New 87 Sr/88 Sr data from invertebrate macrofossils in the Neogene etchegoin formation, San Joaquin basin, California

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NEW $^{87}Sr/^{86}Sr$ DATA FROM INVERTEBRATE MACROFOSSILS IN THE NEOGENE ETCHEGOIN FORMATION, SAN JOAQUIN BASIN, CALIFORNIA

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The Etchegoin Group, comprised of the Jacalitos, Etchegoin, and San Joaquin formations, forms the upper part of the sedimentary fill of the San Joaquin forearc basin of central California. This stratigraphic sequence is locally fossiliferous (i.e., containing plant fossils, invertebrate and vertebrate macrofossils) and consists of siltstone, sandstone, conglomerate, and rare tuff beds deposited in shallow-marine, marginal-marine, and nonmarine environments during the late Neogene regression of the San Joaquin Sea (Loomis, 1990a, 1990b). The Etchegoin Group has a maximum thickness of 8,100 ft (2,470 m) measured from outcrops in the west-central San Joaquin basin.

Assigning an age to the Etchegoin Group and its constituent formations in the west-central San Joaquin basin is difficult because the Jacalitos, Etchegoin, and San Joaquin formations generally lack an age-diagnostic microfauna and contain a macrofauna that is not narrowly constrained biostratigraphically. Although the Etchegoin Formation has traditionally been viewed as Pliocene in age based on marine invertebrate macrofaunal assemblages and fossil horses (e.g., Anderson, 1905, 1908; Merriam, 1915; Nomland, 1917), recent strontium-isotope analyses suggest that a part of the formation is older. Reported here are previously unpublished $^{87}Sr/^{86}Sr$ data from marine invertebrate macrofossils suggesting that the Etchegoin Formation in the west-central San Joaquin basin ranges from late Miocene to early Pliocene in age.

METHODS

The Etchegoin Group was studied in the Jacalitos, Kreyenhagen, and Kettleman hills in the western San Joaquin Valley near the towns of Coalinga and Avenal (fig. 1). The Etchegoin Group and underlying and overlying stratigraphic units were mapped in a ~ 58 mi² (~ 150 km²) region (fig. 2), five stratigraphic sections were measured (fig. 1), and marine invertebrate macrofossils were collected for analyses. The locations and stratigraphic positions of these samples are shown in figures 2 and 3, respectively.

The invertebrate macrofossil shell material was crushed and all matrix material was separated by hand. Fragments of the fossils were examined for evidence of diagenetic alteration, and unweathered material was used for analysis. The fragments were then dissolved, and the strontium was separated from the other elements by precipitation from approximately 90% nitric acid, following the methods of Otto and others (1988).

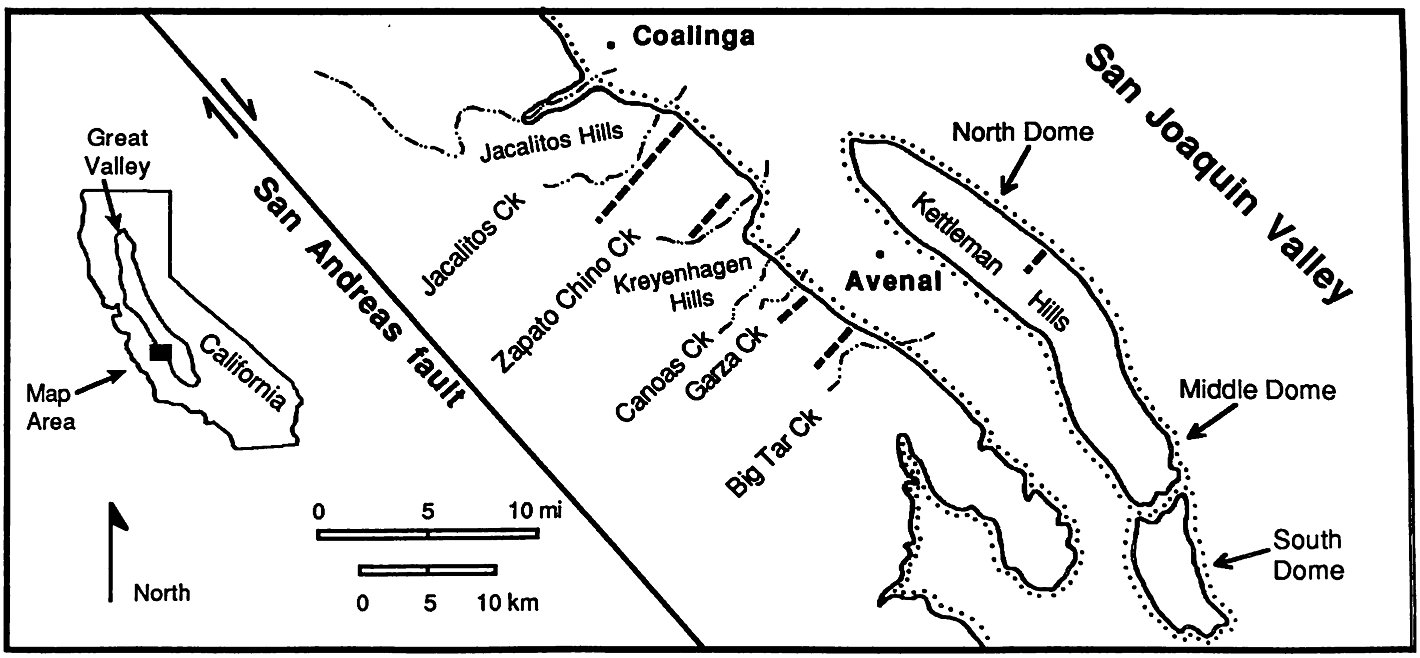

FIGURE 1. Index map showing key geographic and geologic features in the study area. Dashed lines represent locations of measured outcrop stratigraphic sections (see figure 3). The San Joaquin Valley forms the southern half of the Great Valley of California.

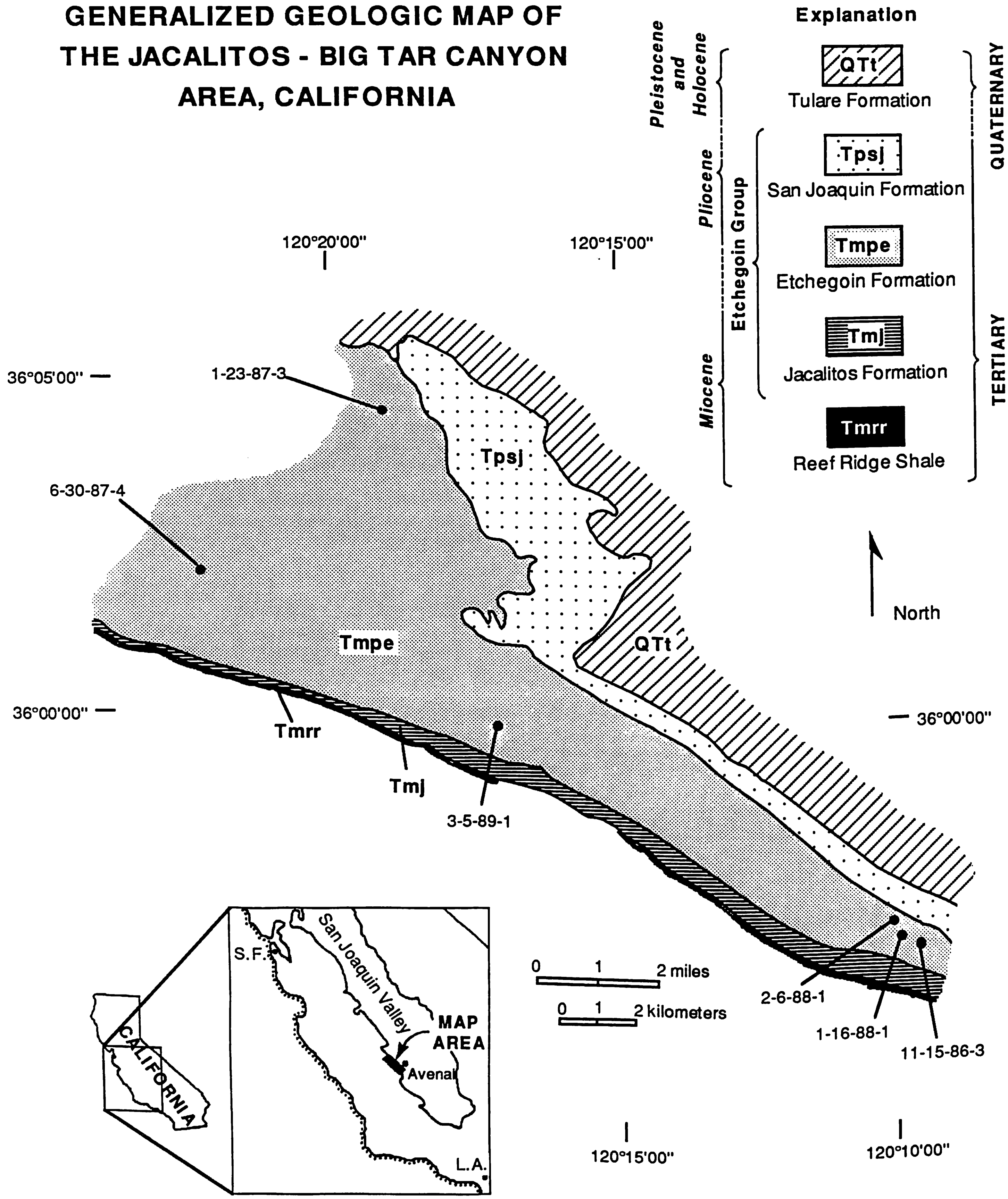

FIGURE 2. Generalized geologic map of the Jacalitos Creek - Big Tar Canyon area, west-central San Joaquin Valley (modified from Loomis (1990b)). The localities of all fossil samples, except those collected from Kettleman North Dome (samples 12-31-88-1, 3-5-89-4, and 3-6-89-1) are shown on the map. For more detailed descriptions of the localities see "sample descriptions" section and Plates 2A-E of Loomis (1990b).

TABLE 1. Results of $^{87}Sr/^{86}Sr$ analyses of marine invertebrate macrofossils[1].

Sample[2]	Specimen	$^{87}Sr/^{86}Sr \pm 2\Sigma$	ΔSW[3]	Age (Ma)[4]
1-23-87-3	*Ostrea* sp.	0.708894 ± 24	-17.6	6.5 ± 1.0
1-16-88-1	*Balanus* sp.	0.708874 ± 28	-19.6	7.5 ± 1.0
1-16-88-1	*Ostrea* sp.	0.708904 ± 27	-16.6	6.0 ± 1.0
1-16-88-1	*Ostrea* sp.	0.708925 ± 33	-14.5	5.0 ± 1.5
2-6-88-1	*Pecten* sp.	0.708891 ± 22	-17.9	6.5 ± 1.0
12-31-88-1	*Patinopecten healeyi* (Arnold)	0.708895 ± 15	-17.5	6.5 ± 0.5
12-31-88-1	*Patinopecten healeyi* (Arnold)	0.708905 ± 30	-16.5	5.5 ± 1.5
3-5-89-1	*Pecten* sp.	0.708896 ± 47	-17.4	6.0 ± 2.0
3-5-89-4	*Ostrea* sp.	0.708886 ± 7	-18.4	6.5 ± 0.5
3-6-89-1	*Hinnites giganteus* (Gray)	0.708892 ± 19	-17.8	6.5 ± 1.0
3-6-89-1	*Hinnites giganteus* (Gray)	0.708944 ± 35	-12.6	4.0 ± 1.5
11-15-86-3	*Anadara trilineata* (Conrad)	0.70841 ± 6	-66.0	20.0 ± 1.0
11-15-86-3	*Mya sp.* (?)	0.70846 ± 5	-61.0	18.0 ± 1.0
11-15-86-3	*Ostrea* sp.	0.708832 ± 34	-23.8	9.0 ± 2.0
1-23-87-1	*Balanus* sp.	0.708806 ± 24	-26.4	11.0 ± 1.5
6-30-87-4	*Pseudocardium densatum* (Conrad)	0.708519 ± 32	-55.1	17.0 ± 0.5
3-5-89-1	*Pecten* sp.	0.708831 ± 21	-23.9	9.5 ± 1.5
3-5-89-4	*Mytilus (Crenomytilus) coalingensis* Arnold	0.708828 ± 32	-24.2	9.5 ± 2.0
3-5-89-4	*Mytilus (Crenomytilus) coalingensis* Arnold	0.708074 ± 14	-99.6	26.5 ± 0.5

[1]The results of the analyses for the samples listed in the lower part of the table are inferred to be spurious (see text for discussion).
[2]Descriptions of sample localities are listed in the "sample descriptions" section, and localities are plotted on figure 2.
[3]See text for calculation.
[4]Ages were derived from the Koepnick and others (1985) $Sr^{87/86}$ seawater curve, and are expressed as the median value ± one-half the possible age range between the minimum and maximum values.

Isotope ratios were measured by comparison with standard $SrCO_3$ National Bureau of Standards (NBS) 987, for which a ratio of 0.71014 has been assumed. $^{87}Sr/^{86}Sr$ values were corrected for the presence of ^{87}Rb and were normalized to $^{86}Sr/^{88}Sr = 0.1194$. The deviation of the $^{87}Sr/^{86}Sr$ ratio between the measured sample and Holocene seawater is represented by a delta notation (ΔSW). Delta seawater values were calculated as follows:

$$\Delta SW = [{}^{87}Sr/{}^{86}Sr \text{ (measured sample)} - {}^{87}Sr/{}^{86}Sr \text{ (Holocene seawater)}] \times 10^5$$

where $^{87}Sr/^{86}Sr$ of Holocene seawater = 0.70907 (Burke and others, 1982).

The ages of the samples were determined by plotting the 2-sigma limits of uncertainty for each $^{87}Sr/^{86}Sr$ analysis on the Koepnick and others (1985) seawater curve, and reading the corresponding minimum and maximum age values from the curve. The $^{87}Sr/^{86}Sr$ ratios, ΔSW values, and calculated ages for the samples are summarized in table 1.

RESULTS

The most reliable ages for the Etchegoin Formation that were derived from $^{87}Sr/^{86}Sr$ analyses range from 6.5 to 4.0 Ma (table 1). Of all the marine invertebrate macrofossils analyzed, the most reliable results were obtained from analyses of oysters (*Ostrea* sp.) and pectens (*Pecten* sp., *Patinopecten healeyi* (Arnold), *Hinnites giganteus* (Gray)). Questionable ages (i.e., ranging from 9.0 to 26.5 Ma; table 1) were derived from analyses of the diagenetically unstable shell material of the bivalved mollusks *Anadara trilineata* (Conrad) (11-15-86-3), *Mya* sp. (11-15-86-3), *Pseudocardium densatum* (Conrad) (6-30-87-4), and *Mytilus (Crenomytilus) coalingensis* Arnold (3-5-89-4). Anomalously old ages derived from an oyster (*Ostrea* sp., 11-15-86-3), barnacle (*Balanus* sp., 1-23-87-3), and pecten (*Pecten* sp., 3-5-89-1) suggest that the shell material had been altered by diagenetic processes. The strontium-isotope age of 7.5 ± 1.0 Ma derived from the analysis of a barnacle (*Balanus* sp., 1-16-88-1) is also believed to be older than the true age of the fossil based on ages derived from oysters occurring in the same fossil bed (6.0 ± 1.0 Ma, 5.0 ± 1.5 Ma; table 1). Based on stratigraphic correlations, the base of the Jacalitos Formation is estimated to have an age of 7.0 Ma (COSUNA, 1984) (fig. 3). This age assignment further suggests that an age of 7.5 ± 1.0 Ma derived from the barnacle in sample 1-16-88-1, which occurs ~3,900 ft (~1,190 m) above the base of the Jacalitos Formation, is too old.

Delta-seawater (ΔSW) values associated with the reliable strontium-isotope results range from −12.6 to −18.4 (table 1). Based on $^{87}Sr/^{86}Sr$ analyses of planktonic foraminifers from the base of the Miocene-Pliocene boundary stratotype at Capo Rossello, Silicy, McKenzie and others (1988) obtained a $^{87}Sr/^{86}Sr$ value of 0.708995 ± 0.00002, corresponding to an age of 4.94 ± 0.5 Ma and a ΔSW value of −17.0 for the Miocene-Pliocene boundary. According to Haq and others (1987), the age of the Miocene-Pliocene boundary is 5.2 Ma, which corresponds to a ΔSW value of −15.0, using the Koepnick and others (1985) seawater curve. Thus, the ΔSW values (−12.6 to −18.4) calculated from the strontium-isotope analyses in this study suggest that the Etchegoin Formation spans the Miocene-Pliocene boundary.

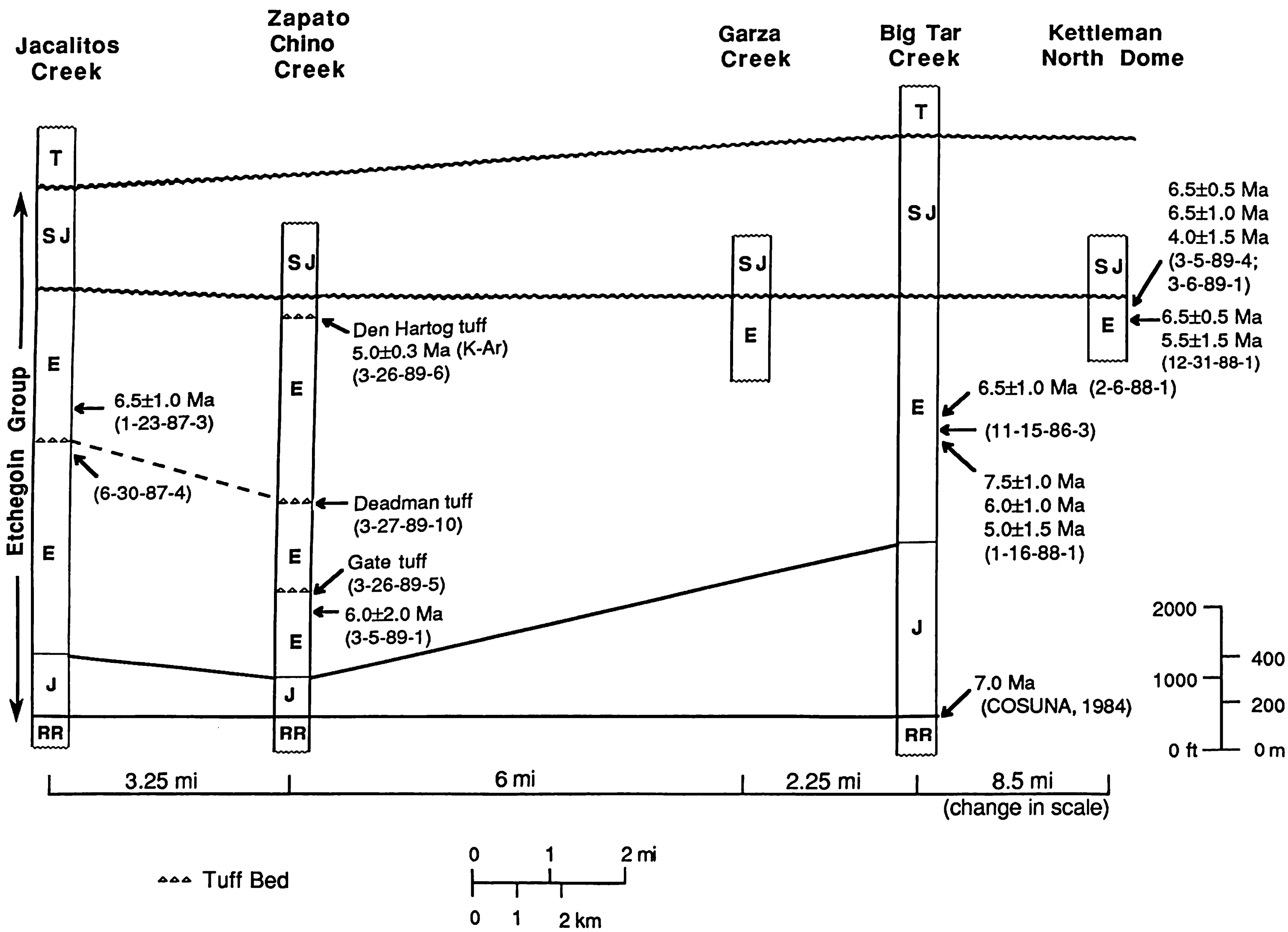

FIGURE 3. Correlation of measured outcrop sections in the study area, showing the ages derived from strontium-isotope analyses of fossil shell material and K-Ar analysis of the Den Hartog tuff. The stratigraphic positions of samples 6-30-87-4 and 11-15-86-3 are shown, but the results of these analyses were spurious and therefore the estimated ages of these samples are not included in this figure (see table 1). RR, Reef Ridge Shale; J, Jacalitos Formation; E, Etchegoin Formation; SJ, San Joaquin Formation; T, Tulare Formation. See figure 1 for locations of measured sections.

In summary, age data derived from strontium-isotope analyses, and the delta-seawater values calculated from the results of the analyses, suggest that the age of the Etchegoin Formation spans late Miocene through early Pliocene time. These data are corroborated by an age of 5.0 ± 0.3 Ma derived from K-Ar analysis of a tuff bed in the upper Etchegoin Formation (Loomis, 1990b; Loomis, this issue) (fig. 3).

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SAMPLE DESCRIPTIONS[1]

1. *1-23-87-3* $^{87}Sr/^{86}Sr$
Ostrea sp. (SW¼ NW¼ S26,T21S,R15E; Kreyenhagen Hills 7.5′ quad., Fresno Co., CA).

2. *1-16-88-1* $^{87}Sr/^{86}Sr$
Balanus sp., *Ostrea* sp. (NW¼ NE¼ S7,T23S,R17E; Garza Peak 7.5′ quad., Kings Co., CA).

[1]See table 1 for analytical results. Sample locations are plotted in figure 2.

3. *2-6-88-1* $^{87}Sr/^{86}Sr$
Pecten sp. (SE¼ SW¼ S6,T23S,R17E; Garza Peak 7.5′ quad., Kings Co., CA).

4. *12-31-88-1* $^{87}Sr/^{86}Sr$
Patinopecten healeyi (Arnold) (NE¼ SE¼ S17, T22S,R18E; La Cima 7.5′ quad., Kings Co., CA).

5. *3-5-89-1* $^{87}Sr/^{86}Sr$
Pecten sp. (NE¼ SW¼ S19,T22S,R16E; The Dark Hole 7.5′ quad., Fresno Co., CA).

6. *3-5-89-4* $^{87}Sr/^{86}Sr$
Ostrea sp. (Center NE¼ S17,T22S,R18E; La Cima 7.5′ quad., Kings Co., CA).

7. *3-6-89-1* $^{87}Sr/^{86}Sr$
Hinnites giganteus (Gray) (SW¼ NE¼ S17, T22S,R18E; La Cima 7.5′ quad., Kings Co., CA).

8. *11-15-86-3* $^{87}Sr/^{86}Sr$
Mya sp., *Ostrea* sp., *Anadara trilineata* (Conrad) (Center NW¼ S8,T23S,R17E; Garza Peak 7.5′ quad., Kings Co., CA).

9. *1-23-87-1* $^{87}Sr/^{86}Sr$
Balanus sp. (SE¼ NW¼ S26,T21S,R15E; Kreyenhagen Hills 7.5′ quad., Fresno Co., CA).

10. *6-30-87-4* $^{87}Sr/^{86}Sr$
Pesudocardium densatum (Conrad) (NW¼ NE¼ S8, T22S,R15E; Kreyenhagen Hills 7.5′ quad., Fresno Co., CA).

11. *3-5-89-1* $^{87}Sr/^{86}Sr$
Pecten sp. (NE¼ SW¼ S19,T22S,R16E; The Dark Hole 7.5′ quad., Fresno Co., CA).

12. *3-5-89-4* $^{87}Sr/^{86}Sr$
Mytilus (Crenomytilus) coalingensis Arnold (Center NE¼ S17,T22S,R18E; La Cima 7.5′ quad., Kings Co., CA).

REFERENCES

Anderson, F. M. (1905) A stratigraphic study in the Mount Diablo Range of California: Proceedings of the California Academy of Sciences, 3rd series, v. 2, no. 2, p. 155–248.

_______ (1908) A further stratigraphic study in the Mount Diablo Range of California: Proceedings of the California Academy of Sciences, 4th series, v. 3, p. 1–40.

Burke, W. H., Denison, R. E., Hetherington, E. A., Koepnick, R. B., Nelson, H. F., and Otto, J. B. (1982) Variation of seawater $^{87}Sr/^{86}Sr$ throughout Phanerozoic time: Geology, v. 10, p. 516–519.

COSUNA (1984) Correlation of Stratigraphic Units of North America (COSUNA) Project; Southern, Central, and Northern California Province Correlation Charts: American Association of Petroleum Geologists, Tulsa, Oklahoma.

Haq, B. U., Hardenbol, J., and Vail, P. R. (1987) Chronology of fluctuating sea levels since the Triassic: Science, v. 235, p. 1156–1167.

Koepnick, R. B., Denison, R. E., Burke, W. H., Hetherington E. A., Nelson, H. F., Otto, J. B., and Waite, L. E. (1985) Construction of the seawater $^{87}Sr/^{86}Sr$ curve for the Cenozoic and Cretaceous: Supporting data: Chemical Geology (Isotope Geoscience Section), v. 58, p. 55–81.

Loomis, K. B. (1990a) Depositional environments and sedimentary history of the Etchegoin Group, west-central San Joaquin Valley, California, *in* Kuespert, J. G., and Reid, S. A., eds., Structure, Stratigraphy and Hydrocarbon Occurrences of the San Joaquin Basin, California: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 64, and Pacific Section, American Association of Petroleum Geologists, v. GB65, p. 231–246.

_______ (1990b) Late Neogene depositional history and paleoenvironments of the west-central San Joaquin basin, California: Stanford University, Ph.D. dissertation, 500 p.

McKenzie, J. A., Hodell, D. A., Mueller, P. A., and Mueller, D. W. (1988) Application of strontium isotopes to late Miocene-early Pliocene stratigraphy: Geology, v. 16, p. 1022–1025.

Merriam, J. C. (1915) Tertiary vertebrate faunas of the North Coalinga region of California—A contribution to the study of paleontologic correlation in the Great Basin and Pacific Coast provinces: Transactions of the American Philosophical Society, v. 22, pt. 3, p. 191–234.

Nomland, J. O. (1917) The Etchegoin Pliocene of middle California: University of California Publications, Department of Geology Bulletin, v. 10, no. 14, p. 191–254.

Obradovich, J. D., Naeser, C. W., and Izett, G. A. (1978) Geochronology of late Neogene strata in California *in* Correlation of Tropical Through High Latitude Marine Neogene Deposits of the Pacific Basin (Abstracts and Program), International Geological Correlation Programme, Project 114, Biostratigraphic Datum-planes of the Pacific Neogene: Stanford University Publications in Geological Sciences, v. 14, p. 40–41.

Otto, J. B., Blank, W. K., and Dahl, D. A. (1988) A nitrate precipitation technique for preparing strontium for isotopic analysis: Chemical Geology (Isotope Geoscience Section), v. 72, p. 173–179.

Sarna-Wojcicki, A. M. (1976) Correlation of late Cenozoic tuffs in the central Coast Ranges of California by means of trace- and minor-element chemistry: U.S. Geological Survey Professional Paper 972, 30 p.

Sarna-Wojcicki, A. M., Bowman, H. W., and Russell, P. C. (1979) Chemical correlation of some Late Cenozoic tuffs of northern and central California by neutron activation analysis of glass and comparison with x-ray fluorescence analysis: U.S. Geological Survey Professional Paper 1147, 15 p.

Sarna-Wojcicki, A. M., Lajoie, K. R., Meyer, C. E., Adam, D. P., and Rieck, H. J. (1991) Tephrochronologic correlation of upper Miocene sediments along the Pacific margin, conterminous United States, *in* Morrison, R. M., Quaternary of the Non-Glacial United States, Decade of North American Geology: Geological Society of America, v. K-2, *in press.*