PaleoBios 20(3):1–10 , December 15, 2000

Magnetic stratigraphy of the type Montediablan Stage (Late Miocene), Black Hawk Ranch, Contra Costa County, California: Implications for regional correlations

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The faunas and strata of the Black Hawk Ranch Quarry in the Sycamore Formation on the south flank of Mount Diablo, Contra Costa County, California, were the original basis of Savage's (1955) late Miocene "Montediablan Stage." Magnetic samples of the Sycamore Formation were taken at the quarry level, and up to 100 m (300 feet) below and 250 m (750 feet) above it. Although some samples had unremovable normal overprints (easily distinguished from primary remanence because of the near-vertical dip of the beds), all of the samples with primary directions had simple one-component reversed magnetizations held in magnetite. Our results are compared to other sections in California where similar faunas occur in a single long zone of reversed polarity. Based on comparison with distinctive faunas from the Dove Spring Formation in Red Rock Canyon, Kern County, California, and with assemblages in the High Plains of North America, the long reversed magnetozone is correlated with Chron C4Ar (9.0–9.7 Ma). This interpretation differs from the conclusions of Wilson and Prothero (1997), who argued that the single, apparently conformable reversed magnetozone in the Tejon Hills, which contain superposed faunas assigned to the early and late Clarendonian land mammal ages, was correlative with Chron C5r (11.0–12.0 Ma).

INTRODUCTION

In 1955 Savage demonstrated the methodology by which chronostratigraphic units could be established from mammalian biostratigraphic data, as an example of the task confronting paleomammalogists if the biochronologic scheme of Wood et al. (1941) was to be converted to a chronostratigraphic basis. In this paper, he abandoned the hybrid biostratigraphic-biochronologic scheme of the Wood Committee and defined formal biostratigraphic units, complete with type sections, that could be regarded as true "stages" in the sense of the North American Code of Stratigraphic Nomenclature. As an example, Savage (1955) defined a "Cerrotejonian Stage," based primarily on the fossils and strata of the Tejon Hills, in the southern San Joaquin Valley, Kern County, California (Fig. 1). Savage also defined a "Montediablan Stage" based on the fossils and strata of the Black Hawk Ranch, south of Mount Diablo, Contra Costa County, California (Fig. 1). He chose these sections because both areas yielded superposed Cerrotejonian and Montediablan mammals. Both sections also interfingered with marine strata, allowing some intercorrelation with marine biostratigraphy.

Whistler and Burbank (1992) suggested a different biostratigraphic scheme for the correlative strata in California. They named a "*Cupidinimus avawatzensis/Paracosoryx furlongi* Assemblage Zone" and a "*Epicyon aphobus/Hipparion forcei* Assemblage Zone" based on their biostratigraphy of the Dove Spring Formation, Ricardo Group, in the Red Rock Canyon area of Kern County, California. Whistler and Burbank (1992) calibrated their biostratigraphy with the magnetic stratigraphy of the Dove Spring Formation, which also contained a number of dated volcanic units. They inferred that the base of the Montediablan Stage (based primarily on the first appearance of *Hipparion forcei*, a critical fossil in Savage's 1955 definition) occurred near the base of magnetic Chron C5n (about 11 Ma).

These correlations were tested when the magnetostratigraphy of other deposits in California with similar faunas were analyzed. In the Tejon Hills (type area of Savage's "Cerrotejonian Stage," and an important reference section for the "Montediablan"), Wilson and Prothero (1997) found that faunas thought to be of Cerrotejonian and Montediablan age occurred in a zone of reversed polarity that they correlated with Chron C5r (11.0–12.0 Ma in the timescale of Berggren et al. 1995). This suggested that some Montediablan mammals of the Tejon Hills (including *Hipparion forcei*) ranged into older strata than they are observed to do in the Dove Spring Formation. These results were apparently corroborated by the magnetic stratigraphy of the Caliente Formation in the Cuyama badlands of northern Ventura County (Prothero et al. *in press*). In the Apache Canyon section of the Cuyama badlands, faunas considered to be both Cerrotejonian and Montediablan in age occur within an apparently continuous, conformable zone of reversed polarity that probably correlates with Chron C5r. To resolve this biostratigraphic conflict, it would be helpful to test the correlation of the type Montediablan at Black Hawk Ranch by means of magnetic stratigraphy.

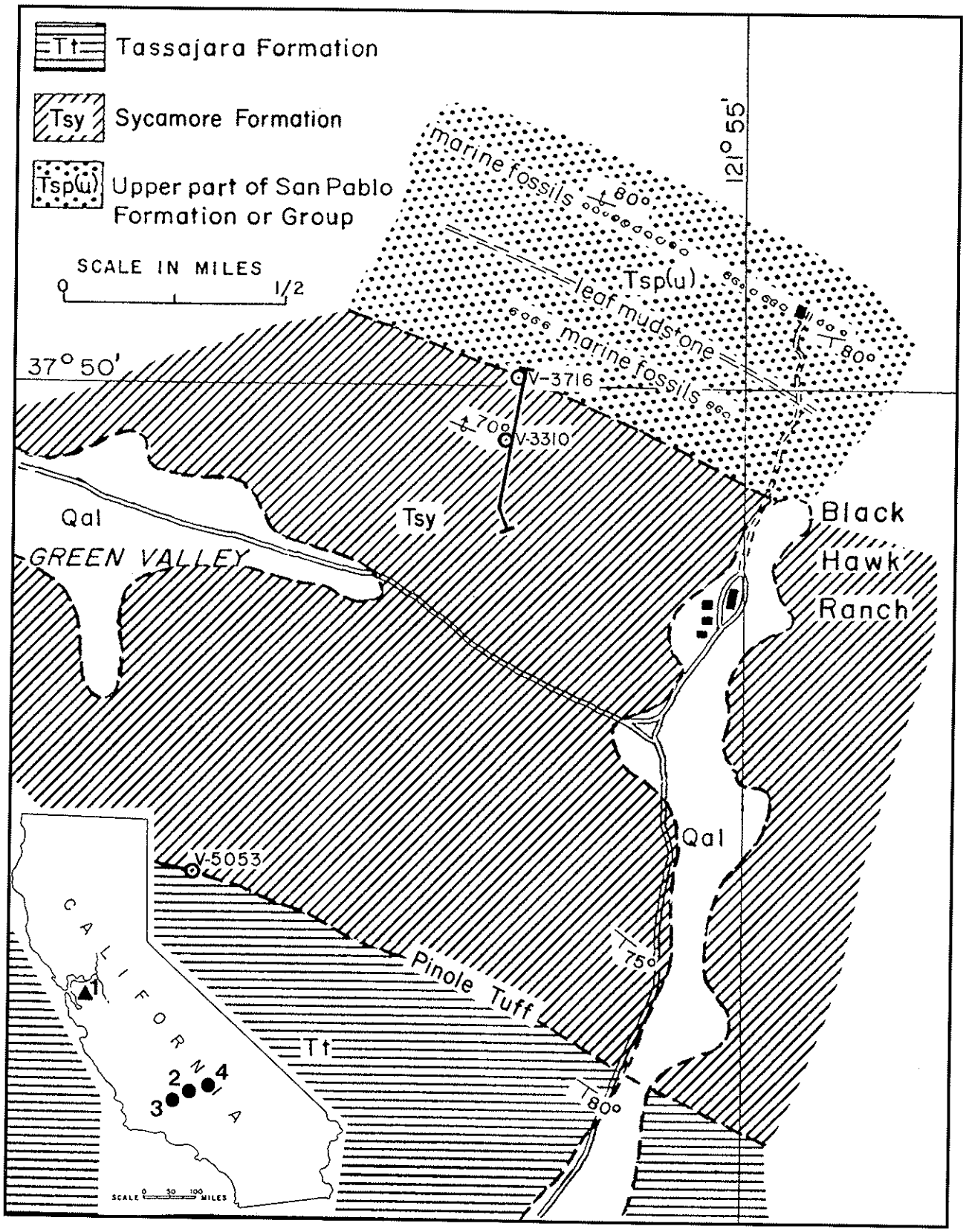

Fig. 1. Map of Black Hawk Ranch vicinity, south side of Mount Diablo, Contra Costa County, California, adapted from Savage (1955, fig. 9). Lithostratigraphy revised and magnetostratigraphic traverse shown by heavy line. UCMP localities: V3310, Black Hawk Ranch Quarry; V3716, "older Black Hawk Ranch faunule," Sycamore Creek local fauna; V5053, Hemme Hills local fauna (Hemphillian). Inset map of California shows localities referred to in this report: 1—Black Hawk Ranch; 2—Tejon Hills; 3—Cuyama Valley; 4—Red Rock Canyon.

GEOLOGY

The geology of the Black Hawk Ranch area was originally described by Clark (1935, 1941), Richey (1948), and Savage (1955). The Black Hawk Ranch flora was described by Condit (1938) and Axelrod (1944), and the fossil mammals were described by Richey (1948), Macdonald (1948), and Savage (1951, 1955). According to these authors, the Black Hawk Ranch Quarry (University of California Museum of Paleontology, or UCMP V3310) is located near the base of the "Green Valley Formation" (now informally called the Finley Road lithofacies of the Sycamore Formation; see Sarna-Wojcicki 1976, Wagner 1978, and Andersen et al. 1995). Approximately 1500 m (4500 feet) of Sycamore Formation occurs on the southern flank of Mount Diablo, overturned steeply to the north (Savage 1955, Fig. 10). About 100 m (300 feet) below V3310 is the Sycamore Creek fauna ("Older Black Hawk Ranch faunule" of Richey 1948), which yields early Cerrotejonian horses such as *Hipparion tehonense* and *Neohipparion trampasense* (Tedford et al. 1987:155). At Mount Diablo, the Sycamore Formation is underlain by over 650 m (2000 feet) of the "San Pablo Formation" (now the Neroly Formation; see Andersen et al. 1995), which yielded not only marine fossils, but also an isolated specimen of a horse referred to *Hipparion tehonense*. The Sycamore Formation is overlain by the Tassajara Formation, which yields a Hemphillian megalonychid ground sloth (at locality UCMP V5053). This superposition of faunas was the main reason for Savage's (1955) choice of Mount Diablo as his type section of the "Montediablan Stage."

The Finley Road lithofacies of the Sycamore Formation (Wagner 1978, Isaacson 1990, Andersen et al. 1995) consists of about 700 m of fine sandstones, siltstones, and claystones, which are interpreted to be the deposits of shallow braided streams. Black Hawk Ranch Quarry (UCMP V3310, on the 1120 ft. contour, SW NE SW 1/4 sec. 24, T1S R1W, Diablo 7.5-minute quadrangle) lies on the slopes of Mount Diablo just west of the original Black Hawk Ranch buildings (which have been replaced by a golf course and subdivisions), and can be reached by a fire road/nature trail. Excavations at the quarry continue under the supervision of the UCMP, and many tour groups and individuals visit the quarry as a part of the active nature programs that are run by the local Black Hawk museum and UCMP personnel.

METHODS

Because the strata are overturned 70° to the north, the stratigraphic section in the strata around Black Hawk Ranch Quarry was measured with a Jacob's staff. In most places, the mudstones and siltstones of the Sycamore Formation are poorly exposed, but the quarry excavation is large, and there are outcrops in the bed of the fire road next to the quarry that allowed continuous sampling of the bedrock. Thirty-eight paleomagnetic sites (three samples per site) were taken using simple hand tools to remove oriented blocks of rock, with three sites in the quarry cut itself, seven sites covering the 100 m (300 feet) of strata below the quarry, and 27 sites covering the 250 m (750 feet) of strata above the quarry. In the lab, cores were taken from the block samples using an air-cooled drill press.

The samples were analyzed on a 2G Enterprises cryogenic magnetometer equipped with an automatic sample changer in the paleomagnetic laboratory at the California Institute of Technology. After measurement of NRM (natural remanent magnetization), each sample was demagnetized in alternating fields (AF) of 25, 50, and 100 Gauss to determine coercivity and also to demagnetize any multi-domain grains. Each sample was then thermally demagnetized at 300, 400, 500, and 600°C in a magnetically shielded furnace. This dehydrates any iron hydroxides, such as goethite, and also allows determination of how much magnetization remains above the Curie temperature of magnetite (580°C).

In addition to AF and thermal demagnetization of every sample, about 0.1 g of several samples were powdered and placed in epindorph tubes for rock magnetic analyses. Each powdered sample was subjected to increasing IRM (isothermal remanent magnetization). Peak IRM and ARM (anhysteretic remanent magnetization) were subjected to AF demagnetization in a modified Lowrie-Fuller test (see Pluhar et al. 1991, for further details). Finally, polished thin sections were examined under reflected light to determine magnetic mineralogy.

RESULTS

The behavior of each sample was plotted as an orthogonal demagnetization plot ("Zijderveld plot") to analyze the components of the remanence (Fig. 2). Twenty-five of the 110 samples had an unremovable modern normal direction before the dip correction, showing that they were overprinted by the Earth's present magnetic field; they were excluded from the data set. Of the remaining samples, nearly all showed reversed directions at NRM (after dip correction), and appeared to have only a single reversed component of magnetization. The samples shown in Figure 2 are representative of the results. Most showed a considerable decrease in intensity during AF demagnetization, suggesting that a low-coercivity mineral such as magnetite is a primary carrier of the remanence. In addition, nearly all the remanence was gone by 600°C, indicating that there was very little hematite in most of the samples.

IRM acquisition analysis (Fig. 3) of representative lithologies of the Sycamore Formation showed clear saturation at 300 mT (millitesla), confirming that magnetite is the primary carrier of the remanence (even in the reddish sandstone, which might be expected to have significant hematite). In the same samples, the ARM was more resistant to AF demagnetization than the IRM, suggesting that

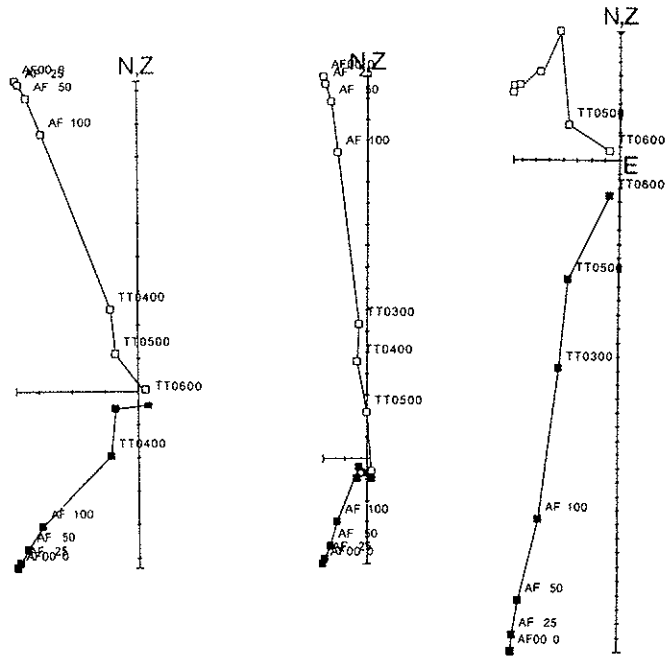

Fig. 2. Orthogonal demagnetization plots of representative samples. Solid squares indicate horizontal component; open squares indicate vertical component. AF demagnetization steps ("AF") in Gauss; thermal demagnetization steps ("TT") in degrees Centigrade. Each division = 10^{-5} emu. All four samples show a single component of reversed polarity which was apparent at NRM, and disappeared at 600°C. Most showed a significant response to AF demagnetization, suggesting that a low-coercivity mineral such as magnetite is the primary carrier of the remanence.

the remanence is held in single-domain or pseudo-single domain grains (Fig. 3). Polished thin sections were examined, and appeared to show tiny euhedral grains of magnetite, with slight alteration to hematite on the rims of the crystals.

Based on this analysis, a stable reversed component was calculated using the least squared method of Kirschvink (1980), and averaged using the statistics of Fisher (1953; see Butler 1992). Sites were classified by the scheme of Opdyke et al. (1977). Class I sites (n = 17) were statistically separated from random at the 95% confidence level. Class II sites (n = 10) had only two non-overprinted directions available for analysis, so site statistics could not be calculated. Class III sites (6 sites) showed two concordant directions, but the third direction was divergent, so they were not statistically significant. Three sites yielded only overprinted directions, so they were considered indeterminate.

Although the homoclinal dip prevented a fold test, the extreme overturning of the strata made it possible to clearly distinguish a modern normal overprint from a characteristic direction. The lack of normal sites precluded a true reversal test, but the means of all the tilt-corrected reversed directions was D = 206.1, I = -38.5, k = 6.8, a_{95} = 12.2. This is antipodal to the expected normal direction for this latitude, suggesting that the magnetization is primary and relatively free of overprinting.

The mean directions are plotted as VGP latitudes in Figure 4. The entire 350 m (1050 feet) of reversed strata includes not only the purported Cerrotejonian Sycamore Creek fauna ("Older Black Hawk Ranch faunule" of Richey 1948) near the base of the section, but also the Black Hawk Ranch quarry itself, and the 250 m (750 feet) of strata above the quarry. Thus, the Black Hawk Ranch section is now the third important Montediablan sequence in coastal California (Fig. 5) which is largely within a single zone of reversed polarity previously correlated with Chron C5r (11.0–12.0 Ma). This appears to conflict with the interpre-

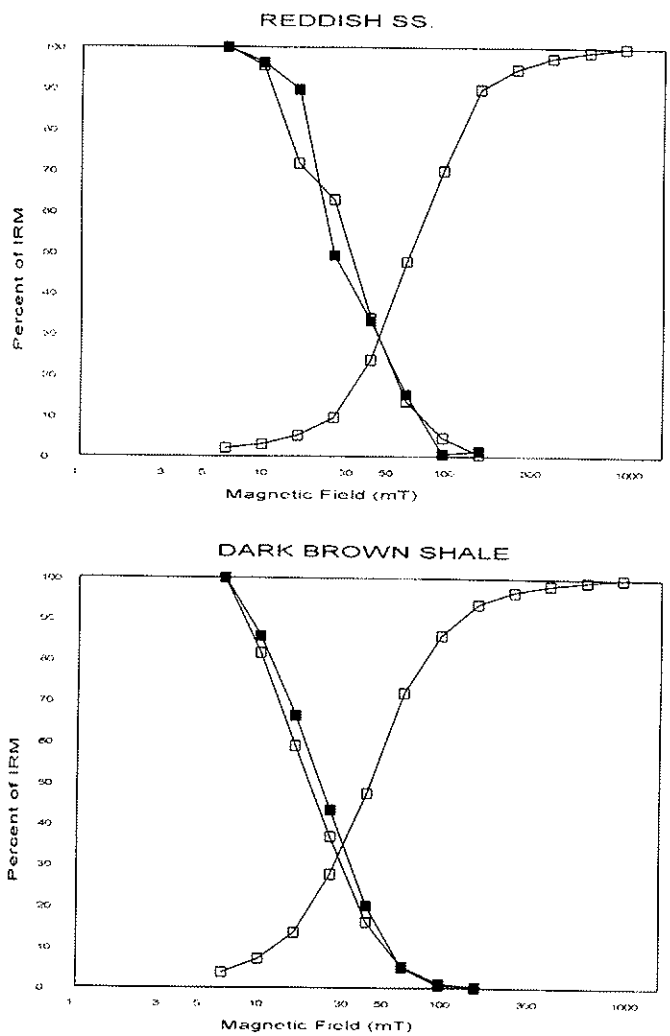

Fig. 3. IRM acquisition analysis and modified Lowrie-Fuller test (see Pluhar et al., 1991, for details) of representative powdered samples. Open squares = IRM; solid squares = ARM. In both cases, the IRM (ascending curve on right) saturate at 300 mT, indicating that remanence is held in magnetite. In addition, the ARM is more resistant to AF demagnetization than the IRM (descending curves to left), suggesting single domain or pseudo-single domain grains.

tation that this stage began in Chron C5n (10.0–11.0 Ma), based on the results from the Dove Spring Formation (Whistler and Burbank 1992).

BIOSTRATIGRAPHIC IMPLICATIONS

Three critical biostratigraphic sequences in coastal California now have magnetostratigraphies covering the same apparent interval of time. In order to place selected taxa into this stratigraphic framework we have brought together data on the better-represented large mammal species from the Tejon Hills and Cuyama Valley of the southern San Joaquin Valley region with comparable data from the flanks of Mount Diablo on the western fringe of the San Joaquin Valley east of the Bay Area. We have been guided by the recent taxonomic re-evaluation of the equine horses by MacFadden (1984) and Kelly (1995, 1998); the canids by Wang, Tedford, and Taylor (1999); the nimravids and felids by Baskin (1981); and artiodactyl identifications proposed in Tedford et al. (1987).

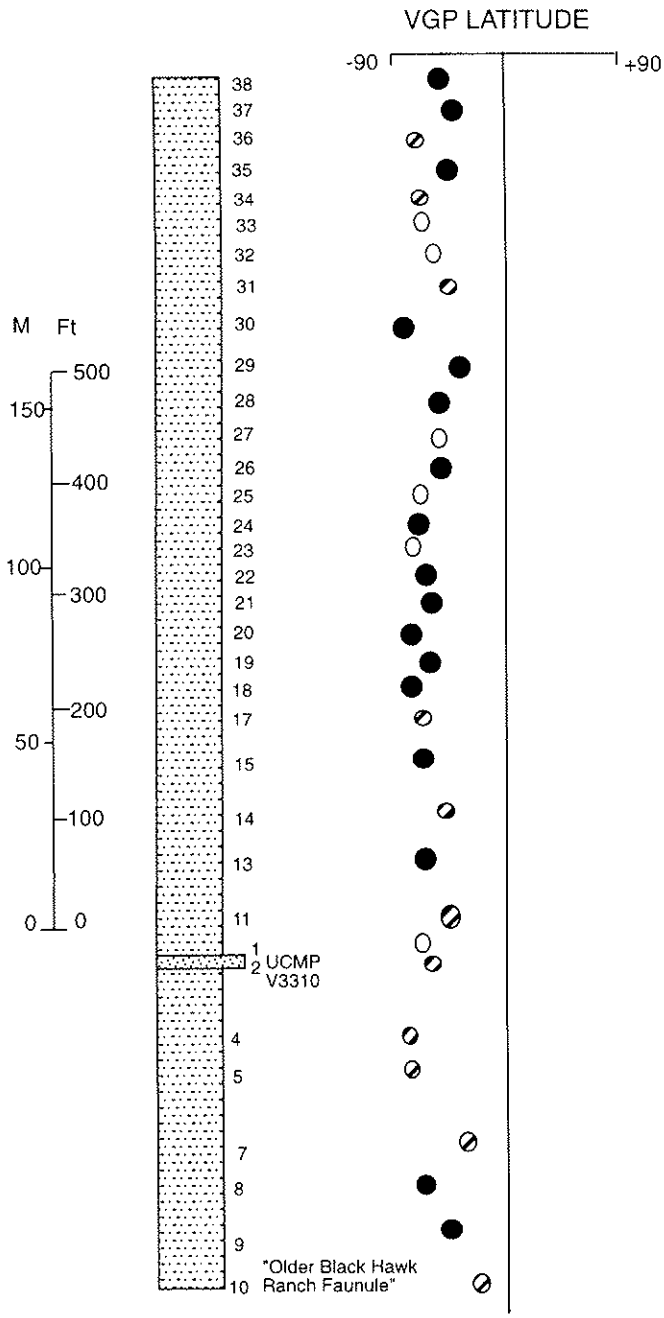

Fig. 4. Magnetic stratigraphy of the Sycamore Formation at Black Hawk Ranch. Site numbers and position of two main fossiliferous levels indicated on section. Solid circles indicate Class I sites of Opdyke et al. (1977); circles with diagonal pattern are Class II sites; open circles are Class III sites. VGP = virtual geomagnetic pole.

Coastal California

Because vertebrate remains at these localities are concentrated at specific fossiliferous horizons, rather than scattered throughout the local sections, the biostratigraphy of the coastal sections can be summarized as a sequence of local faunas as indicated in Table 1.

With one important exception (Nettle Springs Fauna) to be discussed below, the distribution of taxa leads to a bipartite division of local faunas as indicated by the vertical line in Table 1 corresponding to a consistent stratigraphic subdivision of the faunas into older ("Cerrotejonian") and younger ("Montediablan") biostratigraphic units as proposed by Savage (1955). In terms of the magnetostratigraphies now available, both units are mostly contained within reversed rocks. These lithostratigraphic sequences lack evidence of important physical hiatuses with the possible exception of that containing the Tejon Hills Local Fauna. Bartow and McDougall (1984) place the South Tejon Hills Local Fauna in the Bena Formation which is said to be overlain with angular unconformity by nearshore marine ("Santa Margarita Formation") and interfingering continental (Chanac Formation) strata containing the Comanche Point and North Tejon Hills Local Faunas, respectively. Unfortunately, the nature of the local outcrops prevents sampling of the strata containing the South Tejon Hills Local Fauna, so we have no magnetics for that part of the local section.

As indicated above, the Nettle Spring Fauna, a composite of taxa from 15 stratigraphically associated localities in the Caliente Formation of the Cuyama badlands, does not contain *Hipparion forcei* and *"Pliohippus" leardi*, index fossils for the Montediablan stage, yet it has been assigned there unequivocally in the past (James 1963, Kelly 1995). The Nettle Spring Fauna contains *Cormohipparion occidentale, Heteropliohippus hulberti*, a large pliohippine of uncertain identification (but possibly *"P." leardi*), and *Megahippus* sp. cf. *M. matthewi* (*fide* Kelly 1995). This horse fauna is shared with other sites of Cerrotejonian age (see Table 1) as are the long-ranging *Borophagus littoralis* and *Paracosoryx* cf. *furlongi* (*Merycodus* cf. *cerroensis* in James 1963). Comparison of the small-mammal faunal lists for the Maethews Ranch and Nettle Spring Local Faunas

Table 1. Distribution of some significant taxa in the local faunas discussed in the text. Abbreviations for local faunal names: BHR, Black Hawk Ranch; CMP, Comanche Point; MAT, Mathews Ranch; NSP, Nettle Springs; NTH, North Tejon Hills; STH, South Tejon Hills; SYC, Sycamore Canyon. Vertical line separates Cerrotejonian (left) from Montediablan local faunas, sensu Savage (1955).

Taxon	STH	MAT	NSP	CMP	SYC	NTH	BHR
Equidae							
Hipparion tehonense	x	x	—	—	x	—	—
"Pliohippus" tehonensis	x	x	—	x	—	—	—
"Pliohippus" leardi	x	—	?	—	—	x	—
Heteropliohippus hulberti	—	x	x	—	—	—	—
Cormohipparion occidentale	—	—	x	x	—	—	—
Neohipparion trampasense	—	—	—	—	x	—	—
Hipparion forcei	—	—	—	—	—	x	x
Megahippus cf. *matthewi*	—	x	x	—	—	—	—
Canidae							
Borophagus littoralis	x	x	x	—	—	x	x
Aelurodon taxoides	—	—	—	—	—	—	x
Epicyon haydeni	—	—	—	—	—	x	—
Felidae							
Nimravides thinobates	—	—	—	—	—	x	x
Nimravidae							
Barbourofelis lovei	—	—	—	—	—	x	x
Merycoidodontidae							
Ustatochoerus californicus	—	?	—	—	—	x	x
Dromomerycidae							
Cranioceras sp.	x	—	—	—	—	—	—
Antilocapridae							
Paracosoryx cf. *furlongi*	x	x	x	—	—	—	—

(James 1963, Table 3 vs. Table 4) also reveals near identity of the species present. The implications of this comparison is that the composition of the Caliente Formation faunas are closer than that between other faunas, and that the Nettle Spring Fauna is not demonstrably "Montediablan." This suggests that little time separates these assemblages, in accord with the local magnetostratigraphy.

Southwestern Great Basin

Data comparable to that discussed above is now available for a long section in the Dove Spring Formation of the Ricardo Group of the northwestern Mojave Desert (Whistler and Burbank 1992). This important section broadly overlaps the interval of interest in coastal California and gives a longer view of the local range zones of the same or comparable taxa. In Figure 5, we show the local range zones of some of these horse taxa in the Dove Spring Formation taken from Figure 4 of Whistler and Burbank (1992). Surprisingly, the local range zones of the four taxa shared with the coastal local faunas nearly completely overlap in the Great Basin within the *Epicyon aphobus* (=*E. haydeni*)/*Hipparion forcei* Assemblage Zone of the Dove Spring Formation. This overlap is largely contained within a long normal interval correlated with Chron C5n, but extends into Chron C4A and C4r for some taxa. An added complication in this comparison is that there is a disconformity in the Dove Spring section at the top of the lower basalt. Judging from the magnetostratigraphy (Fig. 5), this appears to have removed part of Chron C5r to which the reversed interval of the coastal sections had been correlated.

The Dove Spring Formation biostratigraphy (Whistler and Burbank 1992) does not show range extensions of many of the coastal horse taxa into Chron C5r, but the lower part of their ranges are in the older part of Chron C5n. Thus, the consistent biostratigraphy shown in the coastal sites is not recorded in the Dove Spring Formation. Rather, all the comparable equid taxa overlap in Chron C5n. On the other hand, the range terminations in the Dove Spring Formation does follow the order shown in the coastal sites, i.e., the local ranges of *Hipparion tehonense* and *"Pliohippus" tehonensis* end before those of *H. forcei* and *"P." leardi*. The coastal biostratigraphy is duplicated by the local ranges of these taxa in the upper part of their Dove Spring Formation, particularly for the latter two taxa and nearly for the former pair if their ranges more completely overlapped upward. This raises the probability that the reversed interval containing the coastal biostratigraphy actually lies in Chron C4Ar rather than C5r.

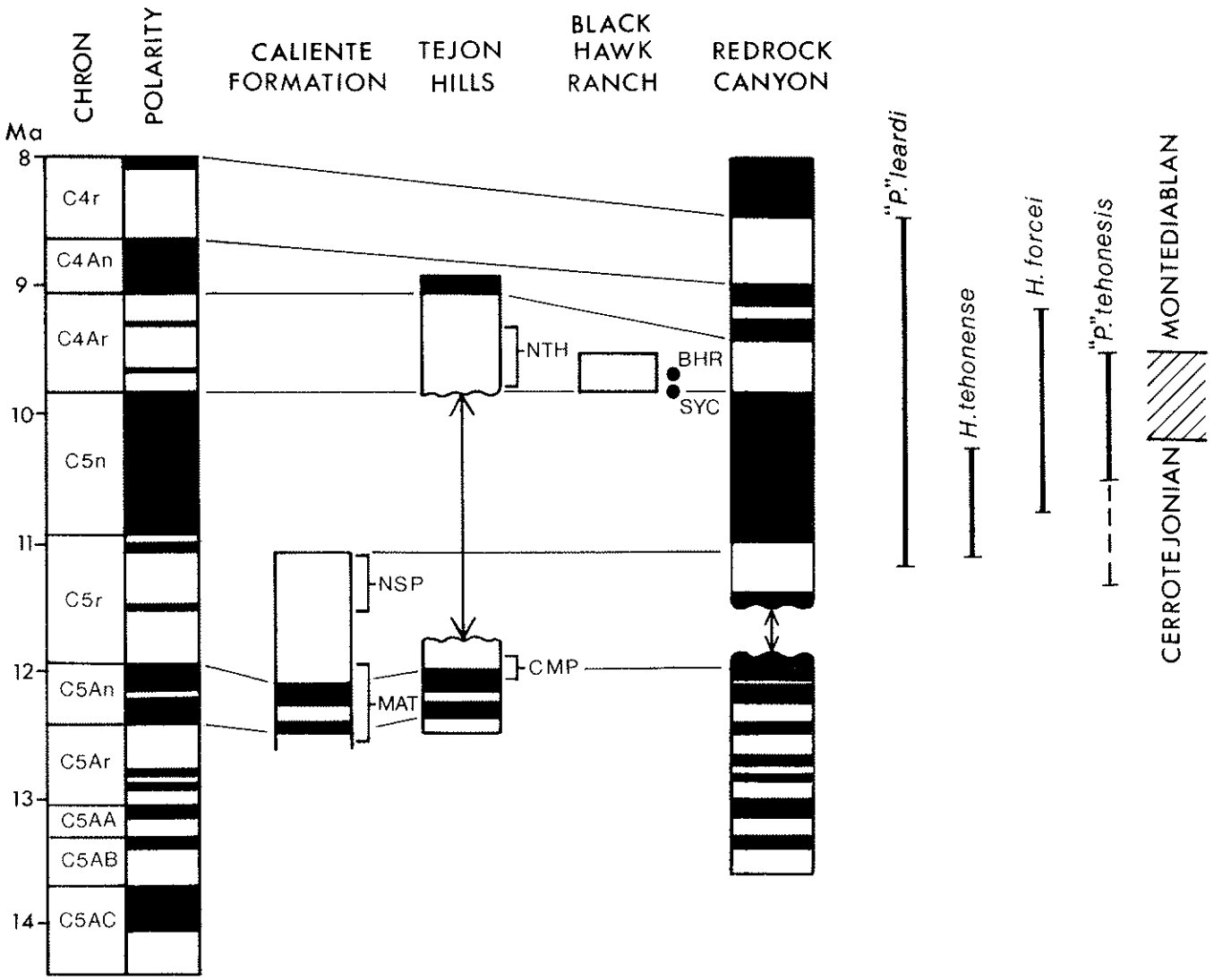

Fig. 5. Correlation of magnetostratigraphies of coastal sections as advocated in this paper. Chronozones of horse taxa within Dove Spring Formation, Red Rock Canyon (data from Whistler and Burbank 1992). The North Tejon Hills section is broken below the base of the nearshore marine Santa Margarita Formation where it unconformably overlies the top of the non-marine Bena Formation. Abbreviations for faunas: BHR, Black Hawk Ranch; CMP, Comanche Point; MAT, Mathews Ranch; NSP, Nettle Springs; NTH, North Tejon Hills; SYC, Sycamore Creek.

On the other hand, the Mathews Ranch Local Fauna of Apache Canyon, Cuyama Valley, contains *Copemys russelli* (type locality) and *Megahippus* sp., and lies in a mixed polarity interval that can be correlated with Chron C5An and the older part of C5r (Prothero et al. *in press*). The ranges of these taxa are restricted to the same interval in the Dove Spring succession strongly supporting the correlation of this Cuyama fauna, and the closely related Nettle Springs assemblage, with the span between 11.5–12.5 Ma.

Great Plains

Since the two alternative correlations of the coastal magnetostratigraphies cannot be resolved on the basis of a unique biostratigraphic array of taxa, stage-of-evolution comparisons of some of the taxa may be useful. The best-represented and most completely described fauna is that from the Black Hawk Ranch Quarry (UCMP V3310) (Table 2). Of the 21 taxa identified, only some of the horses and carnivores have been compared broadly enough to establish their chronological relationships with faunas of the Great Plains, which have provided most of the typification of the mid and late Miocene land mammal "ages."

Among the horses, the relationships of the taxon *"Pliohippus" leardi* have been the subject of discussion (Kelly 1998), but it seems morphologically close enough to the concept of *Pliohippus supremus* advocated by Webb (1969) to encourage comparison with that long-ranging taxon (latest Valentine through Ash Hollow Formations of north central Nebraska, essentially a Clarendonian range). *Hipparion forcei* has been widely recognized in the Great

Table 2. List of taxa from the Black Hawk Ranch Local Fauna (UCMP locality V3310).

Leporidae
Alilepus hibbardi White, 1991
Sciuridae
Spermophilus (*Otospermophilus*) sp., Richey, 1948
Castoridae
Eucastor cf. *lecontei* Stirton, 1939
Canidae
Leptocyon vafer (= *Vulpes vafer* Macdonald, 1948)
Caninae, near *Urocyon*, Macdonald, 1948 (= *Proturocyon* cf. *macdonaldi* nomen nudum, Baskin, *in* Webb et al. 1981)
Borophagus littoralis (= *Osteoborus diabloensis* Macdonald, 1948)
Procyonidae
Bassariscus parvus Macdonald, 1948
Leptarctidae
Leptarctus sp. (Procyoninae Macdonald, 1948)
Mustelidae
Mustelinae Macdonald, 1948
Felidae
Nimravides thinobates (Macdonald, 1948)
Nimravidae
Barbourofelis lovei Baskin, 1981 (= Machairodontinae, Macdonald, 1948)
Gomphotheriidae
Gomphotherium productum Tobien, 1973 (= *Trilophodon* sp., Richey, 1948)
Equidae
Hipparion forcei Richey, 1948
"*Pliohippus*" *leardi* Richey, 1948
Tayassuidae
Prosthennops sp. Richey, 1948
Merycoidodontidae
Ustatochoerus sp. Savage, 1955
Camelidae
Procamelus sp. Macdonald, 1948
Megatylopus sp. Macdonald, 1948
Aepycamelus sp. (= *Alticamelus* sp., Macdonald, 1948)
Antilocapridae
?*Merycodus* sp., Stirton, 1939 (= *Capromeryx* n. sp., Savage, 1955)

Plains in deposits of late Clarendonian (Snake Creek Formation of western Nebraska) to early Hemphillian age (Ogallala Group at the Box T quarries of the Texas Panhandle region) (MacFadden 1984).

Relevant to our present enquiry is the work of Baskin (in Webb et al. 1981, Baskin 1981) on the Love Bone Bed of Alachua County, Florida. Baskin compared the carnivores found there with those from the Great Plains and Pacific Coast, especially those from Black Hawk Ranch. One of the most important results was the determination that the Black Hawk nimravid is very close to *Barbourofelis lovei*, a taxon that is intermediate in size and morphology between *B. morrisi* of the Nebraska late Clarendonian and *B. fricki* of the medial Hemphillian of Nebraska. The smaller taxa, *B. osborni* (holotype from strata within Chron C5n at Dove Spring) and *B. whitfordi* (early Clarendonian of Nebraska and Clarendon, Texas), represent the older part of a putative anagenetic sequence. *Barbourofelis lovei*-like forms are known from the early Hemphillian of Oklahoma. Likewise, *Nimravides thinobates* from Black Hawk Ranch is similar to the Love Bone Bed *N. galiani*, and taxa like these extend from the late Clarendonian into the early Hemphillian in the Great Plains to be succeeded by *N. catocopis* in the medial Hemphillian. The larger canids have contrasting Great Plains ranges. Although the North Tejon Hills Local Fauna has a record of *Epicyon haydeni*, like Dove Spring and later Clarendonian assemblages of the High Plains, no species of *Aelurodon* extends into the early Hemphillian in the Plains (or anywhere else) and no species of *Borophagus* appears in the Plains before the early Hemphillian.

Borophagus littoralis seems to be geographically restricted to the west during the Clarendonian prior to the eastward expansion of species of this genus (*B. pugnator*) in the Hemphillian (Wang et al. 1999).

The evidence just summarized places the Black Hawk Ranch Fauna at the close of the Clarendonian in terms of correlative faunas from the Great Plains. In north-central Nebraska, fission-track ages for vitric tuffs within the late Clarendonian Merrit Dam Member of the Ash Hollow Formation range from 10.2 ± 0.7 to 9.7 ± 1.2 Ma for the Davis Ash near the base of the unit and 9.95 ± 0.3 Ma for the Machaerodus Ash higher in the section (Skinner and Johnson 1984). These dates and the above chronostratigraphic considerations support the correlation of the reversed interval containing the Black Hawk Ranch and North Tejon Hills Local Faunas to Chron C4Ar, rather than C5r.

On the other hand, the magnetostratigraphy containing the Cuyama Valley faunas is better correlated with Chrons C5A and C5r. We suspect that the biostratigraphically correlative South Tejon Hills Local Fauna (James 1963, Table 3) will also be attributed to this older interval. Thus, the previous assumption (Wilson and Prothero 1997) that all the coastal assemblages belong to a single reversed interval is now rejected. Despite these findings, the Cerrotejonian and Montediablan are demonstrably successional, as originally conceived (Fig. 5), and indeed correlate with early and late elements of the Clarendonian land mammal "age."

CONCLUSIONS

Magnetostratigraphic analysis of the 300 m (1000 feet) of apparently conformable strata encompassing the older Sycamore Creek Fauna and the younger Black Hawk Ranch Fauna shows that both of these faunas are contained within a single reversed magnetozone. Wilson and Prothero (1997) argued that this reversed interval correlated with Chron C5r (11.0–12.0 Ma). Further biostratigraphic analysis indicates that the Black Hawk Ranch and correlative North Tejon Hills Local Fauna reversed magnetozone correlates with Chron C4Ar (9.0–9.7 Ma). Furthermore, our review of the magnetostratigraphy and paleontology of the other coastal sites places the Apache Canyon succession and correlative South Tejon Hills Local Fauna in late Chron C5A and early Chron C5r (11.5–12.5 Ma) (Fig. 5).

ACKNOWLEDGMENTS

Prothero was supported by NSF grant EAR97-06046 during this research. We thank Clio Bitboul, Christine Couch, Linda Donohoo, Elana Goer, Karina Hankins, and Juliet Robinson for their help in the field. We thank Joseph Kirschvink for access to the Caltech paleomagnetics lab. We thank L. Barry Albright, Jon Baskin, Tom Kelly, Dave Whistler, and Mike Woodburne for their helpful comments on the manuscript.

LITERATURE CITED

Andersen, D.W., K.A. Isaacson, and V.E. Barlock. 1995. Neogene evolution of the Livermore basin within the California Coast Ranges. *Pacific Section SEPM* 75:151–61.

Axelrod, D.I. 1944. The Black Hawk Ranch flora. *Carnegie Institution of Washington Publications* 553:91–101.

Bartow, J.A. and K. McDougall. 1984. Tertiary stratigraphy of the southeastern San Joaquin Valley, California. *U.S. Geological Survey Bulletin* 1529J:1–41.

Baskin, J.A. 1981. *Barbourofelis* (Nimravidae) and *Nimravides* (Felidae) with descriptions of two new species from the late Miocene of Florida. *Journal of Mammalogy* 62:122–39.

Berggren, W.A., D.V. Kent, M.-P. Aubry, C.C. Swisher III, and K.G. Miller. 1995. A revised Paleogene geochronology and chronostratigraphy. *SEPM Special Publication* 54:129–212.

Butler, R.F. 1992. Paleomagnetism: Magnetic Domains to Geologic Terranes. Blackwell Scientific Publishers, Boston.

Clark, B.L. 1935. Tectonics of the Mt. Diablo and Coalinga areas, middle Coast Ranges of California. *Geological Society of America Bulletin* 46:1025–78.

Clark, B.L. 1941. Notes on California Tertiary correlation. *California Division of Mines Bulletin* 118(2):187–92.

Condit, C. 1938. The San Pablo flora of west central California. *Carnegie Institution of Washington Publications* 476:217–68.

Fisher, R.A. 1953. Dispersion on a sphere. *Proceedings of the Royal Society* A217:295–305.

Isaacson, K.A. 1990. Late Tertiary synorogenic sedimentation in the northern Livermore basin, California. M.S. Thesis. San Jose State University. 104 pp.

James, G. 1963. Paleontology and nonmarine stratigraphy of the Cuyama Valley Badlands, California. Part I: Geology, faunal interpretations, and systematic descriptions of Chiroptera, Insectivora, and Rodentia. *University of California Publications in Geological Sciences* 43:1–154.

Kelly, T.S. 1995. New Miocene horses from the Caliente Formation, Cuyama Valley badlands, California. *Natural History Museum of Los Angeles County, Contributions in Science* 455:1–33.

Kelly, T.S. 1998. New middle Miocene equid crania from California and their implications for the phylogeny of the Equini. *Natural History Museum of Los Angeles County, Contributions in Science* 473:1–43.

Kirschvink, J.L. 1980. The least-squares line and plane and the analysis of paleomagnetic data: Examples from Siberia and Morocco. *Geophysical Journal of the Royal Astronomical Society* 62:699–718.

Macdonald, J.R. 1948. The Pliocene carnivores of the Black Hawk Ranch fauna. *University of California Publications in Geological Sciences* 28:53–80.

MacFadden, B.J. 1984. Systematics and phylogeny of *Hipparion, Neohipparion, Nannippus,* and *Cormohipparion* (Mammalia, Equidae) from the Miocene and Pliocene of the New World. *Bulletin of the American Museum of Natural History* 179:1–195.

Opdyke, N.D., E.H. Lindsay, N.M. Johnson, and T. Downs.

1977. The paleomagnetism and magnetic polarity stratigraphy of the mammal-bearing section of Anza-Borrego State Park, California. *Quaternary Research* 7:316–29.

Perkins, M.E., F.H. Brown, W.P. Nash, W. McIntosh, and S.K. Williams. 1998. Sequence, age, and source of silicic fallout tuffs in middle to late Miocene basins of the northern Basin and Range Province. *Geological Society of America Bulletin* 110:344–60.

Pluhar, C., J.L. Kirschvink, and R.W. Adams. 1991. Magnetostratigraphy and clockwise rotation of the Plio-Pleistocene Mojave River Formation, central Mojave Desert, California. *San Bernardino County Museum Association Quarterly* 38(2):31–42.

Prothero, D.R., K.J. McCardel, E.L. Wilson, and T.S. Kelly. *in press.* Magnetic stratigraphy and tectonic rotation of the Miocene Caliente Formation, Ventura County, California. *Geological Society of America Bulletin.*

Richey, K.A. 1948. Lower Pliocene horses from Black Hawk Ranch, Mount Diablo, California. *University of California Publications in Geological Sciences* 28:1–44.

Sarna-Wojcicki, A.M. 1976. Correlation of late Cenozoic tuffs in the central Coast Ranges of California by means of trace element geochemistry. *U.S. Geological Survey Professional Paper* 972:1–30.

Savage, D.E. 1951. Late Cenozoic vertebrates of the San Francisco Bay region. *University of California Publications in Geological Sciences* 28:215–314.

Savage, D.E. 1955. Nonmarine lower Pliocene sediment in California: A geochronologic-stratigraphic classification. *University of California Publications in Geological Sciences* 31:1–26.

Savage, D.E. and D.E. Russell. 1983. Mammalian Paleofaunas of the World. Addison Wesley Publishing Company, Reading, Massachusetts.

Skinner, M.F. and F.W. Johnson. 1984. Tertiary stratigraphy and the Frick Collections of fossil vertebrates from north-central Nebraska. *Bulletin of the American Museum of Natural History* 178:215–368.

Stirton, R.A. 1939. Cenozoic mammal remains from the San Francisco Bay region. *University of California Publications, Bulletin of the Department of Geological Sciences* 24:339–410.

Tedford, R.H., T. Galusha, M.F. Skinner, B.E. Taylor, R.W. Fields, J.R. Macdonald, J.M. Rensberger, S.D. Webb, and D.P. Whistler. 1987. Faunal succession and biochronology of the Arikareean through Hemphillian interval (late Oligocene through earliest Pliocene Epochs) in North America; pp. 153–210 *in* M.O. Woodburne (ed.). Cenozoic Mammals of North America, Geochronology and Biostratigraphy. University of California Press, Berkeley.

Tobien, H. 1973. On the evolution of mastodonts (Proboscidea, Mammalia). Part I: The bunodont trilophodont groups. *Notizblatt der Hessischen Landesamtes für Bodenforschung zu Wiesbaden* 101:202–76.

Wagner, J.R. 1978. Cenozoic history of the Coast Ranges east of San Francisco Bay. Unpubl. Ph.D. diss. University of California, Berkeley.

Wang, X.-M., R.H. Tedford, and B. Taylor. 1999. Phylogenetic systematics of the Borophaginae (Carnivora: Canidae). *Bulletin of the American Museum of Natural History* 243:1–391.

Webb, S.D. 1969. The Burge and Minnechaduza Clarendonian mammalian faunas of north-central Nebraska. *University of California Publications in Geological Sciences* 78:1–191.

Webb, S.D., B.J. MacFadden, and J.A. Baskin. 1981. Geology and paleontology of the Love Bone Bed from the late Miocene of Florida. *American Journal of Science* 281:513–44.

Whistler, D.P. and D.W. Burbank. 1992. Miocene biostratigraphy and biochronology of the Dove Spring Formation, Mojave Desert, California, and the characterization of the Clarendonian land mammal age (late Miocene) in California. *Geological Society of America Bulletin* 104:644–58.

White, J.A. 1991. North American Leporinae (Mammalia: Lagomorpha) from late Miocene (Clarendonian) to latest Pliocene (Blancan). *Journal of Vertebrate Paleontology* 11:67–89.

Wilson, E.L., and D.R. Prothero. 1997. Magnetic stratigraphy and tectonic rotation of the middle-upper Miocene "Santa Margarita" and Chanac Formations, north-central Transverse Ranges, California. *Pacific Section SEPM Special Publication* 82:35–48.

Wood, H.E., II, R.W. Chaney, Jr., J. Clark, E.H. Colbert, G.L. Jepsen, J.B. Reeside, and C. Stock. 1941. Nomenclature and correlation of the North American continental Tertiary. *Geological Society of America Bulletin* 52:1–48.

Woodburne, M.O., and C.C. Swisher III. 1995. Land mammal high-resolution geochronology, intercontinental overland dispersals, sea level, climate, and vicariance. *SEPM Special Publication* 54:335–64.