

REVISED MIOCENE BIOSTRATIGRAPHY AND BIOCHRONOLOGY OF THE DOVE SPRING FORMATION, MOJAVE DESERT, CALIFORNIA

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ABSTRACT--The Dove Spring Formation (DSF; formerly the Ricardo Formation) is an 1800 m thick succession of fluvial, lacustrine, and volcanic rocks that contains a nearly continuous sequence of vertebrate fossil assemblages. The fossil faunas represent one of the most complete Clarendonian-age successions in North America, thus they provide key information for local and continental-wide correlations. Previous paleomagnetic, radioisotopic, and biochronologic work in the DSF yielded age correlations that have come under increased scrutiny from more recent studies in this and other similarly aged formations in California. Tephrochronological studies of volcanic horizons widely distributed across the Great Basin, including the DSF, yield additional geochronological information. The best fit combination of these studies provides for a revised temporal interpretation indicating that the DSF ranges from 12.5 Ma to about 8 Ma. A formerly proposed 0.7 million-year-long unconformity in Member 4 is no longer recognized. Although updated taxonomic studies on the carnivores, insectivores, rodents, horses, and antilocaprids of the DSF have resulted in significant modifications to earlier interpretations, renewed biostratigraphic analysis continues to recognize three superposed mammalian faunas. Characterization of these faunas reinforces conclusions regarding the provincial nature of the assemblages when compared with those of the Great Plains, and clearly marks the region as a discernable zoogeographic entity. Regional and continental comparisons of the faunas confirm a lower boundary for the Clarendonian at 12.5 Ma and a Clarendonian/Hemphillian boundary at 9.0 Ma. Composition of the youngest fauna in the DSF provides insight into the nature of the otherwise poorly represented earliest Hemphillian assemblages.

INTRODUCTION

Whistler and Burbank (1992) presented a detailed geochronological and biostratigraphic characterization of the Dove Spring Formation. A more recently revised magnetic polarity time scale (MPTS; that of Lourens et al., 2004) in concert with renewed field mapping, revised taxonomic and biostratigraphic interpretations, paleomagnetic studies in similar-aged strata elsewhere in California (Wilson and Prothero, 1997; Prothero and Tedford, 2000), and tephrochronological work including new data presented here (Perkins et al., 1998; Perkins and Nash, 2002; Bonnicksen, et al., 2008), all warrant a revision of the former work. We therefore propose in this paper an alternative temporal framework, particularly in the lower part of the section, that yields a better overall fit with all available data.

Stratigraphic analysis of the El Paso Basin, western Mojave Desert, California (Loomis and Burbank, 1988), led to the elevation of the Ricardo Formation (Merriam, 1919; Dibblee, 1952, 1967) to group rank and subdivision into two formations, the overlying Dove Spring Formation and the underlying Cudahy Camp Formation. The Dove Spring Formation is an 1800 m thick succession of fluvial, lacustrine, and volcanic rocks that contains a nearly continuous sequence of diverse vertebrate fossil assemblages. When the Wood Committee (Wood et al., 1941) first defined North American Land Mammal Ages (NALMAs), the fossils of the DSF were chosen as one of the assemblages characterizing the Clarendonian. These fossils were also recognized as correlative with faunas characteristic of the

original Montediablan west coast provincial stage (Savage, 1955). Later workers (Whistler, 1969; Whistler and Burbank, 1992; Tedford et al., 1987, 2004) would also recognize these faunas as correlative to both the Cerrotejonian and Montediablan west coast provincial stages. Early radioisotopic work (Evernden et al., 1964) yielded a maximum age of 10.3 Ma for the lower part of the DSF, but all subsequent attempts to replicate this have been unsuccessful and independent lines of evidence have supported older dates. Concurrent studies of the fossil mammalian assemblages of the DSF by Tedford (1965) recognized a succession of three superposed faunas: in ascending order, the Iron Canyon Fauna, the Ricardo Fauna, and the Dove Spring Fauna. Compared to faunas of the Great Plains and elsewhere, Tedford concluded that the three faunas of the DSF spanned most of the interval spanning the Clarendonian age. We continue to recognize three faunas similar to those used previously (Tedford, 1965; Tedford et al., 1987, 2004), but with the advantage of taxonomic revisions and new age interpretations as provided herein.

Detailed geologic mapping of the DSF, and precise stratigraphic positioning of fossils, permitted Whistler and Burbank (1992) to develop a biostratigraphy consisting of four mammalian fossil assemblage zones. Additionally, paleomagnetic studies revealed thirteen normal and thirteen reversed magnetozones that were correlated with chrons C5AB through “Chron 7” (= C4n), spanning a then interpreted interval of 13.5 Ma to 7.0 Ma (Burbank and Whistler, 1987; Loomis and Burbank, 1988:fig.7; Whistler and Burbank, 1992). In contrast to Tedford (1965) and Tedford et al. (1987), who considered the entire DSF to be Clarendonian, Whistler and Burbank (1992) proposed that these zones ranged from late Barstovian to early Hemphillian. On the basis of their biochronology, and on comparisons with faunas of the Great Plains, they placed the Barstovian/Clarendonian boundary between the two lower assemblage zones at 12.5 Ma and the Clarendonian/Hemphillian boundary between the upper two assemblage zones at 8.9 Ma. This lower limit for the Clarendonian was about 0.9 m.y. older than was generally accepted at the time (Tedford et al., 1987). Because they concluded that one of the normal subchrons in C5r was missing, Whistler and Burbank (1992) proposed an unconformity above the lower basalt in Member 4, representing a gap of as much as 0.7 m.y. More recent geological mapping together with revised geochronological correlations presented here no longer support this unconformity.

Woodburne (2006:fig. 10) provided the first detailed alternative interpretation of the paleomagnetic correlations within the DSF. As repeated here, a correlation of magnetozones N1 and N2 (Burbank and Whistler, 1987; Loomis and Burbank, 1988; Whistler and Burbank, 1992) to chron C5An rather than C5AB is the key that corrects the older age estimate. Woodburne (2006) also selected the local range of the horse *Hipparion forcei* Richey, 1948, in the DSF for a revised characterization of the boundary between the Cerrotejonian and Montediablan provincial stages. This differs from previous interpretations of a zone of overlap between these stages (Tedford et al., 1987; Whistler and Burbank, 1992; Prothero and Tedford, 2000; Tedford et al., 2004). We propose a somewhat different interpretation in other parts of the section that does not differ markedly from previous ones (Tedford et al., 2004; Woodburne, 2006).

METHODS

The geologic mapping used as a basis for this study was undertaken by two of us (RHT and DPW) during the 1960s and 1970s (Whistler, 1969; Whistler and Burbank, 1992). Stratigraphic sections were measured using an alidade and/or Jacob’s staff (Whistler, 1969; Whistler and Burbank, 1992). Details of the paleomagnetic analyses are provided in Loomis and Burbank (1988) and Whistler and Burbank (1992). Radioisotopic and fission track dates are derived from a number of sources (Figure 1). Our revised correlations are based on the MPTS of Lourens et al. (2004). Tephrochronological data and interpretations follow the previous work of Perkins et al. (1998), Perkins and Nash (2002), and Bonnicksen et al. (2008), plus additional data presented here. Significant fossil collections from the DSF are housed at the Natural History Museum of Los Angeles County (LACM) and the University of California Museum of Paleontology, Berkeley (UCMP). Collections formerly housed at the University of California, Riverside, are now at the UCMP. Minor collections are also housed at the American Museum of Natural History, New York, and the San Bernardino County Museum of Natural History, Redlands, California.

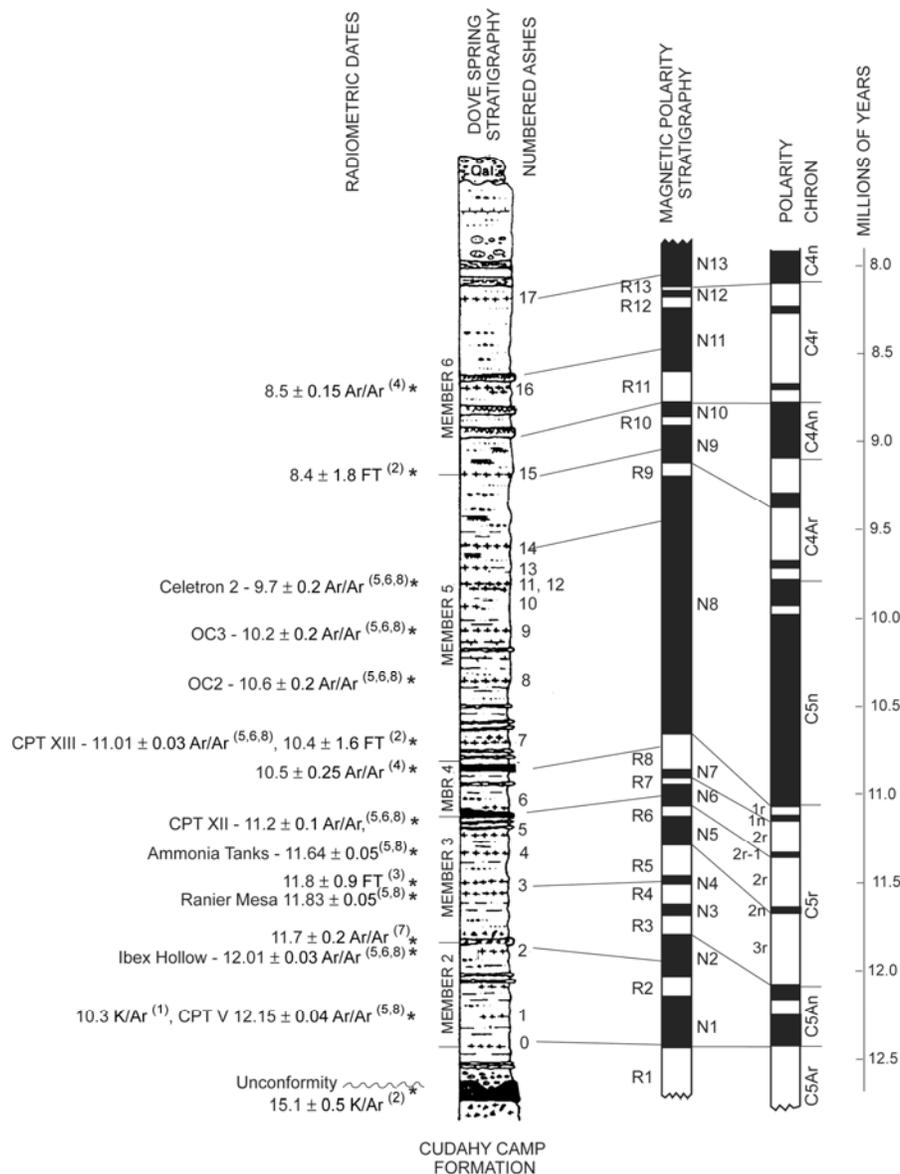


Figure 1. Generalized columnar section of the Dove Spring Formation (Whistler and Burbank, 1992) showing 1) stratigraphic position of radioisotopically dated samples, 2) stratigraphic position of ash beds correlated with tephras of known ages within the Great Basin (Perkins et al., 1998; Perkins and Nash, 2002; Bonnicksen et al., 2008), 3) stratigraphic occurrence of numbered DSF Ashes 0-17, and 4) a revised correlation between the magnetostratigraphy of the DSF (Loomis and Burbank, 1988; Whistler and Burbank, 1992) and the MPTS of Lourens et al. (2004). Sources of radioisotopically dated tuffs: ⁽¹⁾ Evernden et al. (1964), ⁽²⁾ Cox and Diggles (1986), ⁽³⁾ Loomis and Burbank (1988), ⁽⁴⁾ Whistler and Burbank (1992), ⁽⁵⁾ Perkins et al. (1998), ⁽⁶⁾ Perkins and Nash (2002), ⁽⁷⁾ Smith et al. (2002), ⁽⁸⁾ Bonnicksen, et. al. (2008), ⁽⁹⁾ Perkins, this study. The subdivisions of the magnetozone C5r added to facilitate understanding of revised interpretations. Abbreviations: CPT= Cougar Point tephra, OC = Opal Canyon tephra.

DEFINITIONS AND ABBREVIATIONS

Ash--As used here, a general term used for lithologic beds composed of air-fall volcanic material, mostly volcanic glass; term ash is interchangeable with tuff and tephra.

⁴⁰Ar/³⁹Ar--Radioisotopic age determinations using the decay of radiogenic argon isotopes.

DSF--Dove Spring Formation

Fauna--An assemblage of vertebrate fossils of similar taxonomic composition obtained from a small

number of sites considered to have limited temporal range.

FT--Fission track radioisotopic age determination.

K/Ar--Radioisotopic age determinations using the decay of radiogenic potassium and argon isotopes.

LACM--Natural History Museum of Los Angeles County

Local Fauna--An aggregate of fossil vertebrate species that have a limited distribution in time from a number of closely grouped localities in a limited geographic area.

Ma--Megannum. One million years in the radioisotopic time scale.

MPS--The local magnetic polarity stratigraphy derived from direct analyses of rocks within the Dove Spring Formation.

MPTS--Magnetic polarity time scale (as used herein: Lourens et al., 2004).

m. y.--A segment of geologic time one million years in duration.

NALMA--North American Land Mammal Age. An interval of time based on the biochronologic succession of mammalian evolution.

Tephra--As used here, a general term used for lithologic beds composed of air-fall volcanic material, mostly volcanic glass; term tephra is interchangeable with tuff and ash.

UCMP--University of California, Berkeley, Museum of Paleontology

GEOLOGIC SETTING

The Dove Spring Formation was deposited in an elongate, fault bound trough, the El Paso Basin, in the western part of the Basin and Range Province. Uplift of the El Paso Mountains along the El Paso Fault has exposed over 6.2 km of Cenozoic terrestrial sedimentary and volcanic rocks, including the DSF, in mostly western dipping homoclines. The El Paso Fault parallels the Garlock Fault, a major tectonic boundary within the Basin and Range province (Davis and Burchfield, 1973).

The sedimentary fill of the El Paso Basin includes coarse clastic sediments of the Paleocene Goler Formation (Dibblee, 1952; Cox, 1982, 1987; Cox and Diggles, 1986) and sediments and volcanics of the Miocene Ricardo Group (Merriam, 1919; Dibblee, 1952, 1967; Loomis, 1984; Loomis and Burbank, 1988; Whistler and Burbank, 1992), the latter of which were originally recognized as a single formation (Dibblee, 1952, 1967). The Ricardo Formation was composed of a basal 450 m thick sequence of dominantly volcanic rocks unconformably overlain by over 2000 m of fluvial and lacustrine sediments and air fall and flow volcanic rocks. The overlying fluvial, lacustrine, and volcanic rocks are the source of the long recognized, Clarendonian-aged, Ricardo Formation fossil assemblages (Merriam, 1919; Wood et al., 1941; Whistler, 1969; Tedford et al., 1987). Cox and Diggles (1986) determined that the underlying volcanic rocks, with a minimum age greater than 15 Ma, were in unconformable contact with the overlying fossil-bearing strata. Because of the unconformity, Dibblee's (1952) Ricardo Formation was elevated to group status and two new formations were defined (Loomis and Burbank, 1988). The underlying volcanic rocks were named the Cudahy Camp Formation, and the overlying, primarily fluvio-lacustrine and fossiliferous, strata were named the Dove Spring Formation. Unconformably overlying the DSF are Quaternary deposits representing coalesced bajadas emanating from the Sierra Nevada to the west. Finer-grained lignitic stream deposits within these alluvial deposits yield fossil vertebrates of Rancholabrean-age and a radiocarbon date of $10,730 \pm 110$ years before present (Whistler, 1990). Detailed maps, measured sections, and lithologic descriptions of the DSF are provided elsewhere (Dibblee, 1952, 1967; Whistler, 1969; Loomis and Burbank, 1988). Figure 1 is a generalized stratigraphic section of the DSF showing members and key ash beds used in the following magnetostratigraphic and biostratigraphic discussions.

LITHOLOGY

The more than 1800 m of fluvio-lacustrine sediments and volcanic and volcanoclastic rock of the DSF can be broadly separated into five lithofacies: (1) fine-grained lacustrine deposits of clay, silt, reworked volcanic ash, fresh-water limestone, and bedded chert, the latter forming resistant outcrops, particularly in the Last Chance Canyon area; (2) fluvial deposits of channel sandstone and channel conglomerates that weather reddish in color and regularly form prominent cliffs that are the source of the name "Red Rock Canyon" for the major outcrop area of the DSF; (3) overbank and floodplain silts; (4)

poorly sorted alluvial fan deposits, and (5) paleosol, caliche, and silicified hardpan deposits (silcretes), the latter forming prominent exposures and easily traceable beds in the upper part of the sequence. Deposition in the lower portions of the DSF resulted primarily from meandering, intermittent streams feeding into a semi-permanent lake in the center of a broad basin. The upper portions become coarser as alluvial fans prograded into the filling basin.

Volcanic air-fall vitric ashes are common, particularly in the more basin-ward portion of the section. Eighteen of these ashes are traced throughout most of the mapped section and serve as critical marker beds for correlation of measured sections and delineation of fossil range zones. They are the source rock of many of the radioisotopic age determinations within the DSF (Evernden et al., 1964; Cox and Diggles, 1986; Loomis and Burbank, 1988; Whistler and Burbank, 1992; Perkins, this study), and many are recognized as having sources in the southern Great Basin and from the Yellowstone “Hot Spot” (Perkins et al., 1998; Perkins and Nash, 2002; Bonnicksen et al., 2008). Two prominent pink lithic tuff breccias that form cliffs in the lower part of the section in the Red Rock Canyon area can be traced along strike toward the center of the basin where they are expressed as yellow, fluvially reworked tuffaceous siltstones. These tuff breccias are over 100 m thick in the southwestern part of the outcrop area.

The DSF also contains two basalt flow sequences that thicken to the southwest in a similar fashion to the pink tuff breccias. Each of these sequences contains a number of individual flows displaying pahoehoe texture, often with distinct baked zones at the bottom and vesiculated zones at the top. The flows thin and eventually pinch out to the northeast toward the center of the depositional basin. A source of these basalts, and the underlying pink tuff breccias, has been identified south of the Garlock Fault in the Lava Mountains (Smith et al., 2002), and the upper basalt sequence is the source of one of the more reliable radioisotopic dates (Whistler and Burbank, 1992).

Paleocurrent studies show a strong preferred orientation from the southeast, suggesting a source from the elevated Mojave Block south of the Garlock Fault (Loomis and Burbank, 1988). Coarser detrital material in the lower two-thirds of the DSF are dominated by volcanic and metamorphic clasts. Volcaniclastic conglomerates in this part of the section are characterized by sub-rounded to rounded clasts of purple porphyritic andesite, banded felsite and dacite, and vesicular basalt. Plutonic rocks make up less than 5% of the clasts. Clast sizes range up to 20 cm suggesting moderately flowing water as a transport medium. In contrast, clasts of microcline-biotite granite and granodiorite containing dark, schistose, xenoliths are the dominant detrital component above DSF Ash 14, Member 5, and in all of Member 6. Mudflow conglomerates in Member 6 with rounded granitic boulders up to 2 m in diameter suggest a source in the Sierra Nevada Mountains, which were unroofed by erosion during this interval. Well-developed paleosols with siliceous hardpans, suggesting slowing of deposition in a semi-arid climate, became a prominent part of the lithology above DSF Ash 14.

FOSSIL OCCURRENCES

Fossils are broadly distributed throughout the DSF, but are most commonly recovered from finer grained sediments representing floodplain or overbank deposits (Whistler and Burbank, 1992: fig. 3). They are also commonly found in paleosols, particularly in the upper part of the section, but they are rare in channel deposits. Most microvertebrate fossils were recovered from lignitic siltstones interpreted as pond or slow moving, shallow water deposits. Bones and teeth are permineralized with amorphous silica and marrow cavities are generally filled with secondary crystalline calcite. Silicified root casts are common throughout the section and suggest seasonal climatic fluctuations.

Most fossils occur as single elements or a few associated bones or teeth. Partially articulated specimens are uncommon. The only articulated specimens yet recovered are two partial frog skeletons from a lignitic mudstone and a partial bird skeleton from a silicified paleosol (Rich, 1980). Disarticulated fossil owl pellets provide a source for much of the microvertebrate assemblage. Many fossil bones display carnivore gnawing and rodent chewing marks. A majority of limb bones were broken prior to fossilization by bone-crushing carnivore activity, and many have checkered surfaces indicative of weathering before fossilization.

The plants are known primarily from fossil wood, a common source of which is the “petrified forest” in Last Chance Canyon from reworked tuffaceous siltstones representing the basin-ward

expression of one of the pink tuff breccias (Webber, 1933; Dibblee, 1952). A single fossil leaf was recovered by amateurs (Axelrod, 1939), but repeated efforts to relocate it have been unsuccessful. Silicified grass stems representing the earliest confirmed record of C4 grasses (Nambudiri et al., 1978) were recovered from cherts in the Last Chance Canyon area, and preliminary fossil pollen studies provide additional valuable insight for the fossil floral associations (L. Fisk, personal communication).

PALEONTOLOGY

Vertebrate fossils from the DSF have been known for nearly a hundred years. The first published report was by Baker (1912), which was followed by Merriam (1919) who provided the first comprehensive study and established the Ricardo Formation fossils as the most diverse assemblage of this age from the southwestern United States. Subsequent studies made modest additions to the fossil diversity (Stock and Furlong, 1926; Furlong, 1927; Stock, 1928; Miller, 1930; Osborn, 1933; Frick, 1937; Green, 1948; Richey, 1948; Tedford, 1961; Estes, 1963; Schultz et al., 1970; Baskin, 1980; Rich, 1980; MacFadden, 1984; Whistler and Wright, 1989). Fossil wood (Webber, 1933) and a small leaf flora (Axelrod, 1939) were also described. Whistler and Burbank (1992: table1) provided a composite floral and faunal list of the known diversity at that time. More recent work has added new taxa or revised previously recognized species (Korth and Reynolds, 1994; Wang et al., 1999; Wang et al., 2005; Lander, 2005a, b; Prothero, 2005; Woodburne, 2007, Tedford et al. 2009, Tseng et al., in press). For this study we have undertaken further analyses of specific taxonomic groups that have a particular bearing on the DSF biostratigraphy (carnivorans: Wang, Tseng, and Takeuchi; horses: Takeuchi; heteromyid rodents: Tseng; other rodents, lagomorphs, insectivores, and antilocaprids: Whistler).

Table 1 is a revised faunal and floral list for the DSF. Significant changes from the list previously provided (Whistler and Burbank, 1992) include the following: the addition of the plesiosoricid insectivore *Meterix* sp.; seven additional carnivores including *Borophagus littoralis* Vanderhoof (1931), *Epicyon haydeni* Leidy (1858), *Metalopex macconnelli* Tedford et al. (2009), *Paratomarctus temerarius* (Leidy, 1858), *Martinogale faulli* Wang et al. (2005), *Martes* sp. B, and *Barbourofelis whitfordi* (Barbour and Cook, 1915); six additional rodents including *Mylagaulus* sp., *Ammospermophilus fossilis* James (1963), *Arctomyoides* sp., *Spermophilus* sp., *Phelosacomys shotwelli* Korth and Reynolds (1994), and *Prosigmodon* sp.; and one additional lagomorph, *Pronotolagus apachensis* (Gazin, 1930).

Our recent recognition of the primitive skunk, *Martinogale faulli*, in the upper part of the DSF represents the first appearance of North American mephitids (Wang et al., 2005). Such an immigration event can potentially serve as an important biochronologic marker, although its restricted distribution in the DSF limits its utility. The bone-crushing dog, *Borophagus littoralis*, from the upper part of the Ricardo Fauna is nearly contemporaneous with its occurrence in the Black Hawk Ranch local fauna of northern California, lending further support for the correlation of the Ricardo fauna to the Montediablan Stage. In addition, its apparent restriction to the west coast of the United States reaffirms the zoogeographic importance of the DSF as a potential source of progenitors for this top predator on the eastside of the Continental Divide. The presence of *Carpocyon webbi* provides a western extension of its geographic range from Nebraska and New Mexico, and although precise stratigraphic information is lacking, the identification of a left jaw with p4-m2 of *Paratomarctus temerarius* (LACM 150860), previously known from Barstovian sites elsewhere (Wang et al., 1999), extends its temporal range. The presence of the large cat *Nimravid* Kitts (1958) also provides a correlation with Black Hawk Ranch, where *Nimravid* *thinobates* (Macdonald, 1948) occurs.

The nimravid saber-tooth *Barbourofelis* has been used as an important immigrant to characterize the Clarendonian (Tedford et al., 1987, 2004). It ranges in the DSF from about 12.0 Ma to 8.4 Ma. The oldest occurrence is represented by a distal left humerus found between Ashes 1 and 2. The youngest occurrence is represented by an isolated left p4 found just above Ash 15. The recent discovery of a nearly complete set of dentition of *Barbourofelis whitfordi* above Ash 9 represents the first occurrence of the upper dentition of the species (Tseng et al., in press). Along with the holotype dentary of *B. osborni* (= *B. whitfordi*) discovered earlier between Ashes 8 and 9, the new dental material represents the most complete specimen of the genus in California. Considering both the dental and post-cranial material, there

is now a record of this biostratigraphically important genus on the West Coast from the beginning of Cl2 to the middle of Hh1.

The single specimen of *Mylagaulus*, common in the Great Plains, provides the first record from southwestern North America. The squirrel *Arctomyoides*, previously known only from the Barstovian of Montana (Douglass, 1903; Bryant, 1945), lends additional evidence for the transitional age of the basal assemblages of the DSF.

One of us (ZJT) evaluated the large sample of heteromyids in an attempt to distinguish greater species diversity as a tool in biostratigraphic differentiation. Univariate distributions and T-tests of coefficient of variation were used to determine the statistical probability that multiple species are represented in the DSF samples. There were too few specimens of *Cupidinimus* to arrive at statistical conclusions, although three species appear to be recognizable on the basis of morphology (Table 1). Results supported the presence of two species of *Perognathus*, *P. furlongi* Gazin (1930) and *P. minutus* James (1963). The large sample of *P. furlongi* allows an evaluation of variation in this species over time and indicates that if only the smaller and larger end members were present, separate, morphology-based species most likely would be recognized - a valuable lesson in the use of paleontological morphospecies in biostratigraphy.

Recent reviews shed new light on the early “gopher-like” rodents with high-crowned teeth (Korth and Reynolds, 1994; Korth and Chaney, 1999). These species have a distribution in the Great Plains and southwestern United State from the middle Barstovian to the Clarendonian. One of these, *Phelosacomys shotwelli* Korth and Reynolds (1994), formerly called “*Thomomys*” sp. (Whistler and Burbank, 1992:table 1), is restricted to the Iron Canyon and Ricardo faunas.

Previously recognized from near the top of the DSF were two derived, high-crowned species of cricetid referred by Whistler and Burbank (1992) to *Repomys*. Reexamination of this material suggests referral to an undescribed species of *Prosigmodon* instead. There are also at least two undescribed species of *Paronychomys*. Both of these taxa were formerly thought to be restricted to middle Hemphillian or younger assemblages (Jacobs, 1977; Baskin, 1979; Jacobs and Lindsay, 1981). Together, these occurrences appear to represent the earliest record of a cricetid radiation leading toward modern grasshopper mice and cotton rats. This, in turn, may prove to have biostratigraphic significance once the phylogenetic relationships are better understood.

Taxonomic review of the horses from the DSF has revealed only a single unambiguous specimen of “*Pliohippus*” *tejonensis* Merriam (1915). All other specimens previously assigned to this small species are now assigned to the larger, longer ranging *Pliohippus tantalus* Merriam (1913). “*Pliohippus*” *tejonensis* was used, in part, to characterize the Cerrotejonian provincial stage (Savage, 1955).

Genus and/or species reassignments have occurred among other taxa, as well, including referral of *Epicyon aphobus* (Merriam, 1919) to the widespread *E. haydeni* (Wang et al., 1999), the reassignment of *Cormohipparion occidentalis* (Leidy, 1856) (see MacFadden, 1984) to a separate, unnamed species (Woodburne, 2007), and the two species of *Ustatochoerus* to *Merychys medius* Leidy (1858) and *Merychys major* Leidy (1858) (Lander, 1998, 2005a).

Accounting for some of the more common fossils in the DSF are the antilocaprids, an important group for continent-wide biostratigraphic correlations. Taxonomic distinctions within this group are dependent primarily on horn core structure (Frick, 1937; Janis and Manning, 1998). With the exception of *Paracosoryx furlong* Frick (1937), which is amply represented by diagnostic horn cores, only two basal horn core fragments questionably assigned to cf. *Illingoceros* sp. are available to facilitate taxonomic identity of the remaining antilocaprid material. One of us (RHT) examined a horn core fragment in the early 1960s that was assigned to *Plioceros*, but this specimen is now missing. Later, DPW undertook a character and biometric analysis of the dental and postcranial material (mostly distal portions of limbs), which resulted in at least three morphological groupings. One of these groups from the lower part of the section below the basalts was assigned to *Paracosoryx furlongi* on the basis of associated dental, cranial, and horn core fossils. Above the basalts is an abundance of dental and postcranial material, but no horn cores, thus suggesting the presence of a small, hornless antilocaprid tentatively referred to *Cosoryx* sp. The largest taxon, based on tooth measurements and horn core base fragments, is assigned to cf. *Illingoceros* sp. The teeth are not as large as topotypic *Illingoceros alexandrae* Merriam (1909) or other

material assigned to *Illingoceros* in collections of the LACM (Furlong, 1943), but it is the largest species in the DSF. Lacking further diagnostic fossils, the fairly abundant intermediate-sized material is assigned to *Plioceros* sp.

As shown in Table 1, the DSF also contains additional fossil taxa not included in the above discussion. The fish cf. *Empetrichthys* sp. is referred to the highly endemic living genus that today is restricted to fresh water pools within the southern Great Basin (Nelson, 2006). The DSF occurrence represents only the second record of the family (Uyeno and Miller, 1962) and may demonstrate a wider Miocene distribution.

The well preserved and diverse microfossil herpetofauna (Whistler, 1969) is currently undergoing study by J. Mead and D. Whistler. Preliminary findings suggest a significantly greater diversity than reported in Table 1 and heretofore unrealized biostratigraphic and zoogeographic implications. Pond turtles (*Clemmys* sp.) are commonly associated with lithofacies interpreted as pond deposits. Tortoises (*Geochelone* sp. and ?*Gopherus* sp.) with carapaces up to 0.5 m in length are found throughout the section. These suggest a paleoenvironment that did not experience freezing temperatures.

As is usual in terrestrial fossil occurrences, birds are underrepresented. The screen-sieved microvertebrate assemblages have yielded post-cranial material of small birds whose taxonomic identity is undetermined. A single specimen of *Neophrontops ricardoensis* Rich (1980) is a “vulture” of Asiatic affinities. In addition to fossil owl pellets providing indirect evidence of owls, metatarsals and phalanges assignable to the Strigidae are also present.

In addition to the insectivore *Meterix*, noted previously, the Eurasiatic immigrant *Lanthanotherium* was also recovered from a very few sites. Shrews are represented low in the section by a single record of *Limnoecus* sp. together with other species showing a transitional aspect between the Barstovian and Clarendonian. Two other shrews, *Alluvisorex chassae* (Tedford, 1961) and an undescribed new genus and species of soricine (Whistler, 1969), are abundant throughout the section. Repenning (1967) proposed a relationship between *Alluvisorex* and the late Miocene to Pleistocene European shrew *Petenya*. Moles are also a common microvertebrate component of the fauna, easily diagnosed by the distinctive elements of the forearm and carpus. Hutchison (1968) assigned the mole from the DSF, *Scapanus schultzi* Tedford (1961), to the subgenus *Xeroscapheus*, and concluded that *Xeroscapheus* had more derived fossorial adaptations than living moles, adaptations shared with several other Miocene moles from the Great Basin.

Early records of shovel-tusked gomphotheres were assigned to *Trilophodon* sp. (Stock, 1928), but these are now referred to *Amebelodon burnhami* (Osborn, 1933), the type of which is from the DSF. *Amebelodon burnhami* is also reported from China (Guan, 1996), suggesting an additional link between Asia and North America.

Rhinos are uncommon, but have been recognized since the early days of collecting in the DSF. Originally assigned to *Aphelops* sp. and *Peraceras* sp. (Stock and Furlong, 1926), the material more recently has been referred by Prothero (2005) to *Aphelops megalodus* (Cope, 1873).

RADIOISOTOPIC DATING

Radioisotopic dating within the DSF is summarized in Figure 1. A sample presumably collected from DSF Ash 1 (D. Savage, personal communication) yielded the first K/Ar date for the DSF (10.3 Ma; Evernden et al., 1964). Efforts to replicate this date using single crystal $^{40}\text{Ar}/^{39}\text{Ar}$ analyses (Whistler and Burbank, 1992) were unsuccessful due either to contamination or diagenetic alteration of sanidine in the lower part of the DSF. The first direct radioisotopic dating in the upper part of the DSF yielded FT dates of 10.4 ± 1.6 Ma for Ash 7 and 8.4 ± 1.8 Ma for Ash 15 (Cox and Diggles, 1986). The relatively large error envelopes diminish the value of these dates, but subsequent work confirms their general accuracy. An additional FT date of 11.8 ± 0.9 Ma for Ash 3, the Cudahy Mine ash, was obtained to supplement the magnetostratigraphic correlations of Loomis and Burbank (1988). Later, Whistler and Burbank (1992) made additional attempts to secure unambiguous FT dates from below the basalts in Members 2 and 3. As with Evernden et al.'s (1964) K/Ar date, the range of individual zircon crystal dates in these ashes (12 Ma to >30 Ma) suggests sample contamination. However, Whistler and Burbank (1992) obtained two reliable $^{40}\text{Ar}/^{39}\text{Ar}$ dates from the upper basalt and from Ash 16 at 10.5 ± 0.25 Ma and 8.5 ± 0.13 Ma, respectively.

These more recent dates, including those in Table 2 provided for this study by MEP, appear somewhat more reasonable relative to that of Evernden et al. (1964).

TEPHROCHRONOLOGIC CORRELATIONS

A detailed chronology based on the widespread occurrence of hundreds of siliceous fallout tuffs in middle to late Miocene sedimentary basins across the central and northern Great Basin, including the El Paso Basin and the DSF (Perkins et al., 1998; Perkins and Nash, 2002), provides an additional correlation tool with which to enhance our interpretation of the age of the DSF. Tuffs across this broad region are matched on the basis of glass shard composition at their source areas, and most of them have been radioisotopically dated using a variety of high precision techniques. As such, they provide indirect radioisotopic ages for a number of tuffs within the DSF (Figs. 1-3).

Air-fall tuffs are common in the DSF and many of the thicker mapable horizons provide important marker beds for both stratigraphic and biostratigraphic control (Loomis and Burbank, 1988; Whistler and Burbank, 1992). In addition, their correlation with tuffs outside the DSF for which radioisotopic ages have been previously determined provides a highly refined chronostratigraphic framework (Whistler and Burbank, 1992: fig. 3). These isotopic ages indicate that the basal strata of the DSF may be as old as ~13.5 Ma and that the uppermost strata may be younger than about 8.4 Ma, which was thought to be in general conformity with both the fossil record and the interpreted magnetic stratigraphy for the formation (Loomis and Burbank, 1988; Whistler and Burbank, 1992). More recent work by Perkins et al. (1998) on the regional correlation of middle and late Miocene tephra across the Basin and Range supported previous age estimates for Member 4 and the lower part of Member 5 of the DSF, but noted that a revision is required for the age and magnetostratigraphic correlation of Members 2 and 3.

Tables 2 and 3 list the ages of 12 key tephra in Members 2, 3, 4, and 5. Also listed are the reported magnetic polarities, where known, of the dated tephra to which those in Members 2-5 are correlated. The stratigraphic positions of these tephra are shown on Figure 1. The ages/polarities of the tuffs in Members 2 and 3 support our revised correlations of the magnetostratigraphy to the current MPTS of Lourens et al. (2004). The ages for tephra in the lower part of Member 5 confirm that the lower part of N8 correlates with the lower part of chron C5n. The presence of Cougar Point Tuff unit XII in Member 4 indicates that there is no significant time gap across the unconformity in Member 4, contrary to the previous interpretation of Whistler and Burbank (1992).

To put published $^{40}\text{Ar}/^{39}\text{Ar}$ ages into congruence, all dates are expressed relative to an age of 28.02 Ma for the Fish Canyon sanidine (FCs) neutron fluence monitor. Evaluation of the best age for $^{40}\text{Ar}/^{39}\text{Ar}$ dating fluence monitors is a topic of active research (e.g., Jourdan and Renne, 2007; Kuiper et al., 2008), but an interim age of FCs = 28.02 Ma has been recommended by Earthtime for the reporting of $^{40}\text{Ar}/^{39}\text{Ar}$ ages (Swisher, 2006). All ages in Table 3 are based on interpolations between tephra that are correlated with ash-flow tuffs with $^{40}\text{Ar}/^{39}\text{Ar}$ dates or, in the case of the Celetron 2 tephra, estimated by extrapolation from a K-Ar dated tuff using a sediment accumulation rate based on varve thickness in a diatomite at the Hazen Quarries section of Perkins et al. (1998).

MAGNETOSTRATIGRAPHIC CORRELATION

A magnetostratigraphic framework recognizing thirteen normal and thirteen reversed intervals was developed in the 1980s-1990s throughout nearly 1600 m of the DSF (Burbank and Whistler, 1987; Loomis and Burbank, 1988; Whistler and Burbank, 1992). Samples were taken in the Last Chance Canyon and Opal Canyon areas in finer grained, dominantly lacustrine, sediments. Following the MPTS of Berggren et al. (1985), it was concluded that the DSF spanned magnetozones C5AB at 13.5 Ma to Chron 7 (= C5r) at 7.0 Ma. This interpretation was anchored on a correlation of the 600 m-long normal interval N8+N9 with C5N. In turn, magnetozones R1-R8 and N1-N7 were correlated to C5AB through C5r, in part due to the single FT date of 11.8 ± 0.9 Ma. Interpretation of the magnetostratigraphy above N8 and N9 was less straight forward, which may have been a result of sporadic deposition in a continental setting and/or relatively large spacing between samples.

Subsequent magnetostratigraphic analyses in similarly aged strata elsewhere in California

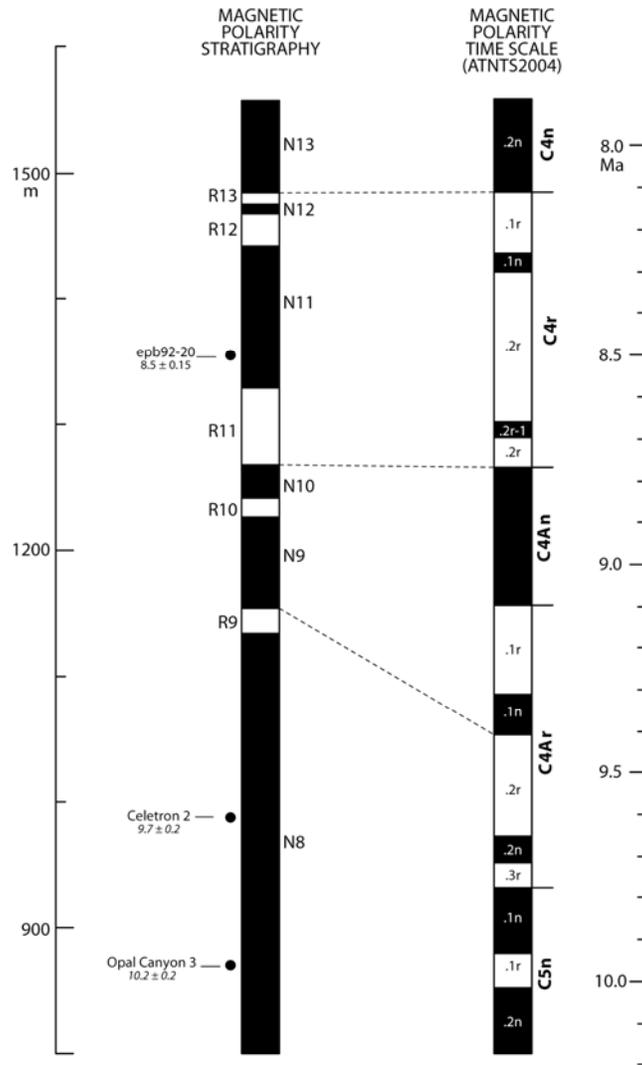


Figure 2. Distribution of tephra locations, magnetostratigraphy, and MPTS in the upper part of the Dove Spring Formation (upper Opal Canyon). See Figure 1 and Tables 2 and 3 for abbreviations. Data from Perkins (this paper).

(Prothero and Tedford, 2000), plus tephrochronologic and biostratigraphic data presented herein suggest that much of the original magnetostratigraphy may have contained flaws unrecognized in our original study. Specifically, there appears to have been a strong normal polarity overprint that was not removed by thermal demagnetization of the samples, which effectively increased the number of normally magnetized zones in the section, in turn resulting in ambiguous correlations to the MPTS. Even in the study presented here, ambiguities remain that will only be resolved with additional radioisotopic dating and/or paleomagnetic studies. We provide the following revised interpretation based on current evidence.

As noted above, the striking aspect of the original magnetostratigraphy of the DSF was the long normal interval N8 that ranged from Ash 7 to Ash 15. A correlation to chron C5n based on the most recent MPTS of Lourens et al. (2004) appears straight forward. This conclusion is bolstered by tephrochronological considerations indicating an age of 10.6 ± 0.2 Ma for OC 2 (DSF Ash 8), 10.2 ± 0.2 Ma for OC3 (DSF Ash 9), and 10.96 ± 0.03 Ma for the Cougar Point XIII tephra (DSF Ash 7) (Figs. 1-3). If the above correlations are correct, the FT date of 10.4 ± 1.6 Ma on DSF Ash 7 and the $^{40}\text{Ar}/^{39}\text{Ar}$ date of 10.5 ± 0.25 Ma from near the base of the upper basalt, appear young. The FT date was obtained from a normal polarity zone, which likely correlates with the lower part of C5n. The basalt sample is of reversed

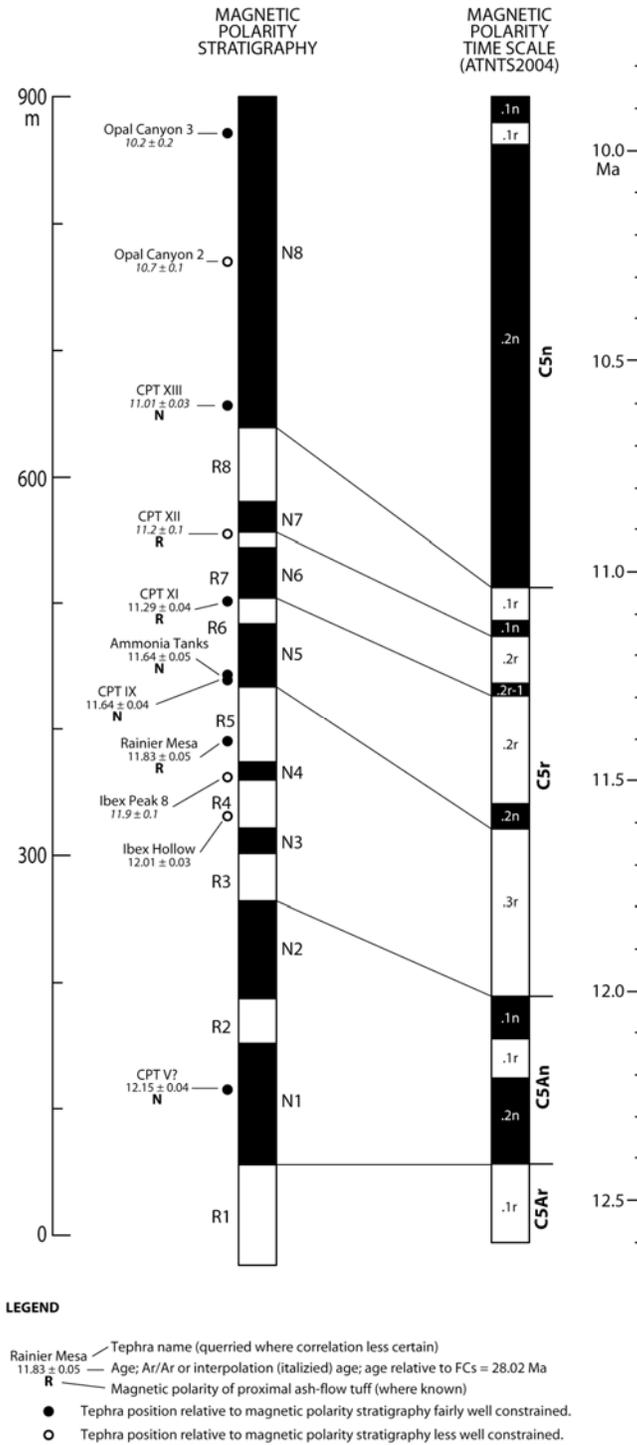


Figure 3. Distribution of tephra locations, magnetic polarity stratigraphy and magnetic polarity time scale (Lourens et al., 2004) in the lower part of the Dove Spring Formation. in lower Opal Canyon. See Fig. 1 and Tables 2 and 3 for abbreviations. Data from Perkins (this volume).

polarity, and it likely represents the lowest reversal at 10.8 Ma in the otherwise normal C5n (Evans et al., 2007). However, reversed magnetozone R8 appears too robust to represent this very short (<50,000 years) reversed excursion.

Available radioisotopic ages within the section below the basalts (Figs. 1 and 3), together with

paleontological data (see below), support an alternative magnetostratigraphic correlation. N1 and N2, the two robust normal intervals near the base of the section, more likely correlate with the C5An rather than the million-year older C5AAn and C5ABn. This is further supported by a date of 11.95 ± 0.03 Ma for the Ibex Hollow tephra (= DSF Ash 2) at the level of magnetozone N2 (even though Ibex Hollow tephra is magnetically reversed) and a date of 12.15 ± 0.04 Ma in the Cougar Point V tephra (= DSF Ash 1) in magnetozone N1. This correlation is in marked contrast to the previous correlation which was the source of the 13.5 Ma age for the base of the DSF.

Continuing up section, magnetozones R3-R5 can be accommodated within C5r, rather than C5A as previously proposed, which is supported by the 11.8 ± 0.9 Ma FT date (Whistler and Burbank, 1992) on upper DSF Ash 3 (= upper Cudahy Mine tephra), by the 11.83 ± 0.1 Ma date on the Ibex Peak tephra, and by the 11.74 ± 0.05 Ma date on the Rainer Mesa tephra (= lower DSF Ash 3) which, in the present study was confidently correlated with the Cudahy Mine tephra. The magnetically reversed Rainer Mesa tuff in magnetozone R4 is now correlated with chron C5r.3r. Magnetozone N5 is now correlated with chron C5r.2n, which is strongly supported by the 11.59 ± 0.04 Ma Cougar Point IX tephra and the 11.64 ± 0.05 Ma Ammonia Tanks tephra (=DSF Ash 4) (Figs. 1 and 3). This is in contrast to the correlation of the base of N6 with C5r.2n and the top of N6 with C5r.1n by Woodburne (2006) in order to accommodate the presumed long-duration unconformity within magnetozone N6 - an unconformity we no longer recognize. Neither we nor Woodburne (2006) accommodate magnetozones N3 or N4.

Regardless of which interpretation is favored, the section below the basalts with a preponderance of normally magnetized rock should contain a greater portion of reversed rock if general correlations are correct. One likely possibility is the strong normal overprinting noted above. It is also significant that this part of the stratigraphic section is repeatedly cut by strike faulting in which the fault planes dip into the bedding planes. These faults regularly repeat portions of the stratigraphic section in ways that are difficult to interpret. The “abundance” of paleomagnetic excursions may be the result of failure to fully recognize the effects of this faulting. This faulting mostly dies out or is accommodated by soft sediment failure in the upper part of the section above the basalts.

In contrast, the portion above magnetozone N8 is dominated by strata with normal polarity (Fig. 1). The MPTS (of Lourens et al., 2004) above C5n is dominated by intervals of reversed polarity, thus complicating correlations of the DSF magnetostratigraphy to the MPTS. We propose a correlation of R9 with C4Ar.2r and N9 with reversed intervals in C4Ar.1n, in contrast to previous proposals of a correlation between N9 and the older, upper portion of C5n (Burbank and Whistler, 1987; Loomis and Burbank, 1988; Whistler and Burbank, 1992). We further propose a correlation of N10 with C4An and R11-R13 with C4r. The robust N11 appears anomalous. Although falling in the appropriate chronologic level based on our correlations, the presence of DSF Ash 16 in a zone of normal polarity with a $^{40}\text{Ar}/^{39}\text{Ar}$ radioisotopic date of 8.5 ± 0.13 Ma is difficult to reconcile because this date should fall within reversed strata. We continue to correlate the uppermost normal magnetozone N13 with C4n (Chron 7 in Burbank and Whistler, 1987; Loomis and Burbank, 1988; Whistler and Burbank, 1992). The revised ages of chron boundaries in the MPTS of Lourens et al. (2004) relative to that of Berggren et al. (1985) used for our original paleomagnetic work increases the age of the interval above the long normal C5n by as much as 0.5 m.y. This alone mandates rethinking of the previous biostratigraphic interpretations.

The strata in the upper part of the DSF are coarser grained and poorly consolidated, outcrops are often poorly developed, and the low dips (<10 degrees) easily lead to over- or under-estimating of stratigraphic thickness. Short magnetic excursions such as C5n.1r and the lowest reversal in C4Ar could be easily missed. The primarily microvertebrate faunal assemblages above Ash 16 reflect an early Hemphillian character. Although not well constrained, Hemphillian assemblages elsewhere in North America are 9.0 Ma or younger (Tedford et al., 2004).

NO UNCONFORMITY IN MEMBER 4

The previous paleomagnetic interpretations of Whistler and Burbank (1992) resulted in placement of an unconformity at the top of the lower basalt sequence in Member 4 to accommodate strata that were presumed missing on the basis of their original correlation to the MPTS of Berggren et al. (1985). Our revised paleomagnetic correlation eliminates this concern. More recent field observations of the top of

the lower basalt of the DSF for over five km along strike do not provide evidence for an extensive hiatus. A disconformity is most prominent in the up-slope portions of the basin in the Red Rock Canyon area where the lower basalt is entirely missing due either to erosion or non-deposition. Toward the center of the depositional basin, individual flows of the basalt sequence are separated by sections of lacustrine sediment up to several meters thick. In outcrops in the Cudahy Mine area in Last Chance Canyon, both basalt sequences pinch out before reaching the center of the basin. There is no evident unconformity in this central basin area. In the Red Rock Canyon area, the uneven erosional surface on top of the lower basalt is often in-filled with DSF Ash 6. This poorly consolidated tephra should have been completely removed by contemporaneous erosion had the interval represented a long duration hiatus. In the center of the basin, Ash 6 is a discrete unit within lacustrine sediments. Deposition both below and above the lower basalt sequence is primarily fine-grained lacustrine or fluvio-lacustrine in origin suggesting a stable basin both before and after emplacement of the basalt.

REVISED BIOSTRATIGRAPHY

In previous studies (Tedford, 1965; Tedford et al., 1987) a succession of three faunas, the Iron Canyon, Ricardo, and Dove Spring faunas, each characterized by an assemblage of stratigraphically restricted species, were recognized in the DSF. An alternative approach (Whistler and Burbank, 1992) subdivided the fossils of the DSF into four assemblage zones characterized by the restricted or limited range of key species. In the present study, we return to the faunal characterization approach because of its more widespread use by the vertebrate paleontological community. Abandoning the assemblage zone approach is further justified because some species originally used to characterize the assemblage zones are now superseded by newly recognized species or synonymies. For example: *Ustatochoerus profectus* (Matthew and Cook, 1909) is now referred to *Merychys medius*, *Epicyon aphobus* = *E. haydeni*, and *Osteoborus diabloensis* (Richey, 1938) = *Borophagus littoralis*. These changes would require new names for three of the four assemblage zones, an exercise that likely would lead to confusion. Further compromising use of assemblage zones, the single specimen now assigned to *Borophagus littoralis* falls below the level of the zone it previously characterized. Although a biozonation was fairly evident with the large number of taxa presented in the earlier work of Whistler and Burbank (1992:figs. 4, 5), faunal subdivisions are not as evident in our new study using fewer species. However, a common pattern continues to emerge. Comparative lists of all taxa within these faunas are provided in Table 4, and Figure 4 presents a revised biostratigraphy based primarily on the insectivores, carnivores, rodents, horses, and antilocaprids.

Most evident in the Iron Canyon Fauna is the restricted occurrence of a suite of rodents that display Barstovian affinities. These include *Arctomyoides* sp., *Ammospermophilus fossilis*, *Cupidinimus avawatzensis* Barnosky (1986), *Copemys* cf. *C. longidens*, (Hall, 1930), and *C. russelli* James (1963). Also restricted to the Iron Canyon Fauna are the insectivores *Meterix* and *Limnoecus*, the large amphicyonine *Ischyrocyon mohavensis* (Stock and Furlong, 1926), a species of *Megahippus*, and the forked-horned *Paracosoryx furlongi*. A single occurrence of the Asiatic immigrant nimravid, *Barbourofelis*, provides an important link to the Clarendonian (Tedford et al., 2004). Another possible Asiatic immigrant, the shrew *Allivisorex chasseur* Tedford (1961), and other rodents that eventually dominate the overlying Ricardo Fauna, also have first appearances in the Iron Canyon Fauna, as does the widely distributed borophagine *Epicyon saevus* (Leidy, 1858) and the horse *Cormohipparion*. The latter two species also become more prominent in the overlying Ricardo Fauna (Table 4).

The lower part of the interval encompassing the Ricardo Fauna is the most fossiliferous part of the DSF, thus increasing our confidence that the biostratigraphy is accurately represented. The Ricardo Fauna is most prominently characterized by the restricted occurrence of the hipparionine *Hipparion tehonense* (Merriam, 1916), the protohippine “*Dinohippus*” *leardi*, and the common occurrence of *H. forcei*, the latter having a key role in a revised characterization of the Montediablan Stage (see Woodburne, 2006, and further discussion below). The Ricardo Fauna is also characterized by the common occurrence of the dogs *Epicyon haydeni* and *E. saevus*, several long ranging species of the pocket mouse *Perognathus*, and the long-ranging *Copemys dentalis*. The restricted range of the felid *Nimravides* and the nimravid *Barbourofelis whitfordi* likely are due to their limited representation.

Represented by a single specimen, the restricted occurrence of the *Borophagus littoralis* may be less significant. *Cormohipparion* last occurs before the end of the interval and a diverse suite of smaller carnivores make their first appearance (Fig. 4). The diminutive (and primitive) skunk, *Martinogale faulli*, represents the first appearance of mephitids in the New World and thus signals an immigration event, although records of this small predator are still too poor elsewhere in North America to know if this occurrence carries biochronological significance. The first appearance of the *Illingoceros*-like antilocaprid is an early representation of a taxon that otherwise is restricted to Hemphillian assemblages.

The Dove Spring Fauna is depauperate compared to the Iron Canyon and Ricardo faunas due to a coarsening of the lithology and scarcity of large fossil vertebrates in the part of the section from which the fauna originates. The apparent abrupt termination of all carnivore species is likely a reflection of these sedimentological properties rather than a true biostratigraphic event. However, a handful of microvertebrate sites high in the stratigraphic sequence yield significant samples. Most characteristic is the first appearance of the more derived, higher crowned cricetine rodents *Paronychomys* sp. and *Prosigmodon* sp., taxa that become common in the middle Hemphillian. These are the oldest records for both genera. The long-ranged *Perognathus furlongi* and the high-crowned *Cupidinimus tertius* continue into the Dove Spring Fauna, as does the low-crowned cricetid, *Copemys dentalis*. Horn core base fragments assigned to cf. *Illingoceros* are from a single site near the base of the section containing the Dove Spring Fauna.

REGIONAL CORRELATIONS

The Cerrotejonian and Montediablan Stages were proposed on the basis of fossil mammals from a number of disjunct fossil sites in northern and central California (Savage, 1955). At the time, Savage (1955) proposed that the fossils from the DSF (treated as a single fauna) were older than the Black Hawk Ranch Local Fauna (type Montediablan), yet he nevertheless referred them to the Montediablan Stage. The nearly continuous superposed fossil record of the DSF detailed by Whistler and Burbank (1992) provided a basis for an independent evaluation of the chronologic ranges of the key taxa used by Savage (1955) to characterize the stages. The DSF records demonstrated an overlap of the local range zones of some of the taxa used to characterize the stages, particularly the horses (Whistler and Burbank, 1992: fig. 6). All the horses have longer ranges in the DSF than the inferred ranges in the area used to typify the stages. Even though an overlap of ranges existed, Whistler and Burbank (1992) defined the base of the Montediablan Stage on the first stratigraphic occurrence of *Hipparion forcei* at about 10.5 Ma using the MPTS of Berggren et al. (1985), or a little more than 11.0 Ma following that of Lourens et al. (2004).

A more recent paleomagnetic assessment by Prothero and Tedford (2000) of key sites used by Savage (1955), together with a comparison of the DSF faunas with those in the Caliente Formation (James, 1963; Kelly and Lander, 1988, 1992), suggested that Cerrotejonian faunas correlate to chrons C5An, C5r, and C5n, whereas those of the Montediablan are from a shorter interval near the top of C4Ar. Because of the broad interval of overlap in the DSF among the horse species that lay between late chron C5n and early chron C4Ar, or between 10.2 Ma and 9.5 Ma (based on the MPTS of Cande and Kent, 1995), Whistler and Burbank (1992) did not propose a fixed boundary for the base of the Montediablan Stage. Additionally, because all strata originally used to characterize the Montediablan Stage were of reversed polarity, they correlated these strata with dominantly reversed polarity chron C4Ar, at about 9.1 to 9.8 Ma. In a comprehensive review of the North American Miocene biostratigraphy, Tedford et al. (2004) reaffirmed the younger age of the Montediablan and again recognized the broad overlap of the characterizing horses in the upper part of an interval they recognized as Cerrotejonian.

Woodburne (2006) further proposed defining the base of the Montediablan on the stratigraphic first occurrence of *H. forcei* in the DSF. This reinterpretation increased the duration of the Montediablan and placed the base at about 11.0 Ma (using age interpretations of Whistler and Burbank, 1992). The only difference between this and other proposals (i.e., Prothero and Tedford, 2000; Tedford et al., 2004) is the selection of the single taxon, *H. forcei*, as the defining species. The alternative paleomagnetic (Fig. 1) and biostratigraphic (Fig. 4) correlation presented here shifts the beginning of the Montediablan to about 0.1 m. y. older, not a significant change. What is significant is the removal of the “zone of overlap” between the Montediablan and Cerrotejonian stages with a consequent greater duration for the Montediablan.

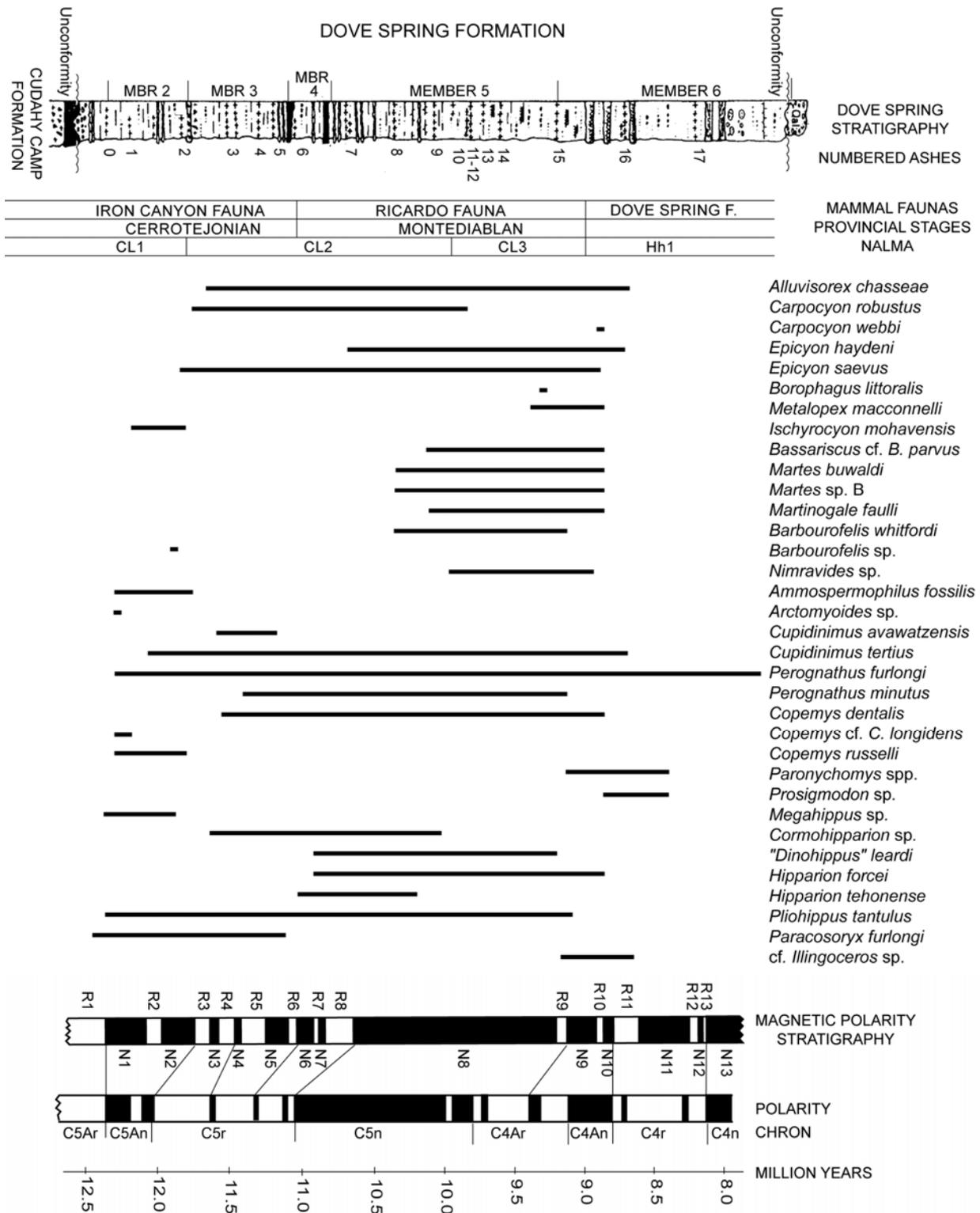


Figure 4. Teilzones of selected vertebrate taxa correlated to the MPTS with the magnetostratigraphy of Loomis and Burbank (1988) and Whistler and Burbank (1992). Taxa included are those with the greatest biostratigraphic significance within the DSF. Numbered ashes are those presented in Figure 1. Mammalian faunal divisions after Tedford (1965), Tedford et al. (1987), and this paper. Provincial stages after Savage (1955), Prothero and Tedford (2000), Woodburne (2006), and modifications discussed herein. North American Land Mammal Age subdivisions after Tedford et al. (2004). See Appendix A for locality and specimen numbers of included taxa.

The taxa within the superposed Matthews Ranch and Nettle Springs Local Faunas of the Caliente Formation in the Transverse Ranges of California (James, 1963; Kelly and Lander, 1988, 1992) support a biostratigraphic correlation with the Iron Canyon Fauna in the lower part of the DSF. These assemblages share the restricted occurrence of a large species of *Megahippus* and the rodents *Ammospermophilus fossilis* and *Copemys russelli*. They also share the occurrence of two which are morphologically similar and at the same stage of evolution, *Cupidinimus cuyamaensis* (Wood, 1937), in the Nettle Spring Local Fauna which is morphologically close to *C. avawatzensis* in the Ricardo Fauna, and forked-horned merycodontines *Merycodus* sp. cf. *M. cerroensis* Frick, 1937, in the Caliente Formation which is close to *Paracosoryx furlongi* in the DSF. Significantly, the younger Nettle Spring Local Fauna also contains the first records in the Caliente Formation of *Cormohipparion* and *Heteropliohippus hulberti*, the latter of which is similar to “*Dinohippus*” *leardi* from the DSF (Kelly, 1995). In the DSF, *Cormohipparion* first appears in the middle of the Iron Canyon Fauna in correlated to chron C5r. The occurrence of *Hipparion tehonense* in the older Matthews Ranch Local Fauna extends the range of this horse beneath the younger Ricardo Fauna of the DSF. The absence of “*Pliohippus*” *tejonensis* in the DSF may suggest a preference by this horse to more coastal habitats.

ZOOGEOGRAPHIC RELATIONSHIPS

When compared to similar-aged assemblages of the Great Plains, later Barstovian and Clarendonian assemblages of the southern Great Basin and Mojave Desert are less diverse and more provincial in composition. Previous publications (Tedford et al., 1987, 2004; Tedford and Barghoorn, 1997) have commented on the zoogeographic relationships of late Barstovian faunas across the United States, with particular attention to the striking differences in composition of those of the Great Basin compared with the surrounding regions. There are useful, chronologically long records, in the northwestern Mojave Desert region within the Barstow (early to late Barstovian, 16-13 Ma) (Woodburne et al., 1990) and the Dove Spring Formation faunal successions (early Clarendonian to early Hemphillian, 12-8 Ma).

In the early Barstovian part of this succession, faunal composition resembles that of the Great Plains. But during the Barstovian (especially the Second Division through Barstow faunal levels, 15.3 - 13.4 Ma; Woodburne et al., 1990) the fauna takes on a more endemic character. Early in this interval the borophagines *Protepicyon*, *Aelurodon*, *Cynarctus*, and *Paratomarctus* appear representing the initiation of clades within the Canidae that became important in Clarendonian faunas of the Great Plains (Wang et al., 1999). In contrast, the Barstow horse record is comparatively depauperate with only three equines, *Acritohippus stylodontus*, *Scaphohippus intermontanus*, and *S. sumani* (Merriam, 1915, 1919; Pagnac, 2006); clades poorly represented in the Great Plains. Anchitheriines are rare, but represent earliest *Megahippus* (*M. mckennai* Tedford and Alf, 1962), last *Archaeohippus* (*A. mourningi* (Merriam, 1913)) and early *Hypohippus*. The equid fauna is more like the northern Great Basin and Columbia Plateau, which have diverse anchitheriines and few equines. Rhinos are very rare, chalicotheres and tapirs absent. Mammutid proboscideans (*Zygodolophodon*) appear earlier in the Barstovian in the Great Basin and are joined by gomphotheriids in the later Barstovian where their initial occurrence involves most of mid-latitude North America. Oreodonts are rare and restricted to species of *Mediochoerus* (*M. mohavensis* Schultz and Falkenbach, 1941), which is the last occurrence of a genus that first appeared in the Great Plains early Hemingfordian. Species of *Ustatochoerus*, common in the Great Plains late Barstovian, do not appear in the Great Basin until the early Clarendonian. *Ticholeptus*, common to the Columbia Plateau and Great Plains Barstovian, has not been identified in the Great Basin. Antilocaprids are restricted to the merycodonts (*Meryceros* and *Paramoceras*) showing loss of diversity leading to their extinction in the Clarendonian. The antilocaprines have not yet appeared. Camelid diversity is also reduced with only species of *Procamelus* and *Aepycamelus* being common. Diverse camel faunas of the Great Plains and contemporary Rio Grande rift on the margin of the Great Basin indicate that the loss of diversity in the latter region is a zoogeographic event. The character of the late Barstovian fauna of the southwestern Great Basin marks that region as a discernible zoogeographic entity. Although not as rich a record in the northern Great Basin of Nevada, scattered late Barstovian faunas from the Carlin Formation in Elko

County in the northeastern corner of the state have a similar character and likewise contrast in taxonomic content with superposed faunas that record the appearance of forms characteristic of the Great Plains.

Regarding this faunal turnover, there are few conformable stratigraphic sections that allow the transformation to be directly observed and calibrated. In the central Mojave Desert, the Cronese Basin contains a small fauna that is directly overlain by a coarse-grained biotite pumice lapilli tuff that has been dated at 12.6 ± 0.1 Ma (Swisher, 1992). The small Cronese fauna contains *Scaphohippus* cf. *intermontanus*, *S.* cf. *sumani*, a gomphotheriid, *Meryceros* sp., *Aepycamelus*, and *Procamelus* sp. resembling the nearby late Barstovian assemblages. The oldest volcanic strata in the Dove Spring Formation (Ash 1, Member 2) have been correlated with the Cougar Point Tuff V dated at 12.15 ± 0.04 Ma. The fauna of Member 2 of the Dove Spring Formation includes the borophagine canid *Epicyon saevus*, the squirrels *Ammospermophilus fossilis* and *Arctomyoides* sp., the pocket mouse *Perognathus furlongi*, the deer mice *Copemys* cf. *longidens* and *C. russelli*, the horses *Megahippus* sp. and *Pliohippus tantalus*, and the merycodont *Paracosoryx furlongi*. Most of these, at either the species or generic level, are identical to, or more closely related to, Great Plains Clarendonian taxa. Evidence from the DSF indicates that the turnover episode in the Great Basin was occurring between 12 - 12.5 Ma.

Recent estimates of elevation of the western Great Basin in medial to late Miocene time derives from paleobotanical and stable isotope studies, which concluded that the Sierra Nevada and the adjacent Great Basin stood nearly 3 km above sea level in early Barstovian time, 1 to 1.5 km higher than present elevation (Wolfe et al., 1997; Poage and Chamberlain, 2002; Horton et al., 2004). Crustal extension and thinning, nearly completed by 12 Ma, reduced the topography of this area to near modern levels. The changes in topography over such a large area would have modified climate allowing greater penetration of Pacific Westerlies, lessening the contrast in environment with the continental interior, permitting westward expansion of mid-continent climate, topography, and faunas.

CONCLUSIONS

We conclude the following from the preceding discussions: (1) the faunal assemblages of the DSF continue to be some of the most complete, nearly continuous Clarendonian age successions in North America; (2) the youngest fauna provides valuable insight into the faunal composition of earliest Hemphillian assemblages; (3) these fossil assemblages provide key information for local and continent-wide paleontologic correlations; (4) ongoing taxonomic studies continue to make significant modifications to the faunal content of the DSF; (5) ongoing biostratigraphic studies (Prothero and Tedford, 2000; Tedford et al., 2004; Woodburne, 2006; this study) continue to generate doubts regarding the 20-year-old paleomagnetic correlations for the DSF (Burbank and Whistler, 1987; Loomis and Burbank, 1988; Whistler and Burbank, 1992), particularly the 13.5 Ma age for the base of the section; (6) the previously defined, basal, *Ustatochoerus profectus/Copemys russelli* assemblage zone of Whistler and Burbank (1992) is entirely Clarendonian in age, not late Barstovian as originally proposed and it has the fortuitous consequence of retaining the maximum age of the Clarendonian at about 12.5 Ma; (7) the MPTS has undergone significant revision since our original biostratigraphic work in 1992, this alone necessitating a reevaluation of DSF chronostratigraphy; (8) reevaluation of existing radioisotopic dates and tephrochronological correlations (Perkins et al., 1998; Perkins and Nash, 2002; Bonnicksen et al., 2008) provides new benchmarks for a revised interpretation of the magnetostratigraphy of the DSF; (9) the additional radioisotopic dates and revised paleomagnetic interpretation presented here reduce the maximum age of the DSF to 12.5 Ma, and the minimum age to approximately 8 Ma; (10) additional field observations and revised paleomagnetic determinations well supported by radioisotopic age correlations do not support a previously proposed 0.7 m.y. hiatus at the top of the lower basalt in Member 4; (11) the biostratigraphy of the DSF continues to support the existence of three superposed faunas; (12) biologic characterization of these faunas is enhanced by new taxonomic analyses reported here, although carnivores, rodents, and horses continue to be of particularly biostratigraphic utility; (13) regional and continental comparisons of these faunas confirm a lower boundary for the Clarendonian NALMA of 12.5 Ma, a Clarendonian/Hemphillian boundary of about 9.0 Ma, and a boundary between the Cerrotejonian and Montediablan Provincial Stages of a little more than 11.0 Ma. These revisions reinforce conclusions about the provincial nature of the faunal change from late Barstovian to early Clarendonian time in the

Great Basin compared with the Great Plains and they clearly mark a discernable zoogeographic event between about 12–12.5 Ma.

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TABLES

Table 1. Composite floral and faunal list for the Dove Spring Formation.

Plants	
Equisetaceae	<i>Equisetum</i> sp.
Palmaceae	<i>Palmoxylodon mohavensis</i> Webber, 1933
Pinaceae	<i>Pinus kelloggii</i> Webber, 1933
Cupressaceae	<i>Cupressus</i> sp.
Fagaceae	<i>Quercus ricardensis</i> Webber, 1933
Rhamnaceae	<i>Ceanothus</i> sp.
Fabaceae	<i>Lycium</i> sp.
	<i>Robinia alexanderi</i> Webber, 1933
Poaceae	<i>Paspalum</i> sp.
	<i>Tomlinsonia thomassonii</i> Tidwell and Nambudri, 1989
Osteichthyes	
Cyprinodontidae	cf. <i>Empetrichthys</i> sp.
Amphibia	
Plethodontidae	<i>Batrachocephalus</i> sp.
	cf. <i>Ensatina</i> sp.
Bufonidae and Ranidae	genera and spp. not determined
Reptilia	
Testudinidae	<i>Clemmys</i> sp.
	<i>Geochelone</i> sp.
	? <i>Gopherus</i> sp.
Iguanidae	cf. <i>Sceloporus</i> spp.
	<i>Leiocephalus</i> sp.
Xantusiidae	<i>Xantusia</i> spp.
Anguillidae	<i>Elgaria</i> cf. <i>E. kingi</i> (Gray)
	<i>Elgaria</i> sp. (large).
	<i>Paragerrhonotus ricardensis</i> Estes, 1963
Boidae	<i>Lichanura</i> sp.
Colubridae	<i>Paracoluber</i> sp.
	<i>Paleoheterodon</i> sp.
	<i>Protychophis achoris</i> Whistler and Wright, 1989
	cf. <i>Thamnophis</i> sp.
Aves	
Anatidae	<i>Branta howardae</i> Miller, 1930
Accipitridae	<i>Neophrontops ricardoensis</i> Rich, 1980
Strigidae	genus and sp. not determined
Mammalia	
Chiroptera	genera and species not determined
Insectivora	
Erinaceidae	<i>Lanthanotherium</i> sp.
Plesiosoricidae	<i>Meterix</i> sp.
Soricidae	<i>Alluvisorex chasseur</i> (Tedford, 1961)
	<i>Limnoecus</i> sp.
	Soricinae new genus and species
Talpidae	<i>Scapanus schultzi</i> Tedford, 1961
Carnivora	
Canidae	<i>Paratomarctus temerarius</i> (Leidy, 1858)
	<i>Borophagus littoralis</i> Vanderhoof, 1931
	<i>Carpocyon robustus</i> (Green, 1948)
	<i>Carpocyon webbi</i> Wang, Tedford, and Taylor, 1999
	<i>Epicyon haydeni</i> Leidy, 1858
	<i>Epicyon saevus</i> (Leidy, 1858)
	<i>Leptocyon vafer</i> (Leidy, 1858)
	<i>Metalopex macconnelli</i> Tedford, Wang, and Taylor, 2009
Amphicyonidae	<i>Ischyrocyon mohavensis</i> (Stock and Furlong, 1926)

Table 1 (continued).

Procyonidae	<i>Bassariscus</i> cf. <i>B. parvus</i> Hall, 1927
Mustelidae	<i>Martes buwaldi</i> (Merriam, 1919) <i>Martes</i> sp. B.
Mephitidae	<i>Martinogale faulli</i> Wang et al., 2005
Nimravidae	<i>Barbourofelis whitfordi</i> (Barbour and Cook, 1915) <i>Barbourofelis</i> sp.
Felidae	<i>Nimravides</i> sp. <i>Pseudaelurus</i> sp. A. <i>Pseudaelurus</i> sp. B
Rodentia	
Mylagaulidae	<i>Mylagaulus</i> sp.
Sciuridae	<i>Arctomyoides</i> sp. <i>Spermophilus</i> sp. <i>Ammospermophilus fossilis</i> James, 1963 <i>Ammospermophilus</i> sp.
Castoridae	<i>Eucastor</i> sp.
Eomyidae	<i>Leptodontomys</i> sp.
Heteromyidae	<i>Cupidinimus avawatzensis</i> Barnosky, 1986 <i>Cupidinimus tertius</i> (Wilson, 1939) <i>Cupidinimus</i> sp. C. (small) <i>Perognathus furlongi</i> Gazin 1930 <i>Perognathus minutus</i> James 1963
Geomyidae	<i>Phelosacomys shotwelli</i> Korth and Reynolds, 1994
Cricetidae	<i>Copemys dentalis</i> (Hall, 1930) <i>Copemys</i> cf. <i>C. longidens</i> (Hall, 1930) <i>Copemys russelli</i> James, 1963 <i>Paronychomys</i> spp. <i>Prosigmodon</i> sp.
Lagomorpha	
Leporidae	<i>Hypolagus</i> sp. <i>Pronotolagus apachensis</i> (Gazin, 1930).
Ochotonidae	<i>Hesperolagomys</i> sp.
Proboscidea	
Gomphotheriidae	<i>Gomphotherium</i> sp. <i>Amebelodon burnhami</i> (Osborn, 1933)
Perissodactyla	
Rhinocerotidae	<i>Aphelops megalodus</i> (Cope, 1873) <i>Teleoceras</i> sp.
Equidae	<i>Megahippus</i> sp. <i>Hipparion forcei</i> Richey 1948 <i>Hipparion tehonense</i> (Merriam, 1916) <i>Cormohipparion</i> sp. <i>Pliohippus tejonensis</i> (Merriam, 1915) <i>Pliohippus tantalus</i> Merriam, 1913 (= <i>P. fairbanksi</i> Merriam, 1915) “ <i>Dinohippus</i> ” <i>leardi</i> (Drescher, 1941)
Artiodactyla	
Merycoidodontidae	<i>Merychys major</i> Leidy, 1858 and <i>Merychys medius</i> Leidy, 1858
Tayassuidae	<i>Prosthennops</i> sp.
Camelidae	<i>Hemiachenia</i> sp. <i>Procamelus</i> sp. <i>Megatylopus</i> sp. <i>Aepycamelus</i> sp.
Antilocapridae	<i>Paracosoryx furlongi</i> Frick, 1937 <i>Cosoryx</i> sp. cf. <i>Illingoceros</i> sp. <i>Plioceros</i> sp.

Table 2. Radioisotopic ⁴⁰Ar/³⁹Ar ages and magnetic polarity of tephra for the Dove Spring Formation. See Fig. 1 for stratigraphic position of ashes.

Sample	Member	Tephra	Code	Polarity	Age (Ma)	Err (1s)	Reference for polarities
epb92-24	4	Cougar Point Tuff XIII	XIII	N	10.96	0.03	Bonnichsen et al., 2008
epb92-28	3	Cougar Point Tuff XI	XI	R	11.29	0.04	Bonnichsen et al., 2008
epb92-49	3	Ammonia Tanks	AT	N	11.59	0.05	Hudson et al. (1994)
epb92-50	3	Cougar Point Tuff IX	IX	R	11.64	0.04	Bonnichsen et al., 2008
epb92-46	3	Raimier Mesa	RM	R	11.74	0.05	Hudson et al. (1994)
epb94-580	3	Ibex Hollow	IH	---	11.95	0.03	---
epb92-40	2	Cougar Point Tuff V	V	N	12.15	0.04	Bonnichsen et al., 2008

Note: Samples shown on correlation chart of Perkins et al. (1998) except epb92-28 which has subsequently been identified as XI; magnetic polarity is for ash-flow tuff associated with the eruption of the ash-fall tephra; all ages are recalculated to Fish Canyon sandine = 28.02 Ma; ages for XI and IX from Bonnichsen et al., 2008; other ages from Perkins et al. (1998); the magnetic polarities of ash-flow tuffs are from the listed references.

Table 3. Interpolation ages and magnetic polarity of tephra for Dove Spring Formation. See Fig. 1 for stratigraphic position of ashes.

Sample	Member	Tephra	Code	Polarity	Age (Ma)	Err (1σ)	It1 (Ma)	Err1	It2 (Ma)	Err2	It3 (Ma)	Err3
epb92-79	5	Celetron 2	CEL2	---	9.7	0.2	---	---	9.69	0.2	---	---
epb92-22	5	Opal Canyon 3	OC3	---	10.2	0.2	10.19	0.2	10.2	0.19	---	---
epb92-23	5	Opal Canyon 2	OC2	---	10.6	0.2	10.74	0.13	10.44	0.17	10.69	0.14
epb92-30	4	Cougar Point Tuff										
	XII		XII	R	11.2	0.1	11.24	0.04	11.26	0.04	11.19	0.09
epb92-42	3	Ibex Peak 8	IP8	---	11.8	0.1	11.83	0.04	11.83	0.07	---	---

Note: Samples shown on correlation chart of Perkins et al. (1998); the polarity for XII is from Bonnichsen et al. (in press); Age and error (Err) is the weighted mean of interpolation ages It2 and It3 where the weights are the inverse squares of the model errors (1σ) Err2 and Err3 respectively; Age is rounded to the nearest 1/10th and Err is rounded up to the nearest 1/10th; It1 and Err1 are the interpolation ages and model errors available for these tephra in the Dove Springs Fm. while It2, Err2, It3, and Err3 are the interpolation ages/model errors available from other sections of Perkins et al. (1998). The age formula for individual interpolation ages is $t = t_1 - c(t_1 - t_2)$ where $c = (z - z_1)/(z_2 - z_1)$; here t_1 is the age of the lower reference tephra for the interpolation and t_2 is the age for the upper reference horizon and, similarly z_1 is the stratigraphic position of the lower reference tephra, z_2 is the stratigraphic position of the upper reference tephra and z is the stratigraphic position of the tephra for which the interpolation age is calculated. The error for an individual interpolation age is $\sigma^2 = [(1 - c)^2 + \sigma_c^2] \sigma_2^2 + \sigma_c^2 (t_1 - t_2)^2$, where σ_1^2 is the square of the 1σ error for t_1 , σ_2^2 is the square of the 1σ error for t_2 , and σ_c^2 is the variance of c . The variance of c is empirically modeled as $\sigma_c^2 = 0.12 * c(1 - c)^{1.5}$ based on the observed variance from section to section throughout the Basin and range of c between any two given control horizons z_1 and z_2 and a given “unknown” horizon z .

Table 4. Distribution of vertebrate taxa within the Dove Spring Formation. Faunal subdivisions as in Figure 4. x = taxon present in fauna, o = taxon absent in fauna.

	Iron Canyon Fauna	Ricardo Fauna	Dove Springs Fauna
Osteichthyes			
Cyprinodontidae			
<i>cf. Empetrichthys</i> sp.	x	x	o
Amphibia			
Plethodontidae			
<i>Batrachoceps</i> sp.	x	x	o
<i>cf. Ensatina</i> sp.	o	x	o
Bufonidae	o	x	o
Ranidae	x	x	o
Reptilia			
Testudinidae			
<i>Clemmys</i> sp.	x	x	x
<i>Geochelone</i> sp.	o	x	x
? <i>Gopherus</i> sp.	x	x	x
Iguanidae			
<i>Sceloporus</i> spp.	x	x	x
<i>Leiocephalus</i> sp.	o	x	x
Xantusiidae			
<i>Xantusia</i> spp.	x	x	x
Anguidae			
<i>Elgaria</i> cf. <i>E. kingi</i> (Gray)	x	x	x
<i>Elgaria</i> sp. (large)	o	x	o
<i>Paragerrhonotus ricardensis</i> Estes, 1963	x	o	o
Boidae			
<i>Lichanura</i> sp.	x	x	x
Colubridae			
<i>Paracoluber</i> sp.	o	x	x
<i>Paleoheterodon</i> sp.	x	x	x
<i>Proptychophis achoris</i> Whistler and Wright, 1989	o	x	x
<i>cf. Thamnophis</i> sp.			
Aves			
Anatidae			
<i>Branta howardae</i> Miller, 1930	o	x	o
Acciptaridae			
<i>Neophrontops ricardoensis</i> Rich, 1980	o	o	x
Strigidae	x	x	x
Mammalia			
Erinaceidae			

Table 4 (continued).

<i>Lanthanotherium</i> sp.	o	x	o
Plesiosoricidae			
<i>Meterix</i> sp.	x	o	o
Soricidae			
<i>Alluvisorex chasseur</i> (Tedford, 1961)	x	x	x
<i>Limnoecus</i> sp.	x	o	o
Soricinae new genus and species	x	x	x
Talpidae			
<i>Scapanus schultzi</i> Tedford, 1961	x	x	x
Canidae			
<i>Paratomarctus temerarius</i> (Leidy, 1858)	x	o	o
<i>Borophagus littoralis</i> Vanderhoof, 1931	o	x	o
<i>Carpocyon robustus</i> (Green, 1948)	x	x	o
<i>Carpocyon webbi</i> Wang, Tedford, and Taylor, 1999	o	o	x
<i>Epicyon haydeni</i> Leidy, 1858	x	x	x
<i>Epicyon saevus</i> (Leidy, 1858)	x	x	x
<i>Leptocyon vafer</i> (Leidy, 1858)	x	x	x
<i>Metalopex macconnelli</i> Tedford, Wang, and Taylor, 2009	o	x	x
Amphicyonidae			
<i>Ischyrocyon mohavensis</i> (Stock and Furlong, 1926)	x	o	o
Procyonidae			
<i>Bassariscus</i> cf. <i>B. parvus</i> Hall, 1927	o	x	x
Mustelidae			
<i>Martes buwaldi</i> (Merriam, 1919)	o	x	x
<i>Martes</i> sp. B.	o	x	x
Mephitidae			
<i>Martinogale faulli</i> Wang, Whistler, and Takeuchi, 2005	o	x	x
Felidae			
<i>Nimravides</i> sp.	o	x	o
<i>Pseudaelurus</i> sp. A	o	o	x
<i>Pseudaelurus</i> sp. B	o	x	o
Nimravidae			
<i>Barbourofelis whitfordi</i> (Barbour and Cook, 1915)	o	x	o
<i>Barbourofelis</i> sp.	x	o	x
Mylagaulidae			
<i>Mylagaulus</i> sp.	o	x	o
Sciuridae			
<i>Arctomyoides</i> sp.	x	o	o
<i>Ammospermophilus fossilis</i> James, 1963	x	o	o
<i>Ammospermophilus</i> sp.	o	o	x

Table 4 (continued)			
<i>Spermophilus</i> sp.	o	o	x
Castoridae			
<i>Eucastor</i> sp.	x	x	o
Eomyidae			
<i>Leptodontomys</i> sp.	o	x	o
Heteromyidae			
<i>Cupidinimus avawatzensis</i> Barnosky, 1986	x	o	o
<i>Cupidinimus tertius</i> (Wilson, 1939)	x	x	x
<i>Cupidinimus</i> sp. C. (small)	o	o	x
<i>Perognathus furlongi</i> Gazin 1930	x	x	x
<i>Perognathus minutus</i> James 1963	x	x	o
Geomyidae			
<i>Phelosacomys shotwelli</i> Korth and Reynolds, 1994	x	x	o
Cricetidae			
<i>Copemys dentalis</i> (Hall, 1930)	x	x	x
<i>Copemys</i> cf. <i>C. longidens</i> (Hall, 1930)	x	o	o
<i>Copemys russelli</i> James, 1963	x	o	o
<i>Paronychomys</i> spp.	o	x	x
<i>Prosigmodon</i> sp.	o	o	x
Leporidae			
<i>Hypolagus</i> sp.	x	x	x
<i>Pronotolagus apachensis</i> (Gazin, 1930)	o	x	x
Ochotonidae			
<i>Hesperolagomys</i> sp.	x	x	x
Gomphotheriidae			
<i>Gomphotherium</i> sp.	o	x	x
<i>Amebelodon burnhami</i> (Osborn, 1933)	x	x	x
Rhinocerotidae			
<i>Aphelops megalodus</i> (Cope, 1873)	x	x	o
<i>Teleoceras</i> sp.	o	x	x
Equidae			
<i>Megahippus</i> sp.	x	o	o
<i>Hipparion forcei</i> Richey 1948	o	x	o
<i>Hipparion tehonense</i> (Merriam, 1916)	o	x	o
<i>Cormohipparion</i> sp.	x	x	o
<i>Pliohippus tejonensis</i> (Merriam, 1915)	o	x	o
<i>Pliohippus tantalus</i> Merriam, 1913	x	x	o
" <i>Dinohippus</i> " <i>leardi</i> (Drescher, 1941)	o	x	x
Merycoidodontidae			
<i>Merychys major</i> Leidy, 1858	o	x	x
<i>Merychys medius</i> Leidy, 1858	x	o	o

Table 4 (continued).

Tayassuidae				
<i>Prosthennops</i> sp.		o	x	o
Camelidae				
<i>Hemiauchenia</i> sp.		x	x	o
<i>Procamelus</i> sp.		x	x	x
<i>Megatylopus</i> sp.		x	x	x
<i>Aepycamelus</i> sp.		o	x	x
Antilocapridae				
<i>Paracosoryx furlongi</i> Frick, 1937		x	o	o
<i>Cosoryx</i> sp.		o	x	o
cf. <i>Illingoceros</i> sp.		o	x	x
<i>Plioceros</i> sp.		o	x	x

APPENDIX

Localities and specimen numbers of specimens used to establish the teilzones presented in Figure 4. Taxa are listed in the same order as in Figure 4. Localities with each taxon are listed in stratigraphic order, oldest first. Individual specimen numbers for abundant species (microfauna) are on file at LACM and UCMP. Specimen numbers are only provided for diagnostic material.

Alluvisorex chasseur: localities LACM 4703, UCMP(UCR) RV 6301, LACM 4844, LACM 4639, LACM 5095, LACM 3678, LACM 5724, LACM 1553, UCMP(UCR) RV 6606, LACM 3444, LACM 5098, LACM 4693, LACM 6376, LACM 6377, LACM 4698, UCMP V 67347, LACM 3652, UCMP V 6651, LACM 5099, LACM 3533, UCMP V 6736, LACM 3776, LACM4702, LACM 3666, LACM 5420.

Carpocyon robustus: UCMP V2733/152193, UCMP V3732/ 33569, LACM 6038/144568

Carpocyon webbi: LACM 3776/150925

Epicyon haydeni: UCMP V2281/21507, LACM 1553/143519, LACM 5537/127790, LACM 6051/131855, UCMP V2769/22470, UCMP V2769/22471, LACM 1003/6

Epicyon saevus: UCMP V2733/22320, LACM 1414/127794, LACM 1553/59697, LACM 5713/59813, LACM 3458/4266, LACM 7572/151493, LACM 3776/150849

Borophagus littoralis: LACM 4771/143520

Metalopex macconnelli: LACM 3552/55219, LACM 3580/122323, LACM 3580/150845, LACM 3574/150839, LACM 3776/55237, LACM 3776/150854, LACM 3776/152694, LACM 4702/150858

Ischyrocyon mohavensis: LACM 1108/1522, LACM 6618/150871, UCMP V2201/26792

Bassariscus cf. *B. parvus*: LACM 6375/142891, LACM 6375/142892, LACM 3445/ 4033, LACM 4791/146134, LACM 3531/150831, LACM 3776/150850, LACM 6128/150869, LACM 4702/150857

Martes bulwaldi: UCMP V2282/21323, LACM 4701/150855, LACM 5688/147445, LACM 3651/61438, LACM 3574/150837, LACM 3574/150838, LACM 5720/150866, LACM 3776/150926, LACM 3776/150927, LACM 3776/150928, LACM 6400/150870

Martes sp. B: LACM 6043/ 146193, LACM 4694/146118, LACM 3552/151475, LACM 3651/150847, LACM 4702/150856

Martinogale faulli: LACM 6375/142893, UCMP V6742/84529, LACM 3776/56230, LACM 3776/151134

Barbourofelis whifordii: LACM 7704/154061, UCMP V1761/19476, LACM 3574/150834

Barbourofelis sp.: LACM 1108/59336, LACM 6260/140853,

Nimravides sp.: LACM 4603/120402, LACM 3571/4281

Ammospermophilus fossilis: localities LACM 4702, 6141, 4712, 3662

Arctomyoides sp.: locality LACM 6141

Cupidinimus avawatzensis: localities LACM 4844, LACM 3677, LACM 5101

Cupidinimus tertius: localities UCMP(UCR) RV 6301, LACM4703, LACM 4704, LACM 3662, LACM 4712, LACM 4697, LACM 4844, LACM 3677, LACM 5101, LACM 4639, LACM 5421, UCMP(UCR) RV 6606, UCMP V 6746, LACM 6375, LACM 6376, UCMP V6742, LACM 4702

Perognathus furlongi: localities LACM 4703, UCMP(UCR) RV 6301, LACM 4704, LACM 3662, LACM 4842, LACM 4696, LACM 4697, LACM 3677, LACM 4707, LACM 5096, UCMP(UCR) RV 6606, LACM 4693, LACM 4694, LACM 4639, LACM 4648, UCMP V 6651, LACM 3652, LACM 5100, LACM 4698, LACM 3447, LACM 6375, LACM 6376, LACM 4701, LACM 4645, LACM 3552, UCMP V 6742, UCMP V 66226, UCMP V 66227, LACM 3533, LACM 3580, LACM 3776, LACM 4702, LACM 3666, LACM 5418

Perognathus minutus: localities LACM 3672, LACM 4844, LACM 3443, LACM 3444, UCMP (UCR) RV 6606, LACM 5098, UCMP V 6651, LACM 3552, UCMP V 6742

Copemys dentalis: localities LACM 4844, LACM3677, LACM 5101, LACM 4707, LACM 5094, LACM 5095, LACM 5096, LACM 5097, LACM 5098, LACM UCMP(UCR) RV 6606, LACM 4693, LACM 4694, LACM 4639, LACM 4645, LACM 4647, LACM 3443, LACM 3444, LACM 4648, LACM 4657, LACM 5719, LACM 6375, LACM 6376, LACM UCMP V 6651, LACM 3652, LACM 5099, LACM 5100, LACM 4698, LACM 4701, LACM 3447, LACM 3552, LACM 3553, UCMP V 6736, LACM 3580, UCMP V 67226,

Copemys cf. *C. longidens*: localities LACM 4703, LACM 4704

Copemys russelli: localities LACM 4703, LACM 4704, LACM 4696, LACM 4712, LACM 4842, LACM 4697

Paronychomys spp.: localities LACM3533, LACM 3531, LACM 3776, LACM 4702, LACM 6380

Prosigmodon sp.: localities LACM 4702, LACM 3666, LACM 6380

Megahippus sp.: LACM 6620/148195, LACM 1738/126135

Cormohipparion sp.: LACM 1745/55685, LACM 1743/59647, LACM 5732/138255, LACM 5732/146241, LACM 5097/146415, LACM 3440/140667, LACM 4785/140854, LACM 3439/148905

“*Dinohippus*” *leardi*: LACM 5733/146263, LACM 3428/59924, LACM 6051/144100, LACM

3591/60516, LACM 3581/3581, LACM 3587/60506, LACM 3532/60214, LACM 3534/60246

Hipparion forcei: LACM 5730/148767, LACM 1412/4087, LACM 3967/146257, LACM 5537/127791, LACM 6045/146287, LACM(CIT) 512/55679, LACM 3415/3637, LACM 3416/146279, LACM 3650/61432, LACM 3650/61433, LACM 4657/135933, LACM 1216/4298, LACM 1216/59452, LACM 1243/55680, LACM 1243/59462, LACM 3422/59896, LACM 3471/4122, LACM 3477/60155, LACM 3652/152324, LACM 4781/144099, LACM 7409/149079, LACM 6377/142700, LACM 3469/146268, LACM 4724/151489, LACM 3438/150619, LACM 3447/60031, LACM 3458/4287, LACM 4791/147569, LACM 7706/154063, LACM 5694/138261, LACM 6499/144094, LACM 7356/148730, LACM 3607/60574, LACM 3581/60496, LACM 7404/149066, LACM 3552/4295, LACM 3651/146282, LACM 3569/55862

Hipparion tehonense: LACM 1414/4127, LACM 1413/59478, LACM 3415/3634, LACM 3419/55683, LACM 7585/151512

Pliohippus tantulus: LACM 6141/143525, LACM 1212/3631, LACM 1736/148901, LACM 1738/59584, LACM 1737/59569, LACM 4741/146418, LACM 1748/3994, LACM 1748/59739, LACM 1741/79450, LACM 1414/4128, LACM 5697/148910, LACM(CIT) 509/59201, UCMP V1389/19434, LACM 5698/147457, LACM 3456/60051, LACM 4661/146416, LACM 4654/148906, LACM 1553/4155, LACM 1553/4156, LACM 4822/146713, LACM 3416/146424, LACM 7407/150938, LACM 7581/152327, LACM 3594/60522, LACM 1243/59814, LACM 3420/143949, LACM 7610/152337, LACM 7614/152345, LACM 3421/59886, LACM 4698/146120, LACM 7410/149080, LACM 5686/148908, LACM 3562/146417

Paracosoryx furlongi: LACM 6620/136059, LACM 7540/150920, LACM 4826 and abundant additional specimens both in the collections of UCMP and LACM, all from below the lower basalt flows, Members 1-3 of the DSF.

Illingoceros sp.: LACM 4701/146503, LACM 4839, LACM 5718/147493