CHAPTER 5

PALEOCENE PALEOGEOGRAPHY AND PALEOCLIMATE

Introduction

Based on the discussion presented in Chapter 4, the paleosols of the Silverado Formation records tropical climatic conditions present during its formation. This conclusion is in accord with studies suggesting that the Paleocene was an unusually warm period. Below is an examination of Cretaceous through the Paleocene climates and also a review of paleobotanical studies in the Silverado. These paleobotanical studies provide additional information as to the climate during the Paleocene.

Prior to 1970, much of what we knew about the Earth's past came from studies of terrestrial and marine sediments that were exposed on land (Pak and Miller, 1992; Zachos *et al.*, 1993). With the inception of the Deep Sea Drilling Project (DSDP) in the 1970's and the Ocean Drilling Program (ODP) in the 1980's, scientists now had access to deep sea sediments that were previously inaccessible (Zachos *et al.*, 1993). Cores obtained from these drilling programs gave scientists new insights into the paleoclimatic history of the Earth. This data, in conjunction with paleoclimatic data from paleosols, fossils, sediments and glaciers, has been used to reconstruct the paleoclimate and paleoenvironment of various locations and times throughout the world.

Late Cretaceous Climate

The Earth's climate during the late Cretaceous was thought to have been warm and ice free (Pak and Miller, 1992; Zachos *et al.*, 1993; Adatte *et al.*, 2002 *in press*), and that the transition to the glacial Neogene period was a gradual one (Pak and Miller, 1992; Zachos *et al.*, 1993). The Maastrichtian era (145-65 Ma) was cooler than earlier Cretaceous periods, and was marked by a series of strong temperature and climate fluctuations from a warm, humid, non-seasonal precipitation climate to cool, seasonally wet one (Dingle and LaVelle, 2000; Adatte *et al.*, 2002). The last warming trend occurred 50 - 100 Ka just prior to the K/T boundary.

Further evidence of a warming trend towards the end of the Cretaceous is present in paleosols in the Hell Creek Formation in Montana. Deeply weathered and moderately well drained paleosols of the middle Hell Creek Formation contain carbonate nodules, suggesting subhumid conditions (Retallack, 1994). Fossilized plant fragments found within paleosols of the upper Hell Creek Formation show an increase in leaf size and an increase in the diversity in mosses, liverworts, and fern spores (Retallack, 1994).

Retallack (1994) suggests that climatic conditions became increasingly humid during the deposition of the upper Hell Creek Formation paleosols, when precipitation rates increased to an estimated 900-1200 mm annually.

Paleocene Climate

The humid climate of the latest Cretaceous continued into the early Paleocene. Paleosol and fossil evidence from Montana's Hell Creek Formation indicates that the region's ecosystem varied from an oligotrophic woodland to a swampland with diverse flora and fauna assemblage, similar to the modern Okeefenokee Swamp in Georgia (Retallack, 1994). Early Paleocene clays in the Weddell Sea, Antarctica (ODP site 690), and the U.S. Atlantic coastal plain (New Jersey to Virginia) are dominated by illite/smectite assemblages (Zachos *et al.*, 1993; Gibson *et al.*, 2000) and suggest that the climate was warm and humid with a dry season and low water percolation (Gibson *et al.*, 2000).

The Late Paleocene Thermal Maximum (LPTM)

Much of the paleoclimatic research for the Paleocene focuses on the Late Paleocene Thermal Maximum (LPTM) - an abrupt, transient (<100,000 years) warming event which caused pronounced changes to the Earth's climate, oceans, and ecosystems (Bralower *et al.*, 1997). Evidence of this event comes from several sources.

Hovan and Rea (1992) studied cores from DSDP site 21 in the Indian Ocean. The cores recorded a decrease in ^{18}O and ^{13}C over a 1.2 my time span at the Paleocene/Eocene boundary and indicates that the deep ocean waters warmed approximately 4-5°C (Hovan and Rea, 1992). The decrease in ^{18}O and ^{13}C values was also seen at ODP site 1001 in the Caribbean (Bralower *et al.*, 1997)

Mass extinctions of foraminifera occurred in the Indian Ocean (Hovan and Rea, 1992). Cores from the ODP site 865 at Allison Guyot (Pacific Ocean) record a diverse yet impoverished benthic foraminifera assemblage (Kelley *et al.*, 1996). Kelley et al (1996) suggest that the surface waters had a poor nutrient supply there was a low rate of organic matter formation during the late Paleocene. Bralower et al (1997) noted that there was a reduced amount of bioturbidity and several tephra layers in the claystone beds which marked the LPTM event at ODP sites 999 and 1001 (Caribbean Sea).

An increase in the amount of kaolinite in late Paleocene sediments was observed in cores sampled along the U.S. Atlantic coastal plain from New Jersey to Virginia (Gibson *et al.*, 2000) and in the Weddell Sea, Antarctica at ODP site 690 (Zachos *et al.*, 1993). The kaolinite increase is considered due to and increase in both temperature and precipitation rates (Zachos *et al.*, 1993; Gibson *et al.*, 2000).

Paleobotanical Studies in the Silverado Formation

Little work has been done regarding the palaeobotany of the Southern California area during the Paleocene. Axelrod (1979) was one of the first to do so. Fossilized leaves, stems, and other plant fragments collected from the Aberhill Clay member of the Silverado Formation in Lake Elsinore (known as the Elsinore Flora) were studied by Axelrod. He concluded that the region was that of a subtropical lowland or savanna, similar to that found in modern northern Australia, which received 50 to 60 inches of rain annually and possibly had a short dry season. This environment persisted through the Oligocene, gradually changing into a temperate rainforest and dry tropical forest, similar to ones found today in southern Mexico, which received more than 60" of rainfall annually and had a brief dry season in the winter.

In 1979, a preliminary geotechnical investigation began for a wastewater treatment plant in Robinson Ranch, a community near Trabuco Canyon in the Santa Ana Mountains (Figure 2-1). During the course of this investigation fossil leaves were discovered in a claybed, which ran through the site. Subsequent study confirmed that this claybed was the Serrano Clay Bed and it was suggested that a paleontologist be on-site during grading to collect and study any fossils from the claybed or other areas on the site. Grading began in 1982 and selected areas of the site deemed "sensitive for paleontological resources"

(Sundberg and Warter, 1984) were monitored during the course of grading. Dr. Howard Schorn (SRS), Dr. Scott Wing (USGS), Dr. Janet Warter (CSULB) and Ms. Mary Rosczyk (CSULB) were instrumental in the identification of the fossils. Samples collected from the Robinson Ranch site yielded a wealth of plant species and genres, including ferns, cycads, various angiosperm species, mosses, ferns, and conifers. The plant assemblages indicate an "alluvial plain forest association, with stream bank and swamp dwelling trees, shrubs, and under story vegetation" (Axelrod, 1979). Annual rainfall would have been about 50-60 inches.

Sundberg and Warter (1984) also studied 24 samples collected from outcrops of the Silverado formation in Aberhill and Rancho Mission Viejo. She found 85 species and 56 genera of spore and pollen assemblages within the lower member. The presence of fungal and pteridophyte (vascular plants that reproduce via spores, such as ferns) spores and angiosperm pollen indicates a swampy or lowland bog that was within a paralic deltaic system. Other plant assemblages found were a part of a warm, temperate to subtropical climate with "adequate rainfall". Flora represented includes fungi, mosses, ferns, gymnosperms, mono and dicot angiosperms. Figure 5-1 represents Sundberg and Warter's interpretation of what the Trabuco Hill/Robinson Ranch area of the Santa Ana

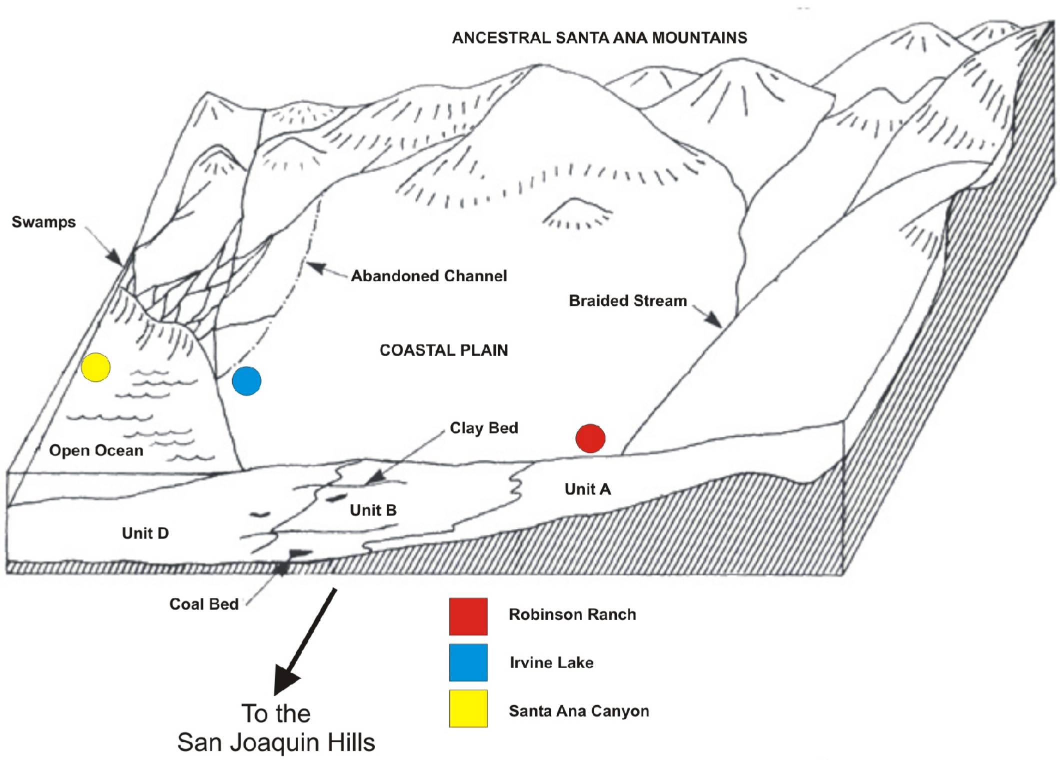

Figure 5-1: Paleogeographic reconstruction of the Trabuco Hill/Robinson Ranch area of the Santa Ana Mountains as it may have looked during the Late Paleocene. From Sundberg and Warter, 1984.

Mountains may have looked like during the deposition of the Silverado Formation in the Paleocene.

As a part of a Master's thesis, Gaponoff (1981) studied pollen and fossil spores found in lignites and carbonaceous clays from the lower non-marine member of the Silverado Formation in the Aberhill region and Rancho Mission Viejo area (Santa Ana Mountains).

She concluded that the fossils were most likely of Paleocene age, and indicate a warm-temperate to subtropical climate. In 1984, Gaponoff conducted a second study of the palynology of the lignites and carbonaceous clays from the lower non-marine member of the Silverado Formation. The palynological assemblages found suggest a temperate/warm-temperate to subtropical climate, with adequate rainfall (Gaponoff, 1984). In addition, the presence of two pollen taxa - *Momipites tenuipolus* Anderson 1960 and *Plicatopollis triradiata* (Nichols) Frederiksen & Christopher 1978 - restrict the lower member to a late Paleocene age (Gaponoff, 1984).

Without any fossils, it is difficult to ascertain the paleoenvironments present in the San Joaquin Hills during deposition of the Silverado Formation. Paleobotanical studies in the Silverado Formation of the Santa Ana Mountains indicate that the region was comprised an alluvial plain with braided streams, marshes and a delta. However, the distance between the Santa Ana Mountains and the San Joaquin Hills is sufficient enough that each site probably had unique ecological, biological and depositional environments. Thus the type of habitat present during the formation of Paleosol 1 cannot be determined at this time.

Paleoclimate Determination

Fossils are not present within the Silverado Formation exposed in the San Joaquin Hills, thus accurate dating of the units is not possible. Stratigraphic relationships between the rocks exposed in the San Joaquin Hills and those in the Santa Ana Mountains have been established by Yerkes et al (1965) and Schoellhamer et al (1981). Based on this, Paleosol 1 may be the stratigraphic equivalent of the Serrano Clay Bed in the Santa Ana Mountains. This claybed has yielded numerous pollen, spore, and leaf fragments which have been dated as late Paleocene by several individuals (Axelrod, 1979; Sundberg and Warter, 1984).

The climate present during the formation of Paleosol 1, however, can be inferred from the paleobotanical studies in the Silverado Formation of the Santa Ana Mountains and from other climate studies conducted throughout the world. Results from deep sea cores and paleosols indicate that the climate of the Paleocene fluctuated between cool and temperate and warm and tropical, culminating in the abnormally warm Late Paleocene Thermal Maximum. Sundberg and Warter (1984) concluded that the climate in the Trabuco Hills, Aberhill and Rancho Mission Viejo areas was warm and temperate to subtropical. Their findings match Axelrod's (1979) interpretation of the overall climate of the Southern California area as subtropical during the upper Paleocene. The distance between the Santa

Ana Mountains and the San Joaquin Hills is not so great that the overall climate regime would be significantly different. Thus, it is reasonable to assume that the climate present in the San Joaquin Hills during the formation of Paleosol 1 was similar to that observed in the Santa Ana Mountains: warm, temperate to subtropical, with 50-60 inches of precipitation annually. These conditions match what is needed for the alteration of rock into a residual soil.