Sea Level Control of Molluscan Diversity in the Pliocene San Joaquin Basin, Central California

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ABSTRACT

The Pliocene San Joaquin Basin was a silled marginal basin 175 km long, 100 km wide, and ~125m deep connected to the Pacific Ocean through the Priest Valley Strait, a seaway 30 km long, 13 km wide, and 10-50 m deep. Paleogeography determined that the environment inside the basin differed substantially from those of the Pacific Coast. Peak molluscan diversity corresponds with highest sea-levels. This suggests that immigrant species entering the basin from the Pacific became established during periods of warm climate and normal marine conditions, corresponding to maximum eustatic levels and basin flooding, where they adapted to the local environment. Upon sea-level fall during colder climates the basin became cooler and brackish and relict faunas from warmer and normal marine conditions, and nearly all immigrants from during the highest eustatic levels, became extinct. Low diversity faunas characterize the periods of low and rising sea-level. This pattern repeated during each of the major eustatic cycles affecting the San Joaquin Basin. During low and rising sea-level circulation from the Pacific Ocean through the Priest Valley Strait was insufficient to maintain normal marine conditions and the San Joaquin Basin remained too brackish for most immigrants from coastal faunas to become established. There were 7 extinction events affecting the molluscan faunas in the San Joaquin Basin: 2 extinctions in the upper Etchegoin Formation and 5 extinctions in the upper San Joaquin Formation including the end-San Joaquin extinction coincident with the final tectonic closure of the Priest Valley Strait. During the end-Etchegoin extinction diversity progressively declined as species adapted to warmer and more normal marine conditions became extinct leaving species tolerant of cooler brackish water. Diversity rebounded but remained low throughout the lower San Joaquin during which brackish-water conditions prevailed and did not recover until marine flooding peaked in the basal upper San Joaquin. Latest San Joaquin faunas are dominated by species characteristic of brackish conditions. Thus the Priest Valley Strait was not a only a corridor between the Pacific and the San Joaquin Basin but also a filter and trapdoor: Species unable to adapt to conditions inside basin were filtered-out while those species that adapted and established became trapped in the basin.

Northwest San Joaquin Basin Late Neogene Stratigraphy

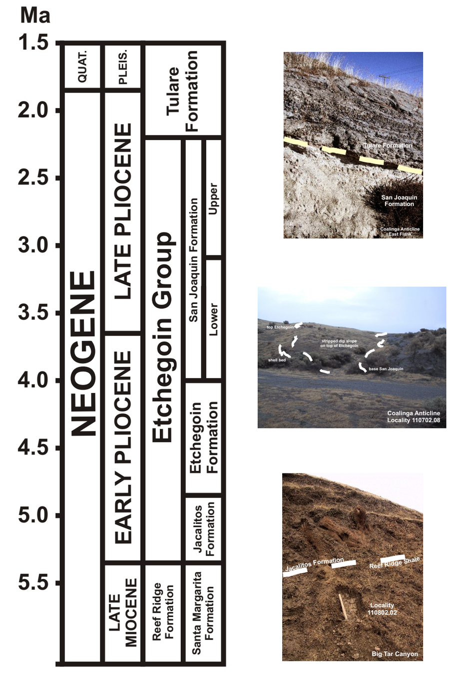

Figure 1. Late Neogene Stratigraphy of the San Joaquin Basin. Shown in the photographs are stratigraphic contacts at the base of the Etchegoin Group (Kreyenhagen Hills), Etchegoin-San Joaquin contact (Coalinga Anticline), and San Joaquin-Tulare contact at the top of the Etchegoin Group (Coalinga Anticline). The Tulare Formation comprises the post-Etchegoin Group lacustrine filling of the San Joaquin Basin following the latest Pliocene closing of the Priest Valley Strait (Figure 3). While the lithostratigraphic name of Etchegoin Group may not conform to the current North American Code of Stratigraphic Nomenclature, it is used here in its historical context (see the discussion in Loomis, 1990).

Generalized Geology of Central California

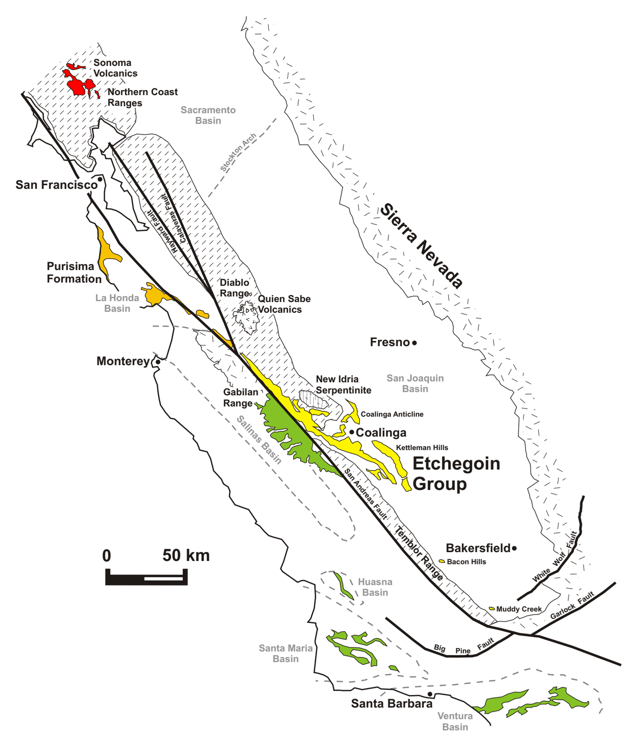

Figure 2. Generalized geology of central California showing outcrops of the Etchegoin Group (yellow), Purisima Formation (orange), and other Pliocene marine strata (green). Modified after Jennings (1977).

Paleogeography of the Early Pliocene San Joaquin Basin

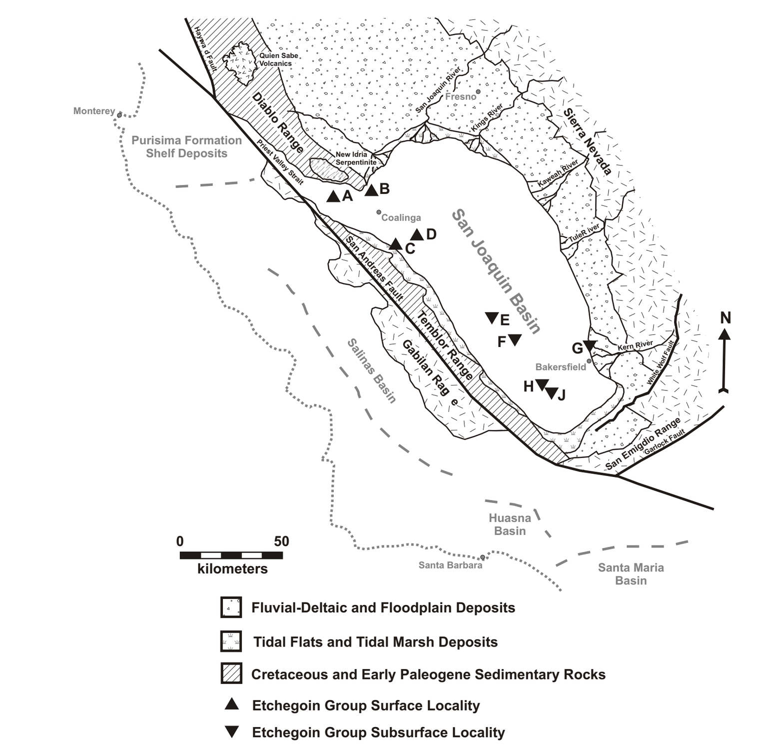

Figure 3. Early Pliocene paleogeography of central California at ~5 Ma (in part modified from Foss, 1972; Harris, 1987; Loomis, 1990a). Faults west of the San Andreas fault are not shown. By this time the Sierra Nevada, San Emigdio Range, Temblor Range, and Diablo Range had been uplifted to near present elevations (Wakabayashi and Sawyer, 2001; Argus and Gordon, 2001). Location of La Honda, Salinas, Huasna, and Santa Maria Basins are shown relative to the San Joaquin Basin at that time. The modern shoreline and cities locations are shown for reference.

Surface and subsurface Etchegoin Group sections are noted:
A – Priest Valley Strait, B – Coalinga, C – Kreyenhagen Hills, D – Kettleman Hills, E – Lost Hills oil field, F – Buttonwillow gas field, G – Poso Creek oil field, H – Elk Hills oil field,

Sea Level, Environment, and Diversity

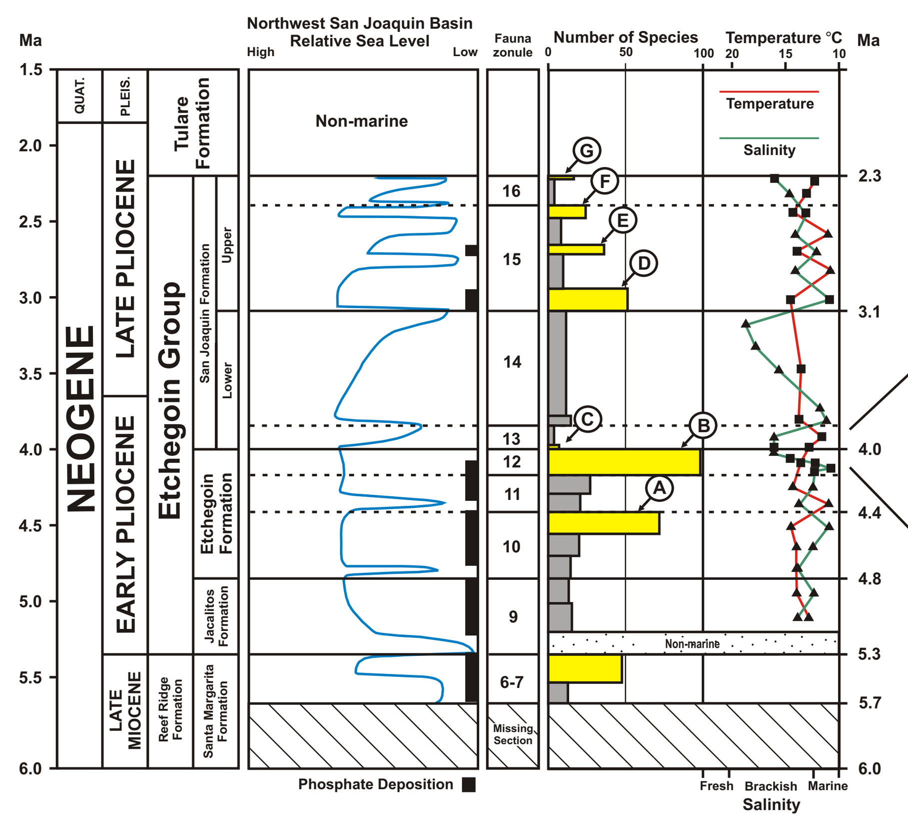

Figure 5. Comparison of molluscan faunal diversity with relative sea-level (modified from Bowersox, 2004a, fig. 3) as total species found in average ~200 m stratigraphic intervals in the Jacalitos and Etchegoin Formation and by fauna zone of Woodring et al. (1940) in the San Joaquin Formation. Correlations of biostratigraphic fauna zonules 6-16 of Adegoke (1969) are noted. Intervals of phosphate deposition (from Figure 4, localities H and J), indicative of upwelling in the basin, are noted with vertical black bars. Interruptions in phosphate deposition and upwelling are coincident with sea-level lowstands and brackish periods in the San Joaquin Basin. Faunal changes at the Jacalitos-Etchegoin contact are coincident with the interruption of upwelling and brackish conditions that are characteristic of sea-level lowstand. Average water temperature (red line – squares, adapted from Stanton and Dodd, 1970, fig. 5; triangles, this study from Adegoke, 1969, and Loomis, 1990b, using the technique of Kern, 1973, and temperature ranges for extant bivalves from Bernard, 1983; Figure 4, locality C) and indicated paleosalinity (green line – squares, adapted from Stanton and Dodd, 1970, fig. 15; triangles, this study from Adegoke, 1969, and Loomis, 1990b, adapted from techniques in Stanton and Dodd, 1970; Figure 4, locality C) are shown for reference. Peak diversity corresponds with maximum basin flooding suggesting ecological filtering and restriction of potential immigrant species from the Pacific Ocean through the Priest Valley Strait to those periods with most nearly-marine conditions. Low diversity corresponds to periods of brackish conditions and suggests slowed immigration and exclusion of species adapted to normal marine conditions. Extinction events are noted A-F at major diversity declines.

Diversity Changes Uppermost Etchegoin Formation

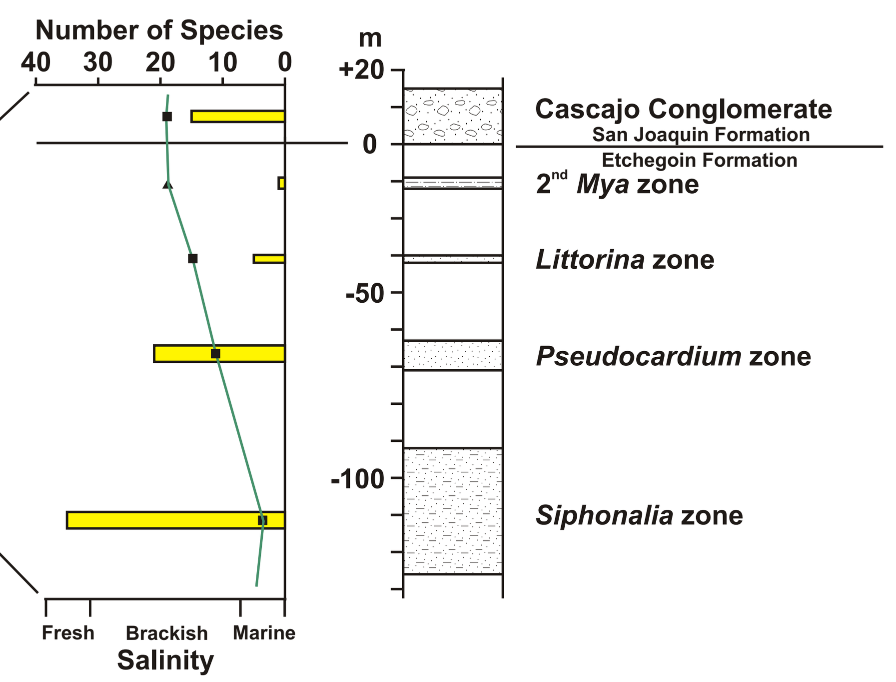

Figure 6. Diversity of molluscan faunas from the uppermost Etchegoin Formation as species per biostratigraphic zone of Woodring et al. (1940) in the Kettleman Hills (see Figure 4 for location). Salinity corresponding to each zone is shown by the dotted line with symbols (from Figure 5). Diversity declined precipitously as the environment deteriorated from the nominally marine *Pseudocardium* to the increasingly brackish *Littorina* and 2nd *Mya* zones. A small rebound in diversity in the Cascajo Conglomerate was a prelude to a long period of low diversity during the lower San Joaquin Formation (Figure 5).

San Joaquin Basin Extinction Model

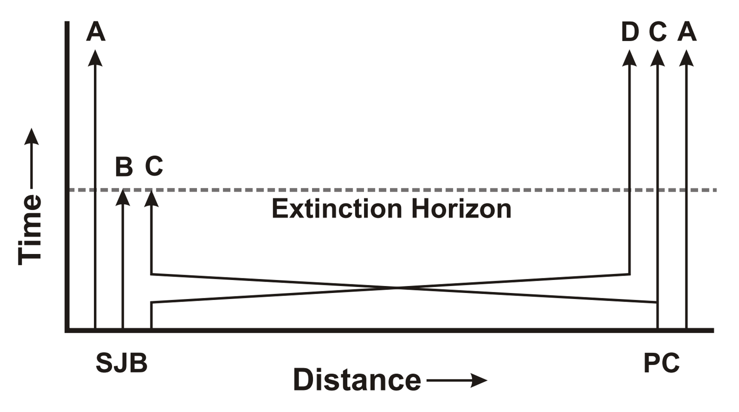

Figure 4. This figure illustrates extinction as used in this paper. Species A is a cosmopolitan species living in both San Joaquin Basin and Pacific Coast faunas. Species B is endemic to the San Joaquin Basin and becomes totally extinct at the extinction horizon. Species C is an immigrant species from the Pacific Coast that becomes locally extinct in the San Joaquin Basin while its core population is extant. Species D originates in the San Joaquin Basin and migrates to the Pacific Coast leaving no core population behind. Extinction as used in this paper includes total extinction, local extinction, and migration.

The Pliocene San Joaquin Basin was a marginal basin with a single connection to the ocean (Figure 3). The restricted connection silled the basin leading to anoxia and nutrient buildup in the central basin depths. Thermal-circulation upwelling redistributed nutrients to the basin margins as evidenced by phosphate deposition noted in Figure 5. Throughout the Pliocene this connection was severed by eustasy and tectonic events leading to regression inside the basin. Diversity is highest during eustatic highstand when normal-marine conditions prevailed and encouraged immigration of coastal species and rapid evolution in the basin. Figures 5 and 6 illustrate how extinction in the Pliocene San Joaquin Basin was controlled by regression-driven environmental changes coincident with climatic changes.

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DISCUSSION

The Pliocene history of the San Joaquin Basin is one of environmental variability caused by sea level changes due to severing of its tenuous connection to the ocean and eustasy. Only the final extinction at San Joaquin-Tulare formations contact (Figure 5, event G) is related to a single cause where the ultimate loss of the basin's connection to the ocean lead to the San Joaquin Basin becoming a fresh-water lake and extinction of all marine taxa. At the Jacalitos-Etchegoin contact sea-level fall lead to brackishness and the apparent interruption of phosphate deposition, upwelling, and productivity (Figure 5, ~4.8 Ma). However, although diversity was low during Jacalitos Formation deposition (Figure 5, ~5.2-4.8 Ma), and remained low during deposition of the lower Etchegoin Formation (~4.8-4.5 Ma), there was no excess extinction across this formation boundary as is seen in the basal San Joaquin Formation (Figure 5, event C). Thus brackish conditions and low productivity together were not sufficient to cause excessive extinction. Major extinction events followed brief periods of immigration and diversification at eustatic highstands then the onset of brackish conditions, cooling, and productivity collapse driven by regression (Figure 5, events A-F). These three controls affected different members of the faunas: 1). species adapted to normal marine conditions, including both bivalves and all predatory gastropods, became extinct as conditions became brackish, 2.) cooling lead to extinction of warm-water species, and, 3). productivity collapse lead to extinction of the large bivalves. Thus, abrupt regression-driven hydrologic change, productivity collapse from coincident geochemical and sedimentary change, and climatic change lead to the major extinction events in the Pliocene San Joaquin Basin.

CONCLUSIONS

1. Extinction in the Pliocene San Joaquin Basin was driven by environmental changes due to eustatic regression.

2. Diversity peaked during periods of highest sea-levels suggesting that immigrant species entering the basin from the Pacific became established during periods of warm climate and normal marine conditions corresponding to maximum eustatic levels and basin flooding. Upon sea-level fall during colder climates the basin became cooler and brackish and relict faunas from warmer and normal marine conditions, and nearly all immigrants from during the highest eustatic levels, became extinct.

3. Low diversity faunas are characteristic of periods of low and rising sea-level during which circulation from the Pacific Ocean through the Priest Valley Strait was insufficient to maintain normal marine conditions and the San Joaquin Basin remained too brackish for most immigrants from coastal faunas to become established.

4. Diversity precipitously decreased during deposition of the latest Etchegoin Formation following due to productivity collapse following the cessation of upwelling, increasingly brackish conditions, and climatic cooling.

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