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SEDIMENTOLOGY OF NORDEN BRIDGE AND EGELHOFF FOSSIL QUARRIES (MIOCENE) OF NORTH-CENTRAL NEBRASKA

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Measured sections demonstrate the positions of the Norden Bridge and Egelhoff fossil quarries in the local stratigraphy and show Egelhoff Quarry to be topographically higher. The sections do not resolve the relative stratigraphic positions of the quarries. Descriptions of sediments at the two quarries demonstrate that coarser sediments exist at Norden Bridge Quarry. However, these coarse sediments, as well as the fossil remains of large vertebrates, are limited to two particular beds at Norden Bridge Quarry, while three other beds comprise sediments either finer or statistically indistinguishable from those at Egelhoff Quarry. The association of large clasts and large bones suggests hydraulic sorting of these sedimentary particles and supports the suggestion that the difference in fossil faunas between the two quarries is depositional. Evaluation of cross-strata sets at both quarries indicates that local paleocurrents do not reflect the easterly regional dip of local Tertiary strata.

† † †

INTRODUCTION

Leidy (1858) published the first report of fossil vertebrates from the fluvial Tertiary rocks in the vicinity of Valentine, Nebraska. Since then, discussions of these rocks have continued, including considerable debate over the propriety of local stratigraphic names, particularly use of the term "Valentine" regarding what is now agreed to be the Valentine Formation and its fossil faunas. These debates are now resolved to the satisfaction of most and are concisely reviewed by Skinner, Skinner, and Gooris (1968).

Attention of vertebrate paleontologists familiar with the Valentine Formation has been focused upon the fossil quarries within the formation since Hibbard (1960) announced the discovery of fossil vertebrates from the now well-known Norden Bridge Quarry (Fig. 1). In 1964 Morris Skinner discovered another site, the Egelhoff Quarry, approximately 2.5 km northwest of Norden Bridge Quarry. Fossil vertebrates from these quarries have been the subject of a series of papers during the last 20 years (Smith, 1962; Klingener, 1968; Lindsay, 1972; Rich and Rasmussen, 1973; Storer, 1973; Holman, 1976). In addition to the principal descriptive and taxonomic purposes of these papers, they demonstrate that the fossil vertebrate remains from the quarries are, in most cases, water-transported, isolated bones.

Remarkably for two such well publicized localities, no stratigraphic section has been published marking their positions in the regional stratigraphy. Holman (1973) and Chantell (1971) reported that Egelhoff Quarry is topographically 7.7 m (25 ft) higher than Norden Bridge Quarry. Holman (1973) suggested additionally that the quarries are temporally equivalent. Similarities in their faunas (*cf.* Tables I and II) support the temporal equivalency of the two sites; however, fossils of larger mammals such as perissodactyls and artiodactyls are much less common at Egelhoff Quarry and proboscideans are entirely absent. Experimental work in taphonomy by Voorhies (1969), Dodson (1973), and Korth (1979) suggests that the difference in the size ranges of fossil vertebrates at the two quarries may be a depositional phenomenon, reflecting a difference in competency between the currents depositing the bones and sediments at the two sites. The observation by Holman (1973) that sediment clast-size is greater at Norden Bridge Quarry than at Egelhoff Quarry supports this suggestion; however, this clast-size difference has not been demonstrated quantitatively.

The purpose of this paper is to present measured sections of the stratigraphy at the Egelhoff and Norden Bridge quarries and to illustrate sedimentological differences between them by means of description and a sieve analysis of sediments. Cross-strata and elongate bone orientations are evaluated as indicators of paleocurrent direction at the quarries.

TABLE I. Fossil vertebrate taxa identified from Norden Bridge Quarry (*from* Falk, Osborn, Pepperl, and Voorhies, 1980).

- **Class Osteichthyes**
  - **Family Lepisosteidae**
    - *Lepisosteus* sp. – garpike
  - **Family Amiidae**
    - *Amia* sp., *cf. A. calva* – bowfin
  - **Family Ictaluridae**
    - *Ictalurus lambda* – large extinct catfish
    - *I. punctatus* – channel catfish
  - **Family Centrarchidae**
    - *Lepomis* sp., *cf. L. microlophus* – sunfish
- **Class Amphibia**
  - **Order Urodela**
    - **Family Cryptobranchidae**
      - *Andrias matthewi* – Matthew's giant salamander
    - **Family Ambystomatidae**
      - *Ambystoma minshalli* – extinct mole salamander
  - **Order Anura**
    - **Family Pelobatidae**
      - *Scaphiopus (Scaphiopus) wardorum* – extinct spadefoot toad
      - *S. (Spea)* sp., *cf. S. bombifrons* – plains spadefoot
    - **Family Bufonidae**
      - *Bufo* sp., *cf. B. hibbardi* – extinct toad
      - *B. valentinensis* – extinct toad
      - *B. kuhrei* – extinct toad
    - **Family Hylidae**
      - *Acris* sp., *cf. A. crepitans* – cricket frog
      - *Pseudacris* sp., *cf. P. clarki* – spotted chorus frog
      - *P. nordensis* – extinct chorus frog
      - *Hyla* sp., *cf. H. gratiosa* – barking tree frog
      - *H.* sp., *cf. H. squirella* – tree frog
      - *H.* sp., *cf. H. versicolor* – gray tree frog
    - **Family Ranidae**
      - *Rana* sp., nr. *R. pipiens* – leopard frog
- **Class Reptilia**
  - **Order Testudinata**
    - **Family Emydidae**
      - *Chrysemys* sp., *cf. C. picta* – painted turtle
    - **Family Testudinidae**
      - *Geochelone orthopygia* – giant land tortoise
      - *G. nordensis* – midget land tortoise
    - **Family Trionychidae**
      - *Trionyx* sp. – softshell turtle

TABLE I. (Continued).

- **Order Squamata**
  - **Family Xenosauridae**
    - *Nordenosaurus magnus* – large extinct lizard
  - **Family Iguanidae**
    - *Sceloporus* sp.
    - *Leiocephalus* sp. – undescribed species of extinct tropidurine lizard
  - **Family Anguidae**
    - *Gerrhonotus* sp., *cf. G. mungerorum* – extinct alligator lizard
    - *Ophisaurus ventralis* – eastern glass lizard
    - *cf. Peltosaurus* – extinct lizard
  - **Family Scincidae**
    - *Eumeces* sp. – striped skink
  - **Family Amphisbaenidae**
    - unidentified genus and species of worm lizard
  - **Family Boidae**
    - *Charina prebottae* – extinct rubber boa
  - **Family Colubridae**
    - *cf. Thamnophis* – garter snake
    - *cf. Neonatrix elongata* – extinct water snake
    - *Paleoheterodon tiheni* – ancestral hognose snake
    - *Nebraskensis skinneri* – archaic colubrid snake
    - *Salvadora paleolineata* – extinct patch-nose snake
    - *Lampropeltis similis* – extinct small king snake
    - *Elaphe nebraskensis* – extinct rat snake
- **Class Mammalia**
  - **Order Insectivora**
    - **Family Erinaceidae**
      - *Parvericius montanus* – small extinct hedgehog
      - *Untermannerix copiosus* – medium-sized extinct hedgehog
      - *Metechinus amplior* – large extinct hedgehog
    - **Family Plesiosoricidae**
      - *Plesiosorex* sp., *cf. P. donroosai* – large extinct insectivore
    - **Family Soricidae**
      - *Alluvisorex* sp. – extinct shrew
    - **Family Talpidae**
      - *Mystipterus* sp. – extinct shrew-mole
      - *Domninoides valentinensis* – extinct mole
      - *Scalopoides* sp. – extinct mole
  - **Order Lagomorpha**
    - **Family Leporidae**
      - *Hypolagus* sp. – archaic rabbit
    - **Family Ochotonidae**
      - *Hesperolagomys* sp. – archaic pika
  - **Order Rodentia**
    - **Family Aplodontidae**
      - *Allomys* sp., *cf. A. stirtoni* – extinct sewellel

TABLE I. (Continued).

Family Mylagaulidae

Mylagaulus sp. – horned rodent

Family Sciuridae

Tamias sp. – extinct chipmunk

Family Castoridae

Monosaulax sp. A – large primitive beaver
M. sp. B – small primitive beaver

Family Eomyidae

Paradjidaumo stirtoni – extinct archaic rodent

Family Zapodidae

Megasminthus tiheni – large archaic jumping mouse
Plesiosminthus sp. – small archaic jumping mouse

Family Heteromyidae

Perognathus sp., *cf. P. furlongi* – extinct pocket mouse
P. trojectioansrum – small extinct pocket mouse
"Diprionomys" sp., *cf. P. agrarius* – archaic pocket mouse
D. sp. – large extinct pocket mouse
Cupidinimus nebraskensis – small extinct pocket mouse

Family Cricetidae

Copemys niobrarensis – extinct deer mouse
Tregomys sp. – extinct deer mouse

Family Geomyidae

undetermined genus and species of extinct pocket gopher

Order Carnivora

Family Amphicyonidae

cf. Pliocyon – large bear-dog

Family Canidae

Aelurodon sp. – large hyaenoid dog
Tomarctus sp. – small hyaenoid dog
Leptocyon vafer – fox-sized dog
Cynarctus sp. – extinct raccoonlike dog

Family Mustelidae

Leptarctus primus – extinct mustelid
undetermined genus and species of small mustelid

Family Procyonidae

Bassariscus sp., *cf. B. parvus* – extinct miner's cat

Order Proboscidea

Family Gomphotheriidae

Gomphotherium sp., *cf. G. productus* – long-jawed mastodon

Order Perissodactyla

Family Rhinocerotidae

Teleoceras sp. – short-limbed rhinoceros
Aphelops sp. – long-limbed rhinoceros

Family Tapiridae

Tapirus sp. – extinct tapir

TABLE I. (Continued).

Family Equidae

Hypochippus sp. – browsing horse
Archaeohippus sp.
Merychippus sp. – primitive grazing horse
Calippus sp. – small grazing horse
Protohippus perditus – tridactyl grazing horse
"Hipparion" sp. – tridactyl grazing horse

Order Artiodactyla

Family Tayassuidae

cf. *Prosthennops* – extinct peccary

Family Merycoidodontidae

cf. *Ustatochoerus* sp. – oreodont

Family Cervidae

Cranioceras (Procranioceras) sp., *cf. C. (P.) skinneri* – extinct three-horned deer
Blastomeryx sp. – small sabertoothed deer

Family Camelidae

Procamelus sp. – ancestral camel
Protolabis sp. – small camel

Family Antilocapridae

Merycodus sp. – forked-horned prongbuck
Ramoceros sp. – large-horned prongbuck
undetermined genus and species of small prongbuck

TABLE II. Fossil vertebrate taxa identified from Egelhoff Quarry (*from* Falk, Osborn, Pepperl, and Voorhies, 1980).

Class Osteichthyes

Family Ictaluridae

Ictalurus sp. – catfish

Family Centrarchidae

undetermined genus and species of sunfish

Class Amphibia

Order Urodela

Family Ambystomatidae

Ambystoma minshalli – extinct mole salamander

Order Anura

Family Pelobatidae

Scaphiopus sp., *cf. S. bombifrons* – plains spadefoot toad
S. sp., *cf. S. holbrooki* – eastern spadefoot

Family Bufonidae

Bufo valentinensis – extinct toad
B. sp., *cf. B. hibbardi* – extinct toad

TABLE II. (Continued).

Family Hylidae
Acris sp., *cf. A. crepitans* – cricket frog
Pseudacris sp., *cf. P. clarki* – spotted chorus frog
Hyla sp., *cf. H. cinerea* – green frog
H. sp., *cf. H. crucifer* – spring peeper
Family Ranidae
Rana sp. – frog

Class Reptilia
Order Testudinata
Family Testudinidae
Geochelone sp. – giant land tortoise
Family Trionychidae
Trionyx sp. – softshelled turtle
Order Squamata
Family Anguidae
Ophisaurus ventralis – eastern glass lizard
Gerrhonotus sp., *cf. G. mungerorum* – extinct alligator lizard
Peltosaurus minimus – extinct lizard
Family Scincidae
Eumeces sp. – striped skink
Family Boidae
Charina prebottae – ancestral rubber boa

Family Colubridae
Neonatrix elongata – archaic water snake
Paleoheterodon tiheni – ancestral hognose snake
Nebraskophis skinneri – archaic colubrine snake
Salvadora paleolineata – extinct patch-nosed snake
Elaphe nebraskensis – extinct rat snake

Class Mammalia
Order Insectivora
Family Erinaceidae
Parvericios montanus – small archaic hedgehog
Untermannerix copiosus – medium-sized archaic hedgehog
Metechinus amplior – large archaic hedgehog
Family Talpidae
Domninoides valentinensis – mole
Order Lagomorpha
Family Leporidae
Hypolagus sp. – archaic rabbit
Family Ochotonidae
cf. Hesperolagomys – archaic pika
Order Rodentia
Family Sciuridae
Tamias sp. – extinct chipmunk
Family Castoridae
Monosaulax sp. – primitive beaver

TABLE II. (Continued).

Family Heteromyidae
Cupidinimus nebraskensis – small pocket mouse
Perognathoides sp. – pocket mouse
Family Zapodidae
Megasminthus tiheni – archaic jumping mouse
Plesiosminthus sp. – small archaic deer mouse
Family Cricetidae
Copemys sp., *cf. C. kellogae* – archaic deer mouse
Order Carnivora
Family Procyonidae
Bussariscus sp. – extinct miner's cat
Family Mustelidae
unidentified weasellike carnivore
Order Perissodactyla
Family Equidae
unidentified genus and species of horse
Order Artiodactyla
Family Blastomerycidae
Blastomeryx sp. – sabertoothed small deer
Family Antilocapridae
Merycodus sp. – forked-horned prongbuck

METHODS AND EQUIPMENT

Stratigraphy

The stratigraphic sections were measured using the clinometer of the Keuffel and Esser pocket transit as an eye level.

Mechanical Analysis of Sediments

Laboratory equipment used in processing sediment samples and in execution of sieve analyses is as follows:

1. Model CL-280-A mechanical sediment separator, Soil Test, Incorporated

2. Torbal PL-800 Balance, Torsion Balance Company

3. Mettler H54 Balance

4. Ro-Tap no. 8017, W. S. Tyler Company

The sedimentary analysis procedure was adapted from Folk (1974).

Orientation Data

The strike and apparent dips of cross-strata foresets and the plunge and trend of elongate fossil bones were read using the clinometer and compass of the pocket transit. Strike and apparent dips of cross-strata were converted to true strike and dip following Billings (1972). Mean vectors and mean angular deviations were calculated following Till (1974). A hybrid *F*-test (Griffiths and Rosenfeld, 1953), modified by Potter and Pettijohn (1977), was used to test the significance of orientation data.

Abbreviations

Localities.	Kp 101	Egelhoff Quarry of the American Museum of Natural History, University of Michigan, Michigan State University (MSU), and University of Nebraska State Museum (UNSM). Keya Paha County, Nebraska.
	Bw 106	Norden Bridge Quarry of the American Museum of Natural History, University of Michigan, MSU, Notre Dame University, and UNSM. Brown County, Nebraska.
Statistics.	M_z	Graphic mean.
	σ_G	Graphic standard deviation.
	σ_I	Inclusive graphic standard deviation.
	H_0	Null hypothesis.

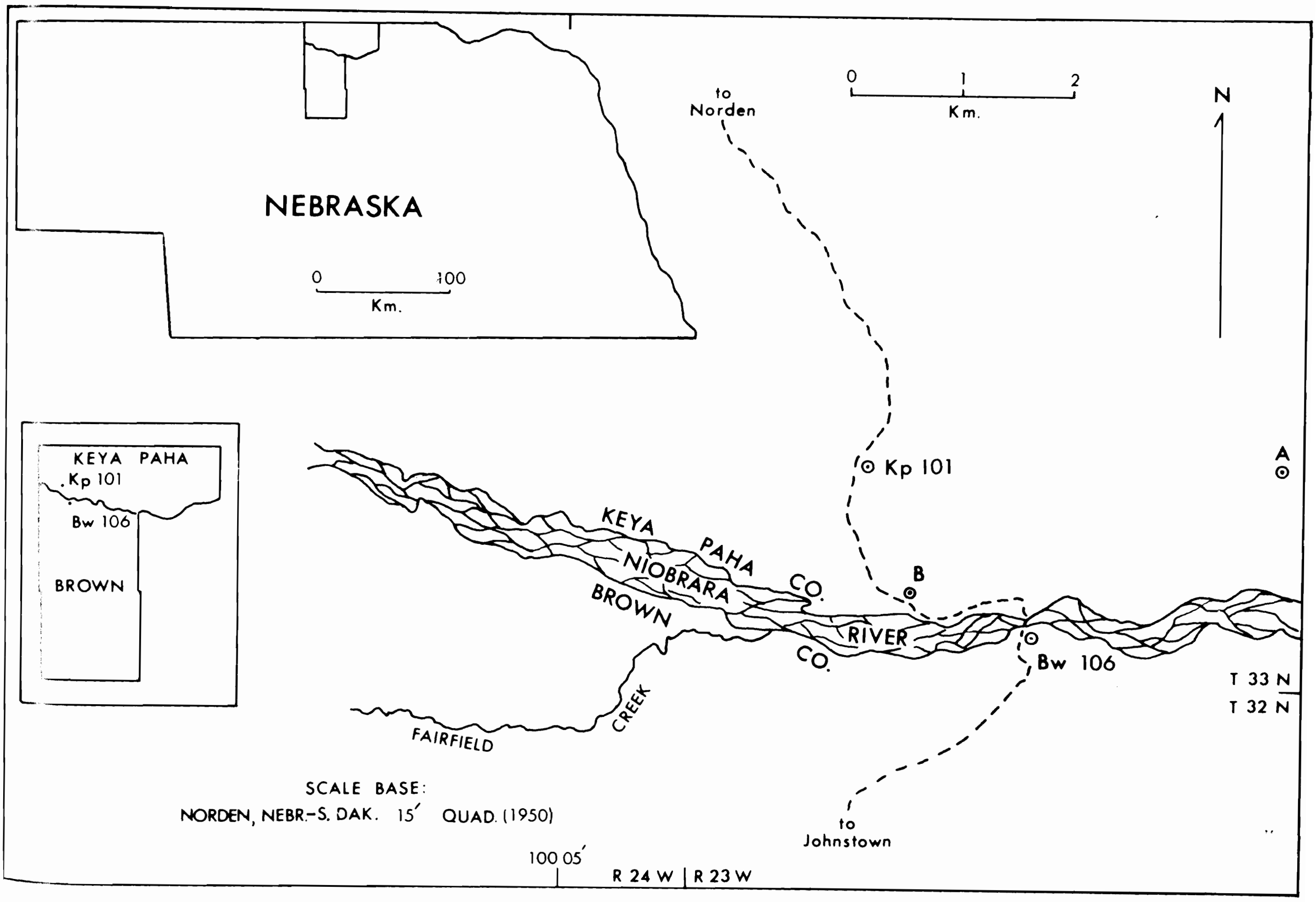

FIGURE 1. Regional locator of Norden Bridge Quarry (Bw 106) and Egelhoff Quarry (Kp 101).

H_1	Alternative hypothesis.
F	F-test statistic.
t	t-test statistic.

STRATIGRAPHY

Measured stratigraphic sections at Egelhoff and Norden Bridge quarries are presented in Figure 2 along with one of the most complete sections of local Tertiary stratigraphy available for reference and comparison. Geographic positions of these measured sections are presented in Figure 1.

Brief descriptions of the local stratigraphy are offered below to review the relevant units. Reference is made to more comprehensive works of the regional stratigraphy.

Cretaceous System

Pierre Shale. The oldest formation exposed in the region is the Cretaceous Pierre Shale, seen at Meadville, some 18 km downstream (east) from Norden Bridge.

Tertiary System

Chadron Formation. A stratigraphic unit which Skinner (Skinner and Hibbard, 1972) referred to the Chadron Formation is exposed north of the Niobrara River in roadcuts along Nebraska Highway 183 approximately 25 km east of the study area. Skinner described the lithology of the formation at this exposure as a yellowish, buff clay with zones of brown iron oxide stain and bearing clear quartz and grains. Although the unit is not exposed in the Norden Bridge vicinity, a similar unit was encountered between the Pierre Shale and Rosebud

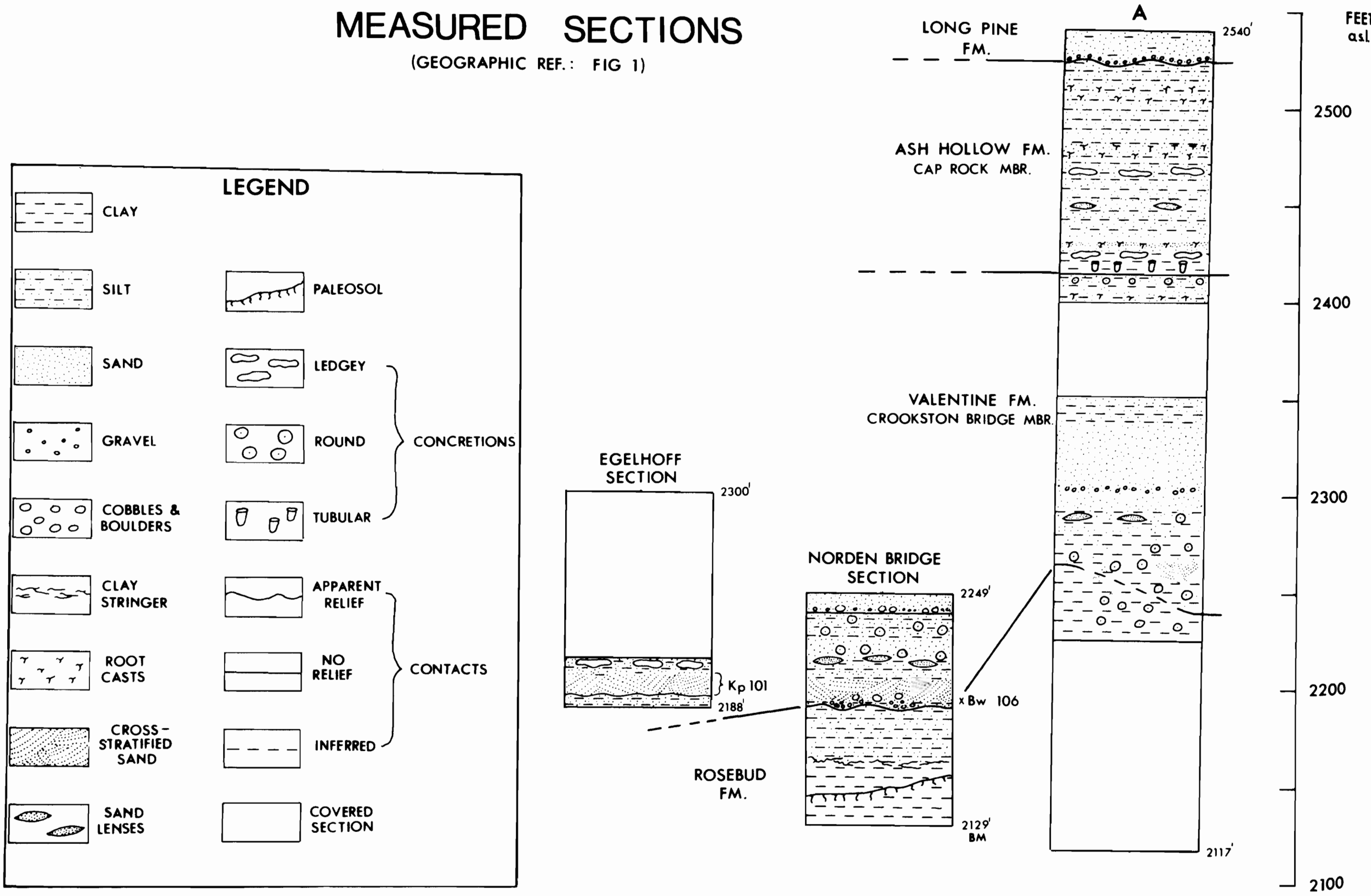

FIGURE 2. Regional stratigraphy. Refer to Figure 1 for location of particular section.

Formation in drill holes near the Norden damsite (Anonymous, 1977). Fragmentary mammalian remains recovered from the highway 183 outcrop are insufficient to corroborate the accepted Chadronian provincial age assigned to the formation. With respect to the European time scale, the formation is considered to be Oligocene (Tedford, *et al.,* 1981).

Rosebud Formation. Disconformably overlying the Chadron Formation is a pinkish, gray or tan, fine sandy or clayey siltstone, which forms high bluffs along stream courses. This report follows Skinner, Skinner, and Gooris (1968) and Webb (1969) in considering the unit to be a southerly extension of the Rosebud Formation of Gidley (1904). The formation has nearly continuous exposures along the Niobrara River between Valentine, Nebraska, and the Old Bruce Mill (SW¼ SE¼ NW¼ Sec. 16, T. 33 N., R. 24 W., Keya Paha County, Nebraska), some 12 km west of the Norden Bridge section, and has intermittent exposure from the mill to Norden Bridge itself. Nearly continuous exposures of the Rosebud Formation resume east of Norden Bridge and continue to Meadville.

At its type section on the Rosebud Agency in South Dakota the Rosebud Formation is approximately 31 m (100 ft) thick (Skinner, Skinner, and Gooris, 1968). The base of the formation is not exposed at Norden Bridge; however, a maximum thickness of approximately 49.5 m (160 ft) is reported for the Rosebud Formation (reported as "Brule" Formation) from drill holes several miles downstream from Norden Bridge (Anonymous, 1977). Local relief upon the contact between the Rosebud and the overlying Valentine formations is at least 24 m (75 ft; Fig. 2).

In the lower one-half of the exposure of the Rosebud Formation at Norden Bridge is a disconformity which may be a weathered surface or fossil soil. The sand content of the formation increases above this disconformity.

The age of the formation is undecided, as estimates range from Arikareean (Skinner, Skinner, and Gooris, 1968; Voorhies, 1973) to Hemingfordian (Webb, 1969) and Barstovian (Macdonald and Harksen, 1968). Tedford, *et al.* (1981) suggest an Oligocene age for the formation in terms of the European time scale.

Valentine Formation. The Valentine Formation is the lowest unit in the Ogallala Group. Skinner, Skinner, and Gooris (1968) have subdivided the formation into the Crookston Bridge, Devils Gulch, and Burge members, lowest to highest.

Crookston Bridge Member. The member is an unconsolidated, highly permeable, quartzose, brownish gray, silty sand. In northern Brown County the unit is generally either highly cross-bedded or horizontally laminated with thick and thin beds following one another in rapid succession. The proportions of sand, silt, and clay vary as well. Cross-bedding, lamination, and textural variability indicate rapidly fluctuating flow regimes during deposition of the member. At its type section in northern Cherry County, Nebraska, it is from 46 to 54 m (150 to 175 ft) thick (Skinner, Skinner, and Gooris, 1968). It is believed that the Egelhoff and Norden Bridge quarries occur in the Crookston Bridge Member, a subdivision of the Valentine Formation. However, Holman (1976) reported that M. F. Skinner is considering a revision of the Valentine stratigraphy.

The thickness of Valentine Formation depicted in section A (Fig. 2) is considered to represent only the Crookston Bridge Member. Because much of the Valentine Formation in Section A above the 700 m (2,325 ft) elevation was examined in freshly dug holes, the weathering characteristics of the unit at these points could not be evaluated. Regardless, these sediments are silty sands, similar to those of the Crookston Bridge Member, and bear no resemblance in color or texture to either of the overlying members of the Valentine Formation described below.

Devils Gulch and Burge Members. Though not exposed in the sections presented, the distinctive Devils Gulch Member is a fine sand, yellowish to olive drab in color. It is extremely rich in clay, which is drawn to the exposed surface by capillary action and cracks upon drying to give the surface a mud-cracked appearance.

As described by Skinner, Skinner, and Gooris (1968), the Burge Member is a predominately unconsolidate, gray, fine- to coarse-grained sand and gravel. It is not represented in the measured sections.

Age of the Valentine Formation. The age of the Valentine Formation, in terms of North American Land Mammal Ages, extends from Barstovian to Clarendonian. Lindsay (1972) suggested a Late Barstovian age for the Crookston Bridge Member on the basis of a portion of its mammalian fauna (see also Wood, Chaney, Clark, Colbert, Jepsen, Reeside, and Stock, 1941; MacGinitie, 1962; Klingener, 1968; and Webb, 1969). The Burge Member is regarded as Early Clarendonian by Webb (1969). No complete study of the fauna from the Devils Gulch Member has been completed; therefore, it cannot be assigned confidently either a Barstovian or Clarendonian age.

In consideration of the European time scale, Tedford, *et al.* (1981) suggest a Miocene age for the formation.

Radiometric dating supports the Miocene age of the formation. Boellstorff and Skinner (1977) reported fission track dates of 13.6 ± 1.3 m.y.B.P. for the Hurlbut Ash in the lower part of the Valentine Formation and 10.6 ± 0.2 m.y.B.P. for the Swallow Ash immediately above the contact of the Valentine Formation and the overlying Ash Hollow Formation. The Valentine Formation thus represents a period of approximately 3 m.y. European radiometric dates for the upper and lower boundaries of the Miocene are 5 m.y. to 5.3 m.y.B.P. and 22.5 m.y.B.P., respectively (Berggren, 1972; Berggren and Van Couvering, 1974). These European dates span those cited for the Valentine Formation.

Lindsay (1972) reported dates of 13.4 m.y.B.P. and 15.1 m.y.B.P. from the upper portion of the Barstow Formation in California. These dates and those from the Valentine Formation suggest some temporal overlap between the two formations.

Ash Hollow Formation. Overlying the Valentine Formation in the immediate study area is the Ash Hollow Formation, represented by its basal member, the Cap Rock (Skinner, Skinner, and Gooris, 1968). The Cap Rock Member forms a nearly continuous escarpment along the northern margin of the Niobrara River Valley between Valentine, Nebraska, and Norden Bridge.

Cap Rock Member. The unit is characterized by ledgey, concretic horizons of fine, light-gray sands. The weathered surfaces of the ledges are jagged due to innumerable root casts which protrude from them. Common also in the unit are pods of comparatively soft sand which sometimes hold concentrations of fossil hackberry seeds. The Cap Rock Member is 8.6 m (28 ft) thick at its type section in Cherry County, Nebraska, and, where exposed, ranges in thickness from 7.7 m [25 ft (Skinner, Skinner, and Gooris, 1968)] to 33.2 m (108 ft) in section A (Fig. 2). In the Norden Bridge area the member bears sharp contacts with the underlying Valentine Formation and overlying sediments. Near the base of the member in measured section A, are tubular concretions in upright positions.

In terms of North American Land Mammal Ages the member is Late Clarendonian (Webb, 1969). Tedford, *et al.* (1981) consider the Ash Hollow Formation to be Miocene.

Fission track dates from the previously noted Swallow Ash [10.6 ± 0.2 m.y.B.P. (Boellstorff and Skinner, 1977)] and the Davis Ash [9.7 ± 1.0 m.y.B.P. (Boellstorff, 1978)] bracket the Cap Rock.

Long Pine Formation. The Long Pine Formation, named by M. F. Skinner (*in* Skinner and Hibbard, 1972) lies unconformably upon the Ash Hollow Formation north of the Niobrara River. As shown in measured section A (Fig. 2), the base of the formation is marked by a coarse gravel containing crystalline igneous and metamorphic clasts, the presence of which distinguishes the formation from all stratigraphic units in the area. In its type area south of the Niobrara River, the formation lies upon the Ash Hollow or Keim (Pleistocene) formations, depending upon the location. The Long Pine Formation is a cross-bedded sand and gravel which has been interpreted as a fluvial-glacial outwash with a northern source (Skinner and Hibbard, 1972) and as a fluvial gravel with a western source (Stanley and Wayne, 1972). At its type section it is approximately 8 m [26 ft (Skinner and Hibbard, 1972)] thick, but in section A is only 4.6 m (15 ft) thick. Fossil vertebrates from the formation show it to be Blancan in age (Skinner and Hibbard, 1972). Tedford, *et al.* (1981) regard the formation to be Pliocene in terms of the European time scale.

Quaternary System

Terrace and Dune Deposits. The youngest strata within the valley of the Niobrara River are unconsolidated terrace gravels and sands, which are primarily local in origin, rarely containing any crystalline clasts. Outside the river valley, the surface is mantled by sand dunes. An age for these deposits more precise than Pleistocene–Holocene is unavailable at this time.

SEDIMENTOLOGICAL COMPARISONS OF NORDEN BRIDGE AND EGELHOFF QUARRIES

Description of Quarries

Norden Bridge Quarry. The Norden Bridge Quarry is located on the east side of the Norden–Johnstown Road in the SW¼ NE¼ SW¼ Sec. 33, T. 33 N., R. 23 W., Brown County, Nebraska (Fig. 1). The fossiliferous horizon can be traced for at least 200 m along the top of the prominent bluff adjacent to Norden Bridge. The specific site regularly searched for vertebrate fossils, however, is that described by Tihen and Chantell (1963) lying near the southern limit of the bluff and is referred to as *the* Norden Bridge Quarry in paleontological literature. This usage is maintained here.

As re-opened by the University of Nebraska field party in the summer of 1976, the Norden Bridge Quarry extended about 10 m laterally and had a vertical backwall approximately 5.5 m high, of which the lower 1.5 m was buried in slump debris. The floor of the quarry as developed by previous excavators was the Rosebud Formation, which is exposed in the banks of the Niobrara River and for nearly 18.5 m (60 ft) above in the adjacent bluff (Fig. 2). The base of the 1976 excavation occurs just slightly more than one meter above the base of the Valentine Formation (672 m). Pleistocene terrace gravels form a sharp contact with the Valentine Formation at the elevation of 691 m (2,249 ft). Above this point the section is covered by vegetation.

At no time was the entire quarry wall exposed for photography, as it was impossible to keep pace with the slumping of the quarry face. Figure 3 is a composite diagram of the quarry face compiled from individual exposures of portions of the quarry.

Sedimentary units recording five distinct episodes of deposition were exposed at the quarry in 1976. The lowest unit exposed was a cross-bedded, coarse gray sand with crystalline gravel and gravel-sized clay balls (Fig. 4A). The coarsest of this gravel was retained on a ϕ -3.5 sieve. Some 50 cm of this unit were excavated, but its base was not found as slumping of the unconsolidated sediment frustrated further digging.

The sand and gravel layer has sharp contact with an overlying white-weathering layer of silt, indurated by interstitial clay (Fig. 4A). The silty layer is approximately 15 cm thick and is blocky in appearance.

Overlying and in sharp contact with the white siltstone is a bed of unconsolidated, medium- to fine-grained, cross-bedded, gray sand, some 35 to 40 cm thick (Fig. 4B).

A fourth episode of sedimentation is represented by a bed of rounded, well-indurated, clayey, intraformational cobbles and boulders (maximum diameter 25 cm) as well as the disarticulated remains of large ungulates and proboscideans (Fig. 4B and C; Table III). This bed varies in thickness from approximately 10 to 50 cm. Upper and lower contacts of the bed are gradational for a distance of a centimeter or two.

The highest bed exposed in the quarry is a bed of unconsolidated, cross-bedded, gray sands approximately 3.0 m thick. The quarry sediments are covered by 25 to 50 cm of sandy soil.

Egelhoff Quarry. The Egelhoff Quarry is located on the east side of the Norden–Johnstown Road across from the 2,188 ft bench mark at the Egelhoff Ranch driveway (SW¼ SE¼ NE¼ SW¼ Sec. 29, T. 33 N., R. 23 W., Keya Paha County, Nebraska).

The stratigraphy is not well exposed at the quarry (Fig. 2). Therefore, the position of the quarry relative to the upper and lower contacts of the Valentine Formation, and the Norden Bridge Quarry as well, are speculative, particularly considering the relief present upon the Valentine–Rosebud formational contact.

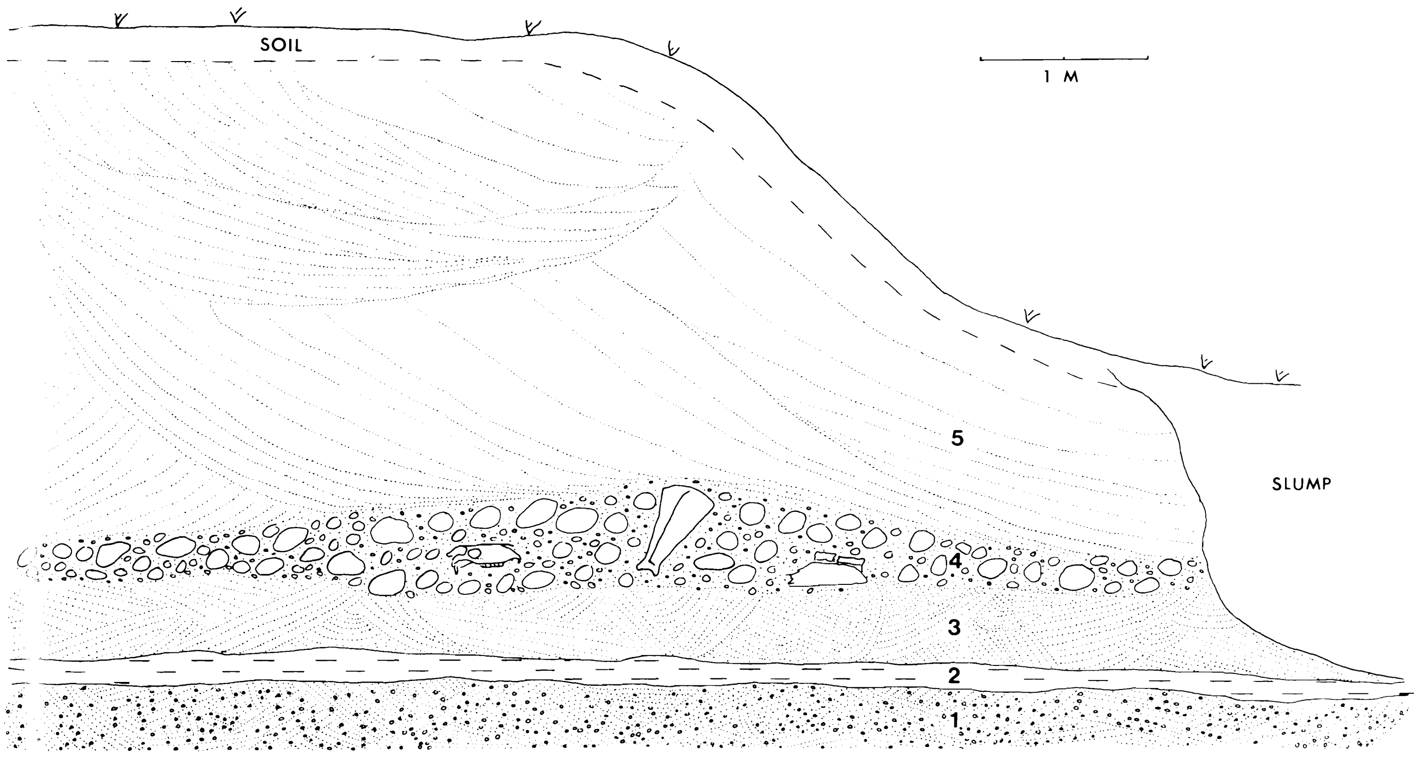

FIGURE 3. Diagram of Norden Bridge Quarry. **1.** Sand and gravel bed. **2.** Silty bed. **3.** Lower cross-bedded sand. **4.** Cobble and boulder bed. **5.** Upper cross-bedded sand.

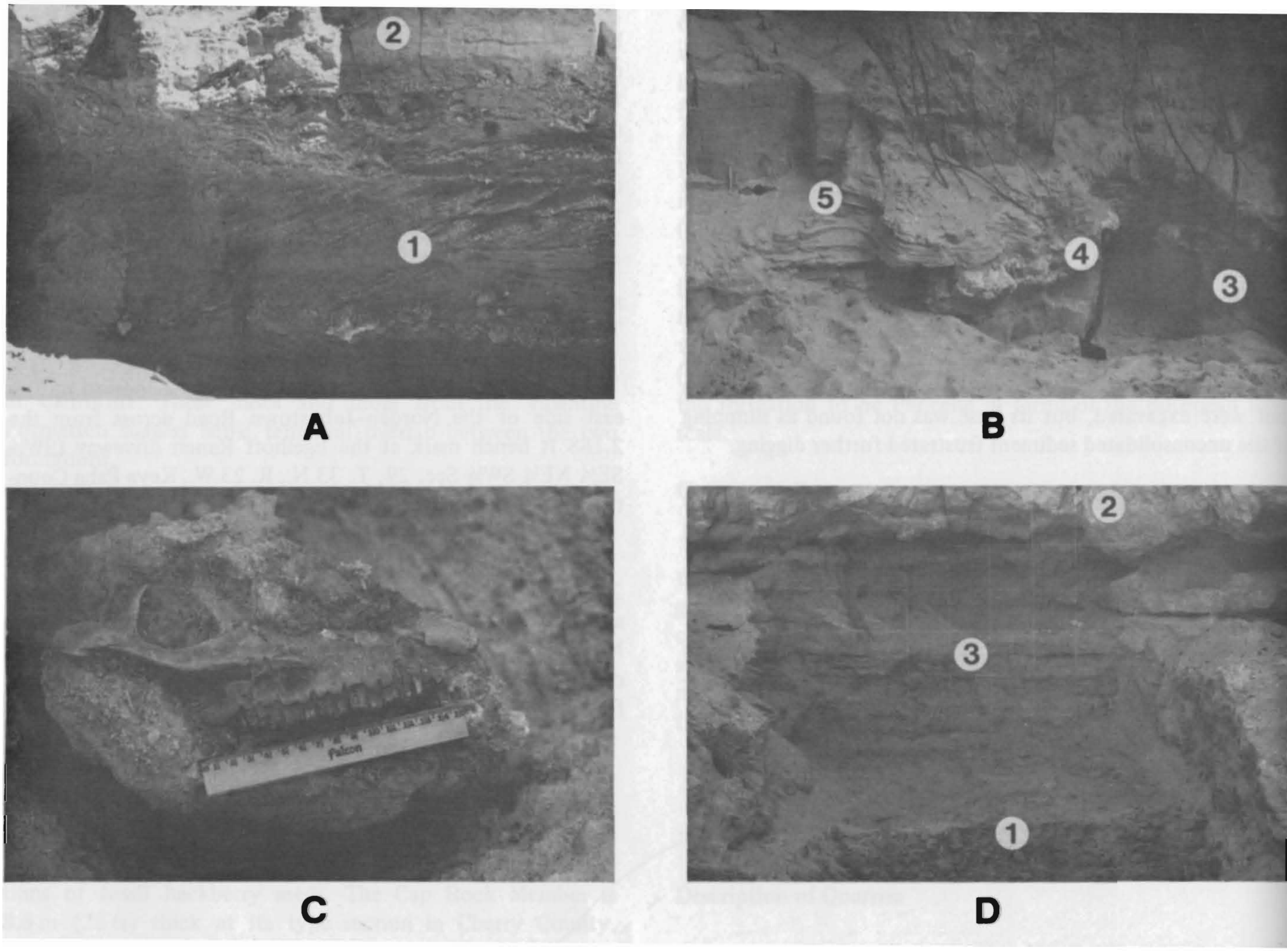

FIGURE 4. A and B. Norden Bridge Quarry. **A.** Sand and gravel (1) and silty bed (2) of Figure 3. Scale: ice pick, 10 cm long. **B.** Beds 3, 4, and 5 of Figure 3. Scale: shovel handle, 75 cm. **C.** Skull of *Protohippus perditus,* UNSM 56063. Scale: ruler in cm. **D.** Egelhoff Quarry with sediment sampling grid for lower (1) and upper (2) silty beds and Egelhoff Quarry sands (3). Scale: grid unit is 30 cm.

TABLE III. Examples of large vertebrate remains from Norden Bridge Quarry boulder bed, summer 1976.

Identification	Maximum Length (cm)	Museum Number
Protohippus skull	27	UNSM 56053
Camelid scapula	43	UNSM 56055
Proboscidean tusk fragment	44	UNSM 56056
Proboscidean tusk fragment	33	UNSM 56057
Proboscidean dentary with 2 molars	40	MSU Specimen

The sediments of the quarry comprise a single bed of unconsolidated, cross-bedded, gray sands approximately 1.6 m thick, bounded above and below by unfossiliferous beds of fine-grained sand and silt indurated by interstitial clay (Fig. 4D).

The lower fine-grained layer is olive drab in color when fresh, but dries to an off-white shade. Only the top of the bed was exposed in 1976. The bed bears a sharp erosional contact with the quarry sands at 675 m (2,195 ft).

The quarry sands themselves are a group of interfering trough cross-strata, each relatively uniform in grain size.

Successive cross-strata become finer-grained upward, however. At their upper limit the quarry sands grade over a distance of 10 to 15 cm into the overlying fine-grained layer, which is similar to the fine-grained bed underlying the quarry sands, and overhangs the quarry as a ledge. The quarry exposure is approximately 9 m wide.

Discussion

From their descriptions it should be apparent that the Norden Bridge and Egelhoff quarries have had different depositional histories. The sediments at Norden Bridge Quarry represent more frequent changes in flow regime than do those at Egelhoff Quarry and demonstrate a wider variation in minimum stream competence as evidenced by a more extreme clast-size range.

Considering inter-quarry clast-size differences on a bed-by-bed basis, it seems clear that the sandy gravel (Ø -3.5) and boulder (Ø -6) beds at Norden Bridge are much coarser than the fossiliferous cross-bedded sands of Egelhoff Quarry, as Holman noted. On the other hand, the consolidated silty layer [clast-size range Ø +4 to Ø +8 estimated from Blatt, Middleton, and Murray (1972)] is much finer than the sands of Egelhoff Quarry. More comparable are the beds of unconsolidated, cross-bedded gray sands at each quarry. In order to assess any clast-size difference that may exist between the cross-bedded sands, a sieve analysis of samples from these beds seems appropriate.

SIEVE ANALYSIS

The sieve analysis technique is well adapted to a comparison of these sands, for the results are generally agreed to be precise and repeatable (Blatt, Middleton, and Murray, 1972). Descriptions of the sampling plan, laboratory procedure, and analysis of data follow:

Collection of Samples

Because in practice the random sample is difficult to obtain, a systematic, mechanical scheme was employed to collect an initial 25 (1 kg estimated) sediment samples (number of samples set arbitrarily). A square grid was erected against the face of the bed to be sampled. This grid was constructed from thick string with horizontal and vertical axes at 30 cm intervals. Each intersection of axes was projected visually against the quarry face and the sample was taken at that point. Slumping of the quarry face made the lower cross-bedded sand at Norden Bridge generally inaccessible to the sampling scheme. Therefore, samples were taken from the Egelhoff sands and only from the upper bed of cross-bedded sand at Norden Bridge Quarry.

Laboratory Procedure

The goal of the analysis was to investigate a possible, statistically significant, clast-size difference between two sand beds rather than a finer sedimentary environmental distinction. Toward this end, James B. Swineheart, Conservation and Survey Division of the University of Nebraska-Lincoln, suggested that the project could be justifiably expedited by working with one-half of the collected samples from each unit. The handling of the samples up to the actual mechanical analysis was suggested by Swineheart and is described below:

In the laboratory a table of random numbers (Steel and Torrie, 1960, Table A.1) was used to select 12 of the original 25 samples from each quarry. The coarsest and finest of the 12 were determined visually and splits of approximately 100 gm were taken from both. A second pair of 100 gm splits was combined with 100 gm splits from the other 10 selected samples from each quarry. These twelve, 100 gm splits were combined in a large seamless, plastic tub and mixed with a spoon and rotating motion of the tub for 10 min. Three 100 gm splits were then taken from this homogeneous mixture. The three homogeneous splits and the coarse and fine splits from each quarry were individually processed by sieve analysis as dictated by Folk (1974).

Because examination revealed no clast-size larger than Ø -3, the sieve stack used ranged in ½ Ø intervals from Ø -3 to Ø +4. The results of the sieve analysis are presented in Figures 5 and 6 as families of cumulative curves plotted against the probability ordinate.

Analysis of Results

Population Estimators. The following three statistical population estimators have been calculated from the cumulative curves and are presented in Table IV.

1. Graphic mean, M_z, the best graphic estimator of grain size.
2. Graphic standard deviation, σ_G, which is very similar to the statistical standard deviation and used here to calculate the standard error.
3. Inclusive graphic standard deviation, σ_I, the best estimator of overall sorting.

Formulae for these parameters are presented in Folk (1974).

The graphic mean, M_z, and the graphic standard deviation, σ_G, of the coarse sample from each of the two beds were used to perform Student's *t*-test of the null hypothesis that there is no significant grain size difference between the

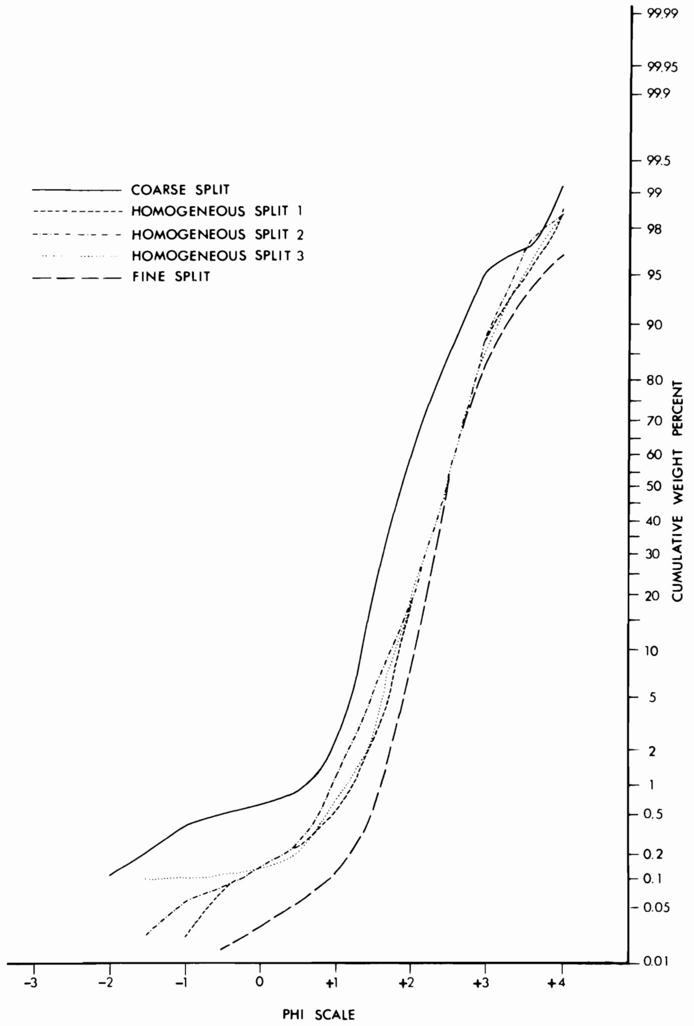

FIGURE 5. Cumulative curves: upper cross-bedded sand at Norden Bridge Quarry.

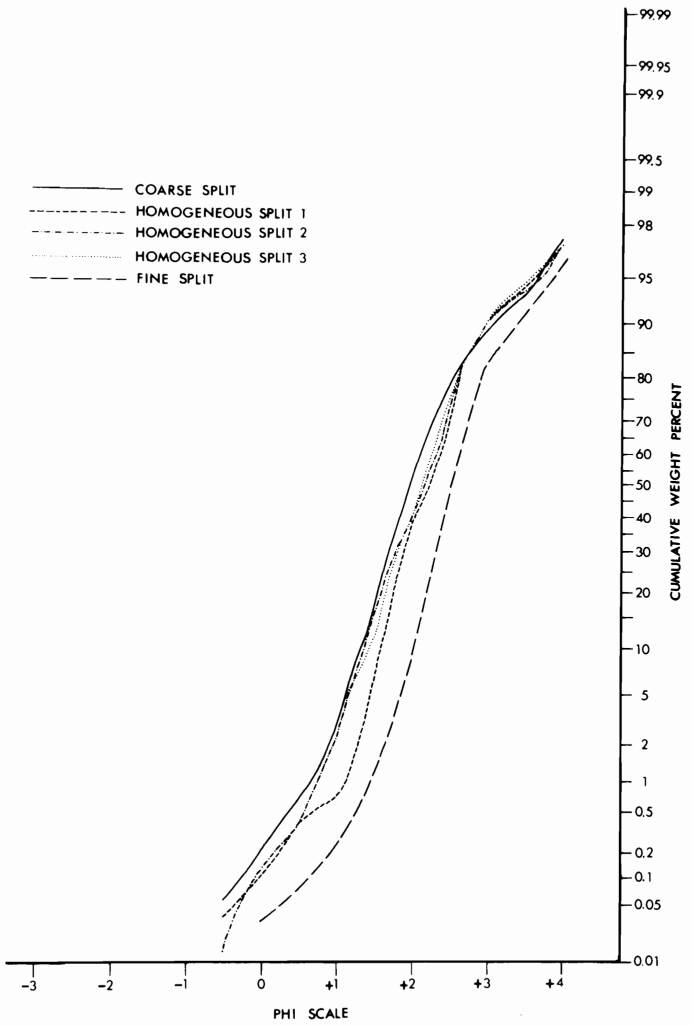

FIGURE 6. Cumulative curves: Egelhoff Quarry.

cross-bedded sands of Egelhoff Quarry and the upper bed of cross-bedded sands at Norden Bridge Quarry. The level of probability chosen for the test was taken at 0.05. N is the number of ϕ intervals.

Calculation of standard error:

$$S_{\bar{d}} = \frac{\sigma_{G\,\text{Norden Bridge}} + \sigma_{G\,\text{Egelhoff}}}{N} = 0.029 \qquad (N = 16)$$

t-test:

$$H_0: M_{z\,\text{Norden Bridge}} = M_{z\,\text{Egelhoff}}$$

$$H_1: M_{z\,\text{N. B.}} \neq M_{z\,\text{E.}}$$

$$t\text{-calc}: \frac{M_{z\,\text{E.}} - M_{z\,\text{N. B.}}}{S_{\bar{d}}} = \frac{0.15}{0.209} = 0.718$$

$$t_{(0.05,\,15)} = 2.131.$$

The probability of obtaining a *t* value less than 2.131 merely by chance were H_0 true is greater than 0.05. The null hypothesis cannot be rejected. No significant difference in grain size between the two beds of cross-bedded sands could be demonstrated.

Average sorting, $\bar{\sigma}_I$, for the sediment samples from Norden Bridge Quarry is 0.538; that for the samples from Egelhoff Quarry is 0.666. Both averages are within the moderately well sorted category of Folk (1974), but are significantly different:

Calculation of standard error:

$$S^2_{\bar{d}} = \frac{s_1^2 + s_2^2}{N} = \frac{0.0002135 + 0.00346}{5} = 0.000735$$

$$S_{\bar{d}} = 0.02711$$

t-test:

$$H_0: \bar{\sigma}_{I\,\text{Norden Bridge}} = \bar{\sigma}_{I\,\text{Egelhoff}}$$

$$H_1: \bar{\sigma}_{I_{\text{N.B.}}} \neq \bar{\sigma}_{I_{\text{E.}}}$$

$$t_{(\text{calc})} = \frac{0.666 - 0.538}{S_{\bar{d}}} = \frac{0.128}{0.02711} = 4.722$$

$$t_{(4,\,0.05)} = 2.776$$

The probability of obtaining a t value greater than 2.776 merely by chance if H_0 were true is less than 0.05. The null hypothesis can be rejected and it can be concluded that there is a significant difference in sorting in the two cross-bedded sands compared.

TABLE IV. Sediment sample statistics.

Quarry	Sample	M_z (ϕ)	σ_G (ϕ)	σ_I (ϕ)
Norden Bridge	coarse	1.95	0.525	0.535
	homogeneous 1	2.48	0.475	0.525
	homogeneous 2	2.48	0.475	0.533
	homogeneous 3	2.48	0.475	0.533
	fine	2.53	0.055	0.563
Egelhoff	coarse	2.10	0.650	0.719
	homogeneous 1	2.25	0.550	0.616
	homogeneous 2	2.17	0.650	0.719
	homogeneous 3	2.18	0.600	0.686
	fine	2.65	0.550	0.593

The results of this last test suggest that, while there is no significant difference in average grain size between the two beds of sand, there is a wider size range about the mean at Egelhoff Quarry, as is borne out by σ_I values for samples from Egelhoff Quarry in Table IV.

Analysis of Variance. An analysis of variance of the sieve analysis can be performed, considering the sieve analysis as a block design in which the quarries are treated as blocks, the samples as units within blocks, and ϕ size as treatment. Because each sample was processed through the same stack of sieves, the assignment of treatment to each unit was not random, but was decided prior to the sieve analysis.

The analysis of variance (Table V) shows no significant variation in ϕ-class sediment weights attributable to differences between the *quarries* or to differences between *samples.* The significant variation in *ϕ-class* sediment weights is a direct result of the sieve analysis, as more clasts were retained on some screens than on others. More difficult to explain is the variation indicating significant interactions between *ϕ size and samples* (s) and *ϕ size and quarries* (q). These interactions occurred during the sieving and reveal some differential effect of the sieving on some samples, but not on others, which affected samples of one quarry differently from those of the other.

Since the samples were treated alike, it is difficult to imagine what caused these interactions. Perhaps clast shape and roundness, the result of subtle intra- and inter-quarry differences in source area, and distance travelled by the clasts affected their negotiation of the sieve openings. Differences in mineralogy, thus specific gravity, of the clasts may have had some effect also. However, no appropriate mineralogical study of the sediments at the two quarries has

TABLE V. Analysis of variance for sediment samples.

Source	df	SS	MS	F calc.	Results of F-test	EMS
Total	159	15,855.716				
Quarry	1	15.194	15.194	2.374	not significant at $p = 0.05$	$\sigma^2 + 80\,\theta^2_q$
Sample	4	48.592	12.148	1.898	not significant at $p = 0.05$	$\sigma^2 + 32\,\theta^2_s$
ϕ-class	15	13,245.502	883.034	137.991	significant at $p < 0.05$	$\sigma^2 + 10\,\theta^2_\phi$
q x s	4	10.605	2.651	0.414	not significant at $p = 0.05$	$\sigma^2 + 16\,\theta^2_{q \times s}$
s x ϕ	60	1,883.115	31.385	4.905	significant at $p < 0.05$	$\sigma^2 + 2\,\theta^2_{s \times \phi}$
q x ϕ	15	268.758	17.917	2.800	significant at $p < 0.05$	$\sigma^2 + 5\,\theta^2_{q \times \phi}$
q x s x ϕ	60	383.950	6.399			σ^2

been attempted. Because the explanations offered are only guesses, the interactions in the analysis of variance remain a difficulty.

ANALYSIS OF PALEOCURRENT INDICATORS AT NORDEN BRIDGE AND EGELHOFF QUARRIES

The results of a study of directional features at Norden Bridge and Egelhoff quarries are presented in this section. Directional readings were taken from cross-strata sets (*sensu* McKee and Weir, 1953) at both quarries and from elongate fossil bones at Norden Bridge Quarry. No suitably large bones were encountered in the course of this portion of the study at Egelhoff Quarry.

Cross-strata as Paleocurrent Indicators

Potter and Pettijohn (1977) concluded that cross-bedding studies are good indicators of local flow direction. However, limitations imposed upon field work by the outcrop must be acknowledged. For example, the criteria of Allen's (1963) detailed classification of cross-strata types are of little practical use if the cross-strata studied cannot be exposed in three dimensions. When it is necessary to work with trough cross-strata [*see* Michelson and Dott (1973) and Pi and Nu types of Allen (1963)] as at Norden Bridge and Egelhoff quarries (discussed below), it is preferable to measure the axis of the trough rather than the dip of the foresets (Dott, 1973; Potter and Pettijohn, 1977). Unfortunately, the nature of many outcrops renders the axis of the trough inaccessible. This is the case at Norden Bridge Quarry, where unpredictable slumping of the quarry face precluded excavation of the cross-strata sets, and at Egelhoff Quarry where the ponderously overhanging, white siltstone layer made such excavation not only impossible in the absence of heavy equipment, but also dangerous.

Forced to evaluate the type of cross-strata at the two fossil quarries in two dimensions only, the sets are interpreted to be the trough type upon the following criteria:

1. Upper and lower surfaces of the sets are convergent.

2. Lower surfaces of the sets are curved, concave upward.

3. The sets are present as interfering groups.

These criteria are in general accordance with discussions of trough cross-strata presented by McKee and Weir (1953), Allen (1963), Blatt, Middleton, and Murray (1972), Pettijohn, Potter, and Siever (1972), and Potter and Pettijohn (1977, Fig. 4.2).

Lacking access to the trough axis, the strike and apparent dip of the foresets of both limbs of a trough cross-strata set may be combined to calculate the azimuth of the set. However, because the characteristic interfering pattern of trough cross-strata sets originates from a scour-and-fill style of deposition, both limbs of a trough set are rarely preserved at Norden Bridge and Egelhoff quarries. As a result of this limitation, the field data collected from each set of trough cross-strata were readings of strike and apparent dip of foresets revealed in each of two vertical, planar surfaces cut into the preserved trough set limb. These raw data were converted into a true dip and strike for each cross-strata set following the method described by Billings (1972). Azimuths were then calculated for each dip and strike reading. In all, azimuths were calculated for 47 sets of cross-strata at Norden Bridge Quarry and for 58 sets at Egelhoff Quarry. The raw data, corrected data, and azimuth for each cross-strata set are recorded in work by Wellstead (1977). Circular histograms of the azimuths are presented in Figure 7A and B.

Fossil Bones as Paleocurrent Indicators

In what Dodson (1980) recognized as the classic work in vertebrate taphonomy, Voorhies (1969:11) used fossil bone orientations to estimate current direction. More recently similar estimates have been made in a study by Hunt (1978).

During the collection of cross-strata orientation data for the present study, orientations of any elongate bones (minimum 10 cm in greatest length) discovered were recorded. These orientation data consist of the plunge of the bone and the trend of its horizontal projection. Eleven such bones were encountered at Norden Bridge Quarry at this time as no large scale fossil excavations were conducted simultaneously. No elongate bone fragment was encountered at Egelhoff Quarry during this study. A circular histogram for the bone orientation data is presented in Figure 7C.

Analysis of Orientation Data

Statistical Tests. Several authors (*e.g.,* Curray, 1956; Pincus, 1956; Pelletier, 1958; Potter and Pettijohn, 1977) discussed the uncertainty inherent in representing the preferred orientation of sedimentary structures and fossils by an arithmetic mean and standard deviation. Calculation of the mean vector and the mean angular deviation for the body of data is one solution. Till's (1974) method was used for this calculation and the resulting mean vectors and mean angular deviations for cross-strata azimuths and bone orientations are presented in Figure 7.

A hybrid F-test was used to test the null hypothesis that the distribution of a set of directional features, such as cross-strata azimuths from either quarry or the fossil bone

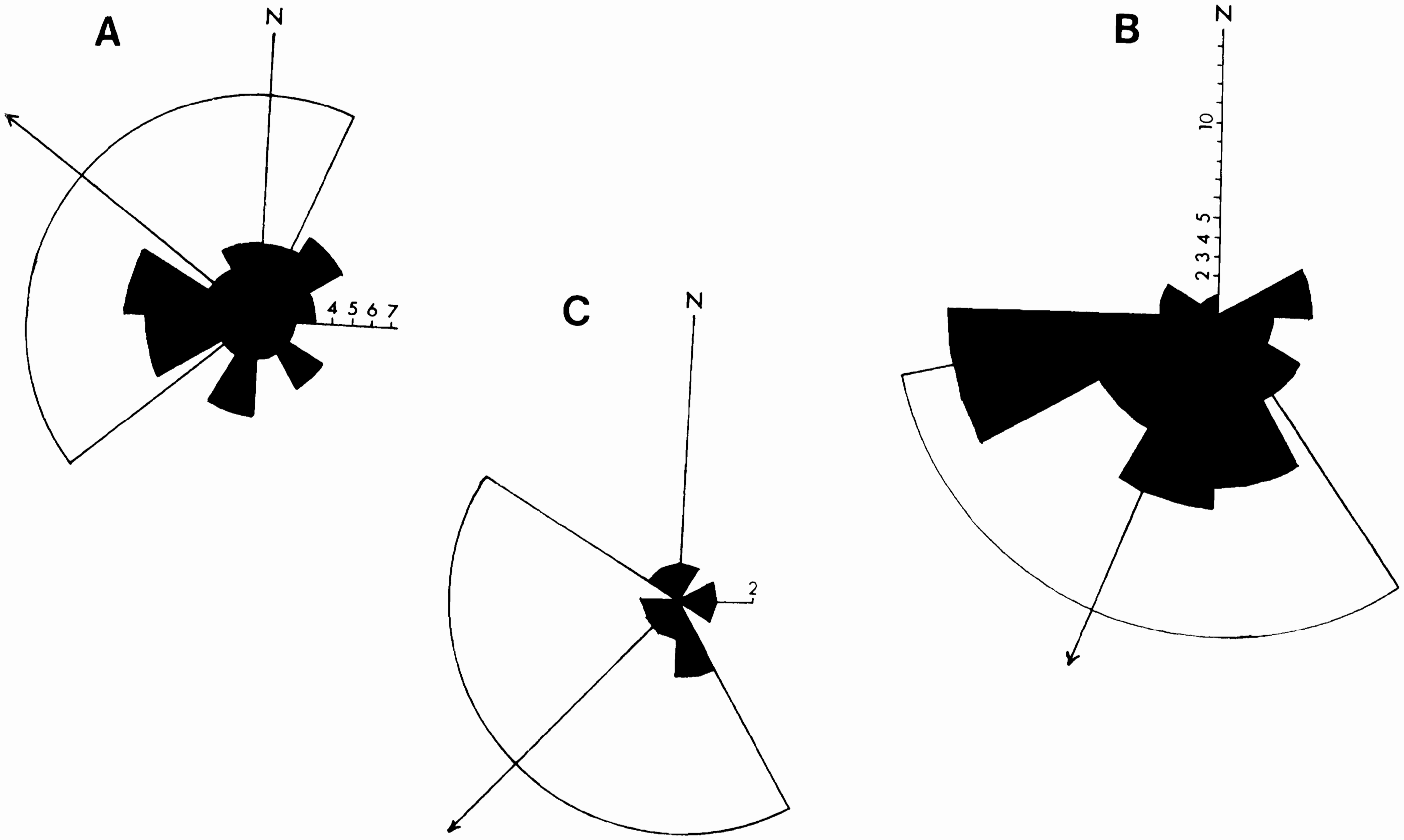

FIGURE 7. Rose diagrams of directional features at Norden Bridge and Egelhoff quarries. **A.** Cross-strata azimuths at Norden Bridge Quarry. Mean vector, 305 ± 75, mean angular deviation, 75.489°. **B.** Cross-strata azimuths at Egelhoff Quarry. Mean vector 202 ± 56, mean angular deviation, 56.047°. **C.** Bone trends at Norden Bridge Quarry. Mean vector 222 ± 77, mean angular deviation, 76.933°.

orientations, does not differ significantly from a uniform distribution. If the set of directional features does differ significantly from the uniform distribution, the test assumes it to be unimodal. The test does not discriminate bimodal or polymodal distributions. This potential limitation is not serious if the Valentine Formation sediments are fluvial, as generally agreed, and thereby, unimodal.

The test term (error term) in the *F*-test is $(180°)^2$ (= the square of the maximum by which an azimuth may vary from the true stream flow direction). The mean angular deviation (Fig. 7) is used as the denominator in the *F*-test. The tests and their results follow:

For each *F*-test:

H_0: The body of data does not differ significantly from a uniform distribution.

H_1: The body of data differs significantly from a uniform distribution.

In this test, degrees of freedom for both denominator and numerator are n−1. The probability level, chosen arbitrarily, is 0.05.

1. Norden Bridge Quarry, cross-strata data.

$$N = 47$$

$$F_{\text{calc.}} = \frac{(180°)^2}{(\pm\ 75.489°)} = 1.895$$

$$F_{(0.05,46,46)} = 1.67.$$

The probability of obtaining an *F*-value greater than 1.67 merely by chance if H_0 were true is less than 0.05. Grounds exist to reject H_0 and to conclude that the data differ significantly from a uniform distribution.

2. Norden Bridge Quarry, fossil bone orientations.

$$N = 11$$

$$F_{\text{calc.}} = \frac{(180°)^2}{(\pm 76.933°)^2} = 1.825$$

$$F_{(0.05,\ 10,\ 10)} = 2.98$$

The probability of obtaining an F-value less than 2.98 merely by chance if H_0 were true is greater than 0.05. No grounds exist to reject H_0 or to conclude that the data differ significantly from a uniform distribution.

3. Egelhoff Quarry, cross-strata data.

N = 58

$$F_{\text{calc.}} = \frac{(180°)^2}{(\pm 56.047°)^2} = 3.438$$

$$F_{(0.05,\ 57,\ 57)} = 1.96$$

The probability of obtaining an F-value greater than 1.96 merely by chance if H_0 were true is less than 0.05. Grounds exist to reject H_0 and to conclude that the data differ significantly from a uniform distribution.

Discussion of Test Results. The statistical tests indicate that the cross-strata have a preferred orientation at both Norden Bridge and Egelhoff quarries. In both instances the implied current direction (N55W at Norden Bridge Quarry and S33W at Egelhoff Quarry) is anomalous relative to the easterly regional dip of Tertiary strata in the area (Bentall, *et al.*, 1971). However, as recognized by Potter and Pettijohn (1977), Steinmetz (1975), and Pettijohn, Potter, and Siever (1972), the directional features at any point along a stream are not likely to correspond exactly with the overall direction of streamflow in the basin.

To obtain an adequate indication of paleocurrents within the Valentine Formation, data must be collected and evaluated on a regional basis. The practical difficulties encountered in this brief study of paleocurrents stem from the lack of three-dimensional access to the cross-strata and indicate that prior to beginning a regional study, a preliminary assessment of relative proportions of cross-strata type within the formation and the amount of excavation necessary to expose them properly should be completed. Steinmetz (1975) suggested a preliminary, regional sampling of orientation data to assess variability at each outcrop and to assist in estimating the number of orientation readings necessary for each site.

Absence of statistical significance in the sample of bone orientations may be due to actual lack of any one preferred orientation, or to small sample size.

SUMMARY

The measured section presented in this report confirms that Egelhoff Quarry is topographically higher than Norden Bridge Quarry, but that a demonstration of their relative stratigraphic positions is impossible as the relationship of Egelhoff Quarry to the Valentine–Rosebud formational contact is not exposed and because the Egelhoff Quarry horizon cannot be traced toward Norden Bridge due to vegetation cover and erosion of the section.

Description of the sediments at the two quarries supports Holman's (1973) contention that coarser sediments are found at Norden Bridge. However, it also reveals that these coarse sediments and fossil remains of large vertebrates are restricted to two beds and do not characterize the entire quarry. Beds of sediments finer than those at Egelhoff Quarry and at least one bed which shows no significant difference in mean grain size from Egelhoff Quarry sediments, exist as well at Norden Bridge Quarry.

While no test of the hydraulic equivalency of fossil bones from the Norden Bridge and Egelhoff quarries has been conducted, the isolation of remains of large vertebrates in the beds of coarser sediments at Norden Bridge and their general exclusion from the finer sediments of both quarries suggests that the remains are hydraulically sorted. This probability supports the recent work of Korth (1979) and also Holman's (1976) suggestion that the faunal differences between the two quarries are the result of depositional factors rather than being due to actual differences in the local faunas.

Mean vectors derived from cross-strata sets indicate that paleocurrents flowed northwesterly at Norden Bridge Quarry and southwesterly at Egelhoff Quarry. These results are surprising considering the easterly regional dip of local Tertiary strata, but emphasize the desirability of a regional approach to paleocurrent analysis.

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