MAGNETIC STRATIGRAPHY AND TECTONIC ROTATION OF THE UPPER PALEOCENE SAN FRANCISQUITO FORMATION, LOS ANGELES COUNTY, CALIFORNIA

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ABSTRACT

The San Francisquito Formation consists of about 4000 m of deep-marine to shallow-marine sandstones and shales, which crop out in several places in the central Transverse Ranges. The formation ranges in age from latest Cretaceous at its base to late Paleocene, although no single section spans the entire interval of time, and most sections are chopped up by faults. We sampled the most complete available section (2000 m of members D, E, and F of Kooser, 1982) along Elizabeth Lake Canyon Road. After removal of overprints, a stable remanence held mostly in magnetite was obtained. The entire sampled section was reversed in polarity. These rocks yield a mean direction of D = 204.9°, I = -51.1°, α_{95} = 9.8, which suggests about 35° of clockwise rotation, consistent with other results in this part of the Transverse Ranges. The inclination is not significantly different from present inclination, suggesting minimal northward translation of these rocks (although error estimates of about 9° make some translation possible). The early late Paleocene (early Selandian) molluscan fauna from Members C and D (including *Turritella peninsularis, T. reversa,* and *Brachysphingus sinuatus*) suggests that the reversed rocks of members D-F correlate with the early part of Chron C26r (early Selandian, or early late Paleocene, 58.0-60.9 Ma), or possibly with with late Danian Chron C27r (61.3-62.5 Ma).

INTRODUCTION

Fossils from beds now called the San Francisquito Formation were first described by Dickerson (1914) in his review of the "Martinez Stage" molluscan fauna. Dibblee (1967) formally named, described and mapped these strata as the San Francisquito Formation, but their age was uncertain. Dibblee (1967) suggested that it might be Paleocene and possibly ?Eocene in age. Sage (1973, 1975) provided a more detailed description of the San Francisquito Formation, and reported Paleocene molluscs such as *Turritella pachecoensis* and *T. infragranulata* at the base of exposures near Big Rock Creek, in the area of Devil's Punchbowl. Saul (1983), in her more detailed study of turritellids, reidentified these specimens as *T. peninsularis*. Kooser (1980, 1982) provided the most detailed analysis of the San Francisquito Formation to date, and her stratigraphic interpretations are followed in this paper.

The San Francisquito Formation consists of up to 100 m of shallow-water deposits overlain by and interfingering with about 4000 m of deep-sea sediments (mostly deep-sea fan sandstones and shales). The formation crops out over about 95 square km in the central Transverse Ranges of Los Angeles County (Fig. 1). Most of the outcrops occur in the Warm Springs Mountain area along the southeastern margin of the Ridge Basin, where they are bounded by the Clearwater fault on the north, and the Bee Canyon and San Francisquito Canyon faults to the south. There are also outcrops along the San Andreas fault north of the San Gabriel Mountains in the Big Rock-Devil's Punchbowl area (Sage, 1973, 1975). In the Ridge Basin, the San Francisquito Formation nonconformably overlies Precambrian and Mesozoic gneisses, migmatites, and quartz diorites. It is unconformably overlain by the middle-upper Miocene Castaic Formation and Ridge Basin Group to the west, and the lower Miocene Vasquez Formation to the south. In the Big Rock-Devil's Punchbowl area, it is unconformably overlain by the upper Miocene Punchbowl Formation.

In the Ridge Basin, the San Francisquito Formation has been extensively faulted and folded, so that no single section completely traverses the

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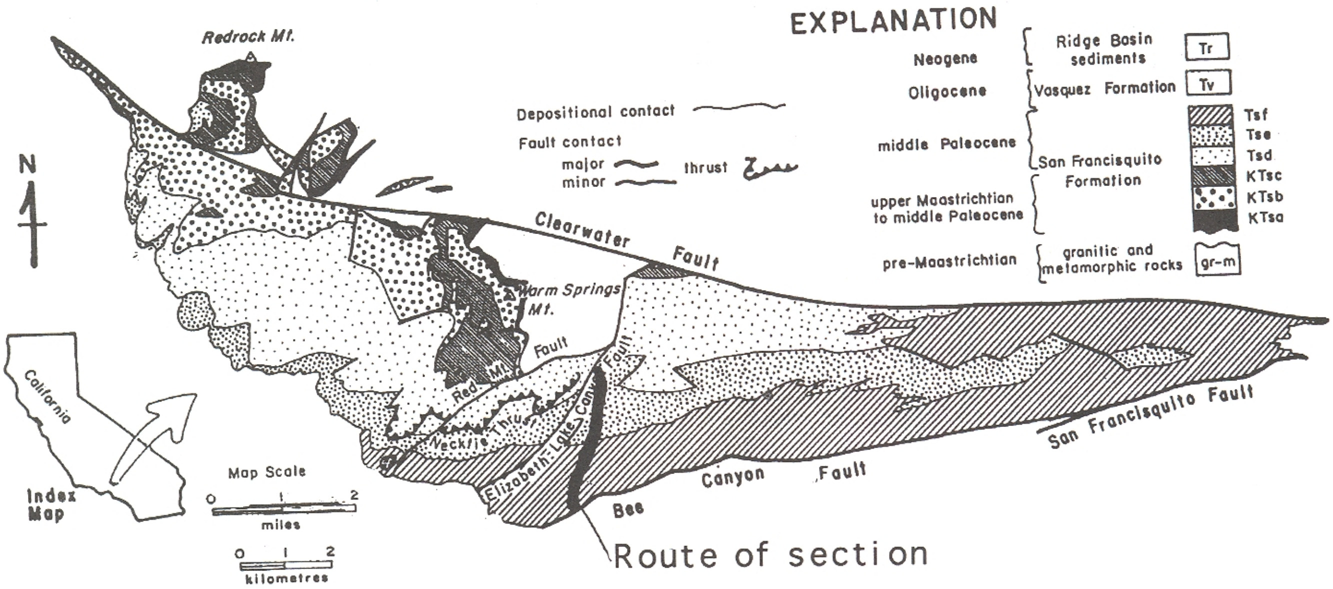

Figure 1. Index map showing location of San Francisquito Formation and measured section along Elizabeth Lake Canyon Road (modified from Kooser, 1982).

formation. Despite the structural complexities, Kooser (1980, 1982) recognized six informal members in this area. The lowest units, Members A and B, yield late Maastrichtian ammonites and *Turritella chaneyi*, *T. orienda*, and *T. webbi*. Member C produces a lower Paleocene (Danian) molluscan fauna including *Turritella peninsularis quaylei*. Kooser (1982, p. 58) reported that the upper part of Member F contains an early late Paleocene (Selandian) fauna including *T. peninsularis*, although this is not shown by Saul (1983).

METHODS

Paleomagnetic sampling was conducted in the spring of 2000, using simple hand tools to collect three oriented blocks per site. The section (Fig. 1) was sampled along Elizabeth Lake Canyon Road, as described by Kooser (1982, Fig. 2, column 4). Samples were located with respect to the detailed field notes and outcrop descriptions taken by Kooser (1980; pers. commun.). The section along Elizabeth Lake Canyon Road covers the upper part of Member D, and thick intervals of Members E and F. Unfortunately, no continuous, well-exposed sections through Members A, B, and C are available for sampling because of access problems to private lands, and extensive brush cover.

In the laboratory, the block samples were cored using an air-cooled drill press, or ground into cylinders using a sanding wheel. Small samples were cast into cylinders using Zircar aluminum oxide ceramic. All samples were measured on the 2G cryogenic magnetometer at the California Institute of Technology, equipped with an automatic sample changer. After measurement of NRM (natural remanent magnetization), each sample was demagnetized at 25, 50, and 100 Gauss to determine the coercivity behavior and demagnetize any multi-domain grains before their remanence is baked in. All samples were then thermally demagnetized at multiple steps up to 600°C. 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), and peak IRM and ARM (anhysteretic remanent magnetization) was subjected to AF demagnetization in a modified Lowrie-Fuller test (see Pluhar et al., 1991, for further details).

RESULTS

Orthogonal demagnetization ("Zijderveld") plots of representative samples are shown in Figure 2. Most samples (Fig. 2A, B) showed significant

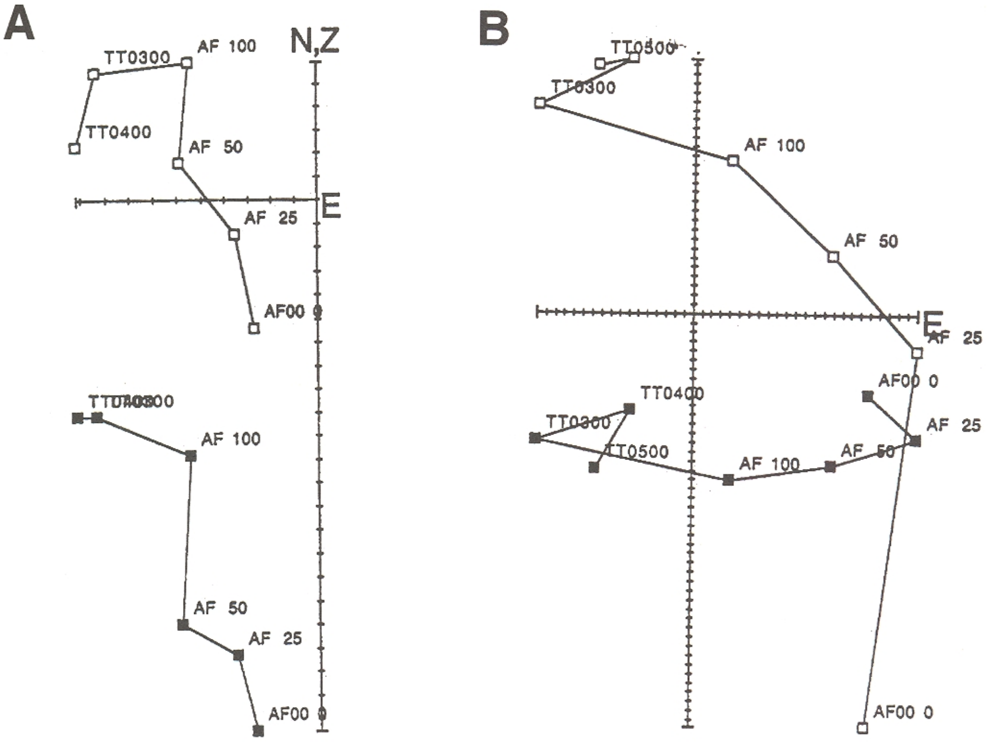

Figure 2. Orthogonal demagnetization ("Zijderveld") plots of representative samples. Solid squares indicate horizontal component; open squares represent the vertical component. Demagnetization steps indicated by "AF" and demagnetization field (in Gauss) and "TT" and thermal step in degrees Centigrade. Each division equals 10^{-7} emu.

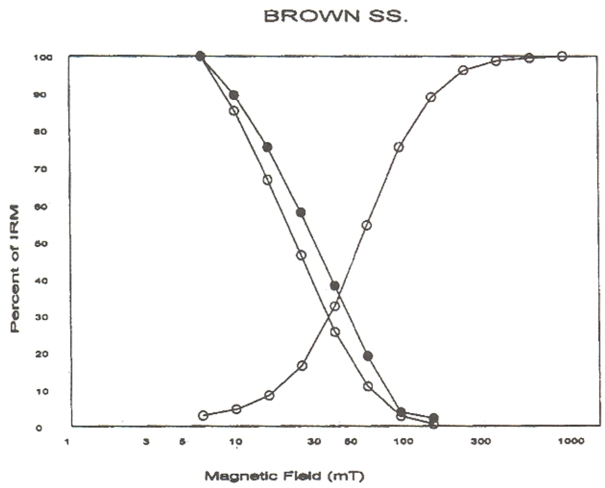

Figure 3. IRM acquisition and Lowrie-Fuller tests of a representative sample. Open boxes are IRM steps; solid boxes are ARM values. The IRM nearly saturates about 300 mT (millitesla), showing that the remanence is carried mostly by magnetite. The ARM is more resistant to AF demagnetization than the IRM, showing that the grains are single-domain or pseudo-single-domain.

response to AF demagnetization, suggesting that the remanence held in magnetite. However, most of the samples also held a significant amount of remanence above the Curie point of magnetite, suggesting that some of the remanence is held in hematite. Nearly all the samples (Fig. 2A) had a single component of remanence that pointed southwest and up after thermal demagnetization (a reversed direction rotated clockwise). A few samples (Fig. 2B) had a modern normal overprint that was removed during the first thermal demagnetization step, also suggesting that remanence is held in magnetite overprinted by goethite.

IRM acquisition studies (Fig. 3) showed that the IRM starts to plateau at 300 mT, suggesting that magnetite is a major carrier of the remanence, with a minor component of hematite or goethite. In the modified Lowrie-Fuller test, the ARM was more resistant to AF demagnetization than was the IRM, showing that the remanence is held in single-domain or pseudo-single-domain grains.

Average vectors for each sample were estimated using the least squared method of Kirschvink (1980), and statistics were calculated using the methods of Fisher (1953). The site statistics for the San Francisquito Formation are shown in Table 1. The formational mean was D = 204.9, I = -51.1, k = 10.9, α_{95} = 9.8 (n = 22). There were no normal directions to perform a reversal test for stability, and the dips were not variable enough to allow a fold test. Nevertheless the fact that the dip-corrected direction shows a clear reversed rotated direction

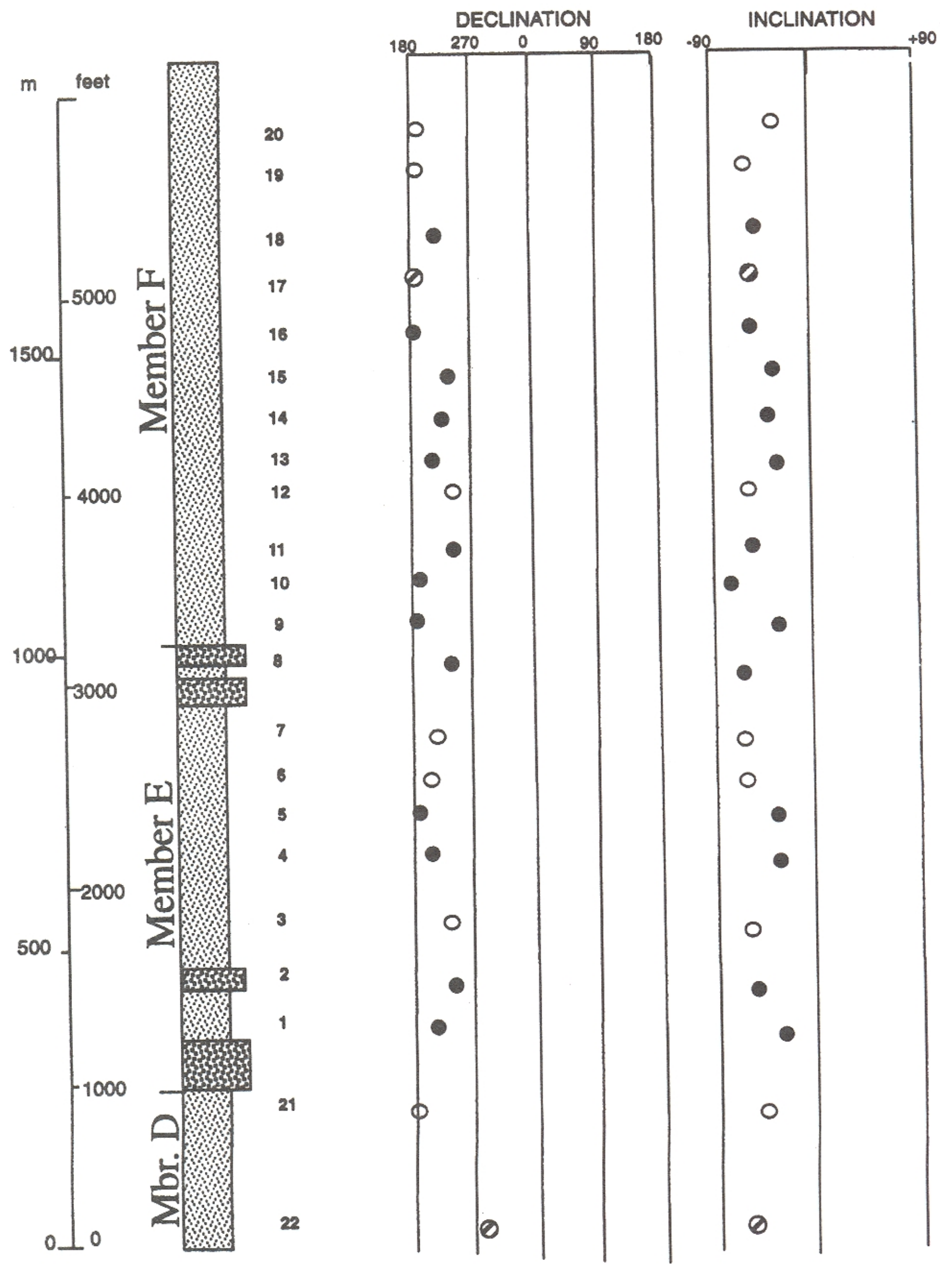

Figure 4. Magnetic stratigraphy of the San Francisquito Formation. Stratigraphy after Kooser (1980, 1982, and pers. commun.). Solid circles are Class I sites of Opdyke et al. (1977), which are statistically clustered; circles with diagonal pattern are Class II sites, which had only two samples, so no statistics could be calculated; open circles are Class III sites, which had one sample divergent.

suggests that it is a primary or characteristic direction, and overprinting has been removed.

The magnetic stratigraphy of the San Francisquito section is shown in Figure 4. Sites were ranked according to the method of Opdyke et al. (1977). Class I sites (n = 13) were statistically separated from a random distribution at the 95% confidence level. Class II sites (n = 2) had one sample missing, so site statistics could not be calculated. Class III sites (n = 7) had two directions which showed a clear polarity preference, but the third direction was divergent.

DISCUSSION

Magnetic Correlation

Figure 5 shows our correlation of our San Francisquito Formation section with the magnetic polarity time scale of Berggren et al. (1995), and with the results from other Paleocene sections in California. Although the reversed polarity of the San Francisquito Formation is not diagnostic in and of itself, the results from other formations help constrain our interpretations. The strata of the Locatelli Formation of the Santa Cruz Mountains yield a "Martinez" stage *Turritella infragranulata pachecoensis* fauna and Zone P4 planktonic micro-

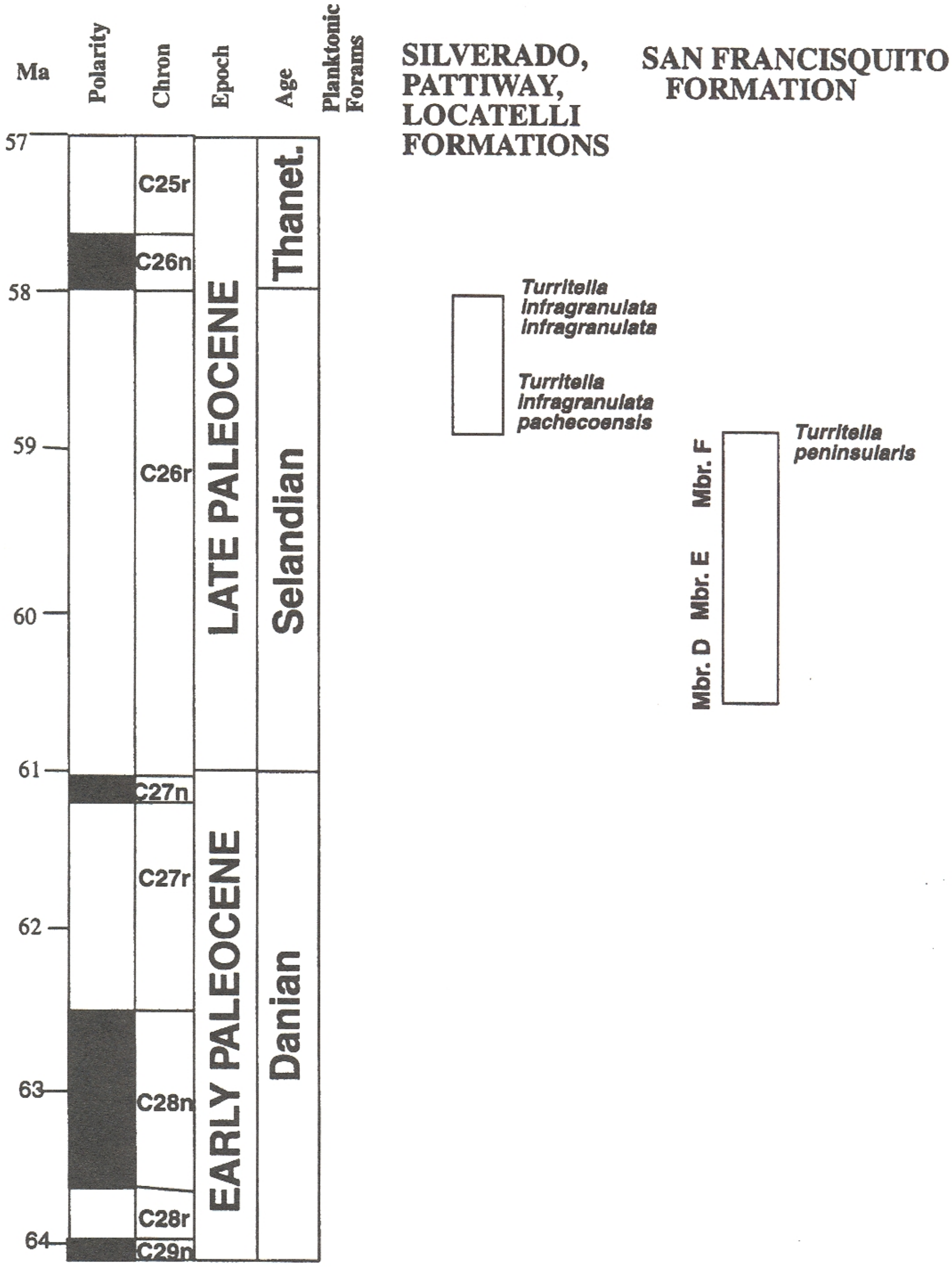

Figure 5. Correlation of the San Francisquito section with the magnetic stratigraphy of the Locatelli, Silverado, and Pattiway Formations, and with the time scale of Berggren et al. (1995). Biostratigraphy after Saul (1983 and pers. commun.), and Kooser (1980, 1982).

fossils, and are entirely of reversed polarity (Prothero and Lopez, this volume). The Silverado Formation of the Santa Ana Mountains of Orange County, and the Pattiway Formation of the southern Caliente Range in San Luis Obispo County, also yield a "Martinez Stage" *Turritella infragranulata pachecoensis* fauna (Prothero and Lopez, this volume). Based on the association of Zone P4 foraminifera with this fauna, the Pattiway, Silverado, and Locatelli Formations were correlated with the latter part of Chron C26r (58.0-60.9 Ma).

The reversed strata of the San Francisquito Formation yield an older molluscan fauna from the slightly earlier *Turritella peninularis* zone of Saul (1983). According to Saul, this fauna is latest Danian or early Selandian (late early Paleocene or early late Paleocene). In addition, the occurrence of *Turritella reversa* (Saul, 1983) and *Brachysphingus sinuatus* (Squires, 1997) support an early Selandian age for the fauna. Based on these lines of evidence, the long reversed succession in Members D, E, and F probably correlate with the early part of Chron C26r (58.0-60.9 Ma) (Fig. 5). However, it remains possible that the section correlates with late Danian Chron C27r (61.3-62.5 Ma), since *T. peninsularis* does occur in the latest Danian (Saul, 1983).

Tectonic rotations and translations

The formational mean inclination value is 51.5 ± 9.8°; its modern latitude suggests an inclination value of 53.9°. Thus, the paleolatitude is not significantly different from the present-day latitude, suggesting relatively little northward translation of this terrane since the Paleocene. However, the error estimates are so large that up to 9° of northward translation cannot be ruled out.

Our formational mean declination of 24.9 ± 9.8° suggests a clockwise tectonic rotation of about 35°, after comparison to the Paleocene stable cratonic pole of Diehl et al. (1983) and correction of the error estimate according to the method of Demarest (1983). This is consistent with the slight clockwise tectonic rotations seen in the same tectonic block in the central Transverse Ranges, such as the 37.1 ± 12.2° of rotation reported from the lower Miocene Vasquez Formation just to the southeast of our study area (Terres and Luyendyk, 1985).

CONCLUSION

Paleomagnetic analyses of upper part of the type San Francisquito Formation in the central Transverse Ranges, California, indicates entirely reversed polarity. Based on the distinctive molluscan fauna found in the early late Paleocene (early Selandian), we correlate the early part of reversed magnetozone with Chron C26r (58.0-60.9 Ma). The San Francisquito Formation shows no significant evidence of northward translation, but a clockwise rotation of about 35°. This latter result compares favorably with other results in the region, and suggests that it has undergone the same clockwise rotations found in nearby blocks of the central Transverse Ranges.

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TABLE 1—Fisher statistics of sites from the San Francisquito Formation. Site numbers as in Figure 4. N: number of samples per site; D, I: declination, inclination; k, α_{95}, precision parameters.

Site	N	D	I	k	α_{95}
1	3	207.9	-37.0	11.4	38.4
2	3	254.6	-51.7	11.4	38.4
3	3	228.5	-50.6	2.7	96.8
4	3	199.9	-33.7	11.0	39.1
5	3	164.5	-39.5	7.5	48.7
6	3	218.2	-49.3	4.8	63.8
7	3	224.1	-62.5	2.6	101.1
8	3	259.8	-63.2	5.5	58.3
9	2	174.9	-18.0	13.1	75.9
10	3	159.3	-70.8	7.5	48.5
11	2	252.1	-48.3	9.9	90.6
12	3	253.4	-51.6	3.3	83.2
13	3	219.6	-23.3	6.4	53.2
14	3	229.8	-34.9	6.0	55.8
15	3	211.4	-38.4	11.5	38.2
16	3	178.0	-53.9	6.7	52.1
17	2	146.6	-50.1	16.6	65.7
18	3	210.0	-44.3	7.0	50.7
19	3	184.0	-50.9	3.7	76.7
20	3	173.2	-35.4	2.9	92.4
21	3	178.6	-53.1	4.5	66.4
22	1	289.1	-68.2	—	—