Revised age constraints for Late Cretaceous to early Paleocene terrestrial strata from the Dawson Creek section, Big Bend National Park, west Texas

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ABSTRACT

We analyzed samples for paleomagnetism, ⁴⁰Ar/³⁹Ar detrital sanidine ages, and mammalian fauna to produce a precise chronostratigraphic framework for the Upper Cretaceous to lower Paleocene Dawson Creek section of Big Bend National Park. Prior to this work, the absolute age and duration of the Upper Cretaceous Aguja and Javelina Formations and Paleocene Black Peaks Formation were relatively poorly constrained. The documented polarity zones can be correlated to C32n-C31n, C29r, and C27r of the geomagnetic polarity time scale (GPTS) with three hiatuses spanning more than 1.5 myr each. Rock magnetic analyses indicate that the

dominant magnetic carrier in the Aguja and Black Peaks Formations is titanomagnetite while the Javelina Formation has varying magnetic carriers including hematite, magnetite, and maghemite. An overprint interval surrounding the K-Pg boundary suggests the primary magnetic carrier, titanohematite, was likely reset by burial and/or overlying basaltic flows. These are the first independent age constraints for the Cretaceous-Paleocene strata at the Dawson Creek section that determines the age and duration of deposition of each formation in the section, as well as the age and duration of multiple unconformities through the succession. As a result, these age constraints can be used to reassess biostratigraphic and isotopic correlations between the Big Bend area and other Cretaceous-Paleogene (K-Pg) basins across North America. Based on this new data, we reassign the age of the mammalian fauna found in the Black Peaks Formation from the Puercan to the Torrejonian North American Land Mammal age. Our age constraints show that the dinosaur fauna in the Javelina Formation in the Dawson Creek area is latest Maastrichtian and restricted to C29r. Thus, the Javelina dinosaur fauna is correlative to the Hell Creek Formation dinosaur fauna from the Northern Great Plains, indicating differences between the faunas are not due to differences in age and providing support for the hypothesis of provinciality and endemism in dinosaur communities in the late Maastrichtian. Further, the age constraints indicate that the previously documented mid-Maastrichtian and late Maastrichtian greenhouse events were rapid (<200 kyr) and correlate closely with climate events documented in the marine record.

INTRODUCTION

The Dawson Creek section within Big Bend National Park, Texas documents a series of Cretaceous through lower Paleocene alluvial deposits that accumulated along a passive continental margin within the Tornillo Basin of west Texas (Fig. 1). This coastal plain succession has been the focus of several lithostratigraphic, cyclostratigraphic, paleopedologic, magnetostratigraphic, and paleontologic studies (e.g., Lawson, 1972; Standhardt, 1986; Lehman, 1989a, 1990; Nordt et al., 2003; Atchley et al., 2004). The Cretaceous dinosaur and early Paleocene mammalian faunas from Big Bend, and particularly from the Dawson Creek area, are key for understanding regional patterns in dinosaur and mammal community diversity and biostratigraphy. Dawson Creek is the southernmost latest Cretaceous (late Maastrichtian) terrestrial vertebrate fossil site in North America. Therefore, it forms a critical dataset necessary for assessing patterns of endemism in Campanian and Maastrichtian dinosaur faunas across North America (e.g., Standhardt, 1986; Lehman, 1997, 2001; Lofgren et al., 2004; Sampson et al., 2010; Lucas et al., 2016). Additionally, analyses of paleosols at the Dawson Creek section have been used to argue for two short-lived greenhouse events during the Maastrichtian (Nordt et al., 2003; Dworkin et al., 2005). Despite the importance of Dawson Creek record for understanding Cretaceous and Paleocene paleoclimate and the composition of vertebrate communities, the absolute age and duration of the Upper Cretaceous Aguja and Javelina Formations and Paleocene Black Peaks Formation are relatively poorly constrained.

In this study, we develop a precise chronostratigraphic framework for the Dawson Creek section using magnetostratigraphy, $^{40}\text{Ar}/^{39}\text{Ar}$ detrital sanidine geochronology, and

biostratigraphy based on a reevaluation of the vertebrate fauna. From these analyses, we determine the age and duration of deposition of each formation in the section, as well as the age and duration of multiple unconformities through the succession. Finally, we use these new age constraints to assess the implications for biostratigraphic and isotopic correlations between the Big Bend area and other Cretaceous-Paleogene (K-Pg) basins across North America and the global marine record.

PREVIOUS WORK

Geochronology

Previous studies used a combination of biostratigraphy, estimates of sedimentation rates based on paleosol maturity, and correlations of local isotope stratigraphy to marine isotope curves to produce a chronostratigraphic framework for the Dawson Creek area (e.g., Lehman, 1990; Nordt et al., 2003; Atchley et al., 2004). The existing age determinations indicate the section spans from the latest Campanian through the early Paleocene (Nordt et al., 2003) when adjusted to reflect the most recent age of the K-Pg boundary (e.g., Renne et al., 2013; Clyde et al., 2016). The Aguja Formation elsewhere in the park is interpreted to be stratigraphically equivalent to the base of the Dawson Creek section and contains a late Campanian vertebrate fauna (Rowe et al., 1992; Lehman, 1985; Wick and Lehman, 2013). Based on this correlation, the base of the Dawson Creek section has been interpreted to be close to the Campanian-Maastrichtian boundary (Lehman and Busbey, 2007). Based on the last occurrence of dinosaur fossils and the first occurrence of Paleocene mammals, the K-Pg boundary has traditionally been

identified in the Dawson Creek section to be at approximately the contact between the Javelina and Black Peaks Formations (Lehman, 1990). However, recent ichnological work documents an abrupt decrease in adhesive meniscate burrow diameter within a sandstone channel of the Javelina Formation at 172 m in the Dawson Creek section, interpreted to represent the post-extinction recovery community, and thus the stratigraphic position of the K-Pg boundary (Fig. 2; Wiest et al., 2017). Lehman (1990) used preliminary magnetostratigraphy (MacFadden in Standhardt, 1986) to argue that the Black Peaks Formation correlated to C29r-C28r meaning that the top of the section is older than 64.6 Ma, which is the end of C28r (Ogg, 2012). Correlations between stable isotopic trends from pedogenic carbonate nodules through the Dawson Creek section and carbon isotopes from marine deposits combined with the location of cyclostratigraphic boundaries, were used to indicate the presence of multiple hiatuses in the section (Nordt et al., 2003; Atchley et al., 2004). However, the duration of these unconformities or their exact age is uncertain.

There was a preliminary attempt to use magnetostratigraphy at Dawson Creek by B.J. MacFadden (*in* Standhardt, 1986) to determine the age of the section. In this work, the local polarity stratigraphy that was developed was correlated to C30n through C28r. However, MacFadden (*in* Standhardt, 1986) noted that large parts of the section were overprinted and as a result this magnetostratigraphic framework has not been accepted, though it was used by Lehman (1990) to estimate an approximate minimum age for the top of the section.

In other areas of the park, volcanic deposits within the upper portion of the Aguja Formation have been dated to 76.9 ± 1.2 Ma (Befus et al., 2008) and 72.6 ± 1.5 Ma (Breyer et

al., 2007) using U-Pb dating, suggesting the Aguja Formation is Campanian. A monazite U-Pb age of 69.0 ± 0.9 Ma for a tuff occurring within the Javelina Formation, 90 m stratigraphically below the K-Pg boundary, from the northern part of Big Bend National Park indicates that all or at least the majority of the Javelina Formation was deposited during the Maastrichtian (Lehman et al., 2006).

Paleoclimate and Depositional Environments

Previous geochemical research focused on paleosols through the succession documented two Late Cretaceous greenhouse events using isotopic composition of pedogenic carbonate nodules, referred to as the mid-Maastrichtian event and late Maastrichtian event (Nordt et al., 2003). This work used correlations of the local isotope stratigraphy with marine isotope curves to adjust the ages of these events. When adjusted to reflect the most recent age of the K-Pg boundary (Ogg, 2012; Renne et al., 2013), the mid-Maastrichtian event occurs from ~71 to 70 Ma and the late Maastrichtian event occurs from ~66.2 to 66.3 Ma. Work done by Lehman (1990) on the Paleocene paleosols found a transition towards increased rainfall and cooler temperatures using paleosol macromorphology.

Alluvial stacking pattern analyses of the Aguja, Javelina, and Black Peaks Formations indicate that deposits in the Dawson Creek area were deposited cyclically (Atchley et al., 2004). Changes in stacking pattern thicknesses were interpreted to represent the rate of change of base level rise and fall and suggest that the primary control on stratigraphic cyclicity in the Dawson Creek section was eustatic sea level change, despite the succession being deposited exclusively

in the continental realm (Atchley et al., 2004). Interestingly, despite evidence for shifts in climate
through the section, there does not appear to be evidence for climate change strongly influencing
deposition (Atchley et al, 2004), which differs from evidence from other parts of the Big Bend
area (Bataille et al., 2016).

Vertebrate paleontology

Fossil vertebrates have been collected from the Big Bend National Park area for over 70
years and the Dawson Creek area contains a record of terrestrial vertebrate fossil localities
throughout the Javelina and Black Peaks Formations. These faunas are of particular interest
because they represent the southernmost latest Cretaceous and early Paleocene faunas of North
America, and thus are important for understanding terrestrial vertebrate biogeographic patterns
across the K-Pg boundary.

Disagreement on the placement of the formational boundaries between these units has
resulted in differences in the taxa reported from each of the formations (e.g., Standhardt, 1986;
Lehman, 1990; Rowe et al., 1992). For example, Standhardt (1986) considered the Javelina and
Black Peaks members of the Tornillo Formation and placed the Javelina-Black Peaks boundary
to be above the mammal-bearing localities discussed here. Herein, we use the stratigraphic
nomenclature and position of formational contacts of Lehman (1990), Nordt et al. (2003), and
Atchley et al. (2004). Thus, we place all Paleocene mammal localities within the Black Peaks
Formation, and all dinosaur faunas within the Javelina and Aguja Formations.

Aguja Formation

The Aguja Formation contains a rich vertebrate fauna that includes microvertebrate fossils collected through screenwashing techniques. These include chondrichthyan and actinopterygian fish (Rowe et al., 1992; Sankey, 1998; Standhardt, 1986), amphibians (Rowe et al., 1992; Lehman, 1985; Sankey, 1998; Standhardt, 1986), squamates (Rowe et al., 1992; Sankey, 1998; Standhardt, 1986; Nydam et al., 2013), turtles (Rowe et al., 1992; Sankey, 2008; Standhardt, 1986; Tomlinson, 1997), crocodylians (Colbert and Bird, 1954; Lehman, 1985; Rowe et al., 1992; Sankey, 2008; Standhardt, 1986), pterosaurs (Rowe et al., 1992), dinosaurs (Davies, 1983; Forster et al., 1993; Larson and Currie, 2013; Lehman, 1982, 1985, 1989b, 2010; Longrich et al., 2010, 2013; Prieto-Marquez, 2013; Rivera-Sylva et al., 2016; Rowe et al., 1992; Sankey, 1998, 2001, 2008; Sankey et al., 2005; Standhardt, 1986; Wagner, 2001; Wagner and Lehman, 2009; Wick et al., 2015), and mammals (Cifelli, 1995; Rowe et al., 1992; Weil, 1992).

Nearly all the seemingly valid dinosaur taxa identified from the Aguja Formation appear to be endemic. Several of the taxa such as *Texacephale* (see Jasinski and Sullivan, 2011) are probably not valid. Several small theropod taxa that are based on isolated teeth (e.g., *Saurornitholestes langstoni*, *Richardoestesia gilmorei*, and *R. isosceles*; Sankey, 2001, 2008) have been identified in temporally and geographically wide-ranging faunas throughout western North America, though it is likely that many, if not most of these, are not correctly identified as small theropod taxa were probably exclusive to discrete time intervals and geographic areas (Larson and Currie, 2013).

Mammals from the Aguja Formation include several genera that are typical of Late Cretaceous faunas of western North America (e.g., *Alphadon*, *Turgididon*, *Pedimys*; Rowe et al., 1992). One species, the multituberculate *Cimolomys clarki*, indicates the Aguja mammalian fauna correlates to the Judithian North American Land Mammal age (NALMA; Cifelli et al., 2004).

Javelina Formation

In the Dawson Creek area, a relatively small vertebrate fauna has been reported from the middle and upper Javelina Formation and fossil specimens tend to be fragmentary, though bone beds containing multiple dinosaurs have been documented within the Javelina Formation in other areas of Big Bend National Park (Hunt and Lehman, 2008). The Javelina fauna includes the giant pterosaur *Quetzalcoatlus* from TMM 41501 in Dawson Creek (Table 1 and Fig. 2) (Lawson, 1975), and a number of dinosaurs, detailed below.

At least one chasmosaurine ceratopsian, *Bravoceratops polyphemus*, is present in the Javelina Formation of the Big Bend area, based on fragmentary specimens (Wick and Lehman, 2013) and this was regarded as being near in age to the Edmontonian-Lancian boundary. Fragmentary skulls and partial skeletons from the middle and upper Javelina Formation have been referred to, or tentatively referred to, *Torosaurus utahensis* (Lawson, 1976; Lehman, 1996; Hunt and Lehman, 2008), a taxon originally described from the North Horn Formation of Utah (see Sullivan et al., 2005). At least one taxon of a large titanosaurian sauropod has been identified from the Javelina Formation. Many of the sauropod specimens lack diagnostic

characters to allow generic identification, but at least some can be confidently referred to
Alamosaurus sanjuanensis (Lehman and Coulson, 2002; Fronimos and Lehman, 2014; Tykoski
and Fiorillo, 2016). Some specimens of a large titanosaurian sauropod, probably representing
Alamosaurus, have been described from the TMM 41450 (LSU VL-106) locality within the
Javelina Formation in the Dawson Creek section (Table 1 and Fig. 2) (Lawson, 1972;
Standhardt, 1986), as well as near the top of the Cretaceous part of the section of the Rough Run
area, which is near Dawson Creek (Fronimos and Lehman, 2014). A large tyrannosaurid,
referred to *Tyrannosaurus rex* (Carr and Williamson, 2000, 2004), is present based on isolated
postcranial bones (Wick, 2014) and on a partial maxilla (Lawson, 1975; Wick, 2014). At least
two small theropod dinosaurs have been documented based on isolated teeth: *Saurornitholestes*
cf. *S. langstoni* and *Saurornitholestes* n. sp.? (Sankey et al., 2005). Other dinosaurs reported from
the Javelina Formation, but not well documented, are indeterminate hadrosaurs, ankylosaurs, and
ornithomimids (Lawson, 1972; Lehman, 1985, 1990).

Several workers have reported that Lancian age mammals and herpetofaunas are present
in the Javelina Formation, citing Standhardt (1986). Standhardt (1986) reported a small
microfauna from LSU locality VL-113 (“Running Lizard”) in the Dawson Creek area, which she
described as being from the upper Aguja Formation; however, based on its stratigraphic position
it is more likely from the Javelina Formation. She indicated a Lancian age for the fauna based on
the presence of a fragmentary tooth that she referred to *Alphadon marshi*, a taxon restricted to
the Lancian NALMA (Cifelli et al., 2004). However, we find that the tooth fragment is too
incomplete to be diagnostic to genus or species.

The Javelina dinosaur fauna has been included in the latest Cretaceous “*Alamosaurus* community” (Sloan, 1969) or “*Alamosaurus* fauna” (Lehman, 1987), based primarily on the presence of the titanosauriform sauropod *Alamosaurus*, which is absent from contemporaneous latest Cretaceous faunas of the northern Rocky Mountain Region. Lehman (1987) argued that *Alamosaurus* was confined to seasonal, semi-arid intermontane basins south of about 35°N latitude, unlike the contemporaneous “*Triceratops* fauna”, which was not environmentally restricted (Lehman, 1987). However, other workers have argued that the distribution of *Alamosaurus* does not reflect latitudinal faunal provinciality, but instead may be related to differences in ages between the *Alamosaurus* fauna of southern North America and the *Triceratops* fauna from the Northern Great Plains or due to other environmental factors such as distance from the shoreline with *Alamosaurus* restricted to more “inland” environments (e.g., Mannion and Upchurch, 2010; Lucas et al., 2016). Therefore, given the limited extent of the *Alamosaurus* fauna, determining the precise age of the Javelina Formation is of interest to further understanding possible latitudinal faunal provinciality or environmental heterogeneity during the latest Cretaceous of North America.

Black Peaks Formation

The Black Peaks Formation contains a diverse vertebrate fauna that includes a ray, a gar, amphibians, lizards, a champsosaur, turtles, crocodiles, and mammals (Schiebout, 1974; Schiebout et al., 1987; Standhardt, 1986; Brochu, 2000; Lehman and Barnes, 2010; Cobb, 2016).

The mammalian fauna found in the Black Peaks Formation has long been recognized as being Paleocene in age (e.g., Schiebout, 1974; Schiebout et al., 1987; Standhardt, 1986), based on the presence of diagnostic Torrejonian, Tiffanian, and possibly Clarkforkian NALMA taxa. In the Dawson Creek area there are two mammalian faunas within the Black Peaks Formation: TMM 41400 (LSU VL-111; “Tom’s Top”; Fig. 2) in Dawson Creek and TMM 42327 (LSU VL-108; “Dogie”) from nearby Rough Run Amphitheater about 5 miles (8 km) east of the Dawson Creek section (Lehman and Busbey, 2007; Cobb, 2016). TMM 41400 and TMM 42327 have both yielded diverse microvertebrate assemblages that are 20 m and 80 m above the highest occurrence of dinosaur bones in those areas, respectively (see Lehman and Busbey, 2007; Cobb, 2016). Standhardt (1986) and Schiebout et al. (1987) described or provided a faunal list of several mammalian taxa recovered from low in the Black Peaks Formation that included a combination of Puercan and Torrejonian genera and species, leading them to conclude that these faunas are late Puercan. However, some workers have argued that those faunas are not Puercan, but Torrejonian in age (Williamson, 1996; Lehman and Busbey, 2007).

METHODOLOGY

Paleomagnetism

Four paleomagnetic block samples were collected from paleosols and fine-grained sandstones at ~1 m intervals (0.3 m minimum and 2 m maximum sample spacing), through the section. A total of 121 localities were sampled. A flat face was shaved onto the samples *in situ*

using a hand rasp and the orientation was measured using a Brunton compass. In the laboratory,
the samples were cut into approximately 2 cm³ cubes using a diamond-bit saw.

Three hundred and sixty samples were measured at Baylor University using a 2G
cryogenic DC-SQUID magnetometer located in a 2-layer magnetostatic shielded room with a
background field typically less than 300 nT. A dip correction was applied to the section based on
field measurements ranging from 14°-36°. All samples were demagnetized using a combined
alternative-field (AF) and thermal demagnetization strategy following the methods of Peppe et
al. (2009). Samples were first given a low-AF pre-treatment (50 and 100 MT steps) to remove
any low-coercivity viscous or isothermal remanence. Thermal demagnetization steps were
performed in 20-50° increments up to the maximum unblocking temperature or until samples
became erratic and unstable (between 250-600°C). Thermal demagnetization was performed
using a nitrogen atmosphere using ASC controlled atmosphere thermal demagnetizer to
minimize oxidation reactions.

The characteristic remanence for samples was isolated using principal-component
analysis (PCA) (Kirschvink, 1980). A best-fit line was calculated from a minimum of three
demagnetization steps that trended toward the origin and had a maximum angle of deviation
(MAD) <20° (Figs. 3A, 3B, and 3C). Specimens that were analyzed by great circles were used if
they had a MAD <20° (Fig. 3D). Virtual geomagnetic pole directions for circles were calculated
using their last stable end point used in the great circle calculation. Data from specimens that had
erratic demagnetization behaviors were excluded from analysis (Fig. 3E). A site mean direction
was calculated for all sites with three samples with statistically significant directions using Fisher

statistics (Fisher, 1953). Only sites that pass the Watson test for randomness (Watson, 1956)
were used. Reversal boundaries were placed at the stratigraphic midpoints between samples of
opposing polarity. The local polarity stratigraphy was then correlated to the geomagnetic polarity
time scale (GPTS) (Ogg, 2012).

Rock Magnetism

Rock magnetic analyses were performed at the Institute for Rock Magnetism at the
University of Minnesota. High temperature susceptibility measurements were collected on 8 rock
samples using a Geofyzika KLY-2 Kappabridge AC Susceptibility meter in air. Measurements
were recorded on warming from room temperature to 650°C and cooling back to room
temperature. The first derivative of the measurements was used to determine the Curie
temperatures. Hysteresis loops were measured on a MicroMag Princeton Measurements
vibrating sample magnetometer (VSM) on eight samples at temperatures ranging from 30°C to
600°C.

The Quantum Design Magnetic Properties Measurement System (MPMS) was used for
low-temperature remanence measurements on eight samples. The protocol included field-cooled
(FC) remanence, zero-field-cooled (ZFC) low-temperature saturation isothermal remanent
magnetization (LTSIRM), and room temperature saturation isothermal remanent magnetization
(RTSIRM) following the methods of Sprain et al. (2016). This method involves initially applying
a sustained DC field of 2.5 T on a sample as it cools from 300 K to 20 K (FC). The field is then
turned off and remanence is measured while the sample warms to 300 K. The sample is cooled

back down to 20 K with no field applied (ZFC) after which a 2.5 T LTSIRM applied.
Remanence is measured while the sample warms back to 300 K. While at 300 K, a 2.5 T SIRM
(RTSIRM) is applied and the remanence is measured while cooling down to 20 K then warming
to 300 K.

Detrital Sanidine Dating

Four samples were collected in the field from channels within the Aguja, Javelina, and
Black Peaks Formations. Sample SS02 was taken at the base of the channel above paleosol 23
(Fig. 2). Samples SS07 and SS08 were taken within the Javelina Formation from the top of the
channel below P10 and from the base of the channel below paleosol 19, respectively (Fig. 2).
Sample SS13, from the Black Peaks Formation, was taken at the base of the channel above
paleosol 28.

All processing and mineral separations were done at the New Mexico Geochronology
Research Laboratory (NMGRL). Sample separation included: crushing & grinding whole rocks,
cleaning with H₂O and HF acid, and sieving to appropriate grain size. Magnetic and heavy liquid
density separation was used to concentrate the K-feldspar grains. Sanidine was hand-picked from
the bulk feldspar separate based on optical clarity as viewed under a binocular microscope. As
shown later by the argon analyses, the picked clear grains contained significant plagioclase and
quartz.

The sample crystals were irradiated at the TRIGA reactor in Denver, Colorado for 16
hours in the NM-276 package along with Fish Canyon Sanidine interlaboratory standard FC-2

with an assigned age of 28.201 Ma (Kuiper et al., 2008). Ages are calculated with a total ^{40}K
decay constant of $5.463\text{e-}10$ /a (Min et al., 2000).

After irradiation, six crystals of FC-2 from each monitor hole and ~100 sample crystals
were loaded into copper trays, evacuated and baked at 140°C for 4 hours. Sample crystals were
fused with a CO₂ laser and the extracted gas was cleaned with a NP 10 getter operated at 1.5 A
for 30 seconds. The gas was analyzed for argon isotopes using an ARGUS VI multicollector
mass spectrometer equipped with five Faraday cups, and one ion counting multiplier (CDD). The
configuration had ^{40}Ar , ^{39}Ar , ^{38}Ar , ^{37}Ar and ^{36}Ar on the H1, AX, L1, L2, and CDD detectors,
respectively. All data acquisition was accomplished with NM Tech Pychron software and data
reduction used Mass Spec (v. 7.875) written by Al Deino at the Berkeley Geochronology
Laboratory. Extraction line blank plus mass spectrometer background data are given in Table
DR3.

Minimum age populations are generally defined by choosing the youngest dates that form
a normal distribution as defined by the MSWD value of the distribution. The minimum age is the
inverse variance weighted mean of the selected crystals and the error is the square root of the
sum of $1/\sigma^2$ values. The error is also multiplied by the square root of the MSWD for MSWD
greater than 1. J-error is included for all weighted mean ages and all errors are reported at 1σ
unless otherwise noted.

A description and reevaluation of the therian component of the mammalian faunas, which is primarily on isolated and often fragmentary teeth, was undertaken by detailed examination of the specimens collected by Schiebout, Standhardt, and collaborators from the TMM 41400 (LSU VL-111; Tom's Top; Fig. 2), TMM 42327 (LSU VL-108; Dogie), and other localities from Big Bend (Schiebout, 1974; Schiebout et al., 1987; Standhardt, 1986). We also reevaluated the taxonomy of the Cretaceous dinosaur faunas from the Javelina and Aguja Formations.

RESULTS

Magnetostratigraphy

Three hundred and sixty samples were analyzed from 121 sampling horizons. The samples can be divided into four subsets based on demagnetization behavior. The demagnetization trajectory of 36% of samples began with a strong north and moderately downward overprint that was mostly removed by about 275°C (Fig. 3A) up to 450°C (Figs. 3B and 3C), after which the stable endpoint was reached. The second subset, encompassing 28% of samples, had a demagnetization trajectory that was best characterized by a great circle. For these samples, the VGP latitude and longitude was calculated using the last coherent direction along a great circle trajectory (Fig. 3D), which was usually not a stable endpoint but which was sufficient to define polarity. The third subset of samples, 11% of samples, had an erratic demagnetization trajectory where a good direction could not be calculated (Fig. 3E). These samples were not used for polarity interpretation. The fourth subset comprised of the remaining 25% of samples had a stable direction between 100-300°C, which then became erratic (Fig. 3F).

The VGPs of these samples consistently overlaps with the modern direction and they have been interpreted to be completely overprinted. Consequently, these samples were not used for polarity interpretation.

In total, 235 samples from 121 sampling horizons composed the first and second subsets above and were used to calculate directions (Fig. 7; Table 2; Table DR4; Table DR5). Site mean directions were calculated from fifteen sample horizons that had three samples with statistically significant directions and passed the Watson test for randomness (Watson, 1956) (Table DR6). The mean VGP latitude and longitude for Late Cretaceous reversed samples (local polarity B-) is -88°N , 274.7°E ($n=23$; $a_{95}=12.1$) and normal samples (local polarity A+, C+) is 76.4°N , 26.7°E ($n=30$, $a_{95}=7.3$). The mean VGP latitude and longitude for K-Pg samples (D-.1) is -79.5°N , 288.2°E ($n=57$, $a_{95}=6.3$). The mean VGP latitude and longitude for early Paleocene samples (D-.2) is -76.9°N , 191.6°E ($n=21$, $a_{95}=12.8$). These pole locations are significantly distinct from the Cretaceous and Paleocene reference paleomagnetic pole for North America (Fig. 7) (Torsvik et al., 2008). There is also a small but consistent clockwise directional offset from the expected direction, which has no effect on our polarity interpretations. The origin of the directional offset and the difference between our calculated VGPs and the Cretaceous and Paleocene reference poles is likely due to variability in dip throughout the section, which may have been overcorrected for, and syndepositional/early post-deposition inclination shallowing, with a flattening factor of $\sim 10\%$.

The local polarity stratigraphy shows each sample direction and site means (Fig. 2). Polarity zones A- through D-.2 are highlighted along with interpreted hiatuses. An overprint

interval is present at the top of the Javelina Formation and the base of the Black Peaks Formation
from 177 to 194 m (Fig. 2). In this interval, there is a high proportion of overprint line fits and
great circles where the direction was calculated from the last stable endpoint.

Detrital sanidine dating

The detrital sanidine dates in this study are used to correlate the deposits to the GPTS and
to constrain the maximum deposition age. The age probability plots for all samples and
associated analytical results are provided in Figure 8. Figure 2 shows the stratigraphic position of
each detrital sanidine sample.

The Aguja Formation sample, SS02, has a minimum age population (= maximum
depositional age) of 76.28 ± 0.06 Ma. Two samples were dated from the Javelina Formation,
SS07 and SS08. Sample SS07 recorded a minimum age population of 68.83 ± 0.13 Ma whereas,
sample SS08 has a well-defined minimum age population at 68.08 ± 0.03 Ma. The sample from
the Black Peaks Formation, SS13, has a minimum age population of 70.6 ± 0.4 Ma. However,
the maximum depositional age is defined by a single grain dated to 65.9 ± 0.4 Ma.

Rock Magnetism

The dominant magnetic mineralogy in the Aguja Formation is a low-Ti titanomagnetite
indicated by a 525°C Curie temperature in high temperature hysteresis loops and a Verwey
transition at about 110 K, lower than expected for pure magnetite (Figs. 9A and 9B). High
temperature hysteresis loops for a normal polarity sample from the A+ interval of the Aguja

Formation show a 600°C Curie temperature suggesting the presence of maghemite as well. Field-cooled/zero field-cooled curves from low temperature rock magnetometry for a reversed polarity sample from the B- interval of the Aguja Formation converge at 300 K suggesting goethite is also a magnetic carrier.

Throughout the Javelina Formation, the dominant magnetic mineralogy varies. For the basal portion of the formation, samples with statistically significant reversed directions (B- interval) have >600°C Curie temperatures measured from high temperature susceptibility and hysteresis loops, which indicates hematite is the primary magnetic mineral (Figs. 9C and 9D). In the overlying C+ interval, low temperature rock magnetometry measurements for a representative normal polarity sample show a pronounced Verwey transition at 120 K, with $M_{FC} > M_{ZFC}$, suggesting single domain magnetite is the dominant magnetic carrier (Figs. 9E and 9F). Both high temperature susceptibility measurements and hysteresis loops demonstrate a 600°C Curie temperature signaling maghemite is the dominant magnetic mineralogy over the D- interval of the Javelina Formation (Figs. 9G and 9H).

A large number of samples are interpreted to be overprinted in the upper portion of the Javelina Formation and lower portion of the Black Peaks Formation (Fig. 2). Rock magnetic analysis for a representative overprinted sample and representative reversed sample within this interval indicates that titanohematite is the dominant magnetic carrier with minor amounts of magnetite. RTSIRM curves indicate an approximate twofold increase in remanence which could suggest either goethite or titanohematite (Figs. 10A and 10C) (Dekkers, 1989; France and Oldfield, 2000). However, FC-ZFC-LTSIRM curves also show little to no separation between

FC and ZFC curves, which would be expected with goethite (Figs. 10B and 10D). Consequently,
titano hematite is the most likely magnetic carrier. This interpretation is further supported by the
similar character of the curves to those interpreted as titano hematite by Sprain et al. (2016).
Overprinted samples were differentiated from a K-Pg normal polarity based on the presence of
titano hematite and VGPs that overlapped with modern.

Titanomagnetite is the dominant magnetic carrier in the Black Peaks Formation above the
overprinted interval as indicated by a 560°C Curie temperature and 110 K Verwey transition in
high temperature susceptibility, low temperature magnetometry, and high temperature hysteresis
loops (Figs. 9I and 9J). Titanohematite also appears to be a secondary magnetic carrier in this
interval.

Vertebrate paleontology

The results of a reevaluation of the lower Black Peaks Formation faunas of the Dawson
Creek, Rough Run, and possibly correlative areas of Big Bend National Park are summarized in
Figures 5 and 6, Table 3, and the Appendix. Mammals originally identified as Puercan NALMA
taxa (i.e., *Eoconodon*, *Periptychus coarctatus* [= *Carsiptychus coarctatus*], and *Ellipsodon*
priscus) were misidentified and instead represent typical and in some cases defining Torrejonian
taxa (*Triisodon coryphaeus*, *Periptychus carinidens*, and *Ellipsodon* cf. *E. inaequidens*) (Table
3). In addition, we describe two new species that are endemic to the Black Peaks Formation of
Big Bend National Park (see Appendix).

The fauna from low in the Paleocene of the Dawson Creek section (TMM locality 41400 [LSU VL-111]; Tom's Top) can be confidently placed within the Torrejonian NALMA based on the presence of several characteristic Torrejonian taxa (see Lofgren et al., 2004): the genera *Bryanictis*, *Mixodectes*, *Plesiolestes*, and *Promioclaenus*. Moreover, two of these taxa are represented by species known only from the middle Torrejonian (To2), *Mixodectes malaris* and *Plesiolestes nacimienti*. *M. malaris* is an index taxon for the middle Torrejonian and is restricted to chron C27r of the Nacimiento Formation (Williamson, 1996), and is also present in the Swain Quarry fauna of the Fort Union Formation of Wyoming (Rigby, 1980). *Promioclaenus lemuroides* is also tentatively identified in the fauna and is restricted to the Torrejonian of western North America where it is present in Montana, Wyoming, Utah, and New Mexico.

The fauna from TMM 42327 (LSU VL-108; Dogie) of Rough Run Amphitheater is also firmly established to be Torrejonian because it contains the defining taxon for the Torrejonian: *Periptychus carinidens*. That fauna also contains a number of other taxa including *Bryanictis*, *Ellipsodon*, and *Mioclaenus* that are elsewhere restricted to the Torrejonian. *Ellipsodon* is from the middle Torrejonian (To2), and the species *E. inaequidens*, which is tentatively identified in the Dogie fauna, is restricted to the lower part of chron C27r in the Nacimiento Formation, in the *Protoselene opisthacus* – *Ellipsodon granger* [Tj2] and *E. granger* – *Arctocyon ferox* [Tj3] zones (after Williamson, 1996).

Following the reevaluation of the Tom's Top and Dogie faunas, we find that no fossil therian mammals that are restricted to the Puercan are present in the Black Peaks Formation, and instead the fauna is comprised of Torrejonian taxa. Thus, we can confidently correlate these

fossil localities to the Torrejonian NALMA (Table 3; a complete description of the therian
mammals from these localities is contained in the Appendix). Further, given the occurrence of
taxa in both localities that are restricted to the middle Torrejonian in the San Juan Basin in New
Mexico, we tentatively correlate both TMM 41400 (Tom's Top) and TMM 42327 (Dogie) to the
Torrejonian 2 NALMA.

The reidentification of taxa from localities low in the Black Peaks Formation and
reevaluation of the resulting biochronology of the Aguja, Javelina, and Black Peaks Formations
indicates that the Aguja fauna correlates to the Judithian NALMA, the Javelina fauna to the
Lancian NALMA, and the Black Peaks fauna to the Torrejonian. Therefore, there is likely a
significant hiatus between the vertebrate localities in the Aguja Formation and the Javelina
Formation and another major hiatus between the vertebrate localities in Javelina Formation and
the Black Peaks Formation.

DISCUSSION

Magnetic mineralogy

The dominant magnetic mineralogy of the Aguja and Black Peaks Formations is
titanomagnetite. The Javelina Formation contains various magnetic mineralogies including
hematite, single domain magnetite, maghemite, and titanohematite. The presence of
titanohematite as a magnetic carrier can explain much of the overprint signal in the upper portion
of the Javelina Formation and lower portion of the Black Peaks. Titanohematite is likely detrital
and has a relatively low Curie temperature ranging from 150-200°C; consequently, the grains

could easily be viscously reset with modest burial heating. Additionally, the Black Peaks Formation in the section is overlain by basaltic flows which plausibly heated the underlying deposits above the Curie temperature of titanohematite, causing these grains to be reset, which could also have resulted in the overprinted interval.

All reversed polarity samples in the section have a natural remanent magnetization (NRM) that overlaps with the modern direction suggesting all samples have a modern overprint. In samples where titanohematite is the primary magnetic carrier, remanence is lost at low temperatures during the stepwise thermal demagnetization process. In most of these samples, low temperature magnetometry curves also indicate a minor presence of magnetite that could hold remanence beyond the Curie temperature of titanohematite. The demagnetization behavior of samples with titanohematite as the primary magnetic carrier behaved in two ways. The samples demagnetization behavior was either (1) too erratic for a statistically significant reversed direction to be calculated (Fig. 3F); or (2) was measurable to approximately 300°C such that a reversed direction could be calculated using a great circle (Fig. 3D). We interpret samples that we were able to calculate a reversed direction to have had a larger proportion of magnetite than samples that behaved erratically. Given that we calculated several lines and great circles indicating a reversed direction within this interval, we interpret that entire interval to be reversed with a strong normal overprint (Fig. 2).

Relationship of Polarity Stratigraphy to GPTS

We correlated the local polarity stratigraphy to the GPTS using a combination of vertebrate paleontology, $\delta^{13}\text{C}$ values of carbonate nodules (Nordt et al., 2003), detrital sandine ages, and stratigraphic thickness (Fig. 4). Using these methods, we correlate our polarity stratigraphy to the GPTS as follows: A+ to >C32n, B- to C31r, C+ to C31n, D-.1 to C29r, and D-.2 to C27r.

The B- and C+ intervals were correlated to C31r and C31n respectively based on the presence of dinosaur faunas and stratigraphic thickness. The change from reversed polarity to normal polarity in the section was pinned to the boundary between C31r and C31n (Ogg, 2012). Given that the strata are a series of stacked paleosols over this interval, there is assumed to be no significant amount of time missing. It is possible that the B- and C+ intervals could correlate to C30r and C30n; however, C30r only spans 173 kyr (Ogg, 2012) and the B- interval corresponds to 77 m of section. Deposition over such a short time interval seems unlikely (see discussion of sedimentation rates below). The detrital age of 76.28 ± 0.06 Ma from SS02, near the base of the B- interval, suggests the sandstone bodies represent reworked older sediments.

Because the B- interval was correlated to C31r, the underlying A+ interval was correlated to C32n. However, there is only one stratigraphic locality associated with this interval and no fossils from Dawson Creek to constrain its age further. The mammalian fauna of the Aguja correlated to the Judithian, which occurs from ~79-74 Ma (Cifelli et al., 2004), suggests the Aguja is likely older than C32n. Additionally, geochronologic studies on the Aguja Formation in other areas of the park also indicate that the age may be older (Befus et al., 2008; Breyer et al.,

2007). Thus correlation to C32n represents the minimum age for the Aguja. The detrital age of 76.28 ± 0.06 Ma in the overlying B- interval also suggests that the A+ interval could be older.

We interpret the D-.1 interval to correlate to C29r for two reasons. First, the detrital sanidine ages support correlation to C29r. At the base of the D-.1 interval, the SS07 detrital age of 68.83 ± 0.13 Ma corresponds to C31n and the SS08 detrital age of 68.08 ± 0.03 Ma, from the middle of the D-.1 interval, corresponds to C30n. Since the deposits in this interval are reversed, these detrital ages constrain the interval to either C29r or C30r. Second, the K-Pg boundary, which occurs within C29r (Ogg, 2012), is within the D-.1 polarity interval (Lehman, 1990; Wiest et al., 2017), indicating D-.1 is correlative to C29r and not C30r.

There is a significant sandstone body with an erosive base indicating an unconformity between D-.1 and D-.2 (Fig. 2) (Atchley et al., 2004). The occurrence of Torrejonian mammals, which first appear in C28n (Lofgren et al., 2004), above this sandstone means that the D-.2 interval cannot correlate to C29r. The identification of To2 mammals, which occur in C27r in the San Juan Basin (Lofgren et al., 2004; Williamson, 1996), allows us to correlate the D-.2 interval to C27r (Fig. 4). The maximum depositional age of sample SS13 located in the sandstone overlying P28 is defined by a single grain dated to 65.9 ± 0.4 Ma, which supports an early Paleocene age. Because we do not have any other age constraints for this interval, we assumed the base of the D-.2 interval starts at the base of C27r, but note that this is a maximum age for this interval.

Sedimentation Rate Calculations

There are multiple chronostratigraphic tie points within the D-.1 local polarity interval, and therefore we used that interval to develop a sedimentation rate model for the Dawson Creek section. To determine the sedimentation rates for C29r, we first used the K-Pg boundary (66.043 Ma, Renne et al., 2013), which occurs at 172 m in the section (Wiest et al., 2017), and late Maastrichtian event, which occurs at 154 m in the section (Nordt et al., 2003) as known tie points. The late Maastrichtian event has been estimated to occur approximately 250 kyr before the boundary (Li and Keller, 1998a, 1998b; Westerhold et al., 2011; Tobin et al., 2012), thus we used an age of 66.25 Ma (C29r) for it (Fig. 4). Using these tie points, the resulting sedimentation rate is 87 m/myr. Extrapolation of this sedimentation rate throughout the underlying portion of the reversed D-.1 interval would put the base of the polarity zone at 66.77 Ma, which is well within C30n (Ogg, 2012). Given that this interval is of reversed polarity, the age estimate is impossible, thus, we interpret the sedimentation rate of 87 m/myr to be too slow.

Second, we assumed the maximum depositional age for the base of the D-.1 interval correlates to the base of C29r or 66.398 Ma (Ogg, 2012). A sedimentation rate was then calculated from the base of the D-.1 local polarity zone to the K-Pg boundary at 172 m, resulting in a rate of 203 m/myr. This sedimentation rate estimates an age of 66.157 Ma for the onset of the late Maastrichtian event, which is similar to age estimates from the marine record (Li and Keller 1998a, 1998b; Westerhold et al., 2011; Tobin et al., 2012). Thus, we favor the second interpreted sedimentation rate, and extrapolated it to the remainder of the section to estimate the durations of deposition (Fig. 4). The B- interval spans 379 kyr, the C+ interval spans 54 kyr, the D-.1 interval spans 459 kyr, and the D-.2 interval spans 280 kyr.

Unconformities

The magnetostratigraphy from B.J. MacFadden (*in* Standhardt, 1986) correlated the section to C30n to C28r with no recognized unconformities. Atchley et al. (2004) documented unconformities in the section, but concluded that they did not span any significant amount of time. Our new age constraints indicate the Dawson section spans from C32n to C27r (71.6 Ma to 63.2 Ma) with significant hiatuses (Fig. 4), which supports the suggestion in Nordt et al. (2003) that considerable time is missing from the section. The hiatuses in the section correspond with amalgamated sandstone channel complexes suggesting incision into the landscape. Based on our chron assignments and sedimentation rate estimates, the minimum duration for the hiatuses between A+ and B- intervals spans ~1.75 myr, between C+ and D-.1 spans ~2.82 myr, and between D-.1 and D-.2 spans ~2.4 myr. Mammalian biostratigraphy from the Javelina and Black Peaks Formations supports the duration of the unconformity between D-.1 and D-.2 because the last occurrence of Lancian dinosaurs near the top of the Javelina Formation and the lowest occurrence of Torrejonian mammals suggests a hiatus of ~2.5 Ma (66.04 Ma for the K-Pg boundary to 64.49 for base of C27r [Ogg, 2012]). The occurrence of Judithian mammals in the Aguja (~79-74 Ma [Cifelli et al., 2004]) and the Lancian dinosaur assemblage of the Javelina (~69-66 Ma [Cifelli et al., 2004]) suggests that the unconformity between the A+ and B- intervals is likely longer than ~1.75 myr.

Relating the section and associated hiatuses to the global sea level curve from Miller et al. (2005) in Figure 4 demonstrates the hiatuses are associated with falling stage and lowstand

tracts while intervals of deposition occurred during transgressive and highstand tracts. Increases in accommodation due to relative sea level rise could have resulted in deposition along the coastal plain while relative sea level fall resulted in loss of accommodation and non-deposition and/or erosion (e.g. Wright and Marriott, 1993; Shanley and McCabe, 1994). The detrital ages also suggest that the sediment deposited in the section represents recycled material from the missing time intervals. These results support the conclusion in Atchley et al. (2004) that the deposition of the section was controlled by eustatic sea level; however, at a different time scale than previously suggested. The trend of deposition during transgressive and highstand system tracts and non-deposition/erosion during falling stage and lowstand tracts provides an independent check on the reasonability of the calculated sedimentation rate, as deposition throughout the section is internally consistent.

Biostratigraphic implications

A Lancian biostratigraphic age for the middle and upper part of the Javelina Formation (which also includes the base of the Black Peaks Formation of some workers [e.g., Lehman and Busbey, 2006; Cobb, 2016]) is based on the presence of three dinosaurs: *Alamosaurus*, *Tyrannosaurus rex*, and *Torosaurus*, which have been regarded as part of its distinctive *Alamosaurus* fauna (Lehman, 2001; Lehman et al., 2006). *Alamosaurus sanjuanensis* has been reported from several latest Cretaceous faunas restricted to the American Southwest: the North Horn Formation of central Utah, the Naashoibito Member, Kirtland Formation of the San Juan Basin northwestern New Mexico, the McRae Formation of central New Mexico, and the Javelina

Formation of west Texas. In all the faunas where *Alamosaurus*, *Tyrannosaurus rex* or cf *T. rex*,
and the large ceratopsian *Torosaurus utahensis* or a similar taxon (identified as either
Torosaurus cf. *T. utahensis* [Big Bend National Park] or *Ojoceratops*, a taxon considered by
some workers to be synonymous with *Triceratops* [e.g., Longrich, 2011] or *Torosaurus*
utahensis [see Wick and Lehman, 2013]) are present. None of these taxa are known from pre-
Lancian age faunas and *Tyrannosaurus* is restricted to Lancian faunas of the northern Rocky
Mountain region, supporting a Lancian assignment for the faunas of the Javelina Formation.
Additionally, our age constraints indicate that the dinosaur fauna in the Javelina Formation is
confined to C29r. Thus it is contemporaneous to the dinosaur fauna of the Hell Creek Formation
in the Northern Great Plains. The Hell Creek Formation dinosaur fauna is the most complete,
continuous end-Cretaceous North American record and has been well studied with respect to
dinosaur diversity prior to the boundary (e.g., Sheehan et al., 1991; Pearson et al., 2002;
Fastovsky and Sheehan, 2005; Fastovsky and Bercovici, 2016). Our age constraints for the
Dawson Creek section indicate that differences between the Javelina and Hell Creek faunas are
not the result of them being different ages as suggested by Lucas et al. (2016). Instead, the
differences in the faunas are likely driven by other factors such as isolation between populations
and/or environmental conditions leading to endemism and provinciality in the Latest Cretaceous
as suggested by Lehman (1987, 2001). Additionally, it suggests that the magnitude of extinction
at the K-Pg boundary may have been larger than previously suggested (e.g. Brusatte et al., 2015),
because these taxa restricted to the American Southwest also likely went extinct at the boundary.

Future work comparing the Javelina and Hell Creek dinosaur faunas will be valuable for
evaluation of dinosaur endemism, provinciality, and extinction.

The mammalian fauna in the Black Peaks Formation has been reassigned as age
equivalent to Torrejonian 2 fauna found elsewhere in western North America. Any difference
between the mammals found in Dawson Creek and other Torrejonian localities would reflect
environmental or biogeographic variability rather than temporal. Thus, the Black Peaks fauna is
an important addition to evaluate North American early Paleocene mammalian diversity and
biostratigraphy across other basins.

Paleoclimate implications

Our age constraints suggest that the two warming events presented in Nordt et al. (2003)
document rapid (<200 kyr) changes in climate within the Maastrichtian. At the top of the B-
interval, the pedogenic carbonate $\delta^{13}\text{C}$ values previously identified as the mid-Maastrichtian
Event occur (Nordt et al., 2003). The age constraints in this paper assigns the mid-Maastrichtian
event an age between 69.35 to 69.30 Ma. The mid-Maastrichtian Event observed in the marine
record contains multiple peaks in isotopic values, one that occurs from approximately 69.0 to
69.4 Ma (Li and Keller, 1998a, 1998b), suggesting a possible correlation (Fig. 4). Using the
sedimentation rate that was calculated independent of the marine record late Maastrichtian event
chemostratigraphic correlation, the onset of the late Maastrichtian event in paleosol 19 is at
66.157 Ma with the peak excursion value occurring at 66.092 Ma. These ages are in general
agreement with the marine record where the peak excursion values occur at 66.25 Ma (Li and

Keller, 1998a, 1998b; Westerhold et al., 2011). However, it should be noted that there is likely a sedimentation rate change associated with the late Maastrichtian event in the Dawson Creek section suggested by the much lower sedimentation rate calculated between the K-Pg boundary and the late Maastrichtian event onset (87 m/myr) compared to the sedimentation rate calculated for the entire D-.1 interval from the K-Pg boundary and the assumed base of C29r at the base of the D-.1 zone (203 m/myr). Thus, it is possible that the age estimated here for the late Maastrichtian event from the calculated sedimentation rate is too young. Nonetheless, the age estimate supports the correlation between the terrestrial late Maastrichtian event greenhouse event (Nordt et al., 2003) and the greenhouse event recorded in the marine record (Li and Keller, 1998a, 1998b; Westerhold et al., 2011; Tobin et al., 2012).

Our age constraints demonstrate that the Dawson Creek section correlates differently to strata in Big Bend National Park and western North America than previously thought. The Dawson Creek C27r strata correlate with the lower portion of the west Tornillo Flat section in the northern area of Big Bend where pedogenic carbonate carbon and oxygen isotopes have also been characterized through the Eocene (Bataille et al., 2016). They observe a correlation between early Paleogene global temperature trends and the sediment accumulation rates and lithostratigraphy, concluding climate was the dominant control on deposition rather than global sea level as we suggest. However, the Tornillo Flats and Dawson Creek sections are not age equivalent. The Dawson Creek section is predominantly Cretaceous while the Tornillo Flat section is predominately Paleogene, which suggests the primary controls on deposition in the Big Bend region changed from eustatic sea level in the late Cretaceous and early Paleocene to

climate in the middle Paleocene and Eocene, possibly reflecting the retreat of the Western Interior Seaway in the Paleogene (Davidoff and Yancey, 1993). The Dawson Creek C27r strata also correlate to terrestrial deposits of the San Juan Basin, New Mexico where work is ongoing reconstruction paleosol bulk carbon $\delta^{13}\text{C}$ values and climate trends from paleosol geochemical proxies (e.g., Secord et al., 2016; Leslie et al., 2016). The age model for Dawson Creek presented here constrains the timing of climate trends from the Late Cretaceous through early Paleocene, bolstering the significance of the Dawson Creek section as part of the North American terrestrial record.

CONCLUSIONS

Paleomagnetic analysis of the Dawson Creek Section in Big Bend National Park combined with reexamination of the fauna indicates the section correlates to C32n-C31n, C29r, and C27r of the GPTS with three large hiatuses that are longer than 1.5 myr each. These hiatuses correspond to falling stage and lowstand tracts of the global sea level curve, while deposition correlate to transgressive and highstand tracts (Miller et al., 2005), indicating that eustatic sea level change was the primary driver of environments of deposition within the Dawson Creek section. Rock magnetic analyses indicates that the dominant magnetic carrier in the Aguja and Black Peaks Formations is titanomagnetite, while the Javelina Formation has varying magnetic carriers including hematite, magnetite, and maghemite. We conclude that the overprint interval surrounding the K-Pg boundary was likely a result of titanohematite that was reset by burial or overlying basaltic flows.

This new age model has implications for biostratigraphic and isotopic correlations between the Big Bend area and other Cretaceous-Paleogene (K-Pg) basins across North America. The Javelina Formation dinosaur fauna is limited to C29r and age equivalent to the dinosaur fauna of the Hell Creek Formation in the Northern Great Plains, which supports the concept of provinciality. Additionally, it implies the K-Pg extinction of non-avian dinosaurs was larger than previously suggested because all non-avian dinosaur taxa endemic to the Big Bend area also went extinct at the boundary. The mammalian fauna previously identified as Puercan by Standhardt (1986) is reidentified as Torrejonian taxa and allows for future diversity comparisons to other basins. This is one of only a few Torrejonian faunas in North America, which makes it important for understanding mammalian evolution following the K-Pg boundary on both local and regional scales. Lastly, our findings show the mid-Maastrichtian and late Maastrichtian greenhouse events documented by Nordt et al. (2003) represent rapid (<200 kyr) changes in climate during the end-Cretaceous and correlate closely with the marine record. This work contributes to ongoing work developing a more complete late Cretaceous through Paleogene chronology for southern North America through a combination of detrital sanidine dates, magnetostratigraphy, and biostratigraphy, and suggests the application of the method to others areas in Big Bend would significant improve the chronology of this important region.

APPENDIX

THERIAN MAMMALS FROM THE LOWER BLACK PEAKS FORMATION

Vertebrate fossils are found within the Javelina and Black Peaks formations in the Dawson Creek section (Fig. 4). Fossil mammals from two localities TMM locality 41400 (LSU VL-111), Tom's Top in Dawson Creek and TMM locality 42327 (LSU VL-108), Dogie, were originally described by Schiebout (1974). LSU VL-109 ("Hot White") (locality 8, Fig. 2) yielded turtle, lizard, and crocodilian fossils (Standhardt, 1986). Additional fossils were later collected by Standhardt (1986) using screenwashing methods and described in an unpublished dissertation. The fauna has appeared primarily in faunal lists (Schiebout et al., 1987; Standhardt, 1995) and briefly evaluated by Williamson (1996). The only mammal previously described in the published literature is a single specimen of a multituberculates mammal from Tom's Top, *Stygmys vastus*, was described by Lofgren et al. (2005). *Stygmys* is known from the Puercan through the Torrejonian of western North America and the species *S. vastus* is endemic to the Tom's Top locality and therefore does not aid in refining its biostratigraphic correlation. The therian mammals from these faunas are illustrated and briefly described here.

Standhardt (1986) reported the presence of *Eoconodon coryphaeus* from locality LSU VL-107 ("Glen Eleven"), a locality is from outside the study area from the near Glen Draw, 3.4 km southeast of Glenn Springs. Standhardt (1986) was not able to precisely place this locality into any regional stratigraphic section because it is within faulted sediments in a syncline. We included a reassessment of this specimen because it was identified as a mammal known elsewhere only from the Puercan.

Included in the Appendix is the systematic paleontology and a brief description of the
reidentified material. A more complete description and discussion is available in the
Supplemental Data.

SYSTEMATIC PALEONTOLOGY

Infraclass METATHERIA Huxley, 1880

Family PERADECTIDAE Trouessart, 1979

Genus PERADECTES Matthew and Granger, 1921

Peradectes sp.

Fig. 5A-D

Peratherium sp. Standhardt, 1986, p. 210, fig. 68.

Material.—LSU V-895, right partial M?; and LSU V-705, left m? from TMM locality 42327.

Description.—A small metatherian mammal is represented by a partial upper molar (LSU V-895;
Fig. 5A) and a lower molar (LSU V-705; Fig. 5B-D).

Order CIMOLESTA McKenna, 1975

Family CIMOLESTIDAE Marsh, 1889

Genus and Species indeterminate

Fig. 5E-G

744

745 *Gelastops* sp. Standhardt, 1986, p. 213, fig. 69.

746

747 Material.—LSU V-708, left P3; and LSU V-841, partial right M2 from TMM locality 42327.

748 Description.—A small cimolestid is represented by a complete crown of a poorly preserved and

749 abraded left P3 (LSU V-708; Fig. 5E-F) and a partial M2 (LSU V-841; Fig. 5G) that includes the

750 mesial and lingual portion of the tooth including part of the paracone and a complete parastylar

751 lobe and the protocone and talon basin.

752

753 Legion CARNIVORAMORPHA Wyss and Flynn, 1993

754 Family VIVERRAVIDAE Wortman and Matthew, 1899

755 Genus BRYANICTIS MacIntyre, 1966

756 *Bryanictis* new species

757 Fig. 5H-L

758

759 *Protictis* (*Bryanictis*) *terlinguae* Standhardt, 1986, p. 218, figs. 71, 72. [nomen nudum]

760

761 Material.—TMM 41400-10, left p4 from TMM locality 41400, and LSU V-709, incomplete P3

762 from TMM locality 42327.

763 Description.—A small viverravid carnivoramorph representing a new species of *Bryanictis* is

764 represented by at least two isolated teeth, an incomplete P3 (LSU V-709; Fig. 5H-I) and a p4

(TMM 41400-10; Fig. 5J-L). Standhardt (1986) referred an additional specimen to this taxon
consisting of an isolated p2 (LSU V-960). However, this specimen could not be located for this
study.

Order DERMOPTERA Illiger, 1811

Family MIXODECTIDAE Cope, 1883a

Genus MIXODECTES Cope, 1883a

Mixodectes malaris Cope, 1883a

Fig. 5M

Indrodon malaris Cope, 1883a, p. 60.

Mixodectes malaris Cope, 1883a [see Szalay, 1969 for synonymy]; Rigby, 1980, p. 63, table 16;

Taylor, 1984, p. 147, table 10; Standhardt, 1986, p. 222, fig. 73; Williamson, 1996, p. 38.

Material.—LSU V-924, partial left M3; and LSU V-928, partial left M2 from TMM locality

41400.

Description.—The mixodectid *Mixodectes malaris* is represented by two fragmentary upper
molars, a partial left M3 (LSU V-924; Fig. 5M) and a partial left M2 (LSU V-928).

Unfortunately, the partial left M2 was not available for this study. The partial left M3 consists of
the distal half of the crown.

786 Order PRIMATES Linnaeus, 1758

787 Family 'PALAECHTHONIDAE' Szalay, 1969

788 Genus PLESIOLESTES Jepsen, 1930

789 *Plesiolestes nacimienti* Wilson and Szalay, 1972

790 Fig. 5N-R

791

792 *Palaechthon nacimienti* Wilson and Szalay, 1972, p. 5, figs. 2-9; Taylor, 1984, p. 164, table 13;

793 Standhardt, 1986, p. 225, fig. 74; Williamson and Lucas, 1993, p. 121, Williamson, 1996, p. 39.

794 *Plesiolestes nacimienti* (Wilson and Szalay, 1972). Gunnell, 1989, p. 24; Silcox and Williamson,

795 2012, p. 810, fig. 4.

796

797 Material.—LSU V-921, right P4; TMM 41400-17, left M2; and LSU V-923, right m3 from

798 TMM locality 41400.

799 Description.—*Plesiolestes nacimienti* is represented by three isolated teeth including a right P4

800 (LSU V-921; Fig. 5N), left M2 (LSU V-923; Fig. 5O), and right partial m3 (LSU V-923; Fig.

801 5P-R).

802

803 Order 'CONDYLARTHRA' Cope, 1881b

804 Family PERIPTYCHIDAE Cope, 1882b

805 Genus HAPLOCONUS Cope, 1882a

806 *Haploconus* sp.

Fig. 6A-E

Haploconus inopinatus Standhardt, 1986, p. 248, fig. 82.

Material.—LSU V-710, partial right M1; LSU V-711, partial right M2; and LSU V-835, left m2
from TMM locality 42327.

Description.—The periptychids “condylarth” *Haploconus* is represented by three partial teeth.

Two isolated teeth represent a partial M1 (LSU V-710; Fig. 6A) and a partial M2 (LSU V-711;
Fig. 6B) that likely come from a single individual.

Genus PERIPTYCHUS Cope, 1881a

Periptychus carinidens Cope, 1881a

Fig. 6F-H

Periptychus carinidens Cope, 1881a, p. 337 [see Taylor, 1984 for synonymy], Rigby, 1980, p.
111, pl. XIV, figs. 7-9, table 42, Archibald, 1998, p. 312, fig. 20.3c; Williamson and Lucas,
1992, fig. 15i-k; Williamson and Lucas, 1993, p. 125; Williamson, 1996, p. 45.

Periptychus gilmorei Gazin, 1939, p. 272, fig. 3; Archibald, 1998, p. 313.

Carsiptychus coarctatus Standhardt, 1986, p. 243, fig. 81.

Material.—LSU V-888, right m3; LSU V-873, right dentary fragment with partial m?; and LSU
V-1554, right partial M? from TMM locality 42327.

Description.—*Periptychus carinidens* is represented by a dentary fragment with a partial and
highly abraded lower molar, an isolated partial right upper molar (LSU V-1554), and a nearly
complete m3 (LSU V-888; Fig. 6F-H).

Family MIOCLAENIDAE Osborn and Earle, 1895

Genus PROMIOCLAENUS Trouessart, 1904

Promioclænus cf. *P. lemuroides* Matthew, 1897

Fig. 6I-J

Promioclænus sp. Standhardt, 1986, p. 256, fig. 84.

Ellipsodon priscus Standhardt, 1986, (in part), p. 251, fig. 83a.

Material.—LSU V-875, right P3; and LSU V-920, partial left M3 from TMM locality 41400.

Description.—*Promioclænus* cf. *P. lemuroides* is represented by an isolated P3 (LSU V-875;
Fig. 6I) and a partial M3 (LSU V-920; Fig. 6J).

Genus MIOCLAENUS Cope, 1881d

Mioclænus new species.

Fig. 6K-U

848

849 *Nexus plexus* Standhardt, 1986, p. 258, fig. 85. [nomen nudum]

850

851 Material.—LSU V-890, left M2; LSU V-891, left M1; LSU V-833, left P4; LSU V-703, right
852 partial dentary with erupting m2; LSU V-839, V-840, partial right m2; and LSU V-881, left m3
853 from TMM locality 42327.

854 Description.—A small mioclaenid “condylarth” represents a new species of *Mioclaenus*, which
855 represents the most complete taxon reported from TMM locality 42327. The new species is
856 represented by an isolated, poorly preserved P4 (LSU V-833; Fig. 6K-L), an isolated M1 (LSU
857 V-891; Fig. 6M-N), an isolated left M2 (LSU V-890; Fig. 6O-P), an m2 (LSU V-703; Fig. 6Q-
858 R), a partial right m2 (LSU V-839, V840), and a left m3 (LSU V-881; Fig. 6S-U).

859

860 Genus ELLIPSODON Scott, 1892

861 *Ellipsodon* cf. *E. inaequidens* Cope, 1884

862 Fig. 6V-Z

863

864 *Ellipsodon priscus* Standhardt, 1986, p. 251, (in part), fig. 83B-H.

865

866 Material.—LSU V-706, left M1; and LSU V-701, right m1 from TMM locality 42327.

867 Description.—*Ellipsodon inaequidens* is represented by two teeth: a left M1 (LSU V-706; Fig.
868 6V-W), and a right m1 (LSU V-701; Fig. 6X-Z).

869

870 Family 'TRIISODONTIDAE' Scott, 1892

871 Genus GONIACODON Cope, 1888

872 cf. *Goniacodon levisanus* Cope, 1883a

873 Fig. 6AA-BB

874

875 *Eoconodon* sp. Standhardt, 1986, p. 238, fig. 84.

876

877 Material.—LSU V-704, left M3 from TMM locality 42327.

878 Description.— cf. *Goniacodon levisanus* is represented by an isolated left M3 (LSU V-704; Fig.
879 6AA-BB).

880

881 Genus TRIISODON Cope, 1881c

882 *Triisodon quivirensis* Cope, 1881c

883 Fig. DR1

884

885 *Triisodon quivirensis* Cope, 1881c, p. 485; Van Valen, 1978, p. 58; Williamson and Lucas, 1993,
886 p. 123; Williamson, 1996, p. 41.

887 *Triisodon antiquus* Cope, 1882, p. 193 [see Taylor, 1984 for synonymy]; Tomida, 1981, p. 230,
888 pl. 10.2, figs 1-2.

889 *Eoconodon coryphaeus* Standhardt, 1986, p. 232, fig. 77.

Material.—LSU V-1156, partial right M2; and LSU V-1157, partial left m1 or m2 from LSU
locality VL-107.

Description.—The taxon *Triisodon quivirensis* is represented by fragments of two teeth (Fig.
DR1), portions of a dentary, and postcranial fragments. These were found in close association
and likely represent a single individual. However, some of the individual fragments were given
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FIGURE CAPTIONS

Figure 1. A) Location of study area (highlighted with box) within Big Bend National Park modified from Lehman (1991). B) Cross section A-A' through the Tornillo Basin modified from Lehman (1986).

Figure 2. VGP latitude, interpreted polarity zonations, and primary (1°) and secondary (2°) magnetic mineralogies for the section. Location of detrital sanidine samples shown. Faunal localities: 1. LSU VL-110; 2. LSU VL-149; 3. TMM 41450 (LSU VL-106); 4. LSU VL-112 5. LSU VL-145; 6. TMM 41501; 7. TMM 41400, “Tom’s Top” (LSU VL-111); 8. LSU VL-109 (Lehman, 1990). Unconformities are placed based on sedimentological indicators, faunal interpretations, and detrital age dates. MAD - mean angle of deviation.

Figure 3. Representative Zijderveld diagrams and equal-area plots for each subset of data. (A) Demagnetization trajectory of a normal polarity sample from C31n where a line was calculated (36% of data). (B) Demagnetization trajectory of reversed polarity sample from C29r where a line was calculated. (C) Demagnetization trajectory of a reversed polarity sample from C27r where a line was calculated. (D) Reversed polarity sample with demagnetization trajectory best

characterized by a great circle from C27r, direction calculated from last stable endpoint (28% of
the data). Sample is located in overprinted interval. (E) Representative sample of erratic data that
was not used for interpretations (11% of data). (F) Representative overprinted sample where
calculated direction overlaps with modern (25% of data).

Figure 4. Summary chart for the Dawson Creek section showing correlation of local polarity
stratigraphy, GPTS (Ogg, 2012), NALMA (Woodburne, 2004), time scale (Gradstein, 2012), and
local fossil localities. Fossil localities: 1. LSU VL-110; 2. LSU VL-149; 3. TMM 41450, LSU
VL-106; 4. LSU VL-112; 5. LSU VL-145; 6. TMM 41501; 7. TMM 41400, “Tom’s Top” (LSU
VL-111); 8. LSU VL-109 (Lehman, 1990). Gray boxes highlight hiatuses in the record, KPB: K-
Pg boundary. $\delta^{13}\text{C}_{\text{PDB}}$ isotopic values from pedogenic carbonate modified from Nordt et al.
(2003), MME: mid-Maastrichtian Event and LME: late Maastrichtian Event. Marine temperature
curves calculated from stable O isotopes using Erez and Luz (1983) equation assuming a -1.2‰
ice-free standard mean ocean water (SMOW): DSDP 1209 in the North Pacific (Westerhold et
al., 2011), and DSDP 525A (Li and Keller, 1998a) and DSDP 525 (Li and Keller, 1998b) in the
South Atlantic. Global sea level curve from Miller et al. (2005).

Figure 5. Metatheria, Cimolesta, Carnivoramorpha, and Euarchonta from the Dawson Creek and
Rough Run areas, Big Bend National Park, Texas. A-D, *Peradectes* sp.: A, partial right M1
(LSU V-895) in occlusal view; B-D, left m2 or m3 (LSU V-705), in occlusal (B), buccal (C), and
lingual (D) views; E-G, Cimolestidae indeterminate: E-F, left P3 (LSU V-708) in occlusal (E)

and buccal (F) views; G, partial right M2 (LSU V-841) in occlusal view; H-I, *Bryanictis* new sp.:
H-I, left P3 (LSU V-709) in occlusal (H) and buccal (I) views; J-L, left p4 (TMM 41400-10,
holotype) in occlusal (J), buccal (K), and lingual (L) views; M, *Mixodectes malaris*, partial left
M3 (LSU V-924) in occlusal view; N-R, *Plesiolestes nacimienti*; N, right P4 (LSU V-921) in
occlusal view; O, left M2 (TMM 41400-17) in occlusal view; P-R, partial right m3 (LSU V-923)
in occlusal (P), buccal (Q), and lingual (R) views. Specimens have been dusted with magnesium
oxide to increase visibility of surface features.

Figure 6. ‘Condylarthra’ from the Dawson Creek and Rough Run areas, Big Bend National
Park, Texas. A-E, *Haploconus* sp.: A, partial right M1 (LSU V-711) in occlusal view; B, partial
right M2 (LSU V-710) in occlusal view; C-E, partial left m1 (LSU V-835) in occlusal (C),
lingual (D), and buccal (E) views; F-H, *Periptychus carinidens*: nearly complete m3 (LSU V-
888) in occlusal (F), lingual (G), and buccal (H) views; I-J, *Promioclænus* cf. *P. lemuroides*: I,
left P3 (LSU-875) in occlusal view; J, partial left M3 (LSU V-920) in occlusal view; K-U,
Mioclænus new sp.: K-L, left P4 (LSU V-833) in occlusal (K), and buccal (L) views; M-N, left
M1 (LSU V-891) in occlusal (M) and buccal (N) views; O-P, left M2 (LSU V-890, holotype) in
occlusal (O) and buccal (P) views; Q-R, partially erupted right m2 (LSU V-703) in occlusal (Q)
and lingual (R) views; S-U, left m3 (LSU V-881) in occlusal (S), buccal (T), and lingual (U)
views; V-Z, *Ellipsodon* cf. *E. inaequidens*: V-W, left M1 (LSU V-706) in occlusal (V) and
buccal (W) views; X-Z, right m1 (LSU V-701) in occlusal (X), buccal (Y), and lingual (Z)
views; AA-BB, cf. *Goniacodon levisanus*: AA-BB, left M3 (LSU V-704) in occlusal (AA) and

buccal (BB) views. Specimens have been dusted with magnesium oxide to increase visibility of
surface features.

Figure 7. Equal area plot of characteristic magnetization directions calculated from: A) all lines
B) all lines from Late Cretaceous interval C) all lines from K-Pg boundary interval D) all lines
from early Paleocene interval.

Figure 8. Age probability diagrams for the four analyzed samples. The plots show, from bottom
to top, the age probability distribution spectrum where the dashed line represents the probability
curve for all of the data whereas the solid line is for the data shown with solid circles,
distribution of individual single-crystal ages with 2σ errors, K:Ca ratios, and percentage of
radiogenic ^{40}Ar .

Figure 9. Rock magnetic analysis results including low temperature magnetization curve of
representative samples, high temperature VSM (vibrating sample magnetometer) curves of bulk
magnetic susceptibility, and high temperature heating and cooling curves of bulk magnetic
susceptibility in air. Room temperature (RT) plots show magnetization measurements at room
temperature following the application of saturation isothermal remanent magnetization (SIRM).
FC (field-cooled) and ZRC (zero field-cooled) plots show magnetization during warming
following a sustained direct current field of 2.5 T during cooling (FC) and during warming
following a SIRM imparted at low temperature (ZFC). (A) RT curves for a B- polarity zone

reversed polarity sample from the Aguja Fm. indicating titanomagnetite. (B) High temperature VSM curve for a B- polarity zone reversed polarity sample from the Aguja Fm. indicating titanomagnetite. (C) High temperature susceptibility curves for a B- polarity zone reversed sample in the Javelina Fm. indicating hematite. (D) High temperature VSM curve for a B- polarity zone reversed sample in the Javelina Fm. indicating hematite. (E) RT curves for a C+ polarity zone normal sample in the Javelina Fm. indicating magnetite. (F) FC/ZFC curves for a C+ zone polarity zone normal sample in the Javelina Fm. indicating magnetite. (G) High temperature susceptibility curves for a D-.1 polarity zone reversed sample in the Javelina Fm. indicating maghemite. (H) High temperature VSM curve for a D-.1 polarity zone reversed sample in the Javelina Fm. indicating maghemite. (I) High temperature susceptibility curves for a D-.2 polarity zone reversed sample in the Black Peaks Fm. indicating titanomagnetite. (J) RT curves for a D-.2 polarity zone reversed sample in the Black Peaks Fm. indicating titanomagnetite.

Figure 10. Rock magnetic analysis for the overprint interval in the upper Javelina and lower Black Peaks Formations indicating titanohematite. (A) RT curves for an overprinted sample in the overprint interval. (B) FC/ZFC curves for an overprinted sample in the overprint interval. (C) RT curves for a reversed sample in the overprint interval. (D) FC/ZFC curves for a reversed sample in the overprint interval.

¹GSA Data Repository item 201Xxxx, ⁴⁰Ar/³⁹Ar results, argon data, line, circle, and site mean paleomagnetic data, and additional figures and detailed descriptions of the

Leslie et al., accepted, Revised age constraints for Late Cretaceous to early Paleocene terrestrial strata
from the Dawson Creek section, Big Bend National Park, west Texas: *Geological Society of America*
Bulletin. PREPRINT.

1423 **mammals is available online at www.geosociety.org/pubs/ft20XX.htm, or on request from**
1424 **editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301,**

Upper hemisphere expected direction
 Present dipole field
 Lower hemisphere: not used
 Upper hemisphere: not used

TABLE 1. DAWSON CREEK FOSSIL LOCALITIES

Locality	Taxa	Age
1. LSU VL-110	<i>Odontaspis</i> tooth, fish, crocodile, dinosaur	Lancian
2. LSU VL-149	<i>tyrannosaur</i> femur	Lancian
3. LSU VL-106, TMM 41450	<i>Alamosaurus sanjuanensis</i>	Lancian
4. LSU VL-112	fish, turtle, crocodile	Lancian
5. LSU VL-145	scraps of dinosaur bone	Lancian
6. TMM 41501	giant pterosaur, <i>Quetzalcoatlus northropi</i>	Lancian
7. TMM 41400 "Tom's Top"	<i>Bryanictis</i>	Torrejonian
(LSU VL-111)*	<i>Mixodectes malaris</i>	Torrejonian 2
	<i>Plesiolestes nacimienti</i>	Torrejonian
	<i>Promioclænus</i> cf. <i>P. lemuroides</i>	Torrejonian
8. LSU VL-109	turtle remains	Torrejonian

Note: *Taxa reclassified in this paper

TABLE 2. MEAN PALEOMAGNETIC DIRECTIONAL DATA FROM THE DAWSON CREEK SECTION

Subset	<i>n</i>	D (°)	I (°)	k	a ₉₅ (°)	Pole (°N)	Pole (°E)	K	A95 (°)
C32n - lines	3	13.3	31.5	96.2	12.6	72.9	28.4	107.2	12.0
C31r - lines	23	179.3	-46.0	7.3	12.1	87.6	226.2	5.6	14.0
C31n - lines	27	11.4	36.8	12.4	8.2	77.3	19.0	11.1	8.7
C31n - sites	3	358.4	29.5	27.5	24.0	76.5	83.2	24.1	25.7
C29r - lines	58	173.1	-36.6	9.5	6.4	80.8	118.4	8.2	7.0
C29r - sites	9	178.7	-30.8	23.2	10.9	77.7	81.7	24.2	10.7
C27r - lines	21	192.9	-40.6	7.2	12.8	78.4	354.1	6.0	14.2

Note: *n* – number of lines or sites included in the mean; D – declination; I – inclination; k – Fisher's (1953) precision parameter; a₉₅ – radius of 95% confidence cone around mean (Fisher, 1953); pole N and E – mean of virtual geomagnetic poles calculated from each line or site mean; K and A95 – Fisher statistics of paleomagnetic pole.

TABLE 3. THERIAN MAMMALS

Standhardt (1986)	This paper
TMM locality 41400, "Tom's Top"	
Carnivora	Carnivoramorpha
Didymictidae	Viverravidae
<i>Bryanictis terlinguae</i> new species	<i>Bryanictis</i> new species
Insectivora	Euarchonta
Mixodectidae	Mixodectidae
<i>Mixodectes malaris</i>	<i>Mixodectes malaris</i>
?Primates	Primates
Microsyopidae	"Palaechthonidae"
<i>Palaechthon nacimienti</i>	<i>Plesiolestes nacimienti</i>
"Condylarthra"	"Condylarthra"
Mioclaenidae	Mioclaenidae
<i>Promioclaenus</i> sp.	<i>Promioclaenus</i> cf. <i>P. lemuroides</i>
TMM locality 42327, "Dogie"	
Marsupialia	Metatheria
Didelphidae	Peradectidae
<i>Peratherium</i> sp.	<i>Peradectes</i> sp.
Cimolesta	Cimolesta
Palaeoryctidae	Cimolestidae
<i>Gelastops</i> sp.	Cimolestidae indeterminate
Carnivora	Carnivoramorpha
Didymictidae	Viverravidae
<i>Bryanictis terlinguae</i> new species	<i>Bryanictis</i> new species
"Condylarthra"	"Condylarthra"
Arctocyoniidae	"Triisodontidae"
<i>Eoconodon</i> sp.	cf. <i>Goniacodon levisanus</i>
Periptychidae	Periptychidae
<i>Carsiptychus coarctatus</i>	<i>Periptychus carinidens</i>
<i>Haploconus inopinatus</i>	<i>Haploconus</i> sp.
Mioclaenidae	Mioclaenidae
<i>Ellipsodon priscus</i>	<i>Ellipsodon</i> cf. <i>E. inaequidens</i>
<i>Nexus plexus</i> new genus and species	<i>Mioclaenus</i> new species

Revised age constraints for Late Cretaceous to early Paleocene strata from the Dawson Creek section, Big Bend National Park, west Texas

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ADDITIONAL DATA REPOSITORY FILES:

Table DR1

Table DR3

Table DR5

Table DR2

Table DR4

Table DR6

SYSTEMATIC PALEONTOLOGY

Infraclass METATHERIA Huxley, 1880

Family PERADECTIDAE Trouessart, 1979

Genus PERADECTES Matthew and Granger, 1921

Peradectes sp.

Fig. 5A-D

Peratherium sp., Standhardt, 1986, p. 210, fig. 68.

Material.— LSU V-895, right partial M?; and LSU V-705, left m? from TMM locality 42327.

Description.—A small metatherian mammal is represented by a partial upper molar and a lower molar, both from TMM locality 42327(Fig. 5A-D). The upper molar fragment, probably an M1 (Fig. 5A), consists of a distobuccal fragment of a molar preserving the metacone and the distal portion of the stylar shelf. It lacks any indication of an ectoflexus or a sharp indentation in the buccal margin demarcating the limits of Stylar cusp C on M2s and M3s of that taxon, supporting the conclusion that it represents an M1. M1s and M2s of *P. coproxeches* sometimes bear doubled stylar cusp Cs (Williamson and Taylor, 2011).

The lower molar (LSU V-705; Fig. 5B-D) represents either m2 or m3. The apex of the protoconid is damaged, but is larger and evidently would be taller than the metaconid. The paraconid is shorter than the metaconid and projects mesiolingually. The cristid obliqua intersects the distal wall of the trigonid buccal to the protocristid notch. The hypoconid is damaged, missing much of the enamel. The entoconid and hypoconulid are twinned, with the hypoconulid situated near the distolingual margin of the tooth and projecting distally. The entoconid is tall and bladelike. It is larger (length = 1.73; mesial width = 1.00; distal width = 0.99) than corresponding teeth of *Peradectes coprexeches* and falls within the size range of *P. minor* (Clemens, 2006; Williamson et al., 2012).

Remarks.—Unfortunately, there is insufficient material to allow a specific identification of this taxon. *Peradectes* is a wide-ranging genus present in the Puercan, early Paleocene through Eocene of western North America (Williamson et al., 2012).

Order CIMOLESTA McKenna, 1975

Family CIMOLESTIDAE Marsh, 1889

Genus and Species indeterminate

Fig. 5E-G

Gelastops sp., Standhardt, 1986, p. 213, fig. 69.

Material.—LSU V-708, left P3; and LSU V-841, partial right M2 from TMM locality 42327.

Description.—A small cimolestid is represented by a complete crown of a poorly preserved and abraded left P3 (LSU V-708; Fig. 5E-F) and a partial M2 (LSU V-841; Fig. 5G) that includes the mesial and lingual portion of the tooth including part of the paracone and a complete parastylar lobe and the protocone and talon basin.

The P3 (LSU V-708; Fig. 5E-F) is triangular in shape in occlusal view (length = 1.95; width = 1.39), with a small parastyle and a lingually-positioned protocone. A small, distinct cusp distal to the protocone, high on the metacrista represents the metacone.

The parastylar lobe of the M2 (LSU V-841; Fig. 5G; mesial width = 4.5) is large and projects mesiobuccally, supporting two closely appressed distinct cusps which probably correspond to a parastyle and a stylocone. A significant stylar shelf with a marked ectoflexus was evidently present. The paracristid is low, but sharp. The paracone is conical. The protocone is mesiodistally compressed. The paraconule is situated close to the protocone on the preprotocone crest and is separated from it by a deep notch. A postparaconule crista is absent. A postprotocone crest is straight. Basal cingulae are absent.

Remarks.—Standhardt (1986) referred these specimens to *Gelastops*. However, *Gelastops* is a relatively poorly known taxon and represented by few upper teeth making comparison difficult. For example, the P3 of *Gelastops* remains unknown. We find that the upper molar fragment is essentially indistinguishable from corresponding parts of *Acmeodon secans*, a taxon originally described from the Torrejonian of the Nacimiento Formation, San Juan Basin, New Mexico and which is considered to be close to *Gelastops* (Simpson, 1935). Certain identification is not possible given the fragmentary nature of the tooth. Moreover, the isolated P3 (LSU V-708) resembles that of *Acmeodon*, but differs in that the protocone is smaller and situated directly lingual to the paracone rather than distolingual to it. We are unable to identify these specimens to genus or species.

Cimolestids are usually rare components of Paleocene faunas (e.g., Williamson et al., 2011) that decreased in taxonomic diversity from the Puercan through the Tiffanian of western North America.

Legion CARNIVORAMORPHA Wyss and Flynn, 1993

Family VIVERRAVIDAE Wortman and Matthew, 1899

Genus BRYANICTIS MacIntyre, 1966

Bryanictis new species

Fig. 5H-L

Protictis (Bryanictis) terlinguae, Standhardt, 1986, p. 218, figs. 71, 72. [nomen nudum]

Material.— TMM 41400-10, left p4 from TMM locality 41400, and LSU V-709, incomplete P3 from TMM locality 42327.

Description.—A small viverravid carnivoramorph representing a new species of *Bryanictis* is represented by at least two isolated teeth, an incomplete P3 (LSU V-960; Fig. 5H-I) from TMM locality 42327 and a p4 (TMM 41400-10; Fig. 5J-L) from TMM locality 41400. Standhardt (1986) referred an additional specimen to this taxon consisting of an isolated p2 (LSU V-960). However, this specimen could not be located for this study.

The P3 (LSU V-960; Fig. 5H-I; length = 2.38; width = 1.65) is triangular in occlusal view with a large and distally-leaning paracone flanked distally by a smaller metacone. The tooth is encircled by a basal cingulum. A small protocone rises from the lingual cingulum lingual to the paracone.

The p4 (TMM 41400-10; Fig. 5J-L; length = 2.38; width = 1.65) is buccolingually narrow with a tall and slightly recurved protoconid, a low, mesially projecting, bladelike paraconid, and a relatively wide talonid. The talonid bears a low hypoconid that is in line with the paraconid and metaconid. A low hypoconulid is positioned distolingual to that line, forming a distolingual wall to a small talonid basin.

Remarks.—The p4 is similar in length, but a bit smaller than that of *Simpsonictis tenuis* and has a relatively more buccolingually expanded talonid. The p4 resembles that of *Intyriactis* from the Torrejonian of the Nacimiento Formation, San Juan Basin, New Mexico in having a

relatively low protoconid and wide talonid. However, unlike *Intyriactis*, the Black Peaks carnivoramorph lacks a metaconid.

We refer these specimens to the genus *Bryanictis*, a poorly known taxon represented by two species, *B. microlestes* and *B. paulus* (Gingerich and Winkler, 1985; MacIntyre, 1966; Meehan and Wilson, 2002) from the middle Torrejonian of the Fort Union Formation, Montana and the Nacimiento Formation, New Mexico, respectively, because it shares a broadening of the p4 talonid and lacks a metaconid as is found in *Intyriactis*. The Black Peaks taxon is smaller than either species of *Bryanictis* and undoubtedly represents a new taxon.

The oldest unambiguous carnivoramorphs are Torrejonian in age. Puercan carnivoramorphs have been reported from the Puercan of Saskatchewan, Canada based on isolated teeth. However, we do not find their referral of *Ravenictis* and additional isolated lower molars to Carnivoramorpha to be certain. Regardless, these specimens do not include a P3 or p4 so direct comparison with the Black Peaks taxon is not possible.

The Dawson Creek *Bryanictis* represents a new species and represents among the smallest early Paleocene carnivoramorph. Only the putative Puercan carnivoramorph *Ravenictis krausei* is smaller.

Order Dermoptera Illiger, 1811

Family Mixodectidae Cope, 1883a

Genus MIXODECTES Cope, 1883a

Mixodectes malaris Cope, 1883a

Fig. 5M

Indrodon malaris Cope, 1883a, p. 60.

Mixodectes malaris Cope, 1883a [see Szalay, 1969 for synonymy]; Rigby, 1980, p. 63, table 16; Taylor, 1984, p. 147, table 10; Standhardt, 1986, p. 222, fig. 73; Williamson, 1996, p. 38.

Material.—LSU V-924, partial left M3; and LSU V-928, partial left M2 from TMM locality 41400.

Description.—The mixodectid *Mixodectes malaris* is represented by two fragmentary upper molars, a partial left M3 (LSU V-924; Fig. 5M) and a partial left M2 (LSU V-928) from TMM locality 41400. Unfortunately, the partial left M2 was not available for this study. The partial left M3 consists of the distal half of the crown. It includes a pronounced mesostyle, metacone, and the distal portion of the protocone and talon basin. The mesostyle is well developed and projects buccally as a blade shaped crest. The protocone is rounded lingually and bordered by a low distal basal cingulum.

Remarks.—The preserved portion of the tooth (distal width = 3.73) is essentially indistinguishable from the M3 of *Mixodectes malaris*, a taxon known from the middle Torrejonian of the Fort Union Formation, Washakie Basin, southern Wyoming (Rigby, 1980) and the Nacimiento Formation, San Juan Basin, New Mexico (Szalay, 1969). *Mixodectes* is easily recognized by its salient mesostyle and *M. malaris* is distinguished from *M. pungens*, which is known only from the late Torrejonian of New Mexico, by its smaller size.

Order PRIMATES Linnaeus, 1758

Family 'PALAECHTHONIDAE' Szalay, 1969

Genus PLESIOLESTES Jepsen, 1930

Plesiolestes nacimienti Wilson and Szalay, 1972

Fig. 5N-R

Palaechthon nacimienti Wilson and Szalay, 1972, p. 5, figs. 2-9; Taylor, 1984, p. 164, table 13; Standhardt, 1986, p. 225, fig. 74; Williamson and Lucas, 1993, p. 121, Williamson, 1996, p. 39.

Plesiolestes nacimienti (Wilson and Szalay, 1972). Gunnell, 1989, p. 24; Silcox and Williamson, 2012, p. 810, fig. 4.

Material.— LSU V-921, right P4; TMM 41400-17, left M2; and LSU V-923, right m3 from TMM locality 41400.

Description.—*Plesiolestes nacimienti* is represented by three isolated teeth including a right P4 (LSU V-921; Fig. 5N), left M2 (LSU V-923; Fig. 5O), and right partial m3 (LSU V-923; Fig. 5P-R).

The P4 (LSU V-921; length = 2.18; width = 2.41; Fig. 5N) possesses a large paracone, a smaller metacone, and a minute parastyle. The protocone is subequal in size to the paracone and is positioned linguomesially. A preprotocone crest is present, but a distinct postprotocone crest is

absent. Conules are absent, but a small, distinct postparaconule crest extends from the preprotocone crest to the lingual base of the paracone.

A left M2 (TMM 41400-17; Fig. 5O; length = 2.13; mesial width = 3.41; distal width = 3.13) is relatively poorly preserved and appears to be abraded. The tooth is transverse with subequal and widely-separated paracone and metacone and a small parastyle. The styler shelf is narrow. The paraconule is positioned near the base of the paracone with short pre- and postparaconular cristae. The metaconule is similarly positioned close to the base of the metacone and small and short pre- and postmetaconular cristae are present. The protocone is large and attended mesially by a basal precingulum that extends buccally to the base of the paraconule. A postprotocingulum extends distally from the apex of the protocone and joins the postcingulum that proceeds buccally to near the base of the metaconule.

The m3 (LSU V-923; mesial width = 1.42; distal width = 1.46; Fig. 5P-R) is broken into two fragments: one preserving most of the trigonid and the other preserving most of the talonid. It is incomplete, missing portions of the crown between the two fragments. The trigonid is short and includes the subequal protoconid and metaconid. The metaconid is positioned nearly directly lingual to the protoconid. The paraconid is small and is positioned close and mesial to the metaconid, but is separated from it by a narrow cleft. The mesial edge of the trigonid is bordered by a narrow paracristid. The talonid is wider and much longer than the trigonid. The hypoconid is the largest of the talonid cusps followed by the hypoconulid, which is unfissured, and then the entoconid. The cristid obliqua probably met the trigonid between the protoconid and metaconid. A swelling on the cristid obliqua probably represents a small mesoconid. Buccal and lingual

cingulids are not present, but a distinct precingulid extends from the mesial base of the tooth to wrap partway round the buccal side of the protoconid.

Remarks.—The teeth are all similar to those referred to *Plesiolestes nacimienti* from the Nacimiento Formation, San Juan Basin, New Mexico (Wilson and Szalay, 1972; Silcox and Williamson, 2012). We follow Gunnell (1989) in including the species in the genus *Plesiolestes*.

As discussed by Silcox and Williamson (2012), *Plesiolestes nacimienti* is an exceedingly rare taxon in the Nacimiento Formation, San Juan Basin, New Mexico, but appears to have a relatively long stratigraphic ranging, extending from Tj3 to Tj6 (from near the base of chron C27r to at least the middle of chron C27n; see Silcox and Williamson, fig. 14). Gunnell (1989) also assigned two isolated teeth from the North Horn Formation, Dragon Canyon, Utah, to *P. nacimienti*, and at least one of these specimens was collected from near the top of a normal polarity zone correlated with C28n (Tomida and Butler, 1980). Thus, *P. nacimienti* has a stratigraphic range extending through most of the Torrejonian.

Order ‘CONDYLARTHRA’ Cope, 1881b

Family PERIPTYCHIDAE Cope, 1882b

Genus HAPLOCONUS Cope, 1882a

Haploconus sp.

Fig. 6A-E

Haploconus inopinatus, Standhardt 1986, p. 248, fig. 82.

Material.—LSU V-710, partial right M1; LSU V-711, partial right M2; and LSU V-835, left m2 from TMM locality 42327.

Description.—The periptychids “condylarth” *Haploconus* is represented by three partial teeth. Two isolated teeth represent a partial M1 (LSU V-710; Fig. 6A; length = 3.81*) and a partial M2 (LSU V-711; Fig. 6B; length = 3.96) that likely come from a single individual. Both teeth are missing a portion of their crowns, buccal to the apices of the paracones and metacones. They possess the distinctive close convergence of the para- and metacone, protocone, and conules with the protocone and conules being transversely compressed to form a continuous crescentic, cuspidate arc centered on the protocone and a hypertrophied hypocone that extends lingually beyond the base of the protocone. A mesial cingulum terminates lingually in a distinct cusp lingual to the apex of the protocone: the protostyle. Small crests extend between both the bases of the protostyle and the hypocone to the base of the protocone.

A partial fragment of a lower molar (LSU V-835; Fig. 6C-E; mesial width = 3.01) preserves the trigonid, mesial to the apices of the metaconid and protoconid. The paraconid is bladelike and projects mesially as is distinctive of *Haploconus*. A strong mesiolingual cingulid is present mesial to the metaconid.

Remarks.—Standhardt (1986) referred these specimens to *Haploconus inopinatus*, a poorly known taxa from the early Torrejonian of the North Horn Formation, Dragon Canyon, Utah, based partly on the presence of a protostyle. However, a protostyle is sometimes present in other species of *Haploconus* including the middle Torrejonian *H. angustus* and *H. corniculatus*

from the Nacimiento Formation, San Juan Basin, New Mexico. The Dawson Creek specimens differ significantly from the only Puercan species of *Haploconus*, *H. elachistus* in being larger and having less transverse upper molars and having less transversely-compressed trigon. All three specimens are within the size range of *H. angustus*, but we refrain from making a certain specific identification because of the incomplete nature of the available specimens.

Genus PERIPTYCHUS Cope, 1881a

Periptychus carinidens Cope, 1881a

Fig. 6F-H

Periptychus carinidens Cope, 1881a, p. 337 [see Taylor, 1984 for synonymy], Rigby, 1980, p. 111, pl. XIV, figs. 7-9, table 42, Archibald, 1998, p. 312, fig. 20.3c; Williamson and Lucas, 1992, fig. 15i-k; Williamson and Lucas, 1993, p. 125; Williamson, 1996, p. 45.
Periptychus gilmorei Gazin, 1939, p. 272, fig. 3; Archibald, 1998, p. 313.
Carsiptychus coarctatus Standhardt, 1986, p. 243, fig. 81.

Material.—LSU V-888, right m3; LSU V-873, right dentary fragment with partial m?; and LSU V-1554, right partial M? from TMM locality 42327.

Description.—*Periptychus carinidens* is represented by a dentary fragment with a partial and highly abraded lower molar, an isolated partial right upper molar (LSU V-1554), and a nearly complete m3 (LSU V-888; Fig. 6G-F; length = 11.91; mesial width = 8.18; distal width =

7.36), all from TMM locality 42327. All fragmentary teeth show highly distinctive apico-basal ridges on tooth margins or on major tooth cusps.

A complete m3 is represented by LSU V-888 (Fig. 6G-F). It is approximately rectangular in occlusal view. The talonid is slightly narrower than the trigonid and the tooth narrows distally to a rounded distal margin. The occlusal surface is highly worn through attrition, so that it is nearly flat, with the apices of all cusps removed, exposing the interior dentin. The trigonid occupies the mesial half of the tooth. It is only slightly elevated compared to the talonid. The protoconid is the largest cusp, followed by the metaconid. The metaconid is well separated from the protoconid. The paraconid is positioned mesiobuccal to the metaconid. The paracristid is weak and indistinct. A strong crest descends from the lingual side of the paracristid and curves lingodistally to the mesiolingual base of the metaconid. The postcristid is weak and V-shaped, with the legs of the V spreading mesially to attach to the distal sides of the metaconid and protoconid. The apex of the V represents the protocristid notch. The talonid supports three cuspids, the hypoconid, hypoconulid, and entoconid. The cuspids are approximately conical and well-separated. The hypoconulid and entoconid are subequal, the hypoconulid is larger and positioned near the midline of the tooth and at the distal margin. The cristid oblique extends nearly mesially from the hypoconid to the protocristid notch. A continuous crest connects the hypoconid and hypoconulid. A crest between the hypoconulid and entoconid is thin and notched midway between the two cusps. A crest also connects the metaconid and the entoconid. A swelling is present below this crest midway between the two cuspids. An ectocingulid is present between the buccal face of the protoconid and the distal margin of the hypoconulid. It consists of

an irregular, cuspidate ridge. A short cuspidate ridge is also present on the lingual side of the tooth between the lingual sides of the hypoconulid and the entoconid (remnants of a lingual cingulid). A weaker cristid, with single notch, extends along a line drawn between the centers of the hypoconulid and entoconid. A strong crenulated ridge also connects the entoconid and metaconid. The perimeter of the tooth is marked by strong apicobasal plications that originate near the base of the major cusps. The enamel at the base of the tooth is crenulated with fine, apicobasally-aligned ridges around the entire basal margin of the tooth.

Remarks.—Standhardt (1986) originally identified this specimen as the Puercan taxon *Carsiptychus coarctatus*. However, we find that the fragmentary teeth are probably not certainly identifiable. The m3 (LSU VL-888) however, can be confidently referred to *P. carinidens*. It is larger than the m3 of *C. coarctatus* and falls within the size range of *P. carinidens* from the Nacimiento Formation, San Juan Basin. It also resembles *P. carinidens* and differs from *C. coarctatus* in the following features: 1) the talonid is relatively longer and more rectangular in shape as seen in occlusal view with an enlarged and distally extended hypoconulid 2) the trigonid is lower relative to the talonid 3) the apices of the primary molar cusps are not strongly convergent as in *C. coarctatus*, but are generally erect as in *P. carinidens* 4) the postcristid is V-shaped, rather than straight and 5) segments of the buccal and lingual cingulids are strongly developed.

Schiebout (1974) tentatively considered all the *Periptychus* specimens from the Big Bend National Park then known to be referable to *P. superstes*. The m3 (LSU V-888) differs from that

of *Periptychus superstes* in having a relatively smaller and shorter talonid with a less-expanded hypoconulid.

Periptychus carinidens is an index taxon for the Torrejonian Land Mammal Age (Lofgren et al., 2004) and the first appearance of *P. carinidens* is used to define the base of the Torrejonian.

Family MIOCLAENIDAE Osborn and Earle, 1895

Genus PROMIOCLAENUS Trouessart, 1904

Promioclænus cf. *P. lemuroides* Matthew, 1897

Fig. 6I-J

Promioclænus sp., Standhardt, 1986, p. 256, fig. 84.

Ellipsodon priscus in part, Standhardt, 1986, (in part) p. 251, fig. 83a.

Material.—LSU V-875, right P3; and LSU V-920, partial left M3 from TMM locality 41400.

Description.—An isolated P3 (LSU V-875; Fig. 6I; length = 3.28; width = 2.48) approximates a triangle with rounded apices in occlusal view with a large, central, and swollen paracone. A small parastyle is located mesially and a metastyle is present distally. A basal cingulum is not continuous around the entire margin of the tooth, but is absent from mesiolingual side of the tooth, and is discontinuous along its buccal margin. A basal cingulum is accentuated

near the lingual apex of the tooth, where it forms a low elongate ridge, representing an incipient protocone. The basal cingulum becomes more pronounced as it approaches the para- and metastyles. A ridge rises from the parastyle at the mesial side of the paracone. It is convex in buccal view. The lingodistal face of the paracone is flat to concave and recessed between ridges that ascent to the apex of the paracone from the protocone and metastyle.

A partial M3 (LSU V-920; Fig. 6J) is complete, but for the mesiobuccal, or parastylar, region and the distobuccal corners of the crown. The enamel surface is crenulated. The tooth is approximately oval in occlusal view with a large paracone. The metacone is missing, but it is clear that the tooth decreased in transverse width distally. A large protocone dominates the lingual side of the tooth. A paraconule is present approximately midway between the paracone and protocone. A short postparaconule crista extends from the paraconule to the lingual base of the paracone. The metaconule is circular and a premetaconular crista extends to near the lingual base of the metacone. A post protocingulum extends from the apex of the protocone to a postcingulum. A weak and irregular precingulum is also present.

Remarks.—*Promioclænus* spans the Torrejonian and is widely geographically distributed in western North America where it is represented by several species. The specimens from Dawson Creek are close in size to *P. lemuroides*. However, because of their incomplete nature, they are only tentatively referred to that species.

Genus MIOCLAENUS Cope, 1881d

Mioclænus new species.

Fig. 6K-U

Nexus plexus, Standhardt, 1986, p. 258, fig. 85. [nomen nudum]

Material.— LSU V-890, left M2; LSU V-891, left M1; LSU V-833, left P4; LSU V-703, right partial dentary with erupting m2; LSU V-839, V-840, partial right m2; and LSU V-881, left m3 from TMM locality 42327.

Description.—A small mioclaenid “condylarth” represents a new species of *Mioclaenus*, *M. lehmani*, which represents, the most complete taxon reported from TMM locality 42327.

An isolated, and poorly preserved P4 (LSU V-833; Fig. 6K-L; length = 4.49; width = 5.18) is highly pitted and discolored by weathering, but the salient features are readily visible. It is approximately triangular in occlusal view with a highly inflated and subequal paracone and protocone. A small parastyle is present mesial to the paracone and a distinct separate swelling distal to the paracone represents a metacone. A distinct metaconule is present between near the distal margin of the tooth, approximately midway between the protocone and paracone. Both a mesial and a distal cingulum is present, but these do not meet lingually. An ectocingulum appears to be absent.

An isolated M1 (LSU V-891; Fig. 6M-N; length = 4.62; mesial width = 5.91; distal width = 5.76), is well-preserved and relatively unworn. A portion of enamel is missing from the distal margin of the tooth, distal to the protocone. The tooth is roughly rectangular in shape, with subequal and widely spaced paracone and metacone and a large and inflated protocone. The

surface of the enamel is smoothly-wrinkled, most evident over the wide and rounded lingual face of the protocone. The paraconule is indistinct and positioned approximately midway between the paracone and protocone and is mesial to a line drawn between the two cusps. A short preparaconule crista is short and not contiguous with a strong precingulum that extends from the mesial side of the protocone to the parastyle. A short, but strong postparaconule crista extends buccally from the paraconule to the base of the paracone. A weak preparacrista connects the paracone and a small, but prominent parastyle, which is situated mesial and slightly buccal to the paracone. The metaconule is relatively larger than the paraconule. A thick and short premetaconule crista descends mesiobuccally towards the center of the trigon basin. Narrow and deep clefts delimit the metaconule lingually and buccally, separating the cusp from the protocone and metacone, respectively. Between the paracone and metacone is a slightly V-shaped centrocrista. It approaches, but does not intersect, the ectocingulum which forms a strong border close to the bases of the paracone and metacone. A strong postcingulum extends from midway up the distal side of the protocone (it is positioned closer to the apex of the protocone than is the precingulum) to the distobuccal corner of the tooth where it becomes confluent with the ectocingulum. A weak metacrista descends from the distal face of the metacone to the postcingulum. No hypocone is present.

An isolated left M2 (LSU V-890; Fig. 6O-P; length = 4.52; mesial width = 6.32; distal width = 5.74), resembles the M1 (LSU V-891), but is relatively wider (transversely) with a relatively large paracone and metacone and the tooth narrows distally so that the buccal margin of the tooth is obliquely angled relative to the anterior margin of the tooth. As in the M1, the

centrocrista is V-shaped, but does not meet the ectocingulum. The ectocingulum is thickened between the metacone and paracone and terminates at the buccal face of the metacone. A distinct mesostyle is absent.

Lower teeth are represented only by three specimens; LSU V-703, a partial right dentary with an erupting m2, LSU V-839 (Fig. 6Q-R), V-840, a partial right m2, and LSU V-881 (Fig. 6S-U), a left m3. The m2 (LSU V-703; Fig. 6Q-R) is erupting from the crypt and virtually unworn. The low, large, and inflated protoconid and metaconid are subequal in size and oriented approximately side-by-side in a transverse line. The metaconid is somewhat larger and higher than the protoconid. The paraconid is small, but distinct and closely appressed to the mesiobuccal face of the metaconid. A curved paracristid connects the protoconid and paracristid. A weak, straight protocristid connects the metaconid and protoconid. The talonid is subequal in size (both length and width) to the trigonid. The hypoconid is the largest and most distinct of the talonid cusps. The cristid obliqua is straight and intersects the posterocristid below the protocristid notch. The distal and lingual wall of the talonid is formed by a continuous curved crest that extends from the hypoconid to a position at the distolingual base of the metaconid. A short postmetaconid crest is separate and distinct from the lingual wall of the talonid. A small cuspid on this crest at the distal midline appears to represent the hypoconulid. There is no distinct entoconid. The talonid basin is shallow and a low crest descends into it from the lingual side of the hypoconid.

An isolated m3 (LSU V-881; Fig. 6S-U; length = 5.18; mesial width = 3.36; distal width = 2.85), is similar to the m2 (LSU V-703). The trigonid is essentially identical to that of the m2,

but the m3 possesses minor attritional wear on the protoconid and metaconid. The talonid is mesiodistally elongated and significantly longer than the trigonid. It narrows distally. The hypoconid is a prominent cusp and the only distinct cusp present on the talonid. The cristid extending from the hypoconid distally and enclosing the talonid lingually is weakly cuspidae, though no distinct hypoconulid or entoconid is visible. As in the m2, a low crest descends mesiolingually from the hypoconid into the talonid basin. A mesial cingulid is present. A short and weak postcingulid is present distal to the hypoconid on the buccal side of the tooth and two small cusps are present within the hypoflexid.

Remarks.—The P4 of *Mioclaenus* new species (Fig. 6K-L) resembles that of *Mioclaenus turgidus* in the relative size and shape and positioning of most of the cusps. It differs from *Mioclaenus turgidus* in having less inflated cusps and a larger, more mesially-positioned metacone. The P4 metacone is variable in *M. turgidus*, and it varies from being a small cusp at the distal margin of the tooth at the base of the paracone, to a small distinct cusp, part-way up the distal slope of the paracone, mesial to, and distinct from, a distal cingulum (e.g., NMMNH P-15988), and the presence of a distal cingulum is also variable. However, in no specimens of *M. turgidus* is the P4 metacone as large, relative to the paracone, as it is in LSU V-833.

The M1-2 of the *Mioclaenus* new species (Fig. M-P) closely resemble those of *M. turgidus*, although they are smaller in size and have less inflated cusps. The upper molars of *M. turgidus* sometimes possesses a centrocrista between the paracone and metacone that sometimes bears a strong and distinct mesostyle or forms an acute V-shape that, in some specimens, intersects the ectocingulum. The M1 of *M. turgidus* also usually bears a small hypocone on the

postcingulum, distal to the apex of the protocone. The M2 is very similar in morphology to that of *M. turgidus*. The metacone is similarly small relative to the paracone and the tooth declines in width distally. This suggests that the M3 of the *Mioclaenus* new species is similarly small in size relative to the other molars.

The lower molars of *Mioclaenus* new species (Fig. 6Q-U) are also similar to those of *M. turgidus*. Differences are: 1) The cusps in the *M.* new species but the cusps are less inflated; 2) the lower molars of *M. turgidus* similarly possess more pronounced cusps of the distal and lingual walls of the talonid; 3) the cristid obliqua of *M. turgidus* intersects the trigonid below the apex of the protoconid rather than at the more lingual position, below the protocristid notch in the Big Bend species; 4) in *M. turgidus*, there is not a distinct crest entering the talonid basin from the hypoconid as there is in the Big Bend species, though the m3 talonid of *M. turgidus* sometimes bears a distinct and isolated cusp within the basin; 5) some specimens of *M. turgidus* sometimes possess a weak, discontinuous, and cuspidae buccal cingulid; and 6) the m2 of *M. turgidus* typically possesses an enlarged basal buttress over the root that extends mesially from the mesiolingual corner of the tooth.

Mioclaenus turgidus is a relatively common taxon in the Torrejonian of the Nacimiento Formation, San Juan Basin, New Mexico, but has only been reported from one other area; the latest Torrejonian or early Tiffanian Grayson Ridge fauna of the Hanna Formation, Carbon Basin, Wyoming (Secord, 1998). This report, therefore documents a southern geographic range extension for the genus *Mioclaenus*.

Genus ELLIPSODON Scott, 1892

Ellipsodon cf. *E. inaequidens* Cope, 1884

Fig. 6V-Z

Ellipsodon priscus, Standhardt, 1986, p. 251, (in part), fig. 83B-H.

Material.— LSU V-706, left M1; and LSU V-701, right m1 from TMM locality 42327.

Description.—*Ellipsodon inaequidens* is represented by two teeth; a left M1 (LSU V-706; Fig. 6V-W), and a right m1 (LSU V-701; Fig. 6X-Z).

The left M1 (LSU V-706; Fig. 6V-W; length = 3.70; mesial width = 4.85; distal width = 4.85) in occlusal view resembles an isosceles triangular with rounded apices. The tooth is inflated and dominated by a large protocone and smaller, round and subequal para- and metacones. A small parastyle is present mesial and closely appressed to the paracone. A distinct metaconule as well as pre- and postmetaconule cristae are absent. Instead, a postprotocrista extends directly to the metacone as a notched crest. In contrast, a large and circular paraconule is present, positioned approximately midway between the protocone and paracone, and offset mesially from a line drawn between the two cusps. The preprotocrista terminates at the paraconule. The postparaconule crista is short and the paraconule and paracone are divided by a deep cleft mesially. A weak preparaconular crista curves distally and buccally and attaches to the lingual face of the paracone. Mesially, a precingulum extends from the distal side of the protocone and extends buccally and uninterrupted to the a distinct parastyle which is closely

appressed to the mesial base of the paracone. A strong postcingulum extends from the distal side of the protocone to the distal base of the metacone. A hypocone is absent, though a low ridge descends from the apex of the protocone to the postcingulum. The postcingulum is higher on the protocone than the precingulum. A distinct metastyle is also absent. A paracrista is weak and directed nearly mesially. The centrocrista are straight. A short, but sharp metacrista descends buccal to the metastyle. An ectocingulum is absent, but for a low remnant that forms a small, distinct cusp, a mesostyle, nestled between the buccal basal margins of the para- and metacones.

The occlusal surface is somewhat worn through attrition so that the apices of all the major cusps (i.e., para- and metacones, protocone, and metastyle) bear flat and circular wear facets exposing dentin bordered by relatively thick enamel. The surface of the tooth is nearly smooth with low, coarse, wavy, and apicobassally-aligned ridges.

A right m1 (LSU V-701; Fig. 5X-Z; length = 3.67; mesial width = 3.1; distal width = 3.15) is approximately rectangular in occlusal view and highly inflated and rounded. The metaconid is the largest cusp and it is swollen and broadly convex over its lingual surface. It is subequal in preserved height to the protocone, which is positioned mesial and buccal to the metacone. The two cusps are strongly conjoined at their bases and their apices are positioned close together but they are separated apically by a low and sharp, mesiodistally-aligned cleft continuous with the protocristid notch. The protocristid is low and indistinct. A low and circular paraconid is positioned mesial to the apex of the metacone, but because the metacone is highly inflated, the apex of the paraconid is well-removed from the lingual margin of the tooth. A distinct paracristid curves mesiolingually from the protoconid and is separated from the

paraconid by a sharp notch. A narrow crest descends from the metaconid to the paraconid. The talonid is subequal in width to the trigonid, but shorter, occupying only about one third the length of the tooth. Only two distinct cusps can be discerned, the hypoconid and entoconid. The hypoconid is the larger of the two and it occupies the distobuccal corner of the tooth. The cristid oblique extends diagonally from the hypoconid to the apex of the metaconid, lingual to the protocristid notch. A deep hypoflexid separated the hypoconid from the protoconid and a distinct notch is present in the cristid oblique at the base of the trigonid. The entoconid is positioned at the lingual side of the trigonid, opposite the hypoconid. It is smaller and lower than the hypoconid. The distal side of the talonid is bordered by a low and curved crest which connects the hypoconid and entoconid. No distinct cuspids can be discerned within this crest. The talonid basin is smooth and concave marked only by a low ridge extending mesially and lingually from the apex of the hypoconid. A narrow and sharp postmetacristid descends from the distal side of the metaconid and it meets a short entocristid to close off the lingual side of the talonid basin. A small sharp notch marks the intersection of the two cristids. The major cusps of the tooth (i.e., metaconid, protoconid, and hypoconid) have apical wear similar to what is present in the M1 (LSU V-706). The tooth has a similar surface ornamentation with weak, coarse, and wavy ridges that are apicobasally-aligned.

Remarks.—Standhardt (1986) originally referred these specimens to the *Ellipsodon priscus*, a taxon known with certainty only from the Puercan of the Nacimiento Formation, San Juan Basin, New Mexico (Williamson and Carr, 2007). Van Valen (1978) erected the genus *Bomburia* for “*E.*” *priscus*. However, because the name *Bomburia* was later found to be

preoccupied, a new name, *Bomburodon*, was subsequently proposed as a replacement (Williamson and Carr, 2012). Regardless, the Big Bend specimens differ markedly from *B. priscus* and closely resemble species of *Ellipsodon*. The upper teeth of *Bomburodon* are unknown with certainty, but are likely represented by teeth referred to *Platymastus palantir* Van Valen, 1978, a probable subjective junior synonym of *B. priscus* (Williamson and Carr, 2007). Upper molars of *P. palantir* differ from the M1 (LSU V-706) of the Big Bend species in a number of prominent features such as presence of an ectocingulum, presence of a metaconule, and presence of a distinct hypocone. Lower molars of *B. priscus* differ from the m1 of the Big Bend taxon in being distinctly less inflated and having a relatively larger talonid. In addition, the relative positions of the talonid cusps of m1 and m2 differ between genera. In *Bomburia*, the metaconid is nearly directly lingual to the protoconid, but in *Ellipsodon*, the metaconid is positioned distal to the protoconid, a condition considered to be an autapomorphy for *Ellipsodon* by Williamson and Carr (2007).

The two teeth are here tentatively referred to the middle Torrejonian *E. inaequidens*. The M1 (LSU V-706) lacks an ectocingulum, but for a small area that forms a small mesostyle between the para- and metacones, a feature considered to be one of the diagnostic characters of *Ellipsodon* (Williamson and Carr, 2007). The m1 (LSU V-701) is also similar to that of *Ellipsodon* in being similarly inflated with a distally positioned metaconid (Williamson and Carr, 2007). Williamson and Carr (2007) recognized three species of *Ellipsodon*, *E. inaequidens* (Cope, 1884), *E. granger* Wilson, 1956, and *E. yotankae* Van Valen, 1978 which are distinguished by size, the relative proportions of upper molar length and width, and the relative

width of the lower molar talonids (Williamson and Carr, 2007). The Big Bend taxon most closely resembles *E. inaequidens*, although both specimens fall below the size range of specimens known from the Nacimiento Formation of New Mexico. *Ellipsodon inaequidens* is extremely rare in the Nacimiento Formation, and m1 measurements are known for only two to three specimens that preserve m1. In measurements of length and width (MW and DW), Big Bend specimens are less than 11% smaller than those documented from the Nacimiento Formation. In addition, the Big Bend taxon differs from other specimens of *Ellipsodon* in that the M1 (V-706) lacks a metaconule, and a metaconule is present on all other known specimens of *E. inaequidens* that preserve a relatively unworn M1, though for some specimens, it is small and relatively indistinct (e.g., NMMNH P-20680, Fig. G.2).

Standhardt referred an isolated tooth that she identified as a right P3 (LSU V-875) to “*E.*” *priscus*. This specimen does not closely resemble premolars of *Bomburodon priscus* or *Ellipsodon inaequidens*. Among other differences, LSU V-875 lacks a distinct protocone and large parastyle that is present in *B. priscus* and does not possess the distinctive, broadly convex occlusal surface mesial and lingual to the paracone and shallowly concave distally as in *E. inaequidens* (Williamson and Carr, 2007). It is tentatively referred to *Promioclaenus* sp. (below).

Family ‘TRIISODONTIDAE’ Scott, 1892

Genus GONIACODON Cope, 1888

cf. *Goniacodon levisanus* Cope, 1883a

Fig. 6AA-BB

Eoconodon sp., Standhardt, 1986, p. 238, fig. 84.

Material.— LSU V-704, left M3 from TMM locality 42327.

Description.—An isolated left M3, LSU V-704 (Fig. 6AA-BB) is an approximately oval occlusal outline (length = 4.71; mesial width = 7.30; distal width = 5.81). The enamel surface is rugose. The paracone and metacone are conical and the metacone is smaller than the paracone corresponding to a transverse narrowing of the tooth distally. The cones are widely separated, but connected by a straight centrocrista. The paracrista and metacrista are straight and in line with the centrocrista. The buccal margin of the tooth is bordered by a narrow ectocingulum that borders a relatively wide stylar region. The parastylar region is broadly rounded in occlusal view and there is a slight ectoflexus between the para- and metastylar regions. The protocone is large and erect with strong pre- and postprotocristae. The paraconule is situated approximately midway between the metacone and protocone and is represented by an elongate expansion along the preprotocrista with at least two swellings. The premetaconule crista continues in a straight line to the mesiobuccal corner of the tooth. A postparaconule crista is lacking. The metaconule is situated on the postprotocrista. A premetaconule crista is lacking. The postmetaconule crista continues to the distal margin of the tooth where it joins a postcingulum distal to the metacone. The pre- and postcingulum are strong and wrap around the lingual base of the protocone to form a continuous lingual cingulum. The precingulum terminates buccally below and mesial to the paracone without joining the preparaconule crista.

Remarks.—Standhardt (1986) referred this tooth to the “triisodontid” “condylarth” *Eoconodon*, a taxon known only from the Puercan of western North America. However, it differs from the M3 described for any *Eoconodon* species, where known. It is too small to be referable to *E. coryphaeus*. It is closest in size to *E. gaudrianus*, which is poorly known and represented by only two M3s (e.g., AMNH 3200 and NMMNH P-72366) and differs in having a relatively larger styler shelf. All other *Eoconodon* species are too small to be conspecific (see Clemens and Williamson, 2005; Clemens, 2011).

The tooth probably represents a “triisodontid” based on the rugose enamel texture, the large conical paracone and metacone that appear to be partially merged at their base and the alignment of their associated crests. It closely resembles the M3 of the Torrejonian “triisodontid” “condylarth” *Goniacodon levisanus*. *G. levisanus* is relatively rare and poorly known taxon and the M3 is represented by only a few specimens (e.g., NMMNH P-21906, 59393), some of which are incomplete (e.g., NMMNH P-59393). However, these are similar in size and morphology to LSU V-704, with a similar rugose enamel surface, and large, conical paracone and metacone. However, it differs somewhat from the specimens on hand to make comparison. The M3 of NMMNH P-21906 lacks a lingual cingulum. Both NMMNH P-21906 and 59393 have a paracone and metacone that are more closely appressed more completely conjoined at their base and have a narrower styler region, without an extoflexus. Based on the similarities and differences, we can only tentatively refer LSU V-704 to *Goniacodon levisanus*.

The genus *Goniacodon* ranges from the late Puercan to the early Tiffanian of western North America. The species *G. levisanus* is restricted to the middle Torrejonian to early Tiffanian of New Mexico, Wyoming, and Montana.

Genus TRIISODON Cope, 1881c

Triisodon quivirensis Cope, 1881c

Fig. DR1

Triisodon quivirensis Cope, 1881c, p. 485; Van Valen, 1978, p. 58; Williamson and Lucas, 1993, p. 123; Williamson, 1996, p. 41.

Triisodon antiquus Cope, 1882, p. 193 [see Taylor, 1984 for synonymy]; Tomida, 1981, p. 230, pl. 10.2, figs 1-2.

Eoconodon coryphaeus Standhardt, 1986, p. 232, fig. 77.

Material.—LSU V-1156, partial right M2; and LSU V-1157, partial left m1 or m2 from LSU locality VL-107.

Description.—The taxon *Triisodon quivirensis* is represented by fragments of two teeth (Fig. A1), portions of a dentary, and postcranial fragments. These were found in close association and likely represent a single individual. However, some of the individual fragments were given different specimen numbers.

A portion of a right M2, LSU V-1156 (Fig. A1A-B), includes the occlusal surface of the protocone. It is weathered through attritional wear so that the apex of the protocone is beveled. The preparaconule crista is similarly positioned, the precingulum, the base of the metaconule is expanded distally and separated from the distal face of the protocone by a groove, the postcingulum ascends the distal face of the protocone and is at a similar position, though a hypocone is more developed in V-1156 and in that specimen, the postcingulum does not extend lingually past the hypocone. In V-1156, remnants of the original surface texture are present adjacent to the postcingulum and are similarly rugose and pebbly.

LSU V-1157 is a partial left m1 or m2 (Fig. A1E-F). The tooth is more heavily worn, but the distinctive cleft separating the metaconid and protoconid is present. The paracristid on the mesial face of the protoconid projects mesially. The cusps are of similar size and exhibit a similar pebbly enamel surface texture.

Remarks.—Standhardt (1986) referred fragments of an edentulous left dentary with tooth roots (LSU V-1158) and postcranial fragments consisting of a right proximal radius (LSU V-1151), and a right femoral head (LSU V-1159) to “*Eoconodon coryphaeus*” (Table DR1). However, the dentary fragments exceed the depth of the dentary of any specimen of *E. coryphaeus* and closely match those of mature representatives of *T. quivirensis* from the Nacimiento Formation (e.g., NMMNH P-2676, 21982 and 44608) and is consistent with an identification of *T. quivirensis* for the other specimens from this locality.

This report of *Triisodon quivirensis* from the Big Bend National Park represents the first from outside of the San Juan Basin, New Mexico. *T. quivirensis* is restricted to the early and

middle Torrejonian (To1-To2) of the Nacimiento Formation, San Juan Basin, New Mexico (*Periptychus carinidens* – *Protoselene opisthacus* zone [Tj1] through *Arctocyon ferox* – *Mixodectes pungens* zone [Tj5] and thus this represents a significant geographic range extension for this taxon.

Figure DR1. *Triisodon quivirensis* from LSU locality V-111 (“Glen Eleven”) compared to *T. quivirensis* from the Nacimiento Formation, San Juan Basin, New Mexico. A-B, trigonid fragment of a left m2 (LSU V-1157) in occlusal (A) and lingual (B) views; C-D, left m2 (NMMNH P-51329) in occlusal (C) and lingual (D) views; E-F, partial right M2 (LSU V-1156) in occlusal (E) and distal (F) views; G-H, right M2 (NMMNH P-20918) in occlusal (G) and distal (H) views. Specimens have been dusted with magnesium oxide to increase visibility of surface features.

TABLE DR1. THERIAN MAMMALS

Standhardt (1986)	This paper
LSUMG V-107, "Glen Eleven"	
"Condylarthra"	"Condylarthra"
Arctocyoniidae	"Triisodontidae"
<i>Eoconodon coryphaeus</i>	<i>Triisodon quivirensis</i>

TABLE DR2. SUMMARY OF $^{40}\text{Ar}/^{39}\text{Ar}$ RESULTS

Mean Age													
Sample	Location (m)	L#	Irrad	min	analysis	n	MSWD	K/Ca	±	2s	Age(Ma)	±	1s
SS02	19	63612	NM-276C	san+	Mean	6	1	43	±	50.3	76.28	±	0.06
SS07	103	63614	NM-276C	mostly san	Mean	4	1.8	7.5	±	28.6	68.83	±	0.13
SS08	135	63616	NM-276C	mostly san	Mean	11	0.7	4.9	±	16.7	68.08	±	0.03
SS13	196	63618	NM-276C	mostly san	Mean	4	4.7	0.4	±	0.8	70.58	±	0.44

TABLE DR3. ARGON DATA

ID	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{38}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{36}\text{Ar}/^{39}\text{Ar}$ ($\times 10^{-3}$)	$^{39}\text{Ar}_K$ ($\times 10^{-15}$ mol)	K/Ca	$^{40}\text{Ar}^*$ (%)	Age (Ma)	$\pm 1\sigma$ (Ma)
SS02, sanidine&plagioclase, J=0.0039178$\pm$0.02%, IC=1.03222$\pm$0.00130, NM-276C, Lab#=63612									
59	13.59	0.0064	0.0173	9.374	0.261	29.5	79.6	75.95	0.38
36	10.93	0.0090	0.0084	0.3619	0.512	60.5	99.0	76.00	0.18
27	11.19	0.0128	0.0086	1.135	0.492	59.6	97.0	76.18	0.18
32	11.02	0.0183	0.0128	0.5403	0.540	39.7	98.6	76.20	0.18
61	14.87	0.0258	0.5990	13.73	0.084	0.85	73.0	76.3	1.1
29	10.96	0.0120	0.0075	0.2640	1.499	67.8	99.3	76.352	0.066
# 62	13.60	0.0172	0.0274	6.610	0.495	18.6	85.6	81.60	0.22
# 06	18.36	0.0157	0.0060	3.966	2.757	85.0	93.6	119.243	0.061
# 35	23.07	0.0150	0.0062	8.320	0.497	82.4	89.3	142.12	0.28
# 28	23.10	0.0149	0.0034	2.964	1.370	148.6	96.2	152.74	0.11
# 19	25.77	0.0126	0.0019	1.103	2.628	267.1	98.7	173.866	0.071
# 12	27.34	0.0146	0.0019	1.681		263.5	98.2	183.01	0.11
# 05	27.23	0.0126	0.0024	1.294	3.111	213.4	98.6	183.014	0.068
# 14	31.49	0.0138	0.0053	11.10	1.666	97.0	89.6	191.83	0.15
# 17	29.68	0.0131	-0.0034	2.289	0.629	-	97.7	196.97	0.27
# 48	31.59	0.0155	0.0027	2.996	0.891	185.6	97.2	207.87	0.19
# 16	32.04	0.0120	0.0032	1.530	1.451	160.6	98.6	213.49	0.13
# 18	34.29	0.0178	0.0021	3.153	0.399	248.2	97.3	224.81	0.45
# 10	35.25	0.0139	0.0017	1.041	5.760	303.7	99.1	234.791	0.050
# 23	40.67	0.0152	0.0037	3.740	0.940	139.5	97.3	263.75	0.22
# 40	40.02	0.0126	0.0013	1.246	1.132	407.0	99.1	264.29	0.20
# 46	59.74	0.0060	-0.0064	3.307	0.216	-	98.4	379.2	1.1
Mean age $\pm 1\sigma$					n=6 MSWD=0.99			76.3	0.1
SS07, sanidine&plagioclase, J=0.0039193$\pm$0.02%, IC=1.03378$\pm$0.00143, NM-276C, Lab#=63614									
16	10.20	-0.0147	1.721	2.740	0.045	0.30	93.4	67.1	1.0
14	10.31	0.0175	1.373	2.534	0.075	0.37	93.8	68.12	0.63
47	9.904	0.0151	0.0176	0.4041	0.529	29.0	98.8	68.840	0.097
01	10.95	0.0311	1.571	4.059	0.084	0.32	90.2	69.52	0.60
# 05	12.17	0.0049	1.647	7.505	0.070	0.31	82.9	71.01	0.74
# 04	11.13	0.0131	3.004	4.108	0.049	0.17	91.3	71.56	0.97
# 21	11.47	-0.0401	2.320	4.828	0.036	0.22	89.2	72.0	1.3
# 23	10.44	0.0109	0.0096	0.2665	0.799	53.3	99.3	72.813	0.066
# 38	11.78	-0.1124	2.188	4.970	0.037	0.23	89.0	73.8	1.3
# 24	12.97	0.0035	3.261	9.310	0.038	0.16	80.8	73.8	1.3
# 25	20.77	0.0229	6.674	36.53	0.019	0.076	50.6	74.2	2.7
# 30	14.76	0.0070	3.454	15.00	0.017	0.15	71.8	74.7	3.0
# 19	12.01	0.0914	4.305	5.636	0.046	0.12	89.0	75.3	1.1
# 12	11.38	0.0177	2.244	2.763	0.054	0.23	94.4	75.57	0.90
# 34	12.49	-0.0086	1.294	3.219	0.044	0.39	93.2	81.7	1.2
Mean age $\pm 1\sigma$					n=4 MSWD=1.81			68.8	0.1

SS08, sanidine&plagioclase, J=0.0039123±0.02%, IC=1.03378±0.00143, NM-276C, Lab#=63616

36	24.67	0.0618	10.98	54.09	0.025	0.046	38.8	67.8	2.3
46	14.91	-0.0498	4.291	18.98	0.065	0.12	64.7	67.95	0.86
37	12.40	0.0582	5.358	10.79	0.049	0.095	77.8	67.99	1.00
13	11.31	0.0614	7.484	7.726	0.038	0.068	85.2	68.0	1.3
30	9.841	0.0134	0.0283	0.5344	1.204	18.0	98.4	68.023	0.047
40	9.745	0.0121	0.0241	0.1775	1.683	21.1	99.5	68.089	0.032
43	9.873	0.0139	0.0369	0.6095	0.824	13.8	98.2	68.101	0.062
10	10.60	0.0021	3.273	3.979	0.141	0.16	91.4	68.21	0.37
41	10.60	0.0221	2.761	3.672	0.104	0.18	91.9	68.52	0.48
35	9.977	-0.0017	2.943	1.571	0.070	0.17	97.7	68.61	0.66
06	14.04	0.0501	7.386	16.00	0.051	0.069	70.6	69.96	0.99
# 23	10.91	0.0182	3.517	4.044	0.144	0.15	91.6	70.36	0.36
# 14	13.10	0.0191	4.665	11.46	0.052	0.11	77.0	71.0	1.0
# 48	10.62	0.0191	0.1400	1.663	0.750	3.6	95.5	71.183	0.077
# 15	10.76	0.0177	3.513	2.604	0.152	0.15	95.5	72.26	0.34
# 19	12.90	0.3995	7.350	10.86	0.050	0.069	79.8	72.6	1.1
# 42	11.77	0.0245	4.218	5.966	0.083	0.12	87.9	72.78	0.67
# 38	15.25	0.0122	3.974	17.44	0.027	0.13	68.3	73.3	1.9
# 08	10.54	0.0119	0.0274	0.2974	1.141	18.6	99.2	73.338	0.048
# 34	10.74	0.0544	2.036	1.499	0.070	0.25	97.4	73.50	0.70
# 07	12.19	0.0156	3.231	6.634	0.114	0.16	86.0	73.73	0.47
# 24	11.94	0.0342	2.400	3.725	0.081	0.21	92.4	77.45	0.65
# 18	12.30	0.0196	0.1300	3.859	0.595	3.9	90.8	78.22	0.12
# 17	12.20	0.0048	0.2288	3.434	0.108	2.2	91.8	78.48	0.47
# 04	13.37	0.0670	3.057	8.103	0.021	0.17	83.9	78.8	2.5
# 44	12.17	0.0138	0.0043	2.577	0.806	119.0	93.7	79.894	0.088
# 21	33.93	0.2098	2.073	73.87	0.043	0.25	36.2	85.9	1.7
# 49	13.71	0.0236	4.440	3.185	0.073	0.11	95.7	91.91	0.74
# 32	17.16	0.0170	0.0122	5.551	1.320	41.9	90.4	107.84	0.21
Mean age ± 1σ			n=11 MSWD=0.69				68.1		

SS13, sanidine&plagioclase, J=0.0039009±0.02%, IC=1.03222±0.00130, NM-276C, Lab#=63618

# 84	13.43	0.0321	3.262	14.58	0.240	0.16	69.9	65.92	0.43
34	18.90	0.0304	0.4991	30.51	0.389	1.0	52.5	69.51	0.37
56	15.93	0.0146	3.524	20.83	0.289	0.14	63.1	70.59	0.41
29	14.87	0.0086	1.713	16.37	0.321	0.30	68.4	71.23	0.35
07	16.23	0.0128	3.098	21.27	0.194	0.16	62.8	71.46	0.59
# 39	10.55	0.0129	0.0071	0.6060	3.924	71.7	98.3	72.548	0.029
# 26	16.76	0.0213	2.603	22.22	0.353	0.20	62.1	72.90	0.38
# 18	11.45	0.0178	1.965	3.946	0.652	0.26	91.2	73.12	0.16
# 06	11.65	0.0113	2.291	3.965	0.406	0.22	91.5	74.66	0.24
# 04	12.40	0.0144	0.0149	5.698	1.798	34.1	86.4	74.921	0.090
# 57	11.29	0.0136	0.0095	1.488	3.537	54.0	96.1	75.849	0.037
# 55	11.20	0.0131	0.0067	1.168	3.630	76.1	96.9	75.874	0.036
# 58	23.40	0.0284	5.976	44.21	0.095	0.085	46.2	75.9	1.2
# 35	11.82	0.0146	1.159	3.275	0.504	0.44	92.6	76.57	0.19
# 79	11.15	0.0106	0.0101	0.2971	3.502	50.7	99.2	77.262	0.030
# 05	11.76	0.0148	0.0119	2.327	4.929	42.9	94.2	77.345	0.034
# 21	11.75	0.0134	0.0077	1.761	2.919	66.6	95.6	78.457	0.049
# 28	12.36	0.0162	0.0084	3.400	1.720	61.1	91.9	79.259	0.073
# 30	11.92	0.0136	0.0066	1.804	4.459	77.6	95.5	79.535	0.035
# 60	11.58	0.0168	0.0084	0.5838	6.110	60.9	98.5	79.615	0.023
# 45	12.04	0.0150	0.0063	2.090	2.887	81.1	94.9	79.722	0.050
# 62	11.96	0.0128	0.0118	1.806	2.106	43.2	95.5	79.747	0.059
# 13	12.42	0.0125	0.0064	1.471	6.893	80.3	96.5	83.614	0.024

# 61	12.58	0.0126	0.0197	0.2522	6.854	25.9	99.4	87.162	0.020
# 69	21.44	0.0138	0.0008	7.555	5.716	603.1	89.6	132.218	0.052
# 36	51.28	0.0365	2.283	99.08	0.076	0.22	43.3	152.2	1.9
# 71	23.25	0.0112	0.0010	1.346	1.500	525.7	98.3	156.242	0.098
# 27	24.86	0.0223	0.0053	6.795	1.403	96.6	91.9	156.28	0.13
# 41	23.87	0.0126	0.0026	2.803	1.690	196.6	96.5	157.49	0.10
# 70	24.50	0.0129	0.0009	2.539	1.784	547.3	96.9	162.153	0.093
# 15	29.76	0.0161	0.0136	19.08	1.794	37.5	81.1	164.59	0.15
# 01	28.63	0.0136	0.0027	3.566	4.418	190.2	96.3	186.991	0.059
# 48	33.72	0.0138	0.0014	4.976	7.957	367.4	95.6	216.846	0.045
# 10	34.77	0.0122	0.0032	4.677	1.860	157.8	96.0	224.04	0.11
# 47	35.64	0.0131	0.0029	1.660	7.100	175.4	98.6	235.171	0.047
# 52	36.31	0.0131	0.0013	1.482	8.447	381.6	98.8	239.664	0.038
# 24	36.99	0.0133	0.0026	1.352	8.376	195.0	98.9	244.21	0.11
# 38	37.65	0.0139	0.0054	2.401	5.607	95.3	98.1	246.359	0.052
# 20	46.14	0.0461	0.0170	30.94	0.125	30.0	80.2	246.8	1.3
# 25	37.88	0.0127	0.0040	2.523	4.661	127.8	98.0	247.568	0.071
# 42	38.40	0.0153	0.0037	3.830	1.501	137.7	97.1	248.42	0.15
# 83	54.55	0.0395	0.1644	54.89	0.252	3.1	70.3	255.11	0.92
# 16	62.98	0.0586	0.0746	77.26	0.130	6.8	63.8	266.3	1.8
# 81	57.98	0.0126	0.0022	2.188	2.814	232.8	98.9	369.45	0.11
# 64	61.92	0.0134	0.0042	2.003	4.953	121.1	99.0	392.577	0.083
# 37	85.56	0.0128	0.0016	1.979	3.585	309.9	99.3	524.00	0.13
# 08	170.4	0.0659	0.2780	213.5	0.088	1.8	63.0	640.5	4.5
# 51	519.9	0.2198	1.280	75.03	0.254	0.40	95.8	#####	3.3
Mean age $\pm 1\sigma$				n=4 MSWD=4.71				70.6	0.4

Notes:

Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interfering reactions.

Errors quoted for individual analyses include analytical error only, without interfering reaction or J uncertainties.

Mean age is weighted mean age of Taylor (1982). Mean age error is weighted error

of the mean (Taylor, 1982), multiplied by the root of the MSWD where MSWD>1, and also

incorporates uncertainty in J factors and irradiation correction uncertainties.

Isotopic abundances after Steiger and Jäger (1977).

symbol preceding sample ID denotes analyses excluded from mean age calculations.

Ages calculated relative to FC-2 Fish Canyon Tuff sanidine interlaboratory standard at 28.201 Ma (Kuiper et al., 2008).

IC = detector intercalibration; Measured $^{40}\text{Ar}/^{36}\text{Ar}/295.5$.

- No detectable ^{37}Ar above blank values.

Decay Constant (LambdaK (total)) = $5.463\text{e-}10/\text{a}$ (Min et al., 2000)

Correction factors:

$$(^{39}\text{Ar}/^{37}\text{Ar})_{\text{Ca}} = 0.0007064 \pm 0.000004$$

$$(^{36}\text{Ar}/^{37}\text{Ar})_{\text{Ca}} = 0.0002731 \pm 0.0000005$$

$$(^{40}\text{Ar}/^{39}\text{Ar})_{\text{K}} = 0.00808 \pm 0.00041$$

TABLE DR4. PALEOMAGNETIC DATA: LINES

Formation	Paleosol number	Strat level (m)	Sample prefix	Sample number	Temperature steps	Stratigraphic Declination	Stratigraphic Inclination	MAD*	Stratigraphic VGP latitude	Stratigraphic VGP longitude
Aguja	P42	0.3	C14BB	01A	460-500	6.4	33	14	77.3	48
Aguja	P42	0.3	C14BB	01C	480-520	11.8	35.5	10.1	75.6	26.2
Aguja	P42	0.3	C14BB	01D	300, 360, 380	21.1	25.5	7.1	64.8	21.4
Aguja	ss	7.5	C14BB	126B	250-300	187.4	-22.8	8.9	-71.3	233.7
Aguja	ss	26.0	C14BB	128B	430-480	118.4	-54.9	20.7	-38.4	10.5
Aguja	P39	30.0	C14BB	04C	480-520	223.8	-45.7	20.6	-51.6	159
Javelina	P01	57.5	C14BB	16B	250-300	192.6	-35.8	16.5	-75.2	203.5
Javelina	P01	57.5	C14BB	16C	250-300	193.0	-16.7	12.7	-65.9	223.7
Javelina	P01	59.0	C14BB	17B	150-250	195.3	-31.2	4.1	-71.2	205
Javelina	P02	61.0	C14BB	18A	150-250	214.0	-37.3	4.9	-58.2	174.2
Javelina	P02	61.0	C14BB	18B	150-250	163.0	-66.8	18.3	-66.1	48.7
Javelina	P02	61.0	C14BB	18D	150-250	162.3	-36.6	11.5	-71.7	321.7
Javelina	P03	67.0	C14BB	122B	150-250	179.9	-35.4	4.7	-80.3	257.3
Javelina	P03	67.0	C14BB	122C	250-300	203.9	-22.4	7.6	-61.6	200.2
Javelina	P03	68.0	C14BB	123A	150-250	187.9	-38.7	9.3	-79.7	211.3
Javelina	P03	68.0	C14BB	123B	200-300	220.2	-27.2	4.5	-50.1	179.8
Javelina	P04	69.5	C14BB	36A	300-360	135.7	-27.2	17.7	-46.6	336.5
Javelina	P04	69.5	C14BB	36C	250-300	125.2	-25.9	8.7	-37.2	341.8
Javelina	P05	70.5	C14BB	37A	250-275, 500	188.6	-14.8	10.7	-66.8	234.7
Javelina	P05	72.0	C14BB	38A	430-460, 500	262.1	-72.2	13	-28.5	114.3
Javelina	P05	74.0	C14BB	39A	400-460	86.0	-75.8	20.8	-24.2	47.2
Javelina	P05	76.0	C14BB	40A	380-430	186.2	-62.1	13.5	-75.1	94.5
Javelina	P06	77.0	C14BB	21C	430-480	158.0	-24.4	16.5	-63.7	312.4
Javelina	P06	77.0	C14BB	21D	430-480	158.8	-62.9	20	-67.5	34.3
Javelina	P06	80.0	C14BB	24A	480, 520-540	174.6	-78.8	12.9	-50.8	73.6
Javelina	P06	80.0	C14BB	24C	380-430	149	-40.1	7.3	-61.5	341
Javelina	P07	81.0	C14BB	25B	360, 400-430	338.6	11.1	3.1	58.9	121.3
Javelina	P07	81.0	C14BB	25C	250-300	19.5	33.5	12.2	69.1	14.1
Javelina	P07	82.3	C14BB	26A	460-500	325.7	26.1	9.7	54.7	148.1
Javelina	P07	82.3	C14BB	26C	250-300	8.5	18.6	6.6	68.7	53.1
Javelina	P07	82.3	C14BB	26D	275-330	16.8	19.5	8.1	65.1	34.1
Javelina	P07	83.5	C14BB	27A	360-400	31.0	26.8	6.3	57.6	7.9
Javelina	P07	83.5	C14BB	27B	480-520	344.1	47.8	14.9	76.1	168.9
Javelina	P07	83.5	C14BB	27C	150-250	355.7	11.6	9.4	66.2	87.4
Javelina	P07	84.8	C14BB	28A	480-520	0.4	26.5	15	74.7	75.3
Javelina	P07	84.8	C14BB	28B	480-520	24.8	32.8	7.1	64.6	8
Javelina	P07	84.8	C14BB	28D	500-540	21.9	31.7	8.7	66.6	13.1
Javelina	P07	86.5	C14BB	29B	460, 500 - 520	12.9	30.5	9.3	72.5	31.4
Javelina	P07	86.5	C14BB	29C	360-400	357.8	57.2	8	81.3	245.2
Javelina	P07	86.5	C14BB	29D	330, 380-400	358.1	33	18.7	78.6	85.9
Javelina	P07	88.0	C14BB	30D	150-250	19.1	28.8	9.3	67.6	21
Javelina	P08	89.0	C14BB	31B	300-360	63.8	33.5	12.1	31.3	342.1
Javelina	P08	89.0	C14BB	31C	200-275	38.7	45.3	2.4	55.9	341.4
Javelina	P08	89.0	C14BB	31D	360-400	349.3	25.5	16.6	71.3	111
Javelina	P08	89.5	C14BB	32A	275-330	22.3	30.0	11.6	65.6	14.7
Javelina	P08	89.5	C14BB	32B	480-520	23.8	47.6	19.9	69.2	342.5
Javelina	P09	90.5	C14BB	33B	250-275, 330	304.0	74.3	9.2	41.7	223.8
Javelina	P09	90.5	C14BB	33D	200-250, 300	344.2	29.2	7.3	70	126.9
Javelina	P09	92.5	C14BB	34A	TT100-200	24.9	43.6	3.4	67.6	350.6
Javelina	P09	92.5	C14BB	34B	TT100-300	25.6	42.1	5.6	66.7	353
Javelina	P09	95.0	C14BB	35A	TT150-300	17.3	41.9	7.6	73.7	1.1
Javelina	P09	95.0	C14BB	35B	360-380, 480	29.2	36.7	6.3	62.2	358.6
Javelina	P09	95.0	C14BB	35C	TT100-250	24	54.3	14.1	69	325.3
Javelina	ss	102.0	C14BB	125B	430, 480, 520	152.5	-17.5	12.3	-57.2	314.0
Javelina	P10	104.0	C14BB	41D	520-560, 600	170.3	-18.5	4.5	-68.3	282.8
Javelina	P10	103.0	C14DC	02B	460, 480, 560	143.4	-43.8	5.5	-57.4	349.2
Javelina	P10	103.0	C14DC	02C	150-250	178.8	-18.8	7.2	-70.3	260.3
Javelina	P11a	106.0	C14BB	42D	560-600	163.0	-23.9	4.7	-67.0	303.0

Javelina	P12	113.5	C14BB	43A	480-560	161.5	-18.3	1.7	-63.6	301.5
Javelina	P12	113.5	C14BB	43C	540-580	176.7	-43.2	3.3	-85.0	292.6
Javelina	P13	114.0	C14BB	44A	460-500	169.6	-27.0	3.2	-72.2	291.1
Javelina	P13	114.0	C14BB	44C	250, 360-380	176.2	-21.2	4.1	-71.4	267.9
Javelina	P13	114.0	C14BB	44D	500-560	188.0	-67.4	17.7	-68.2	089.9
Javelina	P13	115.0	C14BB	46A	400, 460, 500	182.5	-37.3	11	-81.3	240.4
Javelina	P13	115.0	C14BB	46B	400-430, 500	179.9	-21.8	11	-72.1	256.4
Javelina	P13	115.0	C14BB	46C	430-460, 500	167.2	-18.0	18.9	-66.7	289.6
Javelina	P13	116.0	C14BB	47B	400-460	173.7	-23.2	9.6	-71.9	276.3
Javelina	P13	116.0	C14BB	47C	330-380	103.0	-38.1	13.3	-21.2	000.1
Javelina	P13	116.0	C14BB	47D	480, 520, 600	155.9	-40.3	8.9	-67.5	335.6
Javelina	P13	117.0	C14BB	48A	200-300, 360-380	173.2	-26.4	15.4	-73.5	279.9
Javelina	P13	117.0	C14BB	48C	360-400	174.3	-41.6	7.7	-82.7	301.3
Javelina	P14	119.0	C14BB	49C	330,360,430	178.0	-24.9	12.7	-73.7	263.1
Javelina	P14	119.5	C14BB	50B	150-250	151.5	-20.9	9.4	-57.6	317.8
Javelina	P14	119.5	C14BB	50C	250, 300-330	156.9	-32.1	12.3	-65.8	322.0
Javelina	P14	119.5	C14BB	50D	250-200,480	160.2	-13.8	11.3	-60.9	300.5
Javelina	P14	120.2	C14BB	52A	150-250	221.4	-77.3	15.9	-45.6	098.9
Javelina	P14	120.2	C14BB	52B	300,330,380	185.7	-42.9	13.5	-83.3	205.1
Javelina	P14	120.2	C14BB	52C	100, 300-360	181.4	-32.4	16	-78.3	249.5
Javelina	P15	121.0	C14BB	53A	360, 460-480	188.7	-14.2	5.4	-66.5	234.0
Javelina	P15	121.0	C14BB	53C	250-330	168.2	-34.6	8.1	-75.2	305.2
Javelina	P15	121.0	C14BB	53D	300, 380-400	186.8	-16.3	11.8	-68.1	237.8
Javelina	P15	123.0	C14DC	03A	250-330	188.4	-13.6	13.2	-66.2	235.7
Javelina	P15	123.0	C14DC	03D	200-300	186.2	-24.8	4.6	-72.7	236.0
Javelina	P16	124.0	C14BB	54B	300, 400, 500	189.5	-17.2	5.5	-67.7	230.6
Javelina	P16	124.0	C14BB	54C	360-380, 580	179.6	-18.4	2.2	-70.2	257.3
Javelina	P16	124.0	C14BB	54D	400-430,480	176.1	-13.4	8.7	-067.2	266.8
Javelina	P17	125.5	C14BB	55D	250-330	182.7	-26.0	6.1	-74.3	246.4
Javelina	P17	132.0	C14BB	56A	200-300	170.2	-37.8	7.9	-78.0	306.1
Javelina	P17	132.0	C14BB	56C	200-330	179.7	-30.8	9.8	-77.4	257.4
Javelina	P17	132.0	C14BB	56D	330,400,480	194.7	-62.5	5.5	-71.3	110.8
Javelina	P17	133.0	C14BB	57A	330, 380-400	89.0	-55.3		-15.9	019.3
Javelina	P19	144.0	C14BB	120C	480,540-560	96.2	-50.8	3.8	-19.6	012.6
Javelina	P19	146.0	C14BB	59A	430,520,540	189.8	-19.3	4.7	-68.6	228.7
Javelina	P19	146.0	C14BB	59B	520,580,600	214.3	-40.2	4.6	-58.7	169.6
Javelina	P19	146.0	C14BB	59C	430,480,500	182.5	-21.6	9.3	-71.8	248.2
Javelina	P19	147.5	C14DC	04A	430,550,560	208.1	-62.7	13	-63.3	125.5
Javelina	P19	149.0	C14BB	60B	300, 330, 460, 480	278.4	-58.3	14.4	-12.0	127.9
Javelina	P20	162.0	C14DC	05A	380,400,480	194.6	-52.1	2.7	-77.0	147.8
Javelina	P20	162.0	C14DC	05B	560,580,590	193.6	-38.5	6.5	-75.6	195.5
Javelina	P20	162.0	C14DC	05D	360-400	193.3	-41.8	5.7	-77.0	187.3
Javelina	P20	160.0	C14BB	62A	250-330	205.1	-49.9	16.4	-68.3	155.9
Javelina	P20A	163.5	C14BB	92A	250, 330, 360, 500	197.3	-14.6	11.6	-62.8	216.0
Javelina	P20A	163.5	C14BB	92C	500,560,580	192.1	-31.8	7.3	-73.7	210.7
Javelina	P20A	163.5	C14BB	92D	330,380,430	192.6	-39.0	5	-76.6	195.6
Javelina	P21	169.0	C14DC	06D	430, 460, 580	108.6	-30.4	9.9	-23.9	352.8
Javelina	P22	175.0	C14DC	07A	460-500	149.8	-55.7	18.3	-63.8	010.0
Javelina	P22	175.0	C14DC	07C	330,360,430	150.6	-37.9	11.7	-62.3	336.7
Javelina	P22	175.0	C14DC	07D	460-500	149.9	-22.8	19	-57.0	321.2
Black Peaks	P24	181.0	C14BB	102A	150-200, 380	149.1	-32.7	13.5	-59.5	331.5
Black Peaks	P28	193.0	C14BB	68A	300, 350-380	117.2	-47.7	16.2	-35.8	002.8
Black Peaks	P28	193.0	C14BB	68D	150-200	201.2	-58	12.7	-70.1	132.2
Black Peaks	P29	201.0	C14BB	70C	250-300	223.7	-27.9	16.4	-47.3	356.8
Black Peaks	P29	202.0	C14BB	72A	100-200	195.2	-17.0	11.3	-65.0	218.3
Black Peaks	P31	205.5	C14BB	76C	400-460	249.5	-31.9	15.8	-25.9	160.0
Black Peaks	P32	208.0	C14BB	77C	430,460,500	184.6	-41.2	9.1	-83.1	218.7
Black Peaks	P34	213.0	C14BB	79D	150-200, 300	155.4	-37.1	18.8	-66.2	331.3
Black Peaks	P34	215.0	C14BB	80C	150-200	197.5	-59.1	18.6	-72.1	124.9
Black Peaks	P35	217.0	C14DC	09B	300-360	159.2	-24.6	7	-64.7	310.8
Black Peaks	P35	217.0	C14DC	09C	500-540	156.5	-7.3	16.9	-56	302.2

Black Peaks	plug	220.0	C14BB	107B	150,200,300	184.7	-21.4	18.3	-71.3	241.5
Black Peaks	plug	220.0	C14BB	107C	150-200, 275	185.1	-16.2	13	-68.5	242.2
Black Peaks	P36	226.5	C14BB	83D	150-200,275	195.5	-26.0	7.9	-68.9	210.1
Black Peaks	P36	228.0	C14BB	85C	100-200	213.4	-34.4	16.6	-57.9	177.3
Black Peaks	P37	232.0	C14BB	86A	480, 520-540	355.1	-80.9	20.1	-11.6	78.3
Black Peaks	P37	232.0	C14BB	86C	275-330	221.4	-25.1	8.1	-48.5	179.9
Black Peaks	P37	233.0	C14BB	87A	300-360	188.0	-39.5	5.5	-80	208.7
Black Peaks	P37	233.0	C14BB	87C	250-300	176.0	-67.0	7.3	-69.4	69.4
Black Peaks	P37	233.0	C14BB	87D	300-360	216.6	-36.6	5.5	-55.8	173.4
Black Peaks	P38	236.0	C14BB	89C	AF100-150	186.1	-12.4	13.7	-66.3	241.5
Black Peaks	P38	242.0	C14BB	91A	100-200	124.5	-65.4	7	-44	26.1
Black Peaks	P38	242.0	C14BB	91B	100-200	231.4	-72.9	11.1	-44.6	111.8
Black Peaks	P38	242.0	C14BB	91D	100-200	198.7	-36.9	3.4	-71	189.8

Note: *mean angular deviation

TABLE DR5. PALEOMAGNETIC DATA: CIRCLES

Formation	Paleosol number	Strat level (m)	Sample prefix	Sample number	Temperature step	Stratigraphic Declination of temperature step	Stratigraphic Inclination of temperature step	MAD* of temperature step	Stratigraphic VGP latitude of temperature step	Stratigraphic VGP longitude of temperature step	Temperature steps for great circle	Stratigraphic declination of great circle	Stratigraphic Inclination of great circle	MAD* of great circle
Aguja	mud	10.0	C14BB	07A	500	209.5	-74.4	9.1	-53.2	99.6	430, 460, 500	119.2	3.1	15.3
Aguja	mud	10.0	C14BB	07B	460	174.1	-38.5	7.8	-80.7	293	400, 430, 460	96.5	32	18.3
Aguja	mud	10.0	C14BB	07C	480	231.5	-56.7	10	-46.8	142.1	430, 460, 480	340.4	-13.6	3.9
Aguja	mud	12.0	C14BB	08A	480	154.3	-25.9	14.2	-61.5	318.9	430, 460, 480	195.5	51.8	12.8
Aguja	mud	12.0	C14BB	08B	500	173.1	-57.3	9.6	-79.7	44.9	460, 480, 500	94.8	4.8	3.9
Aguja	mud	13.5	C14BB	10C	520	209.0	-4.6	4.9	-79.7	44.9	430, 480, 520	127.3	52.8	10.8
Aguja	mud	15.5	C14BB	09A	460	153.7	-2.0	8.3	-52.2	303	400, 430, 460	64	28.9	11.4
Aguja	mud	15.5	C14BB	09B	330	246.8	-23.2	380	-26	167.1	275, 300, 330	98.9	-22.4	13.5
Aguja	mud	25.0	C14BB	127B	460	120.7	5.9	6.5	-24.8	327.8	400, 430, 460	213.3	69.6	9.5
Aguja	P39	32.0	C14BB	13D	380	127.6	5.2	2.1	-30.6	323.6	275, 300, 380	225.6	56.8	0.9
Aguja	P40	34.0	C14BB	06B	400	167.5	-21.4	8.8	-68.4	291.9	360, 380, 400	92.4	56.8	16.9
Aguja	P40	34.0	C14BB	06D	520	175.5	39.8	7.9	-37.9	262	460, 500, 520	121.9	-22.5	17.2
Aguja	P40	38.5	C14BB	11C	200	140.2	37.7	14.8	-26.7	298.7	100, 150, 200	83.7	-33	17.3
Aguja	P40	38.5	C14BB	11D	200	114.3	20.1	13.2	-15.4	325.1	100, 150, 200	217.9	30.2	15.6
Aguja	P41	49.5	C14BB	12A	460	139.3	42.0	14.8	-23.7	297.2	275, 300, 460	59.1	-12.3	10.7
Aguja	P41	49.5	C14BB	12B	380	142.5	-6.5	7.7	-45.9	317.7	300, 330, 380	51	-23.6	9.4
Aguja	P41	49.5	C14BB	12C	480	112.2	-6.2	5.3	-20.8	338.3	430, 460, 480	24.4	-10.2	5.8
Aguja	ss	56.5	C14BB	130C	430	179.9	-25.5	8.8	-74.1	257.1	380, 400, 430	121.6	46.7	5.3
Javelina	P01	59.0	C14BB	17A	200	185.2	-4.3	6.5	-62.4	245.5	100, 150, 200	88.1	-10.2	19.4
Javelina	P02	62.2	C14BB	19A	250	209.6	16.7	9.1	-42.6	215.1	150, 200, 250	130.7	-15.9	11.6
Javelina	P02	62.2	C14BB	19B	250	132.8	3.6	8.3	-34.3	317.4	150, 200, 250	41.9	12.5	3.3
Javelina	P02	62.2	C14BB	19D	380	127.3	-70.3	5.4	-44.9	35.9	330, 360, 380	72.9	23.6	19.7
Javelina	P03	64.5	C14BB	20B	500	191.5	-52.2	6.6	-79.6	144.3	460, 480, 500	22	-36.3	5.4
Javelina	P03	67.0	C14BB	122A	250	190.4	-22.6	13	-70	225.7	150, 200, 250	158.2	63.8	5.6
Javelina	P03	68.0	C14BB	123C	150	219.5	21.4	4.5	-34.5	207.5	AF100, 100, 150	134.4	-15.4	6.3
Javelina	P04	69.5	C14BB	36B	250	209.1	-16.9	7.5	-55.8	198.0	100, 150, 200, 250	128.9	25.7	16
Javelina	P05	72.0	C14BB	38B	330	232.3	-15.2	6.2	-36.5	179.6	275, 300, 330	167.2	59.1	17.3
Javelina	P05	76.0	C14BB	40D	460	233.0	-8.6	12	-34.1	182.7	380, 430, 460	333.3	-45.3	5.5
Javelina	P06	78.0	C14BB	22C	360	259.6	-44.3	12.5	-20.9	147.8	250, 300, 360	34	-42.1	16.3
Javelina	P06	79.0	C14BB	23A	480	148.7	23.8	6	-38.5	297.1	400, 460, 480	56.5	3.9	3.8
Javelina	P06	79.0	C14BB	23B	500	190.3	10.5	5.8	-54	239.1	430, 460, 500	91.2	43	4.9
Javelina	P06	79.0	C14BB	23C	400	211.9	-75.3	14	-51	99.7	330, 360, 400	10.2	-12.3	5.2
Javelina	P06	80.0	C14BB	24D	500	198.3	-71.2	11.1	-60.5	97.8	380, 480, 500	321	-22.4	19.3
Javelina	ss	102.0	C14BB	125C	520	121.1	-23.1	14.0	-32.9	342.3	400, 480, 500, 520	17.8	-24.6	17.4
Javelina	ss	102.0	C14BB	125A	500	162.3	38.7	10.6	-36.1	277.2	400, 460, 500	113.3	-39.5	2.6
Javelina	P10	104.0	C14BB	41B	460	168.4	2.2	3.6	-57.6	278.8	380, 400, 430, 460	77.2	26.2	6.5
Javelina	P11a	106.0	C14BB	42A	600	173.9	-30.3	6.8	-075.8	281.4	560, 580, 600	67.3	-24.5	8
Javelina	P11a	106.0	C14BB	42C	600	201.7	-15.4	5.0	-060.4	208.9	560, 580, 600	103.5	-26.9	9.5
Javelina	P11	108.0	C14BB	45A	580	145.6	22.5	8.5	-037.3	300.8	540, 560, 580	264.1	48.3	5.4
Javelina	P14	119.0	C14BB	49A	540	167.4	31.1	13.0	-042.3	273.2	500, 520, 540	70.1	14.2	18.1
Javelina	P14	120.0	C14BB	51D	430	155.9	-40.6	5.9	-67.6	336.6	380, 400, 430	66.5	7.6	9.4

Javelina	P15	123.0	C14DC	03B	560	112.9	-8.5	16.3	-22.0	339.0	430, 540, 560	112.9	-8.5	16.3
Javelina	P17	126.0	C14BB	55B	580	112.1	43.7	9.1	-004.9	313.8	540, 560, 580	41.8	-14.3	15.1
Javelina	P17	125.5	C14BB	55C	600	176.3	-2.8	5.2	-61.9	264.6	560, 580, 600	83.8	-31.3	9.8
Javelina	P19	145.0	C14BB	58A	600	171.4	4.5	3.4	-057.4	272.8	540, 580, 600	81.1	7.7	2.9
Javelina	P19	145.0	C14BB	58C	580	211.8	48.1	9.2	-24.2	226.5	520, 560, 580	90.9	26.7	11
Javelina	P19	147.5	C14DC	04B	480	147.3	-19.5	5.5	-53.9	321.3	400, 430, 480	193.6	62.3	8.4
Javelina	P20	159.0	C14BB	61A	560	311.8	-61.9	14.7	05.2	109.9	300, 380, 560	29.1	6.8	19.6
Javelina	P20	160.0	C14BB	62B	580	11.3	-69.9	5.1	006.3	70.1	250, 300, 580	36.5	17.8	3.7
Javelina	P20	160.0	C14BB	62C	300	32.6	-74.3	3.4	-003.8	61.4	200, 250, 300	52.9	14.7	4.5
Javelina	P21	167.0	C14BB	93C	550	318.2	-61.6	10.7	08.3	106.4	520, 540, 550	43.7	0.4	3.5
Javelina	P22	176.0	C14BB	94A	460	158.9	23.6	9.2	-43.7	285.8	400, 430, 460	92.9	-30.2	12.1
Javelina	P22	176.0	C14BB	94C	330	148.0	25.8	14.6	-20.1	339.2	275, 300, 330	78.4	-29.9	12.5
Javelina	P22	176.0	C14BB	94D	480	109.2	9.4	2.7	-14.2	332.9	430, 460, 480	14.5	14.6	5.9
Javelina	P23	177.0	C14BB	95C	520	173.6	-4.8	4.9	-62.4	270.7	480, 500, 520	76.7	-31.2	20.3
Javelina	P23	177.0	C14BB	95D	520	96.7	68.2	0.8	18.6	297.6	480, 500, 520	109.8	-20.1	2.8
Javelina	P23	177.5	C14BB	96A	480	148.6	27.3	7	-36.8	295.8	430, 460, 480	73	-29.8	15.1
Javelina	P23	177.5	C14BB	96B	250	115.8	18.0	11.2	-17.2	325.2	150, 200, 250	220.7	37.9	10.1
Javelina	P23	177.5	C14BB	96D	400	108.3	-19.1	3	-20.7	346.6	300, 360, 400	28.5	19.6	5.6
Javelina	P23	178.0	C14BB	97C	480	73.1	-18.6	5.3	09.7	003.6	380, 400, 480	340	-4.5	9.3
Javelina	P23	179.0	C14BB	99C	540	188.2	28.6	12.9	-44.8	245.6	480, 500, 520, 540	107.1	-27.1	10.2
Javelina	P23	179.0	C14BB	99D	500	101.2	-14.8	14.9	-13.4	347.9	450, 480, 500	129.7	69.3	14.5
Javelina	P23	179.5	C14BB	100B	400	191.3	5.3	1.5	-56.3	236.1	300, 360, 400	103	-13	2.2
Black Peaks	P24	181.0	C14BB	102C	300	188.5	59.0	6.7	-20.5	249.8	150, 200, 300	57.2	26.2	13.8
Black Peaks	P24	181.0	C14BB	102D	300	168.9	-3.0	2.2	-60.3	279.6	150, 200, 300	78.3	-30.2	19.7
Black Peaks	P24	182.0	C14BB	103A	300	54.9	-53.2	13.2	08.3	033.3	150, 200, 300	89.5	30.6	12.9
Black Peaks	P26	187.0	C14BB	64A	580	102.8	13.7	3.8	-07.6	334.3	520, 560, 580	24.9	-42.3	4.8
Black Peaks	P26	187.6	C14BB	65C	480	241.6	-24.5	5.9	-30.9	169.0	380, 430, 480	180	44.3	12.4
Black Peaks	P27	189.5	C14BB	66B	540	137.0	-40.4	10.8	-51.1	347.9	500, 520, 540	176.4	40.8	3.1
Black Peaks	P27	189.5	C14BB	66C	540	133.2	-13.6	5.8	-40.6	329.3	460, 500, 540	111.3	75.4	0.4
Black Peaks	P28	191.0	C14BB	67A	520	91.4	-32.9	4.4	-09.8	001.9	480, 500, 520	345.7	-24.5	3.3
Black Peaks	P28	191.0	C14BB	67B	520	95.8	-33.9	4.5	-13.9	000.5	460, 480, 520	103.5	55.7	0.4
Black Peaks	P28	191.0	C14BB	67D	250	85.9	-30.3	8.8	-04.4	003.0	150, 200, 250	103.8	58.4	2.2
Black Peaks	P28	193.0	C14BB	68C	250	156.5	27.8	13.5	-40.4	287.2	150, 200, 250	61.3	5.1	6.1
Black Peaks	P29	201.0	C14BB	70A	360	153.4	-25.8	11.7	-60.8	319.9	300, 330, 360	51.1	-11.8	13.6
Black Peaks	P29	202.0	C14BB	72B	200	175.8	-1.6	7.7	-61.2	265.5	100, 150, 200	178.6	-8.6	7.6
Black Peaks	P30	203.0	C14BB	73B	150	249.7	-36.2	12.3	-26.9	157.7	NRM, 100, 150	2.2	-24.5	9.9
Black Peaks	P30	203.0	C14BB	73C	275	210.8	-18.1	10.1	-54.9	195.2	150, 200, 275	114.4	-18.9	2.1
Black Peaks	P30	203.0	C14BB	73D	400	252.6	-49.1	8.6	-28.1	146.2	330, 360, 400	348.1	-8.9	19.7
Black Peaks	P31	205.5	C14BB	76A	330	48.4	-76.3	8.8	-10.7	57.3	275, 300, 330	80.5	13.5	16.1
Black Peaks	P31	205.5	C14BB	76B	250	159.3	6.6	6.8	-51.8	291.6	150, 200, 250	72.8	43.6	19
Black Peaks	P32	208.0	C14BB	77A	460	106.9	-0.8	10.1	-14.9	338.6	400, 430, 460	198.6	58.6	8.5
Black Peaks	P32	208.0	C14BB	77B	300	179.4	1.5	5.1	-59.9	257.9	200, 250, 300	88.1	-2.1	20
Black Peaks	P33	211.0	C14BB	78A	550	170.6	21.8	9.4	-48.4	270.7	480, 540, 550	85.2	-12.5	1.6
Black Peaks	P33	211.0	C14BB	78C	380	120.2	10.4	7	-23.1	326.1	330, 360, 380	35.1	-44.8	6.7
Black Peaks	P33	213.0	C14BB	79B	430	191.2	-73.8	8.4	-58.5	087.5	360, 400, 430	105.2	-0.7	3.4
Black Peaks	P34	215.0	C14BB	80B	300	169.3	-24.9	14.6	-71.0	290.4	250, 275, 300	99.3	47.6	11.4
Black Peaks	P34	215.0	C14BB	80D	250	143.0	-49.0	8.3	-58	357.2	150, 200, 250	3.2	-34.7	15.5

Black Peaks	P35	217.0	C14DC	09D	360	138.9	-35.6	15.4	-51.6	341.8	100, 300, 360	6.6	-45.9	19.2
Black Peaks	P36	225.0	C14BB	82A	300	168.0	-42.3	12.1	-78.3	325.2	200, 275, 300	112.5	33.9	4.5
Black Peaks	P36	226.5	C14BB	83C	150	268.1	-78.0	8.5	-27.5	102.9	AF100, 100, 150	322.1	1.5	9.6
Black Peaks	P36	227.0	C14BB	84C	200	237.1	12.1	9.5	-24.8	189.9	100, 150, 200	324	-14	2.6
Black Peaks	P36	227.0	C14BB	84D	300	191.5	-1.5	6.4	-59.4	233.7	250, 275, 300	104.2	-18.3	10.1
Black Peaks	P36	228.0	C14BB	85B	300	197.5	-40.4	8.3	-73.1	184.4	150, 250, 300	202.5	51.5	5.6
Black Peaks	P37	232.0	C14BB	86D	330	104.6	8.4	7.5	-10.6	335.8	100, 300, 330	16.4	-9.1	2.8
Black Peaks	P37	233.5	C14DC	10B	330	232.2	-37.9	7.7	-42.5	163.9	250, 300, 330	8.6	-45.2	11.7
Black Peaks	P37	233.5	C14DC	10C	430	113.4	-66.2	6.8	-36.6	27.6	380, 400, 430	94.4	22	2.4
Black Peaks	P37	233.5	C14DC	10D	430	161.3	14.6	6.8	-49.1	285.8	300, 380, 430	74.5	-11.6	11.7
Black Peaks	P38	234.0	C14BB	88A	200	159.7	-1.1	3.2	-55.3	294.3	AF100, 150, 200	64.4	-33.8	12
Black Peaks	P38	234.0	C14BB	88B	300	162.3	4.2	5.9	-54.3	288.1	150, 200, 300	74	-24.5	3.1
Black Peaks	P38	234.0	C14BB	88D	200	211.9	17.5	6.3	-40.9	213	100, 150, 200	115.5	10.6	9
Black Peaks	P38	236.0	C14BB	89B	300	232.1	-31.5	13.5	-41	169.2	100, 200, 300	318.8	-2	17.9
Black Peaks	P38	240.0	C14DC	11B	330	191.5	-54.8	13.4	-78.6	132	250, 300, 330	47.8	-25.4	12.1

Note: *mean angular deviation

TABLE DR6. PALEOMAGNETIC DATA: SITE MEANS

Formation	Paleosol number	Strat level (m)	Sample prefix	Sample number	n*	Stratigraphic Declination	Stratigraphic Inclination	alpha-95	Stratigraphic VGP latitude	Stratigraphic VGP longitude
Aguja	P42	0.3	C14BB	1	3	13.3	31.5	12.7	72.7	29
Javelina	P02	61.0	C14BB	18	3	182.7	-49.6	34.5	-87.4	140.2
Javelina	P07	82.3	C14BB	26	3	357.9	22.9	33.6	72.5	83.6
Javelina	P07	84.8	C14BB	28	3	15.4	30.8	18.5	71	25.3
Javelina	P07	86.5	C14BB	29	3	341.5	32.6	25.1	69.5	136.5
Javelina	P13	115.0	C14BB	46	3	176.2	-25.8	19.4	-73.9	270.2
Javelina	P14	120.0	C14BB	50	3	156.2	-22.3	15.5	-61.6	313.1
Javelina	P15	121.0	C14BB	53	3	181.9	-21.9	23.4	-72.0	250.7
Javelina	P16	124.0	C14BB	54	3	181.7	-16.4	10.9	-069.0	252.0
Javelina	P17	132.0	C14BB	56	3	179.4	-44	28.8	-86.4	265.5
Javelina	P19	146.0	C14BB	59	3	194.2	-27.6	28.5	-70.3	211.9
Javelina	P20	162.0	C14DC	5	3	193.8	-44.1	10.9	-77.3	179.2
Javelina	P20A	163.5	C14BB	92	3	194.2	-28.5	19.7	-70.8	210.8
Javelina	P22	175.0	C14DC	7	3	150.1	-38.8	26	-62.1	338.3
Black Peaks	P37	233.0	C14BB	87	3	197.3	-48.8	33.9	-75	160.8

Note: *number of samples used for site mean calculation