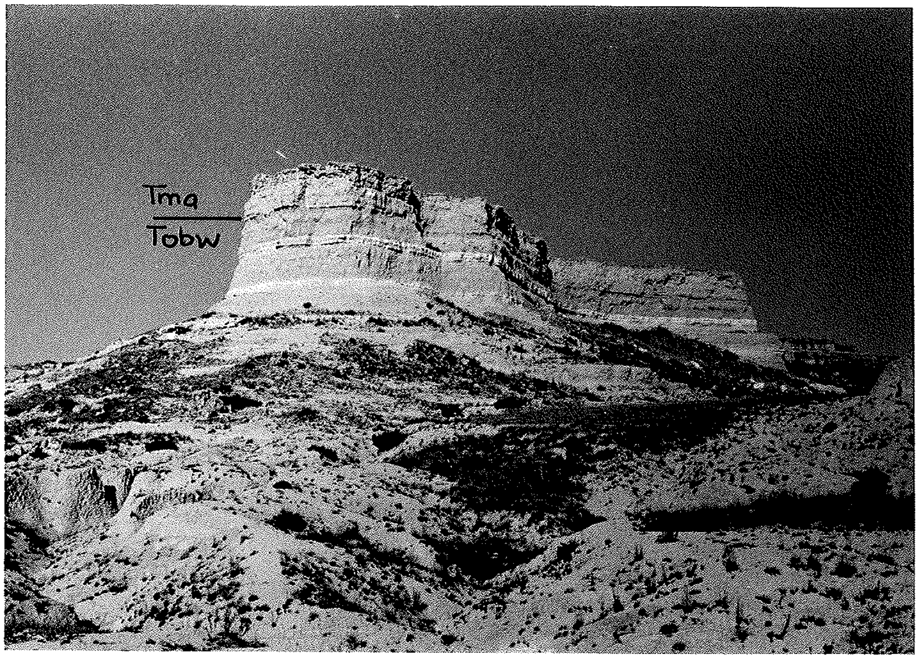
Distribution and Lithology

The Whitney Member of the Brule Formation in the study area ranges from very pale greyish orange (10YR, 7/4), massive, locally calcareous, slightly sandy, clayey siltstone in the stratigraphically lowest exposures to pale yellowish brown (10YR, 6/4), crudely bedded, very silty, very fine grained sand in stratigraphically highest exposures (Pl.

2). The Whitney crops out only in the western half of the study area (Pl. 1). It has a maximum exposed thickness of about 175 feet (Pl. 2; sections 9, 10, and 11; Fig. 8).

In the early stages of mapping I noticed two prominent ash beds,3 foot thick, stratigraphically about 60 feet apart, in the NW sec. 10, T. 18 N., R. 47 W. (Samples LJ78-5 and LJ78-6, Appendix A). I first correlated these with the Upper and Lower Ash beds of the Whitney as was done by Stout and others (1971, p. 75). However, both Hal DeGraw and Morris Skinner projected only the Upper Ash to crop out in this area (personal communications, 1978). These projections were based on elevations of the Upper and Lower Ashes in exposure and in the subsurface west of the study area. Examination of drill cuttings from Conservation and Survey Division test hole 24-A-53 in SE cr. sec. 32, T. 19 N., R. 47 W. (Appendix A, Pl. 1 and 2) confirmed the presence of an ash bed in the Whitney at an elevation of 3574 feet. This ash stratigraphically underlies the two prominent ashes I observed in Whitney outcrops; based on projections of elevations it is the Lower Ash of the Whitney. The lowest of the two exposed prominent ash beds crops out about 0.5 miles east of test hole 24-A-53 and is about 90 feet above the Lower Ash of the Whitney (Fig. 6). An oil and gas test in the NE NE SW sec. 19, T. 19 N., R. 47 W. exhibits the characteristic resistivity curves used by Hal DeGraw (personal communication, 1979) to identify the Upper and Lower Ashes of the Whitney (Pl. 2). The base of the

Figure 8. Contact between Arikaree Group and Whitney Member of the Brule Formation on butte in N½ SW NW sec. 33, T. 19 N., R. 47 W. The butte is capped by a 5 foot thick ledge of Ash Hollow Formation containing locally derived sandstone gravel clasts. Vertical part of the Ruby Ranch section (Section 10, Pl. 2). View looking north.

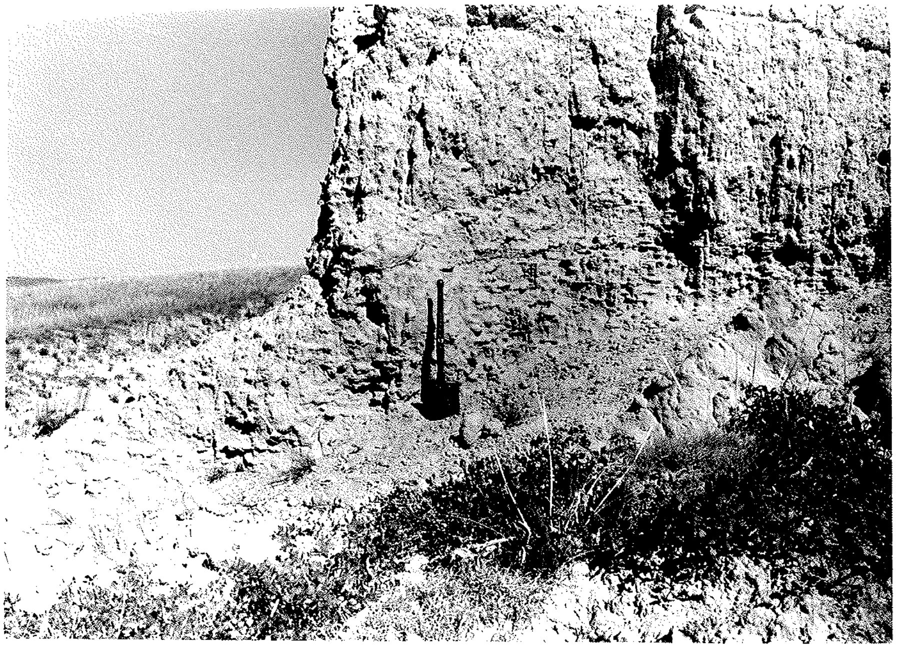

Tmq
Tobw

Upper Ash is 87 feet above the base of the Lower Ash and is correlated with the ash bed in test hole 24-A-53 and the lowest exposed ash bed at the Ruby Ranch East Section (section #3, Pl. 2). On this evidence the lowest exposed ash bed is correlated with the Upper Ash of the Whitney.

There apparently are at least two additional ash beds stratigraphically above the Upper Ash. The prominent one mentioned above (LJ78-6, Appendix A), occurring 60 feet above the Upper Ash, is also present in stratigraphic Section 2 (Pl. 2 and LJ78-40, Appendix A). This ash does not appear to be as continuous as the Upper Ash. An additional indistinct ash bed, 2 feet thick and pale olive to light grey in color occurs at an elevation of 3650 feet in the Ruby Ranch Section (Pl. 2). It contains a large number of small vertical tubules and had a rubbly or brecciated appearance. I was unable to trace it more than 100 feet.

Five to 15 foot thick lenticular sequences of very sandy silt to silty sand occur 75 to 100 feet above the Upper Ash (Fig. 9). They have poorly defined horizontal bedding and indistinct basal contacts. Horizontal laminations are locally present as are small (2 to 8 mm) diameter burrows. These sandy sequences become finer upwards and there may be several such units stacked on top of one another (Pl. 2, Lime Point Section). These sequences will be referred to in this study as the fining-upwards sandy facies of the Whitney. Typical examples of these facies are exposed in S 1/2 sec. 33, T. 19 N., R. 47 W. and the Ruby Ranch East

Figure 9. Basal part of very silty, very fine sand unit in Whitney Member at Tugboat section (Section 9, Pl. 2). Note crude horizontal bedding and indistinct concretions. There are also some small vertical insect burrows (?) visible. This unit fines upwards into a massive moderately sandy siltstone. Location is NE SW NE NE sec. 25, T. 19 N., R. 48 W. Shovel is 28 inches long.



Section (Pl. 2). The sandy units could not be correlated between nearby isolated outcrops (Pl. 3, sections 5, 6, and 7).

Locally, exposures of the "typical" Whitney (ie, massive, buff, clayey siltstone of Schultz and Stout (1955), referred to here as the clayey facies, gradually coarsens and grades into a very sandy siltstone (Pl. 3, section 11). This sequence will be referred to as the coarsening-upwards sandy facies of the Whitney. This facies exhibits poorly developed horizontal bedding and locally contains small (2 to 8 mm diameter) vertical tubules, possibly insect burrows. Small (2 to 8 cm diameter) calcareous "potato" nodules occur locally. In addition, calcite cemented, vertically oriented and interconnected concretions occur locally in both sandy facies of the Whitney. These types of concretions have been called pseudo-pipe concretions by Schultz (1941, p. 76-77) who said they "...characterize the Upper Gering and the Upper Monroe Creek but are not restricted to these horizons." The shape and occurrence of concretions in the Cenozoic sequence of Nebraska is probably a complex function of host rock grain size, sorting, packing and probably many other variables. The concretions are certainly diagenetic features and I have not found them to be reliable indicators of lithostratigraphic correlation.

Several thin (6 inches thick), white, claystones occur near the top of the Whitney. In the Ruby Ranch area (Pl.

2) they can be traced and projected for up to 0.5 miles. These claystones are generally brecciated and contain small diameter insect (?) burrows.

Twenty four samples from outcrops of the Whitney Member were selected for mineralogic analysis and an additional 6 rotary cutting samples were selected from Conservation and Survey Division test hole 24-A-53 (Table 1, Appendix A). The samples were divided into a sandy facies suite (16 samples), a clayey facies suite (3 samples) and a volcanic ash suite (5 samples).

The samples were prepared as described in the methods of investigation. The removal of carbonate cement and clay rims, both probably diagenetic products, facilitated the counting and identification procedure (Figs. 3, 4, and 5). Clay rims were found in all samples and differed somewhat in thickness. X-ray diffraction of clay removed from sample LJ78-89, (Fig. 3) by sonic cleaning for 40 minutes, indicated a smectite group clay with some associated illite. Also, the thin, irregular boxwork nature of the clay (Fig. 4) is typical of smectite morphology (Millot 1979, p. 110). Stanley and Benson (1979) found that the smectite rims are predominantly montmorillonite. For several samples additional grain mounts were made of the silt fraction and the percent glass shards determined. The mineralogy of the silt and very fine sand fractions were generally comparable. Thus, the very fine sand fraction, even though representing less than 10 percent of the total of some samples, provides a reasonably accurate picture of the bulk mineralogy.

TABLE 1. SUMMARY MINERALOGY OF THE VERY FINE SAND FRACTION OF SAMPLES OF STRATIGRAPHIC UNITS. MEANS AND STANDARD DEVIATIONS (± σ) ARE PERCENTAGES

Stratigraphic unit	n	Glass shards	Plutonic quartz	Volcanic quartz		Plagioclase		Potash feldspar	Volcanic rock fragments	Heavy minerals		Others	Percent silt and clay
				Total	glass mantled	Total	glass mantled			Total	glass mantled		
Broadwater Formation	2	-	58 ± 1	5 ± 1		17 ± 1		11 ± 3	2 ± 3	1 ± 1		6 ± 1	29 ± 23
Ash Hollow Formation	1	3	31	5		40	0.3	9	4	2		6	37
Pussy Springs	3	3 ± 2	54 ± 4	5 ± 2		15 ± 3	0.3	13 ± 3	3	2 ± 1		5 ± 1	31 ± 11
Harrison-Monroe Creek Formations undifferentiated	10	41 ± 13	19 ± 7	4 ± 2	0.1	17 ± 6	2.5	7 ± 2	6 ± 2	4 ± 1		1 ± 1	49 ± 12
Gering Formation	4	51 ± 10	10 ± 6	3 ± 1	0.2	18 ± 4	3.0	4 ± 1	8 ± 2	3 ± 1	0.1	2 ± 1	60 ± 9
Arikaree Group	14	44 ± 12	16 ± 8	4 ± 2	0.1	17 ± 6	3.0	6 ± 2	7 ± 2	4 ± 1	0.1	1 ± 1	52 ± 12
Whitney Member (sandy facies)	16	63 ± 12	9 ± 5	4 ± 3	0.2	12 ± 5	2.2	3 ± 2	5 ± 2	3 ± 1	0.2	1 ± 1	67 ± 10
Whitney Member (clayey facies)	3	54 ± 27	8 ± 5	3 ± 2		20 ± 13	2.5	2 ± 2	8 ± 6	3 ± 1	0.2	2 ± 1	86 ± 10
Whitney Member, ash beds	5	82 ± 5	1 ± 1	1 ± 1		8 ± 4	4.3	1	4 ± 1	2 ± 1	0.1	1 ± 1	81 ± 6

Note: Mineralogic data on individual samples given in Appendix A. Location of samples in Appendix B. n is number of samples. Percent silt and clay in total sample determined by sieving.

Excluding the volcanic ash samples, the Whitney can be generally characterized as a volcaniclastic siltstone (Pettijohn, Potter, and Siever 1972, p. 261). Glass shards, both pumiceous and bubble wall (Fig. 4) types, are by far the dominant grain element. Thus these sediments can be further classified as vitric siltstones. Because of the problems in positively identifying volcanically derived quartz, plagioclase, and heavy minerals, the total percentage of volcanic material present in these samples is difficult to estimate. However, by also counting the number of glass-mantled quartz, plagioclase and heavy minerals and combining these percentages with those of glass shards and acidic volcanic rock fragments, a minimum volcanic contribution can be determined. The total percent of these glassy grains was plotted against total quartz and total feldspar. As shown in Figure 10, the Whitney averages a minimum of 75 percent volcanically derived grains and less than 25 percent epiclastic grains. Based on comparisons of glass and non-glass mantled grains, I estimate 80 percent of both the plagioclase and heavy mineral categories are volcanic in origin.

As shown in Figure 10 the mineralogy of the Whitney ash beds is essentially indistinguishable from that of some samples of the Whitney siltstone. This creates somewhat of a semantic problem. One must distinguish between a volcanic ash bed defined on field criteria such as color, texture, distinctive weathering profile, and lateral extent; and one defined essentially on mineralogy. Due to the

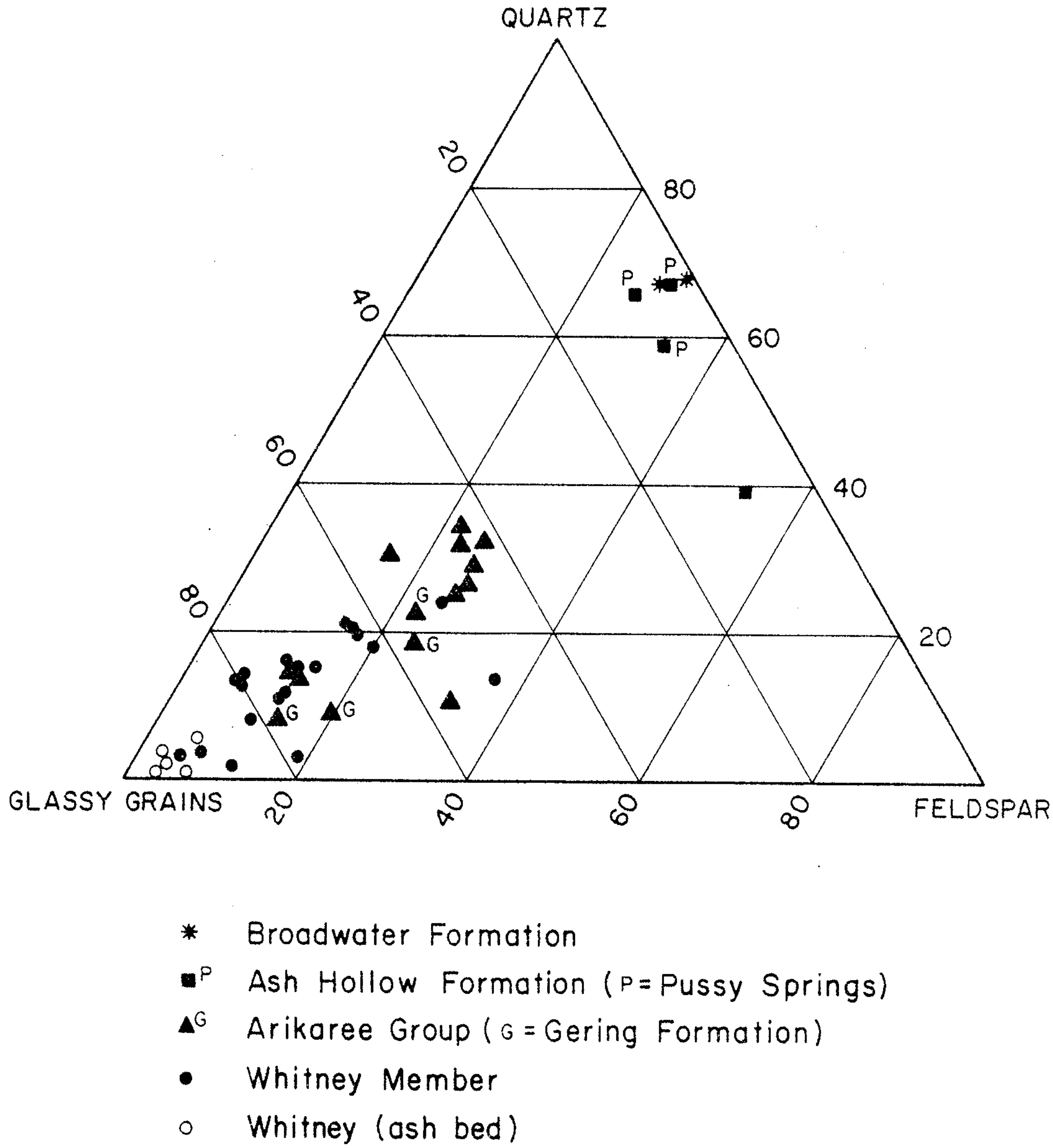


Figure 10. Plot of quartz, feldspar and glassy grains in the very fine sand fraction of stratigraphic units in the study area. Data from Appendix A.

fine grain size, clay rims, and adhering finer particles it is almost impossible to estimate glass shard percentages of the Whitney sediments in the field or in the laboratory using a binocular microscope. Not until the grains are cleaned or a thin section is made can accurate percentages of the grain categories be determined.

Glass shard percentage in the very fine sand size was plotted against the percent silt and clay in the Whitney samples (Fig. 11). The Whitney samples (excepting the ash beds) indicate no correlation between grain size and glass shard percentage. (A value of r was computed to be 0.10 and the value of r at the 5 percent level of significance with 19 degrees of freedom is 0.39). However, removal of the apparently spurious sample (LJ78-37, Appendix 4) yields a small but statistically significant correlation. A value of r was computed to 0.45 and the value of r at the 5 percent level of significance with 19 degrees of freedom is 0.40.

The upper contact of the Whitney Member with either the Gering Formation or the Harrison-Monroe Creek formations, undifferentiated will be discussed in the sections pertaining to those units.

Environment of Deposition

Because of the textural and general lithologic resemblance to the Pleistocene Peorian loess of the Great Plains, Schultz and Stout (1955) and Schultz and Falkenbach (1968) consider the Whitney Member to represent an ancient loess,

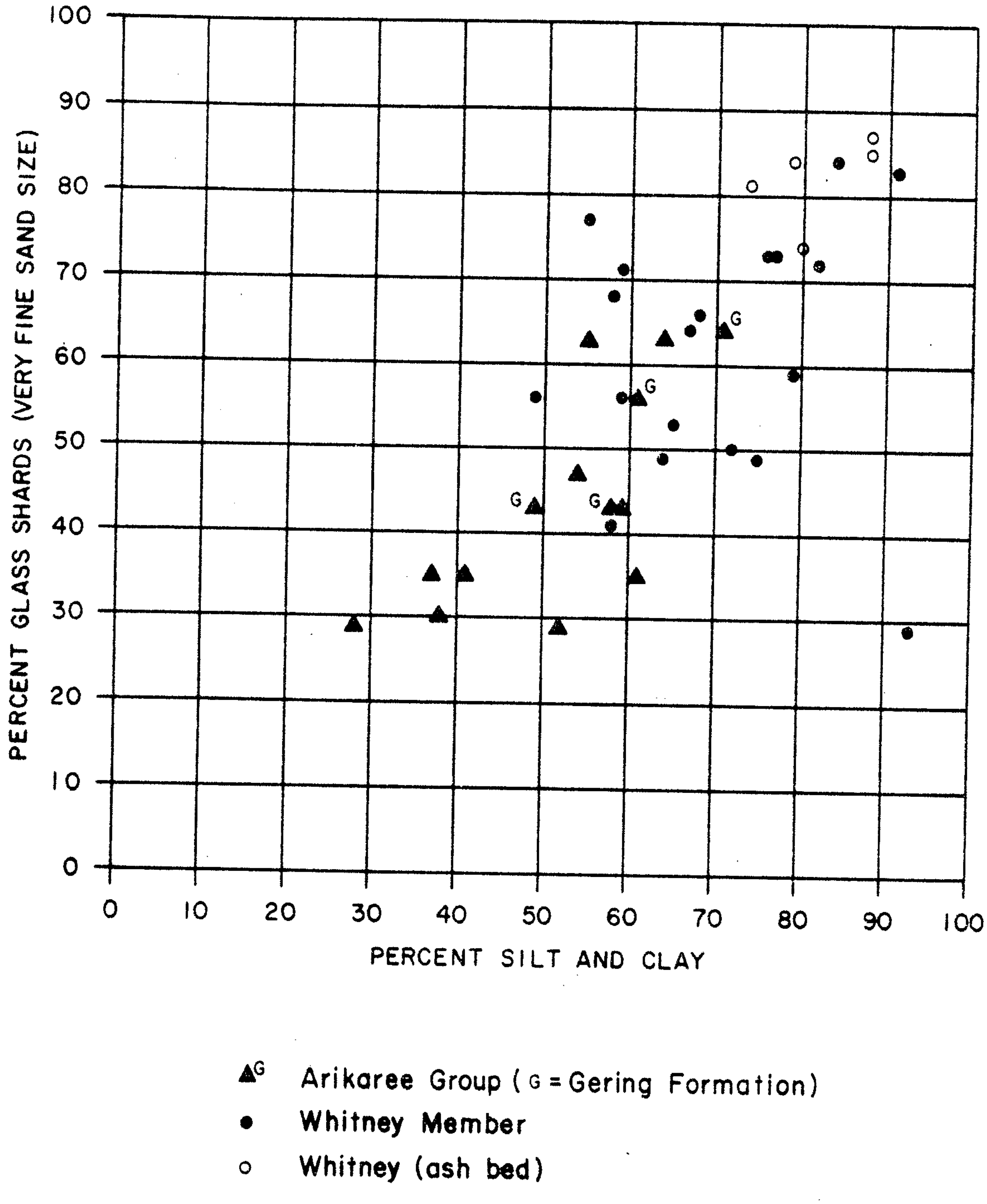


Figure 11. Plot of percent silt and clay vs percent volcanic glass shards in Arikaree and Whitney samples.

except for local fluvial and lacustrine facies. The apparent widespread and uniform occurrence of the two main Whitney ash beds, and the relatively uniform distance between them would be difficult to explain in a largely fluvial environment. The large percentage (about 75 percent) of volcanically derived grains (Fig. 10) and the absence of bed forms and sequences typical of fluvial deposits strongly suggest most of the Whitney Member in the study area was deposited by wind. The small diameter burrows present in these sandy units are similar to some of the insect burrows described by Stanley and Fagerstrom (1974) as typical of braided stream environments. However, I have observed similar burrows in fine sands of eolian dunes in the Nebraska Sand Hills. Ahlbrandt and others (1978) demonstrated that a wide variety of insects produce bioturbation features, including burrows, in eolian deposits.

It is possible the sandy units represent local areas winnowed by the wind after initial eolian deposition of fine grained, unconsolidated material. It is still difficult to explain the absence of all but crude horizontal bedding and local laminations. The lack of distinct bedding and gradual nature of the grain size changes in the Whitney Member may be a product of essentially continuous and slow deposition of the volcanic material and reworking of the newly fallen ash by organisms. Fisher (1966, p. 717) interprets the massive volcaniclastic siltstones of the John Day Formation to have formed as a result of "continuous homogenizing processes... where newly-arrived particles are mixed into the soil zone by "burrowing animals, by frost heaving and root wedging which tend to destroy sharp textural changes."

I agree with Schultz and Stout (1955) and consider the "typical" clayey facies of the Whitney an eolian deposit. The sandy facies represents a continuation of eolian deposition but perhaps with local or secondary eolian reworking. In a general sense, the increase in volcaniclastic particles in the stratigraphically higher parts of the Whitney may be tied to a change in the volcanic source characteristics, such as distance from the Great Plains, or perhaps an increase in high altitude wind strength allowing coarser material to be carried further east.

Schultz and Falkenbach (1968) reasoned on the basis of faunal evidence that deposition of the Whitney Member occurred under essentially desert conditions.

Age

Wood and others (1941) placed the Whitney Member in the Late Oligocene and correlated it with the Chattian of Europe. They also proposed a new North American Mammal Age, the Whitneyan. Schultz and Stout (1955, p. 47) likewise placed the Whitney Member of the Brule Formation in the Late Oligocene but correlated it with the Aquitanian of Europe. Tedford and others (in press) place the Whitney near the middle of the Oligocene, with an upper age of approximately 29 million years (Fig. 2).

I collected only one fossil (an oreodont) from the Whitney (FJ78-38, Appendix D). In the 1950s Morris Skinner (written communication, September, 1978) collected considerable fossil material from the clayey facies of the Whitney in the study area as have field parties of the University of Nebraska State Museum. There appears to be agreement on assignment of these fossils to the Whitneyan. However, fauna collected from the sandy facies of the Whitney in the Ruby Ranch area (Plate 2, Section #10; Fig. 8) has been referred to the Whitney Member by Skinner (written communication, September, 1978) and to the Gering Formation by Schultz and Falkenbach (1968) and Stout (personal communication, 1979). This difference in terminology relates to the Gering "floodplain" problem described earlier and will be discussed in more detail below.

Gering Formation

The Gering Formation was named by Darton (1899) for a series of bedded, fine to coarse sands unconformably overlying the Brule "clay" and conformably underlying the Arikaree Formation. He noted a conglomerate of local origin often occurred at the base of the Gering. As mentioned in the introduction, Darton (1899, Fig. 220 and Pl. CI, A and B) made specific note and illustration of the Gering Formation overlying a stratigraphically high sandy facies of the Brule "clay."

Lugn (1939) after a proposal by Schultz (1938) assigned group status to the Arikaree Formation of Darton (1899) and included the Gering Formation as the lowest formation of the Arikaree Group.

In the Wildcat Ridge area Vondra, Schultz, and Stout (1969) divided the Gering into two members: the Helvas Canyon Member (below) and the Mitchell Pass Member (above). They proposed Helvas Canyon as the type locality for the Gering Formation (Fig. 1). A pumice-pebble conglomerate, designated the Twin Sisters Pumice Conglomerate Bed, was said to occur extensively at the base of the Mitchell Pass Member. Vondra (1963), Schultz and Falkenbach (1968), and Vondra, Schultz, and Stout (1969) characterized the Gering as mixed fluviatile, colluvial, and eolian sediments of an ancient valley system cut into the Whitney Member of the Brule. The axial trends of the valleys are characterized by "grey channel sands" and "loess-like, and colluvial silt partly reworked from the Whitney, occurs progressively as one approaches the valley walls and main divides" (Vondra, Schultz, and Stout 1969, p. 2). Vondra (1963, p. 40-45), studied the deposits mapped as Gering by Darton, primarily channel fill deposits, and traced these sediments laterally away from the channel axes. Vondra reported the channel fill sediments graded and interfingered with Darton's sandy Brule and the unconformity at the base of the Gering, as defined by Darton, underlies these massive sandy siltstones. Vondra (1963) and Schultz and Falkenbach (1968, p. 423) referred to the sandy siltstones as "distant floodplain" deposits. However, most descriptions of modern floodplain and valley fill sediments (Pettijohn 1975, p. 550-551; Schumm 1977, p. 204-210) indicate that floodplain and valley margin deposits should display a wide variety of bedding types, interbedded lithologies, and evidences of exposure such as rootlet zones and caliches. Very few if any of these features are present in the sandy facies of the Whitney described above. Bart (1974) and Stanley and Fagerstrom (1974) presented sedimentological arguments suggesting the Gering and associated Arikaree Group fluvial systems were similar to modern braided or bed load streams. These streams are characterized by only a small percentage of fine-grained material in their valley fills (Schumm 1977, p. 206).

Distribution and Lithology

The Gering Formation is present in the extreme northwest corner of the study area (Pl. 1). In 1979, Robert Diffendal, Jr., first identified these outcrops as Gering because of the presence of pumice pebbles in cross-bedded fine sand. I visited these exposures and measured several sections (Pl. 2, Sections 5, 6, and 7). The dominant lithology of the Gering in these sections is a very silty, very fine to fine sand. Locally derived sandstone pebbles (lithic pebbles), small-scale crossbeds, and abundant abraded bone fragments occur in the Gering at the base of the Mad Bull Section (Pl. 2). In this area the Gering-Whitney contact has about 15 feet of relief. The largest pumice pebbles occur in a fine sand lens interfingered with the lithic pebble sand. At section 6 (Pl. 2) the Gering-Whitney contact is not sharp. The pumice pebbles occur as isolated clasts in a massive very fine to fine sand containing reworked claystone clasts (lithic pebbles) up to 7 cm in diameter.

At the Lime Point Section (Pl. 1) no pumice pebbles were found. However, locally a fine grained, cross-bedded sand up to 1.5 feet thick and containing abundant angular mudstone clasts unconformably overlies moderately sandy silt of the Whitney Member (Fig. 12). A 6- to 8-foot-thick, very thinly laminated limestone, containing mudcracks, burrows, and locally abundant ostracods, overlies the cross-bedded sand. The limestone was traced for about 0.3 miles to the northwest before it pinched out.

A lenticular deposit of light grey volcanic ash (10 feet thick) occurs about 1.3 miles east of the Lime Point Section (Pl. 2, section 8). The ash is thinly laminated in the upper 6 feet and can be traced for about 50 feet. This exposure is tentatively placed in the Gering Formation. A lower contact is not visible at this locality.

Stout (personal communication, 1979) indicated he would place the Gering-Whitney contact at an elevation of about 3690 feet in section 3 (Pl. 2) and at 3735 feet in the Ruby Ranch Section (Pl. 2). This contact is considerably lower than my mapped contact. The maximum thickness of the Gering as mapped in the study area is about 65 feet at the Mad Bull Section (Pl. 2). However the upper contact with the Harrison-Monroe Creek formations is poorly defined.

Figure 12. Contact of Gering Formation and Whitney Member at Lime Point section (Section 7, Pl. 2). The ledge is a laminated, argillaceous limestone with mudcracks and locally abundant ostracods. A discontinuous cross-bedded, fine sand up to 1½ feet thick and containing angular mudstone clasts occurs beneath the limestone and unconformably overlies a sandy silt unit in the Whitney Member. Location is NW corner sec. 23, T. 19 N., R. 48 W. The shovel is 28 inches long.


Teg
Tobw

Four samples of very sandy silt from the Gering Formation were selected for mineralogic analysis (Table 1, Fig. 10, Appendix A). They are similar to the Whitney Member samples in overall mineralogy, but contain about 10 percent fewer glass shards and slightly more plagioclase.

A mineralogic comparison of the 4 Gering Formation samples and the 17 samples of the sandy facies of the Whitney was made using Student's t distribution. A value of t was computed to be 1.48. The value of $t\alpha\,(n-2)$ for $\alpha = 0.05$ and df = 19 is 2.09. Since 1.48 is less than 2.09, I conclude these samples are not significantly different. However with only four samples of Gering Formation the test is not very sensitive.

Pumice pebbles from the Mad Bull Section (Pl. 2) were compared with pumice pebbles from Helvas Canyon, the type section of the Gering Formation (Fig. 1). The glass from each locality has equal indices of refraction of 1.500 as determined by the oil immersion technique. Both samples contained sanidine as the major phenocryst. The pumice pebbles from both samples exhibit a similar color range, ie. light grey to yellowish grey. Diffendal (1979) described the above mentioned similarities between pumice pebbles from north of Broadwater and from Redington Gap, 22 miles west. The very sandy silt matrix occurring with the pumice pebbles, (samples LJ78-85 and LJ78-87, Appendix A) contains plagioclase as the predominant mineral of volcanic origin; only two grains of sanidine out of 600 total grains were noted in the two samples. This suggests volcanic constituents in the matrix have a source different from that of the pumice pebbles.

Environment of Deposition

The Gering Formation in the study area includes sediments deposited in fluvial, lacustrine, and possibly eolian environments. The lowest Gering exposures (Mad Bull Section, Pl. 2) exhibit the best evidence for fluvial origin: (1) cross-bedding; (2) abundant, rounded, small bone fragments; (3) reworked lithic pebbles; (4) an erosional lower contact; and (5) locally abundant pumice pebbles. Izett (1975) suggested the pumice pebbles originated from the Specimen Mountain area in North Park, Colorado. Izett further postulated that the pebbles were swept down the ancestral North Platte and Laramie River valleys and deposited in the Gering Formation along Wildcat Ridge.

Diffendal (1979) interpreted the Gering paleovalley in the Broadwater area to have an east-northeast trend based on the distribution of pumice-pebble conglomerate both in the study area and adjacent areas to the north and west.

The thinly laminated limestone at the Lime Point Section (Pl. 2) was probably deposited in a small shallow lake, possibly a playa. The massive, fining upwards units with floating pumice pebbles may represent eolian reworking of fine-grained fluvial sediments.

Age

Obradovich and others (1973) dated sanidine from pumice pebbles in the Gering type section at 27.0 ± 0.6 m.y. (K-Ar). Zircons from the pumice yielded a fission-track age of 26.8 ± 2.5 m.y. The Mitchell Pass Member of the Gering and the pumice-pebble bearing unit was placed in the early Arikarean North American Mammal Age and in the upper Oligocene by Tedford and others (in press). Traditionally the base of the Gering has been taken to be the base of the Miocene in the Great Plains (Lugn 1939, Wood and others 1941, Schultz and Stout 1961).

Harrison and Monroe Creek Formations, Undifferentiated

Hatcher (1902) divided Darton's (1899) Arikaree Formation into the Monroe Creek beds (lower) and Harrison beds (upper) in northwestern Nebraska. Hatcher's divisions were based primarily on the different types of concretions in the two units and the occurrence of Daimonelix structures in the Harrison Formation. Darton (1899, p. 743) described the Arikaree as a light grey fine sand containing a large amount of intermixed volcanic ash and having characteristic layers of hard, fine-grained, dark grey concretions he called "pipy concretions." Darton said the Arikaree had a thickness of 400 feet in Scotts Bluff County.

Lugn (1939) elevated the Arikaree Formation of Darton to group rank and included in it the Gering, Monroe Creek and Harrison Formations. Mainly on the basis of the type of concretions present in Darton's Arikaree, Lugn (1939, Pl. 1) correlated the Monroe Creek and Harrison Formations with exposures in the North Platte River Valley. I have spent considerable time in the field examining Lugn's Harrison-Monroe Creek contact north of Scottsbluff and Mitchell, Nebraska. I have also examined in some detail Hatcher's typical exposures of the Monroe Creek and Harrison north of Harrison, Nebraska. In addition, I have made a detailed study of the cuttings from a series of 17 test holes drilled by the Conservation and Survey Division between the foot of Monroe Creek Canyon and the edge of the North Platte River Valley. All these observations have made me very cautious in correlating the Harrison and Monroe Creek Formations over long distances. Aadland (1959) mapped the Monroe Creek Formation in the Wildcat Ridge area. I am in complete agrement with his statement (p. 30, 31):

> "In the main parts of the ridge... it is seen that the Monroe Creek-Harrison contact is conformable to such an extent that it is difficult to distinguish the two. Where the Monroe Creek-Harrison contact is conformable, the writer decided that the lithologic break was not distinctive enough to warrant a mappable unit separate from the Monroe Creek."

For the purposes of this study I mapped a Harrison-Monroe Creek Formation, undifferentiated unit which corresponds to Darton's Arikaree Formation. I will refer to these sediments as the Harrison-Monroe Creek unit.

Distribution and Lithology

The Harrison-Monroe Creek unit crops out in the western third of the study area (Pl. 1). The unit reaches a maximum thickness of about 150 feet in sec. 18, T. 19 N., R. 47 W. It thins in a general southeastward direction to a zero edge (Fig. 6).

The Harrison-Monroe Creek unit is predominantly a massive, yellow brown to yellow grey, very fine, well sorted, silty sand. Calcareous pipy concretion ledges and pseudo-pipe concretion zones are present. Poorly defined horizontal bedding and locally abundant vertical tubules (insect burrows ?) are the only common original sedimentary structures present. The vertical tubules generally 2 to 8 mm in diameter can best be seen on the weathered surface of a concretionary ledge. The tubules are tentatively interpreted as insect burrows because they were not observed to taper downwards and occasionally have meniscus layers similar to those described by Stanley and Fagerstrom (1974). However, it is possible some of these tubules represent root molds and casts (Ahlbrandt and others 1978, p. 846).

Local limestone units up to 8 feet thick can be traced for 0.3 miles. The limestones have a variety of laminated, massive, and brecciated subunits and locally contain ostracods. A particularly good example of the limestone is found in the N 1/2 NE sec. 30, T. 19 N., R. 47 W., approximately 15 feet below the Ash Hollow contact. Because no distinctive characteristics were noted for the limestones they are of questionable use for correlation.

Ten samples of the Harrison-Monroe Creek unit were selected for mineralogic analysis (Table 1, Appendix A). The average grain size is essentially at the sand-silt boundary. As in the case of the Whitney and Gering sediments, glass shards are the most abundant grain type. Quartz and plagioclase are about equal in percentage. Fig. 10 indicates volcanically derived grains from Arikaree Group sediments make up 40 to 80 percent of the very fine sand fraction of the samples. This percentage is similar to one reported by Stanley (1976) although the Arikaree Group samples in his study had a mean size of fine sand. Souders, Smith, and Swinehart (in press) report a mean of 27 percent glass shards in the very fine sand fraction for 26 samples of fine grained Arikaree Group sediments from Conservation and Survey Division test holes in Box Butte County.

The glass shard percentages in 16 samples of the sandy facies of the Whitney were compared to those of 14 samples of the Arikaree Group using Student's t distribution. A value of t was computed to be 4.23. The critical value of $t_{\alpha}(n - 2)$ for $\alpha = 0.05$ and df = 28 is 2.05. Since 2.05 is less than 4.23 I conclude there is a statistically significant difference in glass shard content between the two groups.

Souders, Smith, and Swinehart (in press) observed no overlap in glass shard percent in the very fine sand fraction of 26 Arikaree Group samples ($\bar{X}$ = 27 percent) compared to 26 test hole samples of a sandy upper Whitney unit ($\bar{X}$ = 58 percent). Stanley (1976, Table 1, p. 301) apparently considered the volcaniclastic sandstones and siltstones of the Arikaree Group and the Whitney Member to be a single volcaniclastic petrofacies. As described above there are significant mineralogic differences between Arikaree Group and Whitney Member sediments. Thus, it is possible that stratigraphically useful subdivisions of the High Plains volcaniclastic petrofacies can be established. As this petrofacies makes up as much as 80 percent of the total volume of Arikaree and White River Group deposits in western Nebraska, such subdivisions should prove useful.

The percent silt and clay vs percent glass shards was plotted (Fig. 11) for the Arikaree Group and Whitney Member samples excluding the Whitney ash beds. There is a highly significant correlation ($r = 0.65$, significant at the 1 percent level for $\alpha = 0.05$) between grain size and percent glass. The finer grained the sample the greater the percentage of glass in the very fine sand size. This probably reflects the increase of epiclastic material in the coarser sediments of the Arikaree.

The contact between the Harrison-Monroe Creek unit and the Whitney member (primarily the sandy facies) was probably the most difficult contact to map (Pl. 1 and 2). In this study the contact is mapped using:

(1) grain size and texture--the sandy facies of the Whitney is slightly finer grained.

(2) overall bed geometry--individual sandy units in the Whitney are lenticular and cannot be traced for long distances; Harrison-Monroe Creek unit sands are continuous.

(3) color— the Whitney is generally lighter brown and the Harrison-Monroe Creek unit has greyish tones.

In some areas there is a sharp contact between these units (Pl. 2, Section 11) but only 0.5 miles northwest (Pl. 2, Section 9) it is difficult to locate a contact. Darton had the same difficulties at certain localities to the west. Darton (1899, p. 744) states:

> "Along the north side of the Platte Valley, the south side of the Pumpkin seed [Pumpkin Creek] Valley, and in portions of the ridge between these two valleys the Arikaree Formation appears to lie directly on the Brule Clay. In these instances there is often either only a faint suggestion of unconformity between the two formations when the exposures are carefully examined or simply a very rapid change from sandy, pinkish Brule clay, with some small siliceous concretions, to fine grey sands with the typical character and pipy concretions of the Arikaree Formation."

Recognition of the contact between stratigraphically high parts (sandy facies) of the Whitney Member and the Harrison-Monroe Creek unit in the subsurface of western Nebraska is also difficult (Souders, Smith, and Swinehart, in press). In areas where the typical fluvial Gering Formation occurs, based on either sample cuttings or E-log characteristics, it is relatively easy to pick an Arikaree Group-Whitney contact. However, away from the Gering paleovalleys, there is often a transition zone, tens of feet thick, between the Harrison-Monroe Creek unit and the sandy facies of the Whitney. Test drilling by the Conservation and Survey Division in Box Butte and Dawes counties (Swinehart and Souders, 1979) has established the presence of a sequence of sandy volcaniclastic siltstone up to 400 feet thick overlying a clayey siltstone facies of the Whitney Member of the Brule. The base of the sandy siltstone is approximately 180 feet above the Upper Ash of the Whitney. The sandy siltstone is unconformably overlain in south central Dawes County by the Gering Formation and may in part be correlative with the sandy facies of the Whitney discussed above.

Environment of Deposition

The lack of primary sedimentary structures, excellent sorting, and very loose grain packing indicate the wind played a large role in bringing material to the site of deposition. Some reworking by streams probably took place; however, the lack of sedimentary structures suggests fluvial influence was minimal. Discontinuous limestones probably indicates the presence of very shallow lakes. Stanely and Benson (1979) suggested deposition of the upper White River Group and lower part of the Arikaree Group took place under arid to semi-arid conditions. Schultz and Falkenbach (1968), based on faunal evidence, interpreted the climate during deposition of the Gering and Monroe Creek formations to be more humid than during deposition of the Whitney Member.

Age

The Harrison and Monroe Creek formations have traditionally been placed in the Early Miocene (Lugn 1939, Schultz and Falkenbach (1968). Tedford and others (in press) place the Monroe Creek in the Late Oligocene and the Harrison in the Early Miocene.

Brief Review of the Ogallala Group and Ash Hollow Formation

The Arikaree Group is overlain by two stratigraphic units belonging to the Ogallala Group (Pl. 1, Fig. 6 and 7). The Arikaree and Ogallala groups are separated in time by a large hiatus (Fig. 2). Darton (1899, p. 734-735) applied the name "Ogallala Formation" to a "calcareous formation of late Tertiary age... which in Kansas and southward has been called the 'Mortar beds,' 'Tertiary grit' and other names." Lugn (1938) raised the Ogallala to group status and divided the Ogallala into the Valentine, Ash Hollow, Sidney and Kimball formations. He was then informed by Stout that Engelmann in 1876 (Stout and others, 1971) had already proposed the name, Ash Hollow, for rocks exposed at the mouth of Ash Hollow Canyon. Lugn (1939) subsequently proposed a type locality for the Ash Hollow Formation at Ash Hollow Canyon in the NE sec. 3, T. 15 N., R. 42 W. (Fig. 2).

Schultz and Stout (1941), Skinner, Skinner and Gooris (1968) and Stout and others (1971) reviewed the Ogallala Group terminology. Swinehart (1974) and Breyer (1975) present some reinterpretations of this terminology.

Pussy Springs Channel Complex, Ash Hollow Formation

While on a field trip in 1975 with Morris Skinner, Richard Tedford, and Michael Voorhies I became aware of a series of channel-form deposits cut into the Whitney about 7 miles east of Broadwater. These deposits had been the site of fossil vertebrate collections by University of Nebraska State Museum field parties and by Morris Skinner of the Frick Laboratory. According to Skinner (personal communication, September, 1978), this locality has been referred to as the Pussy Springs area by most previous workers. During the course of field mapping I recognized the sediments filling these channels were lithologically different from those of the Ash Hollow Formation and could be mapped. The informal name Pussy Springs channel complex was chosen for this unit. Although the name Pussy Spring does not appear on any of the 1:24,000 scale topographic maps of the area, it does appear on the U.S.G.S. Browns Creek 1:125,000 scale topographic map of 1896 (Pl. 1, NW sec. 10, T. 18 N., R. 47 W.).

<u>Distribution and Lithology</u>

The Pussy Springs unit consists of a heterogeneous set of lithologies, from thin claystones to lenticular sands and gravels, and occupies several channels cut deep into the Whitney Member (Pl. 1, Fig. 6). Exposures of the Pussy Springs unit are confined to secs. 3, 4, and 10, T. 18 N., R. 47 W. The main deposits occur in an easterly trending "anastomosing" channel complex which makes an abrupt turn to the south in the center of sec. 3, T. 18 N., R. 47 W. Two small isolated exposures occur in the N 1/2 SW sec. 33, T. 19 N., R. 47 W. The maximum exposed thickness is about 130 feet in the center NE sec. 4 and NE NW sec. 10, T. 18 N., R. 47 W. The lowest Pussy Springs deposits occur in channels cut about 170 feet below the base of the Ash Hollow Formation and 50 to 60 feet below the Upper Ash of the Whitney (Fig. 6).

The most common lithologies in the Pussy Springs unit are yellow brown to brown, thin-bedded, very silty, very fine to medium sands and crudely bedded, poorly sorted sand and sandstone with local gravel lenses. An exposure of silty sands at the base of the unit in the NE SE 4, T. 18 N., R. 47 W. has an overall pale olive color.

The coarser grained sediments are more common in the lower 50 feet of the channel fills and near the channel margins (Appendix B, stratigraphic sections 13 and 15). There are many excellent exposures of the contact with the Whitney Member. Reworked Whitney siltstone clasts (up to 2 feet in diameter) are common in the basal 5 feet (Fig. 13). The contact (channel edge) locally is inclined as much as 20°. Clasts of reworked Arikaree pipy concretions are also locally abundant and in several localities have been cemented by calcium carbonate into coarse conglomerates. One of the best exposures of this lithic conglomerate is on the south side of a prominent knob in the NW NE NW NW sec. 10, T. 18 N., R. 47 W.

Pebble lenses composed predominantly of granitic clasts with some acidic volcanic pebbles are generally less than one foot thick and are very limited in extent. Because the pebbles form a lag deposit one would estimate a much higher percentage of pebble-sized material then is actually present in the unit.

The upper 30 feet of the Pussy Springs unit near the center of the NE sec. 4, T. 18 N., R. 47 W. consists of thin, bioturbated, sandy siltstones interbedded with thin, ripple laminated, very fine to fine grained sandstones (Appendix B, section 15).

Only rare "mortar beds" and no siliceous root cast (paleosods) horizons, typical of the overlying Ash Hollow Formation, are visible in these deposits. In fact, very little in the way of diagenetic features are present. It is surprising therefore that primary depositional structures such as cross-beds are not common. Crudely expressed horizontal bedding is the most common sedimentary structure. Some cross-bedded units were observed with both planar and trough cross-bed sets up to 1.5 feet thick. Four sets were

Figure 13. Lower contact of the Pussy Springs channel complex with the Whitney Member. Cobble size blocks of Whitney siltstone, reworked concretions and igneous pebbles occur in a poorly sorted silty sand matrix at the base of the Pussy Springs unit. Location is NE NW SE sec. 4, T. 18 N., R. 47 W. Shovel is 28 inches long.

Figure 14. Thin, interbedded pebbly, silty sand and sandy siltstone in the lower part of the Pussy Springs unit. The beds have about a 7^{o} original dip away from the channel edge. The outcrop is 60 feet north of the Pussy Springs and Whitney contact. Location is cen NE SW NE sec. 4, T. 18 N., R. 47 W. Shovel is 20 inches long.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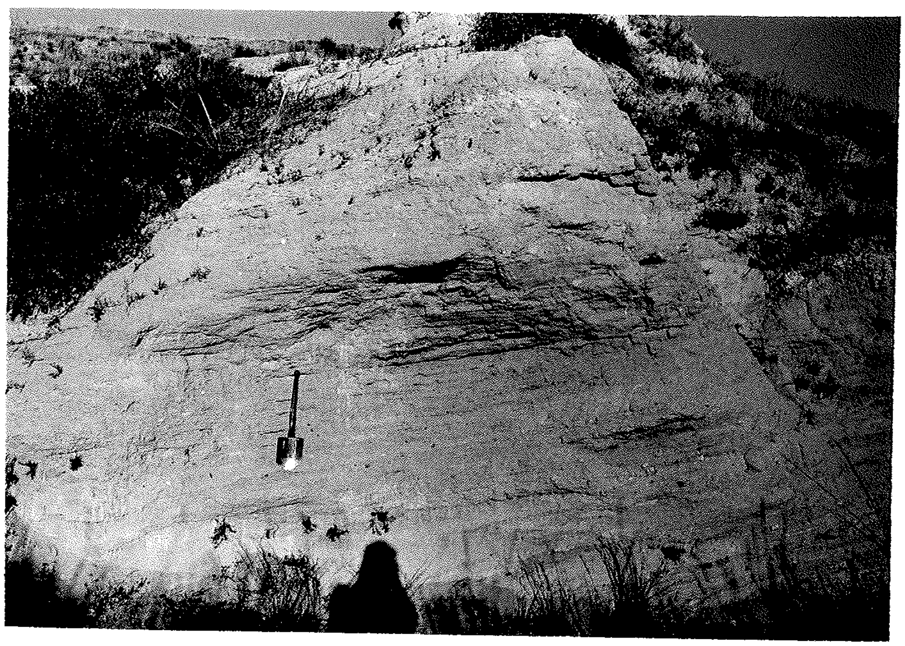


measured at each of three localities. The average cross-bed orientation at each site is shown on Plate 1 (NE sec. 4 and NW sec. 10, T. 18 N., R. 47 W.). Cross-bed orientations essentially agree with the channel trend defined by the channel boundaries. Several localities were noted near the channel margins where the sediments had depositional dips of up to 7° away from the channel edge (Fig. 14).

The mineralogy of three samples from the Pussy Springs unit is given in Table 1 and Appendix A. Samples LJ78-8A and LJ78-45 were taken from silty sands near the base of the unit. Since they have a superficial resemblence to the sandy units of the Whitney I expected them to contain a fair amount of reworked Whitney in the form of glass shards. However, the two samples contain only 4.3 and 0.3 percent glass shards respectively and have over 50 percent quartz and essentially equal amounts of plagioclase and potash feldspar. The silty sands are therefore classified as arkoses. Sample LJ78-96 from higher in the same channel has essentially the same mineralogy. Thus, although the fine-grained material in the Pussy Springs unit is similar in color and appearance to the sandy facies of the Whitney, the two units are very distinct mineralogically (Fig. 10). The only significant incorporation of Whitney material into the Pussy Springs sediments which can be documented occurs near the channel margins where discrete fragments of Whitney siltstone are incorporated in the base of the Pussy Springs unit (Fig. 13).

In the main body of exposures the Pussy Springs channel complex cannot positively be shown to underlie typical Ash Hollow Formation lithologies. However, in the isolated outcrop of the Pussy Springs unit in the SE NW SW 33, T. 19 N., R. 47 W. it can be shown to conformably underlie the Ash Hollow Formation (Pl. 2, Section 3). At this locality the Pussy Springs unit consists mostly of brown sandy siltstones and silty sands with local pebbly lenses that fill a narrow (about 250 feet wide) channel cut into the Whitney Member. This channel has a basal elevation of about 3720 feet. This is approximately 40 feet higher than the highest Pussy Springs exposure one mile to the southeast and 120 feet above the lowest exposures 0.8 mile south southeast.

This local exposure probably represents a small, high gradient (50 to 100 feet/mile) tributary to the main channel.

Environment of Deposition

The Pussy Springs channel complex represents a significant change from eolian-dominated environments of the Whitney and Arikaree Groups to fluvial dominated environments of the Ash Hollow and Broadwater units.

I interpret the Pussy Springs unit to have been rapidly deposited by a combination of fluvial and mass wasting processes. The relations at the channel margins (Fig. 13) suggest that much colluvial material was carried into the channel by mass wasting. The absence of pedogenic features and unconformities suggests the entire sequence was deposited rapidly. The general scarcity of cross-bedding and the geometry of the pebbly lenses suggest that low bars were the predominant bedform in the stream bed . It is possible that these channels were similar to modern arroyos described by Anteves (1952) and Bull (1964) and the sediment fill may be largely the product of ephemeral stream deposition. Cross-stratification produced by migrating large- and small-scale ripples during times of flood in ephemeral streams as described by Williams (1971) would be subject to modification and destruction by wind and animals during times of no flow.

Age

Published descriptions of the vertebrate material collected from the Pussy Springs channel complex by the University of Nebraska State Museum or the Frick Lab are not available. However, Mike Voorhies and Morris Skinner, examined some of the previously collected material along with that collected by Bob Diffendal and myself from various localities in the Pussy Springs unit (Appendix D). Based on this examination Voorhies and Skinner (personal communication, 1979) suggested a Clarendonian Age (Late Miocene) (Fig. 2) for the unit. This agrees with the stratigraphic evidence showing the Pussy Springs unit underlies the Ash Hollow Formation which contains a Hemphillian Age mammal fauna in this area.

Ash Hollow Formation

The lithology of the unit mapped as Ash Hollow Formation in the study area is very similar to that at its type section in Ash Hollow Canyon (Fig. 1).

The Ash Hollow Formation is exposed throughout the map area and in the eastern half comprises the majority of exposures (Pl. 1). It has a maximum thickness of about 200 feet (Fig. 7). The maximum thickness is difficult to estimate accurately from outcrops because of the long distance one must traverse from the lower to upper contact.

Ash Hollow Formation sediments are characterized by a heterogeneous assemblage of sands to sandstones, sandy siltstones, sand and gravels, carbonate cemented sandstone ledges ("mortar beds"), bedded and massive silts and clays, volcanic ash beds, and siliceous fossil root cast horizons (paleosods). Predominant colors include light browns, yellow browns, red browns, and pale olives. Volcanic ash beds and carbonate cemented ledges ("mortar beds") are generally light grey in color.

Attempts were made to trace out individual homogeneous units (eg. volcanic ash beds) or assemblages of beds such as sand and gravel bodies. Generally this approach proved successful in only limited areas. For example, two sand and gravel filled channels, about 30 feet thick and from 200 to 700 feet wide were traced for almost one mile in sec. 17, T. 18 N., R. 46 W. (Pl. 1). However in most cases it was not possible to relate vertical and horizontal lithologic changes within a local area to those of a nearby area. For example, Ash Hollow exposures in sec. 2, T. 18 N., R. 47 W. are predominantly sands and gravels with local lenses of silty very fine to medium sand to sandstone and relatively few "mortar bed" ledges. Another group of Ash Hollow exposures, about 1.2 miles southeast of sec. 2, are characterized by "mortar bed" ledges, siliceous root cast horizons, and very local sands and gravels.

One exception to these essentially unpredictable sequences of lithologies was a group of lenticular calcareous mudstones, laminated sandy siltstone, and cross-bedded pebbly sand associated with a light grey volcanic ash bed, up to 20 feet thick, occurring intermittently over a distance of about 5 1/2 miles (secs. 18, 19, 20, 29, 30, 33 and 34, T. 19 N., R. 47 W. and sec. 13, T. 19 N., R. 48 W.). The mudstones locally contain ostracods and gastropods. The sediments range in color from pale greenish yellow to very pale orange. This sequence occurs 10 to 50 feet above the base of the Ash Hollow Formation (Fig. 6). Three other volcanic ash localities were noted (Pl. 1), including one with two ash lentils in superposition (SW SW 19, T. 18 N., R. 46 W.). However, because of the distance between these limited exposures, I did not attempt to correlate these ashes.

As mentioned above, trends of some sand and gravel channels were visible (Pl. 1). In addition cross-bed orientations were measured at several localities. The mean orientation of the cross-beds (3 to 5 measurements were made at each locality) are plotted on Plate 1. The channel orientation and cross-bed data suggest a general east to southeast paleoflow direction for the Ash Hollow streams.

Only one sample of Ash Hollow sediments was selected for mineralogic analysis (Table 1, Appendix A). Plagioclase is the predominant mineral and, like the Pussy Springs samples, this Ash Hollow sample is classified as an arkose.

Two Ash Hollow gravel samples were collected for pebble type analyses and determinations of maximum clast size were made on Ash Hollow gravels at two localities. These gravels were relatively easy to characterize mineralogically as over 90 percent of the pebbles in the 16 to 32 mm size range (-4 to -5 phi) could be classified either as granite, quartz, or as acidic volcanic pebbles (Table 2 and 3). The presence of about 10 percent rhyolitic to andesitic, purplish to reddish volcanic pebbles and the general absence of "dark-colored" pebbles (Table 2) were easily recognized in the field. Casual examination of gravels during field mapping suggests this pebble assemblage is characteristic of Ash Hollow gravels. Fossil bone fragments were relatively easy to find, although they comprised much less than 1 percent of any Ash Hollow gravel deposit. A similar composition, except for a lower percentage of volcanic pebbles, was reported by Stanley and Wayne (1972) for Ash Hollow gravels in the southern Panhandle of Nebraska. The absence of anorthosite and related mafic plutonic pebble types suggests the Ash Hollow gravels had a source area

TABLE 2. PERCENTAGES OF PEBBLE TYPES IN THE BROADWATER, COARSE GRAVEL AND ASH HOLLOW UNITS. SAMPLE LOCATIONS IN APPENDIX C.

Unit Sample Number	Pink granite and feldspar	Grey granite and feldspar	Quartz	Quartzite	Anorthosite	Mafic plutonic	Acidic volcanic	Gneiss	Schist and phyllite	Aphanite	Chert	Sandstone, siltstone	Other	Number of pebbles
Broadwater														
GJ78- 1	43.5	16.0	9.7	3.3	1.8	4.1	0.5	2.8	–	0.7	2.0	8.6	6.6	393
GJ78- 2	41.5	21.3	9.0	1.1	4.8	2.1	0.9	5.9	–	1.1	1.3	5.6	7.0	456
GJ78- 5	41.3	13.7	9.6	5.2	3.8	4.9	0.8	5.6	0.2	0.2	2.5	8.4	3.8	366
GJ78- 6					1.3									300
GJ78- 7					3.9									335
GJ78- 9					1.6									378
GJ78-11	33.6	14.7	11.8	15.6	–	8.2	2.5	–	2.0	–	4.1	4.7	2.7	441
GJ78-15	40.2	18.0	11.4	4.4	1.5	4.4	0.8	7.2	0.2	0.4	4.4	4.0	2.9	473
$\bar{x} \pm \sigma$	40±4	17±3	10±2	6±6	3±1	5±2	1±1	4±3	< 1	< 1	3±1	6±2	5±2	
Coarse gravel														
GJ78- 3	36.4	15.5	4.7	4.4	1.7	3.4	0.4	13.8	2.3	1.1	3.0	1.3	11.9	528
GJ78-13	32.0	22.5	15.4	6.2	1.4	2.7	0.9	3.2	1.4	1.8	4.4	3.7	4.4	435
GJ78-14	32.3	10.8	16.9	8.1	1.8	11.6	0.8	1.0	2.0	3.3	3.0	2.0	6.3	492
$\bar{x} \pm \sigma$	34±2	16±6	12±7	6±2	2±0.2	6±5	< 1	6±7	2±0.5	2±1	3±1	2±2	8±4	
Ash Hollow														
GJ78- 4	40.1	24.4	14.7	–	–	–	8.9	1.5	0.5	0.3	–	3.6	6.3	394
GJ78-12	45.9	23.5	10.1	0.4	–	–	14.1	2.2	–	0.2	0.4	1.8	1.4	553
$\bar{x} \pm \sigma$	43±4	24±1	12±3	< 1	–	–	12±4	2±0.4	< 1	< 1	< 1	3±1	4±3	

TABLE 3

SUMMARY OF SELECTED PEBBLE TYPE PERCENTAGES IN THE BROADWATER, COARSE GRAVEL AND ASH HOLLOW UNITS IN THE STUDY AREA

	Number of Samples	Granitics and Quartz	"Dark" Pebbles Mafic plutonic Anorthosite Schist and phyllite Aphanite	Acidic volcanic
Broadwater Formation	5	67 ±4	8 ±2	1 ±1
Coarse gravel	3	62 ±7	11.5 ±6	<1
Ash Hollow Formation	2	79 ±1	<1	12 ±4

south of the Laramie Range anorthosite complex (Smithson and Hodge, 1972). The source of the volcanic pebbles, primarily ash flow tuffs, may have been the Miocene acidic volcanics of either North or Middle Park, Colorado (Izett, 1975).

In the study area, Ash Hollow gravel clasts were generally less than 6 cm in diameter. Measurements of the diameter of the intermediate (B) axis of the 10 largest clasts at 2 localities yielded values of 5.3 and 5.7 cm (Table 4). Stanley and Wayne (1972, Fig. 4) indicate a Tertiary (Ash Hollow ?) gravel locality between Broadwater and Lisco where the diameter of the intermediate axis of the 10 largest clasts is approximately 8 cm. Since no legal description was given for this sample, I was unable to examine this site. Of the many Ash Hollow gravels I studied during the field mapping none would have come close to an intermediate axis value of 8 cm.

The lower contact of the Ash Hollow, whether on the Pussy Springs unit (Pl. 2, Section 3), the Arikaree Group (Pl. 2, Sections 7, 8, 9, 11), or the Whitney Member, is often characterized by a platy, sandy, limestone up to 8 feet thick. Small carbonate nodules and, less often, small siliceous nodules occur locally in this basal unit. Zones rich in siliceous fossil root class, (pedotubules) comprising up to 50 percent of the zone, are also common in the basal parts of the Ash Hollow. Cross-bedded sands and gravels may also occur at the base of Ash Hollow such as at the Breakneck Hill section (Pl. 2) and in the E 1/2 sec. 33,

TABLE 4
MAXIMUM CLAST SIZE IN BROADWATER, COARSE GRAVEL AND ASH HOLLOW UNITS. SAMPLE LOCATIONS IN APPENDIX C

Sample number	Diameter of intermediate (B) axis in cm $\bar{x} \pm \sigma$	Diameter of long (A) axis in cm $\bar{x} \pm \sigma$	Distance above base of unit in feet
BROADWATER			
GS- 1	9.4 ± 0.7	17.0 ± 2.7	0- 25
GS- 8	6.4 ± 0.3	9.5 ± 1.2	100
GS-12+	8.1 ± 0.8	10.3 ± 1.4	60- 80
GS-13	6.6 ± 0.3	9.4 ± 0.8	110-120
GS-16*	8.2 ± 0.7	10.5 ± 1.9	5- 10
Breyer (1975)			
locality 2*	7.7 ± 1.4	16.0 ± 1.9	15- 30
locality 4+	7.4 ± 0.6	13.0 ± 1.2	60- 80
Maroney (1978) Broadwater type area*	9.3 ± 1.0	18.3 ± 1.6	0- 30
Stanley and Wayne (1972)			
locality 12*	13.0		15- 25
locality 13+	∿ 12.8		60- 80
COARSE GRAVEL			
GS- 3	14.3 ± 1.2	19.4 ± 3.9	
GS- 5	11.3 ± 0.3	18.2 ± 3.6	
GS- 6	13.2 ± 1.3	17.5 ± 1.8	
GS- 7	15.5 ± 1.4	18.9 ± 4.1	
GS- 9	13.2 ± 0.5	16.5 ± 1.9	
GS-10	12.5 ± 1.1	15.8 ± 3.1	
GS-14	13.9 ± 1.1	17.8 ± 1.9	
GS-15	11.6 ± 1.3	16.8 ± 3.5	
Breyer (1975) locality 15	14.7 ± 1.0	29.6 ± 2.0	
ASH HOLLOW			
GS- 2	5.3 ± 0.8	8.1 ± 1.6	
GS- 4	5.7 ± 0.5	8.3 ± 1.5	

* sample from the Broadwater Formation type section
+ sample from the Lisco C locality

T. 19 N., R. 47 W. Generally there is less than 30 feet of relief on the lower contact in 1/4 of a mile (Fig. 6).

Environment of Deposition

The cross-bedded sands along with sand and gravel filled channels indicate deposition in a fluvial environment. Unfortunately there are only scattered outcrops where sediment transport directions can be obtained (either cross-beds or channel orientation). As noted above, these sparse data suggest an east to southeast sediment transport direction. The observed maximum width of any single channel is approximately 700 feet and the maximum thickness of any sand and gravel unit, in either outcrop or Conservation and Survey Division test holes, is about 30 feet. Therefore, in the map area, the Ash Hollow streams apparently were not very large. In a study of the Ash Hollow in the southern Panhandle of Nebraska Breyer (1975, p. 5) concluded that the complex nature and "random spatial distribution of sediment types are the imprint of... braided streams." I did not collect enough data to test this conclusion.

The fine-grained sediments often associated with the thick and extensive volcanic ash bed in the western third of the study area represent a series of small pond deposits.

The platy, structured, nodular, sandy limestones often occurring at or near the base of the Ash Hollow are similar to certain caliches described by Reeves (1976). The carbonate cemented sandstone ledges may also represent immature caliches. The siliceous fossil root cast horizons are interpreted as paleosods formed by a network of grass and associated plant roots and as such would represent old land surfaces. The presence of caliche-type profiles and paleosods argues that the climate of the study area during deposition of the Ash Hollow was semi-arid and probably similar to that of today. However as Reeves (1976, p. 84 and 86) cautions:

> "The ideal environment for caliche formation appears to be neither excessively arid nor excessively humid... The local relationships between precipitation, temperature, runoff and relief are critical for caliche formation. Basically it is the effectiveness in leaching of soil carbonate followed by the effectiveness of infiltration and precipitation of the carbonate which determines caliche formation... Therefore, present caliche formation is not characterized by any particular climatic zone, no more than the presence of ancient caliches can be used as evidence for anything more than generalized paleoclimatic data."

Age

As was the case for the Pussy Springs unit, no published descriptions of the vertebrate fossil material collected from the Ash Hollow exposures in the study area by the University of Nebraska State Museum or other field parties are available. Morris Skinner and Mike Voorhies examined the relatively large amount of vertebrate fossils collected primarily from sand and gravel deposits by Bob Diffendal and me (Appendix D). This material represents about 17 different taxa. Voorhies and Skinner (personal communication, 1979) suggested all the taxa could be referred to the Early Hemphillian (Late Miocene) and was typical of adjacent Ash Hollow Formation faunas (Tedford and others, 1979).

Although none of the volcanic ashes in the study area were dated it is probable they would fall somewhere within the range of dates (9.3 to 6.8 m.y.b.p.) reported by Boellstorff (1976) for a series of ashes in the Ash Hollow Formation of the southern Panhandle of Nebraska.

Broadwater Formation

The Broadwater Formation was named by Schultz and Stout (1945). The type section was given as NE sec. 21, T. 19 N., R. 47 W. (Fig. 1). It was described as consisting of a basal 45 foot-thick gravel member, a middle diatomaceous "marl-peat" and silt bed, 19 feet thick (the Lisco Member); and a 15 foot thick upper gravel member.

The Broadwater Formation was interpreted by Schultz and Stout (1945) and by Stout (1965) to be the fifth and highest (oldest) terrace fill present in river valleys of the High Plains. They related this fill to an ancestral North Platte River Valley with a northwest-southeast trend cut deep into Ogallala sediments. The Lisco Member was correlated with similar fine-grained sediments elsewhere in southwestern Nebraska (Stout 1965, p. 67-73). A large number of fossil mammals have been collected from the Lisco Member in the type area and other correlated localities in the study area (Schultz and Stout 1941, 1948; Stout 1965;

Pl. 3). These fauna have been considered by Schultz and Stout to be significant in defining the base of the Pleistocene in the Great Plains.

Distribution and Lithology

The Broadwater Formation occurs in a continuous belt across the map area, however, few good outcrops are present. Nevertheless it was relatively easy to map its distribution in most areas because the sands and gravels of the Broadwater Formation exhibit a distinctive topographic and aerial photograph signature. Also, outcrops of the Ash Hollow Formation usually occur near the basal contact of the Broadwater Formation so the contact could be located quite accurately in most of the study area.

The Broadwater Foramtion is approximately 65 feet thick at the type section; elsewhere in the study area it varies from 20 to about 230 feet thick (Pl. 3). The maximum thickness observed was in secs. 1 and 2, T. 18 N., R. 47 W. and secs. 35 and 36, T. 19 N., R. 47 W.

The Broadwater Formation consists primarily of medium to coarse sand and fine to medium (4 to 32 mm) gravel. The lower part of the formation generally contains the coarsest clasts. Conservation and Survey Division test holes 48-B-53 and 25-B-72 (Appendix E) probably give the best picture of vertical changes in grain size and lithology in the Broadwater Formation.

Pebble types in the 16 to 32 mm size fraction (-4 to -5 phi) were determined for five samples of the Broadwater Formation. For an additional 3 samples only anorthosite and non-anorthosite pebbles were counted (Table 2).

The Broadwater gravels have a more complex pebble assemblage than the Ash Hollow gravels in the study area. The Broadwater Formation gravels are distinguished from the Ash Hollow gravels by the presence of about 8 percent dark-colored pebbles and generally only about one percent acidic volcanic pebbles (Table 3). Broadwater gravels also contain more chert and sedimentary rocks (Table 2).

Stanley and Wayne (1972, Fig. 4) reported anorthosite contents of 8 and 7 percent respectively for gravels from the Broadwater type section and the Lisco C locality and implied that anorthosite was always present in the Broadwater Formation. I obtained a smaller percentage of anorthosite from these localities (2.3 and 1.8 percent, respectively) and found that anorthosite was not always present in the Broadwater Formation (Table 2, GJ78-11). Stanley and Wayne (1972, p. 3678) interpreted the gravels of the Broadwater to have been derived, at least in large part, from the area of the anorthosite body in the Laramie Range.

The diameter of the intermediate (B) axis of the 10 largest pebbles was measured at 5 localities in the Broadwater Formation (Table 4). Also included in this table are data from the Broadwater collected by Stanley and Wayne (1978), Breyer (1974), and Maroney (1978). It is difficult to explain how Stanley and Wayne obtained such a large value for the maximum clast size at the Broadwater type section. Their value is about 1.5 times larger than that of the other three independently measured samples. The same is true of the Lisco C localities. I can only conclude that there may be some sort of systematic error in Stanley and Wayne's data.

Note that the pebble size data (Table 4) suggest the coarsest gravel in the Broadwater Formation occurs near its base. Sample GS-1 was collected from the base of the thickest (about 230 feet) exposed section of the Broadwater.

The Lisco Member was defined by Schultz and Stout (1945, p. 234) as "including all sediments between the basal and upper gravel members" and included diatomaceous marl, thin peats, sandy silt, and fine sand. Silt beds and diatomites in the Broadwater are shown on Plate 1. The diatomites are laminated and are up to 6 feet thick. In the E 1/2 NW sec. 21, T. 19 N., R. 46 W., and within Broadwater Locality A (Schultz and Stout 1948, Fig. 1), two superposed, laminated, silty sand horizons occur separated by about 15 feet of Broadwater sand and gravel (Fig. 6; Appendix B, Section 2). The mineralogy of these two silty sands is given in Table 1 and Fig. 10. The lower silty sand contains many disarticulated diatom valves. These silty sands are similar to those of the Pussy Springs unit and likewise are classified as arkoses.

Conservation and Survey Division test hole 25-B-72 penetrated three silty sand or sandy silt units within the Broadwater Formation. Test hole 48-B-53, drilled directly north of the type section, penetrated two fine-grained units separated by 15 ft of sand and gravel (Appendix E). Because of the unconsolidated nature and coarse grain size of the Broadwater Formation sediments the fine grained units are often talus covered and, thus, the chances of the fine grained units being visible in outcrop are small. The "Lisco Member" or any other fine grained unit cannot be physically traced from the Broadwater type section (Broadwater A quarries) to the Lisco C quarry locality (N 1/2 NW SW sec. 21, T. 18 N., R. 45 W.). Considering the test hole and outcrop data presented above I contend that more than one fine grained unit occurs in the Broadwater Formation in the map area. Thus, the term "Lisco Member" should not be applied indiscriminately to any fine grained unit occurring in the Broadwater Formation.

At the Broadwater Formation type section (Fig. 1) the Broadwater-Ash Hollow contact is conformable in a general sense for at least a mile in either direction (Plate 1). However, as is evident from both Plates 1 and 3, there is considerable relief on the contact, particularly in sec. 15, T. 19 N., R. 47 W. Here the contact between the Broadwater and Ash Hollow formations drops a minimum of 120 feet in about one mile. Generally, in the eastern half of the study area the contact is almost horizontal or rises gently to the east (Pl. 3). In places the Broadwater Formation erodes faster than the Ash Hollow Formation and an erosional bench is developed near the contact of the two units (Fig. 7).

In the type area the Broadwater Formation is overlain by loess-like sandy silts (Fig. 6, Plate 1) or by dune sand. It is difficult to estimate how much, if any of the Broadwater Formation has been removed by erosion.

Environment of Deposition

The sands and gravels of the Broadwater were certainly deposited in a fluvial environment capable of carrying rather coarse material. However, as there are not any essentially undisturbed exposures of the sediments, data on primary sedimentary structures and sequences could not be obtained. Therefore, it could not be determined whether the Broadwater represents a braided, meandering, or mixed fluvial system. Stanley and Wayne (1972, p. 3682-3823) interpreted sedimentary structures and grain size parameters of Broadwater-equivalent deposits in central Nebraska to be characteristic of braided rivers (bed-load streams). However recent work by Gustavson (1978) on the Nueces River in Texas has shown that all coarse-grained fluvial deposits cannot simply be catagorized as deposits of braided rivers.

The fine-grained units of the Broadwater Formation were probably deposited in slow moving or standing water; possibly on flood plains or in abandoned channels. The diatomites at the Broadwater type section and the Lisco C locality (Pl. 1) were examined by Dr. David Maroney. He concluded (written communication, February 1979) the diatomites both contained a very similar assemblage to those described by Maroney (1978) from diatomites in Broadwater equivalent deposits exposed along the Middle Loup River in central Nebraska. According to Maroney the diatomites were deposited in shallow depressions having essentially no detrital sedimentation. Several cycles of inundation and dessication may be represented in each diatomite. The diatom assemblage is indicative of near-alkaline to alkaline conditions similar to that in many Sand Hills Region lakes and to playas occurring in many arid regions of the world. Diatom assemblages consisting predominantly of disarticulated valves typical of diatomites in the Broadwater type section and Lisco C localities were found in very sandy silts in test hole 25-B-72 (Appendix E) and in stratigraphic section 2 (Appendix B) (Maroney, written communication, February, 1979).

Schultz and Stout (1948, p. 562) interpreted the silty units ("Lisco Member") to represent loess as well as colluvial deposits. They considered the fauna from the Broadwater sites to represent a stream-side river habitat while the Lisco sites were thought to indicate an upland or prairie habitat. Later Stout (1965, p. 67) suggested the presence of an unconformity between the loess-colluvial silts and the underlying diatomite-peat beds. He indicated a caliche was often developed on the silts. The Broadwater gravels below the "Lisco Member" were interpreted as outwash gravels from "Nebraskan" mountain glaciers and those above the "Lisco Member" outwash from "Kansan" glaciation. The loess and colluvial silts were interpreted to have been deposited during a cold period ("Kansan") after deposition of the "diatomite-peat" beds during the preceeding warm period ("Afton"). I did not see any evidence to suggest an eolian origin of the silt nor did I observe any evidence for caliche in these sediments.

Stout (1965, Fig. 9-42a) interpreted the Broadwater sediments as fills in a series of narrow northwest to south-southeast trending paleovalleys. Plate 3 indicates that the Broadwater Formation occurs throughout the northeast half of the study area and apparently represents the fill of one major paleovalley with an easterly to southeasterly trend. Stanley and Wayne (1972, Fig. 6), based in large part on my analysis of subsurface data, suggested an easterly direction of gravel transport for the Broadwater sediments in the southern Panhandle of Nebraska. They also interpreted the Broadwater Formation as having been deposited in a broad, shallow valley a few tens of miles wide. The thickness and distribution of the Broadwater gravels (Pl. 3) is more compatible with Stanley and Wayne's interpretation than that of Stout.

Age

The mammalian fauna from the Brodwater quarries (Pl. 3) are well known and are considerably different from the faunas of the upper Ash Hollow Formation termed "Kimball" by previous authors (Barbour and Schultz 1937, Schultz and Stout 1941, 1948; and Schultz and Martin 1970). The Broadwater faunas are considered to be equivalent to the

Blanco fauna at Mt. Blanco Texas (Schultz and others, 1978). The Blanco fauna is overlain by a volcanic ash dated at 2.8 ± 0.3 m.y.b.p. (fisson-track glass, Boellstorff, 1978). Therefore, depending on the criteria used to establish the Plio-Pleistocene boundary, at least the lower part of the Broadwater is probably Pliocene in age (Fig. 2).

Stout (1971) considers the Broadwater and Lisco faunas to be equivalent to the Villafranchian faunas of Europe, which he believes to be Early Pleistocene in age. It appears, as indicated by Boellstorff (1976 and 1978), that a hiatus of several million years is present between the Broadwater and the underlying Ogallala Group sediments (Fig. 2).

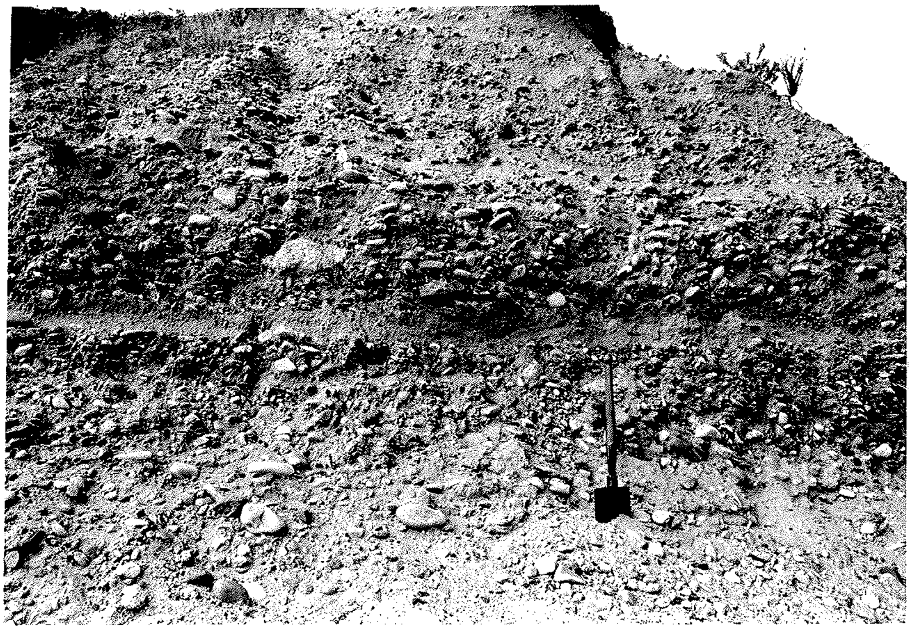
Coarse Gravel of Uncertain Stratigraphic Position

Deposits of very coarse gravel and sand containing large cobbles are exposed in several localities throughout the study area (Pl. 1). They were first described by Breyer (1974) and he considered them to be a coarse, basal phase of the Broadwater Formation.

Distribution and Lithology

An excellent exposure of the coarse gravel unit (Fig. 15) occurs in secs. 33 and 34, T. 19 N., R. 47 W. Here it occurs predominantly in two deep and narrow anastomosing channels cut through the Ash Hollow Formation and into the Whitney Member (Pl. 1, Fig. 6). The maximum thickness of gravel in these channels is approximately 120 feet. As

Figure 15. Coarse gravel unit showing crude stratification, and poorly sorted nature of sediments. Based on orientation of paleochannel, flow direction was to the NE. Pebble imbrication suggested a NE to E flow direction. View looking south-southeast. Location is NW SE NE SE sec. 33, T. 19 N., R. 47 W. Shovel is 28 inches long.



the field mapping progressed I realized that these gravels were more extensive than I had originally thought. It is difficult to accurately map the limits of the coarse gravel unit where no defined valley or channel edge was present. There are undoubtedly more exposures of the coarse gravel unit than shown on Plate 1.

The most striking attribute of these deposits is the presence of large, white quartzite clasts. At eight localities I measured the diameter of the intermediate (B) axis of the 10 largest clasts (Table 4). Breyer (1975, p. 22) determined the maximum clast size for one locality in the coarse gravel unit (Table 4). It is clear that the clasts in the coarse gravel unit are significantly larger than those of the Broadwater Formation (except for the anamolous and suspect values of Stanley and Wayne, 1972).

A 10-foot thick sandy silt overlies about 50 feet of the coarse gravel unit in SE NE SE sec. 22, T. 18 N., R. 46 W. The lower 3 feet of the silt is diatomaceous. The diatom assemblage is essentially the same as that of the Broadwater Formation diatomites (Maroney 1979, personal communication).

The pebble types in 3 samples of the coarse gravel unit are given in Tables 2 and 3. The samples are quite similar to the Broadwater Formation gravels but have a slightly higher percentage of dark-colored pebbles and quartzite and a lower percentage of sedimentary rocks. The source area for the coarse gravel unit probably is similar to that for the Broadwater gravels.

The lower contact of the coarse gravel unit is best exposed in sec. 33, T. 19 N., R. 47 W. where there is a marked unconformity between the coarse-gravel unit, the Ash Hollow Formation and the Whitney Member (Figs. 16 and 17). In other areas it is not as clear that the coarse gravel unit has cut into the Ash Hollow (Fig. 7). No upper contact of the coarse gravel unit was observed.

Environment of Deposition

The large grain size and the horizontally stratified and crudely bedded sediments observed in a few exposures of the coarse gravel unit (Fig. 15) suggest deposition in high energy streams, probably under upper regime flow conditions (Harms and others, 1975, p. 147-153).

These deposits may represent the fill of the deeper parts of a much more extensive paleovalley stream. Furthermore, if the coarse gravel unit is part of one system, its trend (Pl. 3) suggests a general east to southeast paleoflow direction with a gradient of approximately 10 to 15 ft/mile.

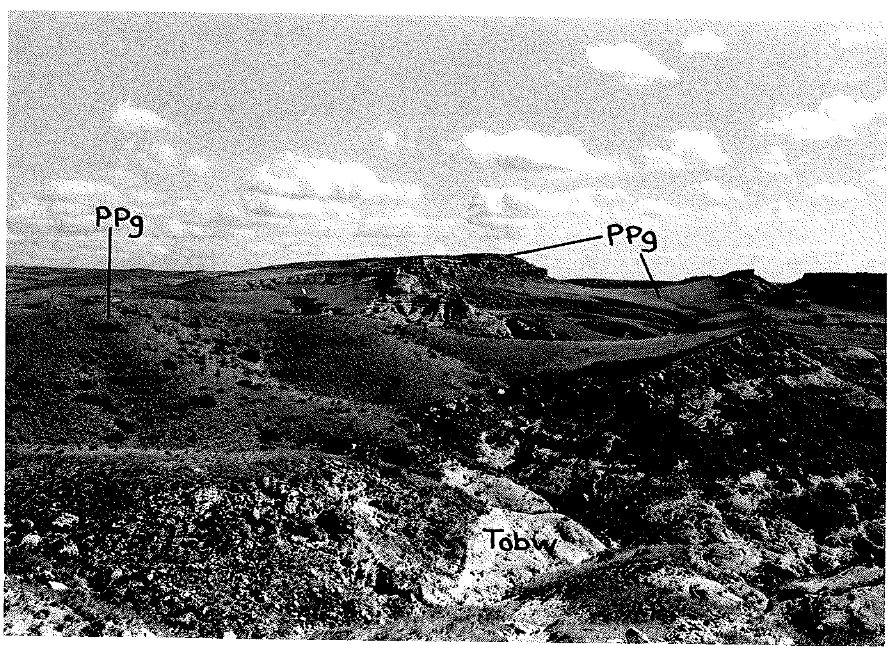
Age

Since these gravels cut into the Ash Hollow Formation they are probably at least younger than the Hemphillian North American Mammal Age. Although the clast size data of Stanley and Wayne (1972) appears to be in error, they are correct in recognizing the very large increase in clast size at a given locality between Ogallala Group and post-Ogallala Group gravels. The maximum clast sizes measured

Figure 16. South edge of coarse gravel unit paleochannel cut into Whitney Member. Butte of Ash Hollow Formation in left center of photograph is capped by the coarse gravel unit. Location is cen N½ SW sec. 33, T. 19 N., R. 47 W.

Figure 17. Coarse gravel unit paleochannels cut into Ash Hollow and Whitney units. Photograph was taken from the SW NE NW SW sec. 33, T. 19 N., R. 47 W., looking to the ESE.


Tmah
PPg
Tobw


PPg
PPg
Tobw

in the coarse gravel unit (Table 4) are over twice the size of Ogallala Group gravels and this suggests the unit is post-Ogallala Group in age. The pebble types (Table 2) indicate the coarse gravel unit is more similar to the Broadwater Formation than to the Ash Hollow Formation. However this only suggests a similar source area of the two units and not necessarily age equivalence.

Based on clast size and channel orientation Breyer (1974, p. 22) considered the coarse gravels to be a basal phase of the Broadwater Foramtion. He said the coarse gravel cut more than 200 feet below the base of the Broadwater Formation at its type locality. Geologic sections A-A' and B-B' (Fig. 6 and 7) also show the coarse gravel unit cut about 200 feet below the base of the Broadwater. However, the coarse gravel unit mapped in the E 1/2 SW NW sec. 20, T. 19 N., R. 47 W., 1.3 miles southwest of the type Broadwater, is only 30 feet below the base of the type Broadwater Formation.

Some interesting relationships between the coarse gravel unit and the Broadwater Formation are shown on Plate 3. Note that the well defined channels in the coarse gravel unit in secs. 33 and 34, T. 19 N., R. 47 W. are oriented due east, heading directly towards the area where the Broadwater Formation cuts deeply into the Ash Hollow Formation. The largest average clast size measured in the Broadwater

(Table 4, GS-1) is from the area of this deep cut. The maximum depth of cutting by Broadwater streams cannot be determined because the Ash Hollow-Broadwater contact is not exposed in this deep cut. The elevation of the lowest exposure of the coarse gravel unit in the vicinity of this deep cut is about 3710 feet (cen. sec. 34, T. 19 N., R. 47 W.). The lowest exposures of the Broadwater Formation are at an elevation of about 3760 ft and are located 0.75 of a mile southeast of the lowest exposure of the coarse gravel unit (Pl. 1). These relationships also suggest that the Broadwater Formation and the coarse gravel unit are part of the same depositional sequence.

An additional line of evidence suggesting the coarse gravel unit is related to the Broadwater Formation was discovered by Bob Diffendal in 1978. He found partial left and right lower jaws of a large mature camel (Appendix D, locality FJ78-10) occurring in situ near the base of the coarse gravel unit. Mike Voorhies, Lloyd Tanner, and George Corner (personal communication, 1979) compared it to specimens from the Broadwater quarries and from the younger Hay Springs and Rushville quarries. They found it to be larger than any specimens from Hay Springs and Rushville but within the size range of camels from the Broadwater quarries. This also suggests that the coarse gravel unit is at least older than the Hay Springs-Rushville deposits, considered to be Irvingtonian in age by Schultz and others (1978).

From the arguments presented above, I tentatively assign the coarse gravel unit to the basal phase of the Broadwater Formation and recognize that it could possibly be younger.

Alluvium and Colluvium, Undifferentiated

A wide variety of materials of different ages have been combined in this category. Colluvium, consisting of very silty sand to coarse gravel from reworked Whitney, Arikaree, and Ogallala sandstones and siltstones is present throughout the map area. Terraces, loess-like sandy silts, and all alluvial deposits in the sand draws draining into the Platte River are included in the alluvium and colluvium, undifferentiated unit.

I had initially intended to map the various terraces, easily visible farther west in the North Platte Valley. However, once mapping commenced it was clear that the origin of the scattered small flats present on the valley sides were the reflection of a variety of processes such as: differential erosion; cap rock protection, especially on the Ash Hollow Formation; mass wasting resulting in low-gradient slopes; and terrace formation.

A deposit of silty sand exposed on the county road between secs. 31 and 32, T. 18 N., R. 45 W. was reported by Schultz and Stout (1945, Fig. 2) to have yielded mammoth remains and was assigned by them to Terrace-3 of their terrace sequence.

The lower three terraces, T°, T' and T , of Schultz and Stout (1945, Fig. 2) are well expressed (the highest is about 30 feet above river level) but were not mapped in this study.

Dune Sand

Dune sand (fine to medium grained) is the predominant material on the tableland in the northeast part of the study area. A prominent northwest to southeast topographic lineation is visible on the tableland (northeast part of Pl. 1). It appears to be related to the general southeastward dune sand transport direction of the Sand Hills Region (Ahlbrandt and Fryberger, in press). These topographic lineations apparently were the trends used by Stout (1965) to establish the direction of his Broadwater "Hanging Valleys."

Near the edge of the tableland, particularly above the Broadwater type locality, a loess-like sandy silt forms a lip (Fig. 6) and extends a mile or more back onto the table.

STRUCTURAL GEOLOGY

The study area is on the northeastern edge of the Denver-Julesburg Basin (DeGraw, 1971, Fig. 5) and on the western side of a large (10 to 15 miles across) structural depression (the Rush Creek Structure) first described by Diffendal (1978). He reported dips of up to 8 1/2° in the Rush Creek area south of the North Platte River. The "Lisco

Anticline" (Stout and others 1971, p. 76) shown in secs. 27 and 28, T. 18 N., R. 46 W. is apparently a small undulation of the flank of this larger structure. The Rush Creek Structure is apparently centered about one mile southeast of Lisco and there is a general dip towards that locality from all directions. Lugn (1935, Fig. 26) and Schultz and Stout (1945, Fig. 2) published geologic sections drawn through or near the Lisco area which indicated sediments of the Whitney Member should be at or just above river level. However, as shown on Fig. 7, based on a Conservation and Survey Division test hole, the Ash Hollow-Whitney contact is about 100 ft below river level. In addition, the Geologic Bedrock Map of Nebraska (Burchett, 1969) shows a continuous belt of Brule between Broadwater and Lisco. As seen on Plate 1 the Ash Hollow-Whitney contact dips sharply to the east at about 70 feet/mile before the Whitney disappears beneath the North Platte River Valley. It does not reappear again until just west of Coumbe Bluff, about 6 miles west of Oshkosh and 10 miles southeast of Lisco.

GEOLOGIC HISTORY

The geologic history of the rocks exposed in the study area began about 30 million years ago while volcanic ash laden winds slowly deposited a thick blanket of predominantly silt-size volcanic glass shards and crystals on a gently rolling upland topography. The volcanic material originated hundreds of miles to the west during the eruption of great ash flow tuff sheets. The monotony of the steady rain of volcanic debris was punctuated several times by rapid deposition of essentially pure volcanic glass. These episodes spread a lighter colored sediment over the arid environment. Some reworking by slope processes and wind and perhaps a slight change in the source area produced a slightly coarser grained sequence. These deposits make up the Whitney Member.

About 28 million years ago, after almost 200 feet of Whitney Member had been deposited, uplift or climatic changes initiated erosion resulting in a valley system. The portion of this valley in the Broadwater area was cut into the Whitney and later partially filled with the deposits of a low energy stream that carried pumice-pebbles from volcanic deposits in northern Colorado. Limestone also accumulated in local playas. These stream and playa deposits make up the Gering Formation.

Meanwhile the slow rain of fine-grained volcanic debris continued and once again asserted dominance over the influx of epiclastic material and fluvial processes. The volcanic centers producing these pyroclastic fragments may have been closer to Nebraska than those during deposition of the Whitney. There was a greater mixing of epiclastic and volcanic material than during deposition of the Whitney. Local playas were again the sites of limestone deposition. This style of deposition continued until about 21 million years ago making up the Harrison-Monroe Creek unit.

Deposits representing the next 10 million years or so are not preserved in the area. Apparently during this time the amount of pyroclastic material being carried into the area declined tremendously because the next younger sediments are predominantly epiclastic.

About 10 million years ago some climatic or structural process initiated the erosion of a series of deep channels cut into the Whitney Member. These cuts filled rapidly with material washed down the channel sides and with sediment brought from the Front Range of Colorado making up the Pussy Springs channel complex.

After this squence of channels had filled, deposition was sporadic and there was enough time to form "caliche" soils between and during establishment of grassland sod horizons. Locally small streams and rivers carried debris from the Colorado Front Range and deposited sediment on the Whitney and Arikaree units. During the early stages of deposition of this sequence at least one major volcanic eruption occurred in the west (?). The resulting glass shards were blown into western Nebraska and preserved as volcanic ash beds in areas of slack water. These deposits make up the Ash Hollow Formation.

Deposition virtually ceased about 7 million years ago and 3 to 4 million years passed before the next set of beds was deposited. At this time, narrow and deep channels, in addition to a broad valley, were cut into earlier Tertiary deposits and at least partially filled with very coarse gravel. The major cause of this erosion was probably a regional uplift during this time throughout much of the Rocky Mountains. This gravel had a more northerly source area, probably the Laramie Mountains of Wyoming, than the Ash Hollow gravels. These deposits constitute the coarse gravel unit.

Deposition in the valley continued, this time with finer grained gravel from essentially the same source as the coarse gravel unit. During the filling of the paleovalley abandoned channels or local shallow depressions on flood-plains were filled with fine-grained silt. Small alkaline playas were present and relatively thick diatomites accumulated. Perhaps 2 million years ago deposition of this sand and gravel sequence ceased. These fluvial and lacustrine sediments make up the Broadwater Formation.

The record from this time on is essentially one of erosion. Almost 500 feet of sediment has been removed in the formation of the present day North Platte River Valley. Erosion of the above units and deposition of alluvium, colluvium, and windblown silt and sand continue today.

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APPENDIX A

MINERALOGY OF GRAIN MOUNTS OF THE VERY FINE SAND FRACTION FROM SELECTED SAMPLES OF STRATIGRAPHIC UNITS

Explanation: 300 grains were counted on each grain mount. Percent silt and clay in total sample determined by sieving. Only glass shards, volcanic rock fragments and other grains were counted in the samples from test hole 25-A-53. Location of samples given in Appendix B.

Sample Number	Glass shards	Plutonic quartz	Volcanic quartz Total	Volcanic quartz glass mantled	Plagioclase Total	Plagioclase glass mantled	Potash feldspar	Volcanic rock fragments	Heavy minerals Total	Heavy minerals glass mantled	Others	Percent silt and clay
Broadwater Formation												
LJ78-9		58.4	4.7		17.3		9.0	4.0	1.3		5.3	13
LJ78-10		57.3	6.0		16.3		12.7	0.3	0.3		6.4	45
Ash Hollow Formation												
LJ78-44	3.3	31.0	5.0		40.0	0.3	9.3	4.3	1.7		5.7	37
Pussy Springs Unit												
LJ78-8A	4.3	56.0	3.7		12.7	0.7	12.0	2.3	2.7		6.0	38
LJ78-45	0.3	56.7	6.7		18.0		11.3	2.3			3.6	19
LJ78-96	5.0	49.0	5.0		14.0	0.3	17.0	3.0	2.0		5.0	35
Harrison-Monroe Creek Formations, undifferentiated												
LJ78-11	63.3	11.0	2.3	0.3	9.3	1.3	5.0	3.7	4.0		1.3	55
LJ78-13	35.3	28.3	2.7	0.3	14.7	2.7	9.7	5.3	2.7		1.3	41
LJ78-16	43.3	23.7	4.0		13.0	2.7	4.7	4.7	2.0		1.3	59
LJ78-23	30.0	14.3	9.7	0.1	20.0	3.7	9.3	9.3	4.3			38
LJ78-28	30.0	14.3	9.7	0.3	20.0	3.7	9.3	9.3	4.3	0.3		38
BNH-2	29.0	24.0	6.3		19.7	2.7	8.0	8.0	3.7		1.3	52

APPENDIX A (continued)

Sample Number	Glass shards	Plutonic quartz	Volcanic quartz Total	Volcanic quartz glass mantled	Plagioclase Total	Plagioclase glass mantled	Potash feldspar	Volcanic rock fragments	Heavy minerals Total	Heavy minerals glass mantled	Others	Percent silt and clay
BNH-3	35.0	18.3	5.3		18.7	3.0	8.0	7.0	6.3		1.3	37
BNH-4	29.3	23.3	3.6		22.6	4.7	6.7	8.0	4.7		1.7	28
BNH-6	63.3	12.0	2.7		8.7	1.0	3.7	6.3	2.7		0.7	64
LJ78-43	46.7	8.3	2.0		29.0	2.7	5.3	5.7	3.0		0.7	54
LJ78-92	34.7	27.0	3.7		14.7	1.0	6.7	4.3	4.3		1.3	61
Gering Formation												
LJ78-32	64.0	4.3	3.7	0.3	13.3	2.0	3.0	9.3	1.7	0.3	0.7	71
LJ78-85	43.0	13.7	4.0	0.3	23.3	4.0	4.0	6.3	3.7		2.0	58
LJ78-86	55.7	6.3	2.3		16.0	2.3	4.7	8.0	3.3	0.3	2.7	61
LJ78-87	43.0	17.0	3.7	0.3	20.7	3.7	5.0	6.3	2.3		2.0	49
Whitney Member (sandy facies)												
LJ78-8B	71.3	10.3	2.0		8.7	3.0	2.0	3.3	1.7		0.7	59
LJ78-14	52.7	16.7	3.0		11.3	2.7	7.3	5.3	2.3		1.3	65
LJ78-15	49.0	12.3	5.3		11.3	2.3	7.7	6.3	4.7		2.0	64
LJ78-21	71.7	7.3	6.0		4.3	0.7	3.3	4.3	1.7		1.3	82
LJ78-22	50.0	13.3	8.0	0.3	11.3	1.7	6.0	10.7	2.7	1.0	4.3	72
LJ78-25	55.7	8.3	7.3	0.3	13.3	3.7	2.0	10.0	2.7	0.7	0.7	59
LJ78-26	66.0	4.3	7.3	0.7	11.3	1.3	2.0	5.3	2.0		1.7	68
LJ78-28	56.0	8.0	7.0	1.0	14.7	3.7	2.0	7.0	2.7		2.7	49
LJ78-30	72.7	5.3	2.7		9.3	1.3	3.0	4.7	1.7		0.7	76
LJ78-41	76.7	1.3	0.3		12.7	3.0	1.7	4.3	2.0		1.0	55
LJ78-42	67.7	1.7	1.0		20.3	3.7	2.7	3.3	2.7	0.7	1.0	58
LJ78-83	86.0	2.3	0.7	0.3	3.0	1.0	3.3	3.7	1.0	0.3		84
LJ78-88	58.7	12.7	2.0		15.0	2.3	2.0	7.3	2.0		0.3	79
LJ78-89	41.0	19.3	3.3		23.3	4.0	4.3	2.3	6.0		0.3	58
LJ78-91	64.0	9.0	2.7		10.7	1.0	1.7	6.0	4.0	0.3	2.0	67
BNH-9	72.7	8.0	5.0		5.7	1.3	2.0	4.7	0.7		0.7	77

APPENDIX A (continued)

Sample Number	Glass shards	Plutonic quartz	Volcanic quartz		Plagioclase		Potash feldspar	Volcanic rock fragments	Heavy minerals		Others	Percent silt and clay
			Total	glass mantled	Total	glass mantled			Total	glass mantled		
Whitney Member (clayey facies)												
LJ78-6	48.7	13.0	4.0		20.0	3.0	2.7	7.7	3.3		0.7	75
LJ78-37	29.0	8.0	5.0		34.0	3.3	4.0	14.7	3.7	0.7	2.7	93
LJ78-82	83.3	2.7	0.7		7.7	1.3	0.7	2.0	1.3		2.5	91
Whitney Member ash beds												
LJ78-5	84.3	0.7	1.0		9.3	5.0	0.3	2.7	1.7			79
LJ78-7	85.3	2.0	1.3		3.0	1.7	1.0	4.3	2.7		0.3	88
LJ78-38	80.7	0.7	0.3		11.3	4.7	0.3	5.0	1.7			74
LJ78-40	87.0	0.3			5.3	2.7	0.7	4.0			2.7	88
LJ78-90	73.7	3.0	2.3		11.7	7.3	1.3	4.0	3.3	0.7	0.7	80
Test Hole 24-A-53												
60-70 ft	66.0							7.0			27.0	
75-80 ft	78.3							2.7			19.0	
80-81.5 ft	83.7							2.7			13.7	
81.5-85 ft	66.7							6.0			27.3	
95-105 ft	46.0							4.0			50.0	
115-120 ft	41.0							2.0			57.0	

APPENDIX B

MEASURED STRATIGRAPHIC SECTIONS AND LOCATIONS OF SAMPLES USED IN THE PETROGRAPHIC STUDY

All of the measured stratigraphic sections, except for 2, 13 and 15, are illustrated on Plate 2. The location and elevation given is for the base of the measured section. Sampled intervals used in the petrogrphic study (Table 1 and Appendix A) are noted in the section descriptions. Samples from other than measured sections are listed after the section descriptions. Colors given are on wetted material.

SECTION 1

Breakneck Hill

Location: NE SE NE SW sec. 19, T. 19 N., R. 47 W.; 3780 ft

Lithologic unit	Description	Thickness (in feet)
	White River Group Brule Formation Whitney Member	
1	Silt to siltstone, moderately sandy, yellow gray (5Y 7/2); massive; sample BNH-9 taken 6 ft above base of section; unit is not well exposed------	15
	Arikaree Group Harrison and Monroe Creek formations, undifferentiated	
2	Silt, very sandy; pale yellowish-brown (10YR 6/2); faint horizontal laminations and vertical tubules (pedotubules ?); lower contact not well exposed; two pipy concretion ledges; sample BNH-2 taken at top of unit------	8
3	Sand, very fine to fine, very silty at base grading upwards to moderately silty yellowish-brown (10YR 4/2); abundant glass shards, 5 to 10 percent elongate, dark grains; well sorted, loosely packed grains; faint horizontal bedding in upper 20 ft, otherwise massive; several pipy concredtion ledges with "pipes" oriented 67-247°; lower contact gradational; sample BNH-3 taken 15 ft above base; sample BNH-4 taken 55 ft above base----	73

(Section 1, continued)

4	Siltstone to silt, very to moderately sandy; massive; local vertical tubules, 2 to 6 mm in diameter; small pipy concretions and small, scattered "potato" concretions; upper 7 ft contains siliceous root casts and has a fractured appearance, probably represents a weathered zone of top of Arikaree; sample BNH-6 taken 5 ft above base of unit-------------------------------	25
	Ogallala Group Ash Hollow Formation	
5	Sand, fine to very coarse, local pebbly (granitic) lenses and interbeds, especially in lower 6 ft; trough and planar cross-bed sets up to 1.5 ft thick common; paleoflow directions east to southeast; very fine to medium sand-size volcanic ash disseminated throughout much of unit; some ash occurs in local, relatively pure lenses, light grey (N7); lower contact irregular-------------------------------	30 to 35
6	Limestone to marl, sandy; ostracods and small gastropods present---------------	2

SECTION 2

Location: Cen S½ section line SE SE NE sec. 20, T. 19 N., R. 47 W.; 3920 ft

Lithologic unit	Description	Thickness (in feet)
	Ogallala Group Ash Hollow Formation	
1	Sand to sandstone, very fine to fine, silty; local calcareous streaks and siliceous root cast horizons; pale olive (10Y 6/2) to light brown (5YR 5/6)------------------------------	14
2	Claystone, moderately silty; mottled dark reddish-brown (10R 3.4) to pale olive (10Y 6/2)------------------------------	9

(Section 2, continued)

3	Sand, very fine to medium, moderately silty, 10 percent siliceous root casts; massive; more friable in upper 10 ft; pale olive (10Y 6.2) to light grey (N7); upper contact poorly exposed-----	22
	Broadwater Formation	
4	Gravel and sand, 20 to 30 percent pebbles; a few percent anorthosite pebbles and a total of 5 to 10 percent dark-colored pebbles--------------	10 to 15
5	Sand, very fine, slightly silty, siltier towards top; yellowish-grey (5Y 7/3); iron-stained zone above base; this unit thins out about 600 ft to the south and east; sample LJ78-9 from middle of unit, it contains many disarticulated diatom valves, diatoms are similar to those present in diatomite approximately 0.5 miles to the east-----------	5
6	Sand and gravel, 5 percent pebbles; several percent anorthosite pebbles; upper 4 ft finer grained--------------	13
7	Sand, very fine to very silty; laminated, some laminae of coarse sand, some clayey silt; local slight deformation of laminae; distal end of mastodont tusk; 600 ft south the silty sand grades into or is replaced by medium to coarse, pebbly sand; sample LJ78-10 from middle of unit-------------------	7
8	Silt, very sandy; massive, blocky structure; oxidized zone at base; interfingers and grades into a very silty sand; poorly exposed--------------	16 to 18
9	Sand and gravel, 5 to 20 percent pebbles, about 10 percent dark-colored pebbles including anorthosite; top poorly exposed as loess cap drapes over unit----	20
10	Silt, moderately to very sandy; massive; loessic--------------------------------	15

SECTION 3

Location: Cen. south section line SE NE NW sec. 4, T. 18 N., R. 47 W.; 3580 ft.

Lithologic unit	Description	Thickness (in feet)
	White River Group Brule Formation Whitney Member	
1	Siltstone, moderately clayey; grayish-orange (10YR 7/4) to moderate yellowish-brown (10YR 5/4); massive, compact; several thin (0.5 to 1 ft) mottled zones with irregular clumps of darker colored siltstone containing small tubules and "vesicles"; small barite crystal pods common in upper 10 ft; LJ78-37 from lower 1.5 ft-------	32
2	Silt to siltstone, slightly sandy; very pale orange (10YR 8/2); base more indurated, gradational upper contact; Upper Whitney Ash bed; sample LJ78-38 from lower 1 ft----------------------	4
3	Siltstone; slightly clayey; very slightly sandy; massive; several thin lightly mottled zones as below----------------	46
4	Siltstone-silt; slightly sandy; volcanic ash bed; more friable than below; unit thins to the east; sample LJ78-40------	4
5	Siltstone, slightly clayey; massive; small, calcareous, poorly defined concretions in upper part; very silty claystone, 3 to 6 inches thick, with very small tubules, brecciated, white (N9)----------------------------------	25
6	Siltstone to silt, slightly sandy; yellow olive grey (5Y 6/2); massive; small irregular, calcareous nodules; this unit becomes sandier about 0.3 miles east and contains pseudo-pipe concretions--------------------------------	5
7	Silt, very sandy, fining upwards; small burrows (?); local oxidized zones; small irregular "potato" concretions; gradational upper contact; sample LJ78-41 taken 2 ft from base-----------	8 8

(Section 3, continued)

8 Siltstone, moderately to very sandy, more friable than below; yellowish-grey (5Y 7/2); 2 inch thick indurated ledge at top; sample LJ78-42---------------- 6

9 Siltstone, slightly sandy; moderate yellowish-brown (10RY 5/4)--------------- 21

10 Siltstone, slightly sandy; mottled yellowish-grey (5Y 7/2) and moderate yellowish-brown (10RY 5/4) in upper 3 ft------------------------------------ 9

11 Siltstone, moderately sandy; yellowish-grey (5Y 7/2)------------------------ 4

12 Siltstone, slightly to moderately sandy; white (N9) to pale greenish-yellow (10R 8/2); small burrows-------------- 5

13 Siltstone, moderately sandy, fining upwards, massive; small vertical burrows common; 3 inches white, calcareous siltstone at top---------------------- 11

14 Siltstone, very sandy; crude horizontal laminations; small vertical burrows (up to 2 ft long) common; poorly defined pseudo-pipe concretions; siliceous root casts near top; sample LJ78-43 from middle of unit------------------------ 9

Ogallala Group
Ash Hollow Formation
Pussy Springs Channel Complex

15 Conglomerate, clasts up to 10 inches in diameter, larger clasts composed of reworked Arikaree and Whitney calcareous concretions (lithic clasts), some igneous pebbles; this unit caps a small knob just south of saddle------------- 5

16 Silt to siltstone, very sandy with interbedded silty sand and pebbly sand lenses; moderate yellowish-brown (10RY 5/4); poorly defined horizontal bedding; this unit fills a narrow channel eroded into the Whitney Member. It is a maximum of 70 feet thick. Only 10 ft is shown on the graphic section (Pl. 3)------------------------------ 10

(Section 3, continued)

Ash Hollow Formation

17	Sandstone, very fine to medium, slightly silty; abundant siliceous root casts, calcareous----------------------------------	4
18	Sandstone, fine to coarse, pebbly, interbedded with sandstone, very fine to fine, very silty; calcareous "mortar" bed ledges; siliceous root cast zones; sample LJ78-44 taken 22 ft above base of unit----------------------------------	35
	Coarse gravel unit	
19	Gravel, clasts up to coarse pebble size (15 cm intermediate diameter); dark-colored plutonic pebbles common, less than 1 percent anorthosite-------------	8

SECTION 5

Mad Bull Section

Location: W 1/2 SE NE sec. 14, T. 19 N., R. 48 W., 3725 ft.

Lithologic unit	Description	Thickness (in feet)
	White River Group Brule Formation Whitney Member	
1	Siltstone, slightly clayey; moderate yellowish-brown (10RY 5/4), massive; scattered small, indistinct "potato" nodules in upper part; sample LJ78-82 taken 4 ft above base------------------	8
2	Silt; moderate to very sandy, well sorted; massive; small diameter (1 to 2 mm) burrows up to 60 cm long are common; pipe-like concretions in top of unit----------------------------------	6
3	Silt to siltstone, moderately to slightly sandy; moderate yellowish-brown (10RY 5/4); massive; small burrows common below upper contact; sample LJ78-83 taken 22 ft above base-------------	35 to 50

(Section 5, continued)

Arikaree Group
Gering Formation

4	Sand, very fine to fine and gravel; lithic pebbles up to medium pebble; some small scale cross-bedding; abundant (10 percent) rounded bone fragments; there is about 15 ft of relief on the lower contact--------	2 to 15
5	Sand, very fine to fine, and gravel; pebbles composed of light gray to yellow gray pumice, trace of rounded bone fragments; this unit interfingers in part with unit 4------------------	7
6	Sand, very fine to fine, massive, poorly exposed---------------------------------	10
7	Sand, very fine to fine, very silty, pebbles, grading to very sandy silt; dark yellowish-brown (10YR 4/2); massive; pebbles composed of pumice; they make up about 5 percent of unit; some lithic pebbles also present; sample LJ78-85 taken 6 ft above base---	10
8	Silt, very sandy, dark yellowish-brown (10YR 4/2); indistinct horizontal bedding; abundant sand-size lithic clasts and rounded bone fragments; calcareous concretions (pseudo-pipes) occur in several zones; sample LJ78-86 from middle of unit-------------------	25

Arikaree Group
Harrison-Monroe Creek formations
undifferentiated

9	Sand, very fine to fine, glass shards common, 5 to 10 percent colored elongate heavy minerals; indistinct horizontal bedding; small diameter (2 to 8 mm) burrows abundant; ledge-forming calcareous pipy concretions common, 2 ft thick lithic pebble gravel at base----------------------------------	40

SECTION 6

Location: NW SE SW SE sec. 14, T. 19 N., R. 48 W., 3720 ft.

Lithologic unit	Description	Thickness (in feet)
	White River Group Brule Formation Whitney Member	
1	Siltstone, moderately clayey; slightly sandy; yellowish-brown (10YR 5/4); massive; moderately sandy zone with calcareous "potato" nodules 40 to 45 ft above base----------------------	55 to 60
2	Siltstone to silt, very sandy; massive; large diameter (5 to 30 mm) burrows common; many fossil turtle remains; unit is lenticular in shape-------	1 to 5
3	Claystone, silty, interbedded with siltstone and some cross-laminated sandstone; irregular indistinct bedding, some small diameter burrows------------	10
	Arikaree Group Gering Formation	
4	Sand, very fine to fine, very silty, pebbly, poorly sorted, fining upwards; pale yellowish-brown (10YR 6/2); massive; about 1 percent small pumice pebbles; some claystone (lithic) clasts up to cobble (6 cm) size in upper 2 ft; sample LJ78-87 taken 9 ft above base------------------------------	12
5	Silt to siltstone, very sandy, fining upwards; indistinct contacts-------------	8
6	Silt to siltstone, very sandy, fining upwards; abundant rounded bone fragments; some small burrows; pipy concretions near top-------------------------------	9
	Arikaree Group Harrison-Monroe Creek formations undifferentiated	
7	Sandstone to sand, very fine to fine, moderately silty; massive; calcareous	

(Section 6, continued)

	pipy concretions; a 1 ft thick crumbly limestone occurs 38 ft above the base--	48

SECTION 7

Lime Point Section

Location: NW SE NW NW sec. 23, T. 19 N., R. 48 W., 3710 ft.

Lithologic unit	Description	Thickness (in feet)
	White River Group Brule Formation Whitney Member	
1	Siltstone, slightly clayey, slightly sandy; very pale orange (10YR 8/2); massive; indistinct "potato" nodules and sand-size lithic grains in upper 5 ft----------------------------------	32
2	Siltstone, very to moderately sandy, fining upwards; massive; some small burrows, indistinct contacts-----------	17
3	Sand, very fine to fine, trace of medium, moderately silty, fining upwards; massive; small burrows common at base--	18
4	Sand, very fine to medium, moderately silty; moderate yellowish-brown (10YR 5/4); fining upwards; indistinct horizontal laminations near the base; small burrows locally abundant near the base; upper 4 ft is a moderate to very sandy silt with some small burrows; sample LJ78-30 taken 2 ft below top-----------	44
	Arikaree Group Gering Formation	
5	Sand, fine to very fine, brownish gray (5YR 4/2), cross-bedded, some deformed bedding; many angular claystone and siltstone clasts-------------------	0 to 2
6	Limestone, white (N9); thinly laminated, mud cracks and burrows, both vertical	

(Section 7, continued)

	and horizontal, are common; ostracods locally abundant, upper contact indistinct-------------------------	6 to 8
7	Sand to sandstone, very fine, very silty, fining upwards; pale yellow brown (10YR 6/2); some rounded bone fragments; abundant sand-size lithic grains - indistinct upper contact; sample LJ78-32 taken from middle of unit----------------------------------	12

Arikaree Group
Harrison-Monroe Creek formations
undifferentiated

8	Sand to sandstone, very fine to fine, moderately silty, well sorted; 5 to 10 percent dark-colored elongate heavy mineral grains, glass shards common; massive; some siliceous root casts near upper contact; pipy concretion ledges common---------------------------------	66

Ogallala Group
Ash Hollow Formation

9	Limestone ("mortar bed"), slightly sandy, platy structure; some siliceous root casts----------------------------------	7

SECTION 8

Location: SW NW NW NE sec. 24, T. 19 N., R. 48 W.; 3780 ft

Lithologic unit	Description	Thickness (in feet)
	Arikaree Group Gering Formation	
1	Sand, very fine to fine, moderately silty, indistinct laminations, some with iron stains; this unit interfingers with a very sandy, massive silt with small burrows------------	5 to 15

(Section 8, continued)

2 Silt, slightly sandy, volcanic ash, light grey (N7), laminated, many small burrows; some sand-size lithic grains; the ash occurs in a lenticular-shaped deposit that pinches out to the east 50 ft from the thickest part of the lens; the upper contact is gradational--- 0 to 10

3 Sand, very fine to fine, very silty, massive, abundant small burrows; small pseudo-pipe and pipy concretions; gradational upper contact-------------- 4

4 Sand, fine to very fine, mocerately silty; massive; finer grained in lower 10 ft; sand-size lithic clasts locally abundant, both pipy and pseudo-pipe concretions; small diameter burrows common; angular claystone clasts occur 40 ft above base; siliceous root casts common in upper 6 ft and unit is siltier-------------------------------- 95

Ogallala Group
Ash Hollow Formation

5 Limestone ("mortar bed"), moderately sandy; white (N9); platy structured---- 8

6 Sand-sandstone, very fine to medium; 3 to 5 ft thick zones of abundant siliceous rootlets (paleosods)------------------ 16

SECTION 9

Tugboat Section

Location: SE NE NW NE sec. 25, T. 19 N., R. 48 W., 3665 ft

Lithologic unit	Description	Thickness (in feet)
1	Siltstone, moderately clayey, slightly sandy, moderately sandy in upper 10 ft; massive; 15 ft covered interval in middle unit------------------------	56
2	Silt to siltstone, very sandy, fining upwards, massive; indistinct contacts--	11

(Section 9, continued)

3 Sand, very fine, very silty, fining upwards to slightly sandy siltstone; yellowish-brown (10YR 5/2); indistinct horizontal laminations; trace of sand-size lithic clasts; small diameter burrows abundant near base; indistinct vertically oriented concretions common; indistinct contacts; sample LJ78-28 taken 2 ft above base--- 25

4 Siltstone, moderately sandy, massive with a thin lenticular sand, very fine to fine, at the base; sample LJ78-88 from a 0.5 ft thick sandy siltstone at the top of the unit---------------------- 10

5 Siltstone, very sandy; yellowish- to moderately yellowish-brown (10YR 5/2 to 5/4), massive; a thin wavy-bedded sandstone occurs in the middle of the unit below a zone of small indistinct pseudo-pipe concretions; small burrows locally abundant; "potato" concretions occur in upper 10 ft; upper and lower indistinct; sample LJ78-89 taken from 22 ft above base---------------------- 40

6 Sand; very fine, very silty grading into a silt to siltstone, very sandy; many zones of pseudo-pipe concretions; upper contact indistinct-------------------- 33

Arikaree Group
Harrison-Monroe Creek formations, undifferentiated

7 Sand, very fine to fine, moderately silty; well sorted; massive; about 5 percent dark-colored elongate heavy mineral grains; glass shards common; pipy concretion ledges---------------- 40

Ogallala Group
Ash Hollow Formation

8 Limestone ("mortar bed"), slighlty sandy; platy structure; local sand lens at the base------------------------------ 9

SECTION 10

Ruby Ranch Section

Location: NE NE SE SE sec. 32, T. 19 N., R. 47 W., 3625 ft

Lithologic unit	Description	Thickness (in feet)
	White River Group Brule Formation Whitney Member	
1	Siltstone, moderately clayey, slightly sandy; pale yellowish-brown (10YR 6/4); massive----------------------------------	13
2	Siltstone; moderately sandy, volcanic ash beds; light grey (N7) to pale olive (10Y 6/2); "brecciated"; abundant small burrows, sample LJ78-90----------------	2
3	Siltstone, slightly to moderately sandy; grayish-orange (10YR 7/4) to yellowish-brown (10YR 5/4); massive; several thin "brecciated" zones; a 1 ft thick light grey (N7) to pale olive (10Y 6/2) siltstone occurs 50 ft above the base; Skinner (written communication, 1978) referred to this as the "white zone of the saddle"----------------------------	81
4	Silt, very sandy; well sorted; grayish-orange (10YR 7/4); massive, iron stain in upper 2 ft; upper and lower contacts are indistinct; lithologic sample LJ78-91 taken from middle of unit------	5
5	Siltstone, slightly sandy; pale olive (10Y 6/2) in upper 2 ft with local iron staining; some small burrows------	17
6	Claystone, which (N9), "brecciated" possibly mud cracks--------------------	1
7	Siltstone, slightly sandy; massive; angular claystone clasts occur in basal 2 ft; indistinct calcareous concretions--	14
8	Claystone, white (N9), 0.5 ft thick at top and bottom of unit; sandy siltstone with claystone clasts; additional thin claystone beds occur in this zone to	

(Section 10, continued)

the east several hundred feet; this zone is an easily recognizable marker bed-- 4

9 Siltstone, very sandy; moderate yellowish-brown (10YR 5/4); the unit becomes slightly finer-grained toward its top; small diameter burrows common; a few thin calcareous ledges------------- 7 to 14

Arikaree Group
Harrison-Monroe Creek formations, undifferentiated

10 Siltstone, very sandy at base grading up into very silty, very fine sandstone; massive, locally abundant small vertical tubules (burrows ?), some siliceous root casts; calcareous pseudo-pipe concretions with indistinct boundaries; there are several feet of relief on the lower contact; sample LJ78-92 taken from middle of unit----------------------------- 11 to 14

Ogallala Group
Ash Hollow Formation

11 Sand and gravel, fine sand to small cobbles, gravel is mostly lithic clasts (reworked Whitney and Arikaree concretions); carbonate cemented; some white siliceous concretions and chalcedony nodules; this unit may be a basal lithic conglomerate of the Pussy Springs channel complex---------------- 5

SECTION 11

Location: SW SW SW NE sec. 30, T. 19 N., R. 47 W., 3700 ft

White River Group
Brule Formation
Whitney Member

Lithologic unit	Description	Thickness (in feet)
1	Siltstone, slightly sandy, slightly clayey grading upwards into a moderately sandy silt to siltstone; grayish-orange (10YR 7/4) to yellowish-brown (10YR 5/2); scattered "potato" nodules and several zones of pseudo-pipe concretions; they are best developed on upper 15 ft; locally a 4 ft thick calcareous, massive, cap-rock occurs at the upper contact; small vertical pedotubules (burrows) occur locally; sample LJ78-21 from 78 ft above base and sample LJ78-22 from 98 ft above base-------------------------	103

Arikaree Group
Harrison-Monroe Creek formations, undifferentiated

Lithologic unit	Description	Thickness (in feet)
2	Sand, very fine; moderately silty; pale yellow-brown (10YR 6/2); numerous small vertical tubules (burrows ?); some small scale cross-beds; indistinct and gradational upper contact; sample LJ78-23 taken 1 ft above lower contact------	10
3	Sand, very fine to fine, slightly silty; well sorted, about 5 percent dark-colored elongate heavy minerals, glass shards common; pipy concretion ledges common; a 2 ft thick lenticular limestone with ostracods and small gastropods occurs at the top of the unit-----	35

Ogallala Group
Ash Hollow Formation

Lithologic unit	Description	Thickness (in feet)
4	Limestone "mortar bed," slightly sandy, platy structured, basal 3 ft mottled brown sand with calcareous "boxwork" structure; siliceous root casts common, some yucca-like root casts---------	9 to 12

SECTION 13

Location: Cen S line SE NE NW sec. 10, T. 18 N., R. 47 W., 3540 ft. 50 ft north of Union Pacific tracks and 1000 ft south of highway 26.

Lithologic unit	Description	Thickness (in feet)
	White River Group Brule Formation Whitney Member	
1	Siltstone, slightly clayey, massive------	6
2	Covered interval. A spring occurs at the Whitney-Pussy Springs contact------	10
	Ogallala Group Ash Hollow Formation Pussy Springs channel complex	
3	Sand, very fine to coarse, pebbly; poorly sorted, thick indistinct bedding; some graded beds; some low angle (10°) large scale cross-beds; abundant claystone (lithic) cobbles (up to 45 cm in diameter); a trace of plutonic pebbles; fossil locality FJ78-37 (a complete adult camel metapodial) from middle of this unit------------------------------	15
4	Sand, very fine to very coarse, with some fine gravel lenses; some cross-bedded, well sorted units, both trough and planan cross-beds up to 1 ft thick, paleoflow direction southerly; pebbles mostly granitic with 5 to 10 percent acidic volcanic pebbles----------------	20
5	Siltstone, very sandy; pebbly, yellow-brown (10YR 6/4), laminated; thinly interbedded with sandstone, very fine to medium; local thin claystones-------	18
6	Siltstone to silt, very sandy, pebbly; interbedded with thin sand to sandstone, very fine to fine; beds usually less than 0.5 ft thick-----------------	8
7	Sand, very fine to fine, very silty; interbedded with poorly sorted, pebbly, very fine to fine sand to sandstone;	

(Section 13, continued)

	granitic gravel up to 6 cm diameter of intermediate axis; local cut and fill with fine gravel lenses; in the upper 25 ft there are a few irregularly shaped calcareous sandstone ledges similar to "mortar beds"---------------	52
8	Sand, very fine to medium, very silty, slightly clayey, locally pebbly; indistinct horizontal bedding, poorly exposed------------------------------------	10
9	Covered interval to hill top, gravel-veneered slope may be from the Ash Hollow above the Pussy Springs unit----	14

SECTION 14

Location: NE NE NW SW sec. 30, T. 19 N., R. 47 W., 3705 ft.

Lithologic unit	Description	Thickness (in feet)
	White River Group Brule Formation Whitney Member	
1	Siltstone, slightly sandy; massive; not as compact as typical clayey Whitney---	12
2	Silt to siltstone, very sandy; lenticular; massive; abundant small diameter vertical tubules (burrows); sample LJ78-25 taken from middle of unit---	0 to 4
3	Siltstone, slightly sandy, massive-------	13
4	Siltstone, moderately sandy; lenticular; yellowish-gray (5Y 7/2); indistinct contacts; sample LJ78-26 taken in middle of unit---------------------	2 to 4
5	Siltstone, slightly sandy, massive-------	13

SECTION 15

Location: NE NE SE NE sec. 4, T. 18 N., R. 47 W., 3575 ft. About 2000 ft north of highway 29. Section began in north-south gully bottom.

Lithologic unit	Description	Thickness (in feet)
	Ash Hollow Formation Pussy Springs channel complex	
1	Sand, very fine to fine, moderately silty; moderate yellowish-brown; thick bedded, massive; interbedded with sandy silt; local pebbly sand lenses; some medium-scale cross-bedding; most bedding is indistinct; fossil locality FJ78-13 (horse tooth, rodent post-cranials) 10 ft above base of section; sample LJ78-45 taken from same locality as FJ78-13---------------	35
2	Gravel and sand, gravel clasts up to cobble size and mostly composed of reworked Arikaree and Whitney concretions; granitic pebbles also present; fossil bone fragment also common (fossil locality FJ78-14); this gravel unit is approximately 200 ft wide and lenses out into sandy silts---------	0 to 4
3	Sand, very fine to fine, very silty, poorly sorted; moderate yellowish-brown (10YR 5/4); indistinct, thick horizontal bedding, locally calcareous-----	16
4	Sand, very fine to fine, moderately silty, pebbly with local thin granitic gravel lenses; cut and fill with a maximum of 1 ft of relief, gradational contacts-------------------------------	14
5	Sandstone, very fine to fine, moderately silty, calcareous, thin bedded and cross-laminated; interbedded with thin clayey siltstones and claystones, yellowish-brown (10YR 6/2); some siltstones have abundant small vertical burrows (?); sample LJ78-96 taken 8 ft above base of unit------------------	32

Locations for Samples Not Listed in the Measured Stratigraphic Sections

Stratigraphic unit and sample number	Location and elevation
Pussy Springs channel complex	
LJ78-8A	Cen S line SW SE SW sec. 3, T. 18 N., R. 47 W., 3560 ft
Harrison-Monroe Creek formations, undifferentiated	
LJ78-11	SW cr NW NW SE sec. 21, T. 19 N., R. 47 W., 3780 ft; 2 ft below Ash Hollow contact
LJ78-13	NE cr SE NE SE sec. 32, T. 19 N., R. 47 W., 3770 ft; 15 ft below top of westernmost butte 0.3 miles north of old Ruby Ranch.
LJ78-16	Cen SE SW NE SE sec. 29, T. 19 N., R. 47 W., 3835 ft; 5 ft below Ash Hollow contact
Whitney Member	
LJ78-5	S½ NE SE NE sec. 10, T. 18 N., R. 47 W., 3595 ft; upper Ash Bed, 3 ft thick
LJ78-6	S½ NE SE NE sec. 10, T. 18 N., R. 47 W., 3660; volcanic ash bed, 3 ft thick; 65 ft above upper Ash.
LJ78-83	SW SE SW SE sec. 33, T. 19 N., R. 47 W., 3730 ft
LJ78-14	NE cr SE NE SE sec. 32, T. 19 N., R. 47 W., 3764; 6 ft below LJ78-13
LJ78-15	NE cr SW SE sec. 29, T. 19 N., R. 47 W., 3835 ft

APPENDIX C

LOCATION OF SAMPLES FOR PEBBLE COUNTS AND MAXIMUM CLAST SIZE IN THE ASH HOLLOW AND BROADWATER FORMATION AND IN THE COARSE GRAVEL UNIT

Pebble count samples--the elevation, in feet above sea level is given in parenthesis after each legal location.

Sample No.	Location
Ash Hollow Formation	
GJ78-4	E½ SE SW SW sec. 12, T. 18N., R. 47W. (3670 ft)
GJ78-12	N½ SW NW SE sec. 2, T. 18N., R. 47W. (3730 ft)
Broadwater Formation	
GJ78-1	NE cr NE SE sec. 20, T. 18N., R. 45W. (3845 ft)
GJ78-2	NE SE SE NE sec. 36, T. 19N., R. 47W. (4005 ft)
GJ78-5	NE SW SW SE sec. 17, T. 19N., R. 47W. (3985 ft)
GJ78-6	SE or SE NW NE sec. 20, T. 19N., R. 47W (3780 ft)
GJ78-7	NW or NW SE NE sec. 20, T. 19N., R. 47W (4000 ft)
GJ78-9	NW cr sec. 21, T. 19N., R. 47W. (4020 ft)
GJ78-11	cen W½ NW NE sec. 2, T. 18N., R. 47W. (3790-3805 ft)
GJ78-15	cen NE NE SW sec. 21, T. 19N., R. 45W. (3870-3880 ft)
Coarse Gravel Unit	
GJ78-3	NW SW SW NW sec. 7, T. 18N., R. 46W. (3785 ft)
GJ78-13	NW NW NE SW sec. 22, T. 18N., R. 46W. (3640-3660 ft)
GJ78-14	NW SW SE SE sec. 17, T. 18N., R. 46W. (3720-3740 ft)

Maximum clast size samples--the elevation in feet above sea level is given in parenthesis after each legal location.

Sample No.	Location
Ash Hollow Formation	
GS-2	N½ SW NW SE sec. 2, T. 18N., R. 47W. (3730 ft)
GS-4	SW cr NE SW SE sec. 33, T. 19N., R. 47W. (3730-3750 ft)
Broadwater Formation	
GS-1	SE NE SE NW sec. 2, T. 18N., R. 47W. (3780-3905 ft)
GS-8	NE SE SE NE sec. 36, T. 19N., R. 47W. (4005 ft)
GS-12	NE cr NE SE sec. 20, T. 18N., R. 45W.(3840-3860 ft)
GS-13	cen NE NE SW sec. 21, T. 19N., R. 45W. (3870-3880 ft)
GS-16	NE SE NE SE sec. 22, T. 18N., R. 46W. (3990-3995 ft)
Coarse Gravel Unit	
GS-3	NW NW NE SW sec. 22, T. 18N., R. 46W. (3610-3660 ft)
GS-5	NE NE SE sec. 33, T. 19N., R. 47W. (3700-3740 ft)

APPENDIX C (continued)

GS-6	NW NE SW sec. 33, T. 19N., R. 47W. (3720-3760 ft)
GS-7	SW SE NE NW sec. 4, T. 18N., R. 47W. (3610 ft)
GS-9	NW SW SE SE sec. 17, T. 18N., R. 46W. (3720-3740 ft)
GS-10	E½ SE sec. 18, T. 18N., R. 46W. (3630-3670 ft)
GS-14	NW cr sec. 5, T. 17N., R. 45W. (3560 ft)

APPENDIX D

FOSSIL LOCALITIES

The elevation, in feet above sea level, is given in parenthesis after each legal description.

Stratigraphic Unit and Locality number	Location
Whitney Member	
FJ78-38	NW NW SW SE sec. 14, T. 19N., R. 48W. (3780 ft)
Pussy Springs Channel Complex	
FJ78-7	SE SE NE NE sec. 10, T. 18N., R. 47W. (3670-3675 ft)
FJ78-8	E½ SE NW SE sec. 3, T. 18N., R. 47W. (3620 ft)
FJ78-12	SE NE NW NE sec. 4, T. 18N., R. 47W. (3620-3640 ft)
FJ78-13	SE SE NE NE sec. 4, T. 18N., R. 47W. (3595 ft)
FJ78-14	NE cr SW NE sec. 4, T. 18N., R. 47W. (3610-3620 ft)
FJ78-17	SW or NW NE NE sec. 4, T. 18N., R. 47W. (3640 ft)
FJ78-18	SW or NE NE SW sec. 33, T. 19N., R. 47W. (3700-3720 ft)
FJ78-19	SE SW SW NE sec. 4, T. 18N., R. 47W. (3685-3660 ft)
FJ78-20	NE NW SW NE sec. 4, T. 18N., R. 47W. (3620 ft)
FJ78-21	cen NE NW SE sec. 4, T. 18N., R. 47W. (3540 ft)
FJ78-37	SE NE NW sec. 10, T. 18N., R. 47W. (3540 ft)
FJ78-39	SW SE NE NW sec. 4, T. 18N., R. 47W. (3610 ft)
Ash Hollow Formation	
FJ78-2	NE NE NW SE sec. 12, T. 18N., R. 47W. (3720-3760 ft)
FJ78-3	SE NW SE NE sec. 17, T. 18N., R. 46W.
FJ78-4	SW NW NE sec. 17, T. 18N., R. 46W. (3700-3730 ft)
FJ78-5	E½ SE SW SW sec. 12, T. 18N., R. 47W. (3630-3660 ft)
FJ78-6	NW NW NE sec. 11, T. 18N., R. 47W. (3670-3690 ft)
FJ78-9	NW SE NE NW sec. 3, T. 18N., R. 47W. (3710-3730 ft)
FJ78-11	SW cr NE SW SE, Sec. 33, T. 19N., R. 47W. (3730-3750 ft)
FJ78-15	N½ SW NW SE sec. 2, T. 18N., R. 47W. (3720-3740 ft)
FJ78-16	cen S½ sec. 2, T. 18N., R. 47W. (3700-3760 ft)
FJ78-22	SE SW NE sec. 21, T. 18N., R. 47W. (3990-3995 ft)
FJ78-25	SE NE NW SW sec. 33, T. 19N., R. 47W. (3775 ft)
FJ78-26	SW or NW NW SE NE sec. 33, T. 19N., R. 47W. (3750-3755 ft)
FJ78-27	near cen NE NW SW NE sec. 33, T. 19N., R. 47W. (3740-3750)
FJ78-28	N½ SE NW NE sec. 33, T. 19N., R. 47W. (3760 ft)
FJ78-29	NW or SW SW NW NW sec. 33, T. 19N., R. 47W. (3760 ft)
FJ78-30	NW or NE NE SE sec. 29, T. 19N., R. 47W. (3875 ft)
FJ78-32	NW NE SW NW sec. 34, T. 19N., R. 47W. (3760-3770 ft)

APPENDIX D (continued)

FJ78-33	W½ SW SW sec.34,T.19N.,R.47W. and cen NW NW NW sec. 3, T.18N.,R47W. (3720-3730 ft)
FJ78-34A	NE NE NW NE sec. 19, T.18N.,R.46W. (3670 ft)
FJ78-36	SE NE SE NW sec. 2,T.18N.,R.47W. (3760 ft)

Coarse Gravel Unit

FJ78-10	N½ SE NE SE sec. 33, T.19N.,R.42W. (3700 ft)

Broadwater Formation

FJ78-1	SW NE SW sec. 21, T.18N.,R.45W. (3840-3850 ft)
FJ78-24	SW SW SE NE sec. 21, T.19N.,R.47W. (3990 ft)
FJ78-31	NE SW SW SE sec. 17, T.19 N.,R.47W. (3985 ft)

The assignment of a Clarendonian land mammal age to the Pussy Springs channel complex is based on the occurence of a small primitive *Pliohippus* (horse), *Cosoryx* (merycodont antilocaprid), and a camel with a poorly-fused metapodial (cf. *Protolabis*)

The assignment of a Hemphillian age to at least part of the Ash Hollow Formation is based on the occurence of a large *Dinohippus* (horse), *Astrohippus* (horse), an antilocaprine antilocaprid (cf. *Plioceras*), and a very large *Teleoceras*.

APPENDIX E

LOGS OF TEST HOLES

The following are logs of test holes drilled by the Conservation and Survey Division, IANR, University of Nebraska, Lincoln and utilized in this study. I examined the sample cuttings, electric logs, and field logs on each hole. The surface elevations were determined from 7½ minute topographic maps. Colors are on wet samples.

Test Hole 24-A-53

Location: SE cr. sec. 32, T. 19 N., R. 47 W.
Elevation: 3605 ft.
Depth to water: Artesian flow

	Depth, in feet From	To
Colluvium and alluvium, undifferentiated		
Silt, moderately sandy, yellowish-brown (10YR 6/3)	0 -	25
Sand and lithic gravel	25 -	29
Whitney Member, Brule Formation		
Siltstone, moderately clayey, very slightly sandy, dark yellowish-brown (10YR 6/4); interval from 60-70 feet sampled for mineralogic analysis (Appendix A)	29 -	75
Silt to siltstone, sl. sandy, grayish-orange (10YR 7/4-8/4)- Lower Ash Bed; interval from 75-80 feet and 80-81.5 feet sampled for mineralogic analysis (Appendix A)	75 -	81.5
Siltstone to silt, slightly clayey, slightly sandy, pale yellow brown (10YR 6/4)	81.5-	125

Note: the test hole was drilled to a total depth of 560 feet. However for the purposes of this study I did not examine any sample below 125 feet. The field log notes Chadron Formation from 435 to 500 feet and Lance Formation (probably Pierre Shale) from 500 to 560 feet.

Test Hole 48-B-53

Location: SE cr. sec. 17, T. 19 N., R. 47 W.
Elevation: 4044 ft
Depth to water: 148 ft

	Depth, in feet From	To
Colluvium and alluvium, undifferentiated		
Road fill and soil-------------------	0 -	2
Silt, slightly sandy, yellow-grey (12.5Y 6/4)------------------------	2 -	10
Broadwater Formation		
Sand and gravel, medium sand to fine gravel, some anorthosite pebbles---	10 -	18
Sand, fine to coarse, trace of pebbles----------------------------	18 -	24
Sand, fine to very fine, moderately silty; some indurated fragments; light olive grey (5Y 5/2)----------	24 -	30
Sand, very fine, very silty; no diatoms observed in grain mount of silt fraction------------------	30 -	35
Silt to siltstone, slightly sandy, slightly clayey; no diatoms observed in grain mount of silt fraction---------------------------	35 -	35.5
Sand, fine to very coarse, trace of fine gravel-----------------------	35.5-	42
Sand and gravel, medium sand to fine gravel; trace of anorthosite pebbles---------------------------	42 -	50
Sand, very fine to fine, moderately silty; no diatoms present in grain mount of silt fraction-------------	50 -	53
Sand and gravel, fine sand to coarse gravel; coarser below 56 ft--------	53 -	70.5
Ash Hollow Formation, Ogallala Group		
Sandstone, very fine to medium; many siliceous fossil root casts--------	70.5-	110
Sand to sandstone, very fine to fine, slightly silty-------------------	110 -	130
Harrison-Monroe Creek formations, undifferentiated, Arikaree Group		
Sand to sandstone, very fine to fine; many calcite cemented hard zones---	130 -	210
Marl, white--------------------------	210 -	213
Sand, very fine to fine, slightly silty----------------------------	213 -	230
	T.D.	

Note: the test hole is located directly north of the type section of the Broadwater Formation.

Test Hole 50-B-53

Location: NW cr. SW sec. 18, T. 18 N., R. 46 W.
Elevation: 3642 ft
Depth to water: 87 ft

	Depth, in feet From	To
Colluvium and alluvium, undifferentiated		
Road fill and soil-------------------	0 -	5
Silt, very sandy---------------------	5 -	25
Sand, very fine, trace of medium to coarse, very silty-----------------	25 -	30
Sand and gravel, moderately silty; poorly sorted----------------------	30 -	33.5
Silt, sandy to very sandy; trace of sand and gravel 40 to 45 ft, 45 to 50 ft; coarsest gravel 55 to 60 ft-----------------------------------	33.5-	60
Whitney Member, Brule Formation		
Siltstone, very slightly sandy, slightly clayey; yellow brown (10YR 6/4)-------------------------	60 -	100
	T.D.	

Test Hole 21-B-72

Location: NE SE SE sec. 28, T. 18 N., R. 46 W.
Elevation: 3498 ft
Depth to water: 16 ft

	Depth, in feet From	To
Colluvium and alluvium, undifferentiated		
Top soil and sand, very fine to medium	0	5
Sand, fine to very coarse	5	13
Sand and gravel, fine sand to medium gravel; some interbedded silt	13	20
Sand and gravel; 10 to 15 percent fine gravel	20	30
Sand and gravel; coarser than above, 50 percent fine to medium gravel; interbedded silt in lower 3 ft	30	45
Ash Hollow Formation, Ogallala Group		
Sand to sandstone, very fine to medium, trace fine gravel; some siliceous root casts	45	50
Sandstone to sand; medium to coarse; trace of medium gravel	50	60.3
Sandy siltstone; yellow brown (10YR 5/4)	60.3	75
Sand to sandstone, fine to very coarse, trace fine gravel	75	81
Sand and gravel, fine sand to medium gravel; finer 100-110 ft	81	110
Silt, very sandy, trace medium to very coarse sand	110	120
Sand, very fine to coarse, very silty; trace pebbles	130	130.8
Whitney Member, Brule Formation		
Silt to siltstone, moderately to very clayey, very slightly sandy; moderately yellowish brown (10YR 5/4)	130.8	180 T.D.

Test Hole 25-B-72

Location: SW SW SW sec. 27, T. 19 N., R. 46 W.
Elevation: 3992 ft
Depth to water: 216.5 ft

	Depth, in feet From	To
Colluvium and alluvium, undifferentiated		
Silt, very sandy, yellow brown-------	0	17
Broadwater Formation		
Sand, very fine to very coarse; trace of fine gravel--------------------	17	41
Silt-siltstone, very clayey, slightly sandy; pale olive (5Y 6/4); abundant frustules in grain mount of silt fraction; no diatoms observed----------------------------	41	48
Sand and gravel, fine sand to medium gravel-----------------------------	48	58
Sand, very fine to coarse, moderately silty; brown (5YR 4/4)-------------	58	64
Sand and gravel, fine sand to fine gravel, trace medium gravel; a few percent anorthosite pebbles--------	64	109
Silt, very sandy, diatomaceous; pale brown (5YR 5/4); typical Broadwater-type diatom assemblage observed in grain mounts of silt fraction--------------------------	109	114
Gravel and sand; fine sand to medium gravel, 40 to 60 percent fine gravel; coarser 125 to 130 ft; a few percent anorthosite pebbles, 6 to 10 percent mafic plutonic pebbles---------------------------	114	133
Ash Hollow Formation, Ogallala Group		
Sandstone to sand, very fine to coarse; abundant siliceous rootlets 138 to 150 ft; yellow-brown (10YR 5/3)------------------------	133	150

Note: the test hole was drilled to a total depth of 440 feet. The Ash Hollow Formation - Whitney Member contact was penetrated at 381 feet. For the purpose of this study I did not examine any samples below 150 feet.

Test Hole 26-B-72

Location: NE cr. sec. 14, T. 19 N., R. 46 W.
Elevation: 3603 feet
Depth to water: not determined
Date drilled: July 11, 1972

	Depth, in feet From		To
Colluvium and alluvium, undifferentiated			
Sand, fine-coarse, moderately silty----	0	-	6
Broadwater Formation			
Sand and gravel, medium sand to fine gravel; coarser 20 to 37 feet, gravel contains less than 1% anorthosite pebbles------------------	6	-	37
Gravel, sandy, fine to coarse gravel---	37	-	40
Sand, fine to coarse, trace of fine gravel---------------------------------	40	-	42
Ash Hollow Formation			
Sand-sandstone, fine-coarse, siltier---	42	-	55
Sand-sandstone, fine-coarse, pebbly; trace of pebbles of anorthosite------	55	-	65
Siltstone, moderately sandy with interbedded sandstone, very fine-fine, yellow-brown (10YR 5/4) to olive brown (2.5Y 4/4)--------------	65	-	70
Sand, fine-coarse; very silty 82-83 feet----------------------------------	70	-	83
Sand-sand and gravel, medium to very coarse sand, trace of medium gravel--	83	-	90
Sand-sandstone, fine-coarse, siliceous rootlets------------------------------	90	-	100
Sandstone-silty, fine-medium; siliceous rootlets-------------------	100	-	110

Note: the hole was drilled to 300 feet and did not penetrate any other stratigraphic units.