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MAGNETIC POLARITY STRATIGRAPHY AND BIOSTRATIGRAPHY OF MIDDLE-LATE PALEOCENE CONTINENTAL DEPOSITS OF SOUTH-CENTRAL MONTANA[1]

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ABSTRACT

Exposures of the Fort Union Formation on the divide between Hunt Creek and Cub Creek in the northern Clark's Fork Basin, Carbon County, Montana, were selected for magnetostratigraphic study of the transition between the Torrejonian and Tiffanian Land-Mammal Ages. Paleomagnetic samples were collected from 25 sites within a 160 m-thick section of the Fort Union Formation at that location. Rock-magnetic analyses indicate that alternating-field demagnetization to peak fields in the 10 to 40 mT interval successfully removed secondary components of natural remanent magnetism (NRM). Characteristic NRM directions define three polarity zones, a 50 m-thick normal polarity zone bracketed by two reversed polarity zones. The Cub Creek local faunule CC-2 (To_3 or Ti_1) occurs within the upper portion of the normal polarity zone. Cub Creek local faunules CC-1, CC-3, and Eagle Quarry (all Ti_1) occur in the upper reversed polarity zone. These data, along with faunal and magnetostratigraphic data from the San Juan Basin, New Mexico, and the southern Clark's Fork Basin, Wyoming, allow the transition between the Torrejonian and Tiffanian Land-Mammal Ages to be correlated with the later portion of chron 27. Paleomagnetic and paleontologic data from isolated quarries in the southern Clark's Fork Basin allow Mantua Quarry (Pu_1) to be correlated with chron 29r, while Rock Bench Quarry correlates with the later portion of chron 27r. Data from the Crazy Mountain Basin in Montana indicate that Silberling Quarry (To_3) correlates with chron 27r, while Douglass Quarry (Ti_1), Scarritt Quarry (Ti_2), and Locality 13 (Ti_3) correlate with chron 26r.

INTRODUCTION

The transition between the Torrejonian (To) and Tiffanian (Ti) Land-Mammal Ages (middle and late Paleocene, respectively) appears to represent a major period of faunal change (Sloan 1969; Gingerich 1976), but it is still one of the most poorly known intervals in mammalian history. Correlations between late Torrejonian and early Tiffanian mammal localities from separate depositional basins have therefore proven difficult. Particular difficulty in correlating land-mammal age subdivisions between areas in the northern part of the Western Interior (e.g., Crazy Mountain Basin of south-central Montana, Clark's Fork Basin of northwestern Wyoming and south-central Montana) and the south (e.g., San Juan Basin of northern New Mexico and southern Colorado) makes it important to place the temporal position of zones into a broader context. The objective here, therefore, is to report the results of magnetic polarity stratigraphic sampling in the eastern Crazy Mountain and northern Clark's Fork basins, and to relate that information to earlier studies in the southern Clark's Fork and San Juan basins (Butler et al. 1981; Butler and Lindsay 1985).

Archibald et al. (in press) have recently reviewed the North American Land-Mammal Ages for the Paleocene epoch. They have revised definitions of zones within these land-mammal ages, discussed correlations between various faunal localities, and documented magnetostratigraphic correlations where such data are available. A specific problem discussed by Archibald et al. (in press) is the transition between the Torrejonian and Tiffanian Land-Mammal Ages. The Torrejonian has been divided into three biochronologic zones (To_1 to To_3) and the Tiffanian into six (Ti_1 and Ti_6), but interpretations vary regarding the number of zones that can be adequately defined within each of these land-mammal ages. Also, no magnetostratigraphic data have yet been published from a stratigraphic section containing the Torrejonian/Tiffanian transition. When

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publishing the magnetic polarity stratigraphy of the Black's Peak Formation (Big Bend, Texas), Rapp et al. (1983) interpreted it to contain the Torrejonian/Tiffanian boundary, but Archibald et al. (in press) consider the lowest faunal level in the Big Bend section to be Tiffanian rather than Torrejonian.

Magnetostratigraphic study of the southern Clark's Fork Basin, Wyoming, by Butler et al. (1981) determined the positions of the late Tiffanian, Clarkforkian, and Wasatchian Land-Mammal Ages (and zones therein) within the magnetic polarity time scale. However, the earliest zone of the Tiffanian represented in that section is Ti_2. This zone is contained within the basal reversed polarity zone (Powell A−), which was correlated with chron 26r of the magnetic polarity time scale. From magnetostratigraphic study of early and middle Paleocene continental deposits of the San Juan Basin, New Mexico, Butler and Lindsay (1985) have shown that the youngest Torrejonian zone (To_3) represented in those deposits correlates with the magnetic polarity time scale in the interval between the later part of chron 27r and into chron 27. However, no section in the San Juan Basin contains Tiffanian superposed on Torrejonian. Therefore the Torrejonian/Tiffanian transition is surmised to occur somewhere in the interval between the later portion of chron 27 and the early portion of the following polarity chron 26r. Obviously it would be desirable to obtain magnetostratigraphic data from a continuous section that contains both late Torrejonian and early Tiffanian fossils in order to confirm and perhaps refine the placement of the Torrejonian/Tiffanian transition within the magnetic polarity time scale.

Our first attempt to accomplish this objective was to collect a magnetostratigraphic section from the eastern Crazy Mountain Basin of south-central Montana. This region contains the best known and most well-sampled sequence of middle and late Paleocene localities for fossil mammals. It is the only known basin in which the last Torrejonian (To_3) and the first three Tiffanian (Ti_1–Ti_3) zones are sampled. However, the quality and continuity of outcrop (more accurately the lack thereof) do not permit a continuous magnetostratigraphic section to be constructed in that region. In addition, we found evidence of structural complications (beds terminating in slickensided surfaces, etc.) that would probably make construction of a complete magnetostratigraphic section difficult or impossible even if exposure was more continuous. Accordingly, magnetostratigraphic data from the Crazy Mountain Basin are limited to determinations of paleomagnetic polarity of several of the most important Torrejonian and Tiffanian fossil localities. These data are presented here.

A single stratigraphic section containing both late Torrejonian (To_3 zone) and early Tiffanian (Ti_1 zone) fossil localities does exist in the northern Clark's Fork Basin near the Wyoming-Montana state line on the divide between Hunt Creek and Cub Creek (fig. 1). Magnetostratigraphic data from that section are reported in this paper. Also included is a summary diagram of geochronologic calibration of North American Land-Mammal Ages for the Paleocene and early Eocene epochs provided by magnetostratigraphy.

LOCALITIES AND PALEONTOLOGY

The mammalian taxa used by Archibald et al. (in press) to delimit To_3, namely *Pantolambda* and *Pronothodectes*, appear to have either been rare taxa (*Pantolambda*) or to have had limited geographic distribution (*Pronothodectes*). The first appearance of *Pantolambda* was retained as the lower boundary of zone To_3 by Archibald et al. (in press) primarily for historical reasons and also because a better substitute was unavailable. *Pronothodectes* is locally much more abundant than *Pantolambda* and therefore could be proposed but, unfortunately, it appears to have been geographically restricted to the northern part of North America (i.e., from Wyoming northward). Thus, correlations between the classic and type Torrejonian in the San Juan Basin and areas in the north have yet to be fully resolved.

The first appearance of *Plesiadapis praecursor* marks the beginning of the Tiffanian Land-Mammal Age and the *Plesiadapis praecursor* Lineage Zone (Ti_1). The next two Tiffanian zones are the *Plesiadapis anceps* and the *Plesiadapis rex* Lineage Zones. The type localities of *Plesiadapis praecursor*, *P. anceps*, and *P. rex* are Douglass Quarry, Scarritt Quarry, and Locality 13, all of which occur in the eastern Crazy Mountain Basin of south-central Montana. This basin, therefore,

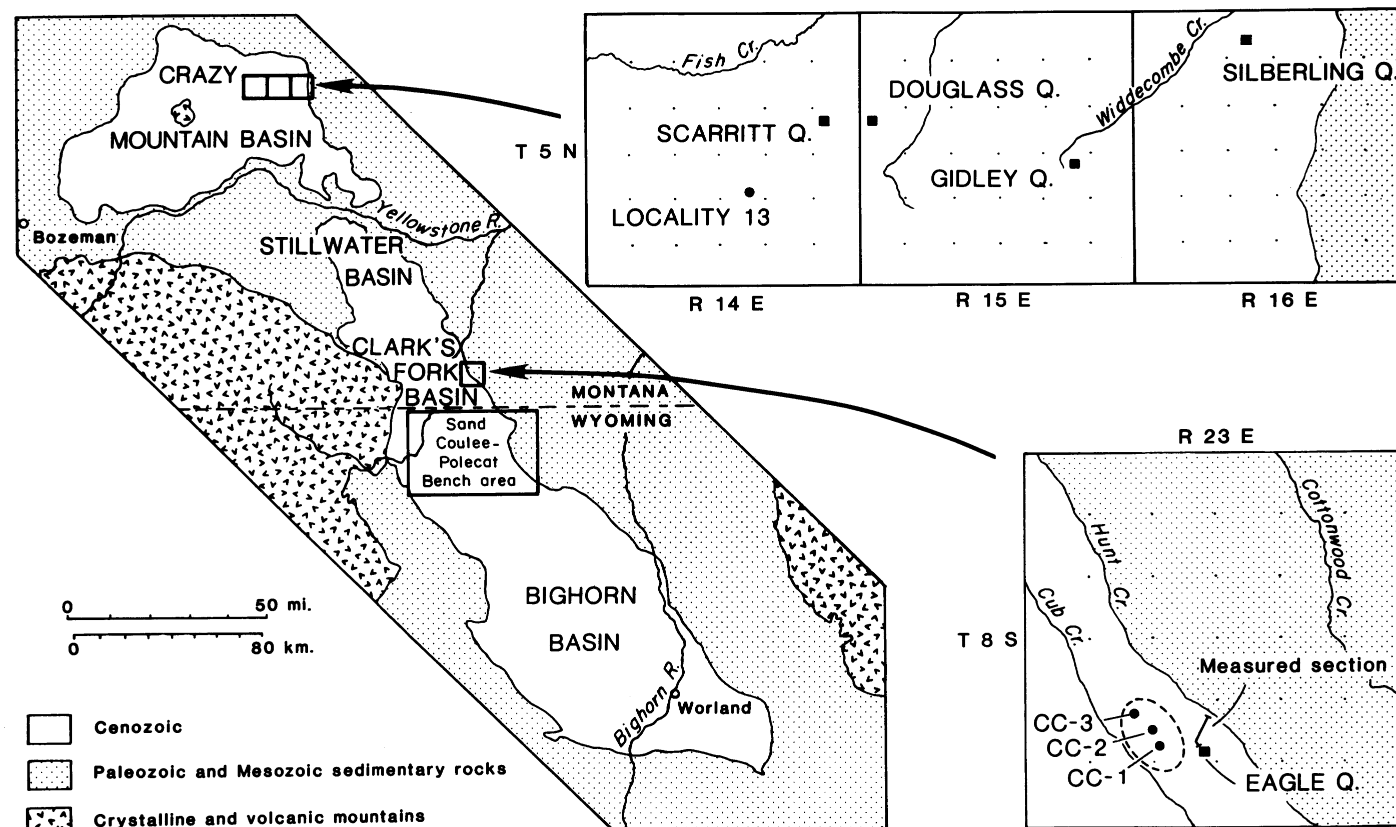

FIG. 1.—Map of the Crazy Mountain Basin-Bighorn Basin structural trough showing the location of fossil sites and the stratigraphic and paleomagnetic sections discussed here. Crazy Mountain Basin sites occupy parts of three townships in the northeastern part of the Crazy Mountain Basin of south-central Montana. Cub Creek/Hunt Creek sites occupy part of one township in the Clark's Fork Basin near the Montana/Wyoming state line. Paleocene and early Eocene paleomagnetic stratigraphy of the Sand Coulee-Polecat Bench area is discussed in Butler et al. (1981).

is of fundamental importance for biochronologic zonation of the early and middle Tiffanian.

The Crazy Mountain Basin is a broad structural depression that is the most northwesterly part of a NW-SE trending trough that also includes, from northwest to southeast, the Stillwater, Clark's Fork, and Bighorn basins (Gingerich 1983; fig. 1). The Crazy Mountain Basin is divided into western and eastern portions by the Crazy Mountains and is bounded to the south by the Reed Point Arch. The Stillwater Basin is in turn separated from the Clark's Fork Basin by the Nye-Bowler Lineament.

Paleocene mammals were first discovered in the eastern Crazy Mountain Basin in 1901 by E. Douglass. These were, in fact, the first fossil mammals ever found in Fort Union deposits. Douglass (1902*a*, 1902*b*) described the specimens and drew tentative correlations with Torrejonian beds in the San Juan Basin. Douglass was accompanied by a resident of nearby Harlowton, Albert Silberling, who later found two of the richest localities in the Crazy Mountain Basin known to date: Gidley and Silberling quarries. Douglass (1908) described the early collection from these two quarries in 1908. In 1909 and 1911, however, Silberling, along with J. W. Gidley, obtained a much larger collection from the two quarries for the U.S. National Museum. These specimens comprised the subject material for a series of papers on the mammalian fauna of the Crazy Mountain Basin by Gidley (1909, 1915, 1919, 1923).

The mammalian faunas from Gidley and Silberling quarries were treated as a whole by Simpson (1935, 1937*a*), who also listed or described mammalian specimens from 55 other localities in the basin (discovered primarily by Silberling). In 1935, a third major quarry, Scarritt Quarry, was developed by Simpson and Silberling, and the fauna from it was described by Simpson (1936, 1937*b*). In addition, one important surface locality, Locality 13, produced mammals of middle Tiffanian age (Ti_3) (Simpson 1937*a*). All of these localities are in Sweetgrass and Wheatland counties, Montana.

Simpson's classic studies document a sequence of middle and late Paleocene mammalian faunas from localities of estimated superpositional relationships. Gidley and Silberling quarries are now considered to be late Torrejonian (To_3) in age and Scarritt Quarry is thought to be of early, but not earliest, Tiffanian age (Ti_2 of Gingerich 1975, 1976; Archibald et al. in press). Mammalian faunas from Gidley and Scarritt quarries were reviewed by Rose (1981). In 1940, a fourth major locality, Douglass Quarry, was developed by Silberling and a small field crew from Princeton University (Bell 1941). A few additional specimens were discovered at Douglass Quarry by University of Michigan field parties during brief visits to the area in the summers of 1978 and 1980. Princeton University and University of Michigan collections from Douglass Quarry, accorded an earliest Tiffanian age (Ti_1), were described by Krause and Gingerich (1983). Large collections of fossil mammals from Scarritt and Douglass quarries, and additional specimens from Silberling Quarry, Locality 13, and several other localities have since been obtained by State University of New York at Stony Brook field crews during the summers of 1982–1986.

Much of the Crazy Mountain Basin is covered by vegetation, and the known quarries and surface localities yielding Torrejonian and Tiffanian fossils can only be placed into relative stratigraphic position by leveling techniques. Gidley and Douglass quarries, which bound the Torrejonian–Tiffanian transition, are separated by a covered interval estimated to be approximately 500 m thick (Simpson 1937*a*). Searching for continuous, well-exposed stratigraphic sections spanning the Torrejonian-Tiffanian boundary, we investigated a series of previously known Princeton University fossil vertebrates localities in badlands on the divide between Cub Creek and Hunt Creek east of the town of Belfry in the northern Clark's Fork Basin, Carbon County, Montana, and prospected for new localities in the area. Tertiary strata in this area consist of dark gray to olive gray carbonaceous shale and mudstone, with subordinate interbedded sandstone, lignite, dark ferruginous concretions, and orange freshwater limestones, all mapped and correlated as the Lebo Member of the Fort Union Formation by Stow (1938; see also Rice 1976; Hickey 1980; Gingerich 1983).

The Lebo Member (at least its upper part) is well dated as Torrejonian in the Crazy

TABLE 1

LATE TORREJONIAN (To_3) AND EARLY TIFFANIAN (Ti_1) FOSSIL VERTEBRATES FROM PRINCETON UNIVERSITY (PU) AND UNIVERSITY OF MICHIGAN (UM) LOCALITIES ON CUB CREEK/HUNT CREEK DIVIDE EAST OF TOWN OF BELFRY, CARBON COUNTY, MONTANA

Locality	Age	Taxon	Specimen
PU Section 28	To_3 or Ti_1	*Pronothodectes jepi* or *Nannodectes intermedius* (Mammalia, Primates)	PU 17930 (right dentary) PU 17931 (left dentary)
PU Section 29	Ti_1	*Aphronorus orieli* (Mammalia, Insectivora)	PU 17308 (left P^4, right P_4)
		Stelocyon arctylos (Mammalia, Condylarthra)	PU 17929 (left and right dentaries—holotype)
		Pantodonta indet. (Mammalia)	PU uncatalogued (incisor crown and molar frags.)
PU Sections 28 and 29	To_3 or Ti_1	Pantodonta indet. (Mammalia)	PU uncatalogued (tooth and bone frags.)
UM Cub Creek 1 (NW¼, SW¼, Section 28)	Ti_1	Dinosaur? (Reptilia)	UM 79667 (bone, reworked)
		Champsosaurus sp. (Reptilia, Eosuchia)	UM 79668 (bone)
		Chriacus pelvidens (Mammalia, Condylarthra)	UM 79666 (right dentary)
UM Cub Creek 2 (¼ corner between Sections 28 and 29)	To_3 or Ti_1	*Trionyx* sp. (Reptilia, Chelonia)	UM 80162 (carapace frags.)
		Allognathosuchus sp. (Reptilia, Crocodilia)	UM 80162 (teeth)
		Mammalia indet.	UM 80161 (tooth frags.) UM 80710 (tooth frags.)
UM Cub Creek 3 (center NE¼ of Section 29)	Ti_1	*Aphronorus orieli* (Mammalia, Insectivora)	UM 80163 (left maxilla)
		Chriacus pelvidens (Mammalia, Condylarthra)	UM 80164 (teeth) UM 83001 (teeth)
UM Eagle Quarry (center SE¼ of Section 28)	Ti_1	*Plesiadapis praecursor* (Mammalia, Primates)	UM 80166 (right dentary)
		Phenacodus bisonensis (Mammalia, Condylarthra)	UM 80167 (left dentary)

NOTE.—All localities are in sections 28 or 29, T 8 S, R 23 E (USGS Long Draw 7-½' quadrangle).

Mountain Basin (type area; Simpson 1937*a*) and on Polecat Bench in the southern Clark's Fork Basin (Stow 1938; Jepsen 1940). Hence it is natural that fossil mammals found in the Lebo Member on the Cub Creek/Hunt Creek divide were all initially assumed to be Torrejonian in age. In recent years, however, earliest Tiffanian mammals have been found at the top of the Hunt Creek/Cub Creek section as well.

The first fossil mammals from the Hunt Creek/Cub Creek area include five specimens found in 1955 by Elwyn Simons, then a graduate student at Princeton University. Each of these specimens is accompanied by locality information placing them in Section 28 and/or 29 of T 8 S, R 23 E, Carbon County, Montana (table 1), but more precise locality information is not available (topographic maps of the Cub Creek area have only recently become available and, consequently, it is difficult to relate any of the specimens to the Hunt Creek/Cub Creek stratigraphic section). The specimens include two plesiadapid primate dentaries from Section 28 identified on labels as *Pronothodectes* and a very fragmentary pantodont from Sections 28 and 29 identified on labels and maps as *Pantolambda cavirictis*. Two additional specimens were collected by Simons' Princeton field party from Section 29 but not initially identified to genus and species.

The first specimens from this area to be published were the two plesiadapid dentaries, identified by Gingerich (1976, p. 19) as *Pronothodectes jepi* (with a caveat that "the material is too fragmentary for an unequivocal determination"). They may, in fact, be referable to Nannodectes intermedius, an earliest Tiffanian species. The Cub Creek pantodont was omitted from Simons' review of Paleocene Pantodonta (Simons 1960; according to J. H. Ostrom it is very fragmentary, certainly not identifiable to species or even genus—it was never assigned a catalogue number in the Princeton collection). The fourth Princeton specimen, consisting of left and right dentaries, was later assigned to a new genus and species of arctocyonid Condylarthra, *Stelocyon arctylos* Gingerich (1978), a taxon providing no information about age because it is as yet unknown elsewhere. The fifth Princeton specimen is here identified as *Aphronorus orieli*, a species elsewhere confined to the earliest Tiffanian (Ti_1). Judging from available evidence, PU specimens from Section 28 could be either latest Torrejonian or earliest Tiffanian in age, while those from Section 29 are earliest Tiffanian.

University of Michigan collections come from four new localities on the Hunt Creek/Cub Creek divide. The fauna from each locality is listed in table 1. Locality CC-1 is from the same stratigraphic interval as CC-3 with *Aphronorus orieli*, and both therefore are likely to be of earliest Tiffanian age. CC-2 is at a level stratigraphically below CC-1 and CC-3, and it may be either latest Torrejonian (To_3) or earliest Tiffanian (Ti_1) in age. Eagle Quarry is at the base of the highest sandstone exposed in Section 28, and it is hence at the top of the Cub Creek/Hunt Creek stratigraphic section. The fauna from Eagle Quarry, while small, includes well preserved dentaries of *Plesiadapis praecursor* and *Phenacodus bisonensis*. *Plesiadapis* and *Phenacodus* make their first appearance in the Tiffanian Land-Mammal Age and *Plesiadapis praecursor* is the principal index fossil of earliest Tiffanian zone Ti_1.

The following discussion of paleomagnetic stratigraphy utilizes a 160 m stratigraphic section measured on the Hunt Creek side of the Hunt Creek/Cub Creek divide. All of the Princeton and University of Michigan fossil localities discussed here occur in the upper 50 m of this section, and those of certain earliest Tiffanian age are likely to be in the upper 30 m.

PALEOMAGNETISM

At Hunt Creek, paleomagnetic samples were collected from 20 levels (sites) within a 160 m thick section. Finer-grained lithologies (clays and fine silts) were preferentially collected. At five sites distributed throughout the stratigraphic section, seven oriented block samples and a bulk sample (2 kg) for magnetic separation were collected, while three oriented samples were collected from each of the remaining 15 sites. Samples from sites containing seven oriented samples were subjected to detailed progressive demagnetization studies to investigate stability of natural remanent magnetism (NRM). All NRM measurements were done with a cryogenic magnetometer (ScT C-102), alternating-field (AF) demagnetization with a Schonstedt GSD-5 tumbling-specimen demagnetizer, thermal demagnetization with a mumetal shielded furnace with magnetic field <10 nanoTesla in the specimen region, and strong-field thermomagnetic analyses with a computerized Cahn 2000 microbalance (Galbrun and Butler 1986).

Curie temperatures revealed by strong-field thermomagnetic analysis of magnetic separates from five stratigraphic levels within the Hunt Creek section were between 150 and 250°C. As shown by Butler and Lindsay (1985) for Late Cretaceous and Paleocene sediments of the San Juan Basin, the dominant ferrimagnetic mineral in the Fort Union Formation of northwestern Wyoming is an intermediate composition ($x = 0.55$) titanohematite. Acquisition of isothermal remanent magnetism (IRM) in progressively higher magnetizing fields indicates that IRM is effectively saturated in magnetizing fields of between 200 and 300 mT. Thus, we do not see any evidence in the bulk magnetic properties for high coercivity phases such as hematite in addition to the detrital titanohematite.

Results of analysis of the NRM were similar to those obtained by Butler et al. (1981) on sediments of the nearby southern Clark's Fork Basin north of Powell, Wyoming. NRM intensities from the Hunt Creek section averaged approximately 4×10^{-4} A/m prior to demagnetization. Examples of progressive AF demagnetization experiments are illustrated in figure 2. Above demagnetizing fields of 40 mT, directions of NRM became very weak ($<1 \times 10^{-4}$ A/m), and components of viscous remanent magnetism (VRM) acquired on short time scales in the laboratory complicated the measurement of remaining NRM at higher demagnetizing fields. The

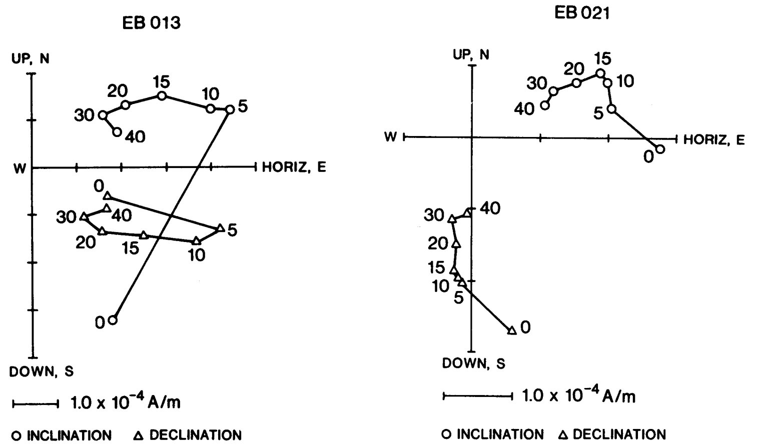

FIG. 2.—Example vector demagnetization diagrams of progressive AF demagnetization behavior for representative sites in the Hunt Creek section. Bar indicates scale for each diagram. Numbers adjacent to data points indicate peak AF in mT.

progressive AF demagnetization results indicate that secondary components of NRM subparallel to the present geomagnetic field at the sampling locality are generally removed by AF demagnetization to peak fields of about 10 mT. Demagnetization in the 10–40 mT interval reveals a trend of the remaining NRM toward the origin on vector demagnetization diagrams suggesting isolation of a characteristic NRM vector.

Thermal demagnetization revealed dominant unblocking temperatures <300°C, consistent with the Curie temperature results. No high blocking temperature components of NRM such as those found by Butler and Lindsay (1985) in magnetically overprinted sediments of the San Juan Basin were observed. The studies of NRM stability thus indicate that secondary components are successfully removed by AF demagnetization at 10 mT and that the polarity of the characteristic component is revealed by AF demagnetization in the 10–40 mT interval. The characteristic component of NRM is interpreted as a depositional remanent magnetism carried by detrital titanohematite.

In order to determine the polarity stratigraphy of the Hunt Creek section, all paleomagnetic samples were progressively demagnetized at several AF levels in the range 5–40 mT. Site mean NRM directions were determined at every AF level, and vector demagnetization diagrams were constructed for each site. This technique proved useful in analysis of the site by site stability of NRM and allowed confidence in extracting polarity determinations from these weakly magnetized sediments. Data from one site were rejected because NRM intensity fell below 5 $\times 10^{-5}$ A/m during the demagnetizing procedures.

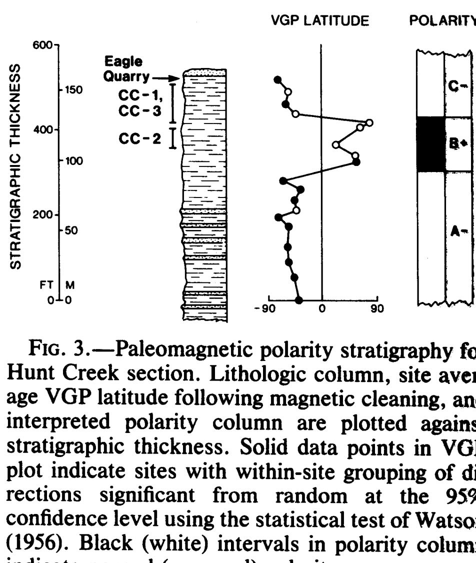

FIG. 3.—Paleomagnetic polarity stratigraphy for Hunt Creek section. Lithologic column, site average VGP latitude following magnetic cleaning, and interpreted polarity column are plotted against stratigraphic thickness. Solid data points in VGP plot indicate sites with within-site grouping of directions significant from random at the 95% confidence level using the statistical test of Watson (1956). Black (white) intervals in polarity column indicate normal (reversed) polarity.

A stratigraphic plot of the resulting data is shown in figure 3. Polarity zones were defined through site by site analysis from which virtual geomagnetic pole (VGP) latitude is simply a convenient parameter for a summary stratigraphic plot. Two reversed

TABLE 2

PALEOMAGNETIC RESULTS FROM FOSSIL MAMMAL QUARRIES

Locality	Zone	Site No.	A.F. mT	J A/m	I o	D o	N	R
Mantua Q.	Pu_1	PB028	30	1.8×10^{-4}	−47.9	153.5	3	1.62
Rock Bench Q.	To_3	PB029	20	6.5×10^{-4}	−28.2	177.5	3	2.89
		PB030	20	2.9×10^{-4}	−51.6	165.7	4	3.71
Douglass Q.	Ti_1	CM010	20	2.5×10^{-3}	−58.2	213.2	4	3.98
		CM011	20	2.1×10^{-3}	−44.5	147.8	4	3.93
Scarritt Q.	Ti_2	CM022	60	9.2×10^{-4}	−32.0	143.1	3	2.70
Locality 13	Ti_3	CM021	40	1.2×10^{-4}	−47.8	104.8	8	3.90
Silberling Q.	To_3	CM012	20	5.1×10^{-4}	−79.4	178.1	4	3.66

NOTE.—A.F. is demagnetizing field, J is intensity of NRM, I and D are mean inclination and declination of cleaned NRM, N is number of samples, R is vector sum of the N unit NRM vectors. Where two sites were collected at a single quarry, the paleomagnetic sampling sites bracket the quarry.

polarity zones (A− and C−) with an intervening normal polarity zone (B+) are determined and are given the prefix "Hunt Creek." The normal polarity zone (Hunt Creek B+), defined by data from five stratigraphically superposed sites, has a thickness of about 50 m. This is thinner than any polarity zone in the Clark's Fork Basin, where the narrowest zone was at least 100 m thick (Butler et al. 1981). Accordingly, we must address the issue of whether Hunt Creek B+ could be an overprinted zone like that found in similar Laramide continental sediments of the San Juan Basin (Butler and Lindsay 1985). The procedures used by Butler and Lindsay (1985) to detect the overprinted zone in the San Juan Basin were virtually identical to those used here. But no evidence, such as high coercivities detected in IRM acquisition or high coercivities or high blocking temperatures of NRM, was observed for sites within Hunt Creek B+. In addition, the average declination observed (D_o = 342°) for the five sites within this normal polarity zone is close to the expected declination (D_x = 348°) predicted by the 60 Ma reference paleomagnetic pole of Diehl et al. (1983) and distinct from the declination of the present geomagnetic field (D = 16°) at the sampling locality. Thus several lines of evidence indicate that Hunt Creek B+ is a reliable recording of a normal polarity geomagnetic interval during deposition of the Hunt Creek stratigraphic section.

Polarities of NRM were also determined for one Torrejonian (Silberling Quarry) and three Tiffanian (Douglass Quarry, Scarritt Quarry, Locality 13) vertebrate fossil localities in the Crazy Mountain Basin. Although the magnetostratigraphic results from the lower portion of the Polecat Bench section in the southern Clark's Fork Basin (Butler et al. 1981) did not allow confident designation of polarity zones, collections made in 1983 at the Mantua and Rock Bench quarries have now allowed polarities of these quarries to be determined. Procedures and results were similar to those described above, with the exception that the dominant ferrimagnetic mineral in the continental deposits of the Crazy Mountain Basin is magnetite rather than titanohematite. Characteristic directions of NRM (summarized in table 2) clearly indicate that all of these localities are within sediments of reversed paleomagnetic polarity. The determination of reversed polarity for Rock Bench Quarry contradicts the statement by McKinney and Schoch (1983, p. 803) that "the typical late Torrejonian fauna of Rock Bench Quarry lies in what may be a normally magnetized magnetozone . . ."

DISCUSSION AND CONCLUSIONS

Magnetostratigraphic studies in the San Juan Basin (Butler and Lindsay 1985) indicate that zone To_3 correlates with the magnetic polarity time scale from approximately the midpoint of chron 27r to the later portion of chron 27. Because the Cub Creek faunule CC-2 of To_3 or Ti_1 zone is contained within the upper half of polarity zone Hunt Creek B+, this normal polarity zone must correlate with chron 27. The overlying reversed polarity zone (Hunt Creek C−) containing the Eagle Quarry and faunules CC-1 and CC-3 (all of Ti_1 zone) must therefore correlate with chron 26r. Given that the Hunt Creek section does not extend to a normal polarity zone correlative with chron 26, it is not possible on the basis of this section to determine an accurate position of the Ti_1 zone within chron 26r. However, in the southern Clark's Fork Basin magnetostratigraphic section (Butler et al. 1981), Ti_2 and the earlier portion of zone Ti_3 also occur within a reversed polarity zone correlative with chron 26r. It thus becomes evident that the Ti_1 zone must occur early within chron 26r (and perhaps late within chron 27). Accordingly, the transition between the Torrejonian and Tiffanian North American Land-Mammal Ages (= transition between To_3 and Ti_1 zones) occurs in the later portion of chron 27.

As indicated in table 2, Rock Bench Quarry containing a fauna of zone To_3 is contained within sediments of reversed paleomagnetic polarity. Given the above determination of the Torrejonian/Tiffanian transition and the magnetostratigraphic limits of zone To_3 in the San Juan Basin, Rock Bench Quarry correlates with the later portion of chron 27r. Table 2 also reports paleomagnetic results for Mantua Quarry, which contains zone Pu_1, the initial Puercan zone. The polarity is reversed and, given the correlation of San Juan Basin Puercan localities (Pu_2 and Pu_3 zones) with chron 29, the Mantua Quarry Pu_1 zone must correlate with the immediately preceding reversed polarity interval, chron 29r. The Hells Hollow local fauna (Pu_1) and stratigraphically lower Lancian faunas also occur within a reversed polarity zone correlative with chron 29r (Archibald et al. 1982 and in press). Thus the Puercan Land-Mammal Age is initiated during the later portion of chron 29r.

Determinations of the paleomagnetic polarities of fossil localities in the Crazy Mountain Basin (table 2) allow some refinements of correlations between those faunas and faunas from the Clark's Fork Basin and other locations. Douglass Quarry contains a Ti_1 zone fauna. Sediments bracketing Douglass Quarry are of reversed polarity as are those containing Eagle Quarry in the Hunt Creek area. From the above arguments, both of these Ti_1 localities correlate with the early part of chron 26r.

Scarritt Quarry contains faunas of zone Ti_2 and is of reversed polarity. This observation is to be expected, as zone Ti_2 in the southern Clark's Fork Basin is entirely within sediments of reversed polarity correlated with chron 26r. The Locality 13 fauna (Ti_3) from the Crazy Mountain Basin is within sediments of reversed polarity. Zone Ti_3 from the southern Clark's Fork Basin correlates with the magnetic polarity time scale in the interval between the later portion of chron 26r and into chron 26. Thus, the Locality 13 fauna must be correlative with the older Ti_3 localities in the Clark's Fork Basin. Silberling Quarry contains a fauna of zone To_3 and is contained in reversed polarity sediments. Given the known limits of To_3 discussed above, Silberling Quarry must correlate with the later portion of chron 27r.

The results of magnetostratigraphic analyses from the San Juan Basin (Butler and

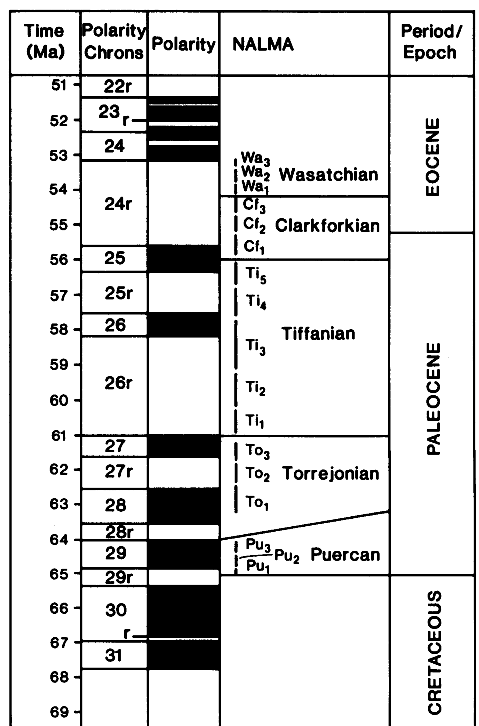

FIG. 4.—Correlation of North American Land-Mammal Ages (NALMA) and zones therein with the magnetic polarity time scale of Harland et al. (1982). Intervals of vertebrate fossil zones are indicated by vertical bars adjacent to polarity column. Land-mammal age boundaries that are relatively poorly defined are shown by slanted lines to indicate the range within which those boundaries may occur.

Lindsay 1985), southern Clark's Fork Basin (Butler et al. 1981), and this paper are summarized in figure 4. Ranges of the Paleocene and early Eocene vertebrate fossil zones and correlations to the magnetic polarity time scale are primarily determined from the San Juan Basin and southern Clark's Fork Basin results. Additional data from the North Horn Formation (Tomida and Butler 1980) and Big Bend, Texas region (Rapp et al. 1983) are also used. Definitions of vertebrate zonation follow Archibald et al. (in press). The current status of knowledge regarding correlation of North American Land-Mammal Ages of the Paleocene and earliest Eocene with the magnetic polarity time scale is summarized in this figure.

Note that we have constructed figure 4 with the view that vertebrate zones will be considered to be of roughly equal duration unless clear evidence to the contrary exists. Because of gaps in the fossil record, durations of vertebrate zonations (e.g., Ti_2, To_1, etc.) shown in figure 4 cannot be taken literally. While transitions between Torrejonian, Tiffanian, Clarkforkian, and Wasatchian Land-Mammal Ages are quite accurately defined, the transition between the Puercan and Torrejonian Land-Mammal Ages is less well determined. However, even this relatively poorly determined transition in the early Paleocene is now known to a precision of about 0.5 m.y. (accepting the precision of relative age calibration of the magnetic polarity time scale of Harland et al. 1982). Magnetostratigraphy has provided a major advancement in geochronologic calibration of North American Land-Mammal Ages.

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