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America. Cambridge Univ. Press, Cambridge.

15. The Whitneyan-Arikareean Transition in the High Plains

RICHARD H. TEDFORD, JAMES B. SWINEHART, CARL C. SWISHER III,
DONALD R. PROTHERO, STEVEN A. KING, AND TIMOTHY E. TIERNEY

ABSTRACT

We bring together lithostratigraphic, biostratigraphic, and magnetostratigraphic data from Nebraska and South Dakota to detail faunal change between 28-30 Ma in medial Oligocene time. This span records the transition from the White River chronofauna to the new assemblages that characterize the younger part of the Arikareean "age." Although a regional disconformity of approximately a half-million year duration breaks the biostratigraphic sequence, the fossil record is reasonably continuous and mostly confined to the eolian facies. Between 28-30 Ma the White River chronofauna experienced significant enrichment in autochthonous clades especially hesperocyonine canids, oreodonts, camels, hypertragulids, and burrowing castoid and geomyoid rodents. Few allochthonous taxa are encountered so that the chronofauna was enriched without marked immigration or extinction. At approximately 28 Ma most of the White River genera leave the record, thus terminating the chronofauna. The fauna that emerges contains representatives of autochthonous lineages, some of which appeared during the enrichment phase of the White River chronofauna. In addition there are allochthonous genera that represent taxa new to mid-continental North America. The better resolved and calibrated fossil record allows re-examination of the definition and characterization of the beginning of the Arikareean mammal "age." We propose that the initiation of the Arikareean Mammal "age" is signaled by the first appearance of taxa that enrich the White River chronofauna in latest Chron C11r and earliest Chron C11n (about 30 Ma). The "age" is defined by the first appearance of the allochthone *Plesiosminthus* and characterized by the autochthonous *Palaeolagus hypsodus* and *P. philoi*, *Palaeocastor nebrascensis*, *Shunkahetanka geringensis*, *Nanotragulus loomisi*, *Sespia nitida*, and *?Mesoreodon minor*.

INTRODUCTION

When the North American Land Mammal "ages" were proposed by Wood and others in 1941, the Arikareean "age" was defined primarily as the geochron of the Arikaree Group. The better documented faunal succession in the later part of that span was used to characterize the "age." The nature of the faunal succession at the beginning of the "age," its relationship to the preceding Whitneyan "age," and the lithostratigraphic relationships between the White River and Arikaree groups were poorly documented. Major rock units, the Sharps Formation of South Dakota (Harksen et al., 1961) and the informal Brown Siltstone beds (Swinehart et al., 1985) of Nebraska, which lie in the upper White River and lower Arikaree groups, were confused with other rock bodies and unrecognized until late in this century. As the faunal content of these units was not known in 1941, its nature and significance to the definition and characterization of the Whitneyan-Arikareean boundary has only been recently established (Tedford et al., 1987) and is still not fully deciphered. This contribution reviews the Whitneyan-Arikareean transition in light of previous work (Tedford et al., 1985; Tedford et al., 1987), and explores, with improved biostratigraphic evidence, the nature of faunal change in this interval.

The attempt of Tedford et al. (1985) to correlate rocks and faunas across the boundary between the White River and Arikaree groups raised many questions that created a focus for further study. These included detailed geologic mapping of North Platte Valley exposures (Swinehart and Diffendal, 1995), and the gathering of additional radiometric and paleomagnetic data at previously studied localities, as well as at newly studied exposures. The most significant advance in our ability to construct tighter correlations came with $^{40}Ar/^{39}Ar$ single-crystal laser fusion dates (Swisher and Prothero, 1990). Ashes that had not yielded reliable ages (eg., the Lower Ash of the Whitney) or had large errors in fission-track or standard K-Ar dates were redated and helped tie the paleomagnetic, stratigraphic, and paleontologic results into a tighter framework. We report four new $^{40}Ar/^{39}Ar$ dates (Table 1) from the Wildcat Ridge and North Platte Valley mapping projects of Swinehart and Diffendal (1995). In addition, although no significant new fossil collections have been made, two of us (Swisher and Tedford) have reviewed the pertinent existing fauna in light of the new information. Pertinent

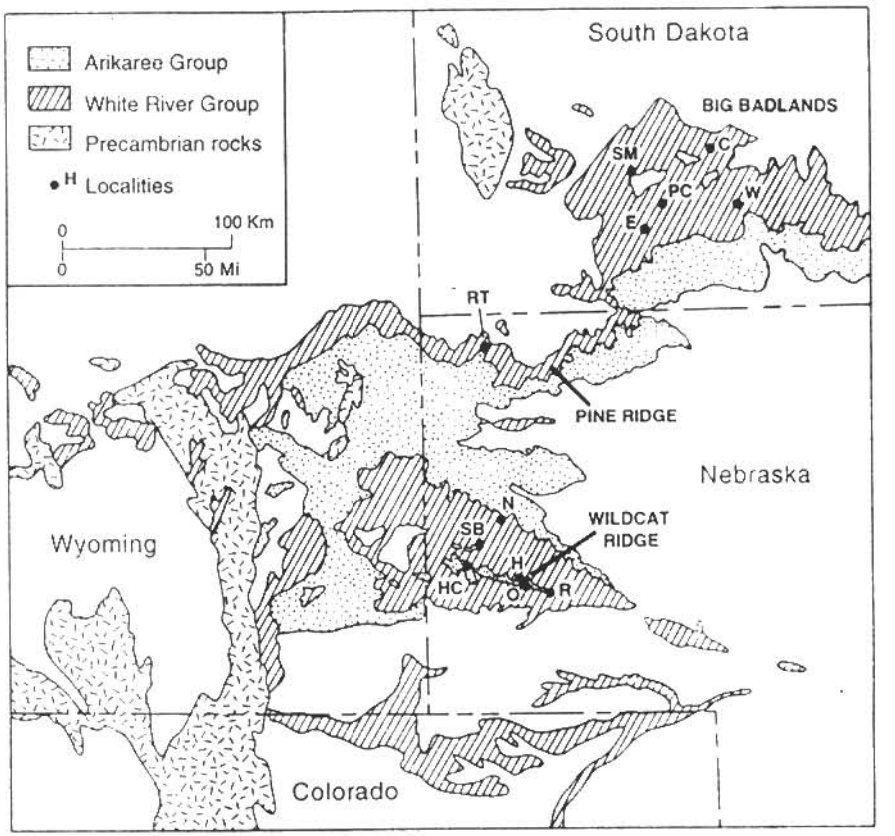


Figure 1. Distribution of White River and Arikaree strata, Precambrian rocks and localities discussed in text. Nebraska geology modified from Swinehart et al. (1985); Wyoming, South Dakota and Colorado modified from Bennison and Chenoweth (1984). Locality abbreviations as follows: C, Cedar Pass; E, Evergreen; H, Horn Ranch; HC, Helvas Canyon; N, Nuss Ranch; O, Olsen Ranch; PC, Palmer Creek; R, Roundhouse Rock; RT, Roundtop/Toadstool; SM, Sheep Mountain Table; W, Wolff Table.

fossil localities of the Nebraska State Museum are indicated by the acronym UNSM, those of the South Dakota School of Mines by SDSM.

LITHOSTRATIGRAPHY

Historically, the region encompassed by this study (Fig. 1) has served as the foundation for development of concepts of Cenozoic stratigraphy of the High Plains for nearly 150 years. The excellent outcrops provided by the dissection of the Cenozoic sedimentary blanket by major tributaries of the Missouri River in western Nebraska and southwestern South Dakota are still the focus of lithostratigraphic study.

Nebraska Panhandle

Recently the extensive drilling program of the University of Nebraska-Lincoln Conservation and Survey Division, coupled with analysis of petroleum and water wells in the region, has extended the stratigraphic record beneath covered terrain for a better appreciation of the regional relationships of the rock bodies recognized from outcrops (Swinehart et al., 1985). The following summary draws on all these sources of data

Whitney Member, Brule Formation, White River Group

Typically the Whitney Member is a massive, brown, volcaniclastic, eolian siltstone as much as 90 meters

thick with local, fine- to coarse-grained fluvial sandstones and mudstone. The type section in the "Round Top to Adelia" traverse (Schultz and Stout, 1955) in the Pine Ridge (Fig. 1) contains essentially no fluvial sediments. The oldest of two regionally extensive ash beds, the Lower Ash (LW) has been $^{40}Ar/^{39}Ar$ dated at 31.85 ± 0.02 Ma and the youngest, the Upper Ash (UW), has a date of 30.58 ± 0.61 Ma (Prothero and Swisher, 1992). The volcaniclastic siltstones themselves are composed of about 50% glass shards, a value close to the average for the Brule Formation as a whole.

Brown Siltstone Beds, Brule Formation, White River Group

Swinehart et al. (1985) significantly modified the regional lithostratigraphy of the upper part of the White River Group as described by Darton (1899) and Schultz and Stout (1955). They demonstrated that the Whitney Member of the Brule Formation, considered to be the uppermost part of the White River Group, was overlain (locally disconformably) by a slightly coarser grained, volcaniclastic siltstone sequence, as much as 135 m thick. These beds were informally named the "Brown Siltstone." Deposited primarily as a volcaniclastic eolian blanket (like the Whitney), it typically contains glass shard percentages from 50 to 60%. Swinehart et al. (1985, fig. 12) described an interval 10 to 20 m thick near the base of the Brown Siltstone that contains three ash beds (Nonpareil Ash Zone, NPZ) traceable over much of western Nebraska. At Roundtop in the Nebraska Pine Ridge (Fig. 1) Swisher and Prothero (1990) obtained a $^{40}Ar/^{39}Ar$ date of 30.05 ± 0.19 Ma on a NPZ correlated with NP_3. Fluvial mudstones and fine- to medium-grained sandstones also occur in paleovalleys that locally cut out the Nonpareil Ash Zone (Fig. 5) and the Upper Ash of the Whitney (Tedford et al., 1985, fig. 2; Souders, 1981, 1986). Geologic mapping by Swinehart and Diffendal (1995) has shown that the Brown Siltstone lies in a complex paleovalley system cropping out in the Wildcat Ridge (Fig. 5), the deposits of which had been included in the Gering Formation (Vondra et al., 1969). In establishing a type section for Darton's Gering Formation at Helvas Canyon (Figs. 1 and 4), Vondra et al. (1969) included within the Gering about 20 m of the Brown Siltstone beds consisting of a local, multiple cut-and-fill fluvial sequence. In addition, they were apparently misled, as was Darton, to include in the basal Gering another local outcrop of a 30-m thick, stacked fluvial sequence that actually lies within the Whitney.

Gering Formation, Lower Arikaree Group

The oldest Arikaree Group strata represent a regional interruption in the aggradation of fine-grained, eolian deposits by widespread fluvial erosion and subsequent deposition of coarser clastics. Two major paleovalleys were developed in the north half of the Nebraska panhandle and a minor one in the south half (Swinehart et al., 1985, fig. 14). There is uncertainty as to how close in time these basal Arikaree fluvial strata were deposited.

Darton (1899) named the Gering Formation for a series of fine- to coarse-grained, predominantly fluvial, volcaniclastic sandstones and conglomerates in the Wildcat Ridge. These rocks contain only 20-30% glass shards reflecting the importance of fluviatile processes during deposition of the Gering. The Gering Formation is separated by an erosional unconformity from the Brule and overlain conformably by rocks of the middle Arikaree Group. Although Darton and later workers were aware that fluvial sequences occurred within the Brule, a series of fluvial cuts and fills that occurred stacked together were often included in the Gering Formation. This concept led to the inclusion of the Brown Siltstone and some Whitney rocks in the Gering type section as discussed above. Believing the Brown Siltstone beds to be Gering, the often conformable relationship with the Whitney was a source of confusion for Darton and other workers. The Gering Formation, as mapped by Swinehart and Diffendal (1995), is redefined to include fluvial pumice-bearing siltstones, sandstones, and conglomerates at its base overlain (and possibly coeval in part) by thin-bedded, horizontally stratified sandstones and mudstones. It contains zones of calcite pseudomorphs after gypsum and vertebrate tracks (Loope, 1986; Swinehart and Loope, 1987) well exposed on Scotts Bluff National Monument (Fig. 4). This widely scattered but distinctive facies probably represents ephemeral stream, playa, and eolian sandsheet deposits.

New $^{40}Ar/^{39}Ar$ dates from the Gering and a basal post-Gering Arikaree ash (Table 1), combined with a consistent paleomagnetic stratigraphy (Fig. 4), suggests that the redefined Gering Formation spans only a few hundred thousand years. This conclusion is supported by dates on sanidine from pumice pebbles in the Twin Sisters Pumice Conglomerate low in the Gering at 28.31 ± 0.03, the Chimney Rock perrierite ash at the base of the thin horizontally bedded sequence at 28.26 ± 0.05 Ma, and the Roundhouse Rock Pisolitic Ash (RRP, Fig. 4) occurring near the top of the pumice-bearing sandstone at 28.11 ± 0.18 Ma. The post-Gering ash (Olsen's third ash, OT, Figs. 4, 5) dates at 27.79 ± 0.08 Ma. The revised Gering attains a maximum thickness of about 25 m (compared with 60 m in Darton, 1899).

Along the Pine Ridge, north of the North Platte Valley, the 100-m thick sequence of coarse- to fine-grained fluvial strata of the basal Arikaree (Swinehart et al., 1985) appears, on faunal criteria discussed below, to be coeval with the type Gering, as assumed by most workers since Hatcher (1902). To date no pumice has been found in these rocks and no reliable dates have been obtained on the several ashes present.

Middle Arikaree Group, Undivided

Conformably overlying the Gering Formation, the undivided Arikaree Group includes gray and grayish brown, fine-grained, poorly indurated, volcaniclastic, eolian sandstone and silty sandstone with carbonate-cemented "pipy concretions." Stratification is typically lacking or indistinct, but zones of eolian, low-angle cross-stratification occur locally (Swinehart and Loope, 1987). Along the Pine Ridge, between Harrison and Crawford, Nebraska, these rocks have been divided into two units, the Monroe Creek and Harrison formations (Hatcher, 1902; Hunt, 1985), but in the North Platte Valley no consistent lithologic criteria or marker beds have been discerned with which to differentiate these units (Swinehart et al., 1985). There are no dated ashes from the lower part of the Middle Arikaree in the Pine Ridge. The oldest dated ash is the 21.9 Ma Agate Ash (corrected from Evernden et al., 1964) in the upper part of the Harrison Formation.

Big Badlands of South Dakota

White River Group

In South Dakota, the White River Group was historically subdivided using biostratigraphic criteria, and later lithogenetic units were recognized (Darton, 1899; Bump, 1956). Bump (1956) subdivided the Brule Formation into the Scenic Member, thin-bedded claystone, siltstones, and channel-form sandstones with prominent beds of nodules cemented by groundwater, and the conformably overlying, massive-appearing siltstones and claystones of the Poleslide Member that include channel-form sandstones ("*Protoceras* channels") but are otherwise rather uniform in lithology and contain scattered calcareous nodules. Traditionally, the Poleslide Member was considered the top of the Brule Formation but the discovery by Harksen et al. (1961) of an additional unit, the Sharps Formation, previously mistaken for Poleslide strata, significantly extended the White River Group lithology. A widespread ash bed, the Rockyford Ash, was used as the base of the Sharps, but the Sharps is coarser grained than the Poleslide with nodular sandy siltstones, silty, very fine sandstones of massive appearance and lenses of marl being the most common lithologies. The unit is about 75 m thick.

Arikaree Group

In the highest outcrops north of the White River, such as at Cedar Pass and the Pinnacles in the Badlands National Monument, the Sharps siltstones are capped by sand and silt-filled stream channels that have incised through the Sharps and Rockyford Ash and deeply into the underlying Poleslide (Parris and Green, 1969, Harksen, 1974; complete section from M. F. Skinner, American Museum of Natural History, MS). Harksen (1974) suggested that the same disconformity is present south of the White River near the mouth of Porcupine Creek, where the Godsell Ranch Channel of Macdonald (1963) likewise cuts through the Sharps and deeply into the Poleslide. Skinner (MS) traced a similar disconformity eastward along the south side of the White River to the Craven Basin. Harksen and Macdonald (1969, p. 19) postulated that this disconformity marks a regional event that corresponds to the White River-Arikaree disconformity in Nebraska. South of the White River, the regional paleoslope carries this disconformity beneath deposits designated by Harksen et al. (1961) as the upper part of the Sharps Formation. The upper Sharps consists of nearly 50 m of friable (but locally silica-cemented) massive concretionary siltstone and fine sandstone. It is gradationally overlain by more than 25 m of indurated massive siltstones and very fine sandstones correlated with the Monroe Creek Formation of adjacent Nebraska largely on the basis of their bold, cliff-forming outcrops.

SINGLE-CRYSTAL LASER-FUSION $^{40}AR/^{39}AR$ DATING

As mentioned in the introduction we utilize a number of new single-crystal laser fusion $^{40}Ar/^{39}Ar$ dates in this study (Table 1). We do not use the 26.3 Ma (corrected) K-Ar date reported by Evernden et al. (1964) for an ash at the base of the Gering at Scotts Bluff National Monument (Fig. 4). Our correlations with the magnetic polarity time scale of Cande and Kent (1992) would place ashes in this part of the Gering close to 28.3 Ma. We report a new $^{40}Ar/^{39}Ar$ date of 28.26 ±0.05 Ma on such an ash (Chimney Rock perriente ash) from the base of the thin-bedded horizontally stratified facies of the Gering. Naeser et al. (1980) reported a fission-track age of 27.2 ± 0.9 Ma for this ash. We also do not use the 27.0 ± 0.7 Ma K-Ar date on the Carter Canyon Ash (CC) obtained by Obradovich et al. (1973) from Helvas Canyon (Fig. 4) on the grounds that stratigraphic and paleomagnetic data argue that this ash should be between 29 and 29.5 Ma old. We use our new $^{40}Ar/^{39}Ar$ date on the Twin Sisters Pumice of 28.31 ± 0.03 Ma in place of the K-Ar date of 27.0 ± 0.6 Ma reported by Obradovich et al. (1973).

The sanidine and plagioclase separated from the Nebraska ashes were each irradiated twice in the hydraulic rabbit facility core of the Omega West research reactor at Los Alamos National Laboratory, with a fast neutron fluence of 5.7 x 10^{13} neutrons/cm^2. In both irradiations, the minerals were loaded into wells of an aluminum (Al) sample disk along with a centrally located monitor mineral and wrapped in Al foil. Samples 4812 and 4818 were irradiated for 28 hours, and samples 2561 and 2562 were irradiated for 24 hours.

Following irradiation, individual grains were placed in separate wells of a copper sample disk, enclosed within the sample chamber, bolted onto the extraction system, and baked at 200°C for eight hours. Total fusion of the minerals was accomplished with a 6W Coherent Ar ion laser. The released gases were then purified by two Zr-

Table 1. $^{40}Ar/^{39}Ar$ laser fusion ash dates from Morrill County and Wildcat Ridge, western Nebraska. All dates by Carl Swisher. * = radiogenic; SD = 1 standard deviation; (SE) = standard error of mean. $\lambda\varepsilon + \lambda\varepsilon' = 0.581 \times 10^{-10}$ yr; $\lambda\beta = 4.9662 \times 10^{-10}$ yr; $^{40}K/^{40}K\text{total} = 1.167 \times 10^{-4}$

Lab number	Mineral	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{40}Ar^*/^{39}Ar$	$\%^{40}Ar^*$	Age(Ma)	SD(Ma)
Olsen's third ash. Arikaree Group, undivided. Center NW NW sec. 13, T19N R53W							
4812-01	Sanidine	0.01066	0.00008	0.70232	96.4	27.94	0.81
4812-02	Sanidine	0.01284	0.00013	0.68249	94.7	27.20	0.21
4812-03	Sanidine	0.01323	0.00008	0.69524	96.5	27.66	0.62
4812-04	Sanidine	0.01067	0.00010	0.70066	95.8	27.88	0.15
4812-06	Sanidine	0.01369	0.00007	0.70465	96.9	28.03	0.40
4812-07	Sanidine	0.01416	0.00007	0.70081	96.8	27.88	0.16
					Mean =	27.76	0.30
					Weighted mean =	27.79	0.08 (SE)
Roundhouse Rock pisolitic ash. Gering Formation. NE SW sec. 21, T19N R51W							
4818-06	Sanidine	0.04588	0.00018	0.70142	93.2	27.90	0.11
4818-02	Plagioclase	1.14853	0.00052	0.70409	91.7	28.01	0.37
4818-07	Sanidine	0.00908	0.00010	0.70958	95.7	28.23	0.13
4818-03	Sanidine	0.00758	0.00012	0.71102	95.1	28.28	0.18
					Mean =	28.11	0.18
					Weighted mean =	28.07	0.07 (SE)
4818-08	Sanidine	0.01748	0.00005	0.72968	97.9	29.02	0.09
4818-05	Plagioclase	3.33706	0.02903	80.52205	90.6	1850.70	5.89
Chimney Rock perrierite ash. Gering Formation. NW NW sec. 20, T20N R52W							
2561-02	Sanidine	0.02938	0.00010	0.89260	97.0	28.23	0.11
2561-03	Sanidine	0.04364	0.00023	0.90022	93.0	28.47	0.12
2461-04	Sanidine	0.03485	0.00067	0.89125	81.8	28.19	0.20
2561-06	Sanidine	0.03125	0.00009	0.89243	97.0	28.23	0.12
2561-10	Sanidine	0.02590	0.00026	0.89233	92.1	28.23	0.10
2561-13	Sanidine	2686	0.00013	0.89217	95.9	28.22	0.10
					Mean =	28.26	0.10
					Weighted mean =	28.26	0.05 (SE)
Twin Sisters pumice conglomerate. Gering Formation. NE NE sec. 6, T20N R55W							
2562-02	Sanidine	0.01856	0.00044	0.88987	87.1	28.15	0.11
2562-03	Sanidine	0.03409	0.00019	0.88760	94.2	28.08	0.09
2562-04	Sanidine	0.08135	0.00008	0.89176	97.3	28.21	0.09
2562-05	Sanidine	0.02098	0.00010	0.88812	96.9	28.09	0.20
2562-10	Sanidine	9.11327	0.00007	0.89907	98.5	28.44	0.10
2562-11	Sanidine	0.01300	0.00004	0.89640	98.7	28.35	0.08
2562-12	Sanidine	0.01580	0.00003	0.89953	99.0	28.45	0.08
2562-13	Sanidine	0.01686	0.00003	0.89756	98.9	28.39	0.08
2562-15	Sanidine	3611	0.00009	0.89706	98.0	28.37	0.09
					Mean =	28.28	0.15
					Weighted mean =	28.31	0.03 (SE)
2562-14	Sanidine	0.54865	0.00033	0.919685	94.4	29.08	0.33
2562-01	Sanidine	0.01811	0.00037	0.877881	88.9	27.77	0.36

Fe-V getters operated at approximately 150°C. Argon was measured with an on-line Mass Analyzer Product 215 noble-gas mass spectrometer, operated in the static mode, using automated data-collection techniques. Sample fusion, gas purification, and mass spectrometry were completely automated following computer-programmed schedules.

^{40}Ar was calculated using a J value of $2.222 \times 0.002 \times 10^{-2}$ for the 24-hour irradiation, as calculated from replicate analyses of individual grains of the co-irradiated monitor mineral Fish Canyon Tuff sanidine with a reference age of 27.84 Ma (modified from Cebula et al., 1986), intercalibrated in-house with Minnesota hornblende MMhb-1 at 520.4 Ma (Samson and Alexander, 1987). Ca and K corrections used during this study were determined from laboratory salts:

$6.38 \times 10^{-4} \pm 1.0 \times 10^{-5}$ and $(40/39)K = 2.4 \times 10^{-3} \pm 7.0 \times 10^{-4}$. Mass discrimination as determined from replicate analyses from an on-line pipette system during this study yielded a mean value of 1.005 ± 0.0005. Weighted means were derived using the method of Taylor (1982). Age determinations not used in calculation of mean age were considered to be contaminant grains.

MAGNETIC STRATIGRAPHY

Magnetic sampling was conducted by Prothero and a variety of field crews over the last decade. Roundtop-Toadstool, Olsen Ranch, Nuss Ranch, and the Sharps sections at Cedar Pass and Wolff Table were sampled in 1986. The Sharps sections at Sheep Mountain Table, Evergreen, and Palmer Creek were sampled in 1987. The lower part of Roundhouse Rock was sampled in 1989, and the remaining Wildcat Ridge sections (Helvas Canyon, Horn Ranch, and the upper parts of Roundhouse Rock and Scottsbluff) were sampled in 1990. Steve King was responsible for the laboratory analysis and interpretation of the Sharps Formation type sections (Evergreen and Palmer Creek). Tim Tierney analyzed and interpreted the 1990 Wildcat Ridge sections.

In all of these field seasons, sampling was conducted with simple hand tools, recovering three oriented blocks from a single horizon at each site. Sites were located about 5.5 ft. (1.6 m) apart stratigraphically, except where precluded by poor exposures. This resulted in more than 700 magnetic sites and more than 2,100 individual samples. All samples were trimmed into 2-cm cubes on a tungsten-carbide-bladed band saw and analyzed at the paleomagnetics laboratory of the California Institute of Technology.

After measurement of natural remanent magnetization (NRM), a suite of samples was demagnetized using both alternating field (AF) and thermal demagnetization. AF demagnetization (Fig. 2) showed that most samples rapidly declined in intensity at higher AF fields, suggesting that a low-coercivity mineral such as magnetite was the primary carrier of the remanence. This was borne out by stepwise thermal demagnetization (Fig. 2) of most samples. Almost all remanence had disappeared by 580-600°C, which is above the Curie point of magnetite.

Analyses of IRM (isothermal remanent magnetization) acquisition further confirmed that both magnetite and hematite were present in many samples. Most rocks (Fig. 3) reached saturation IRM values at 800 mT (millitesla); the remanence in these rocks is carried mostly by magnetite. A modified Lowrie-Fuller ARM (anhysteretic remanent magnetization) test (e.g., Johnson et al., 1975) was also conducted during the IRM analysis (see Pluhar et al., 1991, for details). This test compares the resistance of AF demagnetization of both an IRM acquired in a 100 mT peak field, and an ARM gained in a 100 mT oscillating field. In almost all samples, the ARM (black squares) demagnetizes at higher peak fields than does the IRM (open squares), indicating that the remanence is carried by single-domain or pseudo-single-domain grains.

Since AF demagnetization does not remove high-coercivity overprints due to iron hydroxides, all remaining samples were subjected to stepwise thermal demagnetization. Overprinted components of magnetization were typically removed by 200°C (Fig. 2), and a characteristic component was isolated between 300-500°C. This component was used for statistical purposes, as described by Fisher (1953) and Butler (1992). After statistical analysis, sites were classified according to the scheme of Opdyke et al. (1977). Class I sites were significantly clustered at the 95% confidence level. Class II sites could not be analyzed because one sample was lost or crumbled. In Class III sites, two samples showed a clear directional preference, but the third site was divergent. Sites which gave highly scattered magnetic results, or ambiguous polarity directions, were classed as indeterminate. The results for each site can be seen by the symbols in Figures 4 and 6.

In almost all cases, the strata were nearly horizontal, so it was impossible to conduct a fold test for stability. However, several reversal tests were conducted, and the reversed sites were antipodal to the normal sites (within the margin of error of the analysis). For example, in the Sharps Formation in Evergreen and Palmer Creek, Class I normal sites had a mean declination (D) of 3.6°, and a mean inclination (I) of 61.1°. The precision parameter (k) was 55.5 and the ellipse of confidence had a radius (α_{95}) of 5.4. Class I reversed sites at these same localities had a mean D = 194.2°, I = -50.3° (k = 48.6, and α_{95} = 5.3). The 1990 Wildcat Ridge normal samples produced a mean D = 354.3°, I = 59.1° (k = 5.9, α_{95} = 7.7), and reversed samples had a mean D = 169.5°, I = -42.3° (k = 10.0, α_{95} = 6.3); these are nearly antipodal. Thus, the component isolated between 300-500°C yields a positive reversal test, and is probably the characteristic component of the remanence.

Stratigraphic and paleomagnetic analysis of all the sections studied in this work shows that the Nonpareil Ash Zone (NPZ) consists of three distinct ash beds covering a 20-m interval, that the lowest ash lies at the top of Chron C11r, and that the remaining lie at the base and top of Chron C11n (Fig. 7). The Rockyford Ash (RF) lies low in Chron C11n and may be correlated with the middle ash of the NPZ (NP_2). Correlation of the lower part of the Sharps Formation with the Brown Siltstone shows that both lie in Chrons 11n-10r. The Wolff Table section (Prothero and Swisher, 1992) indicates that the "Second White Layer" (2W) of the Sharps is still within Chron C10r (Fig. 7). The Nebraska sections show a hiatus in Chron C10r with Chron C10n missing. There is weak evidence of part of Chron C10n in the Nuss Ranch section (Figs. 4 and 7).

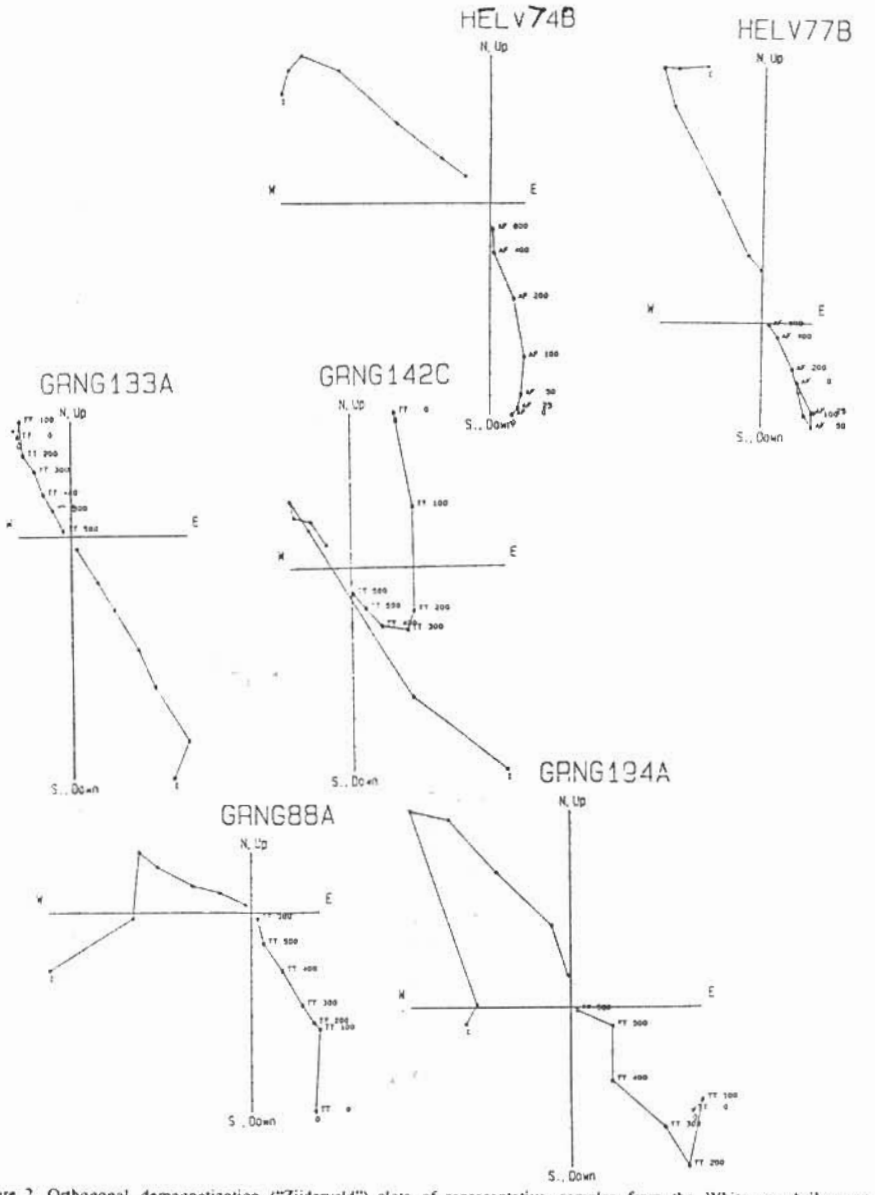


Figure 2. Orthogonal demagnetization ("Zijderveld") plots of representative samples from the Whitneyan-Arikareean transition. Circles show the horizontal component, and asterisks show the vertical component in each plot. Each increment = 10^{-5} emu. In samples HELV74B and 77B, AF demagnetization to 800 Gauss is shown. Note that both samples demagnetized rapidly, indicating that the remanence is carried by a low-coercivity mineral. In samples GRNG133A, 132C, 88A, and 194A, thermal demagnetization to 580°C is shown. Note that after removal of an overprinted component at temperatures up to 200°C, a stable component was isolated between 300-500°C. In most samples, nearly all the remanence was gone at the Curie point of magnetite, suggesting that very little was carried by hematite.

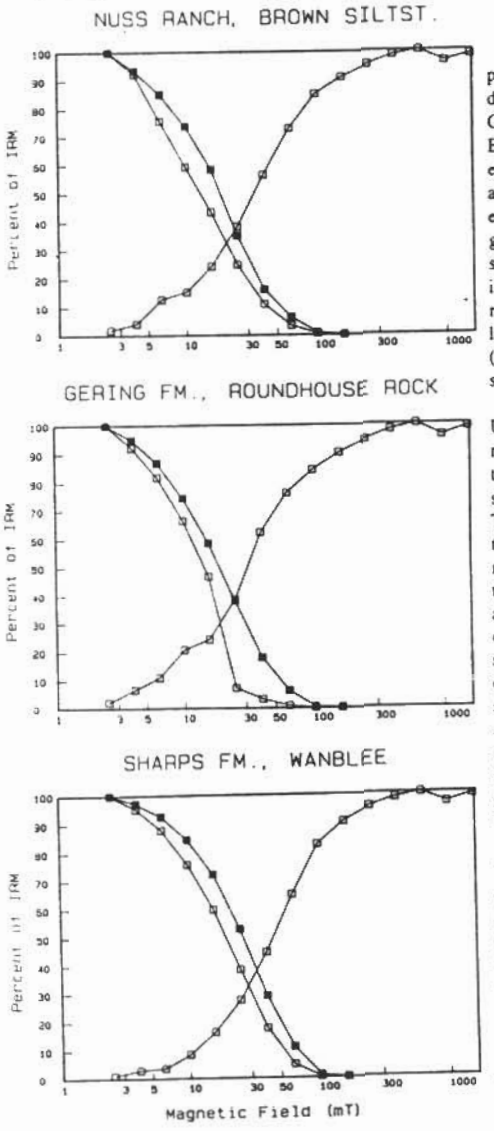


Figure 3. IRM acquisition analysis and modified Lowrie-Fuller test of three representative samples. IRM indicated by open squares, ARM by solid squares. Note that all three samples reached magnetic saturation (ascending curves on right) by about 800 mT, suggesting that the primary carrier of remanence is magnetite. In addition, the ARM in all three samples (descending curves on left) was more resistant to AF demagnetization than the IRM, indicating that the remanence was carried by single-domain or pseudo-single-domain grains. (See Pluhar et al., 1991, for further details).

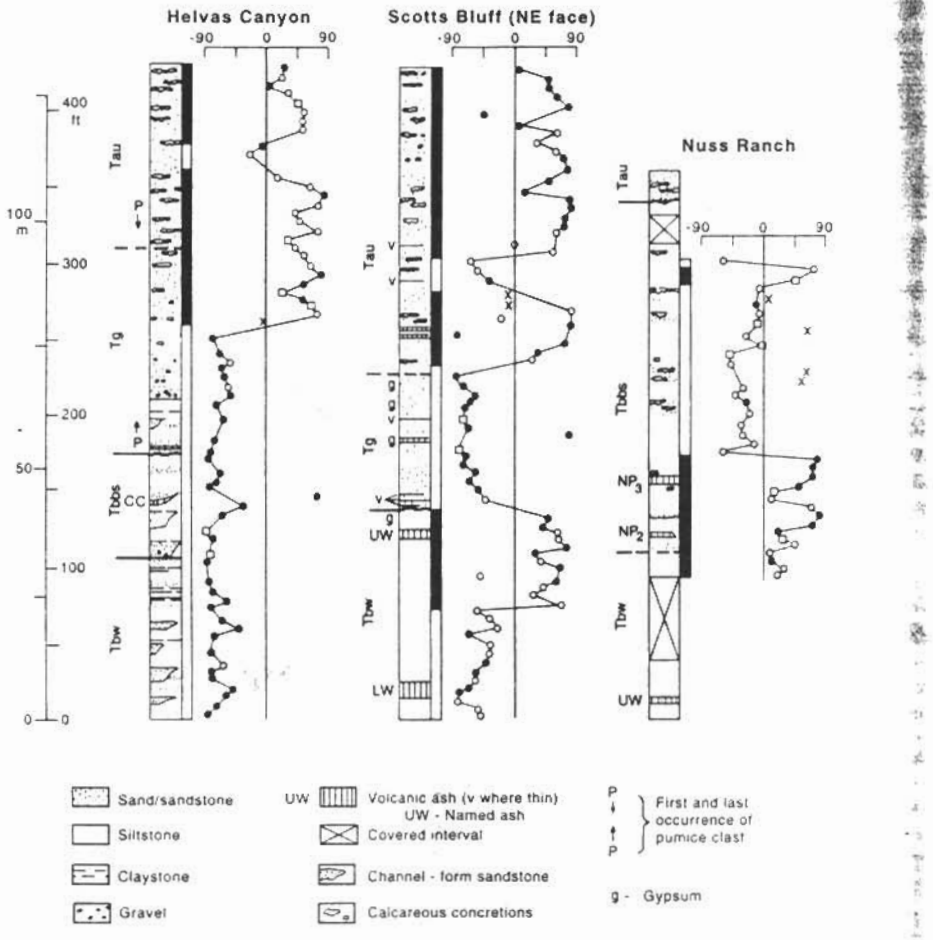
However, given the generally poor quality of the paleomagnetic data in the upper half of this section, we do not have much confidence in the presence of Chron C10n here. The paleovalley fluviatile sequence in the Brown Siltstone of the Roundhouse Rock section in the eastern Wildcat Ridge (Swisher's 1982 Unit A; Figs. 4 and 8b) contains a reversal boundary which must be equated with Chron C11n-Chron C10r if our biostratigraphic correlations are correct. Unfortunately, hiatuses separate depositional units in this area (Fig. 5), preventing assembly of a complete section. At the moment, radiometric dating is of no service either because of the large error (σ = 0.96 Ma) for the Roundhouse Rock Ash (RR) at the top of the postulated Chron C11n at this site.

Correlation of the Gering Formation (Swisher's 1982 Units B-D; Fig. 8b) with the upper Sharps is not so readily tested paleomagnetically for lack of data. Only the Evergreen (Slope) segment of the Sharps type section has a relevant magnetostratigraphy (Fig. 6). The regional unconformity breaking the Sharps Formation occurs in Chron C10n or the top of Chron C10r as normally polarized strata occur in the channels capping the Cedar Pass section (Prothero and Swisher, 1992) and, in truncated form, at the base of unit 14c (Harksen et al., 1961) in the upper 50 m of the Evergreen (Slope) subsection of the Sharps. Reversely polarized strata comprise most of the remainder of the Sharps (the sampled traverse did not reach the top) that must represent Chron C9r. Pumice-bearing Gering Formation reaches upward into the base of Chron C9n in the North Platte Valley (Figs. 4 and 7). The biostratigraphic correlation of the upper Sharps and Gering is supported by these data.

The younger Arikaree strata in the North Platte Valley begin within Chron C9n and our biostratigraphic correlations suggest that the "Monroe Creek" in South Dakota should do the same. The youngest fossil site mentioned below from Scotts Bluff National Monument occurs in a reversed interval that may represent Chron 8r (Figs. 4 and 7).

BIOSTRATIGRAPHY

The Cenozoic rocks of the High Plains contain a rich fossil record that forms the foundation of a biochronologic scheme for the North American Oligocene and Miocene that not only characterizes faunal change in this region but can be extended over the mid-latitudes of the continent (Emry et al., 1987; Tedford et al., 1987). In a previous report, Tedford et al. (1985) assembled biostratigraphic data from the upper White River and lower Arikaree groups of the Niobrara and White River valleys of northwestern Nebraska together with similar information from the Big Badlands of South Dakota. These data were compared and correlations proposed between Nebraska and South Dakota. Very limited paleomagnetic data were available to test the biostrati



graphic correlation. New information from these areas and from the North Platte Valley in Nebraska now makes it possible to extend the biostratigraphic analysis over most of western Nebraska and southwestern South Dakota. The resulting correlation network can in turn be tested against the more comprehensive paleomagnetic and radiometric data summarized in previous sections of this report.

It has long been recognized that lithologic facies of the Brule Formation, White River Group, contain contrasting faunas (Matthew, 1901; Clark et al. 1967; Wilson, 1975) apparently representing coeval biotopes. The most striking contrasts are between the faunas of the shallow stream channels and their proximal overbank facies and those of the interfluve sheet-flood and eolian facies distal to the stream tracts. This phenomenon is best exemplified by the well-known contrast in faunas between the "*Protoceras* channels" and the "*Leptauchenia* clays" within the Poleslide Member of the Brule Formation of South Dakota. Stream channels are rare in the correlative Whitney Member of the Brule Formation and in the lower part of the Sharps Formation and correlative Brown Siltstone beds of the Brule Formation, all of which are dominated by massive to crudely bedded eolian silts. The faunas contained in these rocks contrast with those of the channels in having lower taxonomic diversity. This generalization may be tempered somewhat by the difficulty of

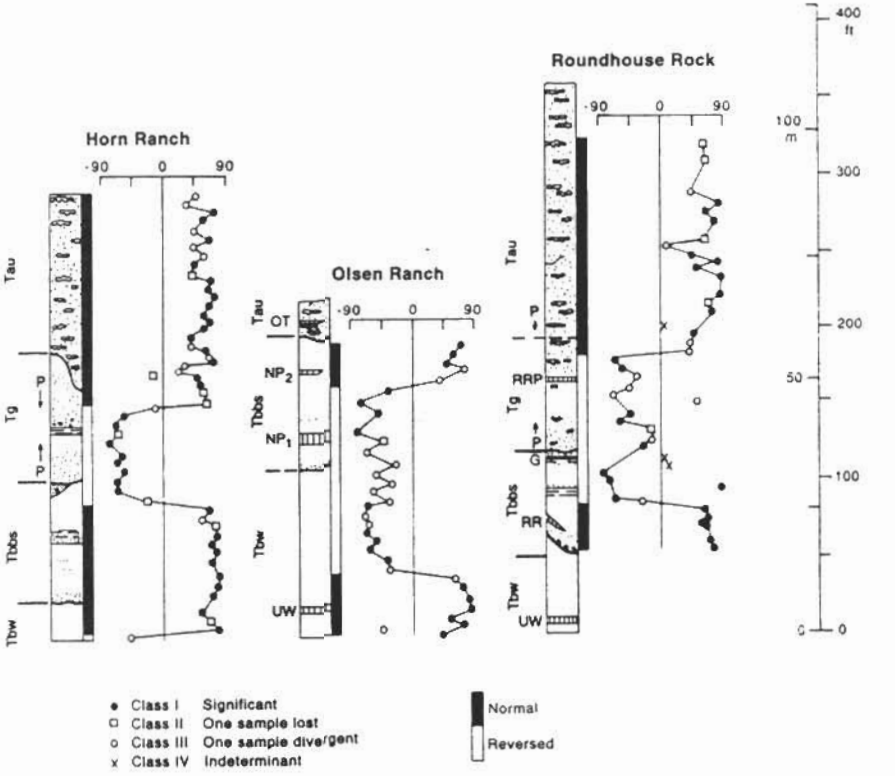


Figure 4. Magnetic polarity stratigraphy of Wildcat Ridge localities, Nebraska. Location of sections as follows: Helvas Canyon (Type section Gering Formation of Voorhies and others, 1969)— NW sec. 6, T.20N., R56W.; Scotts Bluff— E1/2 sec. 33, T.22N., R.55W.; Nuss Ranch—NW SW sec. 18, T.23N., R.53W.; Horn Ranch—NW NE sec. 34, T.20N., R.53W.; Olsen Ranch—SW sec. 21, T.19N., R.51W; Roundhouse Rock—NE SW sec. 21, T. 19N., R. 51W. Abbreviations: Tbw, Brule Formation, Whitney Member; Tbbs, Brule Formation, Brown Siltstone beds; Tg, Gering Formation; Tau, Arikaree Group, undivided; LW, Lower Ash of Whitney Member; UW, Upper Ash of Whitney Member; NP1-3, Nonpareil Ash (1, 2, or 3); RR, Roundhouse Rock Ash; CC, Carter Canyon Ash; G, Grey Ash bed; RRP, Roundhouse Rock Pisolitic Ash; OT, Olson's Third Ash. The pre-Gering portion of the Scotts Bluff section modified from Prothero and Swisher (1992). Reversals shown when indicated by two or more sites.

assessing the diversity of small mammals scattered in the eolian facies in comparison with those in channels where hydraulic processes concentrate the remains.

Rocks of the succeeding Arikaree Group were laid down initially in deeply incised stream valleys, the deposits of which are an intimate mixture of fluviatile and eolian facies. These facies still maintain their faunal characteristics, but are interbedded as depositional tracts shifted across the valley axes (Bart, 1976). Most investigators have tended to collect from bulk units and to ignore the details of the internal stratigraphy of these valley fills so that presently available assemblages are composites of these faunal facies. The upper part of the Sharps Formation and the conformably succeeding "Monroe Creek Formation" in South Dakota may be an exception since the initial paleovalleys, although deeply incised, were narrow and aggradation soon formed a broad depositional plain in which fluviatile systems were a minor component. The fauna obtained from the massive nodular siltstones of the upper part of the Sharps Formation came from sediments largely deposited by eolian processes, a continuation of the lithotope common in the lower part of the unit. In the North Platte valley of Nebraska, fluviatile systems are impor

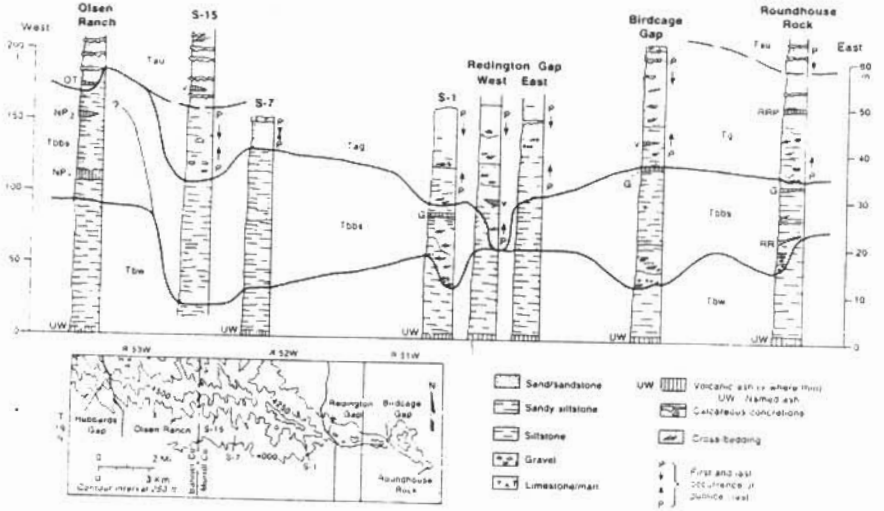


Figure 5. Stratigraphy of Brule and Arikaree strata exposed along southeastern Wildcat Ridge (See Figure 1 for location of Wildcat Ridge). The Brown Siltstone (Tbbs) includes a paleochannel-fill (Unit A of Swisher, 1982) cutting from an undetermined level in the upper part of the Tbbs through the Nonpariel Ash beds (NP_1 and NP_2) and enclosing older Brown Siltstone strata and deeply into the Whitney Member between the Olsen Ranch and S-15 outcrops. Likewise the pumice-bearing Gering (Unit B of Swisher, 1982) fills a paleovalley that locally removed all of the Brown Siltstone in the Redington Gap area. Both paleovalleys are truncated by undivided Arikaree strata in the Olsen Ranch section. Upper Whitney Ash used as a datum for the measured sections. Location of sections not given in Figure 4: S-15, Center NE sec. 18, T. 19N., R. 52W.; S-7, SE SW sec. 17, T. 19N., R. 52W.; S-1, SE NE sec. 22, T. 19N, R. 52W.; Redington Gap, Center N 1/2 SW sec. 14, T. 19N., R. 52W.; Birdcage Gap, NE NE sec. 15, T. 19N., R. 51W. Abbreviations for rock units and ash beds follow those of Figure 4.

tant in the correlative Gering Formation, as they are in the basal Arikaree of the White River valley. Higher in the Arikaree, eolian deposits again become dominant.

Facies localization of taxa and stratigraphic changes in the environment of deposition pose limitations on determination of the range zones of given taxa (Hunt, 1985, p. 188). The ideal would be a long stratigraphic sequence in a single lithotope where hiatuses would be the only complexity to determination of stratigraphic range. The best approximation of the ideal is the Poleslide-Sharps-"Monroe Creek" succession in South Dakota, which lies in the eolian facies for the most part and is broken by a single important hiatus.

In the discussions that follow, the biostratigraphic succession within the White River valley of northwestern Nebraska and the Big Badlands of South Dakota presented in 1985 is re-examined in light of additional evidence. The succession in the North Platte River valley of western Nebraska is added, and a biostratigraphic synthesis of all data for the upper White River and lower Arikaree groups is advanced. As oreodonts are an important part of this record, we follow the taxonomic revisions of CoBabe (this volume, Chapter 26) for leptauchenines and Stevens and Stevens (this volume, Chapter 25) for merycoidodontines and Stevens (MS) for promerycochoerines.

White River Valley, Nebraska

The biostratigraphy of this area lies within the eolian facies and was based largely on the type section of the Whitney Member of the Brule Formation in the "Round Top to Adelia" traverse in Sioux County (UNSM Loc. Sx-22). In this section the widespread Lower (LW) and Upper (UW) Whitney ash beds have been identified, as has the Nonpareil Ash Zone (NPZ). In outcrop the NPZ is represented by a single ashfall that can be correlated magnetically with the third ash (NP_3) of the thick NPZ of the North Platte River valley. These ash beds thus serve as lithostratigraphic markers to anchor the biostratigraphy and to test correlations based on the latter.

In Tedford et al. (1985), the Whitney and succeeding Brown Siltstone interval was partially subdivided faunally in order to discuss the biostratigraphy as a set of exclusive intervals called Fauna I through III that traced the succession of certain taxa into the base of the Brown Siltstone. Fauna I from the top of the UW to the upper ashy zone of the Whitney (UA), possibly part

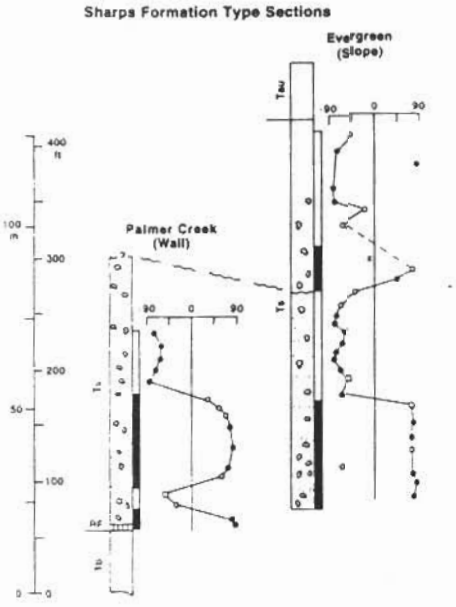


Figure 6. Magnetic polarity stratigraphy of the Sharps Formation type subsections. Lithology modified from Harksen et al. (1961). Lithographic correlation of the subsections proposed by Harksen et al. (1961) is corroborated magnetically. The top of the Palmer Creek subsection approximates the position of the regional disconformity separating the Sharps Formation into two units (see discussion pp. 325-326). This disconformity is identified in the Evergreen subsection by the truncated normally polarized interval postulated to represent Chron C10n (see Fig. 7). Location as follows: Palmer Creek—SW 1/4 NW 1/4 Sec. 31, T. 41N, R. 42W.; Evergreen—NW 1/4 sec. 30 and NE 1/4 sec. 20, T. 39 N., R. 43W.

of NPZ, perhaps NP_1, contains *Hyracodon* and *Leptauchenia decora* plus *Merycoidodon major*. Fauna II, which was obtained from the UA to 4.6 m below the base of what was taken as the NPZ (here correlated with the NP_3 ash of the Wildcat Ridge, Fig. 4), contains the lowest local occurrence of the large *Leptauchenia major* associated with *L. decora* and *Hyracodon*. About 4.6 m below the NPZ, at the base of the interval characterized by Fauna III, *Sespia nitida* has its first local occurrence associated with *Leptauchenia major*. Along the Beaver Wall, 65 km northeast of Roundtop in Dawes County, *?Mesoreodon minor* has its first appearance at the same position below the NPZ if this ash equates with NP_3. These taxa extend for an additional 18.3 m above the NPZ. In the Niobrara River valley, 45 km south of Roundtop in Box Butte County, scattered remains occur in the Brown Siltstone (correlated with the Monroe Creek Formation by Yatkola, 1978) over 61 m above the NPZ. These data show the upward continuation of the range zones of *Sespia*, *Leptauchenia major* and *?Mesoreodon minor*.

A regional disconformity limits the Brown Siltstone in northwestern Nebraska and the succeeding Arikaree Group fluviatile and eolian deposits were laid down in deep valleys excavated up to 91 m into the White River Group (Swinehart et al., 1985). The scattered faunas in these deposits are much more diverse than those of the upper White River because of the fluviatile component in the valley fill.

The massive silty sandstones representing the eolian facies within this Arikaree valley fill contain the oreodonts *Leptauchenia decora* and *L. major*. The thin and lenticular fine to medium fluviatile sands with lenses of lithic gravels bear a large mammal fauna lacking oreodonts, but containing *Miohippus*, *Diceratherium*, *Arretotherium*, and *Pseudolabis*. These friable channel sands also contain a diverse microfauna exemplified by that described by Martin (1973) from UNSM locality Dw-108, a site low in the Arikaree paleovalley sequence south of Chadron. Among the taxa he recorded from this site are the insectivores *Domnina dakotensis* and *Ocajila makpiyahe*; the rabbits *Palaeolagus philoi* and *?Megalagus primitivus*; and the rodents *Kirkomys schlaikjeri*, *Sanctimus stuartae*, *Leidymys blacki* and *Geringia mcgregori*. Another nearby site (UNSM Dw-121), recently discovered by Bruce Bailey (personal communication, 1995), is stratigraphically lower than Dw-108, in the base of the paleovalley, produces a more diverse fauna, but contains the same taxa including *Heliscomys woodi*. In addition, a species of the allochthonous talpine mole *Scalopoides* is present representing the lowest stratigraphic occurrence of this taxon demonstrated to date. Except for *Scalopoides* and *Heliscomys woodi*, both recorded from younger Arikaree rocks in South Dakota, most of the remainder of the taxa listed have local range zones that are either restricted to or include the upper part of the Sharps Formation (Sharps Fauna C of Tedford et al., 1985, and this chapter; see below) of nearby South Dakota.

Big Badlands, Southwestern South Dakota

(local range zones of selected taxa shared with Nebraska are shown in Fig. 8a).

Wilson (1975) contrasted the faunas obtained from the classic "*Leptauchenia* clays" and "*Protoceras* channels" in the Poleslide Member of the Brule Formation in the Palmer Creek Unit of Badlands National Park. In addition to the common occurrence of the oreodonts *Leptauchenia decora* and the large *Merycoidodon major*, the thick-bedded siltstones and claystones distal to the "*Protoceras* channels" contain the rabbit *Palaeolagus*, a round-incisor beaver, *Agnotocastor*, a canid, and the small rhino *Hyracodon* (only *Agnotocastor* was shared between the facies: Wilson 1975, pp. 80-81). Larger collections obtained by Morris Skinner for the American Museum of Natural History from the same

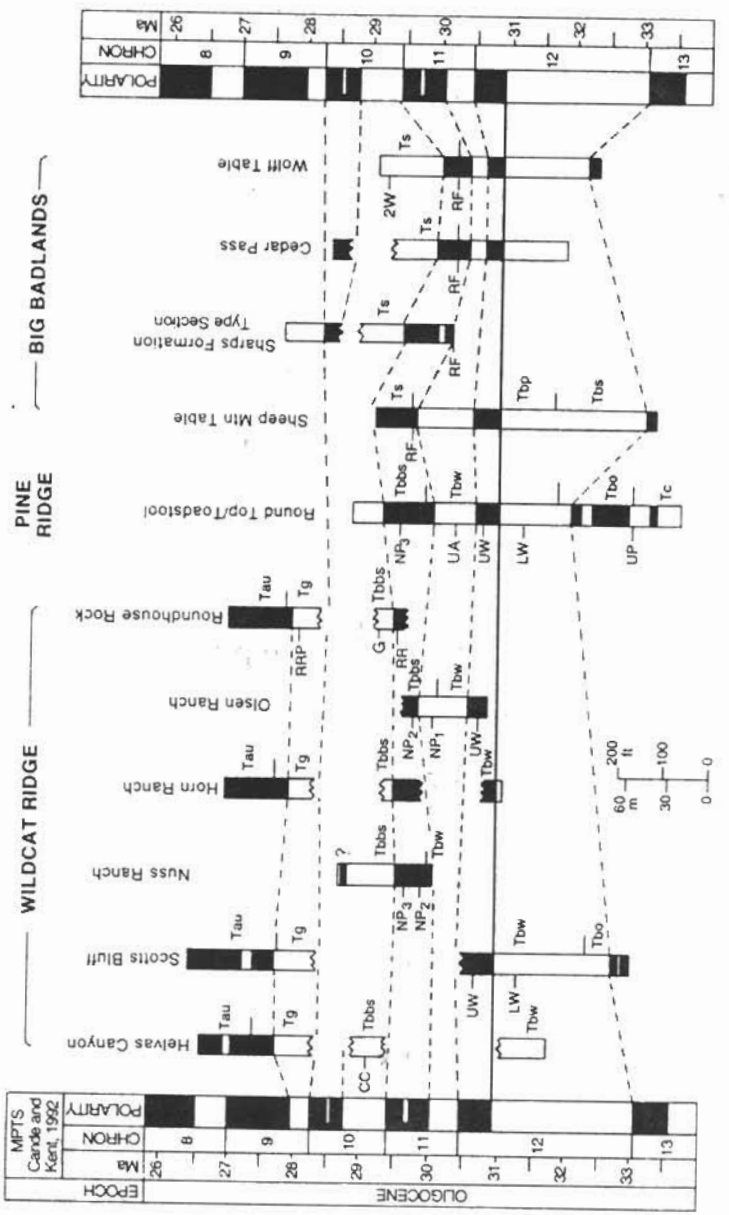


Figure 7. Correlation of Oligocene strata in western Nebraska and southwestern South Dakota with the magnetic polarity time scale (MPTS) of Cande and Kent (1992). The sections are adjusted to the base of Chron 12n which contains the Upper Ash of the Whitney (UW). Round Top, Sheep Mountain Table, Wolff Table, and pre-Arikaree of Scotts Bluff from Prothero and Swisher (1992). Abbreviations not on Figure 4: Tc, Chadron Formation; Tbo, Brule Formation, Orella Member; Tbs, Brule Formation, Scenic Member; Tbp, Brule Formation, Poleslide member; Ts, Sharps Formation; UA, upper ashy-zone of the Whitney; UP, Upper Purplish White bed; RF, Rockyford Ash; 2W, second White Layer.

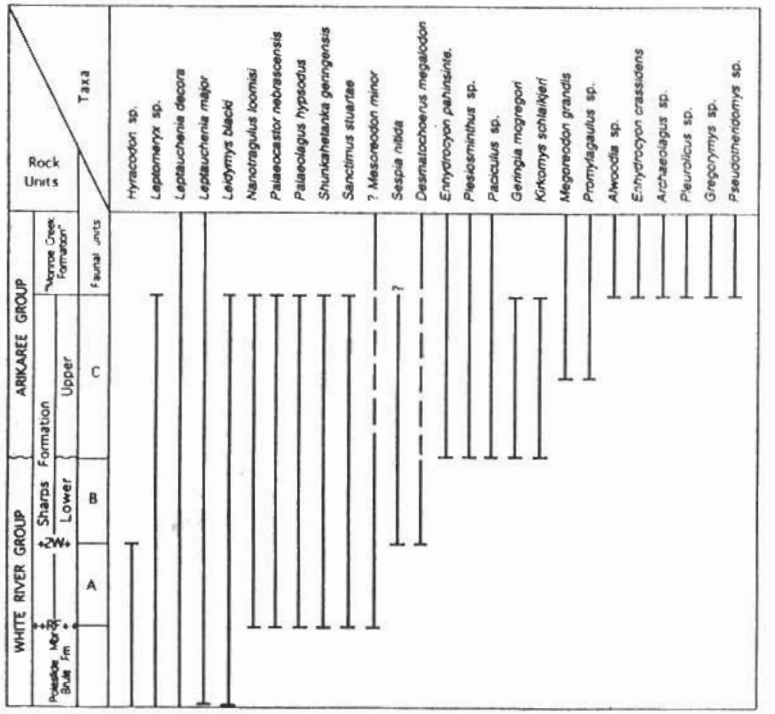
lithofacies and interval at Cedar Pass in the National Monument were also dominated by *Leptauchenia decora*, *L. major* and large merycoidodontine oreodonts with rarer *Hyracodon*, *Miohippus obliquidens*, a carnivore, and peccary. Recent intensive collecting of the Poleslide and lower Sharps by parties from the South Dakota School of Mines has demonstrated the presence of *Leidymys blacki* 15.2 m beneath the Rockyford Ash (P. Bjork, personal communication, 1993) raising the possibility that other Sharps microfauna may also be extended downward in range.

The lithology of the lower part of the Sharps Formation closely resembles the Poleslide Member, but it carries a somewhat more diverse fauna. Tedford et al. (1985) grouped as Sharps Fauna A the material collected by Skinner's and Macdonald's (1963, 1970) parties from the lowest 30.5 m of the Sharps Formation (including material within the basal Rockyford Ash) from outcrops on Sheep Mountain, Cedar Pass and south of the White River within and east of the National Monument (Wolff Ranch area and eastward). These levels contain the last local occurrence of *Hyaenodon* (*H. brevirostris*) and *Hyracodon* (*H. nebraskensis*, *H. leidyanus*), in addition to the continuation of *Leptauchenia decora* and *L. major*; and the first local occurrences of *Nanotragulus loomisi*, *?Mesoreodon minor*, *Diceratherium* (Green, 1958), *Eusmilus olsontau*, *Shunkahetanka geringensis*, *Capatanka cankpeopi*, *Capacikala gradatus* (Parris and Green, 1969), *Palaeocastor nebraskensis*, *Palaeolagus hypsodus*, *Palaeolagus philoi* and *Sanctimus stuartae* (P. Bjork, personal communication, 1993).

A second fauna, Sharps Fauna B, was obtained by Morris Skinner and party from the deposits that begin at the ash bed ("Second White layer," 2W) 50 m above the RF and extend through the next 21 m. This assemblage includes the first local occurrence of *Sespia nitida*, associated with *Leptauchenia decora*, *L. major*, *?Mesoreodon minor*, the flat-incisor beavers, and *Palaeolagus* species recorded in Fauna A. Tedford et al. (1985) correlated this assemblage with Faunal Unit III of northwestern Nebraska largely on the first occurrence of *Sespia*, but this correlation has been rejected paleomagnetically. *Sespia* is rare in these rocks, making it difficult to determine its range zone. At Cedar Pass, Parris and Green (1969) report a fauna containing the giant entelodont *Dinohyus* sp., and a microfauna with *Domnina*, *Tamias*, *Proheteromys*, *Hitonkala andersontau*, and *Plesiosminthus* from the sand- and silt-filled channel that cuts from 53 m above the Rockyford Ash through the ash and 14 m into the underlying Poleslide (Parris and Green, 1969; Harksen, 1974; complete section from M. F. Skinner, MS). Collections made by M. F. Skinner add *Eusmilus olsontau*, *Leptomerys*, *Palaeocastor* cf. *nebraskensis*, and *Leptauchenia* to the fauna from this channel. The section at Cedar Pass is capped by a final channel-form sandstone only 5 m thick that contains a similar fauna, including *Palaeocastor nebraskensis*, *Cormocyon* cf. *copei* and *Leptauchenia*. To the southwest, near the mouth of Porcupine Creek, the Godsell Ranch Channel of Macdonald (1963) has a similar stratigraphic position and likewise cuts through the lower part of the Sharps Formation and deeply into the Poleslide. Macdonald (1963) found a small mammal fauna (SDSM Loc. V5413) from the Godsell Ranch Channel that is similar to that recorded at Cedar Pass, including *Domnina greeni*, *Tamias*, *Heliscomys*, *Proheteromys bumpi*, *Hitonkala andersontau*, and *Scottimus*. Lateral equivalents of this channel (SDSM Loc. V5410) also yielded additional taxa including *Palaeocastor nebrascensis*, *Capacikala gradatus*, *Leidymys blacki*, *Cormocyon copei*, *Oxydactylus* cf. *wyomingensis*, *Leptomeryx*, *Nanotragulus loomisi*, and *Sespia nitida*. All of these taxa range upward into the upper part of the Sharps Formation.

The local faunas from these channels represent the earliest assemblages from the base of the younger part of the Sharps Formation. At the stratotype of the Sharps Formation this level lies at the top of the first subsection (the "Wall"; Palmer Creek magnetic section, Fig. 6). The widespread topographic bench above the "Wall" escarpment from Porcupine Creek to the east denotes the base of the siltstones and fine sandstones of the middle and upper Sharps Formation that yielded most of the fossils used by Macdonald (1963, 1970) to typify his "Wounded Knee-Sharps Fauna." The biostratigraphic data provided by Macdonald (1963, fig. 2, and descriptions of fossil sites, pp. 153-162) indicate that the middle and upper sites lie above the lower subsection 75 m or more above the Rockyford Ash. In the second subsection of the stratotype (the "Slope"; Evergreen magnetostratigraphic Section, Fig. 6), correlative sites occur in the upper third of the section. A comparison of the local faunas of the middle Sharps with the upper Sharps as listed by Macdonald (1963; new locality data were not stratigraphically localized in Macdonald, 1970) reveals more than 70% similarity at the species level. Thus the term "Wounded Knee-Sharps Fauna" should be applied to the collective assemblage that occurs in the Sharps Formation above the disconformity discussed above. This is equivalent in concept to the Sharps Fauna C of Tedford et al. (1985).

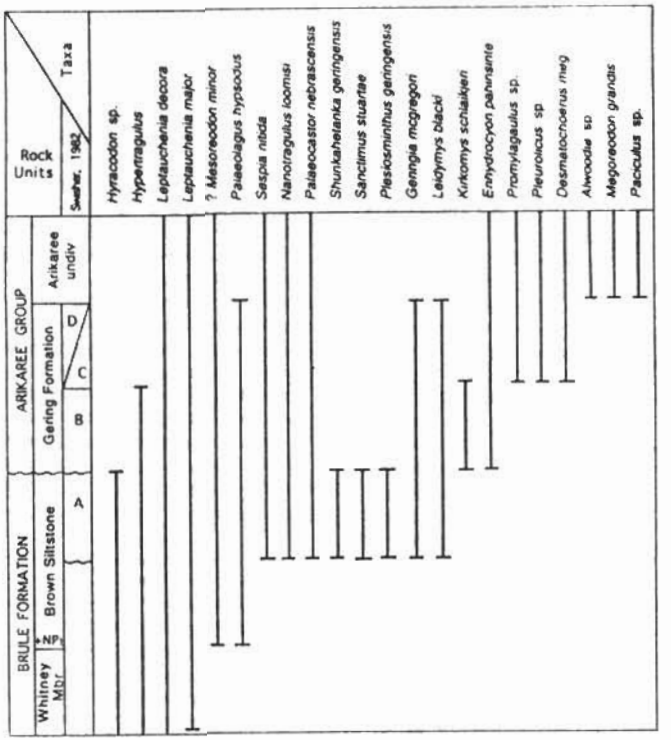
Macdonald (1963, 1970) and his associates assiduously collected smaller mammal remains from the upper part of the Sharps. As a result there are a number of first-occurring taxa at this level, and a major enrichment of the fauna occurs when compared to the lower Sharps. Significantly, these include the appearance of burrowing insectivores (*Arctoryctes* and moles) and burrowing rodents, such as the flat-incisor beavers and diverse geomyoid rodents, the latter outnumbering the cricetids. First occurrences of rodent taxa also found outside South Dakota, and hence valuable in correlation, are: *Paciculus woodi*, *Geringia mcgregori*, and *Kirkomys*



Figures 8a, b. Biostratigraphy of the upper White River through lower Arikaree groups, a) in South Dakota; b) in Nebraska. Stratigraphic ranges of selected taxa common to both South Dakota and Nebraska generalized to the limit of data available to this study. For ease in comparison, lithostratigraphic units are dimensionless and reflect succession only, rather than stratigraphic thickness.

schlaikjeri, which are limited to the upper part of the Sharps. A number of aplodontoid rodents also appear toward the top of the upper Sharps, including species of *Promylagaulus*, *Meniscomys*, and *Niglarodon*. Among the larger mammals, Fauna C shows the continuation of most of the Sharps Fauna B large taxa, with the addition of *Enhydrocyon pahinsintewakpa*, *Megoreodon grandis*, and *Oxydactylus* cf. *wyomingensis* near the top of the Sharps. A number of taxa common in the Brule and lower Sharps formations do not occur above the top of the Sharps, such as the nimravid "cats" *Dinictis*, *Eusmilus*, and possibly *Nimravus* (but see discussion of *N. secator* in Macdonald, 1970), *Palaeolagus hypsodus*, *Megalagus*, *Palaeocastor nebraskensis*, *Capatanka cankpeopi*, *Capacikala gradatus*, *Shunkahetanka*, *Chaenohyus*, *Elomeryx*, *Leptochoerus*, *Leptomeryx*, and *Agriochoerus*.

Gradationally overlying the Sharps Formation are massive siltstones and very fine sandstones correlated with the Monroe Creek Formation of Nebraska. This unit also bears a reasonably diverse mammal fauna (J. R. Macdonald, 1963, 1970; L. J. Macdonald, 1972), containing many of the same elements seen in the Sharps, reflecting a similar depositional environment. Local first occurrences in this unit of the genera *Amphecinus*, *Archaeolagus*, *?Gripholagomys* (Green, 1972), *?Desmatolagus*, *Alwoodia* (*A. harkseni*, Korth 1992), *Pleurolicus* (Rensberger, 1973), *Gregorymys*, *Promartes*, and *Oreodontoides* accompany last generic records within this unit for *Palaeolagus*, *Proscalops*, *Geolabis*, *Meniscomys*, *Eutypomys*, *Miohippus*, *Megoreodon* and possibly leptauchenine oreodonts. In addition, L. J. MacDonald (1972), on the basis of anthill collections below cliff outcrops of the upper part of the "Monroe Creek," recorded *Brachyerix*, *Metechinus*, *Parvericus*, *Trimylus*, *Scalopoides*, *Pseudotheridomys* and *Plesiosminthus*. Except for *Scalopoides* and *Plesiosminthus*, the remaining taxa had not previously



been recorded in the lower Arikaree. All are based on single teeth and could represent float from younger rocks. However, Korth (1992) has reported most of these genera (except *Brachyerix* and *Trimylus*) in the microfaunal sites at McCann Canyon, north-central Nebraska. There they are associated with a fauna otherwise closely comparable to that obtained from the "Monroe Creek" anthills. All of these changes within the "Monroe Creek" coupled with limitations of range of other taxa at the top of the Sharps, indicate that a major faunal turnover took place during the span of this unit (Fig. 8a).

North Platte Valley, Western Nebraska

(local range zones of selected taxa shared with South Dakota are shown in Fig. 8b).

Although initially thought to be poorly fossiliferous (Darton, 1899), the Arikaree sequence in the Platte Valley has been intensively prospected by parties from the University of Nebraska over the past 50 years with significant results. Martin's dissertation (1973) contains the first comprehensive review of the faunal succession obtained from the "lower Miocene Gering Formation" in the Wildcat Ridge area on the south side of the North Platte River valley in Scottsbluff, Banner, and Morrill counties, Nebraska. Vondra's study (1963, and Vondra et al., 1969) of the lithostratigraphy of the upper White River and lower Arikaree groups in this area had been completed as Martin began his work, and this stratigraphic study formed the basis of Martin's biostratigraphy. This lithostratigraphy was too generalized to provide an adequate basis for depicting the biological history of the region at the scale now required by our studies. In 1982, Swisher completed a master's thesis on the lithostratigraphy and biostratigraphy of the eastern Wildcat Ridge in Morrill County where the most fossiliferous Brule and Arikaree sequence is found. Careful mapping by Swisher (1982), and further work by Swinehart and Diffendal (1995) reported herein, have provided a more detailed lithostratigraphic basis for the biostratigraphy.

In this region the eolian facies of the Brown Siltstone beds are typically gradational with the Whitney Member of the Brule Formation and show a consistent trend to slightly coarser grain size. The base can be locally defined in the field and in the subsurface as the first occurrence of silty sand beds above the UW ash. The Nonpareil Ash Zone occurs near the base of the Brown Siltstone and usually is a single ash bed, but at some localities it includes two ash beds separated by as much

as 18 m. In the eastern Wildcat Ridge, the Brown Siltstone beds also contain the fill of a paleovalley (Unit A of Swisher, 1982) cutting obliquely southeastward across the line of outcrop (Fig. 5). We infer that the cutting of this paleovalley has removed the lower 15 to 24 m of the Brown Siltstone (including the NPZ) so that the biostratigraphic sequence contained in Unit A begins above the entire ash zone. The fauna of this paleovalley fill contains the last local occurrence of *Eumys*, *Hyaenodon*, and *Hyracodon*; part of the local range zones of *Leptauchenia decora* and *L. major*; the lower part of the local range zones of *Palaeocastor nebraskensis*, *Sespia nitida*, *?Mesoreodon minor*, *Shunkahetanka geringensis*, *Miotylopus gibbi*, and *Nanotragulus loomisi*. In addition, there are a number of lagomorphs and rodents making their first local appearance at this level: *Palaeolagus hypsodus* and *P. philoi*, *Leidymys blacki*, *Geringia mcgregori*, and the ?primate or ?dermopteran (see McKenna, 1990) *Ekgmowechashala*. *Shunkahetanka geringensis*, *Sanctimus stuartae*, and *Plesiosminthus geringensis* appear to be confined to this interval. *Plesiosminthus* is an immigrant whose earliest North American record is based on two specimens from the Durnal Ranch Quarry assigned by Swisher to his Unit A.

Since disconformities have truncated the Brown Siltstone above the NPZ in the eastern Wildcat Ridge, we must turn to the north side of the North Platte valley to find an unbroken succession of massive siltstones above this ash interval. Outcrops from north of Lake Minatare on the Nuss Ranch in Scotts Bluff County northwest to the Spottedtail Creek drainage in Sioux County show about 70 m of Brown Siltstone beds deposited conformably on the Whitney (Fig. 4). The NPZ is usually present near the base, but may be removed by the stream courses within the paleovalley.

The Sioux County outcrops of the Brown Siltstone about 30 km west of Nuss Ranch have been the most consistently collected. The lower part of this section, including taxa from within the NPZ, contain *Hoplophoneus occidentalis*, *Hypisodus*, *Heliscomys*, *Eumys*, and *Leptauchenia decora*, also known in older White River strata, along with *Diceratherium* cf. *armatum*. Higher in the sequence *Leptauchenia major* occurs with *Palaeolagus hypsodus* and *?Mesoreodon minor* (including the holotype of a synonym, *Desmatochoerus sanfordi*). These rocks are disconformably overlain by 20 m of cross-bedded pebbly sands and thin-bedded silty sandstones that give way upward to massive silty fine sand containing the fauna from the old Ledingham Ranch area mentioned by Skinner et al. (1968). This assemblage contains large leptauchenines, *Desmatochoerus megalodon*, *?Mesoreodon minor*, *Megoreodon grandis*, and *Enhydrocyon pahinsintewakpa* (Wang, 1994, identified as *E. crassidens* in Skinner et al., 1968) which, along with the lithostratigraphy, indicate correlation with the Gering and post-Gering Arikaree strata of the Wildcat Ridge to the south.

The Gering Formation is incised as much as 15 to 20 m into the Brown Siltstone along the Wildcat Ridge (Fig. 5). Its paleochannel axis roughly parallels the east-to-west trend of the Ridge (Swinehart et al., 1985, fig. 14). The lower, pumice-bearing part of this unit (Unit B of Swisher, 1982) contains a locally abundant fauna, which for the most part represents an upward continuation of the assemblage contained in the Brown Siltstone with the addition of *Kirkomys schlaikjeri* and *Enhydrocyon* cf. *pahinsintewakpa*. Some taxa, mostly surviving White River forms, have their last local appearance in these beds: *Palaeolagus philoi*, *Heliscomys*, *Chaenohyus*, *Agriochoerus*, *Hypertragulus*, and *Hypisodus*.

In the upper part of the Gering Formation (Unit C of Swisher, 1982) a number of small mammals appear, which along with the last appearances of taxa from Unit B, marks a faunal turnover within the Gering. The newcomers include the mylagaulid *Promylagaulus*, the beaver *Capatanka*, and the geomyoid *Pleurolicus* cf. *sulcifrons*. *Geringia*, *Palaeolagus hypsodus*, and *Leidymys blacki* have their last local appearances in this unit.

Little is known of the fauna from the thin-bedded fine sands and silts of Unit D, which seem to lie in a broad, low-relief paleovalley within the upper part of Unit C. These beds probably represent a sequence of fluvial sheet-flood, eolian sand-sheet and local playa deposits. The entelodont *Dinohyus* occurs at the base of Unit D and scattered large mammal remains have been obtained higher in the section from the massive, fine sands that cap the cycles of thin-bedded to laminated fine sands filling the paleovalley. *Cormocyon copei*, *Nimravus brachyops*, *Desmatochoerus megalodon*, and *Leptomeryx* sp. were obtained from these rocks in Black Hank's Canyon (UNSM Loc. Mo-109), northwest of Redington Gap. Most of these species have ranges that descend into the Brown Siltstone beds and the Whitney Member of the Brule Formation, although the occurrence of the large oreodont *D. megalodon* may represent the initiation of its local range zone in this sequence.

Units C and D grade upward to predominantly massive, silty fine sandstones of the undivided Arikaree Group. Swisher found micromammals in anthills on the lower part of the latter deposits that indicated the upward continuation of *Proscalops*, *Promylagaulus*, *Palaeocastor nebraskensis*, *Proheteromys*, and *Pleurolicus* from the Gering and Brown Siltstone. The occurrence of *Paciculus nebraskensis* marks the first appearance of the genus in the local section. References to this genus in older rocks (Martin, 1973, 1980) are based on species within or close to *Geringia* (Swisher, 1982). Scattered large mammal remains occur in these rocks, especially in the western part of the Wildcat Ridge.

At Scotts Bluff National Monument, 27 m of thin-bedded Unit D lies directly on the Whitney Member of the Brule Formation and is overlain by thick-bedded or massive undivided Arikaree (Swinehart and Loope, 1987). Fossil mammal remains occur in eolian deposits 18 to 20 m above the base of the undivided Arikaree, including *Promylagaulus*, *Alwoodia*, *Sespia*, and *Nanotragulus*. At Roubadeau Pass, west of the National Monument, large mammal remains occur in the undivided Arikaree at a similar stratigraphic position, including *Sespia*, *Megoreodon* and *Diceratherium*.

It is clear from the data presented above that the Big Badlands and North Platte valley successions are the longest and most completely documented sequences. The White River valley sequence is shorter and less complete, but informative regarding the ranges of some taxa. It is used in an ancillary fashion in determining the total range zones for some species.

If we inspect the South Dakota and Nebraska sections (Fig. 8a-b), a biostratigraphic correlation readily emerges (Fig. 9). The lower part of the Sharps and Brown Siltstone intervals are correlative. An important faunal enrichment occurs in both the eolian and fluviatile facies. A few Whitneyan taxa have their last appearances at these levels but the striking effect is of augmented diversity, magnified by the visibility of the microfauna in the stream channel deposits (Unit A of Swisher) that disconformably overlie the massive siltstones in the North Platte valley section. The upper part of the Sharps and the Gering formations (units B-D of Swisher) are also correlative; the former shows the upper parts of the ranges of *Geringia*, *Leidymys*, and *Kirkomys* and the base of the range of *Promylagaulus*. In the White River valley of Nebraska the disconformity between the Arikaree and White River strata corresponds to an episode of erosion that removed a considerable part of the Brown Siltstone (all of it in the Arikaree paleovalley axis). Arikaree aggradation in this paleovalley began during the span of deposition of the upper part of the Sharps Formation judging from the coexistence of rodent taxa collected from the lower Arikaree Group in the White River valley.

An important turnover takes place in the uppermost Sharps and "Monroe Creek" and the equivalent upper Gering and overlying undivided Arikaree in Nebraska. In South Dakota most of the long-ranging Sharps taxa, with the exception of the oreodonts, terminate at the top of the Sharps. In Nebraska the correlative level records a similar phenomenon. Evidence from both areas shows that some genera ranging up from the Whitney also reach no higher than the top of the Sharps (e.g., most nimravids, *Leptochoerus*, *Chaenohyus*, *Elomeryx*, *Hypertragulus*, *Leptomeryx*, *Hypisodus*, *Agriochoerus*). This turnover marks the termination of the White River Chronofauna (Emry et al., 1987) and a natural biochronological boundary.

BIOCHRONOLOGY

Having tested our biostratigraphic correlations against other data and found no conflict, we can assemble the local range zones of some taxa shared between Nebraska and South Dakota into a magnetically calibrated composite chronostratigraphic chart (Fig. 9). These data place into temporal context the major aspects of the succession detailed above. A phase of enrichment of the White River chronofauna (Emry et al., 1987) is seen early in the geochron of the Brown Siltstone-latest Poleslide interval; i.e., during Chron C11n beginning at 30 Ma. However, true faunal turnover, with extinction and origination components, takes place later in the sequence, and interestingly, does not correspond to the regional stratigraphic hiatus beneath the Gering and upper Sharps. This turnover event, beginning approximately at 28 Ma, effectively ends the White River Chronofauna through extinction of many of its characteristic elements, including some taxa that appeared during the enrichment episode. The new fauna that emerges in the overlying Arikaree Group includes *Megoreodon* and *Oreodontoides* and a suite of oreodonts known in the older deposits, plus more derived species of genera that are recorded earlier (e.g., *Enhydrocyon crassidens*) and a suite of small mammals, including genera which appeared in the immediately underlying strata (*Promylagaulus* and *Paciculus*) as well as genera that represent new lineages (*Archaeolagus*, *Alwoodia*, *Pleurolicus*, and *Gregorymys*), and others such as *Amphechinus*, *Promartes*, *Pseudotheridomys* and *Gripholagomys*, that appear to be immigrants to the Great Plains. The fauna of the McCann Canyon sites reported by Korth (1992) seems to be closely comparable to that of the "Monroe Creek" so the occurrence there of the European aplodontid *Parallomys* may be one of the expected additions to the list of immigrant taxa for this interval.

When Wood et al. (1941) first proposed the North American "provincial ages" to subdivide the mammalian record of the continent, the Arikareean faunas were poorly known, particularly those from the lower part of the Arikaree Group. Thus faunal typification of this mammal age was based largely on the later part of the interval. The fauna of the Gering was included largely because the Arikareean was envisioned as the geochron of the Arikaree Group, rather than a faunal sequence (for discussion see Tedford et al., 1987). With the data now in hand we can re-evaluate the definition of the lower limit of the Arikareean and the faunal content of the early Arikareean.

Even though our data identify an important faunal turnover event lying at the top of the Gering Formation and extending into the immediately overlying strata, typological considerations persuade us to retain the Gering faunas in the Arikareean as originally suggested. Faunal changes leading to the enrichment in Chron C11n could constitute the characterizing fauna of the

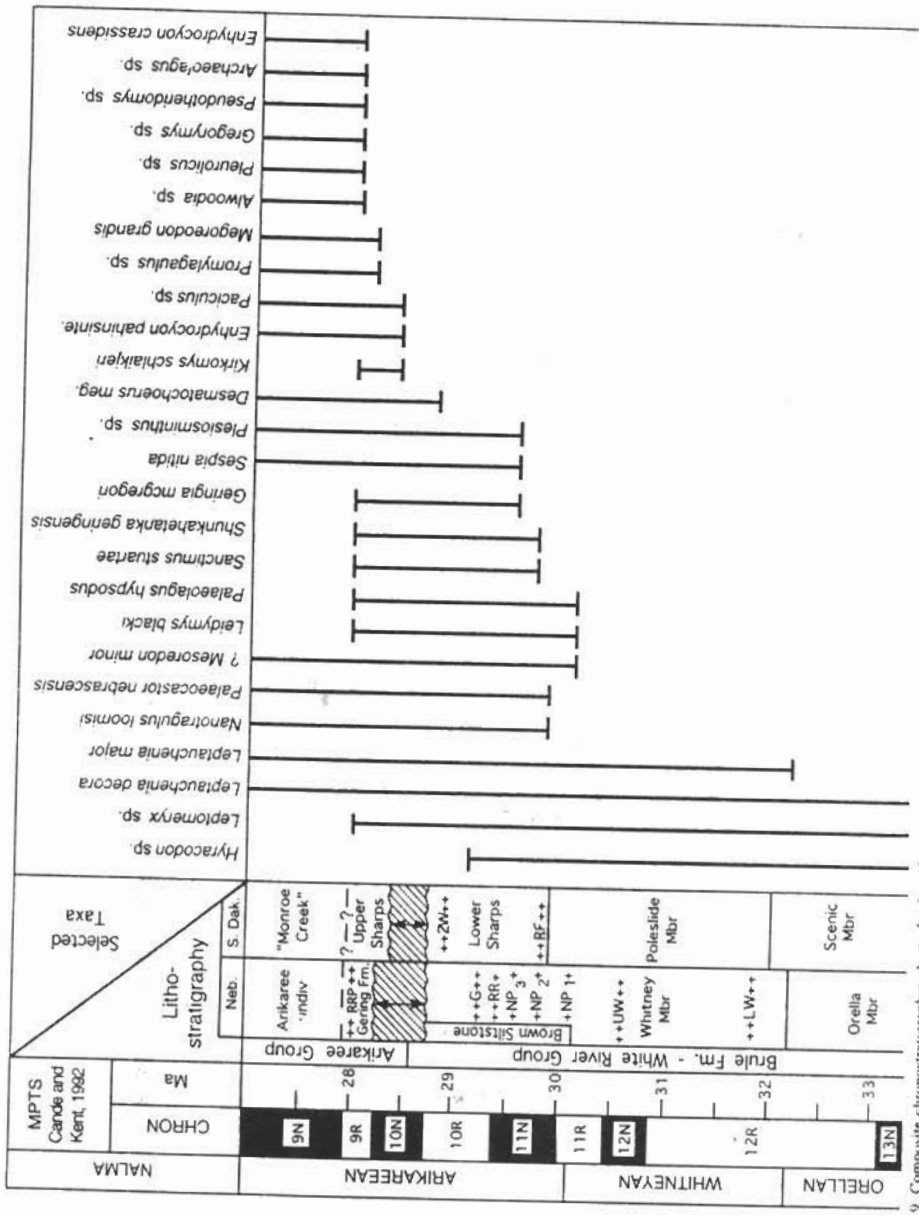


Figure 9. Composite chronostratigraphic chart of selected taxa shared between South Dakota and Nebraska. Biochrons are calibrated by magnetostratigraphy but the chronological ranges are generalized to reflect the limits of knowledge of stratigraphic range within each unit.

earliest Arikareean, with *Plesiosminthus* being the lone immigrant defining the beginning of the age. In addition, the first appearance of a number of autocthonous species, *Palaeolagus hypsodus*, *P. philoi*, *Palaeocastor nebrascensis*, *Shunkahetanka geringensis*, *Nanotragulus loomisi*, *Sespia nitida*, and *?Mesoreodon minor*, could be used to characterize the age. The coexistence of these new taxa and surviving Whitneyan forms could serve as a biostratigraphic typification of the earliest part of Arikareean time in the Great Plains (Fig. 9). This characterization would be particularly useful in the Great Plains where eolian lithofacies are widespread and account for a significant percentage of the lithologic column pertaining to this interval (Swinehart et al., 1985).

In their review of the Arikareean, Tedford et al. (1987) designated a number of defining taxa for the beginning of the age. The present study indicates that of these taxa, the galericine hedgehog *Ocajila*, the talpine *Scalopoides*, the sicistine zapodid *Plesiosminthus*, and the aplodontid *Allomys* (here recognized as *Alwoodia*), have different first appearances with regard to the biostratigraphy presented herein. Of the four taxa cited, only *Plesiosminthus* appears in Chron C11n, during the enrichment phase of faunal change recommended here to mark the beginning of the Arikareean. *Ocajila* and *Scalopoides* appear in the Gering and upper Sharps and *Alwoodia* in the "Monroe Creek" as part of the turnover fauna at that level. The characterizing fauna for the early Arikareean listed by Tedford et al. (1987, pp. 184-185, 193) can also be modified with the data provided in this analysis. Of first occurrences listed, most apply to the turnover fauna. Only *Diceratherium*, *Nanotragulus*, *Sespia* ("hypsodont leptauchenine oreodonts"), and "*Mesoreodon*" remain with demonstrated first appearances in Chron C11n.

Tedford et al. (1987) also noted that the early Arikareean could be subdivided and that the later part could be defined by the first appearance of the hedgehog *Parvericius*, the eomyid *Pseudotheridomys*, the mustelid *Promartes*, and the chalicothere *Moropus*. These taxa, along with the autochthonous lineages mentioned above represent the turnover fauna distinguished here and noted by Korth (1992) in his analysis of the correlative fauna of the McCann Canyon sites in north-central Nebraska.

CONCLUSIONS

In this study we have brought together lithostratigraphic, biostratigraphic, and magnetostratigraphic data, to elucidate the details of faunal change through an interval of medial Oligocene time that records the transition from the White River Chronofauna (Emry et al., 1987) to new assemblages that are part of the Arikareean "age." These events are most completely recorded in the upper White River and lower Arikaree group rocks exposed in western Nebraska and adjacent South Dakota. An $^{40}Ar/^{39}Ar$ calibrated magnetostratigraphy indicates that the succession is broken by a single regional disconformity of less than 0.5 m.y. duration that removed most of the evidence for Chron C10n. In South Dakota this disconformity breaks the Sharps Formation of Harksen et al. (1961) into two parts, the lower of which (including its basal Rockyford Ash) is continuous with the Poleslide Member of the Brule Formation beneath it. Correlative rocks in Nebraska are the recently recognized (Swinehart et al., 1985), informally designated, Brown Siltstone beds. Both the lower Sharps and Brown Siltstone are lithogenetically parts of the Brule Formation of the White River Group. Above the regional disconformity the upper part of the Sharps Formation of South Dakota grades upward into Arikaree Group strata locally referred to the Monroe Creek Formation of Nebraska. Correlative rocks in the North Platte Valley of Nebraska are the Gering Formation and the conformably overlying undivided Arikaree Group.

Although the lower Arikaree Group deposits are on average coarser-grained than the upper White River sediments, both have a high glass-shard content and are dominated by eolian facies (loess and sand-sheets) that accumulated on broad, low-relief interfluves under a seasonal climatic regime. Fossil remains are usually scattered in eolian deposits and only the common mammalian taxa are well represented, often by partial skeletons. Many mammals entombed in these rocks show special adaptations to dry environments such as burrowing habit for smaller mammals (insectivores and rodents such as castorids and geomyoids). Large mammals show low taxic diversity as contrasted with the faunas obtained from contemporary fluviatile deposits. Strong lithofacies localization of taxa makes it difficult to determine biostratigraphic range zones if contrasting sedimentary environments infrequently alternate in the stratigraphic column. Nevertheless the dominance of eolian environments in the mid-continent Oligocene makes it possible to reconstruct the biostratigraphy of the eolian lithofacies, a situation most completely realized in the South Dakota sequence.

Analysis of the biostratigraphic record for the interval studied reveals that the fauna of the highest part of the White River Group (29 Ma) not only shows continuation of most genera typical of the White River Chronofauna (often as derived species) but includes the appearance of new taxa in autochthonous clades (hesperocyonine canids, oreodonts, camels, hypertragulids, burrowing castorid and geomyoid rodents) that are inserted into the fauna enriching taxic diversity. This enriched fauna persisted across the regional depositional hiatus into the base of the Arikaree Group. Faunal turnover (extinction and origination) takes place approximately at the conformable contact of the Gering and Sharps formations with the overlying Arikaree Group strata, at approximately 28 Ma. At that time most of the White River genera leave the record thus

terminating the White River Chronofauna. Some genera that appeared in the enrichment phase of the White River Chronofauna continue into the younger Arikareean (especially tragulids, oreodonts, and burrowing beavers) but the fauna that emerges contains new clades within autochthonous lineages (hesperocyonine canids, large oreodonts, anthracotheres, giant entelodonts, mylagaulid, geomyoid and cricetid rodents, and rabbits), plus allochthonous lagomorphs, insectivores, aplodontid and eomyid rodents, arctoid carnivores, and chalicotheres that invaded mid-continental North America from sources outside the region contributing to the fossil record.

The biological changes summarized above, and in more detail in the preceding text, indicate that an important phase of reorganization of the mammal fauna of mid-latitude interior North America was taking place in mid-Oligocene time. These changes were spread over a 2-m.y. span (28-30 Ma) almost exactly coincident with the last half of the longest glacial episode of the Cenozoic (Miller et al., 1991). According to the data assembled by Prothero (1994), other Oligocene biotas lack evidence of a comparable response, even though eustatic regression should have widely exposed continental shelves and increased the isolation of continental interiors. Gradients of the coastal segments of rivers must have increased, but it is moot whether this would translate base level change nearly two thousand kilometers into the North American continent to account for the White River-Arikaree disconformity. There is clear evidence from the Great Plains that coarser epiclastic debris was contributed to the initial aggradation in the Arikaree paleovalleys, and that the cores of the Front Ranges and their volcanic edifices were being tapped by the headward erosion of Arikaree streams. White River and Arikaree sedimentary blankets ramp up onto (or can be projected onto) the Front Range often with little or no tectonic offset (Evanoff, 1990; Leonard and Langford, 1994) suggesting little differential uplift during the Oligocene and thus a lack of tectonic influence on fluviatile systems (Gregory and Chase, 1994). These observations seem to focus attention on a climate-driven shift to drier and more seasonal regimes, evident from Whitneyan to earliest Arikareean time (Retallack, 1983). A decrease of plant cover may have allowed deep erosion of the higher gradient alluvial apron near the mountain front. Unfortunately the region of interest lacks a detailed botanical record of the critical period that could be used to test a climate-driven model of Oligocene degradation and aggradation.

In 1941 when Wood and others proposed the "provincial" North American Land Mammal "ages," the base of the Arikareean was set at the lower limit of the Arikaree Group, essentially the base of the Gering Formation in the Wildcat Ridge of western Nebraska. Meager knowledge of the fauna of this level led to a biologic characterization of the Arikareean based on the better known assemblages from the upper part of the Arikaree Group. This situation prevailed for nearly fifty years until it was re-examined by Tedford et al. (1987) using the data on "Gering" mammals provided by Martin (1973), the detailed biostratigraphy of Swisher (1982), and the data published by Macdonald (1963, 1970) on the Sharps Formation biostratigraphy. A number of allochthonous insectivores and rodents were proposed to define the beginning of the Arikareean. The record detailed here shows that the basal Arikaree Group retains an augmented White River Chronofauna and that the defining taxa of Tedford et al. (1987) have first appearances that are scattered from these levels to those higher in the Arikaree. Only *Plesiosminthus* accompanies the earliest records of the suite of autochthonous taxa that appear in the Brown Siltstone and its correlate the lower Sharps Formation. It is proposed here that the initiation of the Arikareean Mammal "age" is signaled by the first appearance of these taxa that enrich the White River Chronofauna in the latest part of Chron C11r and early part of Chron C11n, at approximately 30 Ma. The "age" is defined by the first appearance of *Plesiosminthus* and characterized by the appearances of *Palaeolagus hypsodus, P. philoi, Palaeocastor nebraskensis, Shunkahetanka geringensis, Nanotragulus loomisi, Sespia nitida,* and *?Mesoreodon minor*. The coexistence of these taxa, and those surviving the Whitneyan, serve as a biochronological typification of earliest Arikareean time in the Great Plains. The turnover event that terminates the White River Chronofauna could be used to define and characterize the beginning of the medial Arikareean "age."

ACKNOWLEDGMENTS

Prothero was supported by grants from the donors of the Petroleum Research Fund of the American Chemical Society, National Science Foundation grant EAR87-08221, and funds from the University of Nebraska-Lincoln Conservation and Survey Division, during this research. We thank Dr. J. L. Kirschvink of the California Institute of Technology for access to his paleomagnetics laboratory. The Nuss Ranch and Olsen Ranch samples were analyzed by Christopher Brown and Ka Wing Kam. Without the help of the following field crews, the paleomagnetic sampling would never have been possible: 1986—Allison Kozak, Dana Gilchrist, and Kecia Harris; 1987—John Foster, Susan Briggs, and Jill Bush; 1990—Erin Campbell and Dani Crosby.

We thank R. F. Diffendal and V. L. Souders for their help in the field and suggesting important revisions in the manuscript. E. Evanoff, R. M. Hunt Jr., L. D. Martin, and S. D. Webb critically reviewed the manuscript and we are grateful for their insightful comments.

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