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MAGNETIC STRATIGRAPHY OF THE MIDDLE EOCENE (DUCHESNEAN) BACA FORMATION, WEST-CENTRAL NEW MEXICO

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Abstract—The Baca Formation in west-central New Mexico consists of about 180 m of siliciclastic red beds deposited by fluvial and lacustrine systems. It yields a fragmentary but important Duchesnean (late middle Eocene) mammalian fauna, including the primitive entelodont *Brachyhyops wyomingensis*, the creodont *Hyaenodon* sp. (both of which first occur in the Duchesnean), plus the primitive artiodactyls *Protoreodon pumilus* and the brontothere *Diplacodon* sp. (both Uintan holdovers), and fragmentary agriochoerid oreodonts, camelids, and protoceratids. The section at Mariano Mesa (north of the town of Quemado in Catron County) yields Duchesnean age mammals and was sampled for magnetostratigraphy. The samples were then subjected to alternating field demagnetization at 25, 50, and 100 Gauss, followed by thermal demagnetization at 50°C steps from 200 to 630°C. These samples yielded a stable single component of remanence that passed a reversal test, and was held largely in magnetite with minor goethite overprints. The entire sampled section is of reversed polarity. Based on radioisotopic dates of ~ 38.0 Ma from the overlying Spears Formation volcanics (lower part of the Datil Group), we correlate the Duchesnean interval of the Baca Formation with Chron C17r (38.2-38.3 Ma), which is middle Duchesnean. This correlates to the Duchesnean interval of the Galisteo Formation in north-central New Mexico, suggesting a synchronous transition from Laramide tectonism to intermediate volcanism in north-central and west-central New Mexico that began during the middle Eocene.

Keywords: Eocene, New Mexico, Baca Formation, Duchesnean.

INTRODUCTION

The Baca Formation of Wilpolt and Wanek (1946) crops out in a discontinuous belt for about 250 km in west-central (Catron and Socorro Counties) New Mexico, from near Magdalena, New Mexico, westward across the border into Springerville, Arizona (Fig. 1). Most outcrops average about 180 m in thickness, with a maximum of 370 m (Snyder, 1971; Cather, 1980, 1982). The Baca Formation consists mostly of red mudstones, sandstones, and lesser amounts of claystone and conglomerate. This unit is thought to represent a braided fluvial-alluvial fan system to the west, and a lacustrine system to the east (e.g., Cather, 1982). The Baca Formation disconformably overlies the Upper Cretaceous Mesaverde Group (mostly the Crevasse Canyon Formation). It is overlain by the Spears Formation (lower Datil Group) volcanics; the contact between these units is conformable and gradational (Cather, 1982).

Fossil mammals have been found in the braided-alluvial plain facies of the Baca Formation. Snyder (1970, 1971) first reported specimens of the artiodactyl *Protoreodon pumilus*, which suggested a Uintan age for the Baca Formation. Schrodt (1980) and Schiebout and Schrodt (1981) discovered and reported additional mammal fossil including specimens they assigned to brontotheres (which they called *Menodus* sp.), the creodont *Hyaenodon* sp., the entelodont *Brachyhyops wyomingensis*, the oromercyid *Eotylopus* sp., and the ruminant *Leptomeryx* sp. They assigned these mammals a Chadronian age, based largely on comparison with the Porvenir local fauna of Trans-Pecos Texas, which they considered Chadronian, in agreement with Wilson (1978).

However, Lucas (1983) re-examined these fossils, and presented different identifications. He referred the brontothere to *Diplacodon* sp., the "*Leptomeryx*" to a protoceratid such as *Leptoreodon*, and the "*Eotylopus*" to an indeterminate camelid. He also reported the presence of a fragmentary agriochoerid as well. This revised interpretation of these fossils no longer supports a Chadronian age for the Baca Formation, but instead is consistent with a middle or late Duchesnean age.

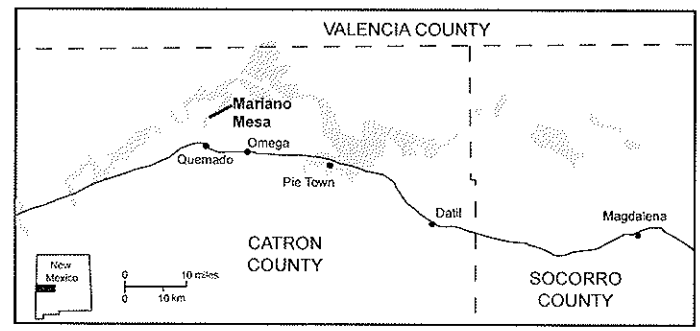

FIGURE 1. Location map of the Baca Formation (after Lucas, 1983).

Diplacodon, *Leptoreodon*, and *Protoreodon* are Uintan holdovers that are also known from the Duchesnean (but not the Chadronian), while *Hyaenodon* and *Brachyhyops* first appear in the Duchesnean and continue into the early Chadronian. Thus, the Duchesnean age of the fauna (as currently known) is well established (Lucas, 1992; Lucas and Williamson, 1993). In addition, there was some confusion because earlier authors considered the Uintan to be late Eocene, the Duchesnean late Eocene or early Oligocene, and the Chadronian early Oligocene. Recent radioisotopic dating and paleomagnetic analysis has shown that the Uintan is late middle Eocene, the Duchesnean latest middle Eocene, and the Chadronian is late Eocene in age (Prothero and Swisher, 1992; Prothero and Emry, 1996). Lucas (1990) reported a brontothere metacarpal from stratigraphically low in the Baca Formation, which suggests that the base of the formation is Bridgerian or Uintan in age.

Further confirmation of this interpretation comes from radioisotopic dates of the overlying Spears Formation (lowermost unit of the Datil Group). A spectrum of K-Ar and fission-track ages from these volcanics yield ages that cluster around 38 Ma for the base of the Datil volcanics (Cather et al., 1987), with a $^{40}Ar/^{39}Ar$ date as young as 37.02 ± 0.15 Ma, and one K/Ar date as old as 41.8 ± 3.0 Ma (this last date

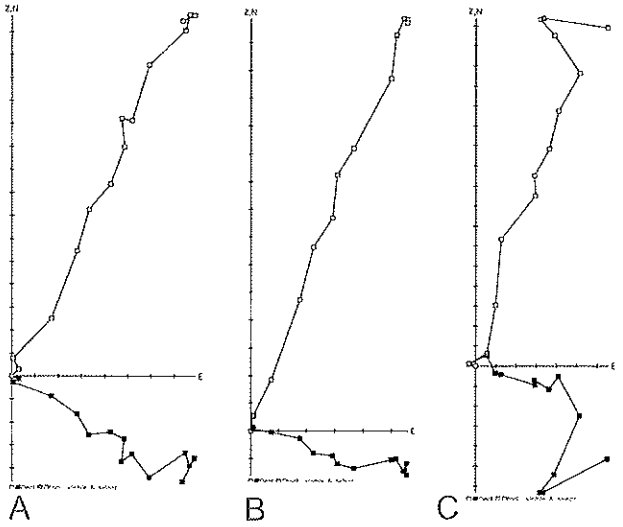

FIGURE 2. Orthogonal demagnetization ("Zijderveld") plots of representative samples. Solid squares indicate declination (horizontal component); open squares indicate inclination (vertical component). First step is NRM, followed by AF steps of 25, 50, and 100 Gauss, then thermal steps from 200° to 630°C in 50°C increments. Each division equals 10^{-5} emu.

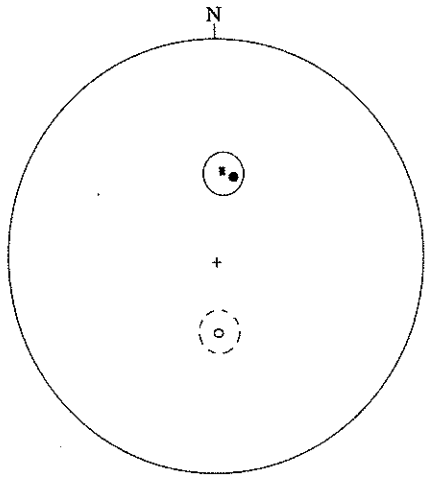

FIGURE 3. Stereonet of mean of reversed sites. Open circle and dashed line indicate mean of reversed samples (upper hemisphere projection). Solid square and solid line indicates projection of reversed mean and error estimates to the lower hemisphere of the stereonet. Solid square indicates the expected Eocene pole position, which is antipodal to the reversed mean for the Baca Formation.

was considered questionable by Cather et al., 1987). Thus, the Baca Formation must be older than 38 Ma, which rules out a Chadronian age for the fauna, since the Chadronian ranges from 34 to 37 Ma (Prothero and Swisher, 1992). Instead, this is consistent with a Duchesnean interpretation of the fossils, which ranges in age from 37 to 40 Ma (Prothero and Emry, 1996). However, the lower limit of the age of the Baca Formation cannot be determined from radioisotopic dates, and can only be constrained by the fauna, and by magnetic stratigraphy.

METHODS

In the spring of 2003, sampling was conducted on the thickest, most fossiliferous section of the Baca Formation on the southwestern face of Mariano Mesa from the base of Sonoreno Draw to the tuff bed at the top of the mesa (NW ¼ NW ¼ SE ¼ , sec. 21, T3N R16W, Mariano Springs 7.5-minute quadrangle, Catron County, New Mexico). Sixteen paleomagnetic sites (3 samples per site) were taken from regularly-spaced intervals covering 80 m of section, with samples of both resistant sandstone ledges and also mudstones. Samples were taken as oriented blocks of rock with simple hand tools, and then wrapped and carried back to the laboratory. There, they were subsampled into cores using a drill press, or if the sample was too crumbly, casts into disks of Zircar aluminum ceramic. The samples were then analyzed on a 2G cryogenic magnetometer with an automatic sample changer at the California Institute of Technology. After measurement of NRM (natural remanent magnetization), they were demagnetized in alternating fields (AF) of 25, 50, and 100 Gauss to prevent the remanence of multi-domain grains from being baked in, and to examine the coercivity behavior of each specimen. AF demagnetization was followed by thermal demagnetization of every sample in 50°C steps from 200° to 630°C to get rid of high-coercivity chemical overprints due to iron hydroxides such as goethite, and to determine how much remanence was left after the Curie temperature of magnetite (580°C) was exceeded.

Results were plotted on orthogonal demagnetization ("Zijderveld") plots, and average directions of each sample were determined by the least-squares method of Kirschvink (1980). Mean directions for each sample were then analyzed using Fisher (1953) statistics, and classified according to the scheme of Opdyke et al. (1977).

RESULTS

Orthogonal demagnetization ("Zijderveld") plots of representative samples are shown in Figure 2. In nearly every sample, there was a single component of remanence that was pointed south and down at NRM, indicating that the sample is reversed in polarity. There was a slight high-coercivity component (shown by the minimal drop of intensity in the first three demagnetization steps in Figure 2), probably due to some chemical remanence due to iron hydroxides, such as goethite. This is not surprising, given the red color of the rocks, but apparently the overprint was not significant, because it was quickly removed by thermal demagnetization at 200°C (above the temperature at which iron hydroxides are dehydrated to hematite). The rest of the remanence appears to be held in magnetite, because it declined in intensity rapidly through thermal demagnetization, vanished above the Curie temperature of magnetite and no remanence was left at 600° or 630°C (Fig. 2).

All 16 sites at Mariano Mesa were reversed in polarity (Fig. 3). Site statistics are given in Table 1. All but one site was statistically

TABLE 1. Paleomagnetic data from the Baca Formation

SITE	DEC	INC	K	α_{95}
1	163.7	-74.1	28.4	23.6
2	184.6	-57.8	11.1	38.9
3	140.3	-62.9	59.6	16.1
4	171.2	-50.5	5.8	56.4
5	180.1	-75.5	32.0	22.2
6	187.2	-49.9	6.6	52.6
7	194.5	-56.9	11.0	39.1
8	199.3	-63.1	9.8	41.8
9	143.6	-66.1	52.1	17.2
10	161.7	-68.4	48.0	36.9
11	205.9	-42.0	14.1	34.2
12	163.6	-59.5	9.8	41.6
13	179.5	-43.6	10.8	39.6
14	192.0	-54.2	17.9	30.1
15	173.6	-62.9	9.3	42.8
16	182.7	-39.2	13.4	35.0

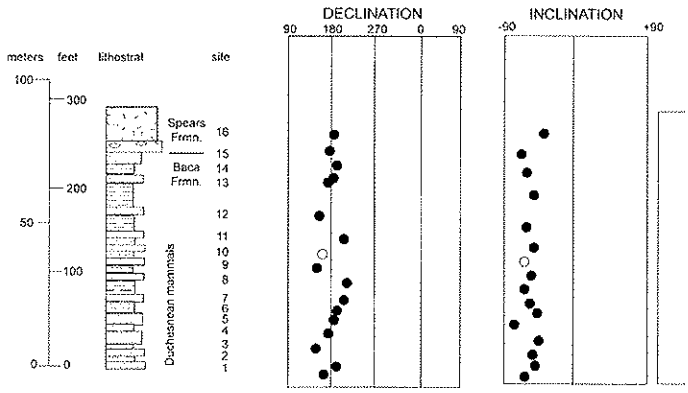

FIGURE 4. Lithostratigraphy and magnetic stratigraphy of the Baca Formation at Mariano Mesa. Declination and inclination of magnetic sites are shown. Solid circles are sites that are statistically removed from a random distribution at the 95% confidence level (Class I sites of Opdyke et al., 1977); open circle represents a site with only two samples, so site statistics could not be calculated (Class II site of Opdyke et al., 1977).

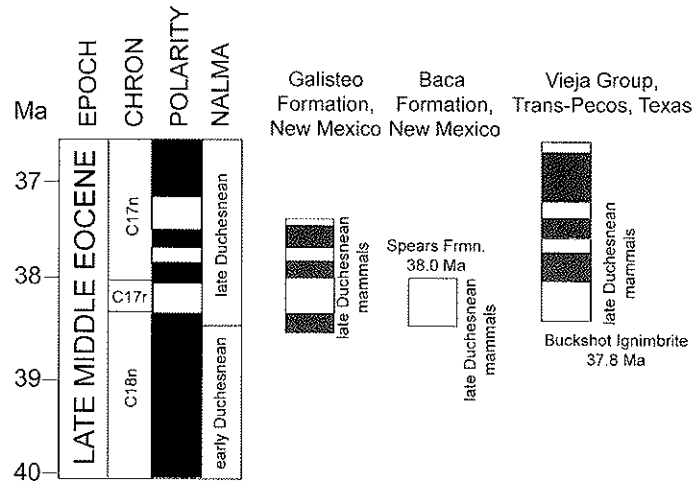

FIGURE 5. Correlation of the Baca Formation paleomagnetic section, based on the dates and age constraints discussed in the text. Magnetic stratigraphy of the Galisteo Formation after Prothero and Lucas (1996), and of the Texas section after Prothero (1996). Time scale after Berggren et al. (1995) and Prothero and Emry (1996).

significant, i.e., separated from a random distribution at the 95% confidence level (Class I sites of Opdyke et al., 1977); the exception (site 10) failed the significance test because one sample crumbled, so only two samples remained to be measured (Class II site of Opdyke et al., 1977).

Because only reversed polarity sites and no normal sites were obtained, it is impossible to conduct a conventional reversal test for stability. However, the reversed mean (D = 179.1, I = -59.1, k = 32.1, α_{95} = 6.6, n = 16) is antipodal to the normal magnetic direction expected for this latitude in the Eocene (Fig. 4), so it is clearly a primary or characteristic remanence, and overprinting has been removed.

DISCUSSION

By itself, the 80 m of reversed polarity in the Mariano Mesa section of the Baca Formation is not age diagnostic. However, the presence of a Duchesnean mammal fauna in the interval of reversed polarity, and the overlying date of ~ 38.0 Ma places age constraints that give one unambiguous correlation of this reversed polarity magnetozone (Fig. 5). According to Prothero and Emry (1996), the early Duchesnean is entirely normal in polarity (Chron C18n), and the only reversed magnetic interval in the time scale of Berggren et al. (1995) that is older than 38.0 Ma is Chron C17r (38.0-38.3 Ma). Thus, our best interpretation is that the Mariano Mesa section of the Baca Formation correlates with Chron C17r.

This correlation is consistent with the interpretation of the Galisteo Formation in north-central New Mexico, which yields middle-late Duchesnean mammals and correlates with Chron C17n-C18n (Prothero and Lucas, 1996). It is also consistent with the earlier interpretation that the Baca mammals are comparable to those of the Porvenir local fauna of Trans-Pecos Texas, which correlates with Chron C17n-C17r, and is underlain by a $^{40}Ar/^{39}Ar$ date of 37.8 ± 0.15 Ma on the Buckshot Ignimbrite (Prothero, 1996). The middle Eocene age of the upper parts of both the Baca and Galisteo formations in north-central and west-central New Mexico indicates that the transition from Laramide deformation to intermediate volcanism began in this part of New Mexico in the late middle Eocene (around 38 Ma).

CONCLUSION

Magnetostratigraphic analysis of the Mariano Mesa section shows that the upper part of the Baca Formation correlates with Chron C17r (38.0-38.3 Ma), i.e., is late Duchesnean in age. Older parts of the formation may be as old as Bridgerian or Uintan. This correlation of the upper part of the Baca Formation is comparable to that of the Duchesnean Galisteo Formation of north-central New Mexico, and suggests that the transition from Laramide tectonism to intermediate volcanism in north-central and west-central New Mexico began in the middle Eocene.

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