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CORRELATION OF THE WHITE RIVER GROUP BY MAGNETOSTRATIGRAPHY

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Abstract

Magnetostratigraphic studies of the White River Group produce a network of paleomagnetic datum planes for detailed correlation. The paleomagnetic data suggest that the "Lower Nodular Zone" of the Big Badlands is time-transgressive and almost a million years younger at the western end of the Badlands than at the eastern end. Correlation with the worldwide magnetic polarity timescale also provides absolute ages for polarity boundaries, which in turn, allows calibration of Oligocene terrestrial events. The following ages are suggested for boundaries of the land mammal "ages": Duchesnean/Chadronian-36.5 Ma; Chadronian/Orellan-32.4 Ma; Orellan/Whitneyan-30.7 Ma; Whitneyan/Arikareean-28.5 Ma.

INTRODUCTION

Although the stratigraphy of the White River Group has been studied by many people (Sinclair, 1921; Wanless, 1923; Schultz and Stout, 1955; Clark *et al.*, 1967; Singler and Picard, 1980; Emry, 1973; among others), detailed correlation has always been a problem. Several workers have attempted correlation of lithologic units, but there are good reasons for questioning the time significance of lithostratigraphic correlations. Biostratigraphic studies now in progress (Emry, 1973; Emry *et al.*, in press; Prothero, 1982 a,b) promise considerable improvement of the resolution of correlation. However, correlation of land mammal biostratigraphy with the global marine record has proven difficult because there are too few places where Oligocene mammal-bearing deposits interfinger with marine deposits in North America. In addition, radiometric dates are currently available only for the Chadronian (Emry, 1973). Orellan and Whitneyan rocks have yet to produce a radiometric date that is considered reliable. Thus, very few absolute dates and little geochronological resolution are presently available for most of the White River Group.

Many of these problems can be circumvented or resolved by magnetic polarity stratigraphy. Magnetic polarity reversals are worldwide, independent of facies or lithology, and geologically instantaneous, so they have the potential of providing a higher resolution of correlation. If the local magnetostratigraphy can be correlated with the global magnetic polarity timescale (MPTS), both absolute dating and correlation with the worldwide geochronological record are possible. Once correlation with the global record is established, local changes in the mammalian fauna can be related to the major paleoclimatic changes that took place during the Oligocene (Prothero, in press a,b).

METHODS

The details of my magnetostratigraphic sampling procedure have been discussed elsewhere (Prothero *et al.*, 1983). In all sections (except those sampled by Denham, discussed below), three oriented samples were taken at each site spaced 5.5 feet (1.7 m) stratigraphically. Samples were subsampled in the laboratory and then treated by both thermal and alternating field (AF) demagnetization. Although many samples responded to AF treatment, normal overprinting by a high coercivity, low blocking-temperature mineral (probably goethite) necessitated thermal cleaning of samples from most sites. The coercivity spectra and the small proportion of remanence remaining above 550°C indicated that the carrier of the characteristic component of remanence is probably some form of titanomagnetite. With a combined AF and thermal demagnetization program, a clear polarity determination was possible on over 90% of the samples. Conventional site statistics were then employed to determine the level of confidence.

All of the Big Badlands sections except Red Shirt Table and Indian Creek were treated in a different manner by Denham. A single sample was collected at each site, and polarity determination was based on the demagnetization behavior of the sample. Only AF demagnetization was used. Because there was only one sample per site, site statistics could not be calculated. Some of Denham's sections, such as Flagstaff Rim, have been redone using more conventional methods (Prothero, in press c).

RESULTS

Over 20 different magnetostratigraphic sections have now been studied within the White River Group (Figure 1). Each section was first correlated biostratigraphically (Prothero, in press a,b,c) using the most abundant and rapidly changing fossil mammalian groups. Individual sections, such as that at Toadstool Park, Nebraska (Figure 2), show a clear polarity pattern. A long normal zone always appears near the base of the Orellan "age". The remainder of the Orellan is reversed, as is the base of the Whitneyan. Another zone of normal polarity appears in the late Whitneyan, near the top of Whitney B. The latest Whitneyan is of reversed polarity until near the base of the overlying Arikaree Group, which begins with a long zone of normal polarity.

These Brule Formation magnetozones are relatively constant in relative thickness. Even sections with higher sediment accumulation rates, such as Slim Buttes, South Dakota (Figure 3), show magnetozones of the same proportional lengths as elsewhere. The relative constancy of thickness and the evidence from the biostratigraphy (Prothero, 1982a) strongly suggest that no significant polarity zones are missing. Of course, floodplain deposits like the White River Group are certainly episodic in their deposition, and there are undoubtedly numerous small hiatuses scattered throughout the section (discussed below). However, the consistent pattern of major polarity zones and the biostratigraphic evidence both suggest that the repeated episodes of floodplain deposition spanned most of the Oligocene, with only one significant hiatus (discussed below).

Sections from the Big Badlands of South Dakota (Figure 4) demonstrate a pattern similar to that seen elsewhere in the White River Group. The base of the Scenic Member consistently produces a long normal zone. Another normal zone appears near the base of the Poleslide Member, and a third normal zone begins at the base of the Sharps Formation.

The magnetostratigraphic pattern of the Chadronian has been discussed elsewhere (Prothero, 1984, in press c). As shown in Figures 1 and 5, most of the Pine Ridge and Big Badlands sections possess a reversed magnetozone that spans the latest Chadronian and early Orellan. Beneath this zone is a short late Chadronian normal

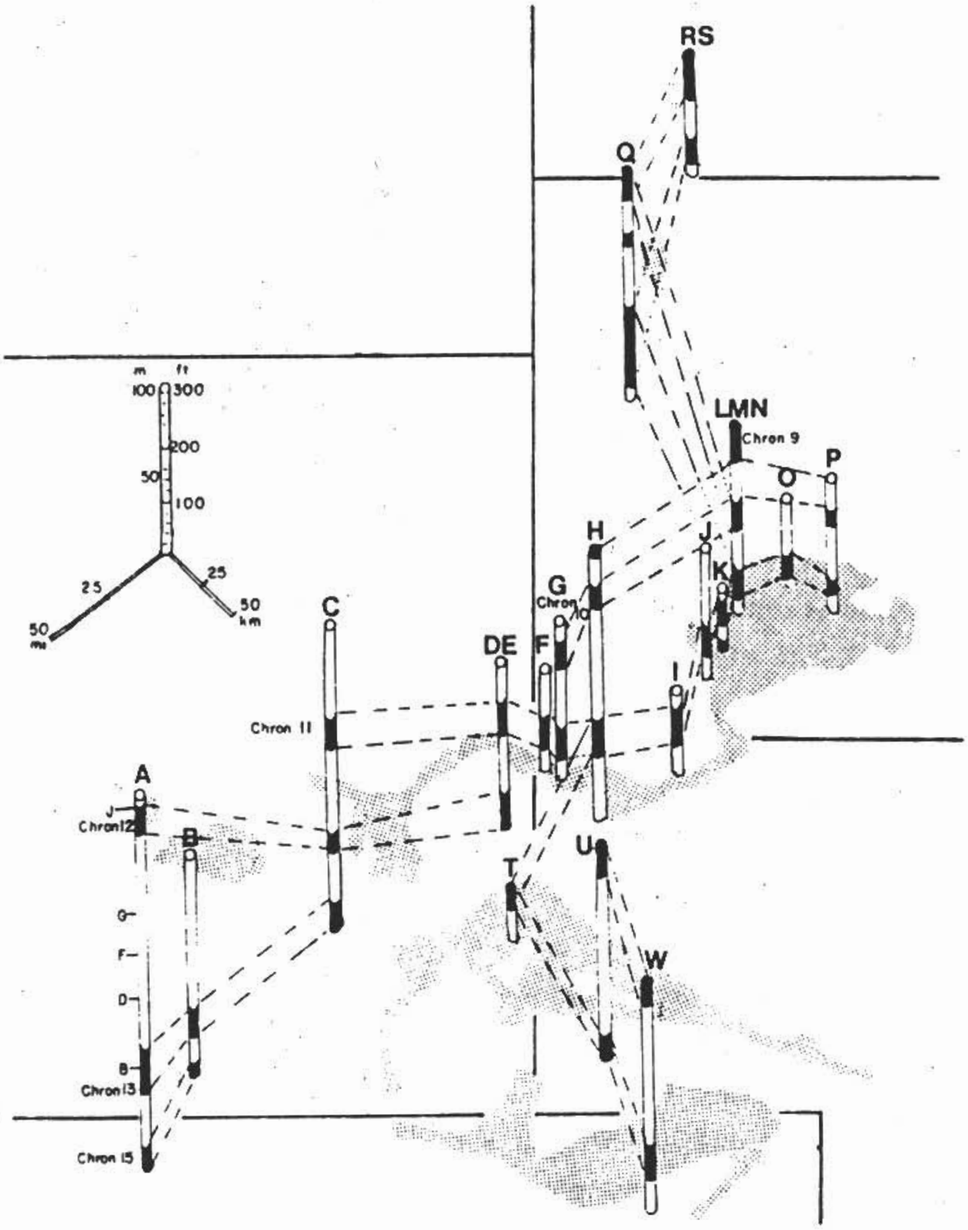

Figure 1. Correlation network of sections within the White River Group (stippled). Black bars are normal polarity, white bars are reversed. A. Flagstaff Rim, Converse Co., Wyoming (Prothero, in press c). Positions of dated ashes B through J are labeled. B. Ledge Creek, Converse Co., Wyoming (Prothero, in press c). C. Composite of Dilts Ranch and Douglas sections, Converse Co., Wyoming. D-E. Composite of Boner Ranch-Thompson Ranch "Anthill" sections, Niobrara Co., Wyoming. F. Geike Ranch, Sioux Co., Nebraska. G. Munson Ranch, Sioux Co., Nebraska. H. Toadstool Park, Sioux Co., Nebraska. I. Trunk Butte and north of Chadron, Dawes, Co., Nebraska. J. Red Shirt Table, Shannon Co., S.D. K. Indian Creek, Shannon Co., S.D. L-M-N. Composite of Sheep Mountain Table-type Scenic-Chamberlin Pass, Pennington Co., S.D. O. Sage Creek Pass, Pennington Co., S.D. P. Cedar Pass, Jackson Co., S.D. Q. Slim Buttes, Harding Co., S.D. R-S. Little Badlands-Fitterer Ranch, Stark Co., N.D. T. Torrington "Harvard Fossil Reserve", Goshen Co., Wyoming. U. Scottsbluff, Scottsbluff Co., Nebraska. W. Chimney Canyon-Flat Top, Logan Co., Colorado. All sections except A-C from Prothero *et al.*, (1983) or Prothero (in prep.).

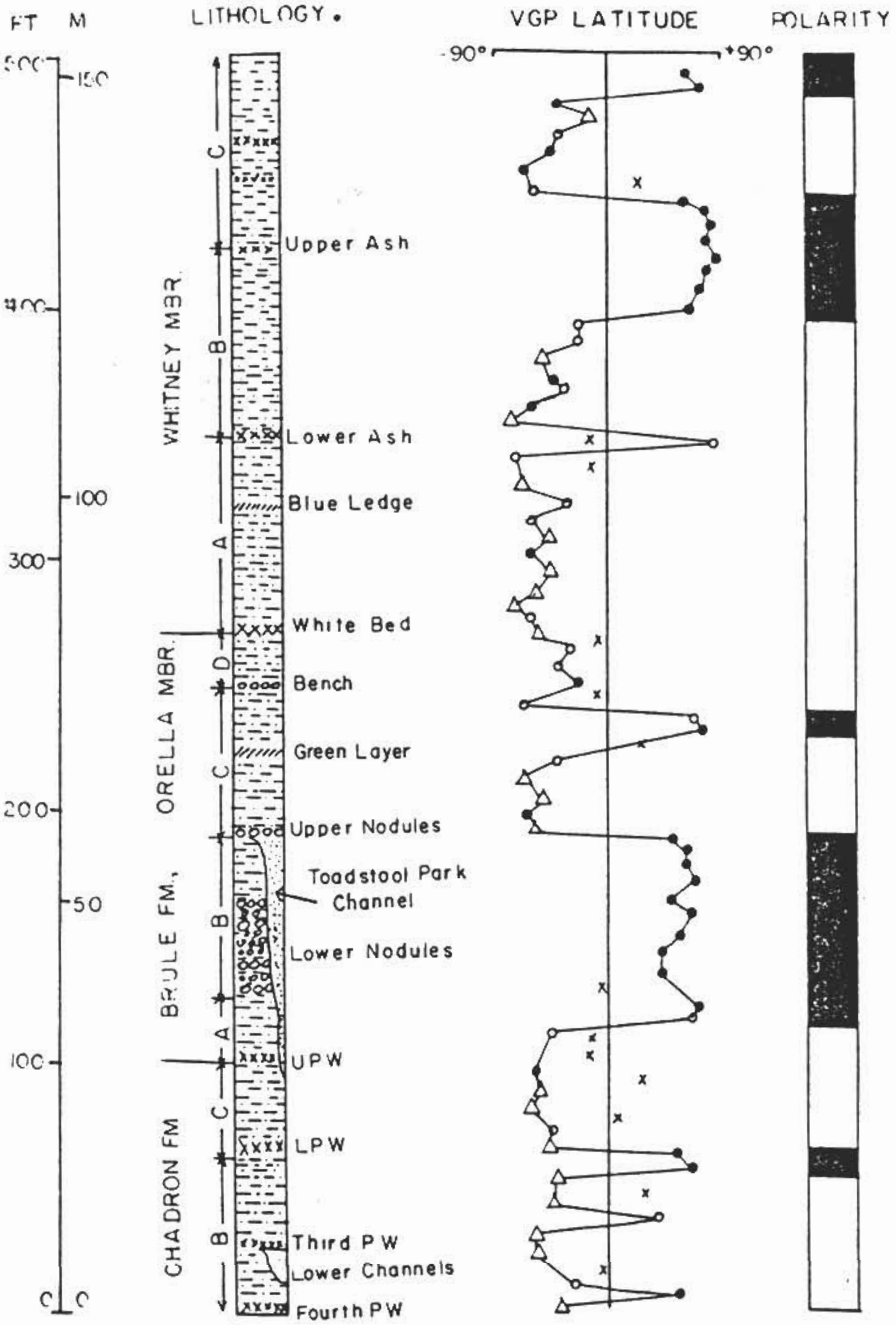

Figure 2. Composite stratigraphy and virtual geomagnetic pole latitude (VGP) plots of Toadstool Park section, Sioux Co., Nebraska. Lithostratigraphy after Schultz and Stout (1955). Positive VGP latitudes indicate normal polarity; negative latitudes are reversed. Site symbols as follows: solid circles = sites with a grouping of cleaned vectors which is significantly removed from a random population at the 95% confidence level (Class I sites of Opdyke *et al.*, 1977). Horizontal tick mark = no thermal samples available. Open circles = sites which failed the confidence test because of lost or crumbled sample (Class II) or one vector which is divergent from the rest (Class III). "X" = indeterminate polarity. Triangle = sites which were stably normal under AF treatment, but reversed after thermal demagnetization.

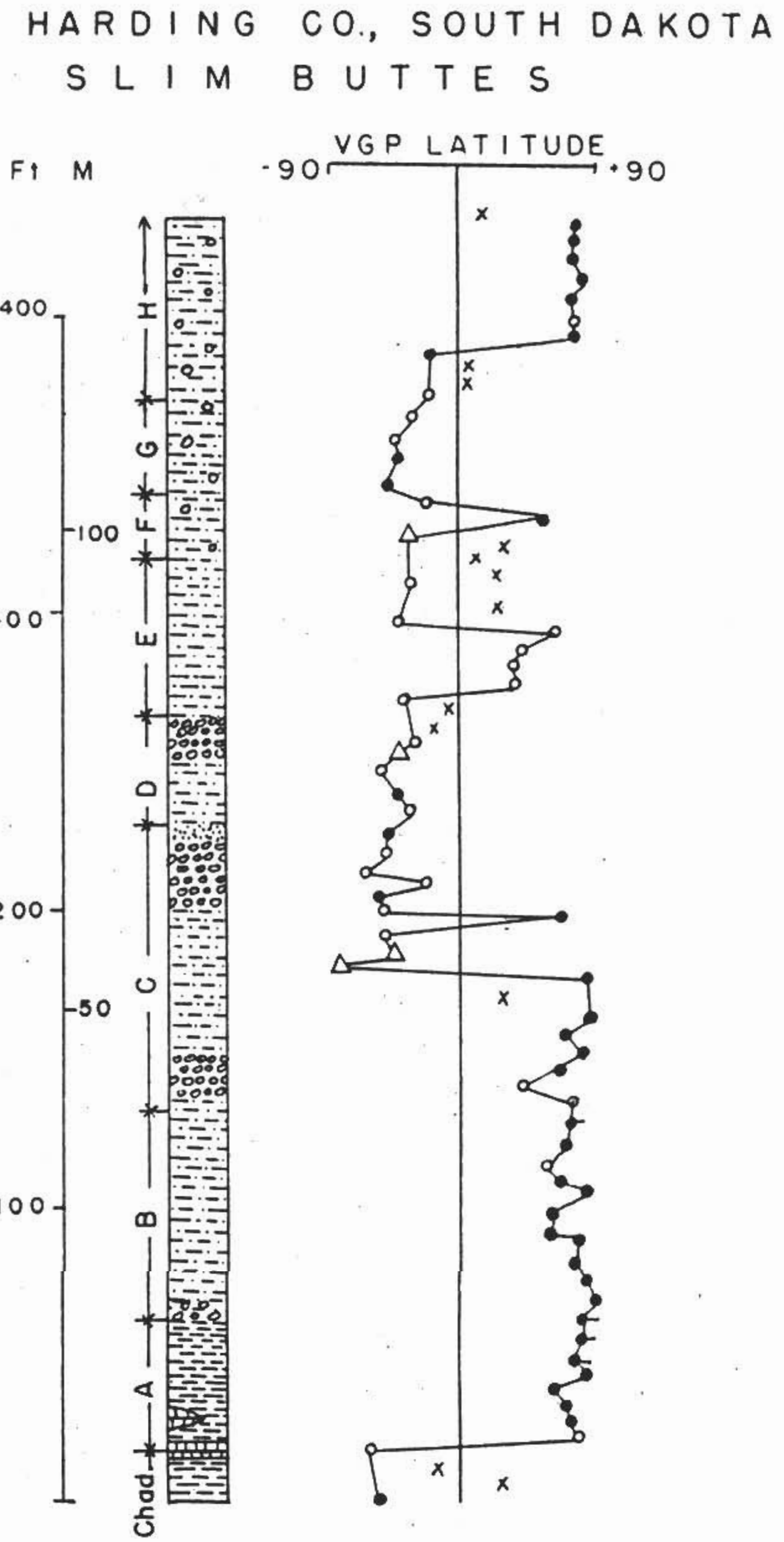

Figure 3. Magnetostratigraphy of the Slim Buttes section, Harding Co., S.D. Terminology and symbols as in Fig. 2. Stratigraphy after Lillegraven (1970).

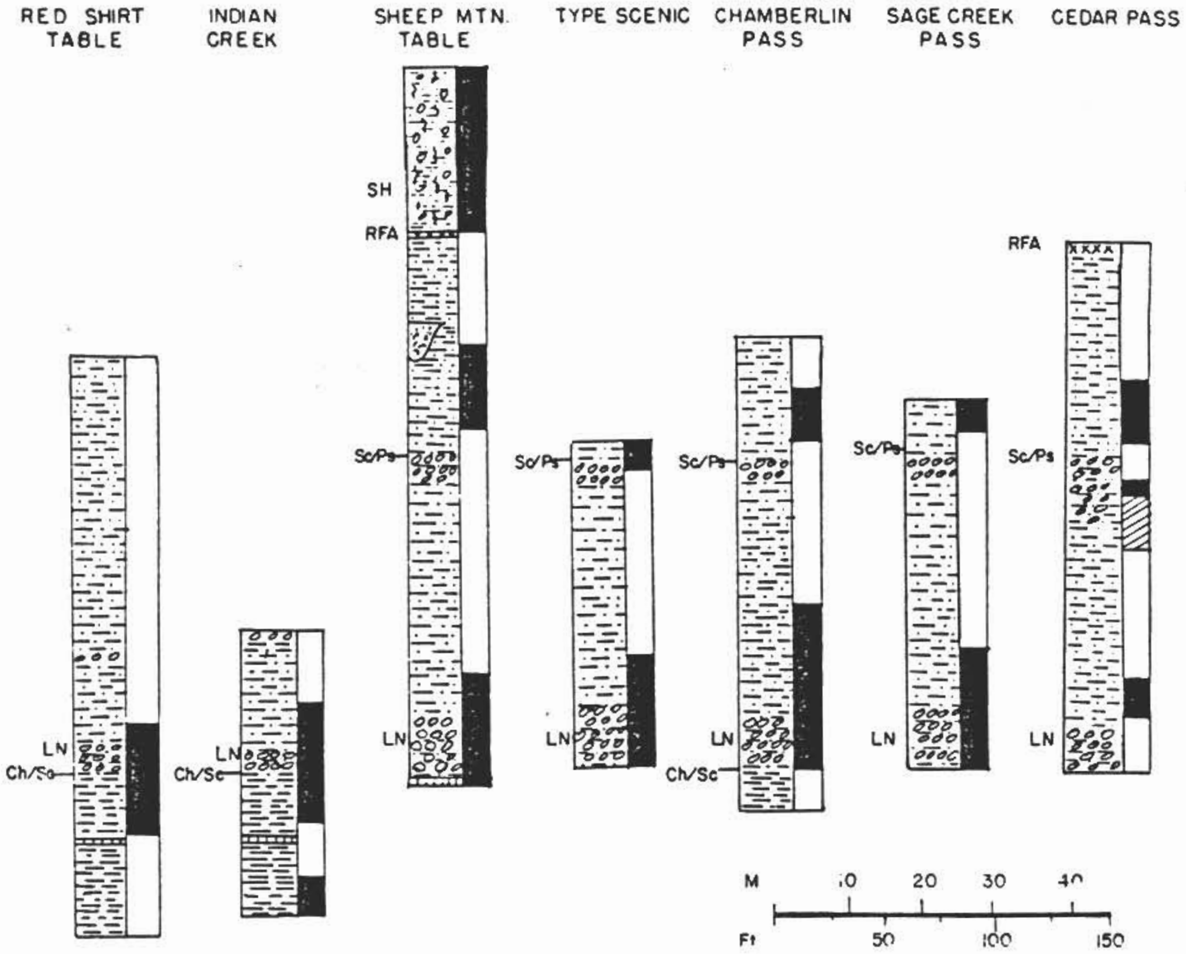

Figure 4. Magnetostratigraphy of seven sections from west to east in the Big Badlands of South Dakota. Solid bars are normal polarity, open bars are reversed. All sections after Prothero *et al.* (1983) or Prothero (in prep.). Red Shirt Table and Indian Creek were sampled by Prothero; the rest were sampled by Denham and Farmer (see text). Abbreviations: Ch/Sc = Chadron/Scenic Formation contact; LN = Lower Nodular Zone of Wanless (1923); RFA = Rockyford Ash; SH = Sharps Formation; Sc/Ps = Scenic/Poleslide Member contact.

zone found at Flagstaff Rim (section A in Figure 1), Dilts Ranch (C), Boner Ranch (D), and Indian Creek (K in Figure 1 and also in Figure 4). The bulk of the Chadronian sections at Flagstaff Rim, Ledge Creek, and Dilts Ranch show an unusually long zone of reversed polarity (Figure 5). At Flagstaff Rim, the age of this zone is bracketed by K/Ar dates of 32.4 and 34.6 Ma (Prothero *et al.*, 1982, 1983; Prothero, in press c). The length and the age span of this zone best fits the long reversed interval between Chrons C12 and C13 of the MPTS. With this tie to the global timescale, it is possible to match the remaining White River magnetozones to the MPTS. It appears that the late Chadronian normal zone is Chron C12, the early Orellan normal magnetozone is

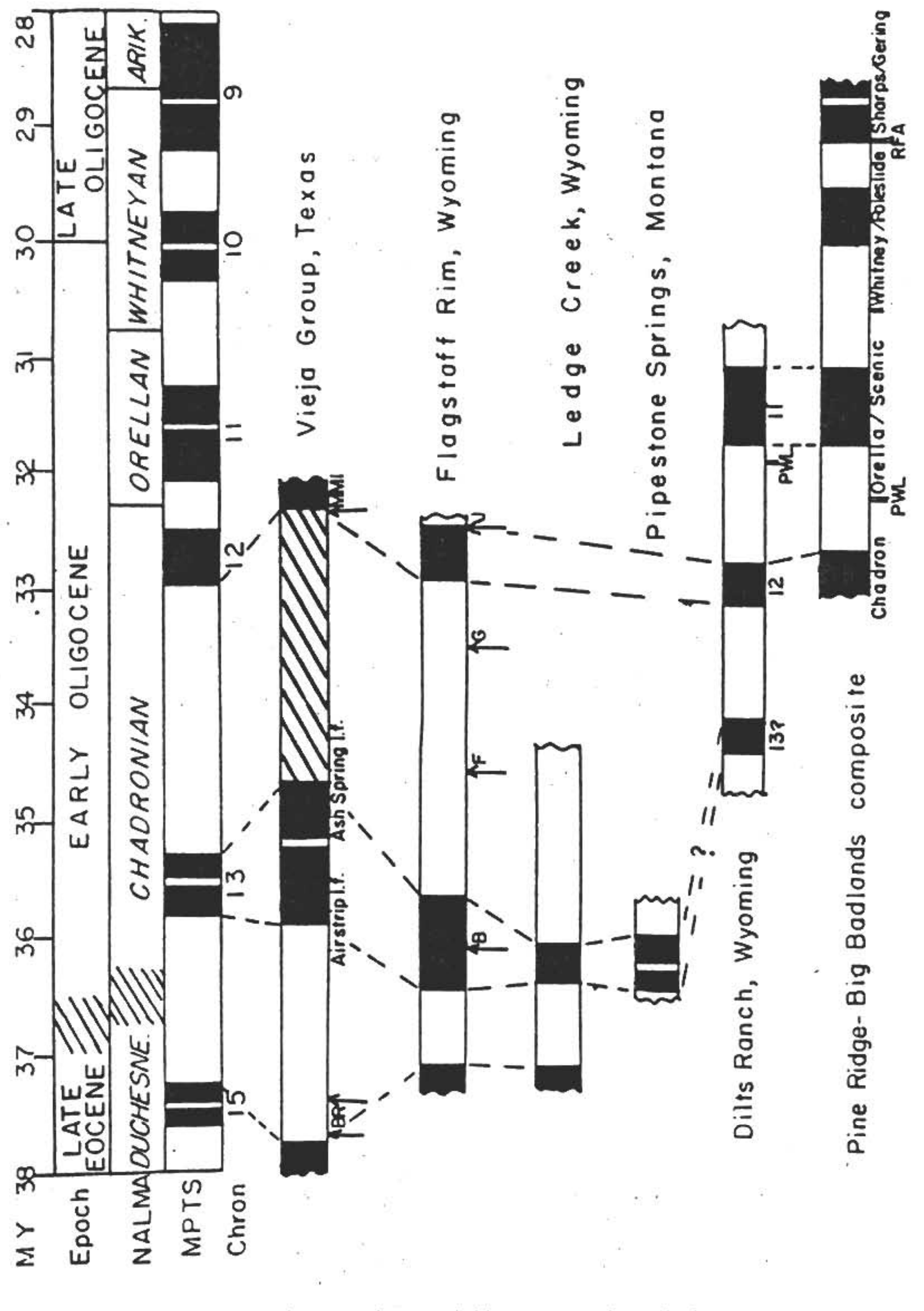

Figure 5. Magnetostratigraphic correlation of Oligocene rocks with the polarity timescale of Berggren *et al.* (1984). Abbreviations: NALMA = North American land mammal "ages"; DUCHESNE. = Duchesnean; ARIK. = Arikareean; MPTS = magnetic polarity timescale; BR = Bracks Rhyolite; MMI = Mitchell Mesa Ignimbrite (dates on these ashes shown by arrows); 1.f. = local fauna; B,F,G, and J = chronologic position of Flagstaff Rim ashes; PWL = Persistent White Layer; RFA = Rockyford Ash. After Prothero *et al.* (1983) and Prothero (1984, in press c).

Chron C11, and the late Whitneyan normal interval is Chron C10. The Whitneyan/Arikareean boundary appears to fall within Chron C9, based on sections at Toadstool Park (Figure 2) and at Castle Rock, Nebraska (Prothero, in prep.).

DISCUSSION

A recent synthesis of Paleogene geochronology (Berggren *et al.*, 1984) has placed constraints on the different disputed versions of the MPTS (Ness *et al.*, 1980; Prothero *et al.*, 1982). The Duchesnean/Chadronian boundary falls within Chron C13R, or very close to the Eocene-Oligocene boundary, about 36.5 Ma. The Chadronian/Orellan boundary falls within Chron C11R, or about 32.4 Ma, so the Chadronian is approximately 4 million years long. The Orellan/Whitneyan boundary occurs in the middle of Chron C10R, or about 30.7 Ma, so the Orellan is about 1.7 million years in length. The Whitneyan/Arikareean boundary appears to fall somewhere within Chron C9, around 28.5 Ma. This would suggest that the Whitneyan is about 2.2 million years in length, although much further work is needed to constrain the age of the Whitneyan/Arikareean boundary. The Oligocene/Miocene boundary occurs with Chron C6C.2R, about 24.0 Ma (Berggren *et al.*, 1984). Paleomagnetic studies of the John Day Formation (Prothero and Rensberger, in press) show that virtually all of the Arikareean is late Oligocene, as recent workers have suggested (Tedford *et al.*, in press).

The network of paleomagnetic datum planes (Figure 1) makes many other studies of rates of sedimentation and evolution possible (Prothero, in press b). Magnetostratigraphic datum planes have been used to test the isochroneity of mammalian biostratigraphic events as well (Prothero, 1982b). One of the more surprising results is the polarity pattern of the Big Badlands sections (Figure 4). Chron C11 (31.2-32.1 Ma) appears near the base of the Scenic Member in each section. However, the famous "Lower Nodular Zone", which yields most of the fossils and has often been used as a stratigraphic marker (Sinclair, 1921; Wanless, 1923; Clark *et al.*, 1967), appears to be time-transgressive. In the western Badlands (Red Shirt Table, Indian Creek), the Lower Nodular Zone occurs near the top of Chron C11. In the west-central Badlands (Sheep Mountain Table, the type Scenic section, Chamberlin Pass, and Sage Creek Pass), the Lower Nodular Zone appears near the base of Chron C11 but clearly above reversed Chron C11R (at Chamberlin Pass). At the eastern edge of the Badlands (Cedar Pass), the Lower Nodular Zone occurs below Chron C11 in reversed Chron C11R. Thus, the Lower Nodular Zone gets progressively younger (by almost a million years) toward the west. This seems to indicate that the nodules are formed by later diagenesis that is unrelated to the time of deposition as Sinclair (1921) first suggested. Retallack (1983) has shown that the nodular layers are calcareous soil horizons ("Conata" and "Gleska Series") which are largely controlled by their proximity to channel sandstones. The main diagenetic effect is cementation by calcite; there is no evidence that this kind of diagenesis affects the magnetic minerals. Systematic comparison of nodular and non-nodular layers throughout the White River Group shows no evidence that nodule formation affects the magnetic signature (Prothero, 1982a). The presence of nodules thus seems to be facies controlled, rather than due to events that were synchronous over the entire Badlands. However, it is not immediately apparent why the process of nodule diagenesis should occur systematically lower in the section from west to east. Whatever the mechanism for their formation, the time-transgressive nature of the nodular layers in the Big Badlands should serve as a caveat for lithostratigraphic correlations based on other widespread "marker" units.

Retallack (1983) calculated rates of sediment accumulation of 0.47-0.65 mm/yr for the Brule Formation in the Big Badlands, based on paleosol criteria. As Retallack points out, rates of accumulation based on paleomagnetic data are at least an order of magnitude lower (0.023-0.027 mm/yr), indicating that there are numerous small hiatuses in the section. The discrepancy in rates may also be due to a large unconformity at the base of the Scenic Member. Biostratigraphic ranges (Prothero, 1982a, b) are abruptly truncated at the base of the Lower Nodular Zone, a strong indicator of missing section. Graphic correlation (Prothero, 1982a) of these biostratigraphic ranges in the Lusk and Douglas sections in Wyoming (sections C and D-E in Figure 1) shows that the Wyoming sections have a record of the latest Chadronian and earliest Orellan that is entirely missing in the Big Badlands (Prothero, in press a,b). This interval of section occurs in the top of Chron C11R, above a marker horizon in the Pine Ridge known to the Frick Laboratory as the "Persistent White Layer", below the base of normal zone C11. Although this interval probably spans only 200,000 to 400,000 years (based on estimates of accumulation rates between paleomagnetic datum levels), many significant changes took place in the fauna (Prothero, in press a,b). Thus, the most crucial phases of the Chadronian/Orellan transition are not even preseved in the Big Badlands.

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