

# *Magnetic stratigraphy and biostratigraphy of the Orellan and Whitneyan land-mammal "ages" in the White River Group*

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## ABSTRACT

Detailed magnetostratigraphic studies conducted over the last 20 yr permit much better chronostratigraphic correlation of the White River Group. In addition, recent systematic revisions of long-unstudied taxa and fine-scale biostratigraphic data from recently studied fossil collections allow us to subdivide the Orellan and Whitneyan land-mammal "ages." Instead of the hybrid of lithostratigraphy and biochronology created by the Wood Committee (Wood et al., 1941), it is now possible to designate biostratigraphic zones and true chronostratigraphic stages and geochronologic ages.

The Chadronian-Orellan boundary (previously based on both the Chadron-Brule formational contact, and on the last occurrence of brontotheres) is here redefined by the first appearance datum (FAD) of *Hypertragulus calcaratus* (latest Chron C13r, 33.7 Ma). This FAD also marks the beginning of the earliest Orellan *H. calcaratus* Interval Zone. The late early Orellan (*Miniochoerus affinis* Interval Zone) is defined by the FAD of *Miniochoerus affinis*, *Eumys elegans*, and the last appearance datum (LAD) of *Ischyromys parvidens* (late Chron C13n, 33.3 Ma). The early late Orellan (*Miniochoerus gracilis* Interval Zone) is recognized by the FAD of *Miniochoerus gracilis* and *Mesohippus barbouri* (earliest Chron C12r, about 32.8 Ma). The latest Orellan (*Merycoiodon bullatus* Interval Zone) is defined by the FAD of *Miniochoerus starkensis*, *Palaeolagus burkei*, and *Merycoiodon bullatus* (early Chron C12r, about 32.5 Ma). The Orellan-Whitneyan boundary is marked by the FAD of *Leptauchenia major*, and abundant *L. decora* (mid-Chron C12r, about 32.0 Ma), so the early Whitneyan has been designated the *L. major* Interval Zone. The late Whitneyan (*Merycoiodon major* Interval Zone) can be recognized by the FAD of *M. major*, *Miohippus intermedius*, *M. gidleyi*, and the LAD of *Miniochoerus* and *Hyaenodon horridus* (late Chron C12r, about 31.3 Ma). The Whitneyan-Arikareean boundary is marked by the FAD of *Nanotragulus loomisi*, *Palaeocastor nebrascensis*, *Leidymys blacki*, and *Mesoreodon minor* (Chron C11n, about 30.0 Ma).

## INTRODUCTION

When mammal fossils were discovered in the Big Badlands in 1846, they were among the first fossil vertebrates reported from west of the Mississippi River. Soon thereafter, collectors

flocked to the Badlands and built up large collections of fossil mammals (see historical reviews by Harksen and Macdonald, 1969b; Emry et al., 1987). In the 150 yr since the first White River fossils were described, these collections have grown enormously. White River fossils are sold commercially worldwide

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and have been studied by many scientists over the past century. Despite this long history of study, however, many aspects of White River paleontology are still poorly known.

The stratigraphic terminology of the White River Group was initially biostratigraphic in character. Hatcher (1893) and Wortman (1893) recognized three units: the "*Titanotherium* beds" (now the Chadron Formation of Darton, 1899); the "Turtle-Oreodon beds" (now the Scenic or Orella Members of the Brule Formation); and the "*Protoceras* beds" (now the Poleslide or Whitney Members of the Brule Formation). Early in this century, William Diller Matthew and Henry Fairfield Osborn (Matthew, 1899; Osborn and Matthew, 1909; Osborn, 1907, 1910, 1929) continued this fundamentally biostratigraphic tradition by recognizing the "*Titanotherium* beds," "lower," "middle," and "upper Oreodon beds," "*Protoceras* beds," and "*Leptauchenia* beds." Although *Titanotherium* and *Oreodon* are no longer valid taxa, Matthew and Osborn laid the foundation for a range-zone biostratigraphy of the White River Group comparable to that practiced by biostratigraphers of marine invertebrate fossils.

When the Wood Committee (Wood et al., 1941) set up the "North American provincial ages" (now known as North American land-mammal "ages"), they abandoned this biostratigraphic tradition. Instead, they used a mixture of lithostratigraphy and biochronology (in the sense of Williams, 1901) to define their "provincial ages." For example, the Chadronian was defined both on the lithostratigraphic Chadron Formation, and also on the overlapping biochronologic ranges of *Mesohippus* and brontotheres. The Wood Committee apparently assumed that the last appearance of brontotheres would always coincide with the top of the Chadron Formation.

Fossils collected by Morris Skinner and other field crews of the Frick Laboratory in the 1950s made the Wood Committee's definition of the Chadronian obsolete. On September 6, 1953, Morris Skinner (unpublished section books, vol. 5, p. 9–11, in the Department of Vertebrate Paleontology Archives, American Museum of Natural History) collected titanotheres bones from a channel-fill deposit cut down from ~6.5 m (20 ft) above his "Persistent White Layer," or "PWL." This is presumably the same marker bed that was used to recognize the Chadron-Brule contact in Nebraska (although called the "Upper Purplish White," or "UPW," layer by Schultz and Stout, 1955, 1961; see the revisions of Terry and LaGarry, this volume). These brontothere specimens came from the Seaman Hills, near Lusk, Niobrara County, Wyoming, in a locality known as the Thompson Ranch Anthill (after its conical shape), located in NE sec. 28, T. 35 N., R. 61 W., Shepherds Point 7.5' Quadrangle, Niobrara County, Wyoming. In his 1960 summary of the Seaman Hills stratigraphy, Skinner again indicated "Chadronian age at least to here" at a level 6.5 m (20 ft) above the PWL.

Some of Skinner's peers did not differentiate between lithostratigraphy and biostratigraphy. On the same diagram is a notation (not in Skinner's handwriting, but initialed by CHF, for Charles H. Falkenbach, and dated 9/9/60) that comments, "The Purple White is considered the top of the Chadron." Falkenbach, Schultz, and

Stout did not distinguish between Chadron Formation (a lithostratigraphic unit) and Chadronian "age" (a biochronologic unit). This confusion between lithostratigraphy and biochronology is apparent in other paleontologic research of that generation. For example, Schultz and Falkenbach (1968) defined their oreodont taxa partly on their lithostratigraphic occurrence, and Schultz and Stout used oreodonts to define the top of the Chadron Formation.

The Seaman Hills brontothere specimens were not unique. In 1958, Skinner (unpublished section books, vol. 6, p. 40–41) noted another channel sequence in the area southeast of Douglas, Wyoming ~7 m (25 ft) above his "100 correlator white zone" in Douglas, also known as the "5 tuff" of Evanoff et al., 1992), which yielded a partial jaw and large scapula of a brontothere. The large size of the specimens makes it very unlikely that they were reworked. These specimens were recorded from Reno Ranch, South of Tower in the SW sec. 31, T. 32 N., R. 70 W., Douglas 7.5' Quadrangle, Converse County, Wyoming. Although neither of these occurrences was published by Skinner, they were widely known among White River researchers, and eventually published by Emry et al. (1987, p. 139). Other researchers reported Brule Formation brontothere specimens about the same time. Schultz and Stout (1955, Fig. 10, section 1) show the position of a titanotheres metapodial from a channel sandstone incised from ~2 m (7 ft) above the UPW (PWL of Skinner) at Scottsbluff National Monument. These authors (p. 27, footnote 1) comment that "the lowest parts of the Brule (basal Orella or Orella A) should be expected to yield titanotheres remains," but they did not elaborate. Terry and LaGarry (this volume) consider these strata to be upper Chadron Formation, not Orella Member of the Brule Formation.

These occurrences of brontotheres above the Chadron Formation show that the original definition of the Chadronian/Orellan boundary has become unworkable. As Emry et al. (1987, p. 139) noted, the Chadronian/Orellan boundary cannot be based on lithostratigraphic criteria, but only on biostratigraphic criteria. They wrote that "it should be placed at the most prominent and most widely recognizable faunal break, which may or may not coincide with lithostratigraphic boundaries. The single criterion of presence or absence of titanotheres is insufficient—the absence of titanotheres at any particular locality does not necessarily mean non-Chadronian."

Similarly, the Wood Committee (Wood et al., 1941) based the Orellan on both the geochron of the Orella Member and on a number of characteristic mammalian taxa. The Whitneyan was based on the geochron of the Whitney Member and on a smaller number of characteristic fossil mammals. As the problem with the Chadronian-Orellan boundary demonstrates, such dual definitions are prone to conflict and ambiguity (see Tedford, 1970; Emry et al., 1987; Woodburne, 1977, 1987; Terry and LaGarry, this volume). In addition, these ages were not true geochronologic ages, that must be based on biostratigraphic units (according to western stratigraphic codes, such as the 1983 North American Stratigraphic Code). Since they were informal stratigraphic ages, the North American land mammal "ages" should properly be put in quotes in publications.

Since the 1950s, some paleontologists (see Savage, 1955, 1962, 1977; Tedford, 1970; Woodburne, 1977, 1987) have attempted to apply more rigorous methods to vertebrate biostratigraphy. Modern vertebrate biostratigraphers accept the possibility that rock units can be time-transgressive over distance, and therefore separate rock units and time units. Also, detailed stratigraphic zonations of mammal fossils provide much higher resolution of time than zonation schemes based on collections in which the only stratigraphic information is the formation they came from. As discussed by Woodburne (1977), detailed zonation could potentially subdivide the Cenozoic Era into time increments of 300,000 yr or less.

However, despite enormous collections, White River biostratigraphy lags far behind zonations proposed for the rest of the Cenozoic. This is primarily due to two factors. The principal impediment is the lack of up-to-date systematics of White River mammals. Since the monographs of Scott et al. (1937–1941), relatively few comprehensive revisions of White River mammals have been published. In addition, some paleontologists oversplit certain groups into many invalid taxa (e.g., Osborn, 1929, on brontotheres; Schultz and Falkenbach, 1956, 1968, on oreodonts). This oversplitting has hindered further investigation, and discouraged many scientists from trying to correct the problem.

A second problem is the biostratigraphic data. Most early collectors of White River fossils had only a vague idea of the stratigraphic or geographic position of each specimen, so their collections cannot be used for high-resolution biostratigraphy. In other cases, some biostratigraphic data was collected (e.g., the Toadstool Park zonation of Schultz and Stout, 1955, for the University of Nebraska State Museum collections, or the zonation of Lillegraven, 1970, for the Slim Buttes collections). The data on these specimens only gives the alphabetically labeled zone (e.g., Orella B in Toadstool Park, or Lillegraven's unit C at Slim Buttes) from which they came, and not the level *within* the zone. Some of these zones are more than 30 m (100 ft) thick, so knowing only the zone does not give very precise information about the exact level of a given fossil in the section. Also, the ranges of taxa within each zone are automatically extended to the lithostratigraphic unit boundaries, whether or not they actually range through the entire unit. This permits only a crude biostratigraphic zonation, when much higher resolution is possible if the collectors make the effort at the time of collection.

Skinner and the field crews of the Frick Laboratory of the American Museum of Natural History in New York were precise in their stratigraphic documentation of fossils. Typically, Skinner would measure a section and establish marker horizons in an area before any extensive collecting was done. Thereafter, all Frick specimens were zoned 2 to 3 m (5–10 ft, some to the nearest foot) from a marker layer (usually a volcanic ash in most collecting areas in the White River Group). These stratigraphic data were usually placed on the specimen itself. Thus, the Frick Collection offers an unparalleled opportunity to construct a range-zone biostratigraphy of the White River Group and replace the land-mammal "ages" with true biostratigraphic stages and ages.

Emry et al. (1987) provided an indication of what such a zonation could be like. They did not propose specific range zones, because too many stratigraphic and systematic problems were unresolved at that time. In 1982, Prothero also made an attempt to zone the late Chadronian through early Whitneyan, but, like Emry et al. (1987), he could not publish a formal biostratigraphy because too many taxonomic problems (especially among key taxa, such as the oreodonts, ischyromyids, and leptomyricids) remained. Since that time, however, a number of systematic studies have been published (various papers in Prothero and Emry, 1996a), so this impediment has been removed in many cases.

Korth (1989) proposed biostratigraphic zones for the Orellan, based on rodent and lagomorph collections in the University of Nebraska State Museum. Unfortunately, these specimens are zoned only to Orella A, Orella B, and so on, with no information as to where they occur within each zone, so the biostratigraphic resolution is no better than the duration of the lithostratigraphic units. In addition, Korth (1989) did not designate type sections for his zones, as required by the 1983 North American Stratigraphic Code. As discussed below, there are additional problems with Korth's zonation. Instead, we have opted to build the biostratigraphy of the Brule Formation from the more finely resolved stratigraphic data of the specimens in the Frick Collection, and we use the Toadstool Park stratigraphy only after high-resolution biostratigraphy has been established in other areas.

The chronostratigraphic calibration of White River biostratigraphic zones has been aided immensely by the addition of magnetostratigraphy and  $^{40}\text{Ar}/^{39}\text{Ar}$  dating (Prothero and Swisher, 1992). Although biostratigraphy is still the fundamental basis for correlations among many White River outcrops, magnetic stratigraphy, and geochronology provide further tests of these correlations. In addition, the magnetic stratigraphy and  $^{40}\text{Ar}/^{39}\text{Ar}$  dates provide time planes for estimation of rates, so that disputes over "how old" or "how long" (e.g., Clark et al., [1967], contended that the Scenic Member spanned only 1,100 to 11,000 yr; Retallack [1983], estimated the duration of Brule deposition in the Pinnacles area of the Badlands) can be resolved. All of the  $^{40}\text{Ar}/^{39}\text{Ar}$  dates used in this study were done by Swisher (Prothero and Swisher, 1992; Swisher and Prothero, 1990). Slightly younger dates for the 5 tuff at Douglas and two of the Flagstaff Rim ashes have been reported by Obradovich et al. (1995). If these dates prove valid, then the chronostratigraphic age assignments in this paper may have to be adjusted slightly back (younger by less than 0.5 m.y.). However, there are no dates by Obradovich on the key Orellan and Whitneyan ashes, so their potential impact on the magnetic time scale is presently unknown. Consequently, we use the time scale of Berggren et al. (1995) and the dates of Prothero and Swisher (1992) for consistency.

Most important, magnetic stratigraphy and  $^{40}\text{Ar}/^{39}\text{Ar}$  dating allow correlation of the North American record to the global time scale, so that the relationship of climatic and faunal events in North America can now be more confidently connected to global climatic and tectonic events. This has resolved many confusing issues in the Eocene and Oligocene (see Prothero, 1994).

The lithostratigraphy and magnetic stratigraphy of many of the collecting areas discussed below are reported elsewhere (Prothero, 1982, 1985a,b, 1996a; Prothero et al., 1982, 1983; Prothero and Swisher, 1992; Evanoff et al., 1992; Terry, this volume; Terry and LaGarry, this volume; LaGarry, this volume). Here we summarize the magnetic stratigraphy of two critical but previously unpublished areas, the Big Badlands of South Dakota and the Seaman Hills of Niobrara County, Wyoming.

## MAGNETIC METHODS

Magnetostratigraphic research on the White River Group began with Charles Denham of the Woods Hole Oceanographic

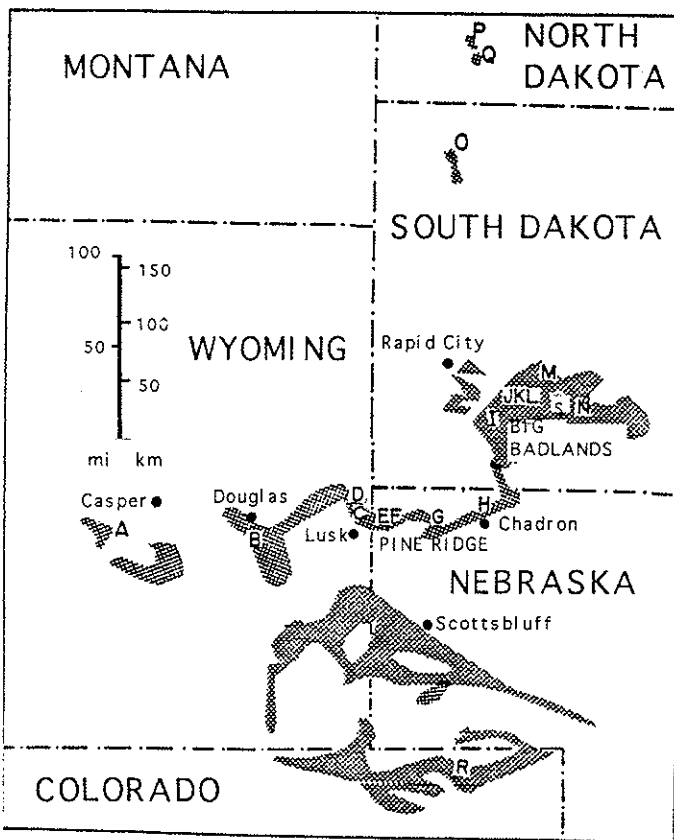


Figure 1. Index map showing localities mentioned in text. Outcrop of White River Group indicated by stipple. A = Flagstaff Rim, Natrona County, Wyoming (Prothero and Swisher, 1992); B = Douglas-Dilts Ranch area, Converse County, Wyoming (see Evanoff et al., 1992); C = Sherrill Hills and Thompson Ranch; D = Boner Ranch, in the Seaman Hills, Niobrara County, Wyoming; E = Geike Ranch; F = Munson Ranch; G = Toadstool Park and Raben Ranch area (E-G in Sioux County, Nebraska); H = Trunk Butte and Morris-Bartlett Ranches, Dawes County, Nebraska; I-N = sections in Big Badlands of South Dakota, including I, Red Shirt Table, J, Cottonwood Pass, K, Sheep Mountain Table, L, type Scenic Member (Chamberlain Pass on some maps), M, Sage Creek and Pinnacles; N, Cedar Pass and Wolf Table-Wanblee; O = Slim Buttes, Harding County, South Dakota (see Prothero, 1985b); P = Little Badlands; Q = Fitterer Ranch, Stark County, North Dakota; R = Flat Top and Chimney Canyons, Logan County, Colorado; S = Pig Dig, Conata Basin, South Dakota.

Institution in 1976 (Denham, 1984). In 1979, Prothero began his dissertation research on the magnetic stratigraphy of White River sections not studied by Denham (Prothero, 1982). Further sampling was conducted in the summers of 1983, 1986, and 1987. Brief summaries of this research (Prothero et al., 1982, 1983; Prothero, 1985a,b; Swisher and Prothero, 1990; Evanoff et al., 1992; Prothero and Swisher, 1992) have been published, but space limitations prevented a detailed presentation of the polarity stratigraphy of each section. This chapter and previous work (Prothero, 1996a) present the details of 20 years of magnetostratigraphic research in the White River Group. (See Fig. 1 for a map of localities mentioned in the text.)

As previously described in Prothero et al. (1983) and Prothero (1985a), all samples were collected with simple hand tools as horizontally oriented blocks of rock. Three samples were collected per site; most sites were spaced 1.7 m (5.5 ft) stratigraphically. In the laboratory, the samples were trimmed into oriented cubes ~2.5 cm in length.

Different laboratories were used for analysis of the samples as they were collected over the years, and our laboratory procedures have changed. Most samples from sections collected in the field summers of 1979-1980 were run on the ScT cryogenic magnetometer at Woods Hole Oceanographic Institution. These samples were treated primarily with AF (alternating field) demagnetization; thermal demagnetization was undertaken later at Lamont-Doherty Geological Observatory when it became apparent that AF demagnetization could not remove overprints due to iron hydroxides. The 1979-1980 sections include most of the Pine Ridge strata in Sioux County, Nebraska, and in the Lusk and Douglas areas of Wyoming. Prothero and field crew also sampled the Red Shirt Table section in the Big Badlands of South Dakota to complement Denham's sections elsewhere in the Big Badlands (Denham, 1984). A more detailed discussion of the geology and stratigraphy of most of these regions follows; for further details, see Prothero (1982).

In 1983, the original data base was expanded with sampling at Scottsbluff National Monument in the North Platte Valley, Scottsbluff County, Nebraska, and in Cottonwood Pass and the Indian Creek drainage west of Sheep Mountain Table in the Big Badlands, near the type sections of Clark's (1937) Ahearn, Crazy Johnson, and Peanut Peak Members of the Chadron Formation. The Scottsbluff section appeared in Prothero and Swisher (1992, Fig. 2.6), but the rest of the 1983 sections have not been published. These samples were run on the ScT cryogenic magnetometer at the laboratory of the South Dakota School of Mines in Rapid City, using mostly thermal demagnetization, with AF demagnetization of pilot samples undertaken to determine coercivity behavior.

In the early 1980s, it became apparent that the original magnetic analysis by Denham and Farmer was inadequate because they used only one sample per site (preventing any calculation of site statistics) and used almost no thermal demagnetization to remove overprinting that might be due to high-coercivity iron hydroxides. The resampling and thermal demagnetization analy-

sis of samples from the Flagstaff Rim section (Prothero, 1985a; Prothero and Swisher, 1992, Fig. 2.4) radically changed the pattern originally obtained by Denham (*in* Prothero et al., 1982, Fig. 1; Prothero et al., 1983, Fig. 6). In addition, the Big Badlands sections needed to be resampled, since none of the results reported by Denham (1984) were based on thermal demagnetization. In 1986, Prothero and field crew conducted a dense resampling program in the Big Badlands, following the measured sections and field notes of the Frick Laboratory (particularly those of Morris Skinner). The Cedar Pass, Pinnacles, and Wolf Table–Wanblee sections were sampled that summer. In 1987, Prothero and crew continued the Big Badlands sampling with a section at Sheep Mountain Table. These Badlands magnetic sections were summarized in Prothero and Swisher (1992, Fig. 2.7). In 1994, Whittlesey added to the Badlands coverage with sections at Sage Creek and in the type Scenic area (labeled Chamberlain Pass on some maps). In 1995, she also sampled a section in the Conata Basin near the locality called Pig Dig.

The samples that were taken in 1979–1980 and 1983 were treated with thermal demagnetization at 300°–500°C, based on detailed stepwise thermal and AF demagnetization of a pilot suite (e.g., Prothero et al., 1983, Fig. 4). All of the samples run since 1986 have been analyzed on a 2G cryogenic magnetometer using extensive thermal and AF demagnetization at the paleomagnetism laboratory of the California Institute of Technology. AF demagnetization (Fig. 2) showed that most samples declined in intensity rapidly, so that the primary carrier of remanence was a low-coercivity mineral such as magnetite. However, in a few samples there is little response to AF treatment, suggesting that hematite or goethite was more important than magnetite. Thermal demagnetization to 600°C removed nearly all the magnetization in some specimens, suggesting that magnetite was the important magnetic mineral in these specimens. Others, however, still had significant remanence above 600°C, probably due to hematite. These analyses showed that overprints were removed between 200° and 300°C, with the best results obtained between 300° and 400°C.

Isothermal remanent magnetization acquisition studies (IRM) (Fig. 3) clearly showed saturation in many samples between 300 and 1,000 mT (millitesla), indicating that the carrier of remanence was mostly magnetite. A few samples, however, did not saturate at fields higher than 1300 mT, indicating the presence of hematite. A modified Lowrie-Fuller anhysteretic remanent magnetization (ARM) 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 most samples, the ARM (black squares) demagnetized at higher peak fields than did the IRM (open squares), indicating that the remanence was carried by single-domain or pseudo-single-domain grains.

Based on these results, the vectors obtained between 300° and 500°C were averaged using the methods of Fisher (1953;

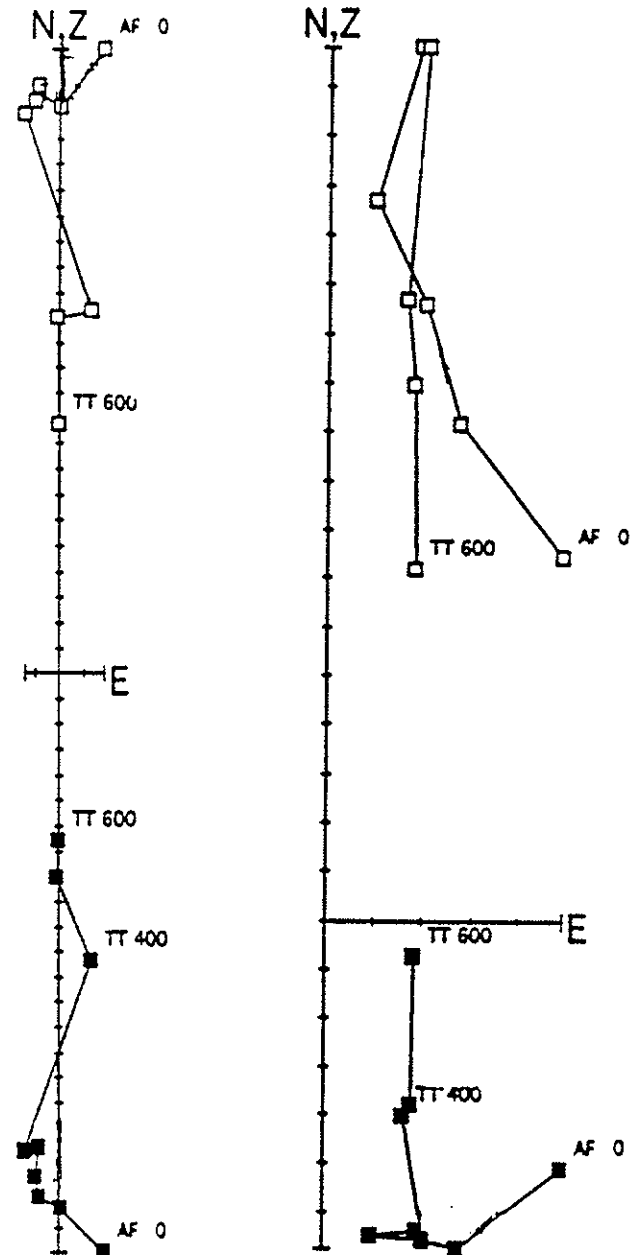


Figure 2. Typical orthogonal demagnetization plots ("Zijderveld" plots) of alternating field (AF) and thermal demagnetization of representative samples. Declination is shown by solid boxes (with the AF field in Gauss or temperature (TT) in degrees Centigrade indicated); inclination by open boxes. Each division =  $10^{-6}$  emu. In most samples, the intensity drops rapidly through AF demagnetization, suggesting that magnetite is the primary carrier of the remanence. In each case, a normal overprint is removed by 200°C, and a stable reversed component is apparent between 300° and 500°C. This component was used in further analysis.

see Butler, 1992). Class I sites of Opdyke et al. (1977) showed a clustering that differed significantly from random at the 95% confidence level. In Class II sites, one sample was lost or crumbled (so no site statistics could be calculated), but the remaining samples gave a clear polarity indication. In Class III sites of

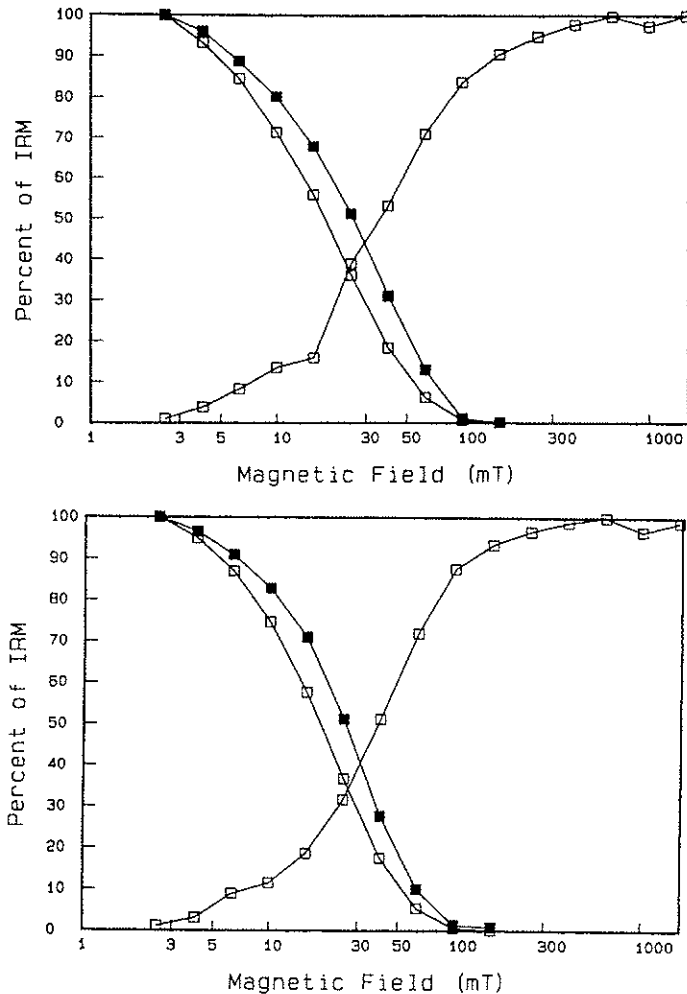


Figure 3. IRM (isothermal remanent magnetization) acquisition (ascending curve on the right) and Lowrie-Fuller test (two descending curves on left) of typical samples. Open boxes indicate IRM; solid boxes indicate ARM (anhysteretic remanent magnetization). In most samples, the IRM saturates by 300 mT (millitesla), showing that magnetite is the dominant magnetic mineral phase. In the Lowrie-Fuller test, the ARM (black squares) is more resistant to AF demagnetization than the IRM (open squares) suggesting that single-domain or pseudo-single-domain grains predominate (see Pluhar et al., 1991, for details of the methods).

Opdyke et al. (1977), two samples showed a clear polarity preference, but the third sample was divergent because of insufficient removal of overprinting. A few samples were considered indeterminate if their magnetic signature was unstable, or their direction uninterpretable.

The means for the normal and reversed sites at each locality were also averaged using the methods of Fisher (1953). The mean of reversed sites ( $D = 164.5$ ,  $I = -51.9$ ,  $k = 26.1$ ,  $\alpha_{95} = 5.9$ ) is antipodal to the mean of normal sites ( $D = 356.0$ ,  $I = 57.3$ ,  $k = 17.7$ ,  $\alpha_{95} = 10.6$ ) within the  $\alpha_{95}$  error estimate. This positive reversal test suggests that the magnetization is primary and not due to secondary overprinting. Most of the strata are horizontal, so no fold test could be conducted.

In some sections, it was not possible to completely remove the overprinting on every site, so that there are isolated single-site "polarity events." In most cases (such as single normal sites within a long reversed interval), these are most likely due to unrecovered normal overprinting. Consequently, the correlations discussed below are based only on magnetozones that are at least two or more sites thick: single-site polarity events are not correlated between regions, since they are not consistently found in every section. However, the possibility that these short polarity events are real cannot be ruled out, since detailed analysis of Oligocene deep-sea cores (Hartl et al., 1993) demonstrates that there were a number of brief polarity events during the Eocene and Oligocene.

## MAGNETIC RESULTS

As mentioned above, three areas with a good record of the Chadronian, Orellan, and/or Whitneyan also yield brontothere bones above the Chadron Formation. The Douglas sections have already been described by Evanoff et al. (1992). The Scottsbluff section was published in Prothero and Swisher (1992, Fig. 2.6). The Seaman Hills sections and the Big Badlands sections have not yet been fully published and are described below.

### *Badlands National Park, South Dakota*

The Big Badlands of South Dakota have always been among the most important collecting areas for White River mammals, and their stratigraphy has been studied by a number of people over the years (e.g., Sinclair, 1921; Wanless, 1923; Clark, 1937; Clark et al., 1967; Harksen and Macdonald, 1969a,b; Retallack, 1983, among others; reviewed by Emry et al., 1987). In addition to these published works, Morris Skinner and parties of the Frick Laboratory have made extensive and well-documented collections in the Big Badlands since the mid-1940s.

Most magnetic sections were measured following Skinner's unpublished field notes, so that Frick Collection fossils could be tied as closely as possible to the magnetic stratigraphy. Sections were chosen to be spaced out throughout the arc of the Badlands escarpment, from Wolf Table on the east to Red Shirt Table on the west. Locations of each section are given in Figures 1 and 4.

As discussed by Prothero and Swisher (1992), there is a clear polarity pattern throughout the White River Group. An early Orellan normal zone is found in nearly every section in other areas, and in most Big Badlands sections (Fig. 4). Based on  $^{49}\text{Ar}/^{39}\text{Ar}$  dates from below and above this zone in Douglas, Wyoming, and Scottsbluff, Nebraska (Swisher and Prothero, 1990; Prothero and Swisher, 1992), this early Orellan normal magnetozone correlates with Chron C13n (33.0–33.4 Ma in the time scale of Berggren et al., 1995).

In the Sage Creek, Pinnacles, and Cedar Pass sections, there is no zone of normal polarity associated with early Orellan mammals. However, the scientists of the Frick Laboratory have long known that the earliest Orellan index taxa (discussed in the following section) found at Lusk and Douglas, Wyoming, are absent

from the Big Badlands. This suggests that there is a subtle earliest Orellan unconformity below the late early Orellan "lower nodular zone" fossils in the Badlands. M. F. Skinner (unpublished field notebooks) had known this since the 1950s, although his ideas reached print only as a figure in Mellett (1977, Fig. 71, p. 129). Skinner's discovery was later published by Prothero (1985b) and Prothero and Swisher (1992). We agree with Skinner that there is an unconformity in this position, and we believe that it removes Chron C13n (and therefore at least 400,000 yr of strata) directly beneath the lower nodules at Sage Creek, Pinnacles, and Cedar Pass. The truncation of the biostratigraphic ranges at this level support this interpretation.

The rest of the Scenic Member is of reversed polarity, as is the lower Poleslide Member. In the middle Poleslide is another normal magnetozone that correlates with the mid-Whitneyan normal magnetozone in Nebraska. This zone includes the Upper Whitney Ash at Scottsbluff, which is  $^{40}\text{Ar}/^{39}\text{Ar}$  dated at  $30.58 \pm 0.18$  Ma (Swisher and Prothero, 1990; Prothero and Swisher, 1992). Based on this date, the mid-Whitneyan normal zone must be Chron C12n, estimated at 30.4 to 30.9 Ma (Berggren et al., 1995). The rest of the Poleslide Member correlates with Chron C11r. Near the base of the Rockyford Ash is the beginning of Chron C11n (30.0 Ma). The correlation of the Sharps Formation with units in Nebraska is discussed further by Tedford et al. (1996).

As is apparent from Figure 4, some of the classic lithostratigraphic units of the Badlands are not good time markers. In particular, the fossiliferous "lower nodular zone" used by nearly all collectors to zone their specimens appears to be noticeably diachronous. At Red Shirt Table, the type Scenic area (known on some maps as Chamberlain Pass), Cottonwood Pass, and Wolf Table, it occurs within Chron C13n, but at Sheep Mountain Table, the top of the lower nodules continues into Chron C12r. At Sage Creek, Pinnacles, and Cedar Pass, the lower nodules appear to lie entirely within early Chron C12r. This is almost a million years of age discrepancy between the base of the lower nodules at the type Scenic and at Sage Creek, yet these sections are only a few miles apart. In this chapter, when we report biostratigraphic data of a Big Badlands fossil with reference to the lower nodular zone, we are referring to collections made in the Sheep Mountain Table-Cottonwood Pass-Big Corral Draw area, where most of the Frick collections come from, and where the lower nodular zone does not transgress time.

The variability of the lower nodules was apparent to M. F. Skinner (unpublished field notes) and to many other Badlands researchers. The top and bottom of the nodules are often hard to define, and in some places this unit is not distinct at all. Thus, it should not be surprising that this marker unit is not the same age in every section. The physical causes of the nodular zones in White River Group are still controversial. Retallack (1983) attributed the nodules in the Pinnacles section to pedogenic processes and implied that there was a synchronous soil-forming event in the early Orellan responsible for the lower nodules. Others have argued that they are due to groundwater-related car-

bonate concentrations, so they need not be synchronous. Wells et al. (1995; this volume) attribute the nodular zones in northwestern Nebraska to the jointing and erosion of sheet sandstones, and deny that they are true nodular zones like those of the Big Badlands. Whatever their cause, it is clear that the lower nodules cannot be used as a time marker, but only as a local lithostratigraphic unit for zoning fossil collections. Consequently, when a Badlands fossil is collected from the lower nodules, one needs to know exactly *where* it was collected in order to use it for biostratigraphy.

### *Seaman Hills, north of Lusk, Niobrara County, Wyoming*

Perhaps the most important area for studying the Chadronian-Orellan transition is the Seaman Hills, southeastern Wyoming (Figs. 1, 5). Here, the Chadronian-Orellan transition is preserved in much greater detail than in the Big Badlands or Toadstool Park, with no significant unconformities (based on the continuity of the biostratigraphic record; see below). The lithology is uniformly fine volcanoclastic siltstones, with few sandstones or nodular zones, so there is little facies variation to affect fossil occurrences. The PWL is prominent throughout the area, so most of the fossils collected by Morris Skinner et al. in the Frick Laboratory are zoned to this marker horizon. In addition, fossils occur almost uniformly throughout the section, unlike the patchy distribution in the Douglas section (Evanoff et al., 1992).

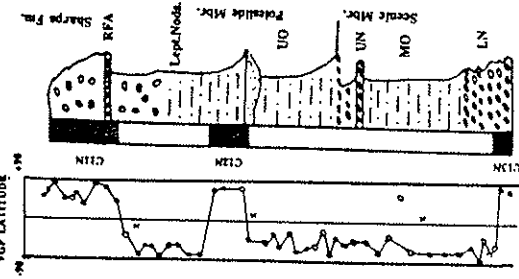
Despite its great significance, however, the geology and stratigraphy of the Seaman Hills have never been adequately documented. Many important Frick specimens shipped to the American Museum ("Lusk-O" box numbers) have been described (e.g., Schultz and Falkenbach, 1968; Mellett, 1977; Prothero and Shubin, 1989), but the stratigraphic level of these specimens is known almost exclusively from Morris Skinner's unpublished field notes. Singler and Picard (1980, Fig. 3, section 6) gave a brief summary of the local stratigraphy in one section, but the area is much more complex, as Skinner realized. We show three magnetostratigraphic sections in Figure 5 that incorporate Skinner's understanding of the stratigraphy. As in other White River sections, there is a late early Orellan normal magnetozone (from about 8–30 m [25–90 ft] above the PWL on all three sections), which we suggest correlates with Chron C13n. Thus, there is an 8-m (25-ft) interval representing late Chron C13r (between the PWL and the base of Chron C13n), which yields the last brontothere and also preserves the Chadronian-Orellan transition in more detail than any other place. In the Boner Ranch section (Fig. 5), there is also a late Chadronian normal magnetozone, which apparently correlates with Chron C15n (based on comparison with Douglas, Wyoming—see Evanoff et al., [1992], and Prothero and Swisher [1992]).

## TAXONOMIC OVERVIEW

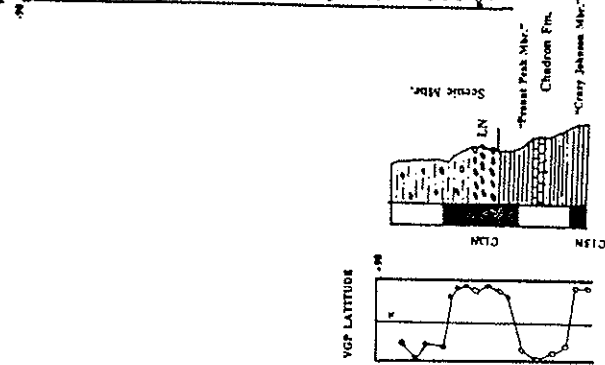
Before discussing the biostratigraphic data in each collecting area, it is necessary to summarize the current systematics of the key mammalian groups.

TYPE SCENIC

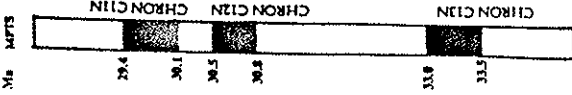
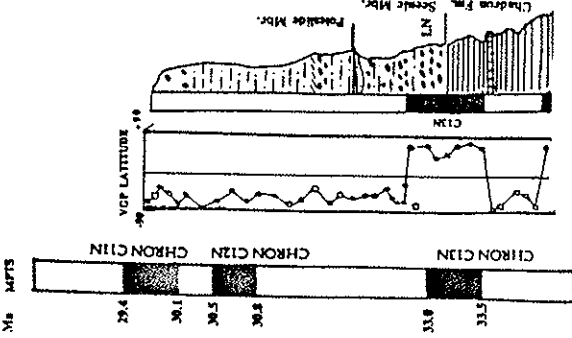
SHEEP MTN. TABLE



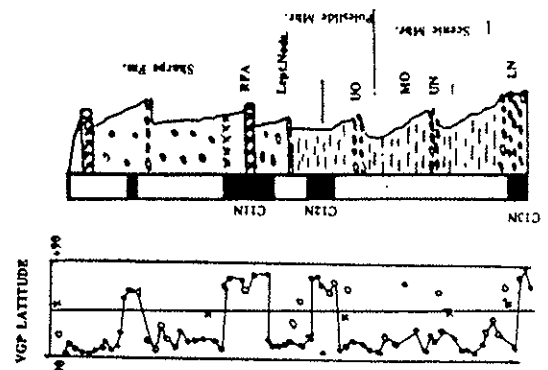
COTTONWOOD PASS



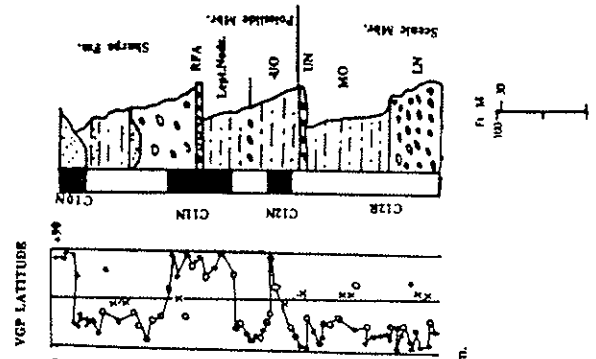
RED SHIRT TABLE



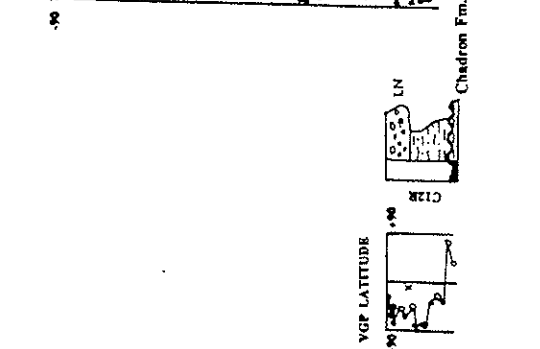
WOLF TABLE



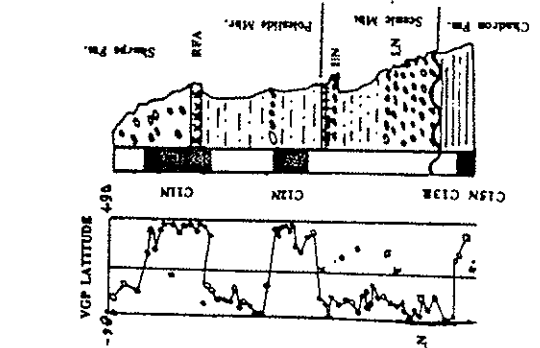
CEDAR PASS



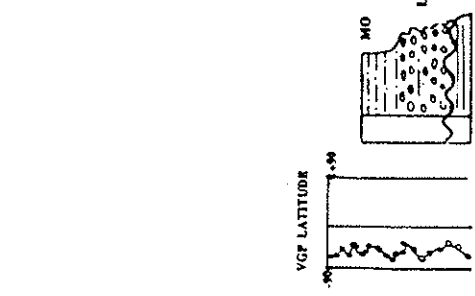
PIG DIG



PINNACLES



SAGE CREEK





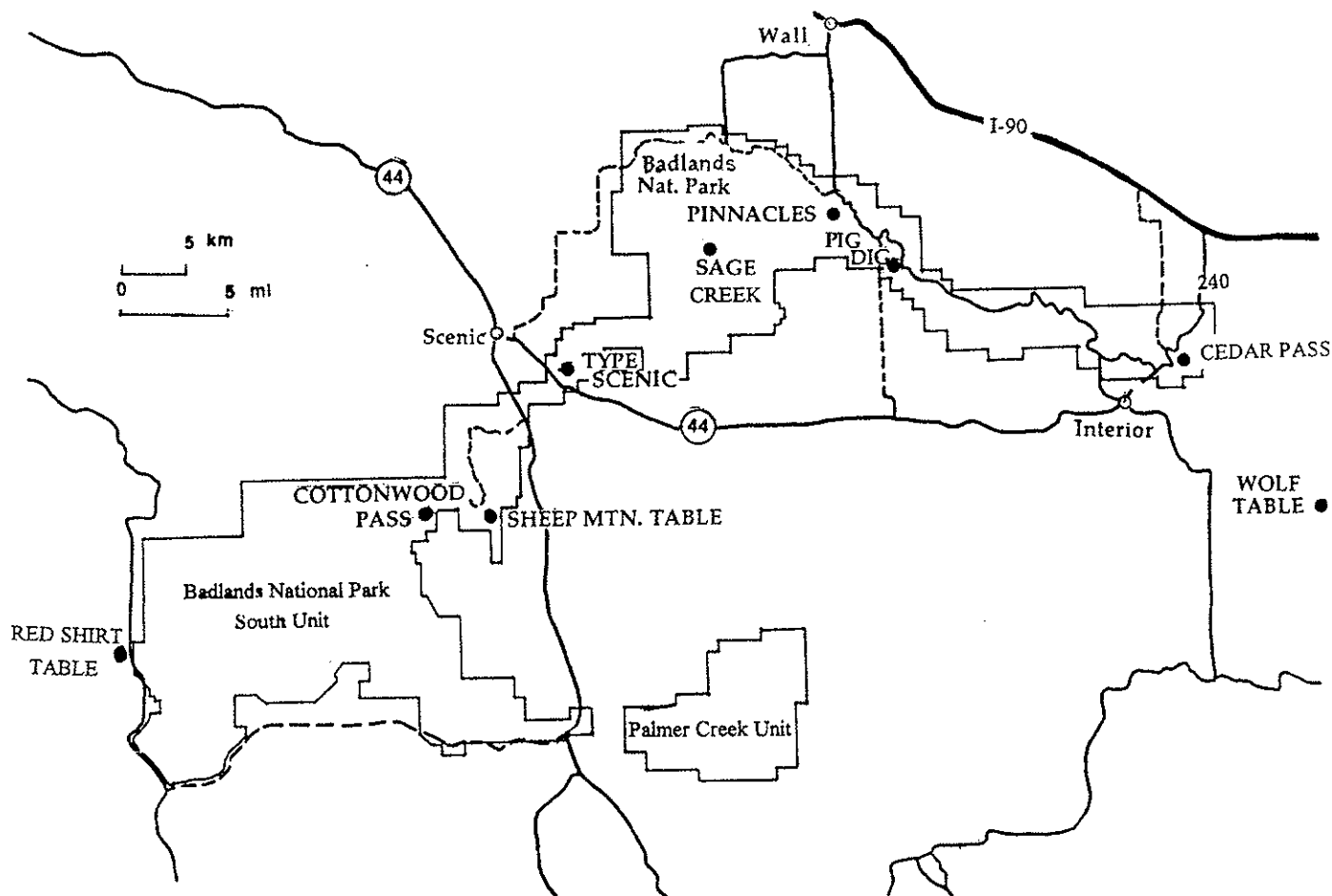


Figure 4 (this and facing page). Magnetic stratigraphy of sections in the Big Badlands of South Dakota (modified from Prothero and Swisher, 1992, Fig. 2.7). Stratigraphic terminology follows the unpublished field notes of Morris Skinner, except for Pinnacles, which follows Retallack (1983). Abbreviations: Lept. Nods. = *Leptauchenia* nodules; LN = lower nodular zone; MO = middle Oredon beds; RFA = Rockyford Ash; UN = upper nodular zone; UO = upper Oredon beds. Solid circles = Class I sites of Opdyke et al. (1977), which are statistically separated from a random distribution at the 95% confidence level. Triangles = Class II sites, which could not be statistically analyzed because only two samples remained; the third was lost or crumbled. Open circles = Class III sites, in which two samples showed a clear polarity preference, but the third sample was divergent. "x" = site of indeterminate polarity. Locations of sections are as follows: Red Shirt Table: S1/2 sec. 34, T. 42 N., R. 47 W., Red Shirt SW 7.5' Quadrangle, Shannon County, South Dakota; Cottonwood Pass: NE SE sec. 10, T. 4 S., R. 12 E., Heutmacher Table 7.5' Quadrangle; Type Scenic area section (also called "Chamberlain Pass")—on the corner of four quadrangles: SE sec. 25, T. 3 S., R. 13 E., Scenic 7.5' Quadrangle, and SW sec. 30 T. 3 S., R. 4 E., Quinn Table SW 7.5' Quadrangle, and NE sec. 36, T. 4 S., R. 13 E., Sheep Mountain Table 7.5' Quadrangle, and NW sec. 31, T. 4 S., R. 14 E., Imlay 7.5' Quadrangle; Sage Creek: SE NW SW sec. 15 and NE NE NE sec. 21, T. 25 N., R. 15 E., Quinn Table NE 7.5' Quadrangle; Sheep Mountain Table: SW NW NW sec. 10, to SE SE NW sec. 9, T. 43 N., R. 44 W., to SE NE SE sec. 4, T. 42 N., R. 44 W., to SE NE SW sec. 28, to SE NE NE sec. 28, T. 43 N., R. 44 W., Sheep Mountain Table 7.5' Quadrangle; Pinnacles: Route indicated by Retallack (1983), from SE SE NE sec. 20 to SW NE NE sec. 20, to NE NW NE sec. 20, to SE SW sec. 17, T. 2 S., R. 16 E., Wall SW 7.5' Quadrangle; "Pig Dig": NW NW sec. 34, T. 2 S., R. 16 E., Wall SW 7.5' Quadrangle; Cedar Pass: Lower Scenic, NE NE SW sec. 27, Cottonwood SW 7.5' Quadrangle; upper Scenic, SE NW NE to NW SE NE sec. 27, T. 3 S., R. 18 E., Cottonwood SW 7.5' Quadrangle; Poleslide, NE NE NW sec. 35 to SE SE SW sec. 26, Interior 7.5' Quadrangle; Wolf Table-Wanblee: SW NE NE sec. 31, T. 43 N., R. 87 W., School Section Butte 7.5' Quadrangle, to NE NW SE sec. 32, to NE SW NW sec. 4, to SW SE SE sec. 9, to SW NE NE sec. 16, T. 42 N., R. 87 W., Wanblee NW 7.5' Quadrangle.

## SEAMAN HILLS, NIOBRARA COUNTY, WYOMING

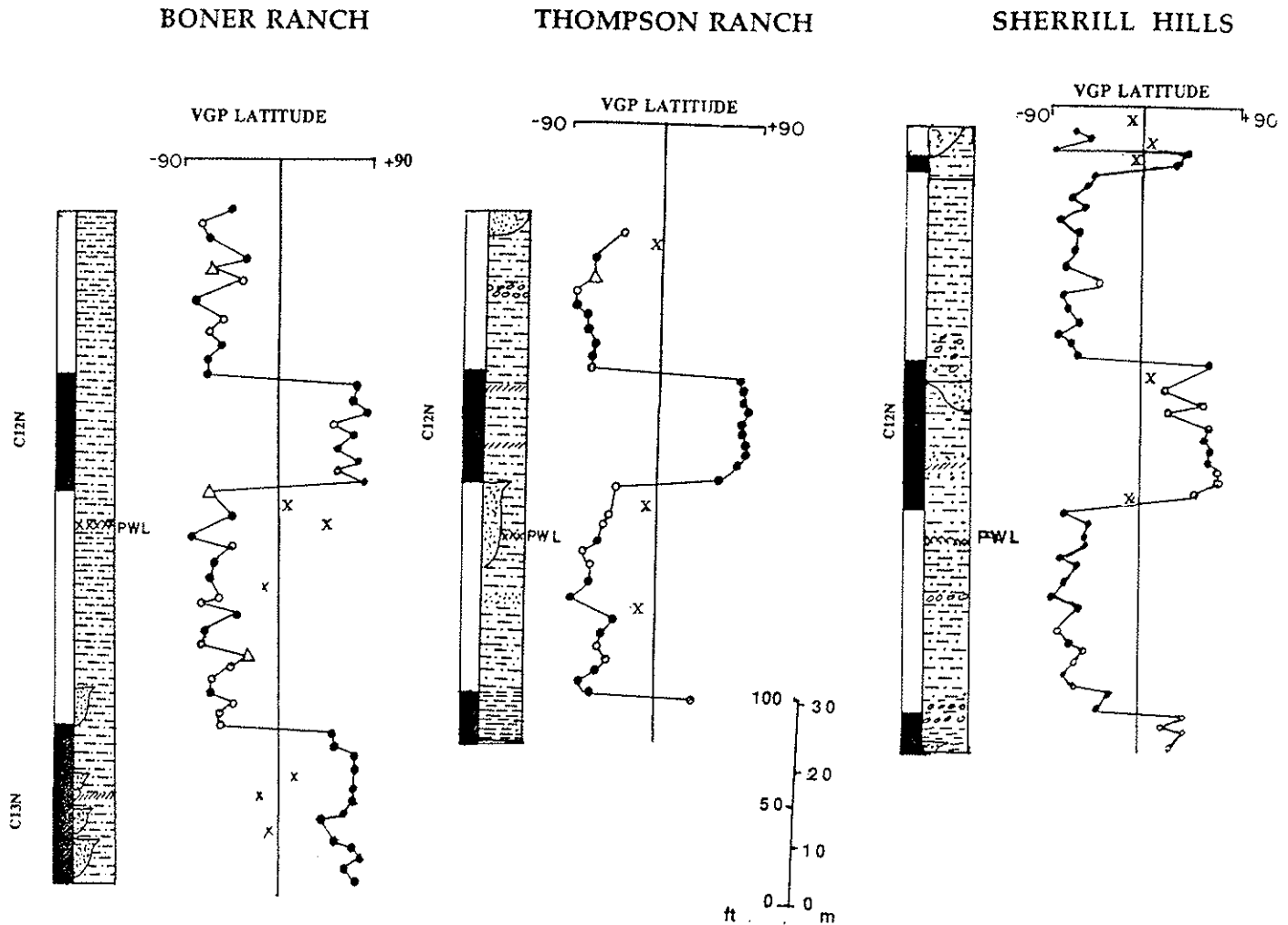


Figure 5. Magnetic stratigraphy of sections in the undifferentiated White River Formation in the Seaman Hills, Niobrara County, Wyoming. Stratigraphy based on the unpublished field notes of Morris Skinner. PWL = Persistent White Layer of Skinner; all other symbols as in Figure 4. Locations of sections are as follows: Thompson Ranch: NE sec. 28, T. 35 N., R. 61 W., Shepherds Point 7.5' Quadrangle; Boner Ranch: SW sec. 9, T. 35 N., R. 61 W., South Oat Creek 7.5' Quadrangle; Sherrill Hills: SW NE SW to SE SE SE sec 17, T. 34 N., R. 60 W., Sherrill Hills Quadrangle.

### Artiodactyls

Oreodonts are by far the most common larger mammal fossils in the Brule Formation. Scott et al. (1941) recognized only three genera and less than a dozen species from the White River Group, and Thorpe (1937) was similarly conservative. Unfortunately, the Schultz and Falkenbach (1956, 1968) monographs obscured the taxonomy of oreodonts. These authors oversplit the family into dozens of invalid species, genera, and even subfamilies based on features due to post-mortem deformation (for example, *Platychoerus*, or "flat pig," was a dorsoventrally crushed *Miniochoerus*, and *Stenopsochoerus*, or "narrow pig," was a laterally crushed *Miniochoerus*). Their taxonomy is also

plagued by inadequate statistical comparisons, taxonomic definitions that were based on stratigraphic boundaries with no morphologic change, and so on. The problems with their taxonomy have been widely recognized (e.g., Harksen and Macdonald, 1969a, p. 13; Lander, 1977; Savage and Russell, 1983, p. 195, footnote 2; Gustafson, 1986, p. 16; Emry et al., 1987, p. 140). Stevens and Stevens (1996) and CoBabe (1996) have recently revised the group, although a full revision of post-Whitneyan oreodonts is not yet in print.

Stevens and Stevens (1996) have reduced the multiple subfamilial lineages of Schultz and Falkenbach (1968) to two lineages in the early Oligocene. The main lineage is the most common of all Badlands fossils, the larger oreodont *Merycoidodon* (incor-

rectly referred to "*Prodesmatochoerus*" by Lander, 1977). Although this genus was grossly oversplit by Schultz and Falkenbach (mostly because they are so common, and intraspecific variability is high), Stevens and Stevens (1996) have recognized only *Merycoiodon culbertsoni* in the late Chadronian and early Orellan. In the late early Orellan (early Chron C12r, upper nodules or "middle Oreodon beds" in the Badlands, and somewhere within Orella C at Toadstool Park), most *Merycoiodon* specimens acquire inflated auditory bullae. This change is the criterion for the recognition of *M. bullatus* of Stevens and Stevens (1996), known as *Epooreodon bullatus* in older literature (e.g., Thorpe, 1937; Scott, 1941), and equivalent to numerous Schultz and Falkenbach (1968) taxa.

Large oreodonts referable to *M. major* appear in the late Whitneyan (late Chron C12r, or "*Leptauchenia* nodules" in the Big Badlands, and Whitney B at Toadstool Park). They are the most abundant and reliable indicator of the late Whitneyan. Stevens and Stevens (1996) reported *Mesoreodon minor* as a zonal indicator of the latest Whitneyan—earliest Arikareean ("brown siltstone" and lower Sharps Formation—see Tedford et al., 1996).

In addition to the *Merycoiodon* lineage of larger oreodonts, another lineage was present in the Orellan. Long known as *Merycoiodon gracilis* in older literature (e.g., Thorpe, 1937; Scott, 1941), Stevens and Stevens (1996) referred all these taxa to *Miniochoerus*. This same lineage was split into multiple genera and dozens of species by Schultz and Falkenbach (1956, 1968) and incorrectly referred to *Oreonetes* by Lander (1977). According to Stevens and Stevens (1996), late Chadronian *Miniochoerus chadronensis* is significantly smaller than contemporary *Merycoiodon culbertsoni*, but otherwise it is difficult to distinguish. In the early Orellan, *Miniochoerus* undergoes a dwarfing trend (30% size reduction in about a million years), so that the size of specimens along this chronocline can be used to zone the early Orellan (Prothero and Heaton, 1996, Fig. 2). Stevens and Stevens (1996) referred specimens from just below the PWL to ~17 m (50 ft) above the PWL at Lusk to *M. chadronensis* (mean  $M^{1-3}$  length, 47 mm; observed range, 44–50 mm). Stevens (1977) originally referred specimens that were intermediate in size (occurring between 0 and 17 m (0 and 50 ft) above the PWL at Lusk) not to *M. chadronensis*, but to *M. "douglasensis"* (mean  $M^{1-3}$  length, 42 mm; observed range, 39–45 mm). The smaller miniochoeres (from the late early Orellan) were referred to *M. gracilis* (mean  $M^{1-3}$  length, 34 mm; observed range, 31–37 mm) and *M. affinis* (mean  $M^{1-3}$  length, 38 mm; observed range, 36–41 mm). *M. affinis* first appears about 17 m (50 ft) above the PWL at Lusk, Wyoming (mid-Chron C13n), and *M. gracilis* first appears about 27 m (80 ft) above the PWL at Lusk (early Chron C12r). Both species range through the early Orellan without further change. In the late Orellan (mid Chron C12r, upper nodular zone in the Big Badlands, Orella D at Toadstool Park [=lower Whitney of LaGarry, this volume], upper Fitterer Ranch in North Dakota), a slightly larger but more advanced species, *M. starkensis*, appears (Stevens and Stevens, 1996). This is the last species of *Miniochoerus*, persisting until the mid-Whitneyan (late Chron

C12r, lower "*Leptauchenia* nodules" in the Badlands, and Whitney A in Nebraska).

In addition to merycoiodontines and miniochoerines, a third subfamily of oreodonts is critical to Brule biostratigraphy. The small hypsodont oreodonts known as leptauchenines are so abundant in the Whitneyan that they were the original indicator of that age. CoBabe (1996) reduced 7 genera and 31 species recognized by Schultz and Falkenbach (1968) to only 2 genera (*Leptauchenia*, *Sespia*), with three species between them. Most specimens are referable to *L. decora*, whose first abundant occurrence marks the beginning of the Whitneyan, although a few rare specimens ("*Pseudocyclopidius*" and "*Hadroleptauchenia*" of Schultz and Falkenbach, 1968) are known from the Orellan. The beginning of the Whitneyan also yields the larger species *Leptauchenia major* (formerly *Cyclopidius* of Thorpe, 1937, and Scott, 1941, and oversplit by Schultz and Falkenbach, 1968). *Sespia* first appears in the early Arikareean (Tedford et al., 1996).

Although oreodonts are the most abundant artiodactyl fossils, others are also important. Heaton and Emry (1996) have updated the taxonomy of the common ruminant *Leptomeryx*. Most of its species occur in the Chadronian, but the first appearance of *L. evansi* is an indicator of the earliest Orellan. Heaton and Emry (1996) recognize no other valid Orellan species, despite the number of names that have been applied to this abundant group.

The small ruminant *Hypertragulus calcaratus* first appeared at the beginning of the Orellan. Tedford et al. (1996) mark the beginning of the Arikareean by the small ruminant *Nanotragulus loomisi*. The tiny, hypsodont ruminant *Hypisodus* was reviewed by Haake and Galbreath (1979), but so far has not proven useful for biostratigraphy.

Prothero (1996b) has reviewed the camels of the White River Group. The primitive Chadronian species *Poebrotherium eximium* (distinguished by its short diastema between  $P_1$  and  $P_2$ ) last occurs about 13 m (40 ft) above the PWL at Lusk, and about 27 m (80 ft) above the 5 tuff at Douglas (i.e., within Chron C13n in both places), so its LAD is a marker of the late early Orellan. *Paratylopus labiatus* first occurs just before Chron C13n at both Lusk and Douglas.

The horned tylopod *Protoceras* was the original basis for the upper Poleslide "*Protoceras* channels" in the Big Badlands. *Protoceras* is unknown outside the Badlands, so its value as an index fossil is limited.

There is currently no up-to-date published taxonomy of the entelodonts, anthracotheres, tayassuids, or the leptchoerines. These artiodactyls, however, are too rare in most White River localities to be very useful in biostratigraphy, although their ranges are mentioned below when they are known.

### Lagomorphs

Korth and Hageman (1988) recently reviewed the lagomorphs from the Toadstool Park area, Nebraska. Korth (1989) renamed Orella A (= upper Chadron Formation of Terry and LaGarry, this volume) as the *Palaeolagus hemirhizis* zone. This

seems to be an improvement over the lithostratigraphically based zonations of Schultz and Falkenbach (1968), but there are problems with this taxon and with the zone itself.

As indicated above, none of the University of Nebraska State Museum collections are zoned *within* Orella A, so it is impossible to tell exactly where the FAD of *Palaeolagus hemirhizis* is located (or any other taxa that might define the earliest Orellan at Toadstool Park). Such imprecision is no longer adequate when higher resolution is possible in the Lusk and Douglas areas. In addition, the upper 13 feet of Orella A are correlative with Chron C13n, so they are not earliest Orellan, but late early Orellan. This makes it questionable whether the Toadstool Park section can be used for high-resolution biostratigraphy.

Besides the lithostratigraphic problems, there are also taxonomic problems with *P. hemirhizis*. Korth and Hageman (1988) erected the taxon for Orella A specimens that are intermediate between Chadronian *P. temnodon* and Orella B *P. haydeni*. *Palaeolagus hemirhizis* was defined on the basis of its intermediate size (but the size distributions between the three taxa overlap greatly) and on the presence of P<sup>3</sup>-M<sup>2</sup> roots on ~50% of the specimens. However, Prothero has closely examined and measured the precisely zoned lagomorph specimens in the Frick Collection, and found that these criteria are very difficult to use. For example, earliest Orellan lagomorphs in the Munson Ranch in Sioux County, Nebraska (Prothero, 1996a), and in the Lusk and Douglas areas show the same range of size variation reported by Korth and Hageman (1988), but at each level, they can be assigned to *P. haydeni* or to *P. temnodon* based on the presence or absence of roots on their upper cheek teeth. We suspect that *P. hemirhizis* is an artificial construct of two different species of rabbits, which were lumped together because of the poor resolution of the University of Nebraska State Museum collections.

Even if the taxonomy of *P. hemirhizis* is accepted, there are other problems with its first occurrence marking the beginning of the Orellan. Storer (1994) reported specimens of *Palaeolagus* cf. *P. hemirhizis* from the Chadronian Kealey Springs West local fauna of the Cypress Hills Formation in southwestern Saskatchewan. In fact, Korth and Hageman (1988, p. 147) conceded that *P. hemirhizis* may occur in the Chadronian of Nebraska and Colorado as well. Thus, we hesitate to name the earliest Orellan biostratigraphic zone after a taxon of doubtful validity that probably occurs in the Chadronian.

*Palaeolagus intermedius* is much rarer, but in most localities (e.g., Lusk and Douglas, Wyoming; Munson Ranch, Nebraska; Cedar Creek, Colorado) its FAD is also an indicator of the earliest Orellan, since it first appears 3 m (10 ft) above the PWL at Lusk and 3 m (10 ft) above the 5 tuff at Douglas. Korth and Hageman (1988) have only recorded it from Orella D (= lower Whitney of Terry and LaGarry, this volume) at Toadstool Park, although Prothero's examination of the University of Nebraska State Museum collections turned up specimens assigned to this taxon from Orella A-C.

The distinctively small species *Palaeolagus burkei* first occurs in mid-Chron C12r (at the base of the upper nodules in the

Badlands and in Orella C at Toadstool Park). It is a good indicator for the early late Orellan.

Korth and Hageman (1988) reported *Megalagus turgidus* from the entire Orella Member, and point out that it increases in size through the Orellan. In the Frick Collections, *M. turgidus* first appears 10 m (30 ft) below the PWL at Lusk and 10 m (30 ft) below the 5 tuff at Douglas, so its FAD could be used as an indicator of the latest Chadronian. However, it is difficult to distinguish from the typical Chadronian species *M. brachyodon*.

*Litolagus molidens* is an extremely rare rabbit. Four specimens are known between 13 and 30 m (40-90 ft) above the PWL at Lusk (late C13r-early C13n) and one specimen from 10 m (30 ft) below the 5 tuff at Douglas (late C13r). Its rarity makes this range discrepancy less surprising, but its presence does seem to indicate latest Chadronian-earliest Orellan.

### Rodents

One of the most common Orellan rodents is the ischyromyids. Their taxonomy has recently been revised by Heaton (1993, 1996), who found that both the larger *Ischyromys typus* and the smaller *I. parvidens* are present in the earliest Orellan, although the latter species is far more abundant. The supposed anagenetic size increase reported by Howe (1966) is actually the replacement of *I. parvidens* (which last appears in latest Chron C13n, or in Orella B at Toadstool Park, and just below the upper nodules in the Big Badlands) by the larger species *I. typus*. Thus, the last appearance of *I. parvidens* (leaving only *I. typus*) is a good indicator of the late early Orellan. *I. typus* continues to be abundant throughout the late Orellan, so its last appearance is also a good marker of the Whitneyan.

Another common rodent group is the eumyine cricetids, which have been reviewed by Wood (1980), Martin (1980), and Korth (1981). The most common species is *Eumys elegans*, which first occurs in mid-Chron C13n (27 m or 80 ft above the PWL at Lusk, Wyoming, Orella B at Toadstool Park). Korth (1989) used it as the nominal taxon of his *Eumys elegans* zone (Orella B-C). However, a number of specimens supposedly referable to *E. elegans* have been reported from the Chadronian. Some of these may be "float" from the Orellan (according to Ostrander, 1985) or may actually be referable to *Scottimus viduus* (Martin, 1980; Korth, 1981). Storer (1994) reported *E. elegans* from the late Chadronian of Saskatchewan, but it is possible that this locality is actually Orellan with some late Chadronian taxa that persist unusually late in Saskatchewan. *Eumys* also occurs in the early Orellan (Chron C13r) of Montana (Tabrum et al., 1996).

A number of other species of eumyines are recognized by Martin (1980) and/or Korth (1981). *Eumys obliquidens* is restricted to the late early Orellan (mid-Chron C13n). *E. parvidens* is restricted to the early late Orellan (early Chron C12r, Orella C at Toadstool Park, upper nodules in the Big Badlands). *Wilsonium planidens* is also restricted to the late Orellan (mid-Chron C12r, Orella D at Toadstool Park). *Scottimus lophatus* is restricted to the later Whitneyan (latest Chron C12r, upper Whit-

ney B and Whitney C at Toadstool Park, late Whitneyan in Slim Buttes, South Dakota, according to Lillegraven, 1970).

*Diplolophus insolens* is a rare (only nine specimens are known) enigmatic rodent whose occurrence was the basis for the *D. insolens* bench marker bed that separates Orella C and D at Toadstool Park (Barbour and Stout, 1937; Schultz and Stout, 1955; Wood, 1980; see LaGarry, this volume). Korth (1989) renamed Orella D as the *D. insolens* zone. It also occurs early in Chron C12r in Colorado (Galbreath, 1953), and at an unknown horizon in the Big Badlands.

Korth (1989) summarized a number of other rodent occurrences that could be used to characterize zones of the Orellan. Unfortunately, their exact occurrence in the Orellan is difficult to reconstruct, since they are zoned only as Orella A, Orella B, and so on. In addition, these rodents have not yet been studied in the Frick Collection, so their stratigraphic ranges in the important Lusk and Douglas areas are presently undocumented. Once these rodents have been adequately studied outside the Toadstool Park area, they may prove useful to Orellan-Whitneyan biostratigraphy.

#### *Perissodactyls*

The species-level taxonomy of brontotheres is still problematic since the oversplitting of Osborn (1929). Mader (1989) has revised the group at the generic level, but the number of Chadronian brontothere species and criteria for their recognition are still unknown.

Prothero and Shubin (1989) recently revised the horses from the Orellan and Whitneyan. *Meshippus bairdi* and *M. westoni* range up from the middle Chadronian, and last occur in the late Orellan (mid-Chron C12r, upper nodules in the Big Badlands, Orella C–D at Toadstool Park). *M. exoletus* first occurs 2 m (5 ft) below the top of the Chadron Formation in the Big Badlands and Lusk, and last occurs in the late Orellan (mid-Chron C12r, upper nodules in the Big Badlands, Orella C–D at Toadstool Park). *M. barbouri* ranges from the late early Orellan to the late Orellan (early Chron C12r, lower nodules to upper nodules in the Big Badlands, and also in the late Orellan Harvard Fossil Reserve in Torrington, Wyoming; see Schlaikjer, 1935). *Miohippus obliquidens* is an extremely long-ranging taxon, occurring from the late Chadronian through the late Whitneyan.

Prothero and Shubin (1989) referred certain late Chadronian specimens to *Miohippus assiniboiensis*, but Storer and Bryant (1993) have shown that they are correctly referred to *M. grandis*, which ranges up from the early Chadronian (Calf Creek Local Fauna in Saskatchewan) and last occurs in the upper Chadron Formation in the Big Badlands (Clark et al., 1967) and 10 m (30 ft) above the PWL at Lusk and 10 m (30 ft) below the 5 tuff in Douglas. Thus, its LAD could be used to recognize the Chadronian-Orellan boundary. *Miohippus gidleyi* and *M. intermedius* are rarer, but both are restricted to the late Whitneyan (Chron C12n, "Leptauchenia beds" in the Big Badlands).

Prothero (1996c) revised the rhinocerotid *Hyracodon*. In the late Chadronian, *H. priscidens* is replaced by the type species,

*H. nebraskensis*, which ranges to the end of the Whitneyan with no observable change. However, in the early Whitneyan ("upper Oreodon beds" in the Big Badlands, late Chron C12r), a larger, more advanced species referable to *H. leidyani* appears; it also persists to the end of the Whitneyan. The extinction of both of these *Hyracodon* species is one good indicator of the Whitneyan-Arikareean boundary (Tedford et al., 1996).

The common Badlands rhinocerotid, *Subhyracodon occidentalis*, also first occurs in the late Chadronian and shows no noticeable change in the Orellan (Prothero et al., 1989). In the early Whitneyan, it is replaced by *Diceratherium tridactylum*, but all of these rhinos are too rare to be useful to biostratigraphy. Some rare rhinocerotids have unusual distributions. For example, both *Penetrigonas dakotensis* and *Amphicaenopus platycephalus* occur in the Chadronian and Whitneyan, but not in the intervening Orellan. However, both are very rare, so this distributional anomaly is probably due to sampling error.

The amynodontid rhinocerotoid *Metamynodon planifrons* was the basis for the name of the *Metamynodon* channels in the lower Scenic Member in the Big Badlands. Like *Protoceras*, however, its utility for correlation is limited by the fact that it is restricted to South Dakota.

White River tapirs have not been revised recently, but their extremely rarity throughout the Oligocene limits their biostratigraphic utility.

#### *Creodonts and carnivorans*

Mellett (1977) revised the common White River creodont *Hyaenodon*, using the large collections compiled by the Frick Laboratory. Both *H. horridus* and *H. crucians* first occur in the middle Chadronian. The common small species *H. crucians* last occurs near the base of the upper nodules (mid Chron C12r), so its LAD is an indicator of the latest Orellan. The largest species, *H. horridus*, last appears in the mid-Whitneyan (late Chron C12r, upper *Oreodon* beds in the Big Badlands, mid-Whitney B in Toadstool Park), so its LAD is a good indicator of the late Whitneyan. *H. brevirostris* is restricted to the early Arikareean.

Wang (1994) and Wang and Tedford (1996) have recently revised the early North American canids. They have shown the group to be much more diverse than previously expected, with a number of species occurring in the Orellan and Whitneyan. The commonest canid is *Hesperocyon gregarius*, which ranges from the Duchesnean through Whitneyan. "*Mesocyon*" *temnodon* first occurs in the Orellan in South Dakota, and in the Whitneyan in Nebraska and Colorado. *Cynodesmus thooides* first occurs in the Whitneyan of Nebraska, South Dakota, and Montana. *Osbomodon renjieii* occurs in the Orellan of North Dakota, and in the Whitneyan of South Dakota and Nebraska. *O. sesnoni*, *Parenhydrocyon josephi*, and *Ectopocynus antiquus* are known from the Whitneyan of South Dakota. The small, primitive borophagine *Cormocyon pavidus* occurs in the Orellan of Colorado and in the Whitneyan of South Dakota and Nebraska. *Oxetocyon cuspidatus* is restricted to the Whitneyan of South Dakota and Nebraska.

The amphicyonids, or "beardogs," have been updated by Hunt (1996). The last appearance of *Brachyrhynchocyon* may occur about 3 m (10 ft) above the PWL at Arner Ranch (UNSM locality Sx-29) in Sioux County, Nebraska. *Daphoenictis* last appears at the end of the Chadronian, and *Paradaphoenus* first appears in the earliest Orellan. *Daphoenus vetus* and *D. hartshornianus* range from the late Chadronian through early Orellan.

Considerably more common in the White River Group are the cat-like nimravids, which have been recently reviewed by Bryant (1996). *Dinictis felina* ranges from the mid-Chadronian to the late Whitneyan. *Pogonodon platycopis* occurs in the Orellan of South Dakota and in the Whitneyan of South Dakota and Nebraska. *Hoplophoneus primaevus* occurs throughout the Orellan and Whitneyan (and may range into the Chadronian). *H. occidentalis* occurs in the late early Orellan of South Dakota (lower nodules), North Dakota, Nebraska, and Wyoming, and in the Whitneyan of South Dakota. *H. sicarius* is known from three specimens, one from the lower nodules in the Badlands, and two from unknown levels in Wyoming. *H. dakotensis* first occurs in the late Whitneyan "Protoceras beds" of South Dakota and ranges into the early Arikareean. *Eusmilus cerebralis* first occurs in the late Whitneyan of South Dakota also. *Nimravus brachyops* first occurs in the late Whitneyan of Nebraska, South Dakota, and possibly Saskatchewan.

In addition to amphicyonids, canids, and nimravids, there are a number of smaller White River carnivores that were recently reviewed by Baskin and Tedford (1996). Most are known from only a few specimens, so their biostratigraphic utility is limited. For example, *Drassonax harpagops* is known from two specimens, one from the Scenic Member in the Big Badlands and one from the Orella Member in Nebraska; both are from unknown levels. *Palaeogale sectoria* occurs in the Orellan of Colorado, Montana, and South Dakota. The majority of the taxa discussed by Baskin and Tedford (1996), however, are from the Chadronian.

### Insectivorans

Numerous large collections of insectivorans from the Brule Formation exist, but their systematics have not been adequately published to be useful for biostratigraphy. For example, M. J. Novacek (personal communication) has revised the leptictids, and recognizes *Leptictis dakotensis* (late Chadronian to late Whitneyan), as well as some Chadronian taxa. The apternodontids are also abundant, but lack an updated analysis. *Centetodon* was recently revised by Lillegraven et al. (1981), but it is also very rare and sporadically distributed. The insectivorans might prove biostratigraphically useful once their systematics is updated, and when enough screen-washing is done throughout the section to get a more uniform sampling of micromammals (Emry et al., 1987).

## BIOSTRATIGRAPHY

### Chadronian-Orellan boundary and earliest Orellan

The Chadronian-Orellan transition is best preserved in detail in the Lusk (Fig. 6) and Douglas (Evanoff et al., 1992) sections in

Wyoming. The truncation of the base of the biostratigraphic ranges of most early Orellan taxa in the Big Badlands sections (Fig. 7) is further evidence of an unconformity beneath the lower nodules. Thus, we will examine key biostratigraphic datum levels between the PWL (the traditional top of the Chadron Formation in Wyoming) and the base of Chron C13n (which is late early Orellan), mostly in the Lusk and Douglas sections.

This earliest Orellan time interval is also preserved in "Orella A" (= upper Chadron of Terry and LaGarry, this volume) in the Toadstool Park area, Sioux County, Nebraska (Schultz and Stout, 1955, 1961). Schultz and Falkenbach (1968) based their "Oreodont Faunal Zone Orella A" on this unit, and Korth (1989) also based his biostratigraphy on the Toadstool Park sequence and the University of Nebraska State Museum collections. Indeed, the lower 7 m (20 ft) of "Orella A" at Toadstool Park (Prothero and Swisher, 1992, Fig. 2.5) does correlate with Chron C13r above the PWL (UPW of Schultz and Stout, 1955), so lower Orella A fossils are equivalent to those found in the lower 8 m (25 ft) at Lusk, and the lower 13 m (40 ft) at Douglas. Unfortunately, the existing University of Nebraska State Museum collections do not indicate at what level specimens were found within "Orella A." So specimens with the "Orella A" field data might come not only from the earliest Orellan (late Chron C13r) part of the unit (the lower 7 m, or 20 ft) but also from the late early Orellan (early Chron C13n) part of Orella A (the upper 4 m, or 13 ft). This unfortunate lack of stratigraphic resolution and mixing of collections from different levels makes the current Toadstool Park collections less than ideal for examination of the detailed changes in the fauna.

As discussed above, the LAD of brontotheres was part of the Wood Committee's (1941) original definition of the Chadronian. However, these last few brontothere specimens occur very sporadically. Even though they have long been part of the classic concept of the Chadronian, brontotheres are so scarce that they are a very impractical marker of the end of that land-mammal "age." In addition, their last appearance is highly variable within late Chron C13r. At Scottsbluff (Prothero and Swisher, 1992, Fig. 2.6) they occur just above the PWL (or UPW). At Lusk, they occur in a channel cut down from 8 m (25 ft) above the PWL, and thus at the C13r-C13n boundary (~33.5 Ma). But in Douglas, they last occur 3 m (15 ft) below the C13r-C13n boundary. This lack of consistency between last occurrences in various areas makes the brontothere LAD less useful than other datum levels.

According to Stevens and Stevens (1996), there are two valid generic lineages of oreodonts in the Orellan. The larger is the well-known and abundant *Merycoiodon culbertsoni*. Although specimens are extremely abundant and highly variable, there is no consistent trend that allows any other species in this lineage to be distinguished in the late Chadronian or early Orellan. Thus, the merycoiodont "faunal zones" of Schultz and Falkenbach (1968) are invalid. However, the other, smaller lineage of Orellan oreodonts, the miniochoeres, do show changes that are biostratigraphically useful, as discussed above (Fig. 6).

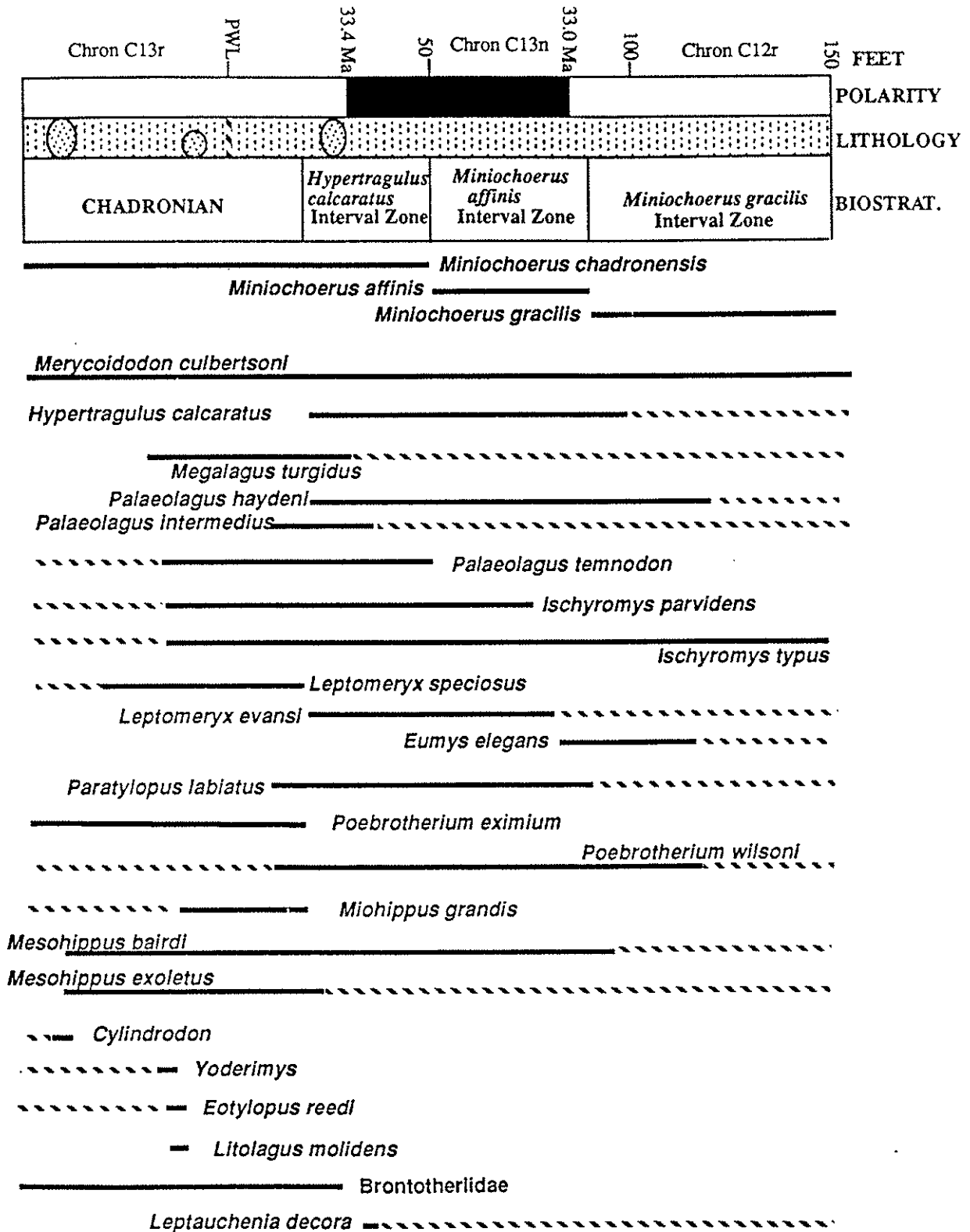


Figure 6. Biostratigraphy of key taxa in the undifferentiated White River Formation, Seaman Hills area, Niobrara County, Wyoming. Magnetic stratigraphy and lithostratigraphy as in Figure 5. Solid lines show documented ranges of taxa; dashed lines are inferred range extensions based on occurrences elsewhere in the White River Group (modified from Prothero, 1982).

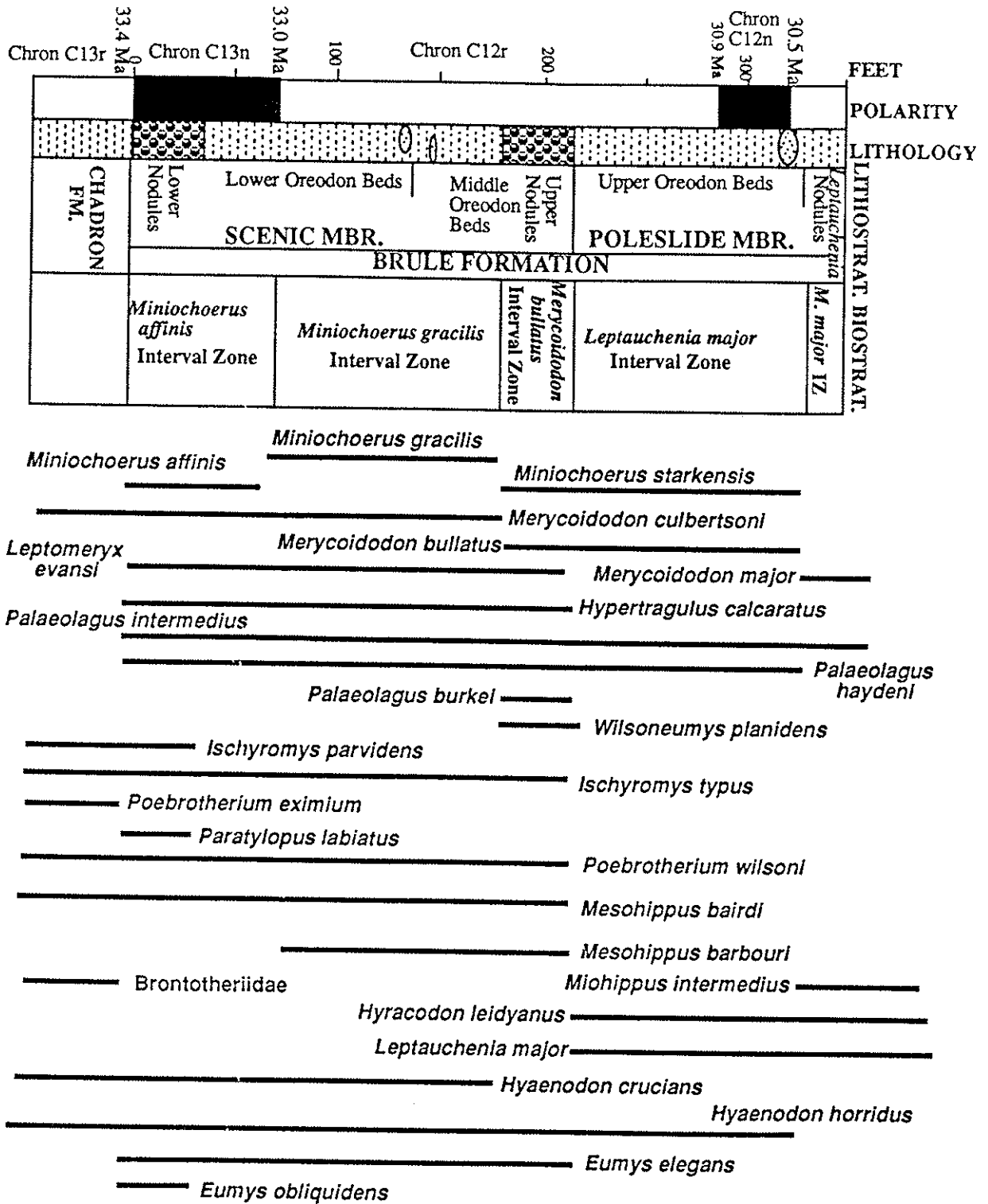


Figure 7. Biostratigraphy of key taxa in the Sheep Mountain Table-Cottonwood Pass-Big Corral Draw areas of the Big Badlands, South Dakota (based on the Frick Collection). Magnetic stratigraphy and lithostratigraphy as in Figure 4. Note the truncation of ranges at the base of the lower nodules and the absence of early Orellan taxa (*Hypertragulus calcaratus* Interval Zone), indicating an unconformity at this level. Based on data in Prothero (1982).



Next to oreodonts, the most common mammals in the Orellan are the small deer-like artiodactyls *Leptomeryx* and *Hypertragulus*. Heaton and Emry (1996) recognized a gradual transition from *L. speciosus* of the late Chadronian to *L. evansi* of the early Orellan. Although several highly variable characters are used to distinguish the two species, one of the easiest to recognize is the lingual to labial shift of the ridge behind the  $P_3$  protoconid. Prothero (1982) found that this shift first occurs in specimens about 7 m (20 ft) above the PWL at Lusk and 13 m (40 ft) above the 5 tuff at Douglas. Given the great number of *Leptomeryx* lower jaws in all early Orellan localities, this biostratigraphic datum is potentially very useful for recognizing the beginning of the Orellan.

Even more useful is the FAD of *Hypertragulus calcaratus*. Unlike *Leptomeryx evansi*, which is only subtly distinguished from the similar *L. speciosus* of the Chadronian, *H. calcaratus* appears in the White River group with no late Chadronian predecessor. *Hypertragulus heikeni* (Ferrusquia-Villafranca, 1969) was reported from the early Chadronian Rancho Gaitan local fauna in northeastern Chihuahua, Mexico, but no *H. calcaratus* have been reliably reported from *in situ* Chadronian deposits in the White River Group. (The reports by Ostrander [1985] and Gustafson [1986] are apparently loose Orellan specimens reworked out of Pleistocene terraces in the Chadron area). *H. calcaratus* appears suddenly about 7 m (20 ft) above the PWL at Lusk and 7 m (20 ft) above the 5 tuff at Douglas, so it is very easy to recognize and use as the indicator of the beginning of the Orellan. It also first appears at the beginning of the Orellan in northeastern Colorado (Galbreath, 1953), Slim Buttes in northwestern South Dakota (Lillegraven, 1970), and the Big Badlands and Toadstool Park (Prothero, 1982).

As Emry et al. (1987, p. 138) pointed out, the Chadronian-Orellan transition is a subtle one. "At most localities there is no significant lithologic change across the boundary, no evidence of a significant break in the stratigraphic record, and very little change in the fauna, except that in the Brule fossil mammal remains are much more abundant and the titanotheres that were a prominent part of the Chadronian fauna are missing." Emry et al. (1987, p. 139) recommended that the boundary "be based on biostratigraphic criteria and that it should be placed at the most prominent and most widely recognizable faunal break, which may or may not coincide with lithostratigraphic boundaries." Clearly, the Chadron-Brule contact cannot be used as the boundary, since it is time-transgressive in some places, such as the Big Badlands. Where it is marked by a synchronous volcanic ash (such as the PWL), there are no biostratigraphic datums that coincide with it precisely.

Although the boundary is subtle with no major "faunal break," a number of taxa can be used to characterize the Chadronian-Orellan transition and the earliest Orellan. The most useful of these are the FADs of *Hypertragulus calcaratus*, *Leptomeryx evansi*, *Palaeolagus intermedius*, and small *Miniochoerus chadronensis* (= *M. "douglasensis"* of Stevens, 1977), and the LAD of *Poebrotherium eximium* and *Miohippus grandis*. Murphy

(1977) and Woodburne (1977, 1987) recommended that biostratigraphic zones be characterized by a number of distinctive taxa, but defined on the basis of a single taxon to prevent confusion and ambiguity. We recommend that the beginning of the Orellan be defined by the FAD of *Hypertragulus calcaratus*, and characterized by the rest of the taxa listed above. Based on this criterion, the Chadronian-Orellan boundary occurs about 7 m (20 ft) above the 5 tuff at Douglas, Wyoming, 7 m (20 ft) above the PWL in the Seaman Hills, Wyoming, and somewhere within the lower 7 m (20 ft) of Orella A in Toadstool Park, Nebraska. In compliance with the 1983 North American Code of Stratigraphic Nomenclature, we formally designate the earliest Orellan as the *Hypertragulus calcaratus* Interval Zone, using the concept of interval zones that are based on the successive first occurrences of index taxa as described in the Code (NACSN, 1983, Fig. 4C1). This type of zone was also used by Archibald et al. (1987) to zone the Paleocene. We designate the type section for the *Hypertragulus calcaratus* Interval Zone as the strata 7 to 17 m (20–50 ft) above the 5 tuff in the Reno Ranch East section (Evanoff et al., 1992, Fig. 6.6), located in NW NW sec. 32, and W1/2 sec. 29, T. 32 N., R. 70 E., Irvine 7.5' Quadrangle, Converse County, Wyoming. The top of this zone is marked by the FAD of the name-bearer of the overlying zone, *Miniochoerus affinis*.

Chronostratigraphically, the Chadronian-Orellan boundary falls midway between the 5 tuff (33.9 Ma, according to Swisher and Prothero, 1990, and Prothero and Swisher, 1992) and the Chron C13r–C13n boundary (33.5 Ma, according to Berggren et al., 1995). Thus, its age would be ~33.7 Ma if sedimentation rates are assumed to be constant. However, the new  $^{40}\text{Ar}/^{39}\text{Ar}$  dates reported by Obradovich et al. (1995) may recalibrate this geochronologic estimate to a slightly younger age.

#### Late early Orellan

A number of faunal events can be used to characterize the late early Orellan. The FAD of *Miniochoerus affinis*, *Eumys elegans* (in the White River Group, but not in Montana or Saskatchewan), *Pelycomys brulanius*, *Adjidaumo minutus*, *Cedromus wardi*, and *Hoplophoneus occidentalis* all occur in strata that correlate with early Chron C13n; *Ischyromys parvidens* last occurs within this interval. Korth (1989) called this the *Eumys elegans* zone, but as noted above, there are problems with the FAD of *Eumys*. Instead, we call the late early Orellan the *Miniochoerus affinis* Interval Zone, and designate its type section as the strata between 17 and 27 m (50–80 ft) above the PWL in the Boner Ranch section (SWsec.9.T.35N., R.61W., South Oat Creek 7.5' Quadrangle) in the Seaman Hills, Niobrara County, Wyoming. The top of this zone is marked by the FAD of the zonal indicator of the overlying zone, *Miniochoerus gracilis*. This zone can also be recognized in the strata 17 to 25 m (50–75 ft) above the 5 tuff in Douglas, Wyoming, and correlates with some portion of Orella B in Toadstool Park. Most of the "early" Orellan fossils from the lower nodular zone of the Big Badlands are correlative with this zone. It is also correlative with most of Chron C13n (33.0–33.5 Ma).

### Early late Orellan

The FAD of the dwarfed oreodont *Miniochoerus gracilis* and the horse *Mesohippus barbouri*, and the last appearance of *Ischyromys parvidens* occur 27 m (80 ft) above the PWL in the Lusk sections. ~57 m (170 ft) above the 5 tuff in the Douglas sections, at the base of Orella C in Toadstool Park, Nebraska, and at the top of the lower nodular zone in the Big Badlands. These taxa can be used to recognize an interval that might be called early late Orellan, or what we designate as the *Miniochoerus gracilis* Interval Zone. According to Korth (1989), there are several rodent taxa (*Agnotocaster readingi*, *Paradjidaumo validus*, *Eutypomys thomsoni*, and *Eumys parvidens*) restricted to Orella C in the Toadstool Park area; if their ranges are found to be consistent in the rest of the White River Group, they could also serve as indicators of this zone. The top of this zone is marked by the FAD of the zonal indicator of the overlying zone, *Merycoidodon bullatus*. We designate its type section as the strata 27 to 50 m (80–150 ft) above the PWL in the Boner Ranch section (SW sec. 9, T. 35 N., R. 61 W., South Oat Creek 7.5 quadrangle) in the Seaman Hills, Niobrara County, Wyoming. This zone begins in latest Chron C13n (33.1 Ma) and continues through the early part of Chron C12r (to 32.5 Ma).

### Latest Orellan

Several distinctive taxa mark the latest Orellan, including the first appearances of the oreodont with large bullae, *Merycoidodon bullatus*, the last of the miniochoeres, *Miniochoerus starkensis*, the rabbit *Palaeolagus burkei*, the rodents (fide Korth, 1989) *Prosciurus magnus*, *Ecclesimus tenuiceps*, *Tenudomys basilaris*, *Pelycomys placidus*, *Heliscomys vetus*, *Heliscomys mcgrewi*, *Wilsonemys planidens*, *Campestrallomys annectens*, and the last appearance of a great number of typically Orellan taxa, including *Hyaenodon crucians*, *Ischyromys typus*, *Paratylopus labiatus*, *Archaeotherium mortoni*, *Thinohyus lentus*, *Stibarus quadricuspis*, *Leptochoerus emilyae*, *Subhyracodon occidentalis*, "*Hesperocyon*" *coloradensis*, *Prosciurus*, *Pelycomys*, *Protosciurus*, *Oligospermophilus*, *Eutypomys*, *Adjidaumo*, *Heliscomys*, *Wilsonemys*, *Eoemys*, *Tenudomys*, *Pipestoneomys*, *Megalagus*, *Palaeolagus intermedius*, *Centetodon marginalis*, *Leptictis huydeni*, *Herpetotherium fugax*, *Copedelphys stevensoni*, *Nanodelphys hunti*, and all surviving species of *Mesohippus* (*M. bairdi*, *M. exoletus*, *M. westoni*, and *M. barbouri*). However, the ranges of many of the micromammals in this list may eventually be extended upward once adequate screenwashing is done in the Whitneyan.

This interval was called the "*Diplolophus insolens* zone" by Korth (1989), but as discussed above, this rodent is too rare to serve as an index fossil. We redesignate it as the *Merycoidodon bullatus* Interval Zone, with a type section in the "upper nodular zone" strata (termed "middle *Oreodon* beds" by some workers) on the east side of Sheep Mountain Table, just east of where the road climbs to the top (SW,NE,NW sec. 9, T. 43 N., R. 44 W.,

Sheep Mountain Table 7.5' Quadrangle, Shannon County, South Dakota). We choose the Badlands sections over those in Nebraska or Colorado to typify the late Orellan and Whitneyan because the Frick collections from the Sheep Mountain Table–Cottonwood Pass–Corral Draw area are much larger and better documented than any other for this stratigraphic interval. Correlative strata include the upper part of Orella C and Orella D in the Toadstool Park area, and the upper part of the Cedar Creek Member in Colorado (Galbreath, 1953). These strata correlate with early Chron C12r (32.0–32.5 Ma). See Figure 8 for biostratigraphic data within the Orellan and Whitneyan.

### Early Whitneyan

The resolution of the biostratigraphic data for the Whitneyan collections is not as good as that for the Orellan. Most of the fossils come from the Big Badlands of South Dakota, where they are typically recorded as coming from Upper Oreodon, *Protoceras* beds, and *Leptauchenia* beds of Osborn (1907), Osborn and Matthew (1909), Wanless (1923), Skinner (unpublished field notes), and other workers: seldom is the exact stratigraphic level within these three units (each ~30m, or 100 ft thick) recorded, even by the Frick Laboratory. The other large Whitneyan collections come from the Toadstool Park–Roundtop area (where they are zoned as Whitney A, B, and C of Schultz and Stout, 1955). Hence the Whitneyan cannot be as finely subdivided as the Orellan with the present database.

Nevertheless, the early Whitneyan can be recognized by a number of species that first occur in Whitney A or in the "upper Oreodon beds." Traditionally, the Whitneyan was indicated by the first abundant occurrence of *Leptauchenia decora*; this is by far the most common fossil in these beds. In addition, the early Whitneyan is marked by the first occurrences of *Leptauchenia* (formerly "*Cyclopidius*") *major*, *Hyracodon leidyianus*, *Paratylopus primaevus*, *Paralabis cedrensis*, *Diceratherium tridactylum*, *Protapirus obliquidens*, *Ectopocynus antiquus*, *Oxetocyon cuspidatus*, *Cynodesmus thoooides*, *Agnotocaster praetereadens*, and *Oropycctis pediasius*. A number of taxa, including *Miniochoerus starkensis*, *Stibarus obtusilobus*, *Hyaenodon horridus*, *Cedromus wilsoni*, *Metadjidaumo hendryi*, *Agnotocaster praetereadens*, and *Oropycctis pediasius* last occur in the early Whitneyan.

Of this list, we feel that the best index fossil is *Leptauchenia* (formerly "*Cyclopidius*") *major*; so we designate this interval as the *Leptauchenia major* Interval Zone. Its type section is the upper Oreodon beds (0–30m, or 0–90 ft above the upper nodular layer, or the Scenic-Poleslide contact) on the south side of Sheep Mountain Table, SE,NE,SE sec. 4, T. 42 N., R. 44 W., Sheep Mountain Table 7.5' Quadrangle, Shannon County, South Dakota. It correlates with mid-Chron C12r (32.0–31.4 Ma).

### Late Whitneyan

A number of taxa first occur in the later part of the Whitneyan ("*Protoceras* beds" and "*Leptauchenia* beds" in the Big Badlands,

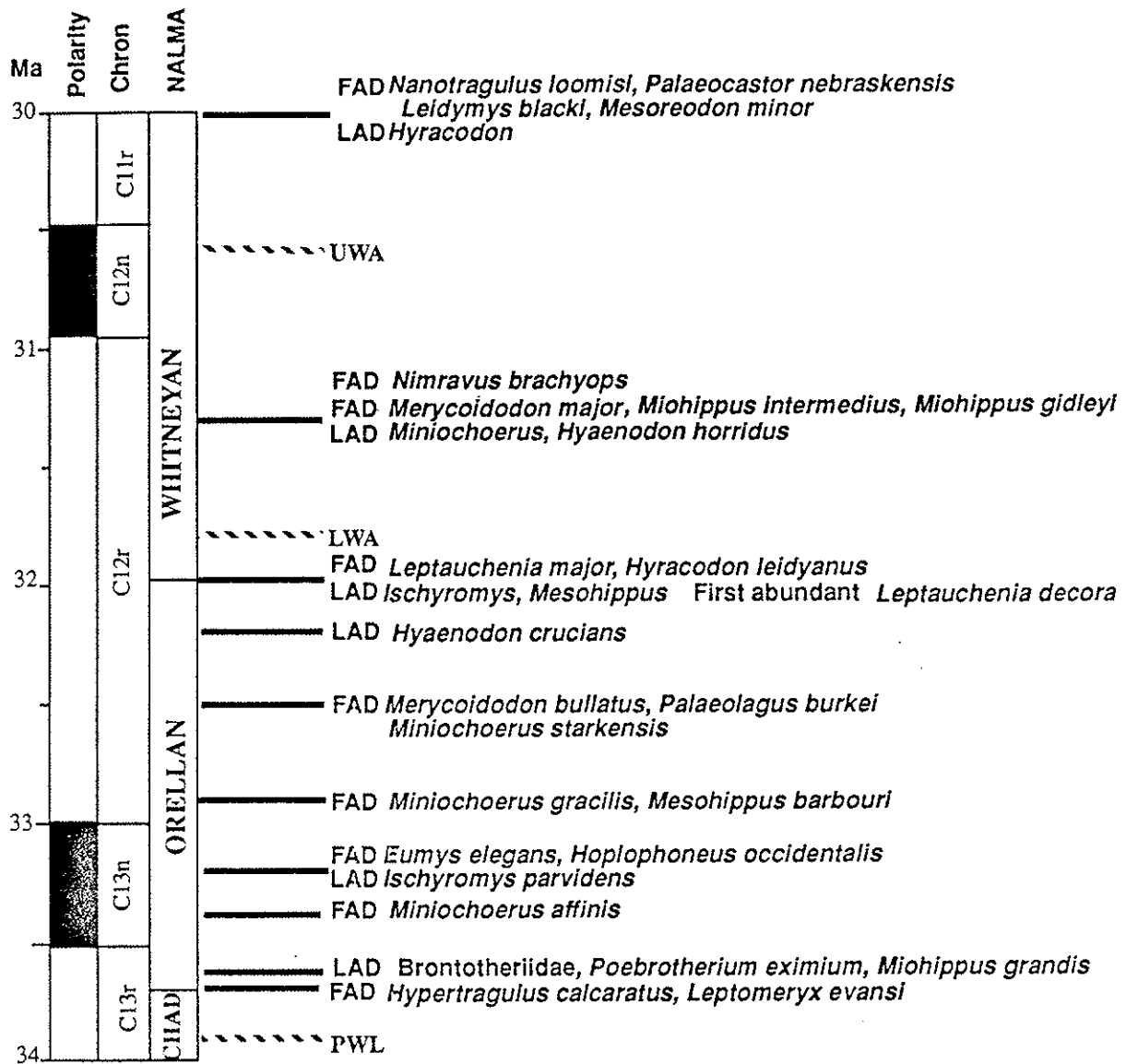


Figure 8. Important biostratigraphic datum levels within the Orellan and Whitneyan. Abbreviations: FAD = first appearance datum; LAD = last appearance datum; PWL = Persistent White Layer; LWA = Lower Whitney Ash; UWA = Upper Whitney Ash; NALMA = North American land-mammal "age." Time scale after Berggren et al. (1995) and Prothero and Swisher (1992).

and Whitney B–C of Toadstool Park). They include the large oreodont *Merycoïdodon major*, the protoceratid *Protoceras celer*, the camel *Pseudolabis dakotensis*, the horses *Miohippus intermedius*, *M. annectens*, *M. equinanus*, and *M. gidleyi*, the nimravids *Hoplophoneus dakotensis*, *Eusmilus cerebralis*, and *Nimravus brachyops*, the creodont *Hyaenodon brevirostris*, and the rodents *Eumys brachyodus* and *Scottimus lophatus*. The rabbit *Palaeolagus burkei* and the oreodont *Miniochoerus starkensis* last occur at this level. Of these taxa, *Merycoïdodon major* is the most abundant and easy to recognize, so we designate the late Whitneyan as the *M. major* Interval Zone. Its type section is the "Protoceras" and "Leptauchenia beds" (30 to 103 m, or 90–310 ft above the upper

nodular layer, or from 30 m (90 ft) above the Scenic-Poleslide contact to the Rockyford Ash) on the south side of Sheep Mountain Table (the type section of the Poleslide Member illustrated by Harksen and Macdonald, 1969a), NE,SE,SW sec. 28, T. 43 N., R. 44 W., Sheep Mountain Table 7.5' Quadrangle, Shannon County, South Dakota. This interval correlates with late Chron C12r to early C11r (31.4–30.0 Ma).

#### Whitneyan-Arikareean boundary

Tedford et al. (1996) have discussed the problem of the recognition of the Whitneyan-Arikareean boundary; they recom-

mend basing it on the FAD of *Nanotragulus loomisi*, *Palaeolagus hypsodus*, *Palaeocastor nebrascensis*, *Leidymys blacki*, and *Mesoreodon minor*. In addition to these, a number of taxa first occur in the earliest Arikareean, including *Palaeolagus philoi*, *Shunkehetanka geringensis*, *Sespia nitida*, *Diceratherium armatum*, *Diceratherium annectens*, *Sanctimus stuartae*, *Geringia mcgregoryi*, and *Plesiosminthus*. These taxa first occur low in the Sharps Formation in South Dakota (near the Rockyford Ash), and near the second Nonpareil Ash Zone (NPAZ) of the "brown siltstone" member of the Brule Formation in Nebraska. These strata correlate with the base of Chron C11n (30.0 Ma). In addition, *Leptomeryx*, *Merycoidodon*, *Paratylopus*, *Paralabis*, *Perchoerus*, *Heptacodon*, *Leptochoerus*, *Colodon*, *Protapirus*, *Hesperocyon*, *Osbornodon*, *Dinictis*, *Paradjidaumo*, *Eumys*, and *Scottimus* last occur in the late Whitneyan; none of these genera have yet been reported from the Arikareean as currently defined.

## CONCLUSIONS

In the 150 yr since White River fossils were first discovered and described, an enormous volume of fossils and data has accumulated. Early in this century, Osborn and Matthew made the first attempts to erect a biostratigraphic zonation of the White River Group, but their lead was not followed by the Wood Committee. In the 90 yr since the work of Osborn and Matthew, White River biostratigraphy has not kept pace with the biostratigraphic studies of the Paleocene (Archibald et al., 1987) or Eocene (Gingerich, 1983; Krishtalka et al., 1987), although many of the biostratigraphic zones proposed in these chapters lack type sections and therefore do not conform to the 1983 North American Stratigraphic Code (see Prothero, 1995). Now the systematic data base has been updated and detailed biostratigraphic, magnetostratigraphic, and radioisotopic data for most of the key sections are available. White River biostratigraphy can now conform to the methods and principles used by invertebrate biostratigraphers since the time of Oppel more than a century ago.

A biostratigraphic zonation for the Chadronian is still in preparation by R. Emry (personal communication), although its outlines were sketched by Prothero and Emry (1996b). In this chapter, we propose the following biostratigraphic zones for the Orellan and Whitneyan:

The Chadronian-Orellan boundary is defined on the first appearance of *Hypertragulus calcaratus*, and is characterized by the first occurrences of *Leptomeryx evansi*, *Palaeolagus intermedius*, and small *Miniochoerus chadronensis*. Brontotheres are no longer part of the boundary definition. Based on  $^{40}\text{Ar}/^{39}\text{Ar}$  dates and magnetostratigraphy, this boundary is dated at 33.7 Ma (late Chron C13r) following the time scale of Berggren et al. (1995), although it may be slightly younger if the dates of Obradovich et al. (1995) are correct.

The earliest Orellan *Hypertragulus calcaratus* Interval Zone occurs in late Chron C13r (33.7–33.5 Ma).

The late early Orellan *Miniochoerus affinis* Interval Zone spans most of Chron C13n (33.5–33.1 Ma).

The early late Orellan *Miniochoerus gracilis* Interval Zone occurs in latest Chron C13n and early Chron C12r (33.1–32.5 Ma).

The latest Orellan *Merycoidodon bullatus* Interval Zone occurs in mid-Chron C12r (32.5–32.0 Ma).

The early Whitneyan *Leptauchenia major* Interval Zone spans late Chron C12r (32.0–31.4 Ma).

The late Whitneyan *Merycoidodon major* Interval Zone spans latest Chron C12r to late Chron C11n (31.4–30.0 Ma).

The Whitneyan-Arikareean boundary falls early in Chron C11n (30.0 Ma).

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on whose work it was built. Morris deciphered most of the subtleties of the White River Group in the 1950s, but never published much of his immense store of knowledge. We who follow in his footsteps are just now putting into print the basic framework that Morris Skinner figured out 40 years ago.

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