# MAGNETIC STRATIGRAPHY AND TECTONIC ROTATIONS OF THE MIDDLE-UPPER MIOCENE "SANTA MARGARITA" AND CHANAC FORMATIONS, NORTH-CENTRAL TRANSVERSE RANGES, CALIFORNIA

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## ABSTRACT

Magnetostratigraphic sampling was conducted on two key sections of the middle-upper Miocene "Santa Margarita" and Chanac formations to correlate them to the magnetic polarity time scale, and to determine if they had undergone any tectonic rotation. The Tejon Hills, on the southeastern rim of the San Joaquin basin in Kern County, exposes a 200-m-thick sequence of marine "Santa Margarita" and fluvial Chanac formations. It is the type section of Savage's (1955) early Clarendonian "Cerrotejonian Stage." Magnetic analysis yielded a stable remanence that passes a reversal test, and shows no tectonic rotation. These strata are correlated with Chrons C5n to C5An (10.4-12.2 Ma), based on comparisons with the Clarendonian sequence in the Ricardo Group in the northeastern Mojave Desert. However, several taxa which define the late Clarendonian in the Ricardo Group (*Hipparion forcei, Osteoborus diabloensis*) occur earlier in the Tejon Hills (Chron C5r, 11 Ma) than they do in the Ricardo Group (Chron C5n, about 10.5 Ma). This calls into question the criteria for defining the early and late Clarendonian stages.

A second section of about 150 m of the "Santa Margarita" and ?Chanac Formations was taken in Chorro Grande Creek, in the upper Sespe Creek drainage, Ventura County, California. This section was entirely reversed in polarity, and probably correlates with Chron C5r (11.0-11.8 Ma). It is rotated 83° clockwise, which is consistent with other rotations reported for Eocene rocks in this same tectonic block between the Santa Ynez and Pine Mountain faults.

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## INTRODUCTION

The Transverse Ranges of southern California are a critical region for understanding the Miocene stratigraphy of North America. In several places (the Caliente Range and Cuyama Badlands, and the Tejon Hills), there are exposures of interfingering marine and nonmarine middle-upper Miocene rocks which yield both marine (foraminifera and molluscs) and terrestrial (mammals) fossils, allowing direct correlation of the North American land mammal "ages" with marine stratigraphies (Savage and Russell, 1983; Tedford and others, 1987). In other places (such as the middle Miocene Barstow Formation and the upper Miocene Ricardo Group in the Mojave Desert), thick sequences of mammal-bearing strata are punctuated by volcanic layers, allowing direct dating of these beds. For these reason, the southern California Miocene is crucial to the chronostratigraphic calibration of mammalian history in North America (Savage and Russell, 1983; Tedford and others, 1987).

In recent years, another chronostratigraphic method has further refined the dating of these strata. Magnetic stratigraphy is the only means of correlation that is independent of facies or lithology, and can provide geologically-instantaneous time planes with a resolution of less than 100,000 years (Prothero, 1988, 1990). The magnetostratigraphy of the middle Miocene sequences in the Barstow Formation in the central Mojave Desert (MacFadden and others, 1990), the Bopesta Formation in the southern Sierra Nevada (Coles and others, this volume), and the late Miocene strata of the Ricardo Group in the northwestern Mojave Desert (Loomis and Burbank, 1988; Whistler and Burbank, 1992) has

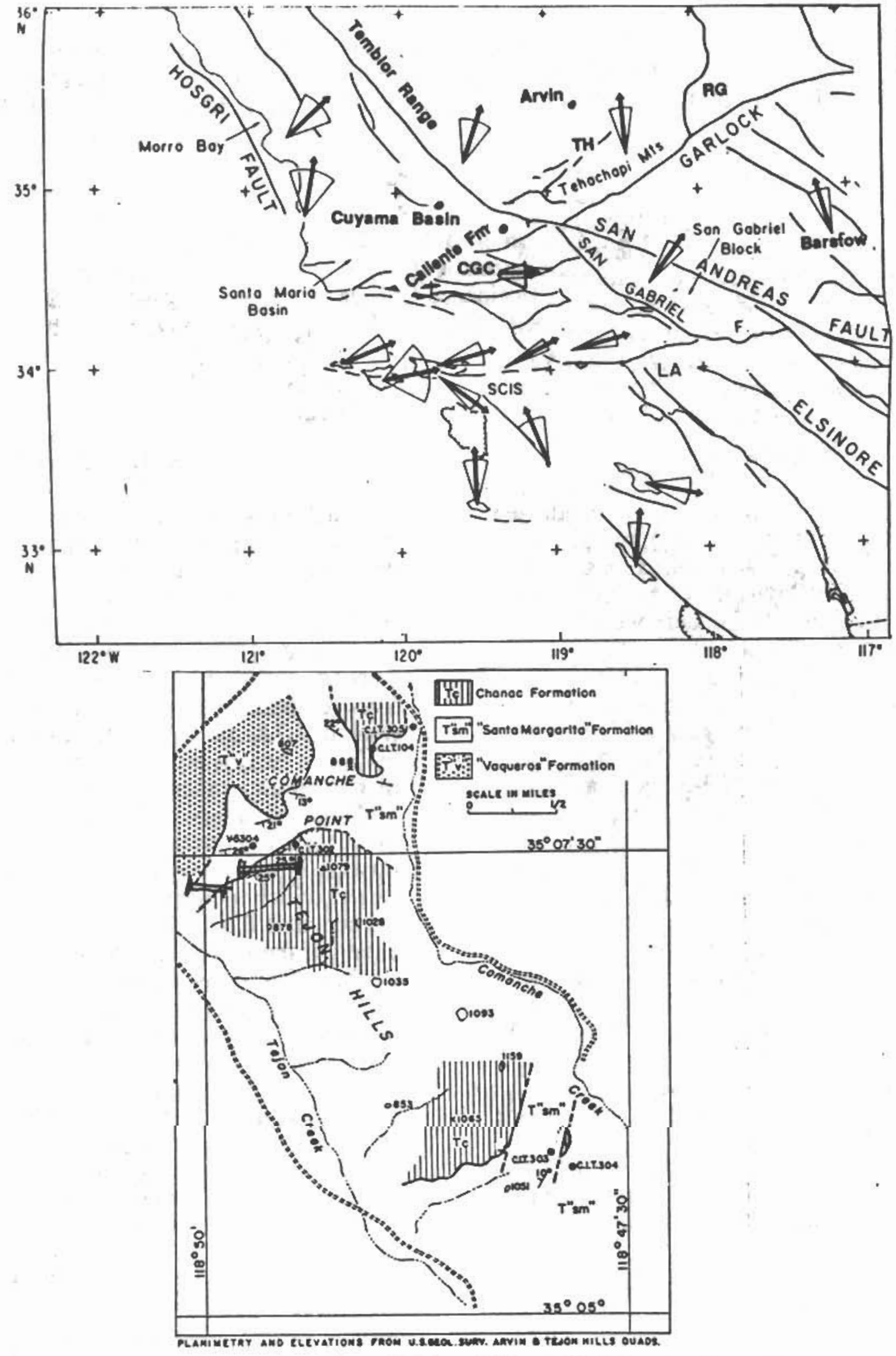


Figure 1.(*Top*) Index map showing location of Tejon Hills (TH), Ricardo Group (RG), Chorro Grande Creek (CGC) with respect to the the major faults and tectonic blocks of the Transverse Ranges. Vectors with error bars indicate middle Miocene magnetic directions and their 95% confidence intervals. (*Bottom*) Detailed map of the Tejon Hills, showing location of the magnetostratigraphic section (after Savage, 1955).

recently been studied. The lower-upper Miocene strata (spanning 18-5 Ma) of the Caliente Formation in the Cuyama Badlands in the central Transverse Ranges are currently under study (McCardel and others, in prep.).

Another crucial sequence is exposed in the Tejon Hills, in the southeastern rim of the San Joaquin Valley, south of Arvin, Kern County, California (Fig. 1). It was first mentioned by Merriam (1915, 1916), who described fossil mammals from the marine "Santa Margarita" Formation overlain by and interfingering with a nonmarine unit that Buwalda (1916) named the Chanac Formation. Hoots (1930) mapped and described the Tejon Hills in greater detail, and perpetuated the usage of the name "Santa Margarita" for the lower marine sequence in the Tejon Hills. Drescher (1941) further described the fossil horses from the Tejon Hills. Savage (1955) summarized the geology, updated the faunal lists, and designated the Tejon Hills as the type section for his early Clarendonian "Cerrotejonian Stage," because the strata also yielded superposed late Clarendonian mammals of his "Montediablan stage" and interfingered with marine units.

In addition to the Tejon Hills sequence, there are several other outcrops in the northern Transverse Ranges which have been referred to the "Santa Margarita" Formation (Fig. 1). Roberts and Vercoutere (1985) described a thick phosphate-rich sequence as the "Santa Margarita" Formation in the Cuyama basin of northern Santa Barbara County. Ryder and Thompson (1989) described similar outcrops of "Santa Margarita" Formation in the southern Temblor Range, in the southwestern San Joaquin basin in Kern County. Another isolated but important outcrop of "Santa Margarita" Formation in the central Transverse Ranges occurs in a tectonic block of Eocene (Juncal, Matilija, Cozy Dell, and Coldwater formations), Oligocene (Sespe and Vaqueros formations), and Miocene (Monterey and "Santa Margarita" formations) strata overridden by the Pine Mountain thrust in upper Sespe Creek, Matilija Quadrangle, Ventura County, California (Dibblee, 1985). Dickinson (1969), Ingle (1969), Vedder and others (1973), and Thor (1978) described a regressive marine to nonmarine sequence in upper Sespe Creek as "Santa Margarita" Formation, based on lithologic similarity and molluscan faunas. The lowest strata in this area are deeper water phosphatic siltstone and sandstone (Facies A of Thor, 1978), and they are overlain by offshore mudstones (Facies B), nearshore and lagoonal sandstones with thick oyster beds (Facies C), gypsiferous peritidal and lagoonal deposits (Facies D), and finally a fluvial sequence (Facies E) that may be equivalent to the Chanac Formation. However, that name was not used by Thor (1978), nor by Dibblee (1985), who referred these strata to the Caliente Formation. However, Facies E of Thor (1978) does not look much like the Caliente Formation (north of the Pine Mountain thrust, in the next tectonic block to the north), and the Caliente Formation in the Cuyama Badlands or Caliente Range is not underlain by the "Santa Margarita" Formation.

Throughout this paper, the name "Santa Margarita" will be placed in quotes except when referring to strata near the type area, because there is considerable doubt as to whether all of the beds given that name by various authors should be referred to that formation. The type Santa Margarita Formation was described by Fairbanks (1904) from outcrops near the town of Santa Margarita, San Luis Obispo County, California. Since that time, the name "Santa Margarita" has been applied to any shallow marine strata in the southern San Joaquin Valley or Coast Ranges which produce "Santa Margarita" molluscan faunas (Weaver and others, 1944) or Mohnian benthic foraminifera (Bartow and McDougall, 1984; Bartow, 1987; Roberts and Vercoutere, 1985; Fischer and Surdam, 1988; Ryder and Thomson, 1989; Reid, 1995). Although Reid (1995, fig. 8) suggests that there was a continuous sheet of sandstone on the "Santa Margarita shelf" at about 10 Ma that may have connected the type area of the Santa Margarita Formation in San Luis Obispo County to the strata in the Cuyama basin and the Tejon Hills, there is still some doubt that the "Santa Margarita" strata in the Tejon Hills really can be referred to that formation. Not only are these strata in a different depositional basin from the type Santa Margarita Formation, but they are also on the opposite side of the San Andreas fault, which has moved hundreds of kilometers in the last 10 Ma. The "Santa Margarita" beds in upper Sespe Creek are clearly in a different depositional basin, and separated from the type Santa Margarita Formation by several other major faults (including the Pine Mountain thrust and the Big Pine fault). For this reason, Hagen (1957) applied the informal name "Munson Creek Formation" to these strata, although later authors have not followed this practice. Because the name "Santa Margarita" has been so widely accepted for these strata, we will follow that questionable usage, indicating our doubts with the quotation marks around the name.

In addition to improved stratigraphic correlation provided by magnetic stratigraphy, the magnetic remanence of these strata can provide important data toward the solution of another geologic problem. Luyendyk and others (1980, 1985) showed that most of the tectonic blocks of the central and western Transverse Ranges have rotated 90° clockwise since the beginning of the Miocene. Prothero and Vance (1996) found evidence of 90° of rotation in the Eocene Coldwater Sandstone, which directly underlies the upper Sespe Creek "Santa Margarita" Formation in the same tectonic block, so we would predict that the Miocene strata are also rotated approximately 90° clockwise. North of the Garlock and San Andreas faults, Kanter and McWilliams (1982) and McWilliams and Li (1985) found no evidence of Miocene or younger rotations, so we would predict that the "Santa Margarita" and Chanac formations in the Tejon Hills are not rotated.

## METHODS

Stratigraphic sections were measured by Wilson using a Jacob's staff, compensating for the dip, lack of exposure, and for recognized faults. The route of the section in the Tejon Hills is shown in Figure 1. The lower part of the section spanned about 65 m (to site 17) of the "Santa Margarita" Formation and ran east up the slope in SW NW SW Sec. 23, T32S R30E, Arvin 7.5' Quadrangle, Kern County, California. The remaining 130 m of section, covering the upper "Santa Margarita" and Chanac exposures, was collected on the northeast wall of the amphitheater in SE NE SE Sec. 23, concluding at the top of the local peak at elevation 1020 feet. Thirty-five sites were collected at 5- to 10-m intervals to cover the 190 m of the Tejon Hills section.

Eight magnetic sites were collected in the 80-m-thick Chorro Grande Creek section in the upper Sespe Creek Drainage, as described by Thor (1978) and Fritsche (1978, p. 78). It is located in the east side of the upper part of Chorro Grande Creek, in SW SE SW Sec. 9, T6N R23W, Wheeler Springs 7.5' Quadrangle, Ventura County, California (Vedder and others, 1973; Dibblee, 1985).

In all sections, three oriented block samples were collected per site, using simple hand tools, and later subsampled into 2.5-cm cubes using a band saw with a tungsten-carbide blade. The samples were then analyzed on the 2G cryogenic magnetometer at the California Institute of Technology paleomagnetics laboratory. The NRM (natural remanent magnetization) of each sample was measured, and then demagnetized with alternating fields (AF) of 25, 50, and 150 Gauss to remove any unstable multi-domain grain remanence, and to determine the coercivity behavior of each sample. After AF demagnetization, 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, removing their remanence, and also allows determination oof how much magnetization remained above the Curie temperature of magnetite (580°C).

In addition to the detailed AF and thermal demagnetization of each 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), and the peak IRM and ARM (anhysteretic remanent magnetization) was subjected to AF demagnetization in a modified Lowrie-Fuller test (see Pluhar and others, 1991, for further details).

Finally, several polished thin sections of representative lithologies were examined under reflected light to determine the magnetic mineralogy.

## RESULTS

### Magnetic Analyses

The magnetic behavior of each sample was plotted on an orthogonal demagnetization, or "Zijderveld" plot, representative examples of which are shown in Figure 2. The horizontal component (declination, D) of the sample magnetization is shown with the closed circles, and indicates the compass direction of each demagnetization step as the intensity decays toward the origin. The vertical component of magnetization is indicated by the asterisks, and shows whether the magnetization direction of the sample was inclined up or down at each demagnetization step. Sample 3C (Fig. 2A) and 8B (Fig. 2B) from the Tejon Hills responded readily to AF treatment and had little remanence left at 600°C, suggesting that most of their magnetization was carried in magnetite. Both appeared to be of normal magnetic polarity,

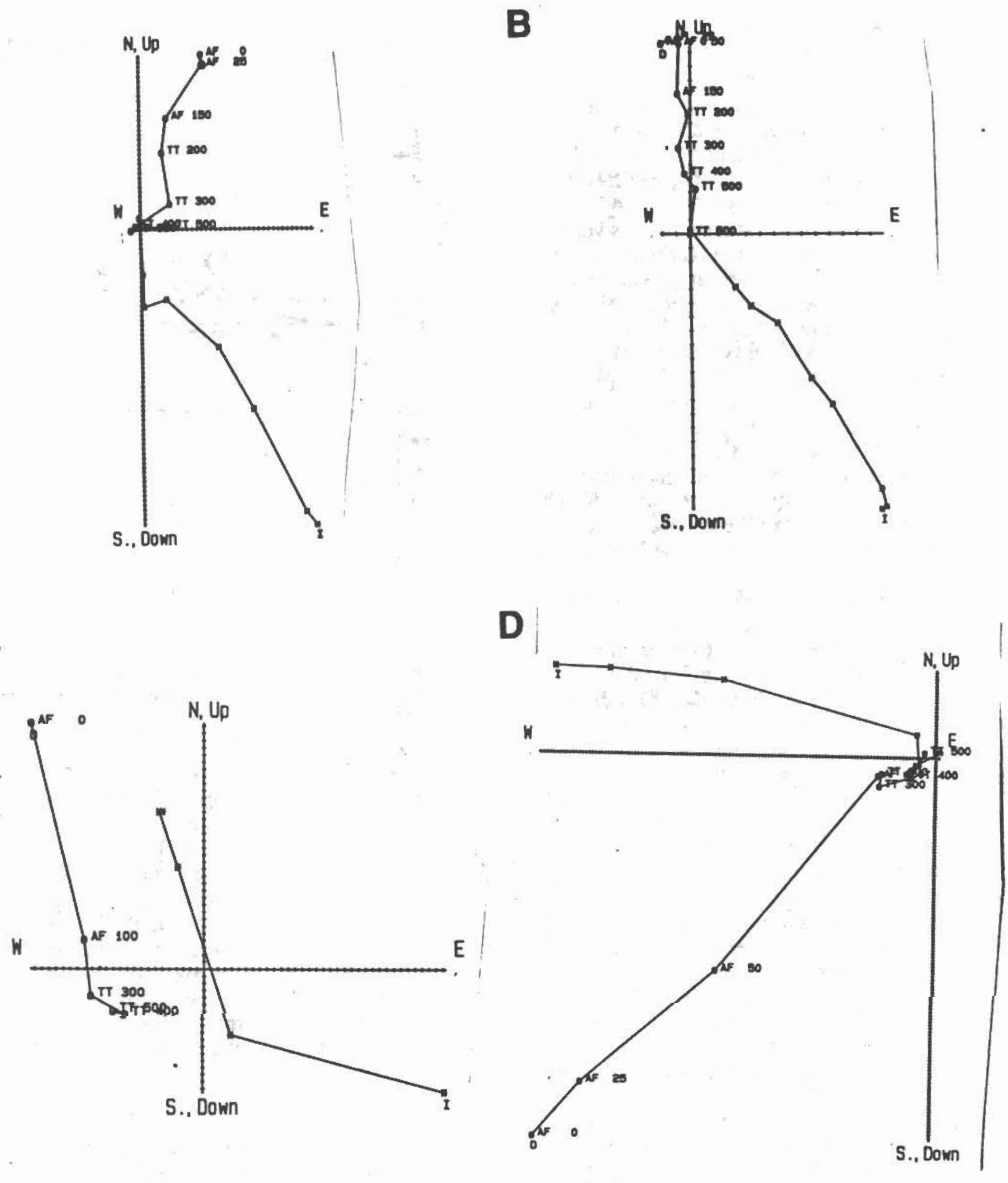


Figure 2. Orthogonal demagnetization ("Zijderveld") plots of samples. Circles indicate declination, asterisks indicate inclination. "AF" indicates alternating field demagnetization step in Gauss; "TT" indicates thermal demagnetization step in degrees Centigrade. Each division equals $10^{-6}$ emu (= $10^{-9}$ $Am^2$). A-C. Representative samples from the Tejon Hills. D. Representative sample from Chorro Grande Creek, showing the west and up directions. See text for further discussion.

because their remanence pointed north and down. Sample 24C (Fig. 2C) from the Tejon Hills is reversely magnetized, with an overprint that disappeared at 300°C, leaving a cleaned direction that pointed south and up; its low coercivity also suggests that a significant portion of the remanence was held in magnetite. Sample 14C (Fig. 2D) from Chorro Grande Creek has a low-coercivity remanence held mostly in magnetite, but its vector points west and up, an indication that this sample is reversed in polarity but rotated approximately 90° clockwise (see Prothero and Vance, 1996, for further examples of similar behavior from the underlying Eocene rocks in this same area).

Rock magnetic analyses of several samples (Fig. 3) showed IRM saturation (ascending curve of open circles on the right) at about 300 mT (millitesla), or 3000 Gauss, indicating that magnetite is the major magnetic mineral in these samples. Even though some of the reddest, most iron-hydroxide-rich samples were selected, none showed the lack of IRM saturation characteristic of hematite.

In the Lowrie-Fuller test (Fig. 3), the ARM (solid circles) is more resistant to AF demagnetization than is the IRM (open circles descending to the right), suggesting that the remanence is carried in single-domain or pseudo-single-domain grains (see Pluhar and others, 1991). This was corroborated by the polished thin sections, which revealed abundant, tiny detrital magnetite grains, as well as larger, rounded, platy detrital hematite grains, which were presumably multi-domain, and thus did not retain a remanance that showed up in our analyses.

Although the strata dipped about 25° to the northeast in the Chorro Grande Creek section, and 8-25° to the northeast in the Tejon Hills, there was not enough dip variation to conduct a fold test for stability. However, a reversal test (Fig. 4) for the samples from the Tejon Hills showed that the directions represent a primary or characteristic remanence, since the mean direction for the normal sites ($D = 15.3°$, $I = 43.0°$, $k = 5.0$, $\alpha_{95} = 17.7$) was antipodal (within the error estimate) to the mean for the reversed sites ($D = 152.4°$, $I = -33.6°$, $k = 1.4$, $\alpha_{95}= 87.8$). This error estimate is large enough to include the modern pole position for this latitude, suggesting no tectonic rotation or translation in this area. This is consistent with previous studies of the Miocene rocks of the southern Sierra Nevada and Tehachapis (Kanter and McWilliams, 1982; McWilliams and Li, 1985).

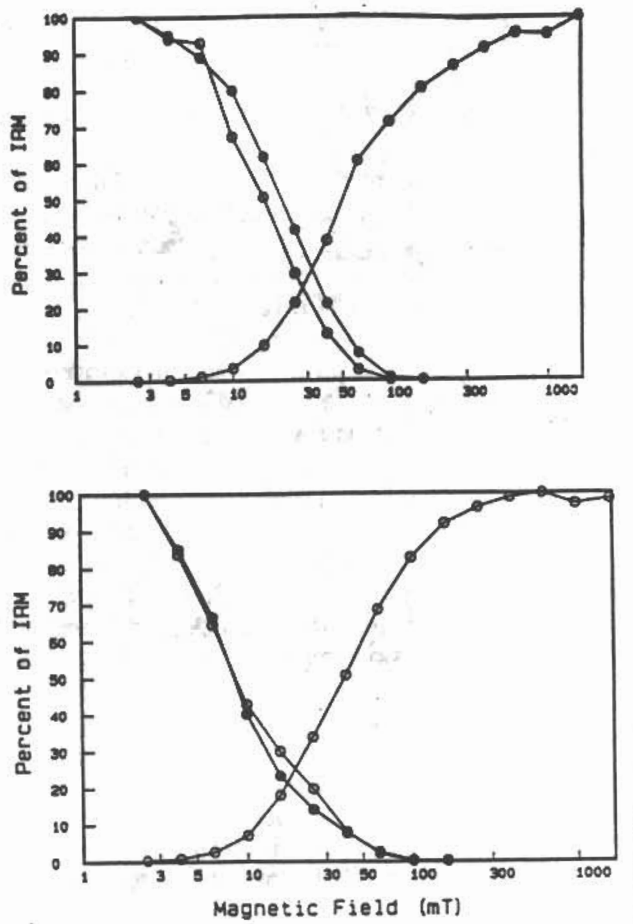


Figure 3. Rock magnetic analyses of representative samples. Open circle indicate IRM intensity, solid circles show ARM intensity. In both cases, the acquisition of IRM (ascending curves on right) saturates around 300 mT (millitesla), or 3000 Gauss, suggesting that the main magnetic mineral is magnetite. In the modified Lowrie-Fuller test (descending curves on left), the ARM is more resistant to AF demagnetization than the IRM, suggesting that the remanence is carried by single-domain or pseudo-single-domain grains (see Pluhar and others, 1991, for further details).

Based on these results, the remanence component obtained between 300-500°C was used for further analyses. The three sample vectors for each site were averaged using the methods of Fisher (1953; see Butler, 1992), and classified using the scheme of Opdyke and others (1977). Class I sites (11 total) are significantly distinguished from a random scatter at the 95% confidence level; they are indicated by solid circles

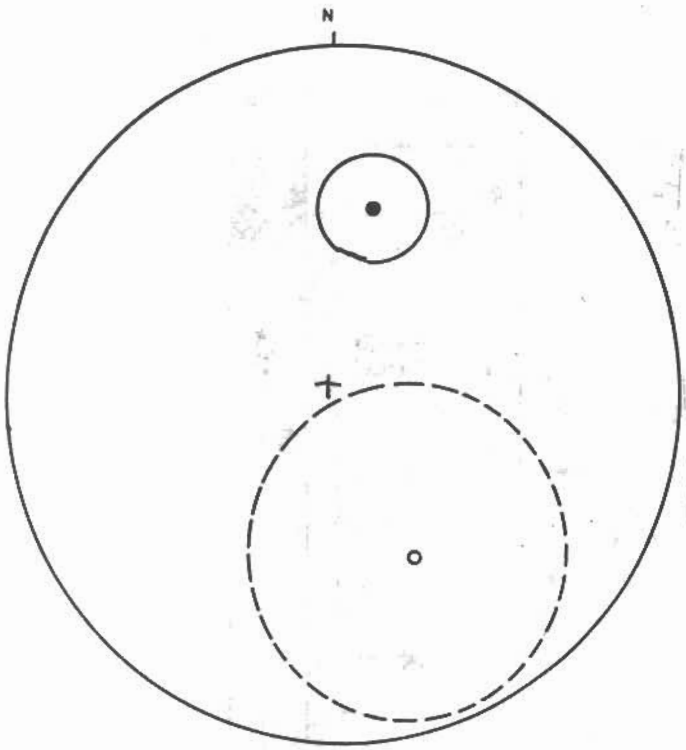


Figure 4. Stereoplot of mean direction and circle of 95% confidence of normal sites from the Tejon Hills (solid dot and circle, lower hemisphere projection) and reversed site mean direction (open and dashed circle, upper hemisphere projection). If the reversed mean is inverted through the center of the stereonet, it overlaps the normal mean. This positive reversal test indicates that the cleaned magnetic direction is primary remanence.

in Figures 5 and 6. Class II sites (4 total) had only two samples, so site statistics could not be calculated; they are indicated by circles with a diagonal slash in Figures 5 and 6. Class III sites (23 total) were not significantly clustered at the 95% confidence level, because one sample from each site was divergent, but two out of three samples showed a clear polarity preference; they are indicated by open circles in Figures 5 and 6.

Because only reversed polarities were obtained from the rocks in Chorro Grande Creek (Fig. 6), it was not possible to conduct a reversal test. However, the west and up magnetic direction is clearly not a normal magnetic overprint, and is consistent with the 90° clockwise rotation reported for the underlying Eocene rocks in the same tectonic block (Prothero and Vance, 1996). The mean direction for the "Santa Margarita" Formation in Chorro Grande Creek was D = 263.6°, I = -35.4°, k = 2.1, $\alpha_{95}$ = 52.7, suggesting about 83° of clockwise rotation in this block since about 10 Ma. This is similiar to results reported in adjacent areas of the Transverse Ranges by Luyendyk and others (1980, 1985), Luyendyk and Hornafius (1987), and Luyendyk (1991), and also is consistent with rotations in the next tectonic block to the north (between the Big Pine and Pine Mountain faults), in the Miocene rocks of the Cuyama Badlands (McCardel and others, in prep.).

## Magnetic Stratigraphy

The magnetostratigraphic patterns in each section are shown in Figures 5 and 6. In the Tejon Hills (Fig. 5), the lowest 25 m of "Santa Margarita" Formation are of normal polarity, followed by about 20 m of reversely magnetized rocks. Sites 15 and 16 (about 15 m of strata) are of normal polarity, and also include Savage's (1955) type Cerrotejonian Comanche Point local fauna (University of California, Berkeley, Museum of Paleontology, or UCMP, vertebrate locality V-5304). At magnetic site 18 (in the next zone of reversed polarity), we found badly abraded mammalian fossils, including gomphothere mastodont bones and a horse metapodial, that also might be referred to the Comanche Point local fauna. From about 55 m to 170 m on the Tejon Hills section, the rocks are entirely of reversed polarity. This reversed interval includes the remaining upper "Santa Margarita" strata, and most of the Chanac Formation, including the beds which yield the late Clarendonian ("Montediablan" of Savage, 1955) North Tejon Hills local fauna (California Institute of Technology, or CIT, localities 104 and 302; these specimens are now deposited in the Natural History Museum of Los Angeles County). The uppermost 20 m of the Chanac Formation is of normal polarity.

As mentioned above, the entire sampled portion of the "Santa Margarita" Formation in Chorro Grande Creek (the lower 80 m) was of reversed polarity (Fig. 6), but rotated 83° clockwise. No samples were taken in the poorly exposed, unfossiliferous, and little studied gypsiferous Facies D of Thor (1978), or in the unfossiliferous nonmarine strata that may be equivalent to the Chanac Formation (Facies E).

Correlation of these sections with the magnetic polarity time scale is shown in Figure 7. The best comparison to our sections comes from the Clarendonian strata of the Ricardo Group in Redrock Canyon, in the northeastern Mojave

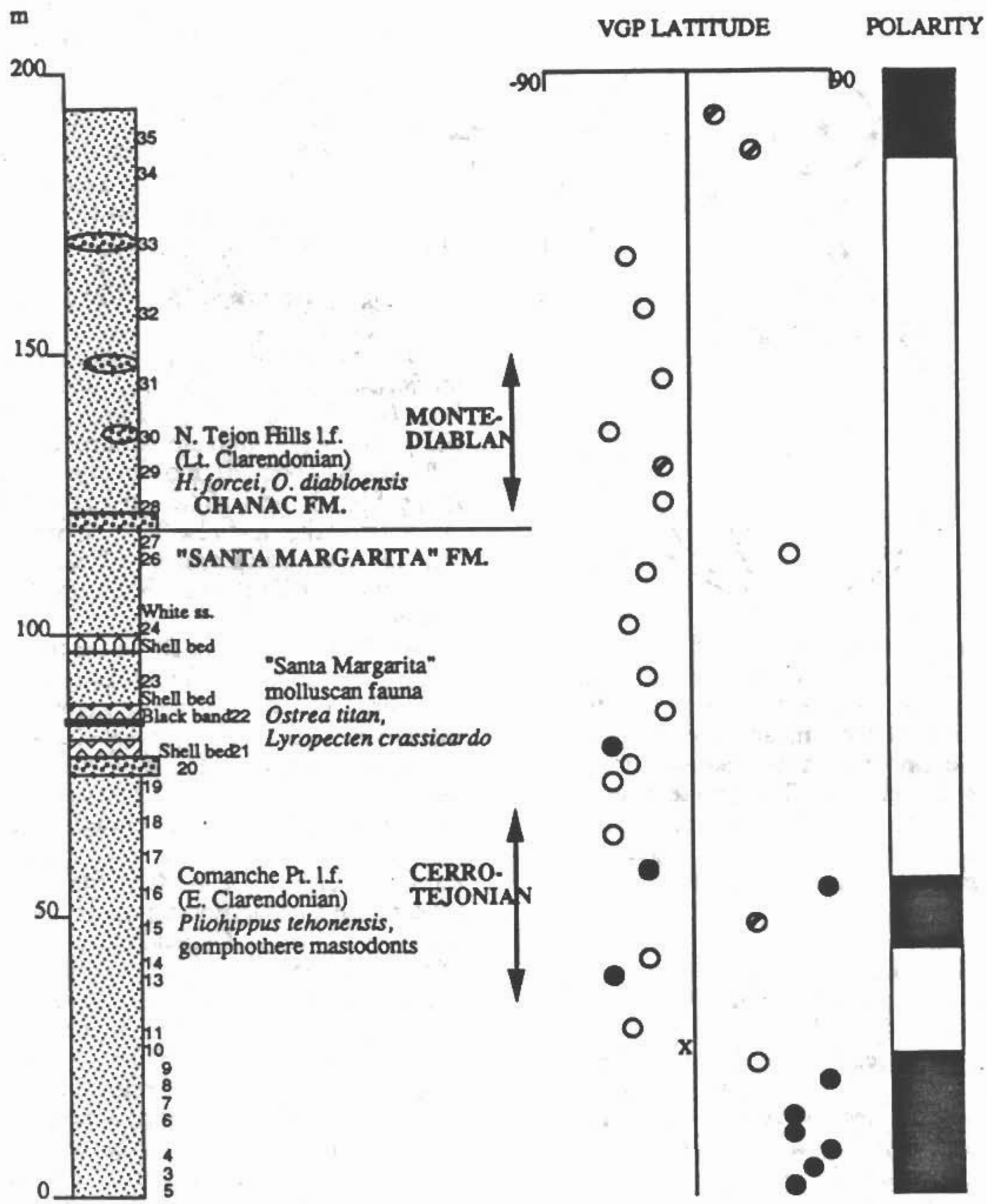


Figure 5. Magnetic stratigraphy of the Tejon Hills section. Lithostratigraphy and biostratigraphy after Savage (1955). Positive VGP (virtual geomagnetic pole) latitudes indicate normal polarity; negative VGP latitudes indicate reversed polarity. Solid circles are statistically significant at the 95% confidence level, or Class I sites of Opdyke and others (1977); circles with a diagonal slash are sites that had only two samples, so no statistics could be calculated (Class II sites); open circles are sites that had one sample divergent, but two samples gave concordant directions (Class III sites); "x" indicates indeterminate site.

Desert about 50 km east of the Tejon Hills (Fig. 1). The Ricardo Group strata are calibrated by dates from several volcanic ashes, giving the magnetic stratigraphy an independent form of age control. In these beds, Whistler and Burbank (1992) found early Clarendonian mammals in strata which they correlated with Chrons C5AB, C5A, and C5r (11.0-13.5 Ma), and late

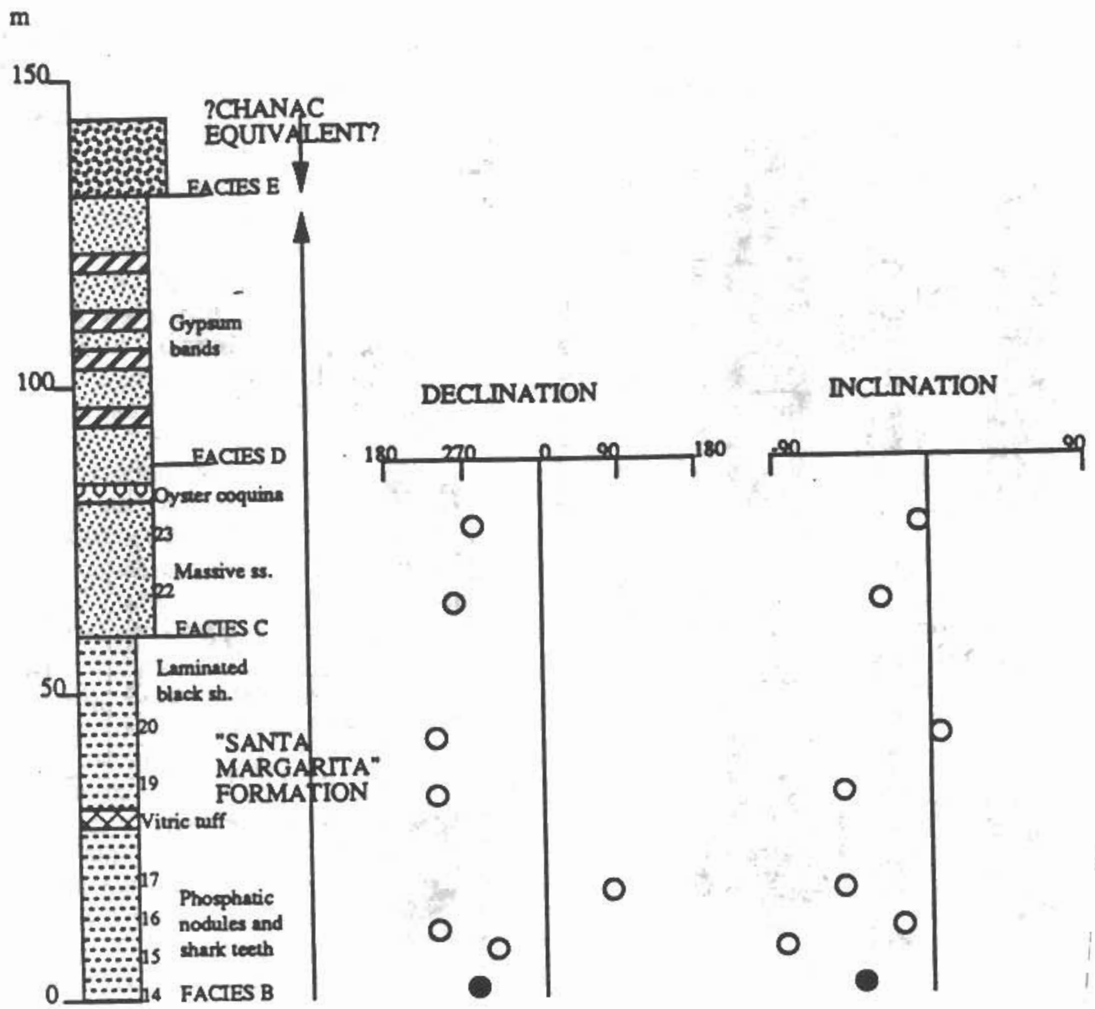


Figure 6. Magnetic stratigraphy of the Chorro Grande Creek section. Lithostratigraphy after Thor (1978). All conventions as in Figure 5.

Clarendonian mammals in strata which they correlated with Chrons C5n through "Chron 10" (Chron C4Ar in current time scales, such as that of Berggren and others, 1995; this interval spans 9.0-11.0 Ma). Based on these correlations, the simplest interpretation of the Tejon Hills sequence (assuming no undocumented unconformities) is that the lower "Santa Margarita" strata (with the early Clarendonian Comanche Point local fauna) correlate with Chron C5An (11.9-12.4 Ma), and that the thick reversed interval with early and late Clarendonian mammals covering the upper "Santa Margarita" and lower Chanac formations correlates with Chron C5r (11.0-12.0 Ma). The uppermost Chanac normal sites probably correlate with early Chron C5n.

If these correlations are correct, then the simplest interpretation of the long, reversed "Santa Margarita"-?Chanac sequence in Chorro Grande Creek is that it represents Chron C5r. The best evidence for this correlation is the distinctive fauna of "Santa Margarita" molluscs found in the upper part of the "Santa Margarita" Formation in both sections (Fig. 7).

## DISCUSSION

Although the magnetic stratigraphy and biostratigraphy of the Tejon Hills section is generally consistent with the Clarendonian biostratigraphy in the Ricardo Group described by

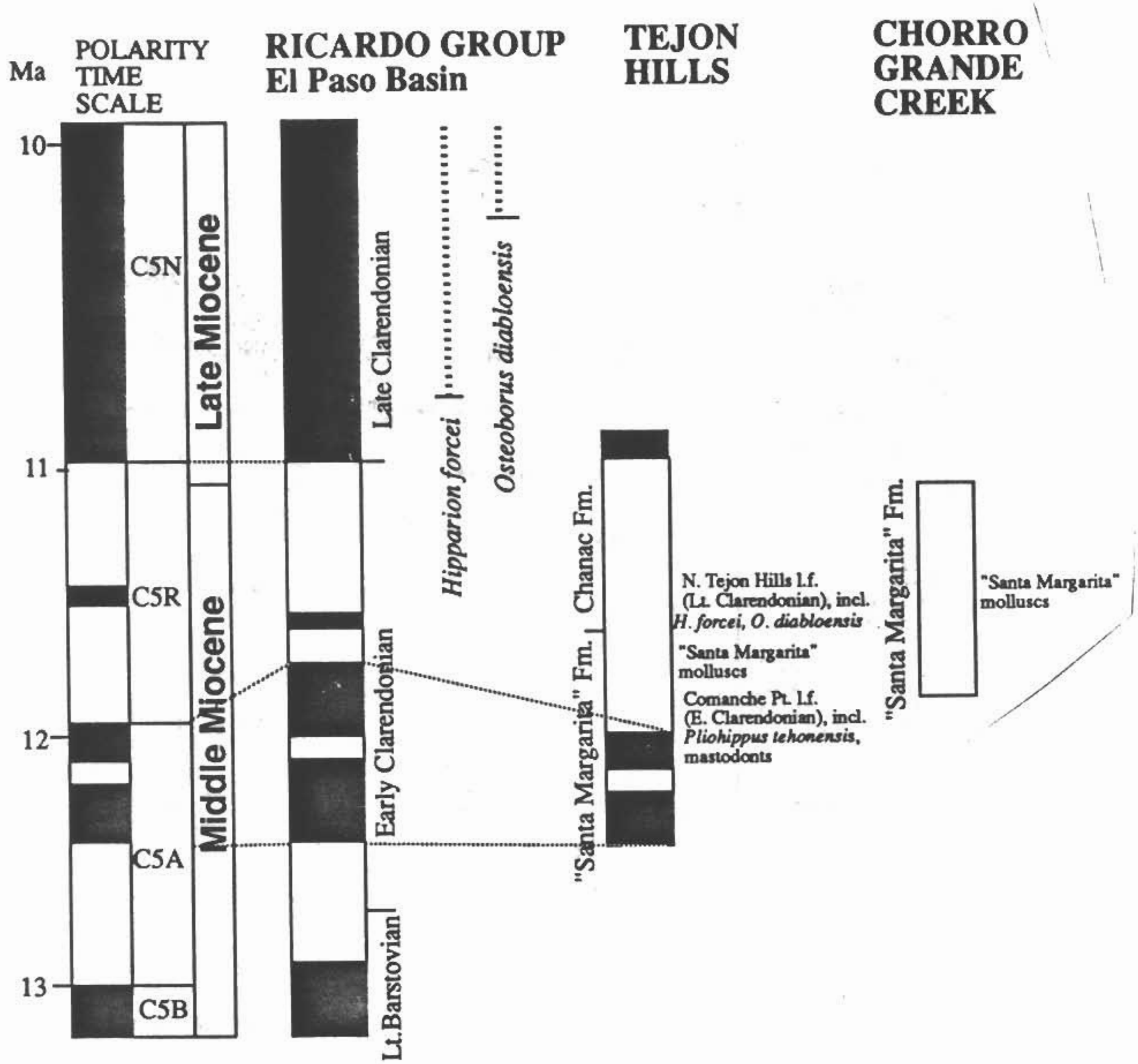


Figure 7. Magnetostratigraphic correlation of the sections discussed in this paper. Ricardo Group magnetic stratigraphy and biostratigraphy after Whistler and Burbank (1992). Polarity time scale after Berggren and others (1995). See text for further discussion.

Whistler and Burbank (1992), there are also some problems. Whistler and Burbank (1992) defined the early/late Clarendonian boundary on the first appearance of a number of late Clarendonian taxa, including the horse *Hipparion forcei* (chosen as the diagnostic taxon of the beginning of this zone, and of the late Clarendonian), the dog *Tomarctus robustus*, and the insectivore *Lanthanotherium* (although they noted that this genus occurs in the Barstovian elsewhere). Other taxa which first occurred in the late Clarendonian in the Ricardo Group included the sabertooth *Barbourofelis osborni*, the horse "*Pliohippus*" *tejonensis*, the mole *Scapanus schultzi*, the rodent *Cupidinimus* (small sp.), and the borophagine dog *Osteoborus diabloensis*. Taxa last occurring in the "*Epicyon aphobus*/*Hipparion forcei* assemblage zone" in the Ricardo Group included the dogs *Epicyon aphobus* and *Tomarctus robustus*, the horses *Pliohippus tantalus*, "*Pliohippus*" *tejonensis*, and *Hipparion tejonense*, and the shrew *Alluvisorex chassae*. The "*Epicyon aphobus*/*Hipparion forcei* assemblage zone" occurred entirely within Chron C5n (9.8-10.9 Ma), according to the calibrations of Whistler and Burbank (1992), updated with the time scale of Berggren and others (1995).

The biostratigraphy and magnetic stratigraphy of the late Clarendonian North Tejon Hills local fauna is in striking contrast to the results from the Ricardo Group (Fig. 7). The unquestioned reversed polarity of the rocks that contain this late Clarendonian fauna show that it cannot be correlated with Chron C5n, as in the Ricardo Group. Whistler (pers. commun. to DRP, 1997) suggested that the late Clarendonian reversed rocks of the Tejon Hills might be correlated to Chron C4Ar. However, this is less likely than correlation to C5r for a number of reasons:

1. There is no evidence of an unconformity in the Tejon Hills that might have removed Chron C5n. In fact, the contact between the "Santa Margarita" and Chanac formations in the Tejon Hills is gradational and interfingering, rather than distinct, abrupt, and possibly unconformable.

2. The reversed intervals that Whistler and Burbank (1992, Fig. 4, reversals R10 and R11) correlated with Chron C4Ar ("Chron 10" of the old terminology) also contain early Hemphillian taxa, including the the pronghorn *Illingoceras* and the rodents "*Repomys*" and *Paronychomys*, which Whistler and Burbank (1992) use as the basis for recognition of their early Hemphillian "*Paranychomys*/*O. diabloensis* assemblage zone." Although some authors (e.g., Tedford and others, 1987) might use different criteria for defining the early Hemphillian, Woodburne and Swisher (1995) accept Whistler and Burbank's (1992) zone as a reasonable proxy of the early Hemphillian, and point out that there are a number of dates which place the beginning of the Hemphillian slightly older than 9 Ma (i.e., within Chron C4Ar). Under these circumstances, it seem highly unlikely that a clearly late Clarendonian fauna such as that from the North Tejon Hills is coeval with early Hemphillian faunas in the Dove Spring Formation, only 50 km to the east.

3. These results are corroborated by recent work in the Caliente Formation in the Cuyama Badlands (James, 1963; Kelly and Lander, 1988; McCardel and others, in prep.). In Apache Canyon, both early and late Clarendonian localities occur in a continuous zone of reversed polarity that apparently correlates with Chron C5r, and there is no indication of Chron C5n, even in the latest Clarendonian part of the section. Both Clarendonian magnetostratigraphic sections in the Transverse Ranges (Cuyama Badlands and Tejon Hills) suggest that the early/late Clarendonian boundary occurs in Chron C5r, and the Ricardo results are now the odd man out.

4. Kelly (pers. commun. to DRP, 1997) points out that correlation of the late Clarendonian North Tejon Hills local fauna and the the late Clarendonian faunas (such as the Nettle Spring local fauna) of the Caliente Formation with Chron C4Ar is inconsistent with a variety of biostratigraphic data:

a) The rodent *Copemys russelli* is restricted to Chron C5Ar in the Ricardo Group, and to the early and late Clarendonian in the Caliente Formation. Correlation of the late Clarendonian Caliente faunas to Chron C4Ar would extend it range through Chron C5n (for which there is no evidence in the Ricardo or anywhere else) to as young as 9.7 Ma.

b) The horse *Megahippus* occurs only in Chron C5AB (late Barstovian) in the Ricardo, in the Barstow Formation, and in the early and late Clarendonian in the Caliente Formation. If the late Clarendonian faunas of the Caliente Formation are correlated with Chron C4Ar, this would represent a considerably upward range extension.

In short, correlation of the late Clarendonian North Tejon Hills local fauna, and the late Clarendonian faunas of the Caliente Formation, with magnetic Chron C4Ar (as suggested by Whistler) seems very unlikely. If this is so, what are the implications for Whistler and Burbank's (1992) biostratigraphy?The ranges of at least two taxa from the Ricardo Group, *Hipparion forcei* and *Osteoborus diabloensis*, have been extended earlier in the Tejon Hills. More importantly, since *Hipparion forcei* was used as the defining taxon of the late Clarendonian by Whistler and Burbank (1992), then the early/late Clarendonian boundary occurs about 500,000 years earlier in the Tejon Hills than it does in the Ricardo Group.

The reasons for this discrepancy are not immediately apparent. *Osteoborus diabloensis* is too rare to make much of its diachronous first appearances. Whistler (pers. commun., 1997) assures us that this interval in the Ricardo Group is very well sampled, and that *Hipparion forcei,* in particular, is an abundant taxon whose first occurrence is well documented. However, it seems clear that even within the Ricardo Group, the sampling is not as complete as might be hoped, and range extensions can be expected when the local biostratigraphy is compared with other areas. This is particularly apparent when examining Figures 6 and 7 in Whistler and Burbank (1992), where many of the taxa with restricted ranges in the Ricardo Group have much longer ranges elsewhere. The alternative to this slight downward range extension of *Hipparion forcei* is the upward range extension of a number of taxa as discussed above. Clearly, the former is more parsimonious than the latter. If we have learned anything about mammalian biostratigraphy in recent years, it is that individual taxa can be misleading, but whole assemblages are less likely to be wrong.

These considerations suggest that caution is appropriate when extending local biostratigraphic units, such as the "*Epicyon aphobus/Hipparion forcei* assemblage zone" to nearby areas, such as the Tejon Hills, let alone to more remote areas, such as Blackhawk Ranch in northern California (type area of the late Clarendonian "Montediablan Stage" of Savage, 1955), or to the classic Clarendonian faunas of Nebraska or Texas.

## CONCLUSIONS

The middle-upper Miocene "Santa Margarita" and Chanac formations in the north-central Transverse Ranges are correlated with Chrons C5n to C5An (10.8-12.2 Ma) in the Tejon Hills in the southeastern rim of the San Joaquin Valley, and with Chron C5r (11.0-11.8 Ma) in the Chorro Grande Creek section in upper Sespe Creek. The correlations in the Tejon Hills suggest that the late Clarendonian North Tejon Hills local fauna is older than late Clarendonian faunas from the Ricardo Group in the northwestern Mojave Desert. This result places the early/late Clarendonian boundary about 500,000 years earlier (based on the occurrence of *Hipparion forcei* and *Osteoborus diabloensis* in Chron C5r) in the Tejon Hills than in the Ricardo Group. The rocks of the Tejon Hills show no post-late Miocene tectonic rotation (consistent with other results in the same block reported by McWilliams and Li, 1985). The rocks of the "Santa Margarita" Formation at Chorro Grande Creek are rotated about 83° clockwise, consistent with paleomagnetic data from other rocks in the Transverse Ranges, and also with data from underlying Eocene rocks in the same tectonic block (Prothero and Vance, 1996).

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