10. Magnetic Stratigraphy of the Duchesnean Part of the Galisteo Formation, New Mexico

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ABSTRACT

Two sections of the Galisteo Formation in central New Mexico, which contain the Duchesnean Tonque local fauna, were sampled for magnetic polarity stratigraphy. The section at Arroyo del Tuerto is of mixed polarity, and probably correlates with Chrons C17r1 to C17n3 (37.5-38.0 Ma), based on similarities with other well-dated Duchesnean faunas. The section of the type Galisteo Formation in the Cerrillos area is mostly of reversed polarity, and probably correlates with Chron C17r (38.0-38.5 Ma) based on comparisons of its faunas to other late Duchesnean faunas.

INTRODUCTION

In the southwestern United States, the sharpest pulse of the Laramide orogeny began during the middle Eocene. In northern New Mexico and Colorado, the northeastwardly moving Colorado Plateau impinged upon the basement buttresses of the Rocky Mountain foreland, producing significant tectonism. This formed a series of en-echelon, asymmetric downwarps, and tilted and subsided blocks that Chapin and Cather (1981) referred to as Echo Park-type basins, and Dickinson et al. (1988) referred to as axial basins.

One of these basins was the Galisteo-El Rito basin of north-central New Mexico. Its principal basin fill, the Galisteo Formation, is as much as 1300 m thick and consists of fluvial sandstone, mudstone, and conglomerate (Gorham and Ingersoll, 1979) (Fig. 1). Two Eocene fossil mammal local faunas (l.f.) are known from the Galisteo Formation. The lower part of the unit produces the Cerrillos local fauna of Wasatchian age, and the upper part produces the Tonque local fauna of Duchesnean age (Fig. 1; see also Lucas, 1982). The Tonque local fauna is one of the more diverse and better known Duchesnean mammal faunas from western North America (Lucas, 1992). Here, we establish the magnetic-polarity stratigraphy of the Duchesnean interval of the Galisteo Formation to correlate these strata and their fossil mammals to other Duchesnean strata outside of New Mexico.

MAGNETIC STRATIGRAPHY

In the spring of 1988 and the summer of 1990, magnetic sampling was conducted in the two main sections of the Galisteo Formation which contain Duchesnean mammals. In the Cerrillos area (Fig. 1), samples of the type Galisteo were taken, starting with Lucas' (1982, fig. 4) unit 73 (magnetic site 241, Fig. 4) and concluding with the base of unit 82 (magnetic site 259), for a total of 200 m of section. Fossil localities C5 and C6 of the Duchesnean Tonque l.f. are located in units 74 and 82, respectively. Sampling was also conducted in the upper Galisteo exposures in the Arroyo del Tuerto (Fig. 5), beginning with the top of Lucas's (1982, fig. 7) unit 1 (magnetic site 230) and concluding with the base of the Espinaso Formation (magnetic site 240), a total of 70 m of section. Note that this is the base of the Espinaso Formation as defined originally by Stearns (1943) and used by Lucas (1982), which is the most readily mappable contact between two lithostratigraphic units. Disbrow and Stoll (1957), Kautz et al. (1981), and Smith et al. (1991) placed the Galisteo-Espinaso contact at the lowest occurrence of volcanic detritus in the Arroyo del Tuerto section, which is at the base of unit 3 of Lucas (1982, fig. 7), a bentonitic mudstone, but this is not so readily mappable as a contact between the two formations.

Horizontally oriented blocks of rock were sampled with simple hand tools. A minimum of three samples was taken at each site. In the type Galisteo section, sites were spaced approximately 10 m apart stratigraphically; in the shorter Arroyo del Tuerto section, sites were spaced about 5-6 m apart. Samples were trimmed on a band saw equipped with a tungsten carbide blade, and analyzed at the California Institute of Technology paleomagnetic laboratory. Poorly indurated specimens were hardened with sodium-silicate solution to preserve them during thermal demagnetization.

After measurement of the NRM (natural remanent magnetization), a suite of samples was subjected to AF (alternating field) demagnetization. Many samples, such as 240A (Fig. 2A), showed a steady decline in

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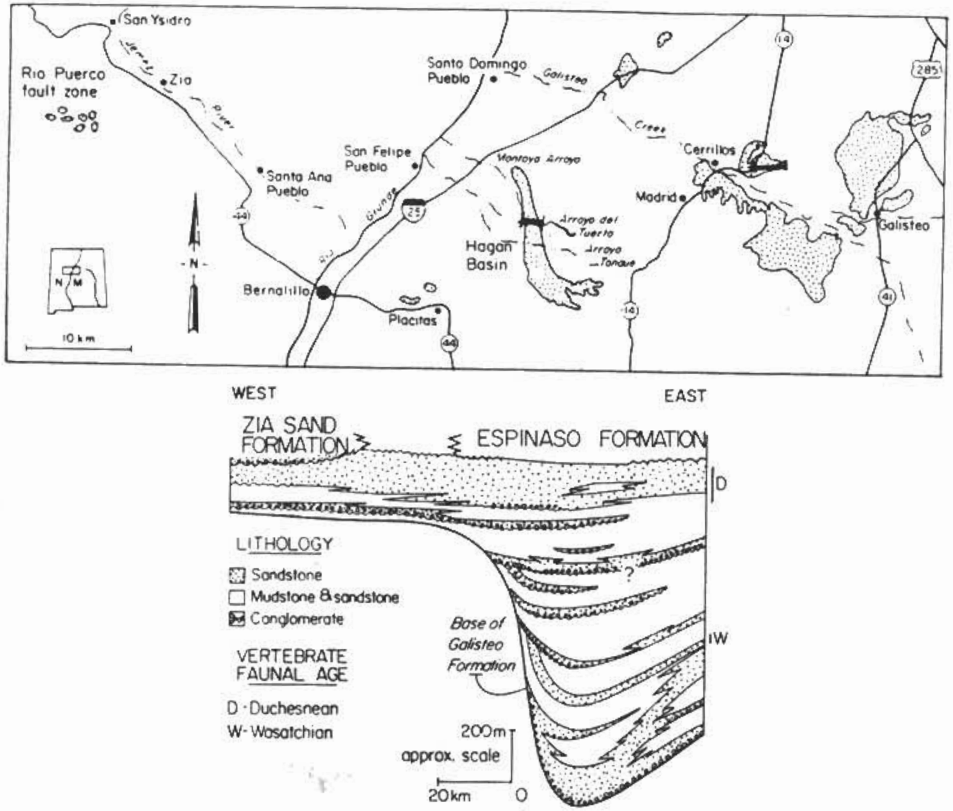

Figure 1. Index map showing location of Cerrillos and Arroyo del Tuerto sections discussed in text (from Lucas, 1982, fig. 1), and diagrammatic west-east cross-section shown stratigraphic relations within Galisteo Formation (from Lucas and Williamson, 1993).

intensity during AF demagnetization. This suggests that a low-coercivity mineral such as magnetite is the main carrier of remanence. Under thermal demagnetization (Fig. 2B), most samples had lost nearly all their remanence by 600°C, which is above the Curie point of magnetite. However, some samples (Fig. 2C) still had significant remanence left by 600°C, suggesting that significant hematite was present. A few reddish samples (Fig. 2D) showed no drop in intensity, even at 600°C; most of their remanence is apparently carried in hematite.

Analyses of IRM (isothermal remanent magnetization) acquisition further confirmed that both magnetite and hematite were present in many samples. Some rocks (Fig. 3A) reached saturation IRM values at 100-300 mT (millitesla); the remanence in these rocks is carried mostly by magnetite. Other specimens (Fig. 3B) showed no evidence of IRM saturation, even at fields of 1300 mT; these samples clearly contained much hematite. A modified Lowrie-Fuller ARM (anhysteretic remanent magnetization) test (e.g., Johnson et al., 1975) was also conducted during the IRM analysis (see Pluhar et al., 1991, for details). This test compares the resistance of AF demagnetization of both an IRM acquired in a 100 mT peak field, and an ARM gained in a 100 mT oscillating field. In almost all samples, the ARM (black squares) demagnetizes at higher peak fields than does the IRM (open squares), indicating that the remanence is carried by single-domain or pseudo-single-domain grains.

Finally, thin sections of representative samples were examined under reflected light. In most slides, euhedral magnetite grains with oxidized rims of hematite could be seen. In addition, several samples had a strong red

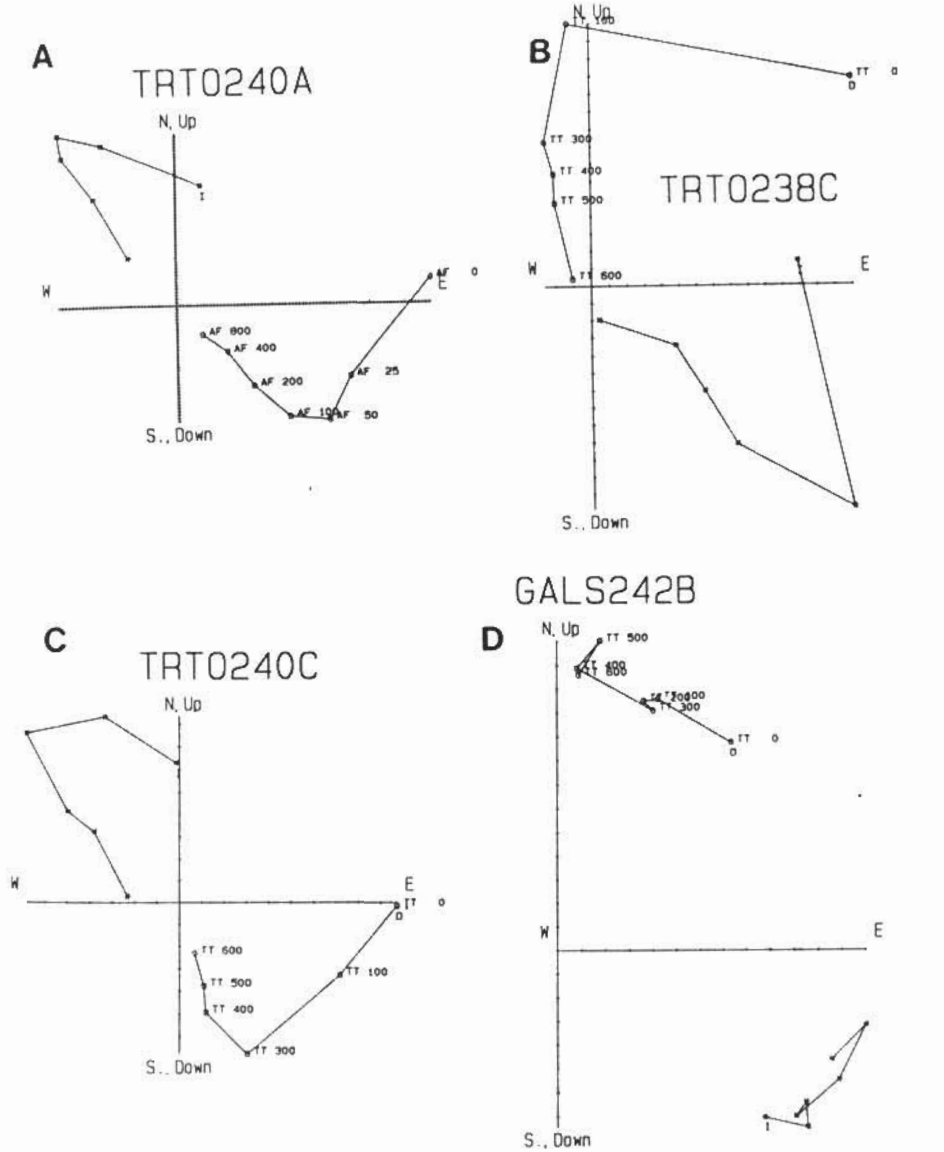

Figure 2. Vector demagnetization ("Zijderveld") plots of representative samples of the Galisteo Formation. Each division = 10^{-6} emu. Horizontal component shown with open circles; vertical component shown with asterisks; NRM direction of vertical component indicated by "I". A) AF demagnetization of sample 240A from Arroyo del Tuerto, showing the overprint removed in fields from NRM ("AF 0") to 50 Gauss, then a stable reversed component at higher fields. The rapid drop in intensity suggests that a low-coercivity mineral such as magnetite is the major source of the remanence. B) Thermal demagnetization plot, showing thermal steps ("TT") in degrees Centigrade. After removal of overprints, a stable normal component was revealed at temperatures between 100-600°C. C) Thermal demagnetization of a reversed sample, with a stable reversed component apparent between 300-600°C. D) Reddish sample with much chemical overprinting from hematite. Note that there was no decline in intensity, even at 600°C, which is close the Curie point of hematite.

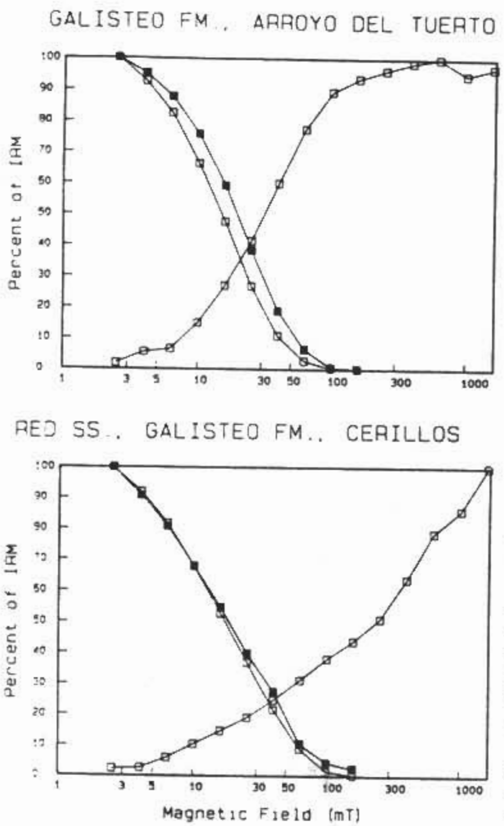

Figure 3. IRM acquisition and Lowrie-Fuller tests for representative samples (see Pluhar et al., 1991, for details). Open boxes are IRM intensities, and solid boxes are ARM values. The IRM acquisition curves (ascending curves on right) show saturation in some samples (top), suggesting that magnetite is the primary carrier of remanence. In red sandstones (bottom), there is no IRM saturation, indicating that hematite is dominant. Both samples showed ARM demagnetization curves which were more resistant to AF demagnetization than the IRM curves (descending curves on left), suggesting that a fine-grained, single-domain or pseudo-single domain mineral is the carrier of the remance.

hematite or goethite stain, which may account for the behavior in some samples (e.g. Fig. 2D).

Based on these analyses, it is clear that a complex magnetic signal is present in the Galisteo samples. All remaining samples were subjected to stepwise thermal demagnetization at 100°C steps. This procedure should remove overprinting by a high-coercivity iron hydroxide (such as goethite), which is not affected by AF demagnetization. As can be seen from Figure 2B and 2C, an overprinted component was removed by 100-300°C, and a stable characteristic reversed component was apparent at temperatures from 300-600°C. The directions of the component between 300 and 500°C were used for further statistical analyses.

The stable sample directions were then clustered by site, and statistically analyzed by the methods of Fisher (1953; 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, but the remaining samples gave a clear polarity indication. In Class III sites of 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 beds of the Cerrillos area range in dip from 30° to vertical, so it was possible to conduct a modified fold test for stability. Before the dip correction, the cleaned mean declination (D) was 1.4°, and inclination (I) was 338.9°; the precision parameter (k) was 1.2 and the ellipse of confidence (α_{95}) was 89.9°. After dip correction, the directions were much less scattered [D = 350.9, I = 44.6, k = 31.8, α_{95} = 16.6], showing that the remanence was acquired before tilting. In addition, the cleaned but uncorrected normal direction above is not parallel to the modern normal magnetic field, nor is the cleaned but uncorrected reversed mean [D = 178.5, I = 50.9, k = 2.7, α_{95} = 18.4]. This suggests that the magnetization was acquired prior to tilting.

Reversal tests for stability were conducted on the samples from both areas. The mean directions of all cleaned normal sites in the Cerrillos area shown above were antipodal to the mean direction of all reversed samples [D = 159.3, I = -36.8, k = 11.5, α_{95} = 12.8], indicating that the magnetization was probably acquired during deposition of the beds. The mean of normal samples in Arroyo del Tuerto [D = 325.3, I = 38.8, k = 13.3, α_{95} = 19.1] is also antipodal to the mean of reversed samples [D = 189.0, I = -48.2, k = 9.1, α_{95} = 19.4].

CORRELATION

The magnetic stratigraphy of the two sections is shown in Figures 4 and 5. The Arroyo del Tuerto section (Fig. 5) was mostly of normal polarity, except for reversed sites (upper unit 2) just below the brontothere quarry (locality T4) and in the uppermost site in the Espinaso Formation (unit 7). The Cerrillos section (Fig. 4) is mostly of reversed polarity, except for the two lowest sites just below locality C5 near Ambush Rock (units 73 and 74), and the top three sites (units 81 and 82), which include localities C6 and C8.

Without radioisotopic dates, these magnetic patterns are not diagnostic by themselves. Kautz et al. (1981,

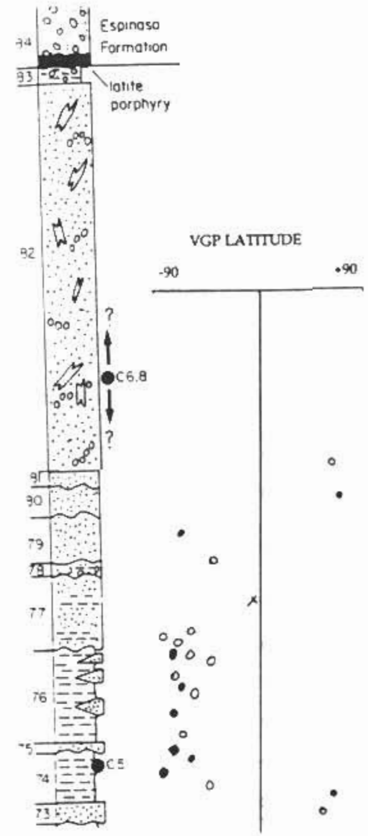

Figure 4. Lithostratigraphy and magnetic stratigraphy of the Duchesnean section in the Cerrillos area, based on Lucas (1982, fig. 4). Solid circles are Class I (significant) sites of Opdyke et al. (1977); open squares are Class II (only two samples) sites; open circles are Class III (one sample divergent) sites. Vertebrate fossil localities C5 and C6 and C8 are shown.

table 1) reported a K-Ar age of 34.3 ± 0.8 Ma for a calcic-quartz-latite clast from conglomeratic sandstone 10 m above the base of the Espinaso Formation in Arroyo del Tuerto, stratigraphically above our highest magnetic sample. This age seems much too young (see following discussion) unless there is a significant unconformity in the Espinaso Formation between our highest magnetic site and the radiometrically dated horizon. Indeed, Kautz et al. (1981, table 1) also reported a K-Ar age of 34.6 ± 0.7 Ma for a calcic-quartz-latite clast in a debris flow unit 200 m above the base of the Espinaso Formation. This supports the conclusion that their stratigraphically lower numerical age is anomalously young.

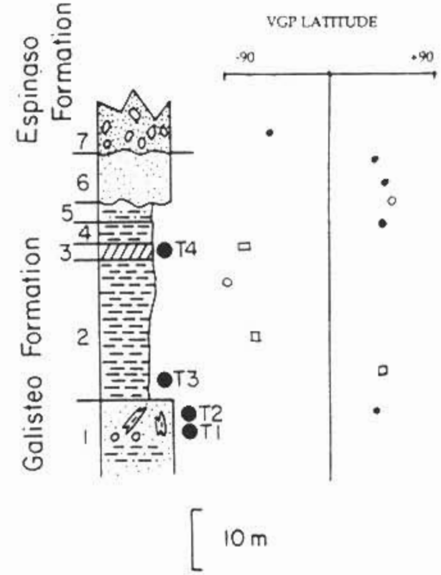

Figure 5. Lithostratigraphy and magnetic stratigraphy of the Arroyo del Tuerto section, after Lucas (1982, fig. 7). All conventions as in Figure 4. Vertebrate fossil localities T1-T4 are shown.

By comparing the Tonque l.f. with other Duchesnean faunas, it it possible to narrow down the possible correlations. Figure 6 shows the current interpretation of the age of several important Duchesnean faunas. In California, the early Duchesnean Pearson Ranch l.f. occurs in Chron C18n, and the late Duchesnean Simi Valley Landfill l.f. occurs in Chron C17r (Kelly, 1990; Kelly et al., 1991; Kelly and Whistler, 1994; Prothero et al., this volume, Chapter 8). In Trans-Pecos Texas, the late Duchesnean Skyline Channels l.f. probably occurs in Chron C17n3, and the late Duchesnean Porvenir l.f. occurs in Chron C17n2 (Prothero, this volume, Chapter 9). The Porvenir l.f. was recovered just above the Buckshot Ignimbrite, which has an $^{40}Ar/^{39}Ar$ date of 37.8 ± 0.15 Ma (Prothero and Swisher, 1992).

The Lapoint Ash in the type Duchesne River Formation of Utah yields a $^{40}Ar/^{39}Ar$ date of 39.74 ± 0.74 Ma (Prothero and Swisher, 1992). Much of the sparse Lapoint l.f. has no locality information, and so occurs an unknown distance above this dated ash (Emry, 1981). The best known locality, the Carnegie Museum *Teleodus* (now *Duchesneodus*—Lucas and Schoch, 1982, 1989) quarry, occurs approximately 50 m (150 feet) above it (Kay, 1934, Plate XLVI). No magnetic stratigraphy was possible in this part of the Duchesne

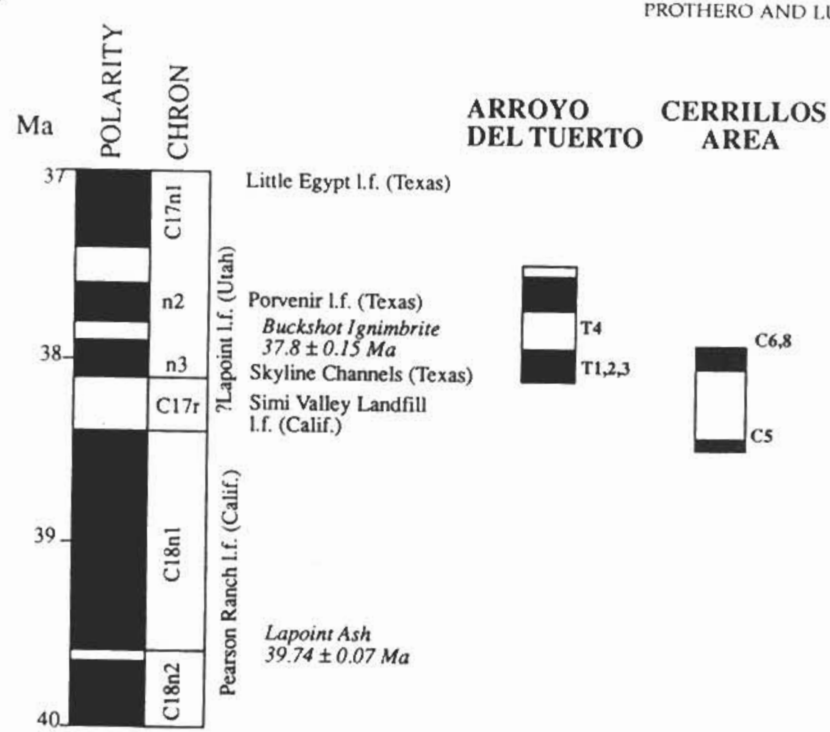

Figure 6. Suggested correlation of the magnetic sections in the Galisteo Formation. Time scale after Berggren et al. (1995). Other correlations and age assignments discussed in text.

River Formation (Prothero and Swisher, 1992; Prothero, this volume, Chapter 1). Some authors (Wilson, 1986; Kelly, 1990; Lucas, 1992) consider the Lapoint l.f. to be late Duchesnean, comparable to the Porvenir l.f. in age, and younger than the Pearson Ranch l.f.

Lucas (1992) suggested that the Tonque l.f. was also late Duchesnean, and most similar to the Porvenir and Lapoint local faunas. If this is true, then the long reversed polarity interval in the Cerrillos section is most likely Chron C17r, the only relatively long reversed interval in the late Duchesnean. The section probably spans the interval between C17n3 and C18n1, or about 38.0-38.5 Ma (Fig. 6). The two long normal polarity intervals of the Arroyo del Tuerto section, on the other hand, suggest a correlation with Chrons C17n2 and C17n3. If the section were younger, it would make the top of the section C17n1, which is correlatable with the Chadronian Little Egypt l.f. in Texas (Prothero, this volume, Chapter 9), a possibility we reject. If the section were older, then the lower normal interval would be C18n1, which is early Duchesnean. Thus, a correlation with Chrons C17r1 to C17n3, or about 37.5-38.0 Ma, appears to be the most reasonable interpretation.

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