

MAGNETIC POLARITY STRATIGRAPHY AND BIOSTRATIGRAPHY  
OF PALEOCENE AND LOWER EOCENE CONTINENTAL DEPOSITS,  
CLARK'S FORK BASIN, WYOMING<sup>1</sup>

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ABSTRACT

Paleomagnetic samples were collected at 273 sites within a 2012 m continental sedimentary sequence in the Clark's Fork Basin near Powell, Wyoming. The lower 1158 m is in the Polecat Bench Fm while the upper 854 m is within the Willwood Fm. Although significant secondary components of magnetization were present, alternating-field demagnetization to 300 oe peak field revealed the polarity of the primary component of the natural remanent magnetism. A well-defined polarity zonation is observed. The Polecat Bench Fm is dominantly of reversed polarity but does contain two normal polarity zones. The Willwood Fm in this section is entirely of reversed polarity. Abundant Tiffanian, Clarkforkian, and Wasatchian faunas indicate that the age range of the sediments is from late Paleocene through early Eocene. These age constraints, along with the characteristic polarity sequence, allow the magnetic polarity sequence to be correlated with the magnetic polarity time scale. The section correlates with the magnetic polarity time scale from the reversed polarity interval preceding anomaly 26 chron into the reversed polarity interval preceding anomaly 24 chron. Tiffanian fossils are found in sediments deposited during the reversed polarity interval preceding anomaly 26 chron up into sediments deposited during anomaly 25 chron. Clarkforkian faunas occur in sediments deposited during anomaly 25 chron into the base of the overlying reversed polarity zone. Wasatchian faunas are found within sediments deposited during the reversed polarity interval preceding anomaly 24 chron. The Paleocene/Eocene boundary occurs in the Clark's Fork Basin in the reversed polarity interval preceding anomaly 24. These data indicate that the age of anomaly 24 chron is early Eocene rather than late Paleocene.

INTRODUCTION

The Clark's Fork Basin (fig. 1) is the type area of the transitional Paleocene-to-Eocene Clarkforkian Land Mammal Age. In the Clark's Fork Basin, sediments of Clarkforkian age rest directly on a thick sequence of sediments yielding late Paleocene faunas of Tiffanian age. Rocks of Clarkforkian age are overlain by lower Eocene sediments yielding mammals of Wasatchian age. Taken together, sediments of Tiffanian, Clarkforkian, and Wasatchian ages in the Clark's Fork Basin are the most complete, most richly fossiliferous sequence of continental sediments spanning the Paleocene-Eocene boundary known anywhere in the world.

Magnetostratigraphic studies of terrestrial sedimentary sequences containing important

vertebrate faunas are of considerable importance in establishing the geochronology of land mammal ages. Establishment of the magnetic polarity sequence in sections containing diagnostic vertebrate faunas and correlation of the resultant sequence to the magnetic polarity time scale allows the faunas to be placed within an independent chronologic framework. This chronologic framework is not dependent upon local lithostratigraphic limits or stage of evolution. Combined magnetostratigraphic and biostratigraphic studies of mammalian fossil bearing sequences thus help to establish the temporal limits of land mammal ages and allow more accurate determination of rates of evolution and dispersal of land mammals.

Previous magnetic polarity stratigraphic and biostratigraphic studies in the San Juan Basin of New Mexico have established the placement of the Puercan (early Paleocene) and Torrejonian (middle Paleocene) Land Mammal Ages within the magnetic polarity

<sup>1</sup> Manuscript received June 9, 1980; revised November 7, 1980.

[*Journal of Geology*, 1981, vol. 89, p. 299-316]

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0022-1376/81/8903-001 \$1.00

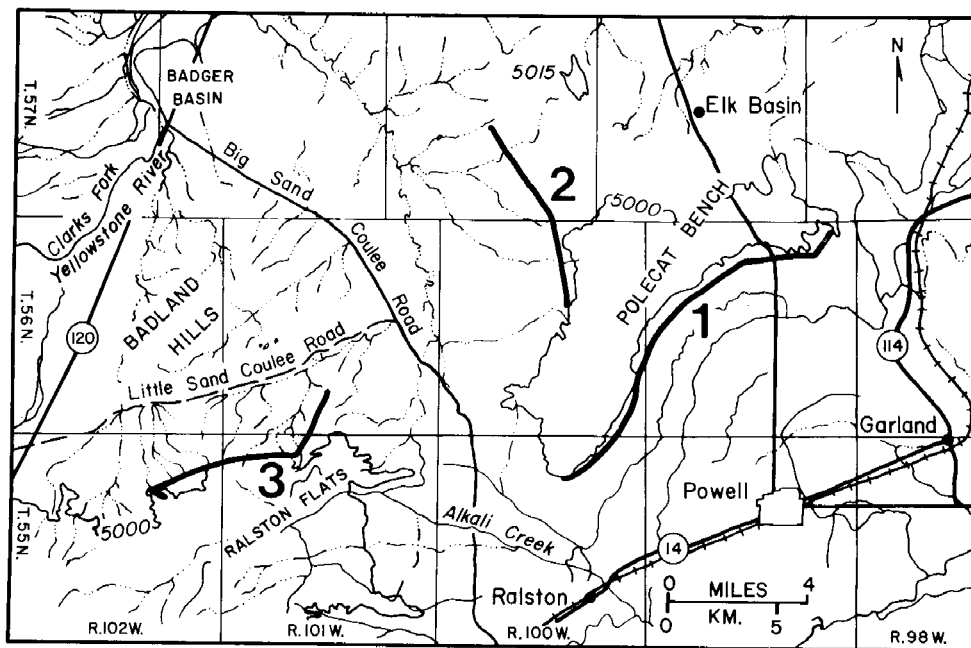


Fig. 1. — Index map of Clark's Fork Basin with locations of paleomagnetic sections. Township and range boundaries and major physiographic features are illustrated. Bold lines are used to illustrate the locations of the paleomagnetic sections. Number 1 is Polecat Bench South, 2 is Polecat Bench Northwest, and 3 is Big Sand Coulee.

time scale (Lindsay et al. 1978, 1980; Taylor and Butler 1980). Magnetic polarity stratigraphy of the North Horn Formation of Dragon Canyon, Utah has allowed determination of the relationship of Dragonian faunas to Puercan and Torrejonian faunas (Tomida and Butler 1980). Continuation of this effort to place North American Land Mammal Ages within the magnetic polarity time scale requires establishment of the magnetic polarity zonation in a sedimentary sequence containing younger vertebrate faunas. The continental deposits of the Clark's Fork Basin, northwestern Wyoming provide an excellent sequence of Paleocene and lower Eocene sediments containing abundant vertebrate fossils. This paper reports the results of paleomagnetic polarity and biostratigraphic study of this sedimentary sequence. The major objective of this work was to establish the magnetic polarity sequence in the Paleocene and lower Eocene deposits of the Clark's Fork Basin and

thereby establish the placement of the Tiffanian, Clarkforkian, and Wasatchian Land Mammal Ages within the magnetic polarity time scale.

#### BIOSTRATIGRAPHY

The first significant collections of fossil mammals from the Clark's Fork Basin were made by William J. Sinclair and Walter Granger in 1911 and 1912. The recognized two new mammalian faunal horizons, the Clark Fork beds and the basal Wasatchian Sand Coulee beds, respectively, below more typical "Wasatch" early Eocene horizons (Sinclair and Granger 1912; Granger 1914). Collections from these transitional Paleocene-to-Eocene Clark Fork and early Eocene Sand Coulee faunal horizons were augmented by Jepsen (1930). Jepsen also documented the presence of a Tiffany-equivalent late Paleocene faunal zone in the Clark's Fork Basin, and middle Paleocene Torrejon-equivalent and early Paleocene Puerco-

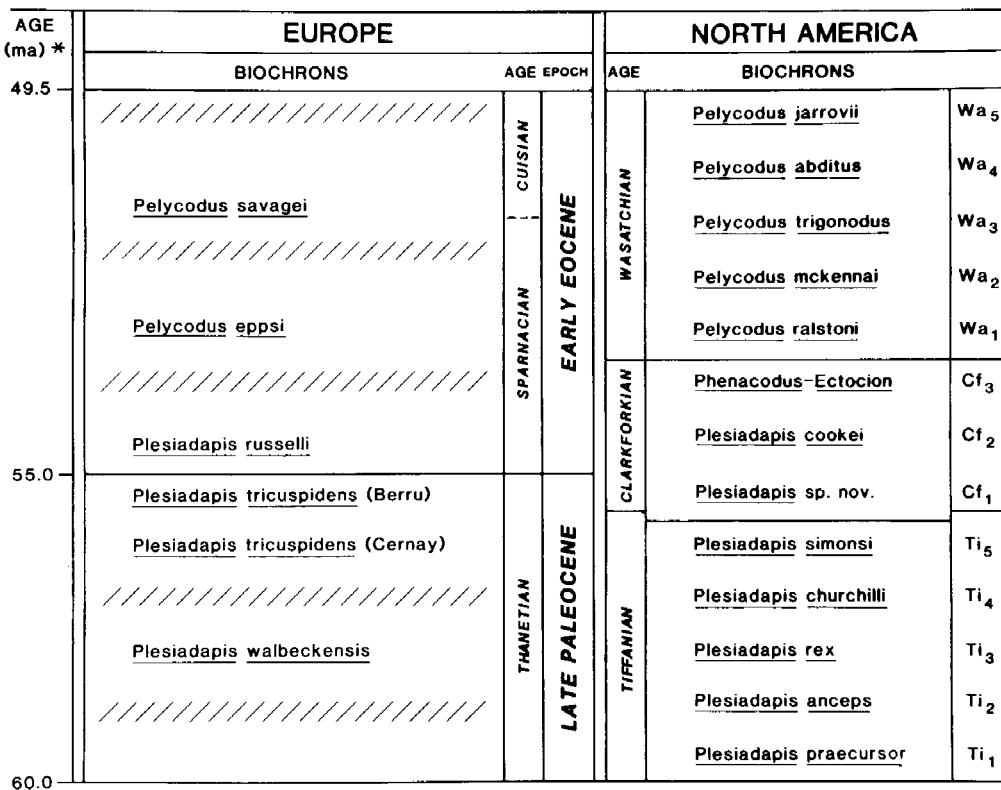


Fig. 2. - Correlation of European and North American land mammal faunas and ages, based on *Plesiadapis* and *Pelycodus* biochrons (Gingerich 1976, 1980; Rose 1980). Hatchures indicate missing section in European sequence, North American sequence is virtually complete. Average duration of each biochron in North America is approximately 0.8 million years. Radiometric ages from Berggren et al. (1978).

quivalent faunal zones on the southeast flank of Polecat Bench, stratigraphically below the Tiffany-equivalent faunal interval. Later Wood et al. (1941) recognized these faunal (e.g., Tiffany, Torrejon, and Puerco) zones as North American Cenozoic provincial land mammal ages. The faunas of the two earliest Cenozoic land mammal ages are still represented in the Clark's Fork-Polecat Bench area principally by two quarry samples: e.g. from the Mantua Quarry (Puercan) and the Rock Bench Quarry (Torrejonian). These are exposed near the base of the Polecat Bench Formation (Jepsen 1940, equals the Fort Union Formation of some authors) on the southeast side of Polecat Bench in a sandstone sequence that

has not yielded reliable paleomagnetic determinations.

Fossils diagnostic of Tiffanian, Clarkforkian, and Wasatchian land mammal ages occur in the Clark's Fork Basin and adjacent Bighorn Basin in a thick sequence of fluvial sediments of the Polecat Bench and Willwood Formations (Van Houten 1944). These three land mammal ages can be subdivided into a sequence of 13 biostratigraphic zones or biochrons (Gingerich 1976, 1980) based on the evolution of the abundant primates *Plesiadapis* and *Pelycodus* (see fig. 2). Biochrons Ti<sub>2</sub> through Wa<sub>3</sub> are all represented by local ranges of diagnostic taxa in one continuous sequence on Polecat Bench and in the Clark's Fork Basin.

The Paleocene-Eocene boundary was originally defined ambiguously by Schimper (1874), and consequently several different boundaries are presently recognized by different authors. Vertebrate paleontologists generally place the boundary at the base of the Sparnacian in the Paris Basin, (e.g., Russell 1968; base of planktonic foraminiferal zone P5). Invertebrate paleontologists sometimes place the boundary at the base of the London Clay (e.g., Curry et al. 1978, at base of zone P6a), or at the base of the Ypresian (Berggren 1972; base of zone P6b) between the Sparnacian and Cuisian (e.g., Hay and Mohler 1967; base of zone P8). Paleobotanists sometimes place the boundary at the top of the Paris Basin Cuisian (Schorn 1971, base of zone P9 or P10). In recent years there has been progress toward agreement on placement of the Paleocene-Eocene boundary at the base of the Sparnacian (Pomerol 1969; Gingerich 1975; Berggren et al. 1978), recognizing the profound change in mammalian faunas that occurs between the *Conglomerat de Cernay* (Thanetian) and the *Conglomerat de Meudon* (Sparnacian). However, there is by no means universal agreement regarding placement of this boundary. In this paper we follow Russell (1968), Pomerol (1969), and others in regarding the base of the Sparnacian in the Paris Basin as the base of the Eocene.

In the Paris Basin the basal Sparnacian mammalian fauna of Meudon differs from older Thanetian faunas (at Cernay and Berru) in having a larger, more advanced species of *Plesiadapis* (*P. russelli*), and the earliest Rodentia, Perissodactyla, oxyaenid Creodonta, and genus *Coryphodon* known from Europe. By comparison with North American faunas the Meudon fauna is equivalent to the Clarkforkian, implying that the North American Clarkforkian Land Mammal Age is early Eocene in age (Gingerich 1976). Recent biostratigraphic work in the Clark's Fork Basin indicates the presence of a zone (Cf<sub>1</sub>) that was not known before. Based on a species of *Plesiadapis*, this new basal Clarkforkian

zone (Cf<sub>1</sub>) correlates with the Thanetian locality of Berru in the Paris Basin, while the overlying *Plesiadapis cookei* zone (Cf<sub>2</sub>) correlates with Meudon and the basal Sparnacian. Thus, the Thanetian-Sparnacian (Paleocene-Eocene) boundary in Europe appears to coincide with the boundary between Cf<sub>1</sub> and Cf<sub>2</sub> in the Clark's Fork Basin (Rose 1980). These relationships are shown diagrammatically in figure 2.

#### PALEOMAGNETIC ANALYSIS

At least three oriented block samples were collected at each of the 273 paleomagnetic sites. Collection and sample preparation techniques are described in Johnson et al. (1975). Paleomagnetic sites were biased towards the finest lithologies and least weathered outcrops available. Most sites were in dark claystone or fine siltstone, and red beds in the Willwood Formation were avoided. Measurements of remanent magnetization were done using a cryogenic magnetometer (Superconducting Technology, C-102) with noise level of  $\sim 1 \times 10^{-7}$  gauss·cm<sup>3</sup>. A Schonstedt GSD-1 single-axis demagnetizer was used for performing alternating-field (AF) demagnetization.

Intensities of natural remanent magnetization (NRM) are low in both the Polecat Bench and Willwood Formations. Mean NRM intensities following AF demagnetization in 300 oe peak field are  $3 \times 10^{-7}$  gauss in the Polecat Bench Formation and  $6.5 \times 10^{-7}$  gauss in the Willwood Formation. Representative progressive AF demagnetization data are illustrated in figure 3. In the progressive demagnetization experiments, all three samples from the site studied were subjected to progressive demagnetization and the site mean intensity and direction were determined following each AF treatment. The site means are plotted in figure 3. This technique was found helpful in analyzing the progressive demagnetization behavior of these weakly magnetized sediments.

Figure 3a (PB203) illustrates a common AF demagnetization behavior observed for sites with a primary NRM of reversed

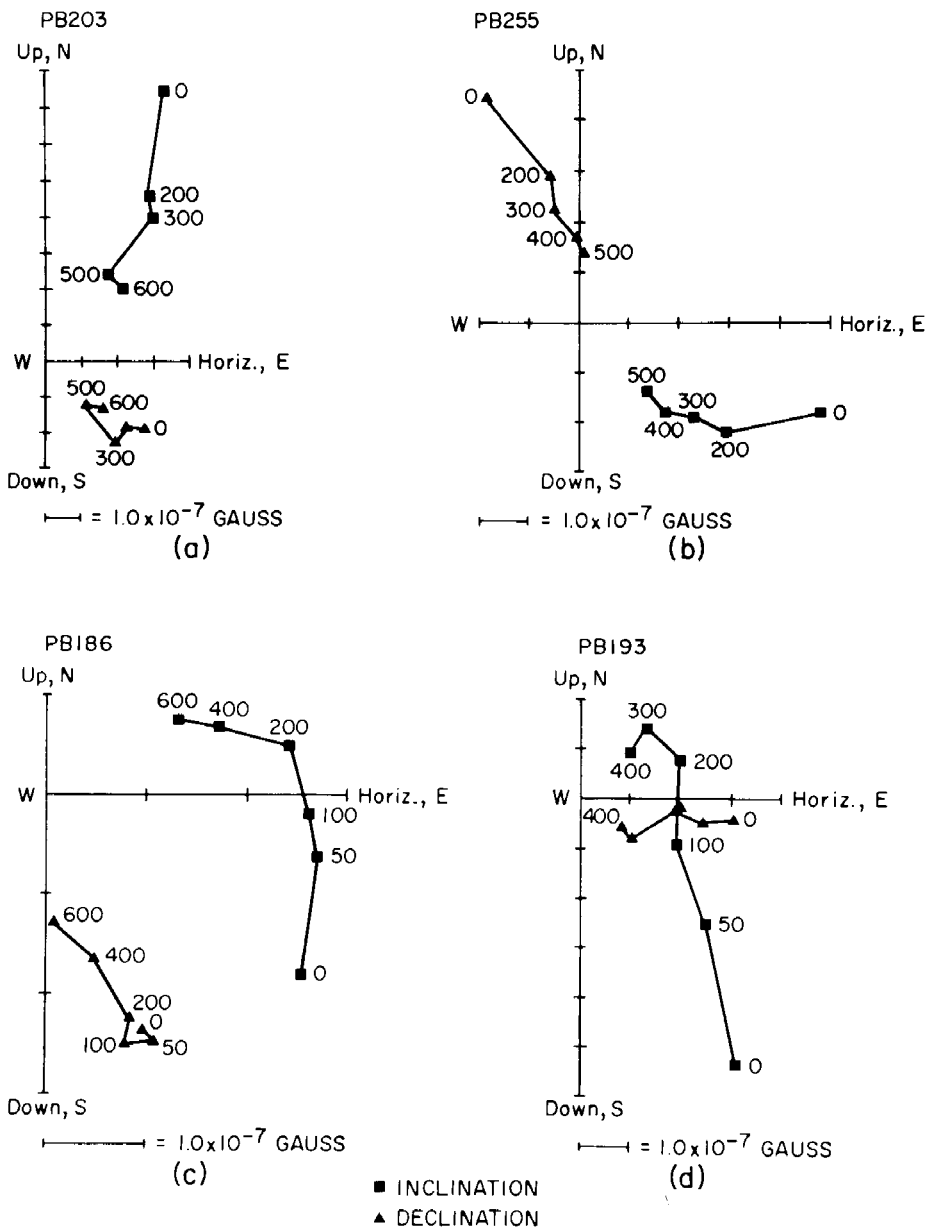


Fig. 3. - Vector demagnetization diagrams. The diagrams are a modification of the Zijdeveld diagram. Squares are used to plot vertical versus horizontal components while triangles illustrate the projection of the magnetization vector on the horizontal plane. Numbers adjacent to data points indicate the peak demagnetizing field in oersteds. Scale of axes in units of remanent magnetization intensity is illustrated at base of figure.

polarity (negative inclination and southerly declination). A basic trend toward the origin with little directional change is observed during demagnetization. A considerable portion of the NRM of this site resides in the 0 to 500 oe remanent coercivity range. Site PB255 (fig. 3*b*) illustrates the progressive AF demagnetization of a site with a primary component of normal polarity (positive inclination and northerly declination). The vector demagnetization diagram shows the desired trend toward the origin following a directional shift between 0 and 200 oe peak field. Again a large proportion of the NRM has remanent coercivity in the 0 to 500 oe range.

Sites PB186 and PB193 (figs. 3*c* and 3*d*, respectively) show a progressive AF demagnetization behavior frequently observed in sites with a primary NRM of reversed polarity. Large directional changes are observed between 0 and 200 oe peak demagnetizing field. This is followed by stabilization of the direction and decrease in intensity of the remaining NRM. Because of the low NRM intensity, it is sometimes difficult to establish the desired linear trend toward the origin of the vector demagnetization diagram at AF fields higher than 400 oe. However, it is fairly clear that the NRM of these sites is of two components. The low coercivity component erased below 200–300 oe is almost certainly a secondary viscous component. This secondary component is almost always of normal polarity and usually is of larger amplitude in the coarser grained samples. The more stable primary components for sites PB186 and PB193 are of reversed polarity and significant proportions of these primary components are contained in the 200 to 600 oe coercivity range.

The AF demagnetization behaviors observed for these samples are similar to those observed for samples from the San Juan Basin (Lindsay et al. 1980). The carrier of the primary NRM has a large proportion of its remanent coercivity spectrum within the 200 to 600 oe interval. This property is commonly observed in sediments where the

primary NRM is a depositional remanence (DRM) carried by detrital magnetite or titanomagnetite. Although polished sections of these fine-grained sediments are difficult to prepare, the few polished sections which have been successfully prepared show magnetite (or titanomagnetite) as the dominant opaque mineral. Isothermal remanence (IRM) acquisition experiments have been performed on one sample from each of 45 sites. In most cases, almost all the IRM is acquired in magnetizing fields less than 3000 oe, with little or no additional IRM acquired at higher magnetizing fields. This behavior is consistent with the other observations indicating that magnetite (or titanomagnetite) is the dominant ferromagnetic mineral. The IRM acquisition data further indicate the absence of high coercivity minerals such as hematite. No correlations between magnetic properties and polarity of primary NRM have been observed. More detailed rock-magnetic and thermomagnetic analyses of these sediments are planned. However, the basic conclusion that the primary NRM is a depositional remanence acquired penecontemporaneous with deposition seems secure.

As illustrated by the progressive AF demagnetization results, determination of the polarity of the primary component required AF demagnetization to at least 300 oe peak field. The NRM of each sample was measured before demagnetization and following AF demagnetization at 200 and 300 oe peak fields. Sites for which significant directional change was observed between 200 and 300 oe were subsequently demagnetized at 400 oe peak field in order to assure that the polarity of the primary NRM could be confidently determined. This additional demagnetization was necessary for less than 10% of the sites. This procedure provided the motion of the site mean direction during progressive AF demagnetization, as well as the final cleaned direction, for determination of the polarity of the primary component. Unambiguous polarity determination was possible for almost all sites.

Site mean directions were calculated by the technique of Fisher (1953), and Watson's (1956) test for randomness was also performed. Statistical parameters of all sites were examined to establish which sites contained grouping of sample NRM vectors which exceeded that expected for selection from a random population at the 95% confidence level. Passage of this test requires  $R \geq 2.62$  for  $N = 3$  and is a rather stringent test for such weakly magnetized rocks. In the Polecat Bench Formation, 116 of the 169 sites passed this test while 62 of the 104 sites in the Willwood Formation passed the test. No data were rejected as a result of this statistical analysis. However, polarity assignments for sites passing the test are felt to be more confident than those with less well clustered directions of NRM. Accordingly, sites whose clustering is significantly different from random at the 95% confidence level are given more weight in interpretation of the polarity zonation.

#### POLECAT BENCH SOUTH

The most complete stratigraphic record of late Paleocene mammalian faunas is on the south side of Polecat Bench (fig. 4). The base of the section is the Cretaceous-Tertiary boundary, immediately underlying Mantua Quarry. The fauna from Mantua Quarry is early Paleocene (Puercan) in age (Jepsen 1930). Some 65 m above the level of Mantua Quarry on the east side of Polecat Bench is Rock Bench Quarry, yielding a fauna of middle Paleocene age (Torrejonian, Jepsen 1930). The Mantua Quarry level can be traced to the southeast of Polecat Bench, 2 km south of Mantua Quarry itself, where our section begins.

The only early Tiffanian fauna in the Polecat Bench section is from locality 263, 175 m above the level of the Cretaceous-Tertiary boundary. This locality yields *Plesiadapis anceps* (Gingerich 1976), establishing its age as early Tiffanian ( $Ti_2$ ). Three middle Tiffanian faunas including *Plesiadapis rex* are now known from localities 262, 261, and 243 on the southeast side of Polecat

Bench. These localities span the stratigraphic interval from 280–425 m above the base of the section.

Late Tiffanian faunas are known from three levels. Localities 239 and 228 are early late Tiffanian ( $Ti_4$ ) in age, yielding *Plesiadapis churchilli*. Locality 239 is also known as the Airport locality (Gingerich 1975; it is now clear that, through an error in mapping, some specimens in the Princeton University collection of 1928 published as coming from this locality were actually collected from the middle Tiffanian several miles to the east). Localities 85 and 86 are higher stratigraphically, at level 840 m, and they yield a late Tiffanian fauna including a specimen referable to *Plesiadapis fodinatus* or possibly its descendant *Plesiadapis dubius*. This specimen indicates a very late Tiffanian age ( $Ti_5$ , probably late  $Ti_5$ ) for these localities.

Clarkforkian faunas are found in the interval from 975 m to 1490 m (975 to 1520 m in the section measured by Gingerich 1976; this slight discrepancy is in total thickness only and there is no significant difference in the relative spacing or sequence of localities). Two localities, 83 and 78, span the early Clarkforkian ( $Cf_1$ ) from levels 975 to 1130 m. The lowest of these includes both *Esthonyx* and *Coryphodon*, genera that first appear in North America in the early Clarkforkian. *Plesiadapis cookei* is found from locality 74 (level 1160 m) to locality 65 (level 1300 m). These span the middle Clarkforkian ( $Cf_2$ ). Late Clarkforkian ( $Cf_3$ ) faunas are found in the interval from 1400 to 1490 m. These include localities 72, 70, etc.

The beginning of the Wasatchian is marked by the first appearance of *Perissodactyla* (*Hyracotherium*), *Artiodactyla* (*Diacodexis*), modern primates (*Pelycodus*), and hyaenodontid *Creodonta* (*Arfia*). These new forms first appear at the same stratigraphic level, level 1500 m in figure 4, where they dominate the fauna from their first introduction. Sediments of Wasatchian age are only present at the very southwest end of Polecat Bench. Localities 67, 69, 68, and others are all

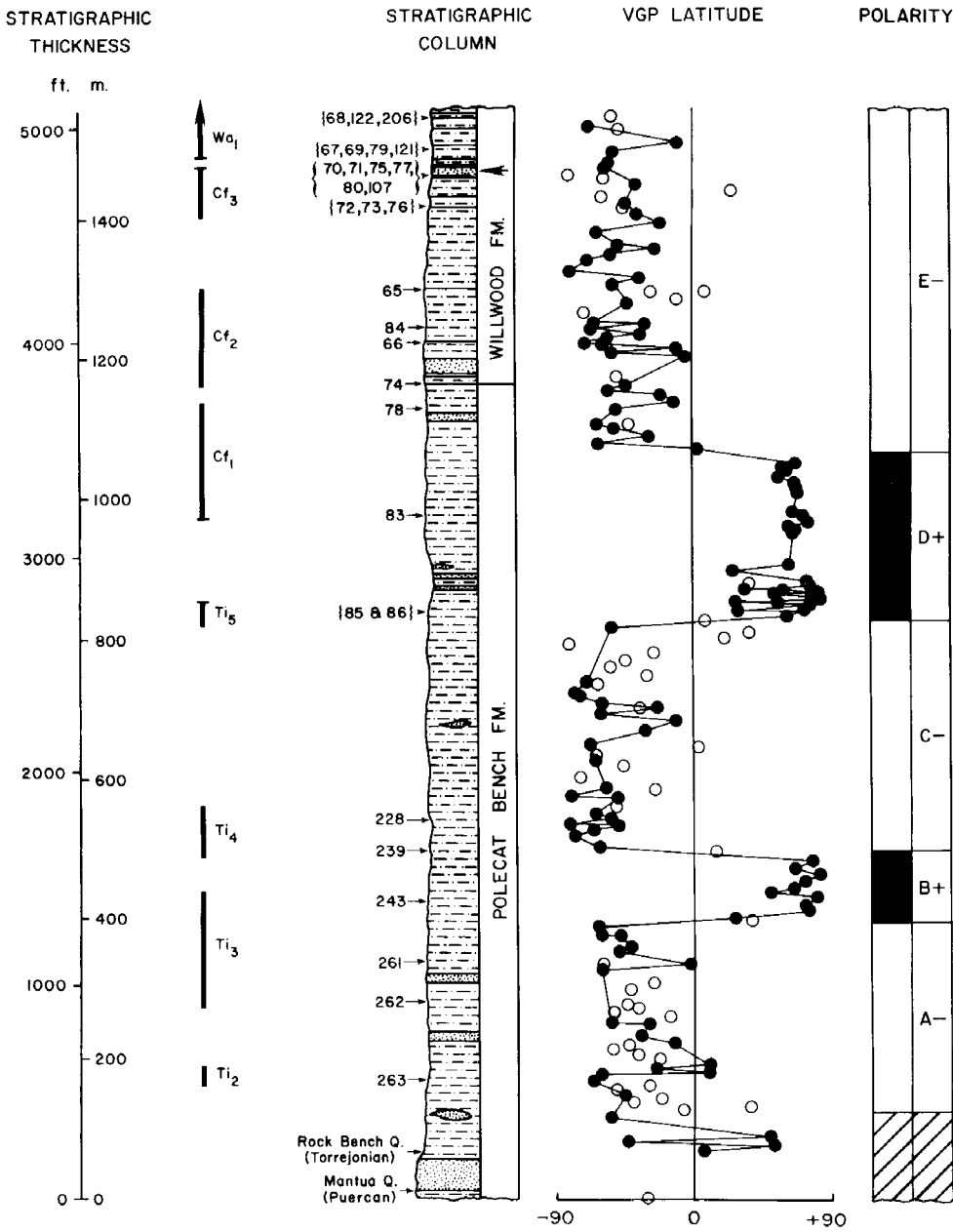


Fig. 4. — Polecat Bench South Section. Stratigraphic column, virtual geomagnetic pole (VGP) latitude, and interpreted polarity column are plotted against stratigraphic thickness. Numbers to left of stratigraphic column are University of Michigan Museum of Paleontology vertebrate fossil localities. Heavy vertical lines to left of lithologic column indicate local range zones of mammal species diagnostic of vertebrate biochronology. Solid circles in VGP plot designate sites with grouping of NRM vectors which is significantly removed from selection from a random population at the 95% confidence level. Open symbols are from sites with poorer clustering. Dot pattern in stratigraphic column indicates sandstone, dot-dash pattern indicates alternating silts and clays, solid lines indicate red beds. Arrow to right of stratigraphic column indicates the location of the boundary sandstone.

earliest Wasatchian ( $Wa_1$ ). No higher levels are present on Polecat Bench.

Site mean virtual geomagnetic pole (VGP) latitudes following AF demagnetization are plotted for the Polecat Bench South section in figure 4. Also illustrated is the interpreted polarity column. Negative VGP latitude indicates reversed polarity and positive VGP latitude indicates normal polarity. Although some sites with reversed primary components do not reach high negative VGP latitudes because of secondary normal polarity overprints which are not easily erased, the motion of the site mean directions during demagnetization are clearly toward reversed polarity. Thus, we can confidently assign a reversed polarity to the primary NRM.

We have not designated polarity zones in the lower 100 m of this section. This is because we do not believe that the results in this interval are reliable. Lithologies in this stratigraphic level are dominated by sandstones and weathering of the outcrop is quite deep in this area. Also, we do not observe a coherent pattern of VGP latitudes which are distributed into stratigraphic intervals of positive and negative VGP latitudes. Above the 100 m level we observe coherent patterns of VGP latitudes which clearly define the polarity zonation. Polarity zones are designated using the labeling system of Alvarez et al. (1977).

The polarity zones from the Clark's Fork Basin described in this paper should be referred to using the prefix "Powell." The basal polarity zone in the section would be designated "Powell A-." This nomenclature is analogous to that used by Alvarez et al. (1977) and is in keeping with recent recommendations regarding magnetostratigraphic nomenclature (*Geology*, 1979, v. 7, p. 578-583). However, where the context makes it clear that the polarity zones being discussed are from the present study, the prefix Powell may be dropped.

Reversed polarity zone A- is ~300 m in thickness and is overlain by normal polarity zone B+ which has a thickness of ~100 m. The Airport fossil locality is at a stratigraphic level near the base of reversed polarity zone

C- which has a thickness of ~350 m. The overlying normal polarity zone D+ has a thickness of ~250 m. Reversed polarity zone E- extends to the top of this section. This magnetozone contains the contact between the Polecat Bench and Willwood Formations near its base and the boundary sandstone near the top of the section (shown by arrow in lithologic column of fig. 4).

#### POLECAT BENCH NORTHWEST

Late Paleocene faunas are also known from the northwest side of Polecat Bench. The most productive locality is Princeton Quarry (Jepsen 1930; Jepsen and Woodburne 1969). This quarry has yielded a large sample of late Tiffanian ( $Ti_5$ ) mammals, including the primate *Plesiadapis fodinatus*. Locality 144 is approximately 100 m above the level of Princeton Quarry (fig. 5), and it also yields a late Tiffanian fauna. Jepsen and Woodburne (1969) described a specimen of *Hyracotherium* said to come from this locality, but there is some reason to doubt locality documentation with the specimen and repeated collecting at locality 144 in recent years has failed to turn up any additional specimens of *Hyracotherium*. Localities 178 and 191 are approximately 300 m above the level of Princeton Quarry. Both of these yield a Tiffanian fauna, but locality 178 also includes the new species of *Plesiadapis* characteristic of the early Clarkforkian. Thus localities 178 and 191 on the west side of Polecat Bench are latest Tiffanian (late  $Ti_5$ ) and should be closely correlative with localities 85 and 86 on the east side of Polecat Bench.

The two polarity zones of this section are quite well defined by the pattern of VGP latitudes illustrated in figure 5. A site with good clustering and positive VGP is found at the 300 m level, but this site showed consistent motion towards reversed polarity during demagnetization. Thus, the positive VGP latitude of this site should not be taken to indicate the presence of a thin normal polarity zone. The basal 350 m of the section are of reversed polarity while the upper 160 m are normal polarity. These

