MAGNETIC STRATIGRAPHY OF EOCENE-OLIGOCENE MAMMAL LOCALITIES IN SOUTHERN SAN DIEGO COUNTY

Donald R. Prothero
Department of Geology
Occidental College
Los Angeles, CA 90041

ABSTRACT

Magnetic sampling was conducted in two important late Paleogene localities in southern San Diego County. Late Uintan (late middle Eocene) mammals from the Mission Valley Formation are associated with a $^{40}Ar/^{39}Ar$ date of 42.18 Ma; they lie within rocks of normal polarity that probably correlate with magnetic Chron C20N. Early Arikareean (late Oligocene) mammals from the Otay Formation occur within a 56-m thick section of reversed polarity dated at 28.86 Ma by $^{40}Ar/^{39}Ar$ methods. Based on this date and the similarity with the Gering fauna of western Nebraska, the Otay fauna at Eastlake probably correlates with Chron C9R. Both localities show shallow paleolatitudes consistent with several hundred kilometers of northward transport since the late Paleogene, although the error bars are too large to conclusively establish this.

INTRODUCTION

Fossil mammals from southern San Diego County are crucial to correlation of the North American land mammal "ages" with the marine timescale. This region is one of the few places in North America where Eocene marine beds interfinger with terrestrial mammal-bearing beds. As such, it was the basis some of the critical marine/non-marine correlations of Berggren et al. (1985) and Flynn (1986), which established calibration points for the geological time scale. Now that the timescale has been revised (Berggren et al., 1992), it is appropriate to review the basis of these correlations.

Although there are abundant exposures of Eocene and Oligocene rocks in southern San Diego County, only a few areas produce fossil mammals. Flynn (1986) studied most of the key Bridgerian and Uintan (middle Eocene) sections in the coastal region. Although Flynn was able to correlate marine plankton stratigraphy with land mammals and polarity sequences, he did not have any numerical dates in his sections. In this study, a new $^{40}Ar/^{39}Ar$ date on the Mission Valley Formation helps calibrate the coastal Eocene sections.

In addition, the important early Arikareean (late Oligocene) localities in the Otay Formation near the Mexican border were previously dated only by land mammals (Deméré, 1988). A new $^{40}Ar/^{39}Ar$ date and magnetic stratigraphy provides a much more precise age estimate of these fossils.

MAGNETIC STRATIGRAPHY

Both the Mission Valley and Otay Formations were sampled with simple hand tools. Hand samples were carved to form a horizontal oriented surface, and the present north direction was marked. They were then trimmed down on a band saw, and measured on the automated 2G cryogenic magnetometer at the California Institute of Technology paleomagnetics laboratory.

Both alternating field (AF) and thermal demagnetization were used to isolate the characteristic component of magnetization. AF demagnetization (Fig. 1A) showed a rapid decay in intensity to fields of 175 Gauss, indicating that the remanence is carried by a low-coercivity mineral, such as titanomagnetite. Isothermal remanent magnetization (IRM) acquisition studies showed magnetic saturation at about 1 KOe, also indicating that magnetite is the primary carrier of the remanence. To avoid problems with high-coercivity chemical overprinting from iron hydroxides, all samples were treated by stepwise thermal demagnetization. Vector demagnetization plots showed that the component of magnetization isolated between 300°C and 400°C is most likely the characteristic component (Fig. 1B).

After demagnetization, all three cleaned sample directions were averaged at each site, and site statistics were calculated, using the methods of Fisher (1953) and Irving (1964).

Mission Valley Formation

Flynn (1986) sampled 62 sites spanning 335 m of the La Jolla and Poway Groups in the San Diego metropolitan area. Although the exposures were discontinuous and the facies relations complex, Flynn managed to patch together a composite polarity pattern. The Delmar Formation begins in a episode of reversed polarity labeled "A-" by Flynn (1986, Fig. 8). The upper Delmar Formation, all of the Ardath Shale, and the lower Friars Formation/Scripps Formation were correlated with an episode of normal polarity labeled "B+" by Flynn. The upper Friars/Scripps

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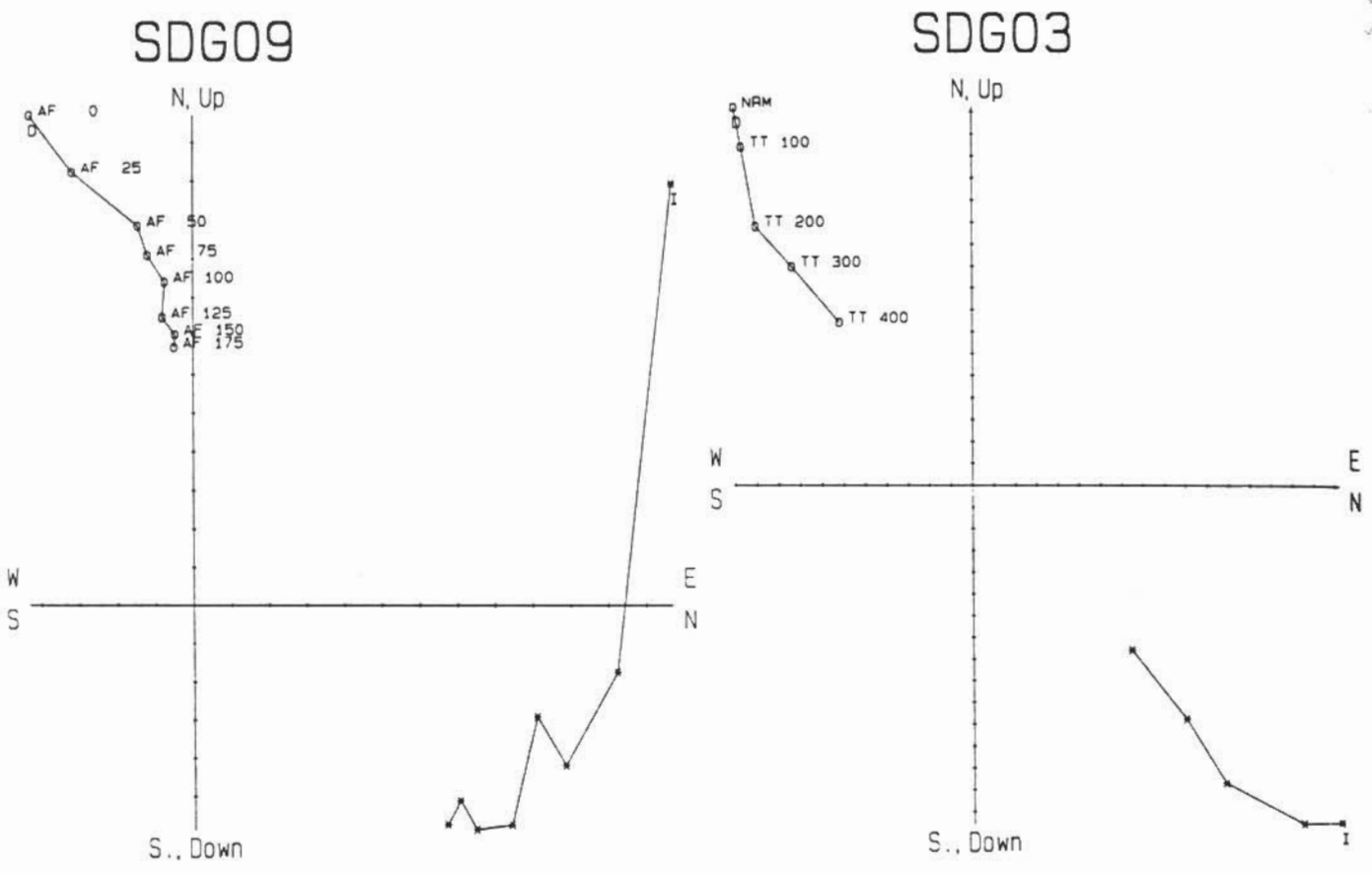

Figure 1. Vector demagnetization plots of representative samples. Open circles indicate horizontal component; stars indicate vertical component. **A**. SDGO 9. AF demagnetization from NRM (= AF0) to 175 Gauss. Note that reversed overprint in the vertical component is removed after cleaning at 25 Gauss. The rapid decline in intensity indicates that magnetite is the primary carrier of the remanence. **B**. SDGO 3. Thermal demagnetization to 400°C. Note the stable component isolated between 200-400°C.

Formations and parts of the Stadium Conglomerate were correlated with a reversed interval labeled "C-" by Flynn. A single isolated section of Mission Valley Formation produced normal polarity, and was labeled "D+" by Flynn.

At the time, there were no radioisotopic dates for calibrating this sequence. However, the Ardath Shale produced microfossils indicative of planktonic foraminifer Zones P10 and P11, and nannoplankton Zone NP14 (Kennedy, 1975). These microfossils correlate the Ardath Shale (and the B+ normal interval) with Chron C21N of the polarity time scale (Berggren et al., 1985). The Stadium Conglomerate contains equivocal microfossils which may indicate correlation with planktonic foraminifer Zones P13, and nannoplankton Zone NP16 (Kennedy and Mooré, 1971; Kennedy, 1975). On this basis, Flynn (1986, Fig. 9) correlated the C- reversed interval with Chron C20R. The Mission Valley Formation was considered to be late middle and/or early late Eocene in age based on sparse microfloras (Kennedy, 1975).

These same formations, or their lateral equivalents, also contained diagnostic fossil mammals. The Ardath Shale and Scripps Formation (within Chron C21N) produce a poorly preserved fauna that is latest Bridgerian or ?earliest Uintan (Flynn, 1986). Several levels in the Friars and Mission Valley Formations (within Chron C20R) produce earliest Uintan (Shoshonian) mammals.

Based on these correlations, Flynn (1986) placed the Bridgerian/Uintan boundary in the base of Chron C20R in the San Diego sections. Since these rocks interfinger with middle Eocene marine rocks, this establishes that the late Bridgerian and early Uintan are middle Eocene, correlative with planktonic foraminifer Zones P10 and P11, and nannoplankton Zone NP14-15.

Flynn (1986) then correlated the San Diego sections with Bridgerian-Uintan rocks in the East Fork and Washakie Basins of Wyoming. These sections had a number of K-Ar dates with which Flynn could calibrate the magnetics. Based on these dates, Flynn placed the Bridgerian/Uintan boundary at 49 Ma. Berggren, Kent and Flynn (1985) used these magnetics and dates as one of their key calibration points for their time scale.

Since 1985, it has become apparent that much of the late Paleogene time scale must be revised (Swisher and Prothero, 1990; Prothero and Swisher, 1992; Berggren et al., 1992). The Eocene/Oligocene boundary is now estimated at 34 Ma, not 36.5 Ma as cited in the 1985 Berggren time scale. This is chiefly because of previously undetected

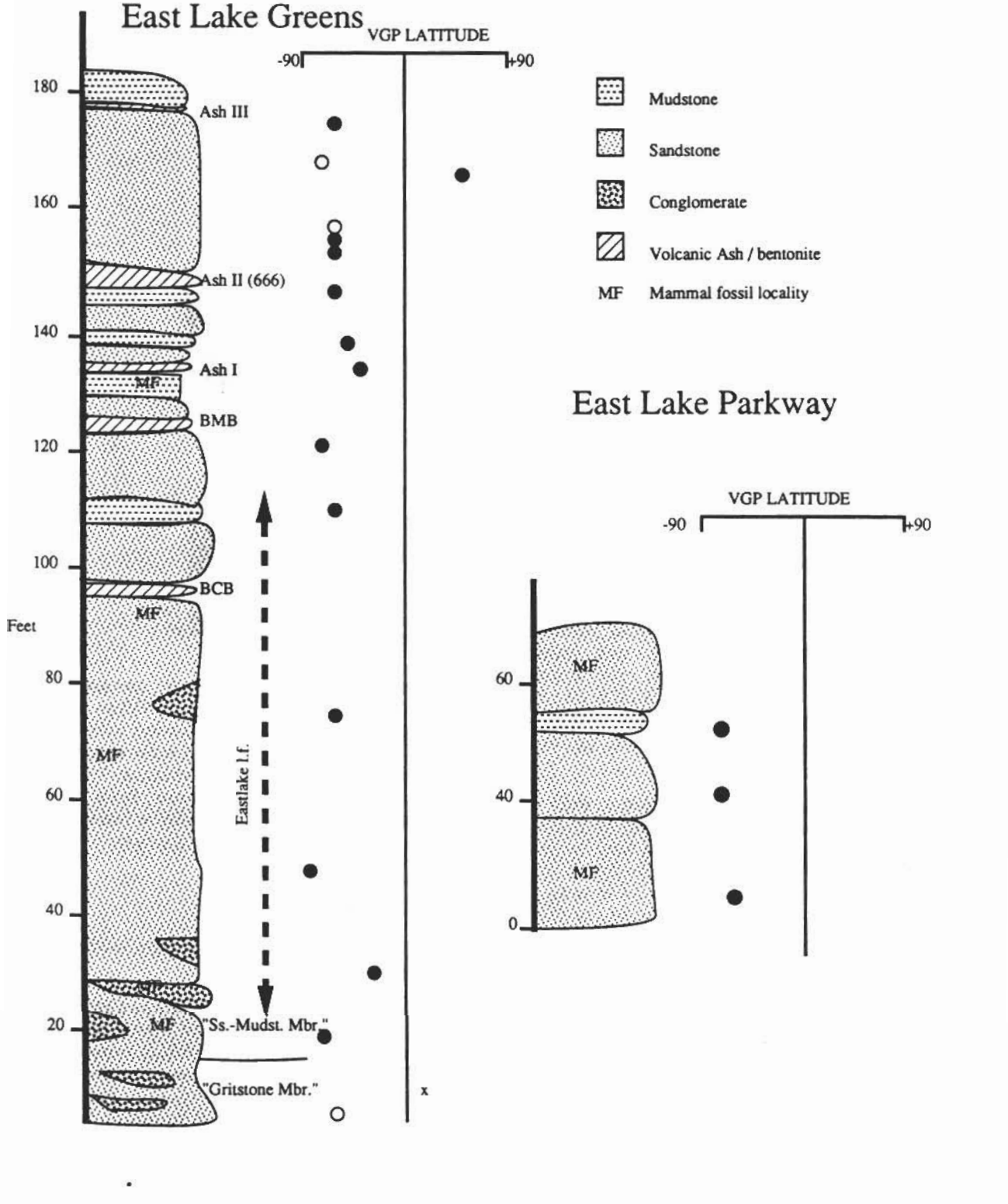

Figure 2. Lithostratigraphy and magnetic polarity stratigraphy of the Otay Formation. Location of sections given in text. Positive virtual geomagnetic pole (VGP) latitudes indicate normal polarity; negative VGP latitudes are of reversed polarity. Solid circles indicate Class I sites of Opdyke et al. (1977), which are significantly different from a random distribution at the 95% confidence level. Open circles are Class III sites, where two out of three samples gave a clear polarity, but the third sample was divergent. X indicates indeterminate site. Stratigraphic section at East Lake Greens measured by Brad Riney. Abbreviations: BCB = "Business Center bentonite"; BMB = "brown marker bentonite."

contamination in most of the K-Ar dates that have been used for the last 25 years. New $^{40}Ar/^{39}Ar$ dates have radically altered nearly all the Eocene and Oligocene calibration points, changing the time scale drastically (Berggren et al., 1992; Cande and Kent, in press). In particular, many of the K-Ar dates used by Flynn are considered questionable (Prothero and Swisher, 1992).

This has a dramatic effect on the dating of the San Diego sections. For example, Flynn correctly placed the Bridgerian/Uintan boundary early in Chron C20R. Based on the questionable K-Ar dates, however, Flynn estimated the age of this boundary at 49 Ma, since the Berggren et al. (1985) time scale placed Chron C21N at 49.5-50.2 Ma. Based on new dates and calibration points, Cande and Kent (in press) estimate the age of Chron C21N at 46.2-48.0 Ma, almost 3 million years younger than the 1985 time scale. Similarly, the Bridgerian/Uintan boundary occurs about 45 Ma, almost 4 million years younger than the Flynn's estimate (Prothero and Swisher, 1992). Clearly, there is a great need for sites with the potential for $^{40}Ar/^{39}Ar$ dating, paleomagnetics, and biostratigraphy.

The first such Eocene site in the San Diego section occurs in the Mission Valley Formation. Nine magnetic samples were collected in three sites around a fresh roadcut exposure of a bentonite at SDNHM locality 3428, on the south side of Interstate 8 (described in Berry, this volume, and Walsh and Deméré, this volume). This bentonite has recently been dated by $^{40}Ar/^{39}Ar$ methods at 42.18 Ma (J.D. Obradovich, in Berry, this volume). Vertebrate fossils from this locality, and from a similar locality to the northeast across Interstate 8 (SDNHM 3539) produce late Uintan fossils, such as *Simimys simplex* and *Sespedectes singularis*, indicating a late Uintan age for this bentonite (S. Walsh, pers. commun.).

All nine samples showed normal polarity, even after extensive thermal demagnetization (Fig. 1B). According to the new magnetic time scale of Cande and Kent (in press), normal polarity at 42.18 Ma is found at the top of Chron C20N. The presence of a late Uintan fauna is consistent with this correlation, since late Uintan faunas in the the Uinta Basin of Utah (Myton Member) and in Trans-Pecos Texas (Serendipity local fauna) also occur in Chron C20N (Prothero and Swisher, 1992; Walton, 1992).

Otay Formation

Another important late Paleogene locality in southern San Diego County is the Otay Formation, near the Mexican border. It produces an early Arikareean (late Oligocene) mammal fauna (Deméré, 1988; Walsh and Deméré, this volume). Until recently, there were no other means of dating this unit.

A total of 20 sites (3 samples per site) were collected from two stratigraphically overlapping sections in the "sandstone-mudstone member" of the Otay Formation as exposed at Eastlake. Seventeen of these sites were collected from the Eastlake Greens development site, located southeast of the intersection of Eastlake Parkway and Otay Lakes Road (Fig. 2). An additional three sites were collected from a north-facing roadcut along Eastlake Parkway (latitude = 32° 39' 18" N, longitude = 116° 57' 33"

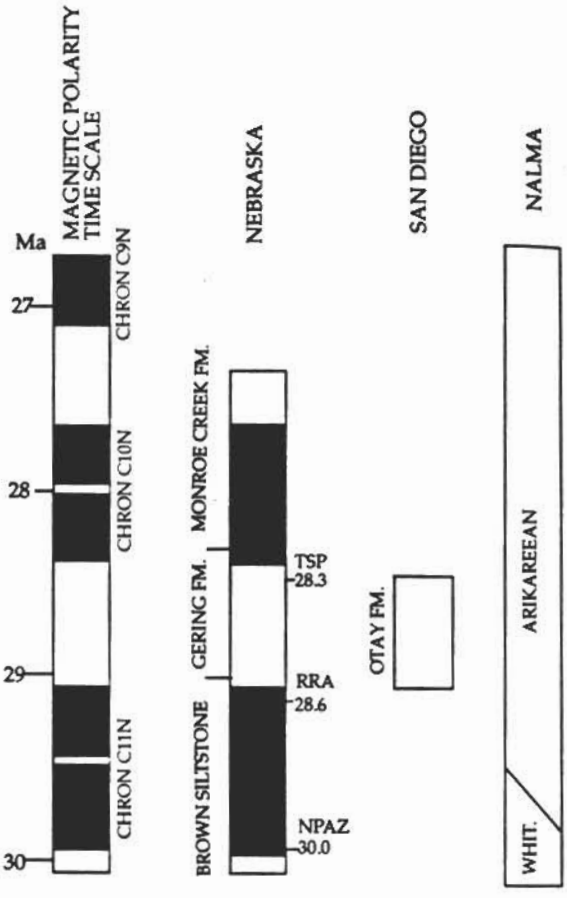

Figure 3. Magnetostratigraphic correlation of the Otay Formation with other late Oligocene sequences. Correlation of Gering Formation after Prothero et al. (1991). Magnetic polarity time scale after Cande and Kent (in press). Dated ashes in Nebraska: TSP = Twin Sisters Pumice; RRA = Roundhouse Rock Ash; NPAZ = Nonpareil Ash Zone. NALMA = North American land mammal "ages"; WHIT. = Whitneyan.

W). Both locations have since been landscaped and are no longer accessible.

Of 17 sites at the main Eastlake Greens section (Fig. 2), 12 were statistically separated from a random distribution at the 95% confidence level (Class I sites of Opdyke et al., 1977). 15 of the 17 sites showed reversed polarity. One Class I site showed normal polarity, but given its isolated position in the section, it is probably due to inadequate removal of normal overprinting. All three sites at the section north of Eastlake Highway were Class I reversed sites (Fig. 2). Thus, it appears that the entire sampled portion of the Otay Formation at Eastlake is of reversed polarity.

Although this is a limited polarity pattern for correlation, other data constrain our interpretation. The $^{40}Ar/^{39}Ar$ date of 28.86 Ma (J.D. Obradovich, in Berry, this volume) from the unit places it in the late Oligocene, probably within magnetic Chron C9R (Fig. 3). The mammalian fauna most closely resembles that found in

the Gering Formation of Nebraska (Deméré, 1988). Recent magnetic sampling of the Gering Formation in Nebraska (Prothero et al., 1991) shows that almost the entire Gering Formation was deposited during the time of Chron C9R. The fossiliferous early Arikareean part of the Otay Formation also correlates with Chron C9R, or between 28.4 and 29.1 Ma.

IMPLICATIONS FOR TRANSPORT

Recent paleomagnetic research has shown that much of the coastal portion of southern California has been transported northward along the San Andreas and related transform faults (Lund et al., this volume; Teissere and Beck, 1973; Morris et al., 1986). Samples taken on the Southern California Batholith in northern San Diego County (present latitude 33°N) indicate that the region was at least 3-11° further south in latitude during the Cretaceous (Teissere and Beck, 1973). This is almost the same displacement reported for Pliocene sediments in Baja California (Strangway et al., 1971). Samples from the Cretaceous Punta Banda Formation (present latitude = 30°N) were about 4° further south during the Cretaceous (Morris et al., 1986).

The mean declination of all 9 samples in the Mission Valley Formation was 339.8°; mean inclination was 26.0° (K = 8.4; α_{95} = 18.8°). This produces a middle Eocene paleolatitude of 13.7°, which is almost 20° further south than its present latitude (Fig. 4). Given the larger error bar of almost 19°, these data are consistent with northward transport, but not conclusive evidence of it.

Flynn (1986, Table V) reported a mean declination of 356.1° and mean inclination of 49.3° for all 32 middle Eocene San Diego area sites (K = 12.0, α_{95} = 7.1°). This produces a paleolatitude of about 30.3°, only about 2° further south than present. Given the large error estimate, this is indistinguishable from the hypothesis of no transport.

The mean declination of all 14 significant reversed sites in the late Oligocene Otay Formation was 165.0°; the mean inclination was -38.4° (K = 9.9, α_{95} = 13.3°). Inverting the reversed mean through the origin of the stereonet (Fig. 4) produces a paleolatitude of 21.6° for the late Oligocene Otay Formation (present latitude = 32.5°N), which is approximately 11° further south than its present position. However, these data are not conclusive, since the ellipse of confidence (α_{95} = 13.3°) is larger than the apparent displacement. Although the Otay data are more consistent with northward translation of southern San Diego County since the late Oligocene, they are not conclusive evidence of that hypothesis.

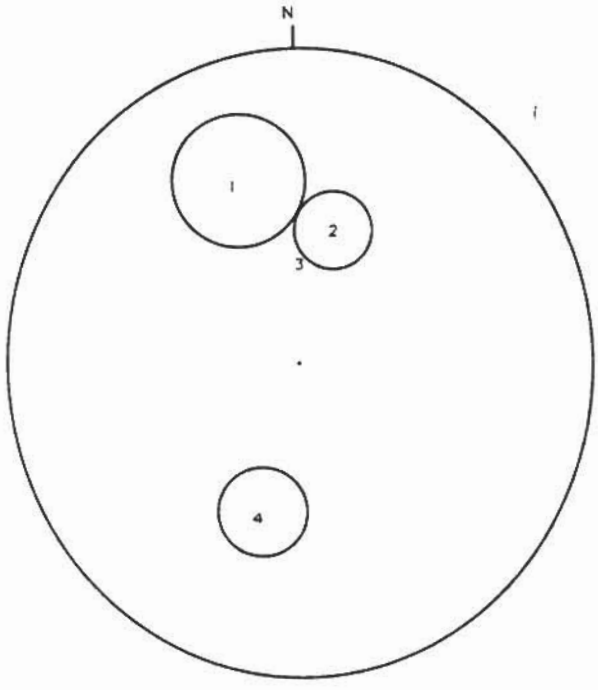

Figure 4. Stereoplot of means for each locality. Circle gives 95% confidence limits on mean (α_{95}). 1 = mean of 9 Mission Valley Formation samples; 2 = mean of all Class I reversed Otay Formation sites (inverted); 3 = present day inclination and declination of sites; 4 = mean of all Class I reversed Otay Formation sites (plotted in upper hemisphere).

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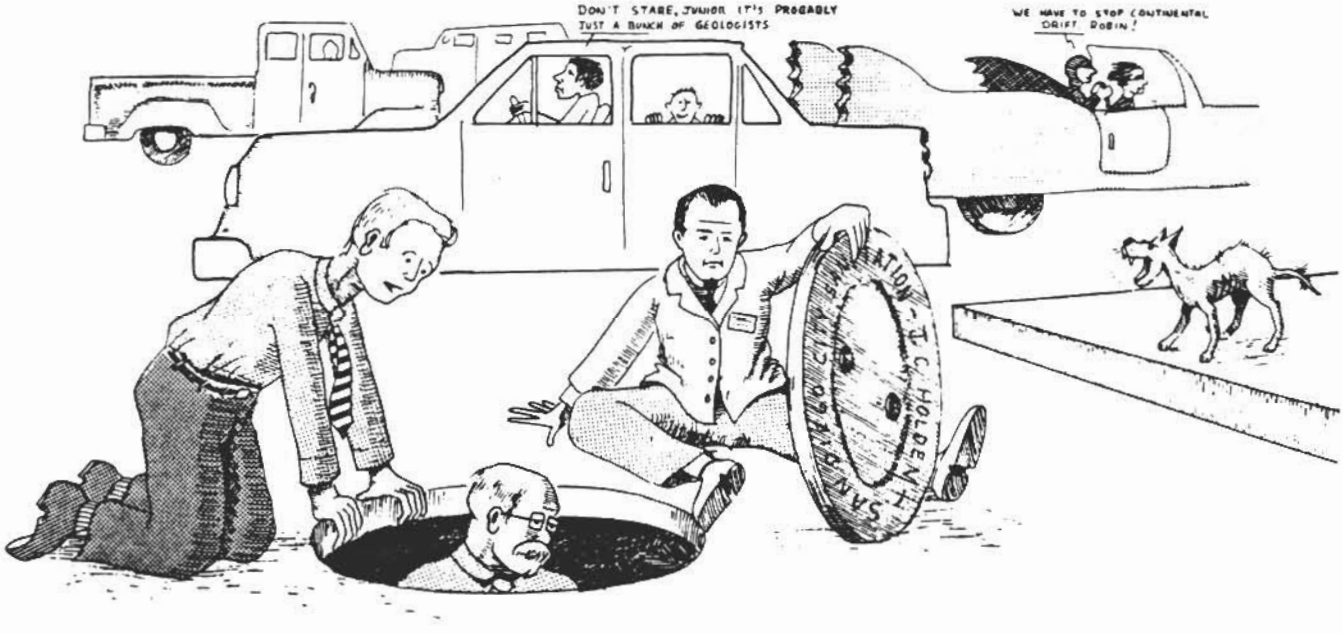

"THERE! RIGHT BETWEEN THE TWO CONDUITS - THAT'S THE TYPE SECTION FOR THE SAN DIEGO FORMATION. IT WAS MORE ACCESSIBLE TWO WEEKS AGO BEFORE THEY BUILT THE SUBDIVISION HERE."

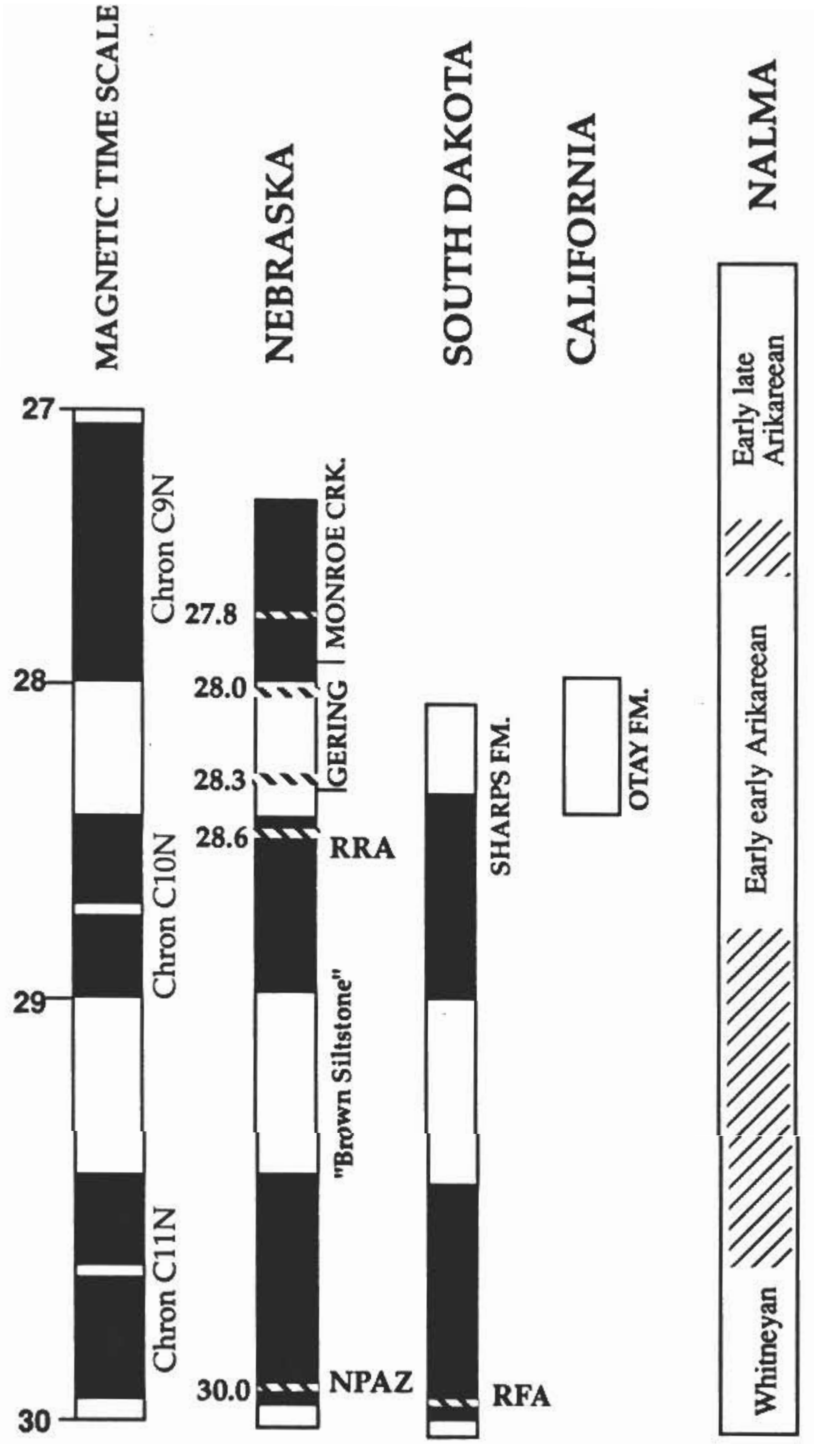

Figure 3 (emended). After this chapter went to press, the complete revised Cande and Kent time scale became available. This figure replaces Fig. 3, and throughout the text, the Otay section should be correlated with Chron C9R, not C10R