MAGNETIC STRATIGRAPHY AND LAND MAMMAL BIOCHRONOLOGY OF THE NONMARINE FACIES OF THE PLIOCENE SAN DIEGO FORMATION, SAN DIEGO COUNTY, CALIFORNIA

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ABSTRACT

The San Diego Formation consists of up to 84 meters of predominantly marine Plio-Pleistocene sedimentary rocks found in southwestern San Diego County. A nonmarine facies in the lower portion of the formation recently discovered in Chula Vista has yielded early Pliocene (Blancan III) mammals including the packrat *Neotoma* (*Paraneotoma*) nr. *fossilis*, the cat *Felis rexroadensis*, and the horse *Plesippus simplicidens*. This assemblage is here named the Poggi Canyon local fauna. Four paleomagnetic sites were collected from a single section through the land mammal-bearing deposits. These samples showed a stable remanence held in both magnetite and hematite, which passed a reversal test. The lowest site was of reversed polarity; the upper three sites were of normal polarity. Based upon the mammalian fauna, we correlate these beds with the upper reversed interval in the Gilbert Chron (C2Ar) and the lower normal interval of the Gauss Chron (C2An.3n), which indicates an age of 3.6 Ma for the Poggi Canyon local fauna. Sequence stratigraphic analysis of the San Diego Formation in Chula Vista recognizes four transgressive marine sequences that are correlated with global eustatic sea level changes during the early and late Pliocene.

INTRODUCTION

The San Diego Formation in southwestern San Diego County (Fig. 1) is a marine sedimentary rock unit that was deposited in a series of marine transgressions during Pliocene to early Pleistocene time (Arnold, 1903, Hertlein and Grant, 1944; Deméré, 1983). This rock unit reaches a maximum thickness of 84 meters and typically consists of yellowish gray, fine-grained, friable sandstones with minor amounts of poorly-sorted conglomerates and finely-laminated claystones. In the vicinity of Chula Vista (Fig. 1) the San Diego Formation overlies the upper Oligocene Otay Formation (Walsh and Deméré, 1991) and underlies unnamed Pleistocene fanglomerates and terrace deposits. To the north the San Diego Formation overlies various Eocene formations (Kennedy and Moore, 1971) and is overlain by the Pleistocene Lindavista Formation or unnamed marine terrace deposits.

The San Diego Formation accumulated in an open marine embayment that was structurally controlled by extensional tectonics (Deméré, 1983). The modern outcrop distribution of this rock unit is also controlled by extensional features related to the La Nacion Fault Zone (Artim and Pinkney, 1973). In the northern portion of the embayment the San Diego Formation has been subdivided into two informal members that have distinct lithofacies and marine invertebrate assemblages (Deméré, 1983). These members document a general transgressive sequence with offshore shelf sandstones at the base grading through nearshore and foreshore sandstones and conglomerates into estuarine and fluvial mudstones, sandstones, and conglomerates at the top.

The San Diego Formation is well known for its rich fossil beds that have yielded diverse assemblages of marine clams, oysters, scallops (Hertlein and Grant, 1972), snails, crabs, barnacles (Zullo, 1969), sand dollars (Hertlein and Grant, 1960), sharks (Deméré and Cerutti, 1981), rays, bony fish, sea birds (Chandler, 1990), walrus (Deméré, 1994), fur seal (Berta and Deméré, 1986), sea cow (Domning and Deméré, 1984), dolphin (Barnes, 1973), and baleen whales (Deméré, 1986). Sparse fossils of terrestrial organisms including vascular plants (Axelrod and Deméré, 1984) and mammals (Deméré, 1994) have also been recovered from the marine sandstones of the San Diego Formation. The limited land mammal assemblage consists of ground

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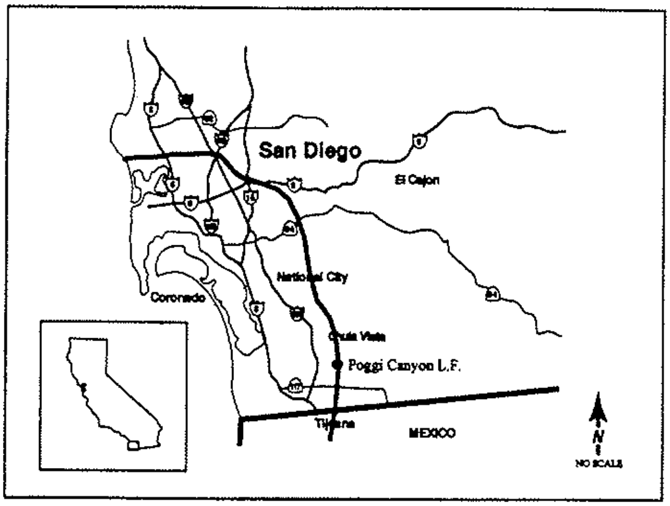


Figure 1. Location map of the Poggi Canyon local fauna from Otay Ranch, Chula Vista, San Diego County, California. Heavy dark line indicates the paleo-shoreline of the San Diego Formation in Pliocene time.

sloth, rodents, rabbit, carnivorans, perissodactlys, artiodactyls, and proboscidean.

Prior to the present report, the age of the San Diego Formation was only imprecisely known and based largely on provincial molluscan and foraminferal biochronology. As reported by Deméré (1983) mollusks from the lower member of the formation are correlative with the "San Joaquin" provincial late Pliocene molluscan stage of Addicott (1972), while mollusks from the upper member are correlative with early Pleistocene assemblages from the Santa Barbara Formation. A meager planktonic foraminiferal assemblage from the lower member suggests correlation with the *Pulleniatina obliquiloculata* Zone, late Pliocene (Mandel, 1973). Together these correlations suggest an age range of late Pliocene (3 Ma) to early Pleistocene (1.5 Ma).

The land mammals previously recovered from the lower marine portion of the San Diego Formation are broadly correlative with the Blancan NALMA, but do not allow for recognition of the microtine subdivisions of Repenning (1987). The recent discovery, however, of nonmarine strata at Otay Ranch in Chula Vista (Figs. 2, 3) with biochronologically significant land mammals including rodents now provides the means for refining the age of the San Diego Formation. In this report we describe this newly recognized nonmarine facies and discuss its magnetostratigraphy, land mammal biochronology, and eustatic sea level history.

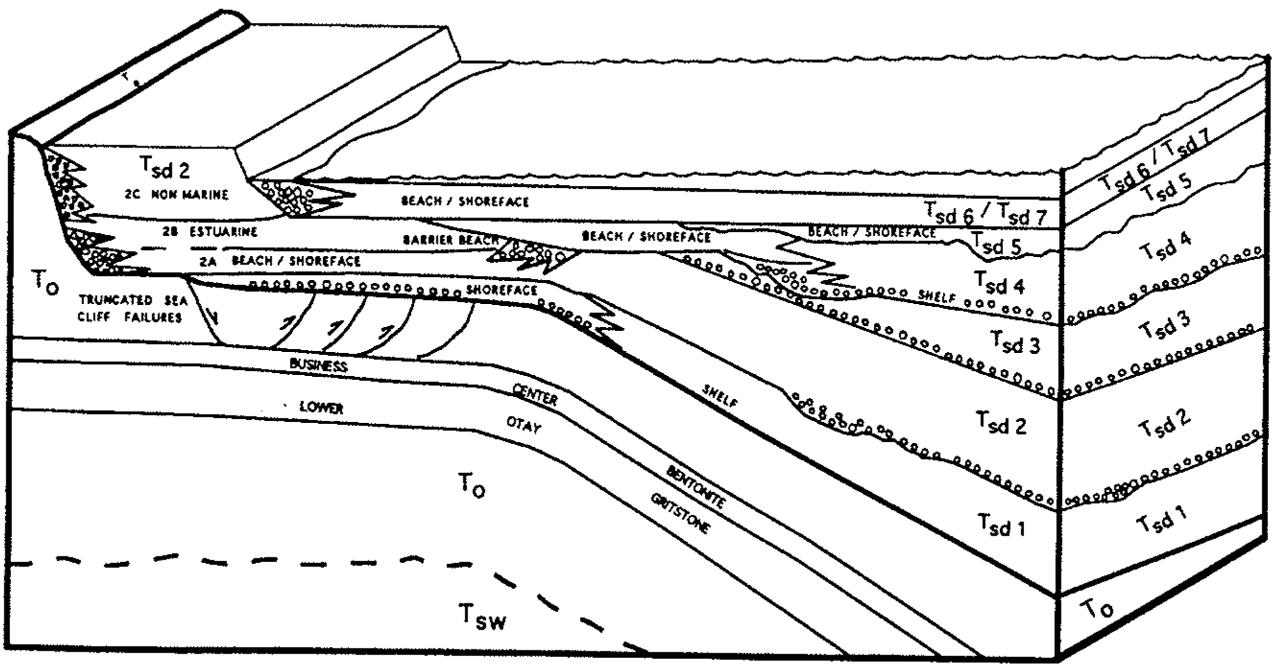


Figure 2. Generalized geologic cross-section of the San Diego Formation in the vicinity of Chula Vista illustrating lithostratigraphic and facies. Tsw = Sweetwater Formation (Eocene); To = Otay Formation (Oligocene); Tsd = San Diego Formation (Pliocene)

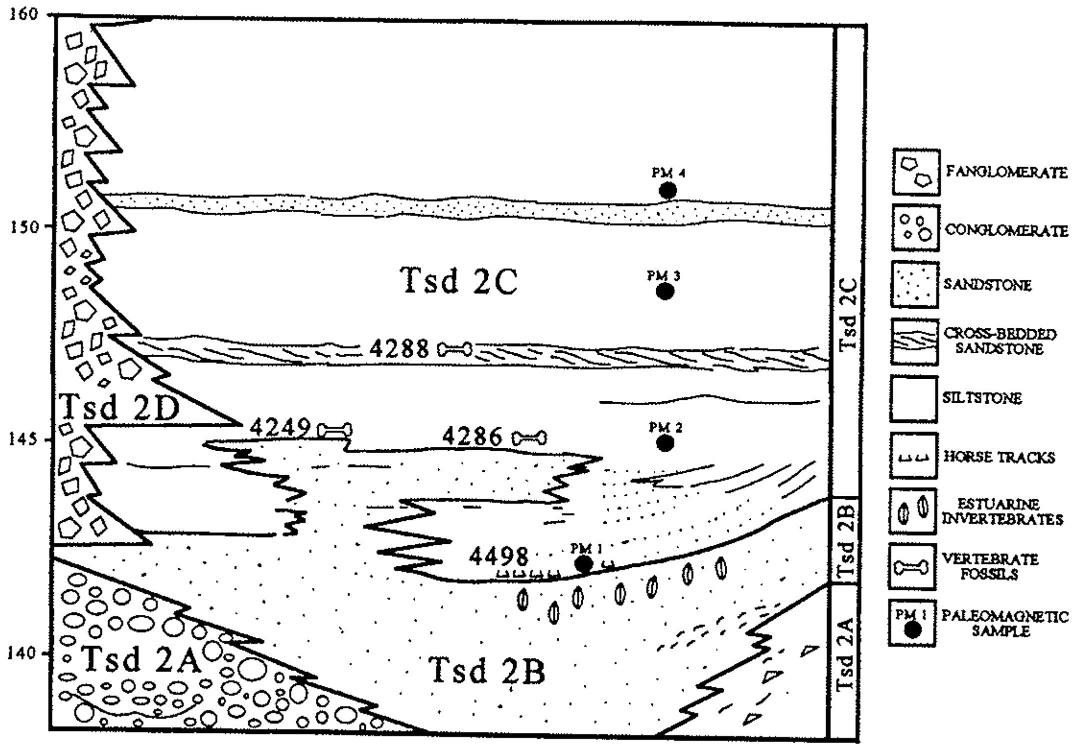


Figure 3. Composite stratigraphic section of the nonmarine facies (subunit 2) of the San Diego Formation showing location of the fossil vertebrate localities (e.g., 4286) and paleomagnetic samples (e.g., PM 2). Elevation in meters above sea-level.

METHODS

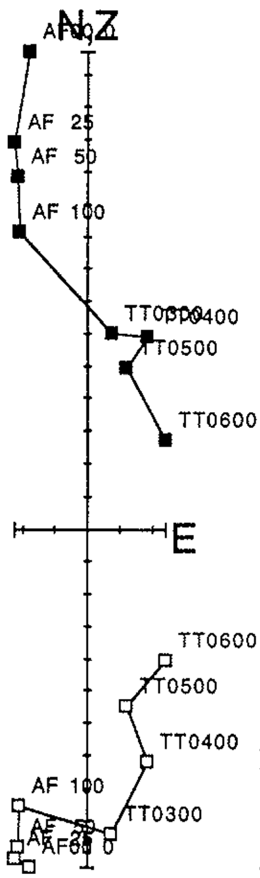
Magnetostratigraphy

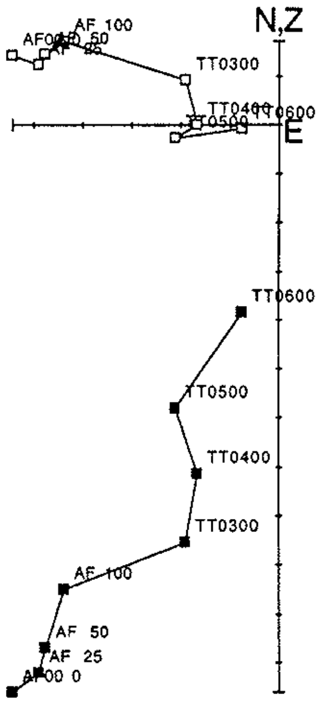
In the winter of 1999 four paleomagnetic sites (3 samples per site) were sampled in the San Diego Formation at Otay Ranch (Fig. 3). Oriented block samples were collected and then hardened with dilute sodium silicate solution in the field to prevent crumbling. In the laboratory, samples were subsampled into a core with an air-cooled drill press, or cast into a cylinder using a Zircar aluminum ceramic. Each sample was then measured in a 2G Enterprises cryogenic magnetometer with an automatic sample changer at the California Institute of Technology paleomagnetics laboratory. After measurement of NRM (natural remnant magnetization), each sample was demagnetized in alternating fields (AF) of 25, 50, and 100 Gauss. This removes any remanence held in multidomain grains, and also allows determination of the coercivity behavior of each sample. After AF demagnetization, each sample was then thermally demagnetized in a shielded furnace in multiple temperature steps ranging from 300-600°C. This removes any chemical remnant overprinting due to iron hydroxides such as goethite and also allows the blocking of temperatures of the magnetic minerals to be determined.

About 0.1 g of powdered rock from several samples was subjected to a series of rock magnetic analyses, including IRM (isothermal remanent magnetization) acquisition, and a modified Lowrie-Fuller test.

Biostratigraphy

Fossil land mammals were discovered and collected at several stratigraphic levels within a nonmarine facies of the San Diego Formation as exposed at Otay Ranch (Fig. 3). One site, San Diego Natural History Museum (SDNHM) locality 4498 produced well-preserved equid tracks and was sampled by exposing a 16 square meter surface of the trackway mudstone. Documentation of tracks was done by photography, field measurements, and grid plotting. SDNHM locality 4249 was a single specimen site and was sampled by hand quarrying. SDNHM locality 4286 was a bone-rich mudstone horizon that was sampled by collecting approximately 2000 pounds of bulk matrix and water washing it through 30 mesh (0.59 mm) stainless steel screens. SDNHM locality 4288 was a coarse-grained sandstone channel-fill horizon that was sampled by initially dry screening approximately 3000 pounds of bulk matrix through 24 mesh (0.7 mm) stainless steel screens and then water washing the resulting





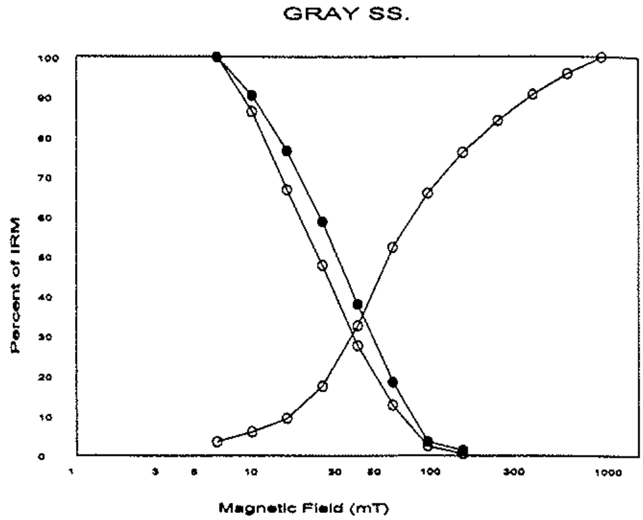


Figure 5. (above) IRM acquisition (ascending curve on right) and Lowrie-Fuller test (two descending curves on left) of a representative powdered sample from the San Diego Formation. Open squares = IRM; solid squares = ARM (anhysteretic remanent magnetization).

Figure 4. (left two figures). Orthogonal demagnetization ("Zijderveld") plots of representative samples. Solid squares indicate horizontal component; open squares indicate vertical component. AF = alternating field step (in Gauss); TT = thermal step (°C). Each division = 10^{-6} emu

concentrate through the same mesh size. Small mammal remains from the Otay Ranch sites were compared with specimens in the vertebrate collections of the San Bernardino County Museum, the Anza Borrego Desert State Park, and the Department of Geological Sciences, University of California, Riverside. The samples of *Neotoma* (*Paraneotoma*) and *Neotoma* ("*Parahodomys*") from Blancan I through Blancan IV faunas were examined extensively at these institutions to determine the grade of dental evolution through this interval.

RESULTS

Magnetostratigraphy

Orthogonal demagnetization plots (Zijderveld plots) of representative samples are shown in Figure 4. In all samples there is a slight decrease in intensity during AF demagnetization, suggesting that some of the remanence is carried by a low-coercivity mineral such as magnetite. However, all of the samples still had significant remanence at temperatures above the Curie point of magnetite (580°C), showing that hematite carries much of the remanence. Reversed directions (Fig. 4B) showed a slight overprint that was removed by 300°C, but these samples still pointed south and up from NRM until the final demagnetization step. Normal samples (Fig. 4A) also showed a slight overprint, but were pointed north and down through the entire demagnetization process.

The stable vectorial components for each sample were determined using the least squares method of Kirschvink (1980) and averaged using Fisher (1953) statistics. Results are shown in Table 1. The lowest site (site 1) was reversed in polarity, while the upper three sites (sites 2-4) were of normal polarity.

TABLE 1—Summary of site statistics

SITE	N	D	I	k	α_{95}
1	3	187.1	-76.7	22.3	26.7
2	3	14.8	22.4	28.3	23.6
3	3	358.3	58.4	21.9	27.0
4	3	326.8	53.0	2.9	91.2

Averaging the vectors of the 9 normal samples gives a formational normal mean of D = 356.8, I = 46.6, k = 9.9, and α_{95} = 41.5. The normal mean direction is antipodal to the reversed mean within error estimates (i.e., a positive reversal test). This result shows that the overprinting has been removed and a primary or characteristic direction has been obtained.

IRM acquistion analysis (Fig. 5) showed no sign of saturation at 300 mT (millitesla), suggesting that hematite is present. The ARM was more resistant to AF demagnetization than the IRM, showing that the remanence is carried in single-domain or pseudo-single-domain grains.

Biostratigraphy

SDNHM locality 4498 produced well-preserved tracks of Pliocene horse in mudstones directly overlying shell-bearing estuarine sandstones. SDNHM locality 4249 produced a single horse palate (*Plesippus simplicidens*). SDNHM locality 4286 produced a diverse mammal assemblage consisting of *Notiosorex* sp., *Hypolagus limentus, Perognathus* sp., *Thomomys gidleyi, Reithrodontomys* sp., *Calomys meadensis, Neotoma* (*Paraneotoma*) nr. *fossilis, Felis rexroadensis, Plesippus simplicidens*, Camelidae, and Gomphotheriidae. SDNHM locality 4288 produced a similar mammal assemblage consisting of *Notiosorex* sp., *Hypolagus limentus, Eutamias* sp., *Perognathus* sp., *Reithrodontomys* sp., *Calomys meadensis, Neotoma* (*Paraneotoma*) nr. *fossilis*, and *Plesippus simplicidens*. The composite terrestrial vertebrate assemblage from these localities is summarized in Table 2 and is here named the Poggi Canyon local fauna after the canyon of that name on Otay Ranch.

DISCUSSION

Prior to this study there were no reports of nonmarine facies in the San Diego Formation. However, with the discovery of fluvial sandstones and paleosols at Otay Ranch and the recovery of terrestrial vertebrate assemblages from these rocks we can now directly integrate land mammal biochronology into the previous correlation web based on marine molluscan and foraminiferal biochronologies. In addition, the magnetostratigraphic analysis of these nonmarine rocks provides for a more accurate age assessment for the lower portion of the San Diego Formation.

The exposure of large surface areas of the San Diego Formation as a result of land development in

TABLE 2. Composite faunal list of the Poggi Canyon local fauna, San Diego Formation, subunit 2.

Amphibia
- Anura indet.
- Urodela indet.

Reptilia
- Chelonia
  - Testunididae

Clemmys sp.
- Lacertilla
  - Iguanidae indet.
- Serpentes
  - Boidae indet.
  - Colubridae indet.
  - Viperidae
    - *Crotalus* sp.

Aves
- Passeriformes indet.

Mammalia
- Soricidae
  - *Notiosorex* sp.
- Leporidae
  - *Hypolagus limnetus* Gazin 1933
- Sciuridae
  - *Eutamias* sp.
- Heteromyidae
  - *Perognathus* sp.
- Geomyidae
  - *Thomomys gidleyi* Wilson, 1933
- Cricetidae
  - *Reithrodontomys* sp.
  - *Peromyscus* sp.
  - *Calomys meadensis* (Hibbard, 1956)
  - *Neotoma* (*Paraneotoma*) nr. *fossilis* (Gidley, 1922)
- Felidae
  - *Felis rexroadensis* Stephens, 1959
- Equidae
  - *Plesippus simplicidens* (Cope, 1892)
- Camelidae indet.
- Antilocapridae indet.

Chula Vista over the past 15 years has resulted in formulation of a refined lithostratigraphic framework and has revealed a complex depositional history for this rock unit. Initial deposition occurred as a marine transgression to the east onto the underlying Eocene and Oligocene rocks. Subsequent extension of the basin resulted in increased deposition to the west in a down-warped basin. This was accompanied by complex eustatic sea level changes with fluctuations in the position of paleo-shorelines. Younger portions of the formation were incised into the older deposits. Seven informal members or subunits are recognized in Chula Vista (Fig. 2) and document a series of perhaps four transgressive marine depositional sequences. Disconformities and/or angular unconformities form the boundaries between each sequence as shown in Figure 2 and provide a means for recognizing distinct sequence stratigraphic units. Subunit 1 consists of yellow, massive, fine-grained, compact to concretionary shelf sandstones to the west and yellow, fine-grained, planar-laminated, friable beach and shoreface sandstones to the east. This subunit constitutes the oldest transgressive sequence and rests unconformably on fluvial sandstones of the upper Oligocene Otay Formation. Subunit 2 typically consists of light gray, fine-grained, micaceous, massive, very friable shoreface sandstone that becomes well-laminated to the east. The disconformity between subunits 1 and 2 is marked by large scale (up to 5 meters deep) basal channeling in western exposures. These channels are filled with poorly sorted pebble and cobble conglomerates that rapidly grade upwards into pebbly sandstones and finally a friable, very-fine-grained ssandstone. Stratigraphic complexities in this subunit occur to the east against the buttress unconformity with the Otay Formation and are discussed below. Subunit 3 consists of light greenish gray, fine-grained, compact, massive shelf sandstones with a thin basal cobble conglomerate. The disconformity between subunits 2 and 3 is a low relief irregular erosion surface. Subunit 4 consists of light yellowish gray, fine-grained compact shelf sandstones with a meter thick basal cobble conglomerate to the west. The contact between subunits 3 and 4 is an angular unconformity with up to 5° of discordance. Subunit 5 consists of black and white, fine-grained, laminated, extremely friable shoreface sandstones to the west grading into gray, very coarse-grained cemented, shelly beach sandstones to the east. The disconformity between subunits 4 and 5 is a high-relief (up to 5-6 meters deep) channeled erosion surface filled with coarse-grained sandstones and cobble conglomerates. Subunit 6 consists of light gray, fine-grained, locally concretionary to friable, massive to laminated shoreface sandstones that gradually grade upwards into the light yellowish, fine-grained, laminated, compact, micaceous, beach sandstones of subunit 7. The upper portion of this subunit consists of reddish-yellow, coarse-grained, cross-bedded, cobbly fluvial sandstones. To the east subunits 6 and 7 terminate in a ìshingle beachî cobble conglomerate against the buttress unconformity cut into subunit 2. The disconformity at the base of subunit 6 cuts across subunits 2 and 4 to the east, while the contact between subunits 5 and 6 appears to represent a planar, possibly conformable surface. This refined lithostratigraphic framework allows recognition of four major depositional sequences in the San Diego Formation. These include sequence 1 consisting of subunit 1, sequence 2 consisting of subunits 2 and 3, sequence 3 consisting of subunit 4, and sequence 4 consisting of subunits 5, 6, and 7.

At Otay Ranch the shoreline angle corresponding to the oldest transgression is associated with subunit 2 and was exposed at an elevation of 138 meters. This shoreline angle and its associated buttress unconformity (paleo-seacliff) were overlain by a 20+ meter-thick sequence of subunit 2 that consisted of four distinct lithofacies (Fig. 3). Facies 2A is a cobble conglomerate that thickens to the east against the buttress unconformity with the Otay Formation. Facies 2A conglomerates at the shoreline angle grade into beach and shoreface sandstones to the west, while upsection this facies interfingers with estuarine sandstones of facies 2B. Directly overlying facies 2B are the non-marine sandstones and paleosols of facies 2C that yielded the Poggi Canyon local fauna. This facies interfingers to the east with angular fanglomerates of facies 2D.

Although Deméré (1994) previously provided a listing of land mammals from the San Diego Formation, these records were all based on transported specimens collected from marine facies. In contrast, fossils representative of the Poggi Canyon local fauna (Table 2) were all collected from the nonmarine facies 2C and can be considered to represent a fairly discrete temporal assemblage. The rodent, *Calomys meadensis*, the cat *Felis rexroadensis*, and the horse *Plesippus simplicidens* in the Poggi Canyon local fauna indicate a general correlation with the Blancan NALMA (s.l.). Cricetid rodents provide refinement of this correlation. The stage of dental evolution of specimens of the packrat *Neotoma* (*Paraneotoma*) in the Poggi Canyon local fauna is intermediate between that of N. sawrockensis from the Temecula Arkose (Blancan I; Repenning, 1987; Reynolds and Reynolds, 1993; Pajak et al., 1996) and *N. fossilis* from the "unnamed sandstone" of the Elsinore Trough (Pajak et al., 1996), the San Timoteo Formation (Albright, 1999), and the Palm Spring Formation (Blancan III; this study). This stage of dental evolution in *Neotoma* (*Paraneotoma*) from early Blancan III assemblages of southern California suggests a correlation with the classic Blancan III Hagerman fauna from the Glenns Ferry Formation of Idaho (Repenning, 1987; Bell, 1998). Repenning (1995) indicates that the Blancan III fauna of the Glenns Ferry Formation occurs in the Hagerman section at a level dated by potassium-argon at 3.48 ± 0.27 Ma (Evernden, et al., 1964).

The results of the limited magnetostratigraphic study of facies 2C reveal that of the four paleomagnetic sites sampled, the lowest site was reversed while the upper three sites were of normal polarity. Calibrating this paleomagnetic signature using the mammalian biochronology and radiometric dating summarized above suggests correlation of the reversed interval in facies 2C with Gilbert Chron C2Ar and correlation of the normal interval with Gauss Chron C2An.3n (Fig. 6). As summarized by Woodburne and Swisher (1999) the Gilbert/Gauss paleomagnetic boundary has been calibrated at 3.6 Ma.

Overall, the correlation web presented here provides the most precise dating yet available for the lower part of the San Diego Formation and indicates that deposition of facies 2C occurred during the mid-Pliocene about 3.6.Ma. This date is significant as it suggests synchroneity between the initial marine transgression in the San Diego Formation and other Pliocene marine transgressions recorded in North America. As reported by Dowsett and Cronin (1990) the Duplin Formation of South Carolina and probably also the Yorktown Formation of North Carolina were deposited during a major marine transgression of the U.S. Atlantic Coastal Plain that they suggest occurred during the mid-Pliocene (3.5–3.0 Ma). Based on measurements of paleoshoreline elevations and estimates of regional uplift rates, Dowsett and Cronin (1990) further proposed that the Duplin marine transgression represented a eustatic sea level about 35 ± 18 meters higher than

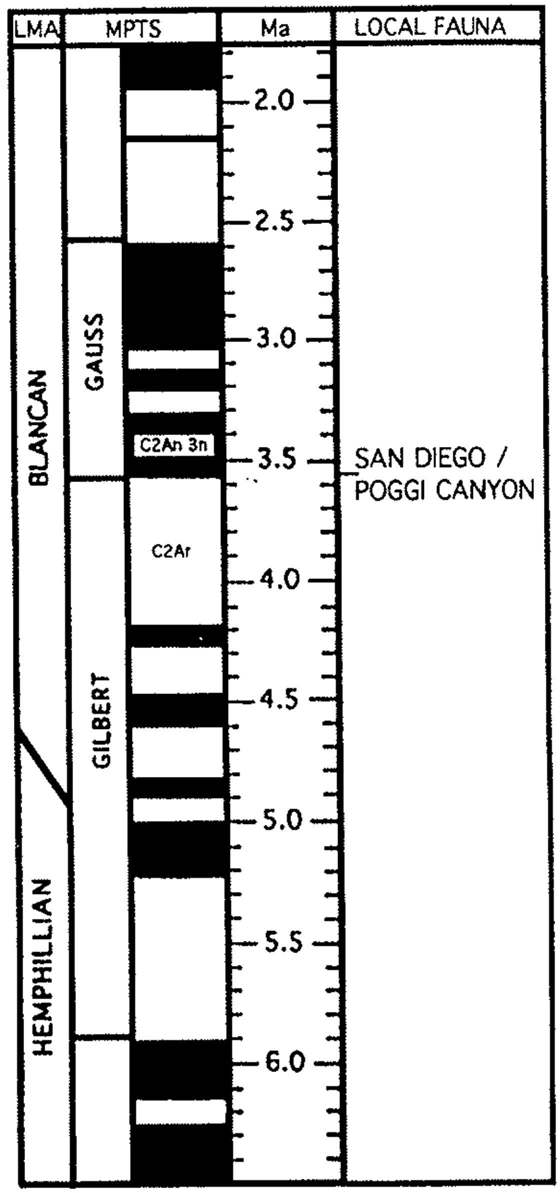


Figure 6. Interpretation of the magnetostratigraphy of the nonmarine Poggi Canyon local fauna of the San Diego Formation on Otay Ranch.

modern sea level. A major Pliocene marine transgression is also shown in the eustatic sea level curve of Haq et al. (1988), which records an interval of coastal onlap (transgression) during the early Pliocene (cycle TB3.5) between approximately 4.5 and 4.2 Ma followed by a period of coastal offlap (regression) between approximately 3.8 and 3.4 Ma and then another period of onlap between approximately 3.4 and 3.0 Ma. The Haq et al., (1988) curve also indicates that sea levels during the periods of coastal onlap were well above (approximately 60 meters) modern sea level. These eustatic data provide a means for correlating the stratigraphic sequences in the San Diego Formation with global sea level events. It is here suggested that deposition of sequence 1 (subunit 1) of the San Diego Formation began during the early Pliocene period of major coastal onlap recorded in the Duplin and Yorktown formations of the Atlantic coast and correlative with cycle TB3.5 of Haq et al. (1988). The maximum extent of this transgression would correlate with the 138 meter shoreline angle observed at Otay Ranch. It is proposed that deposition of sequence 2 (subunits 2 and 3) occurred during the period of coastal onlap represented by cycle TB3.6 between 4.2 and 3.1 Ma. Deposition of sequence 3 (subunit 4) began during the late Pliocene period of renewed coastal onlap represented by cycle TB3.7 between approximately 3.1 and 2.6 Ma. Deposition of sequence 4 (subunits 5, 6, and 7) may have begun during the late Pliocene period of coastal onlap represented by cycle TB3.8 between approximately 2.6 and 1.7 Ma.

CONCLUSIONS

The San Diego Formation as exposed in Chula Vista can be subdivided into a series of seven informal members or subunits that can be grouped into four distinct transgressive marine sequences. Although these subunits are mostly marine in origin, our studies have shown that a distinct nonmarine facies occurs in the second transgressive sequence as exposed at Otay Ranch in Chula Vista. These strata yielded a limited terrestrial vertebrate fauna here named the Poggi Canyon local fauna. Land mammals in this fauna, especially cricetid rodents indicate a correlation with the early Blancan III NALMA, dated at approximately 3.5 Ma. Paleomagnetic analysis of four sites within the newly recognized nonmarine facies documented a lower reversed polarity interval and an upper normal polarity interval. Calibration of this paleomagnetic record using land mammal biochronology suggests that the section spans the Gilbert Chron/ Gauss Chron boundary, dated at 3.6 Ma. This date provides a datum for evaluating the sequence stratigraphy of the San Diego Formation in terms of the global eustatic sea level record. Results indicate that the initial San Diego marine transgression began in the early Pliocene synchronous with a global sea level maximum also responsible for deposition of the Duplin and Yorktown formations on the Atlantic coast. Deposition of the nonmarine facies in the San Diego Formation occurred during a subsequent transgression in the mid-Pliocene and was followed in the late Pliocene by two additional periods of marine transgression responsible for deposition of the upper subunits of the formation.

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