9. Magnetostratigraphy of the Eocene-Oligocene Transition in Trans-Pecos Texas

DONALD R. PROTHERO

ABSTRACT

Previous studies of the Uintan, Duchesnean, and Chadronian rocks and their mammalian faunas of Trans-Pecos Texas are supplemented by more recent magnetostratigraphic research to provide a more up-to-date chronostratigraphic framework. In the Vieja area, reinterpretations of the work of Testarmata (1978; Testarmata and Gose, 1979), plus new magnetics, show that the Vieja Group (Colmena Chambers-Capote Mountain Tuffs) spans the interval from Chron C19r (42 Ma) to C13n (33 Ma). The early Duchesnean Candelaria l.f. occurs in Chron C19n (about 41.5 Ma), the late Duchesnean Porvenir l.f. and early Chadronian Little Egypt l.f. in Chron C17n (37-38 Ma), and the mid-Chadronian Airstrip l.f. in C16n (35.5 Ma). In the Agua Fria area, the Devil's Graveyard Formation spans the interval from C21n (46.5 Ma) to C13n (33 Ma), with a gap between C16n (35.5 Ma) and C18n (39 Ma) (wherein lie the Duchesnean faunas of the Skyline and Cotter channels). Revisions of Walton's (1992) magnetic interpretations place the late Bridgerian Junction l.f. in C21n (46.5 Ma), the early Uintan Whistler Squat l.f. in early C20r (45-46 Ma), the late Uintan Serendipity and Purple Bench l.f. in C19r (42 Ma) and C18r (41 Ma), respectively. The mid-Chadronian Coffee Cup l.f. occurs in Chron C15r (about 35 Ma).

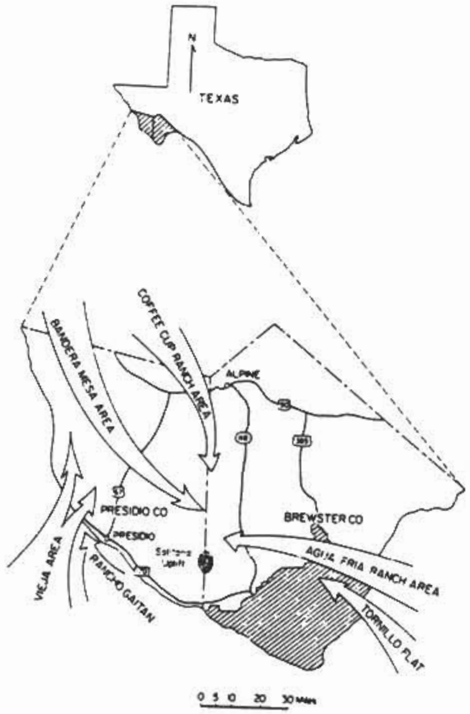
INTRODUCTION

The Trans-Pecos region of Texas is the only place in North America where the middle-late Eocene is recorded by superposed mammalian faunas datable by both radiometrics and magnetic stratigraphy. There is no place in North America that contains interfingering marine/nonmarine sequences of this age, so this area is the key to unlocking the details of the Uintan-Duchesnean-Chadronian transition in land mammals.

The Trans-Pecos rocks (Fig. 1) contain a number of well-studied faunas of middle Eocene (Uintan and Duchesnean) and late Eocene (Chadronian) age (Wilson et al., 1968; Wilson 1978, 1980, 1984, 1986) with extensive radioisotopic dating (McDowell, 1979; Henry et al., 1986; Henry and McDowell, 1986; Henry et al., 1994). The first magnetostratigraphic work in the area was by Margaret Testarmata (1978; Testarmata and Gose, 1979). She sampled rocks in the Vieja area (Fig. 1) between the Buckshot Ignimbrite and the Mitchell Mesa Rhyolite, which included the Chambers and Capote Mountain tuffs. However, Testarmata did not sample the late Uintan sections of Colmena Tuff, or many of the fossil localities of Duchesnean and Chadronian age in the area. Her sites were spaced about 1.5 m apart stratigraphically, but only a single sample was taken at each site, so no site statistics were calculated. Rock magnetic analyses (Testarmata, 1978, pp. 15-18) showed that the remanence was carried by fine-grained magnetite partially oxidized to hematite. Thermal demagnetization at 400-500°C gave the best results in her study.

Testarmata and Gose (1979, fig. 7) summarized their magnetic stratigraphy, which was extremely noisy, with many single-site normal "zones." Most of these "zones" are probably due to unremoved overprinting, which is hard to detect when only one sample per site is analyzed. It is possible, however, that some of these short polarity events might represent true "tiny wiggles" of the magnetic polarity time scale, which have been recently documented in the early Oligocene (Hartl et al., 1993). This "tiny wiggle" interpretation might be more likely in the cases of short polarity zones 2-3 sites in thickness. However, since the short zones cannot be correlated over distance, and do not seem to match any version of the magnetic polarity time scale, they are ignored in my correlations.

Once the shortest polarity events are discounted, Testarmata and Gose (1979) found a relatively long zone of reversed polarity running from just below the Bracks Rhyolite to above the Ford siltstone, which they correlated with Chron C12r (Fig. 2). They based these correlations on the K-Ar dates then known from the volcanic units, and using the magnetic time scale of LaBrecque et al. (1977). At that time, Chron C12r was thought to range from 33-35 Ma, and the K-Ar dates on the Bracks Rhyolite were 36.5 and 36.8 Ma. Unfortunately, a key



N.A. LAND MAMMAL AGE		VIEJA-OJINAGA AREA: Lithologic unit	K-Ar	Local fauna Mexico	Local fauna Texas	AGUA FRIA-GREEN VALLEY AREA: Lithologic unit			K-Ar	Local fauna or locality
CHADRONIAN		Mitchell Mesa Rhyolite	32 28		Ash Spring (Vieja Group undif.) Airstrip			Mitchell Mesa Rhyolite	32 28	
CHADRONIAN		Capote Mt. Tuff							33 04 basalt	
CHADRONIAN		Bracks Rhyolite	37 4 37 7	Rancho Gaitan	Little Egypt	Devil's Graveyard Formation	Bandera Mesa Member			Coffee Cup
DUCHESNEAN	Late	Chambers Tuff			Porvenir					Montgomery Bonebe
DUCHESNEAN	Early	Buckshot Ignimbrite	37 3 37 0				Middle member	Skyline channels		Cotter Channels Skyline
UINTAN	C	Colmena Tuff			Candelaria			Titanothere channels	42 70 tuff	Serendipity
UINTAN	B						Lower member	Basal Ten congl	43 90 biotite 49 70 46 90 tuff	Whistler Squat

Figure 1. Index map and summary stratigraphy of the Trans-Pecos Texas region (modified from Wilson, 1986).

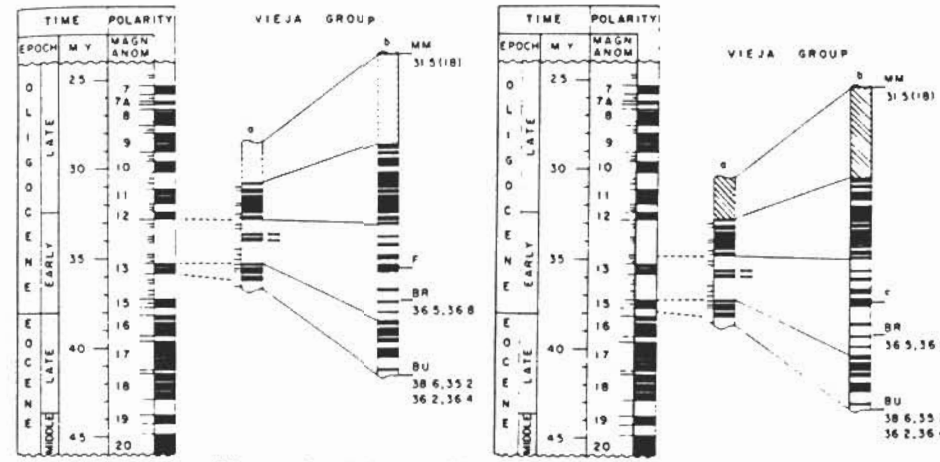


Figure 2. Interpretations of the magnetic polarity results of Testarmata and Gose (1979) on the left, and as reinterpreted by Prothero et al. (1982, 1983) on the right; from Wilson (1986).

interval just below the Mitchell Mesa Rhyolite did not produce a stable polarity signal, and thus was considered of indeterminate polarity.

As a result of magnetic correlations with Flagstaff Rim, Wyoming, Prothero et al. (1982, 1983) reinterpreted Testarmata and Gose's (1979) Vieja correlations (Fig. 2). Prothero et al. (1982, 1983) had found what they believed to be Chron C12r in middle Chadronian rocks at Flagstaff Rim between K-Ar dates of 32 and 36 Ma. Consequently, they thought that the Duchesnean-early Chadronian reversed interval in the Vieja Group (identified as Chron C12r by Testarmata and Gose) was probably correlative with the early Chadronian C13r. This was also in better agreement with the known K-Ar dates on the Bracks Rhyolite and the LaBrecque et al. (1977) time scale.

Another paleomagnetic study in the region was undertaken by Walton (1986, 1992), who sampled the lower and middle members of the Devil's Graveyard Formation in the Agua Fria area (Fig. 1; see also Stevens et al., 1984). Although multiple samples were typically collected per site, no site statistics were calculated. Rock magnetic analyses showed that most samples in her study contained detrital magnetite partially altered to hematite or goethite. Most normal overprints were apparently contained in goethite, as they were typically removed by about 250°C.

Walton (1992, fig. 3.8) correlated her results with Chrons C20n to C20r of the Berggren et al. (1992) time scale, based on the limited K-Ar dates that had been done previously. This placed late Uintan faunas (such as Purple Bench and Serendipity) in Chron C20n, supported by an overlying K-Ar date of 42.7 ± 1.6 Ma on a tuff high in the middle member. This correlation was accepted by Prothero and Swisher (1992) in tying the late Uintan faunas of the Uinta Basin to Chron C20n (see Prothero, this volume, Chapter 1).

Since that time, much better radiometric dating (especially by $^{40}Ar/^{39}Ar$ methods) and major changes in the magnetic polarity time scale (Cande and Kent, 1993; Berggren et al., 1995) have made all the previous correlations obsolete. The revised correlation is discussed below.

MAGNETIC ANALYSIS

For this study, over 100 sites (each containing a minimum of three samples) were collected from a number of key localities between 1990 and 1993. In most sections, sites were spaced at about 10 m intervals. All samples were taken with simple hand tools, then trimmed on a band saw with a tungsten carbide blade, and analyzed at the paleomagnetics laboratory at the California Institute of Technology. Each sample was first measured at NRM, and then demagnetized in alternating fields (AF) of 25-200 Gauss to remove any multidomain remanence. Then each sample was thermally demagnetized between 200° and 600°C in multiple steps.

As can be seen in the vector demagnetization ("Zijderveld") plots (Fig. 3), the magnetic intensity declined rapidly under AF treatment, indicating that a significant component of the remanence (especially in the overprinting) was carried by magnetite. A stable reversed component was apparent at temperatures of 200-300°C. In some cases, this reversed component persisted up to 600°C. This indicates that some of the remanence is carried by hematite, since the Curie point of magnetite is 580°C. Testarmata and Gose (1979, p.

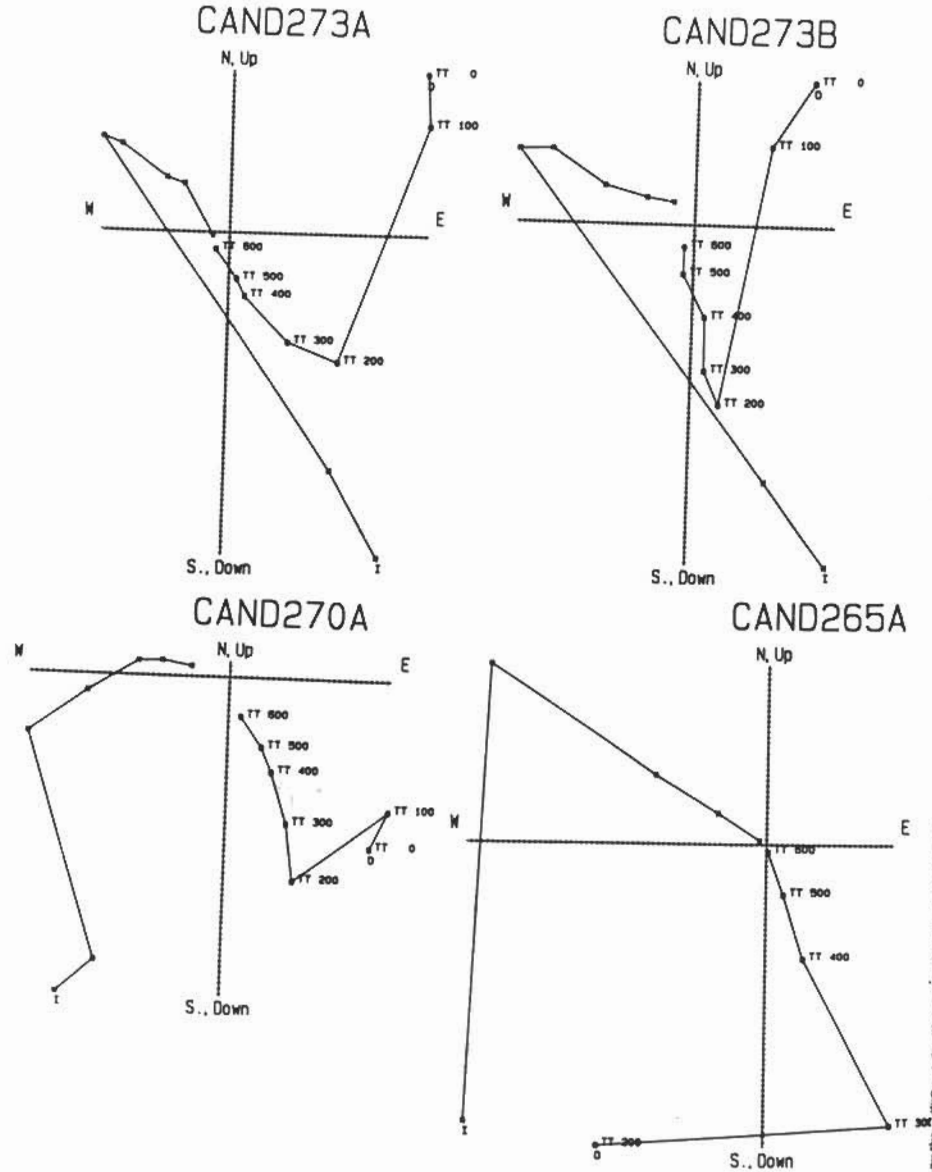


Figure 3. Vector demagnetization plots of thermal results on typical samples from Trans-Pecos Texas. All four samples are reversed, with a component of normal overprinting removed at temperatures of 200-400°C. From 300-600°C, most samples reveal a single stable component of magnetization. Since there is frequently some remanence left at 600°C, some of the magnetization must be due to a high Curie point mineral such as hematite. Open circles indicate the horizontal component, stars show the vertical component; I is the NRM value. Each increment equals 10^{-5} emu.

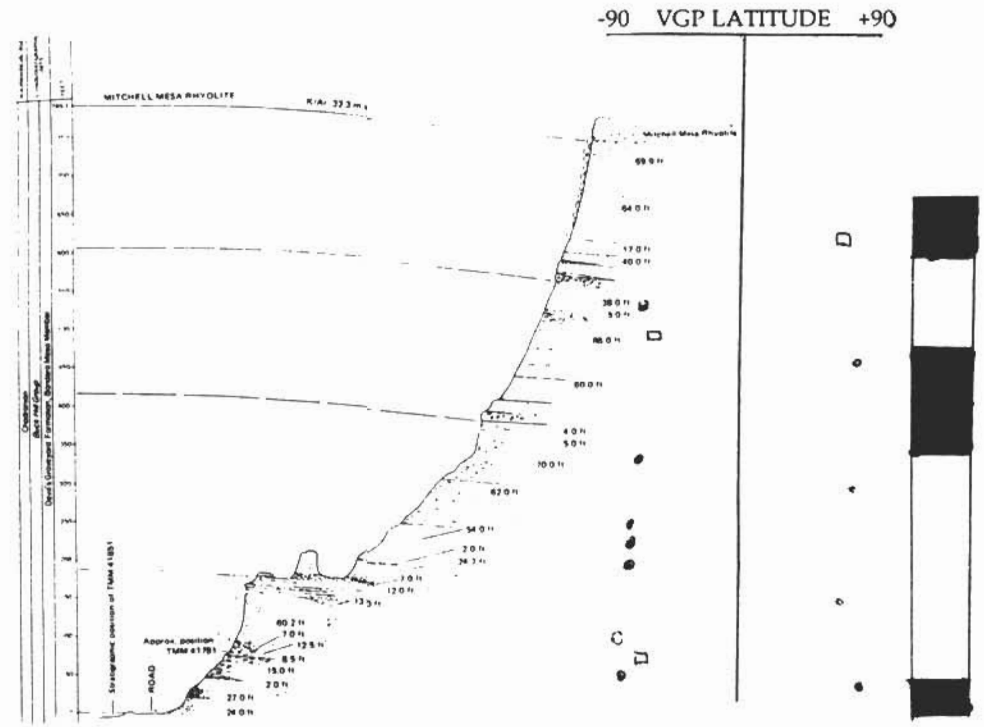


Figure 4. Magnetic stratigraphy of the stratotype Bandera Mesa Member of the Devil's Graveyard Formation, Agua Fria area, Texas (Stevens et al., 1984, fig. 10). The Chadronian Red Hill fauna (TMM 41781) is found at the base, and the Mitchell Mesa Ignimbrite occurs at the top. Positive virtual geomagnetic pole (VGP) latitudes indicate normal polarity; negative VGP latitudes indicate reversed polarity. Solid circles: Class I sites of Opdyke et al. (1977), which were significantly clustered at the 95% confidence level; open squares: Class II sites, in which one sample was lost or crumbled; open circles: Class III sites, in which two directions out of three showed a clear polarity preference. Stratigraphy from Wilson (1978, fig. 6).

57) reported that the polished sections of these rocks examined under reflected light showed magnetite which was partially oxidized to hematite, and this is in good agreement with our results.

Once the overprint was removed, thermal demagnetization at 400-500°C seemed to produce the most stable results, and these directions were used for further analysis. The directions showed good clustering around normal and reversed poles, and produced a positive reversal test, since the mean for the normal sites [n = 24, D = 342.8, I = 57.5, k = 7.3, α_{95} = 11.8] was antipodal to the mean for the reversed sites [n = 26, D = 163.9, I = -50.8, k = 6.4, α_{95} = 12.1].

A number of important sections were sampled. One section spanned about 800 feet of the stratotype Bandera Mesa Member, or upper member of the Devil's Graveyard Formation (Stevens et al., 1984, fig. 10). This section supplemented the research of Walton (1992), who studied the lower and middle members of this formation. As can be seen in Figure 4, the section was mostly of reversed polarity, with a normal polarity zone between 400 and 550 feet on the measured section, and another normal polarity zone from 650 feet to the Mitchell Mesa Rhyolite at the top.

A second long section spanned over 500 feet of the Colmena Tuff (Wilson, 1978, fig. 6), the primary locality for the early Duchesnean Candelaria local fauna. As shown in Figure 5, the first 100 feet of this section were reversed, followed by normal rocks from 100 to 375 feet, and reversed rocks to the top.

Sixty feet of the section in the Reeves Bonebed (Wilson, 1978, fig. 9), the primary collecting locality of the early Chadronian Little Egypt local fauna, were entirely of normal polarity.

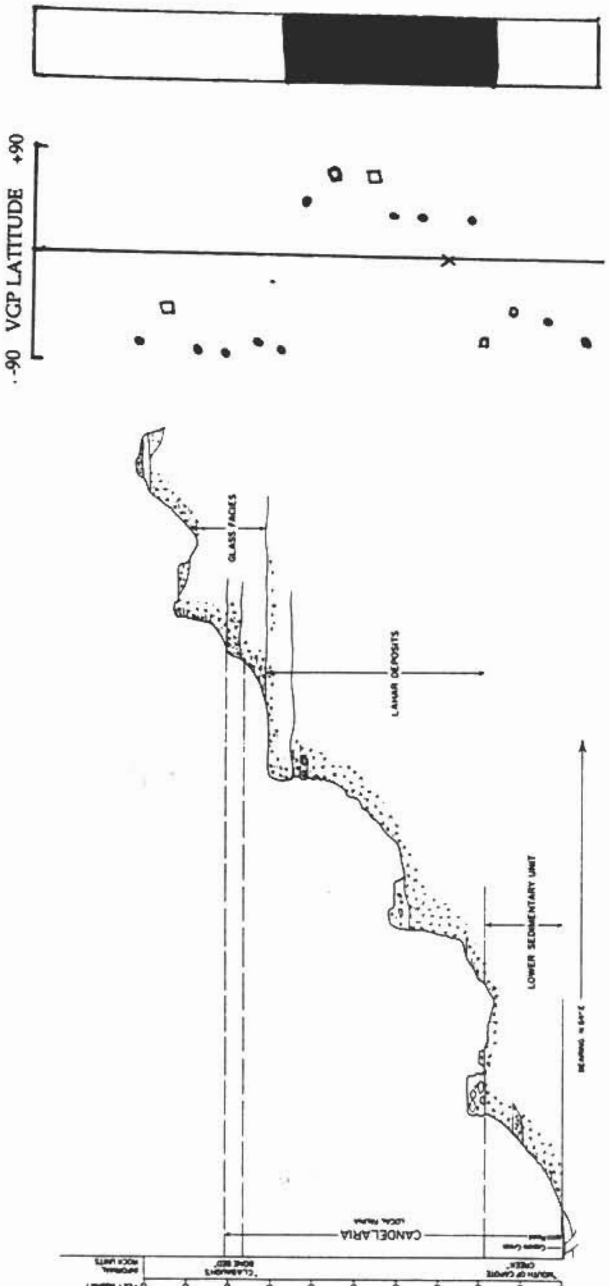


Figure 5. Preliminary magnetic polarity of the Colmena Tuff, near the mouth of Capote Creek, which contains the early Duchesnean Candelaria l.f. Magnetic conventions as in Figure 4.

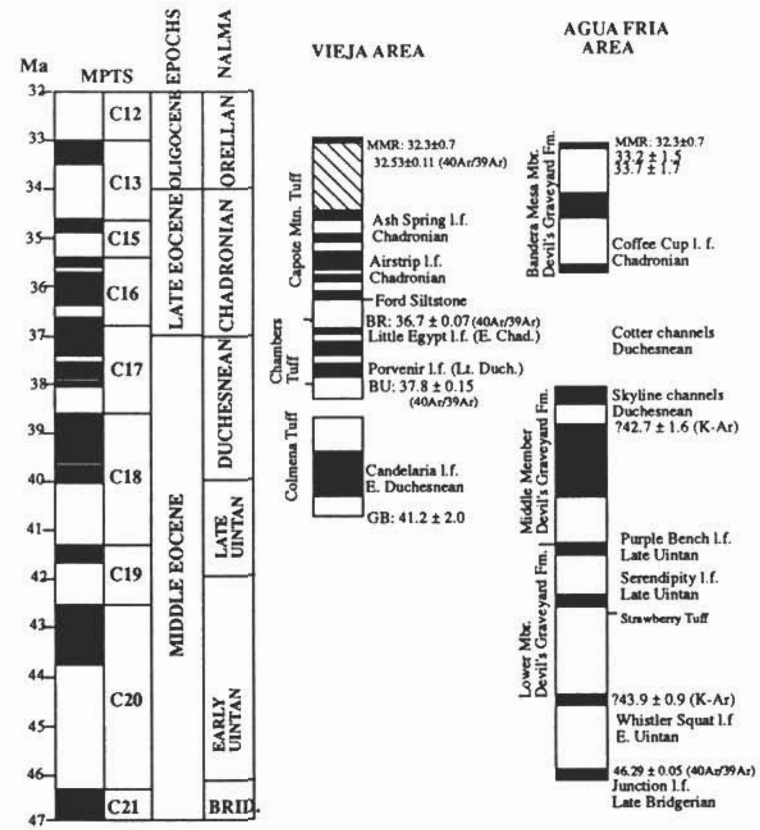


Figure 6. Tentative correlation of the magnetic stratigraphy of Testarmata (1978), Testarmata and Gose (1979), Walton (1992), and this study with the new time scale of Berggren et al. (1995), Cande and Kent (1993) and Prothero and Swisher (1992). Position of important mammalian faunas and radioisotopic dates are shown. All dates are K-Ar (from Henry et al., 1986), unless indicated otherwise. Diagonal cross-hachured pattern denotes section of indeterminate polarity. Abbreviations: BRID. = Bridgerian; BR = Bracks Rhyolite; BU = Buckshot Ignimbrite; GB = Gill Breccia; l.f. = local fauna; MMR = Mitchell Mesa Rhyolite; MPTS = magnetic polarity time scale; NALMA = North American land mammal "age."

The middle Chadronian Airstrip local fauna locality (Wilson, 1978, p. 22), spanning about 80 feet, was of normal polarity for the lower 60 feet; the top of the section was reversed in polarity.

CORRELATIONS

Figure 6 shows summary of the correlations of the sections analyzed in this study, plus those originally reported by Testarmata (1978), Testarmata and Gose (1979) and Walton (1986, 1992). They can be divided into two main areas, the Vieja area north of Candelaria (Wilson, 1978), and the Agua Fria-Green Valley area, just north of the west entrance to Big Bend National Park (Stevens et al., 1984; Wilson, 1986).

Agua Fria-Green Valley area

The Bandera Mesa section (Fig. 4) is constrained by the K-Ar date of 32.3 ± 0.7 Ma on the overlying Mitchell Mesa Rhyolite (Henry et al., 1986). Henry et al. (1994) also obtained $^{40}Ar/^{39}Ar$ dates of 32.53 ± 0.11 and 32.59 ± 0.11 Ma, so the two methods are in good agreement and the age of this unit is well established. Stevens et al. (1984) reported K-Ar dates of 33.2 ± 1.5 on a basalt and 33.7 ± 1.7 on a tuff from the upper part of the section (Fig. 6). The lowest part of the section contains the Chadronian Red Hill local fauna, part of the Coffee Cup fauna (Stevens et al., 1984; Wilson, 1986). Given these constraints, the simplest interpretation is that the lower part of the section probably correlates with C15r, the middle normal zone with C15n, and the upper reversed part of the section with C13r (Fig. 6).

Walton (1992, fig. 3.8) reported magnetic results for the lower and middle members of the Devil's Graveyard Formation. She correlated her section with Chrons C19n-C20r. Since her paper, however, the new magnetic polarity time scale (Cande and Kent, 1993; Berggren et al., 1995) have suggested a reinterpretation. The late Uintan in the Uinta Basin is now thought to begin in Chron C20n, so this moves the late Uintan Serendipity local fauna from C20r (as Walton suggested) to C19r-C19n (in agreement with other late Uintan localities in North America). This revised correlation, in turn, suggests that the long normal zone in the middle of the middle member is probably C18n. The bulk of the reversed rock in the lower member probably represents C19r to C20r, and the late Bridgerian faunas at the base of the section appear to come from rocks of normal magnetic polarity representing Chron C21n. These new interpretations are in agreement with the K-Ar date of 43.9 ± 0.9 Ma on the dated tuff just above the early Uintan Whistler Squat local fauna, with K-Ar dates of 46 Ma on the Alamo Creek Basalt near the base of the section (Henry et al., 1986), and with $^{40}Ar/^{39}Ar$ dates of 46.0 ± 1.0 Ma and 46.29 ± 0.05 Ma on a tuff just below the Alamo Creek basalt (Henry et al., 1994). Only the K-Ar date of 42.7 ± 1.6 from just below the Duchesnean Skyline channels is discordant; it should be reanalyzed by $^{40}Ar/^{39}Ar$ methods. According to Margaret Stevens (personal communication), this 42.7 Ma date came from very tiny flakes of biotite, so it is probably not very reliable. The Duchesnean begins around 39-40 Ma (Prothero and Swisher, 1992), so the 42.7 date seems much too old.

Between the two sections is a 200-foot interval represented by numerous stacked river channels, and little or no continuous section (Stevens et al., 1984). The correlations shown in Figure 6 suggest a 3 million-year gap in the Devil's Graveyard Formation section between the upper C16n rocks at the base of the Bandera Mesa Member section (35.5 Ma) and the C18n rocks just below the Skyline channels (38.5 Ma). These channel sequences produce early Duchesnean mammals from the Skyline channels, and late Duchesnean mammals from the overlying Cotter channels (Wilson, 1986; Wilson and Stevens, 1986). Because this section is discontinuous, the polarity of the individual channel deposits is not very informative, and so they were not sampled.

Vieja area

The thick section of Colmena Tuff (Fig. 5), which produces the Candelaria local fauna, overlies the Gill Breccia (K-Ar dated at 41.2 ± 2.0 Ma), and underlies the Buckshot Ignimbrite ($^{40}Ar/^{39}Ar$ dated at 37.8 ± 0.15, according to Swisher and Prothero, 1990, and Prothero and Swisher, 1992; 37.54 ± 0.11 Ma by Henry et al., 1994). The Candelaria l.f. was originally interpreted at late Uintan by Wilson (1978). Krishtalka et al. (1987, p. 104) compare it to the late Uintan Randlett and Halfway faunas of the Duchesne River Formation. Prothero and Swisher (1992) and Prothero (this volume, Chapter 1) found that the lowest or Brennan Basin Member of the Duchesne River Formation (containing the Randlett horizon) correlates with Chrons C19r-C18r. Consequently, the long normal zone within the Colmena Tuff appears to correlate with Chron C19n, with parts of C19r and C18r also represented (Fig. 6).

The magnetic results of Testarmata (1978) and Testarmata and Gose (1979) have long been controversial (Prothero et al., 1982, 1983; Prothero, 1985; Wilson, 1986; Swisher and Prothero, 1990; Prothero and Swisher, 1992). As discussed above, these rocks produced a very noisy pattern, with many short zones of normal and reversed polarity. By resampling and reanalyzing these data, and rejecting normal polarity zones less than 3 sites thick (typically prone to unremoved normal overprinting), some clarification is possible (Fig. 6). There are three undoubted short zones of normal polarity in the Chambers Tuff between the Buckshot Ignimbrite and the Bracks Rhyolite ($^{40}Ar/^{39}Ar$ dated at 36.7 ± 0.07 Ma by Prothero and Swisher, 1992, and 36.73 ± 0.13 by Henry et al., 1994). These dates, and the Cande and Kent (1993) or Berggren et al. (1995) magnetic polarity time scale, suggest that these normal intervals are the multiple events of Chron C17n. The late Duchesnean Porvenir local fauna occurs in the lower part of the Chambers Tuff, and is probably correlative with early Chron C17n. The early Chadronian Little Egypt local fauna (based on the Reeves Bonebed section, which was entirely of normal polarity) probably correlates with the upper part of C17n.

Although the magnetic results in the Capote Mountain Tuff were particularly noisy and difficult to interpret, there are some constraints on its age. The section is bracketed by dates on the Bracks Rhyolite at the base, and the Mitchell Mesa Rhyolite at the top. The lower third of the section (between the Bracks Rhyolite and Ford Siltstone) was entirely reversed, and probably corresponds to C16r. Above the Ford Siltstone, there were two longer zones of normal polarity, spanning 80-130 m on Testarmata's (1978, fig. 15) section "D"; these plus other short normals probably correlate to the multiple events of Chron C16n. Above 130 meters, the section is mostly of reversed polarity, and probably represents C15r. The upper third of the Chambers Tuff section in the Adobe Spring area was unstably magnetized, and so is labeled "indeterminate" by Testarmata and Gose (1979), and also here (Fig. 6). This interval is probably equivalent to Chrons C15r to C13n, based on the constraining date (see above) of the normally polarized Mitchell Mesa Rhyolite at the top.

On this basis, the normal-reversed pattern in the Airstrip section (which produced middle Chadronian mammals) probably correlates to the events within Chron C16n, based on similarities with the faunas below Ash A at Flagstaff Rim, Wyoming (see Emry, 1992). The Ash Spring section (which produced slightly younger Chadronian mammals) probably correlates with C13r, based on the presence of late Chadronian taxa such as *Merycoidodon culbertsoni* (see Stevens and Stevens, this volume, Chapter 25).

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