AN ABSTRACT OF THE THESIS OF

Douglas Christopher Seedorf for the degree of Master of Science in the Department of Geology presented on December 10, 1982

Title: Upper Cretaceous through Eocene Stratigraphy of the Southern Ventura Basin, California

Abstract approved: Redacted for Privacy

Dr. Robert S. Yeats

Surface and subsurface data indicate that Cretaceous strata in the southern Ventura basin are part of the northward prograding Chatsworth submarine fan. The fan extends westward as far as Trancas Beach in the Santa Monica Mountains and wells in the Oxnard Plain and on Oak Ridge. The eastern edge of the fan is constrained by wells in western San Fernando Valley which contain fine-grained strata which may have been deposited east of the Chatsworth fan. The Nonmarine Simi Conglomerate overlies the Cretaceous and is itself overlain by Paleocene marine beach sandstone and siltstone. These marine strata do not extend eastward into the San Fernando Valley. The lower Paleocene and Cretaceous strata were overlapped by the upper Paleocene Santa Susana and middle Eocene Llajas Formations. Sedimentation patterns for the Santa Susana and Llajas may be explained by two models: (1) A northwest-trending submarine ridge on which muds and silts were deposited, was flanked on the northeast and southwest by troughs receiving deep-water sands. (2) Both formations were deposited on a southwest-facing shelf, slope, and turbidite trough. Subsurface data important in basin analysis include 1) bathyal paleo-
bathymetry for the entire Santa Susana, 2) sand channels in the Santa Susana which possibly funneled sediment westward down a submarine slope, 3) shelf-facies (?) Eocene strata with neritic to upper bathyal paleobathymetry in Oxnard Plain, and 4) Llajas facies in northern Simi Valley suggesting gradation upward from a shallow marine to outer shelf or slope environment. Facies correlations across the Simi fault indicate no large-scale post-Paleogene strike-slip displacement. If these sequences were rotated, as suggested by paleomagnetic data, the restored Cretaceous fan would come from the east and the restored Paleocene shoreline would face south. Thus paleogeography for the Cretaceous is simplified by the rotation hypothesis, but Paleocene paleogeography is made more complicated.
UPPER CRETAEOUS THROUGH EOCENE STRATIGRAPHY OF THE
SOUTHERN VENTURA BASIN, CALIFORNIA

by

Douglas Christopher Seedorf

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed December 10, 1982

Commencement June 1983
APPROVED:

Redacted for Privacy

Professor and Chairman of Geology in charge of major

Redacted for Privacy

Dean of Graduate School

Date thesis is presented December 10, 1982

Typed by Therese Belden for Douglas Christopher Seedorf
## TABLE OF CONTENTS

INTRODUCTION
- Statement of Problem ............................... 1
- Methods ........................................... 1
- Acknowledgements .................................. 4

STRATIGRAPHY OF THE SIMI VALLEY OUTCROP SECTIONS
- Chatsworth Formation .............................. 7
- Pre-Santa Susana Undifferentiated Strata .... 9
- Santa Susana Formation ......................... 11
- Llajas Formation .................................. 13
- Sespe Formation ................................ 15

STRATIGRAPHY OF OTHER OUTCROP AREAS
- Simi Valley-West End ............................. 16
- Northwestern San Fernando Valley ......... 16
- Newhall ........................................... 17
- Santa Monica Mountains ....................... 17

SUBSURFACE STRATIGRAPHY
- Simi Valley ..................................... 21
- Northwestern San Fernando Valley ......... 24
- Santa Susana Mountains ....................... 27
- Newhall .......................................... 27
- Oak Ridge ...................................... 28
- Oxnard Plain .................................. 29

DISCUSSION AND CONCLUSIONS ....................... 31

REFERENCES CITED ................................ 45

APPENDIX ........................................... 52
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Index map of the southern Ventura basin</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Stratigraphic chart showing biostratigraphic zonation applied to the northern Simi Valley section</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Base map of southern Ventura basin</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>26</td>
</tr>
<tr>
<td>Location map of the Frew and Santa Susana faults</td>
<td>26</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
</tr>
<tr>
<td>Distribution of surface Cretaceous rocks</td>
<td>32</td>
</tr>
<tr>
<td>6</td>
<td>34</td>
</tr>
<tr>
<td>Distribution map of the Simi Conglomerate</td>
<td>34</td>
</tr>
<tr>
<td>7</td>
<td>36</td>
</tr>
<tr>
<td>Extent of pre-Santa Susana marine Paleocene strata and the overlapping of the Santa Susana Formation</td>
<td>36</td>
</tr>
<tr>
<td>8</td>
<td>37</td>
</tr>
<tr>
<td>Distribution map of the Santa Susana Formation</td>
<td>37</td>
</tr>
<tr>
<td>9</td>
<td>40</td>
</tr>
<tr>
<td>Distribution map of the Llajas Formation</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>43</td>
</tr>
<tr>
<td>Post Paleogene rotation of the southern Ventura basin</td>
<td>43</td>
</tr>
</tbody>
</table>
### LIST OF PLATES

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Paleocene and Eocene geology of the Simi Valley area, Ventura basin, California</td>
</tr>
<tr>
<td>II</td>
<td>Stratigraphic Section A-A'</td>
</tr>
<tr>
<td>III</td>
<td>Stratigraphic Section B-B'</td>
</tr>
<tr>
<td>IV</td>
<td>Stratigraphic Section C-C'</td>
</tr>
<tr>
<td>V</td>
<td>Stratigraphic Section D-D'</td>
</tr>
<tr>
<td>VI</td>
<td>Structure Section E-E'</td>
</tr>
<tr>
<td>VII</td>
<td>Structure Section F-F'</td>
</tr>
<tr>
<td>VIII</td>
<td>Stratigraphic Section G-G'</td>
</tr>
<tr>
<td>IX</td>
<td>Stratigraphic Section H-H'</td>
</tr>
<tr>
<td>X</td>
<td>Stratigraphic Section I-I'</td>
</tr>
<tr>
<td>XI</td>
<td>Stratigraphic Section J-J'</td>
</tr>
<tr>
<td>XII</td>
<td>Stratigraphic Section K-K'</td>
</tr>
</tbody>
</table>
UPPER CRETACEOUS THROUGH EOCENE STRATIGRAPHY OF THE
SOUTHERN VENTURA BASIN, CALIFORNIA

INTRODUCTION

Statement of Problem

Basin analysis of Paleogene strata in California leads to the conclusion that Paleogene basins follow a far different configura
tion than Neogene basins or present-day topographic lowlands (Yerkes and others, 1965; Yeats, 1968, 1976; Chipping, 1972; Nilsen and Clarke, 1973, 1975; Yeats and others, 1974). Most of the basin analysis of the Paleogene of southern Ventura basin is based upon the outcrop section in the eastern Simi Valley (Fig. 1) with little attention paid to subsurface geology. The Paleogene outcrops in Simi Valley are not representative of much of the Paleogene in the subsurface of the southern Ventura basin. This paper extends the basin analysis of this sequence by considering not only the surface exposures in the Simi Valley (Plate 1), but also the subsurface control as based upon wells in which the structure has been resolved and stratigraphic thicknesses, lithologies, and ages are relatively clear-cut.

Methods

Paleocene and Eocene outcrop localities, including Solstice and Elsmere Canyons and the Simi Valley, were field checked during the summer of 1981. The geologic map of the Simi Valley area was
Figure 1. Index map of southern Ventura basin. Paleocene and Eocene rocks are shown in stippled pattern, (after Jennings and Strand, 1969).
compiled and revised based upon this field reconnaissance and the
mapping of other workers cited on Plate I. Samples from the
California Well Sample Repository at Cal. State Bakersfield were
examined and used in well descriptions (see Appendix). Data for
over 150 wells, including electric and dipmeter logs, well his-
tories, core, sidewall, and ditch sample descriptions, and paleon-
tology reports were obtained from the Division of Oil and Gas and
several different oil companies. The well data were used in con-
structing 11 stratigraphic sections. In most cases, subsurface
formation boundaries were based upon previously constructed
published and unpublished structure sections (for example see Lant,

Paleogene basin analysis required the removal of post-Llajas
structure, including major deformation in the early Miocene, mid-
dle Miocene, late Miocene, and Pliocene-Quaternary. This removal
was accomplished by constructing stratigraphic sections using the
base of the late Eocene to early Miocene nonmarine Sespe Formation
as a datum. Where the base of the Sespe is not present, or where
its stratigraphic position could not be estimated accurately, the
base of the middle Eocene Llajas Formation was used as a datum;
where the Llajas is absent, the base of the Tertiary was used.
The stratigraphic sections show true thicknesses from the youngest
strata in the well upsection to the base of the Sespe for those
wells that spudded in below that datum. True thicknesses are
shown for all outcrop sections. Well logs in the stratigraphic
sections show apparent thicknesses and the angle between the well
bore and the pole to bedding. The true thickness is the product of the well-log apparent thickness and the cosine of this angle.

Paleontological data for wells are based upon company and consultant reports. For those wells with conflicting paleontological data (for example, see Porter Estate 81-16, Sections G-G', H-H', Plates VIII, IX), lithology and electric-log characteristics were used in an attempt to resolve the biostratigraphic conflicts. In several cases, faunal reports were not age-diagnostic, or the samples were possibly contaminated by sidewall cavings. These considerations were taken into account when selecting wells for basin analysis.

Figure 2 presents a summary of the megafossil and microfossil subdivisions used in the Simi Valley. Most dates reported on stratigraphic sections are reported as Pacific Coast microfaunal stages based upon benthic foraminifers. On the basis of planktic foraminifer zonation, Poore (1980) suggested that these benthic foraminifer stages may be time-transgressive over a large area. The southern Ventura basin is probably too small an area to evaluate this possibility, and individual benthic foraminifer stages are assumed to be time-equivalent throughout the area. No attempt was made in this study to evaluate the fossil assemblages on which paleontological interpretations of age or bathymetry were based.

Acknowledgements

Support for this study was supplied by 1) a Tenneco Fellowship
### Figure 2. Stratigraphic chart showing biostratigraphic zonation applied to the Simi Valley. Modified from Schmidt (1970).
awarded to Oregon State University, 2) a summer grant from Arco Oil and Gas Company, and 3) by additional funds provided to Dr. Robert S. Yeats by MCOR Oil and Gas Company. I thank Dr. Yeats for his support, advice, and patience throughout this project. I also received help and advice from Leonard Stitt and Kevin Lant of Conoco, Robert Diem, Stuart Kessling, and Don Sherman of Texaco, and Mark Filewicz and Ed Hall of Union.

Alan Niem, Keith Oles, Richard Squires, and Bob Yeats critically reviewed the thesis. Mike Kuhn and Orrin Sage of Simi Valley helped me obtain aerial photographs and access to private land in the Simi Hills, Harold Weber provided me with his unpublished map of the westernmost Simi Hills, and Jack Tucker assisted me at the California Core Repository. Edwin Howes drafted the illustrations, and Therese Belden typed the manuscript.
STRATIGRAPHY OF THE SIMI VALLEY OUTCROP SECTIONS

Chatsworth Formation

Cretaceous strata in the Simi Valley originally were correlated to the "Chico Formation" by Waring (1914, 1917) and Kew (1924) based upon the similarity of an assemblage of Cretaceous megafossils to those of the Chico Formation of northern California rather than their lithologic similarity to and stratigraphic continuity with a type locality. Colburn, Saul, and Almgren (1981) renamed the Cretaceous sequence in the Simi Valley the Chatsworth Formation, and they designated a type section along Woolsey and Black Canyons in the Simi Hills (Plate I, Fig. 3). Link (1981) characterized the Chatsworth Formation as a turbidite sequence composed largely, but not exclusively, of sandstone and interbedded hemipelagic mudstone. This sequence was deposited on an east- to northeast-trending paleoslope with north- to northwest-oriented channels (Trembly and Kraemer, 1981) as part of the Chatsworth deep-sea fan (Colburn, 1981; Colburn, West, and Carey, 1981; Link, 1981).

The Chatsworth Formation is referred to the upper Campanian through the lower Maestrichian stages as based upon molluscan fossils and benthic foraminifers (Popenoe, 1973; Colburn, Saul, and Almgren, 1981). The Chatsworth Formation was correlated to the "E-zone" of Goudkoff (1945) by Colburn, Saul, and Almgren (1981) on the basis of agglutinated foraminifers found throughout the sequence in the Simi Hills.
Figure 3. Base map of southern Ventura basin. Well names numbered alphabetically, see appendix for listing. Outcrop localities as follows: Black-Woolsey Cyn. - BWC; Blind Cyn. - BLC; Bus Cyn. - BC; Carbon Cyn - CBC; Chatsworth Reservoir - CR; Elsmere Cyn. - EC; Long Cyn. - LC; Meier Cyn. - MC; east of Meier Cyn. - EMC; Montgomery Cyn. - MGC; Oak Cyn. - OC; Poison Oak Cyn. - POC; Runkle Cyn. - RC; Solstice Cyn. - SOC; Squires' (1981) sections - SA, SB, SC, SE, SG; Sycamore Cyn. - SYC; Tapo Cyn. - TPC; Topanga Cyn. - TC; Tuna Cyn. - TUC; and West End - WE.
The Chatsworth Formation is overlain disconformably by the Simi Conglomerate at the type section (Colburn, Saul, and Almgren, 1981), and in northeastern Simi Valley. Elsewhere in the Simi Valley, the unconformity with the overlying Paleocene has been reported as angular (Fantozzi, 1955; Sage, 1971).

**Pre-Santa Susana undifferentiated strata**

The lower Tertiary strata in the Simi Valley were originally referred to the "Martinez Formation" by Kew (1919, 1924), based upon the mapping and fossil collections of Waring (1917). Nelson (1925) divided the "Martinez Formation" into the Simi Conglomerate and the overlying Las Virgenes Sandstone. Fantozzi (1955) informally proposed the name "Calabasas Formation" to replace the "Martinez Formation" because the Martinez correlation is based upon an assemblage of fossils rather than its lithologic similarity to and stratigraphic continuity with a type locality. Sage (1973) divided the "Calabasas Formation" into three members, the Simi Conglomerate, Las Virgenes Sandstone, and Burro Sandstone. Subsequently, the U.S. Geological Survey adopted the name "Calabasas" as a formation name for middle Miocene strata overlying the Conejo Volcanics in the Santa Monica Mountains (Yerkes and Campbell, 1979), and so the name is no longer used for the Paleocene of the Simi Valley. The sequence is referred to in this study as the "pre-Santa Susana undifferentiated" (Plate I); it includes the Simi Conglomerate and marine Paleocene strata below Zinsmeister's (1974) upper boundary of the Las Virgenes Sandstone (marine facies
The Simi Conglomerate consists of a pebble-
to boulder-
conglomerate in a sandstone matrix. West of the Simi Peak fault
(Plate I), the Simi Conglomerate is overlain by a one-meter-thick,
red pisolitic claystone which may have been deposited in a lagoon-
al environment (Sage, 1973). This claystone is probably correla-
tive to the Claymont Clay first described in the Santa Ana Moun-
tains by Roth (1958). The marine Paleocene interfingers with
and overlies the Simi Conglomerate and consists of brown-gray,
fine- to coarse-grained fossiliferous siltstone, sandstone, and
conglomeratic sandstone. Paleocurrent and petrographic data sug-
gest the Simi Conglomerate was deposited by a southwest-flowing
braided river and alluvial fan system that grades upward into a
nearshore or beach deposit (marine Paleocene) composed of reworked
Simi Conglomerate clasts (Sage, 1973; Zinsmeister, 1974).

The pre-Santa Susana Tertiary in the Simi Valley is corre-
lated to the provincial megainvertebrate "Martinez Stage" as based
upon mollusks (Browning, 1952; Mallory, 1959; Zinsmeister, 1974)
and to the Ynezian Stage and Laiming "E" zone as based upon
benthic foraminifers (Browning, 1952; Mallory, 1959; Janes, 1976)
(Fig. 2).

The contact between the pre-Santa Susana Tertiary and the
overlying Santa Susana Formation was reported by Zinsmeister
(1974) as disconformable in Meier Canyon. Browning (1952) and
Janes (1976) found also the contact to be disconformable in Poison
Oak Canyon, whereas Finch (1980) reported a conformable contact in
Bus Canyon.

**Santa Susana Formation**

Nelson (1925) divided the lower Tertiary strata of the Simi Valley into the Simi Conglomerate, Las Virgenes Sandstone, Martinez Marine Member, and the Santa Susana Shale. Zinsmeister (1974) showed that beds of concretionary sandstone of the Martinez Marine Member were actually sandstone tongues interbedded with siltstone and mudstone of the Santa Susana Formation. In this study, the Santa Susana Formation is divided into a sandstone and conglomerate member and a member which consists of thin bedded, blue-gray mudstone, siltstone, and gray-brown silty sandstone. The Santa Susana records outer shelf and slope deposition in a subsiding basin at lower neritic to upper bathyal depths in an open ocean environment (Browning, 1952; Schmidt, 1970; Zinsmeister, 1974; Janes, 1976; Finch, 1980). Zinsmeister (1974) recognized alternating sandstone and siltstone tongues on the south side of the Simi Valley. However, these tongues could not be traced in the subsurface very far from the outcrop.

Clark and Vokes (1936) assigned the Santa Susana siltstone below the Santa Susana Conglomerate to the "Martinez Stage" based upon megafossils. The Santa Susana strata overlying the siltstone were referred to the "Meganos Stage." This correlation is based upon the occurrence of *in situ* "Meganos" fauna found in the upper 300 feet of the Santa Susana in Poison Oak Canyon. Browning (1952), Fantozzi (1955), and Zinsmeister (1974) reported the oc-
currence of "Martinez Stage" fauna well within the Santa Susana Formation. Thus, the upper boundary of the "Martinez Stage" is incorrectly placed in the Simi Valley by Clark and Vokes (1936), and it should be changed to include the lower part of the Santa Susana Formation as well as the pre-Santa Susana Tertiary. A revised boundary based upon Browning's (1952) data is shown in Figure 2.

Laiming (1939) used the Santa Susana Formation in the Simi Valley to establish a provisional foraminiferal zonation for the lower Tertiary in California. He divided the Santa Susana into the "E," "D," "C," "B-4," and "B-3" zones, in ascending order. Browning (1952) extended Laiming's "E" zone up into the middle Santa Susana and suggested that the upper part of the formation could be correlated to the "D," "C," and "B-4" zones. The "B-4" and "C" zones may represent faunas displaced from coeval shallow-water sediments (M. V. Filewicz, written commun., 1982). Based upon both megafossil and microfossil evidence, Mallory (1959) correlated the Santa Susana Formation to his upper Ynezian, Bulitian, and Penutian Stages. Schmidt (1970), Janes (1976), and Finch (1980) correlated the Santa Susana to the P4 and P5 zones of Blow (1969) based upon planktic foraminifers. The upper Santa Susana has also been correlated to the Discoaster multiradiatus-Discoaster diastypus zone based upon nannofossils (M. V. Filewicz, written commun., 1982).

Laiming (1939) correlated his "C," "B-4," "B-3," and "B-2" zones to the Capay Stage of Clark and Vokes (1936), and Mallory
(1959) assigned the upper Santa Susana to the Penutian Stage, which he considered to be correlative to the megainvertebrate Capay Stage. Thus, besides the misplaced "Martinez Stage" boundary mentioned above, there is a discrepancy between the microfossil and megafossil correlations of the upper Santa Susana Formation. Schmidt (1970) suggested that the problem could be the result of one or a combination of the following possibilities:
1) a mis-correlation of fauna to one of the zonation schemes; 2) an incorrect original correlation between megafossil and microfossil zonations; 3) the biostratigraphic units in one or both classifications may be facies-dependent and time-transgressive.

The contact between the Santa Susana Formation and the overlying Llajas Formation is reported as disconformable in Chivo Canyon (Squires, 1981) and Bus Canyon (Finch, 1980), and conformable in Bus, Oak, and Montgomery Canyons (Howell, 1974), and in Poison Oak Canyon (Browning, 1952; Grier, 1953; Janes, 1976) (Plate I, Fig. 3). Nannofossil assemblages, considered together with other faunas, suggest a hiatus of 3 m.y. between the Santa Susana and overlying Llajas, encompassing most of the early Eocene (N. V. Filewicz, written commun., 1982).

**Llajas Formation**

The Llajas Formation was first described by Waring (1917) and Kew (1919, 1924) as the "Tejon Formation" and then later as the "Meganos Formation." The name "Llajas Formation" was first used informally by Schenck (1931) and McMasters (1933). Cushman and
McMasters (1936) formally named the Llajas Formation and designated a type section in Las Llajas Canyon. They also described the Llajas in cores from the Getty Tapo 42 well (Plate I).

In this report, the Llajas is divided into a basal conglomerate and an overlying undifferentiated sequence of light-brown to gray very fine- to fine-grained sandstone. At its type locality, the Llajas was deposited as a transitional alluvial to marine sequence (Squires, 1981). Howell (1974) and Squires (1981) cited faunal and sedimentological evidence to suggest deposition of the Llajas in water depths that varied from neritic to upper bathyal. Howell (1974) measured imbricate clast orientations in the basal conglomerate which indicate a westward direction of flow. Yeats and others (1974) reported data from the Llajas sandstone in western Simi Hills which indicate a northward sediment transport direction. Squires (1981) mentioned that paleocurrent data are random in the lower shallow marine part of the sequence on the north side of Simi Valley.

Clark and Vokes (1936) assigned the Llajas Formation to the provincial megainvertebrate "Capay" and "Domengine" stages based upon mollusks (Fig. 2). Laiming (1939) correlated the Llajas with his "B-3" through "B-1A" foraminiferal zones. Mallory (1959) correlated the basal conglomerate of the Llajas with the upper Penutian Stage and stated that the remaining Llajas belonged to the Ulatisian Stage. New data, including nannofossils, suggest an early middle Eocene age for the Llajas (M. V. Filewicz, written commun., 1982).
The contact between the Llajas Formation and the overlying Sespe Formation was reported to be conformable in Bus, Montgomery, and Oak Canyons (Howell, 1974) and in the Simi oil field (Stipp, 1943). On the other hand, Kew (1924) reported an unconformable contact between the two formations, Hetherington (1957) found the contact to be disconformable in Tapo Canyon, and Squires (1981) found that the contact is unconformable in the Las Llajas Canyon area (Fig. 3).

**Sespe Formation**

The lower part of the Sespe Formation found in the Simi Valley area is composed of nonmarine multicolored sandstone and siltstone with interbeds of pebble- to cobble-conglomerate (Kew, 1924; Bailey, 1947; Fan, 1963; McCracken, 1972). Imbricate clasts in the lower Sespe indicate northwestward sediment transport (Yeats and others, 1974). The Sespe Formation ranges in age from late Eocene (Uintan) to early Miocene (Arikareean) as based upon vertebrate fossils (Stock, 1932).
STRATIGRAPHY OF OTHER OUTCROP AREAS

Simi Valley-West End

Most of the published work on Simi Valley Paleogene stratigraphy describes the sequence which crops out on the north side of the valley and on the south side of the valley as far west as Bus Canyon (Fig. 3, Plate I). West of Bus Canyon, formation boundaries are less well defined due to cover. Some mapping has been completed in the west (MacIvor, 1955; Zinsmeister, 1974; F. H. Weber, in progress; R. Squires, in progress), but biostratigraphy is incomplete. Zinsmeister (1974) mapped interbedded sandstone and siltstone tongues of the Santa Susana Formation to the western end of the Paleogene outcrop. However, due to poor exposure in the area, it is not clear whether the Santa Susana actually becomes sandier westward or if the Llajas Formation thickens appreciably. Zinsmeister (1974) suggested that the increase in sandstone indicates a source area to the southwest. This interpretation is in conflict with paleocurrent data found in Poison Oak Canyon (Janes, 1976) which indicate a source area to the southeast.

Northwestern San Fernando Valley

"Martinez Formation" conglomerate is mapped overlying Cretaceous strata on the northeast edge of Chatsworth Reservoir in the Blind Canyon area, and just east of Brown's Canyon (Figs. 1, 3) (Evans and Miller, 1978). Descriptions of the lithology and the fauna which include Turritella pachecoensis (Evans and Miller,
1978), suggest that these may be Santa Susana conglomerate rather than the Simi Conglomerate, which is nonmarine. The possibility that conglomerate within the Santa Susana contains abundant clasts reworked from the Simi Conglomerate further complicates the problem.

Newhall

The oldest exposed sedimentary rocks in the Newhall area are an Eocene sequence which crops out in Elsmere Canyon (Fig. 1). The outcrops consist of a sequence of blue-gray siltstone and claystone overlain by light-brown to gray, fine- to medium-grained, thick-bedded arkosic sandstone. This sequence is correlated to the type Llajas Formation in Simi Valley as based upon megafauna (Oakeshott, 1958; Winterer and Durham, 1962).

North of Newhall and along the San Gabriel fault in the vicinity of San Francisquito Canyon, strata of Late Cretaceous and Paleocene age crop out. These strata are named the San Francisquito Formation (Sage, 1973; Kooser, 1982). Palinspastic reconstruction of Paleocene paleogeography, which involves removing large-scale right-slip displacement along the San Gabriel fault, indicates that the San Francisquito Formation was deposited far away from the Elsmere Canyon sequence and the Simi Valley (Sage, 1973); hence, it is not considered further in this paper.

Santa Monica Mountains

Cretaceous, Paleocene, and Eocene strata are exposed in several canyons on the south flank of the Santa Monica Mountains.
north of the Malibu Coast fault (Figs. 1, 3). The Tuna Canyon Formation of Late Cretaceous age consists of a sequence of thick-bedded, graded and laminated beds of coarse-grained arkosic sandstone deposited by turbidity currents, with interbeds of fossiliferous sandstone and siltstone (Yerkes and Campbell, 1979). Megafossil collections from the Tuna Canyon Formation are assigned to the upper Turonian through lower Maestrichtian Stages (Wilson, 1942; Champeny, 1961).

Disconformably overlying the Tuna Canyon Formation in Solstice Canyon is a thick-bedded sandy conglomerate overlain by a red sandy pisolithic claystone. This unit is correlated to the Simi Conglomerate (Yerkes and Campbell, 1979) and was deposited in a braided-stream environment (Sage, 1973). The pisolithic claystone is probably correlative to the Claymont Clay of the Santa Ana Mountains.

Overlying the Simi Conglomerate in Solstice Canyon, and overlying the Tuna Canyon Formation east of Solstice Canyon, is a sequence of Paleocene conglomerate, claystone, and sandstone named the Coal Canyon Formation by Yerkes and Campbell (1979). In the Santa Monica Mountains, Sage (1973) separated these Paleocene strata into three different depositional environments. East of Topanga Canyon (Figs. 1, 3), poorly sorted conglomerate and sandstone in the lower part of the section were deposited as a southwest-flowing submarine or alluvial fan. The upper part of the section is characterized by thick bedded sandstone and shale overlain by discontinuous lenses of algal limestone, indicating a
shallow-marine environment.

To the west in Topanga, Tuna, and Carbon Canyons, Sage (1973) interpreted the sequence as submarine fan or channel deposits where deposition took place at neritic depths based upon in situ megafossils including *Turritella pachecoensis* and *Mesalia martinezensis*.

Farther to the west in Solstice Canyon, micaceous sandstone and claystone overlying the Simi Conglomerate are also referred to the Coal Canyon Formation by Yerkes and Campbell (1979). These beds contain neritic fauna, plant fragments, fining-upward sequences, trough cross-bedding, and discontinuous claystone and peaty shale beds. Sage (1973) inferred meandering river and lagoonal deposition in the lower part of the sequence, and shoreline and shallow marine deposition in the upper part.

Paleocurrent trends for the Paleocene in the Santa Monica Mountains indicate a source area to the northeast and east (Sage, 1973). Sage (1973) also noted that 1) maximum average clast size decreases to the west and upsection; 2) clast sorting improves to the west; 3) pebble:sand and sand:mud ratios decrease to the west; and 4) the amount of carbonaceous material in the sandstone decreases upsection and to the west.

These data present problems when trying to explain why the Simi Conglomerate is missing from the sections east of Solstice Canyon and also why greater water depths of deposition are encountered eastward.

It is suggested that the Simi Conglomerate and the lower part
of the Coal Canyon Formation in Solstice Canyon are not time
equivalent to the Coal Canyon Formation east of Solstice Canyon.
Although "Martinez Stage" megafossils are found throughout the
Coal Canyon Formation, it seems probable that the lower part of
the sequence in Solstice Canyon is correlative to the pre-Santa
Susana Paleocene of the Simi Valley, whereas the strata east of
Solstice Canyon are correlative to the lower Santa Susana Forma-
tion. This overlapping relationship with the Santa Susana is
identical to that proposed for the Simi Valley (see discussion
and conclusions and Fig. 6).

The middle Eocene presumed Llajas Formation in Solstice
Canyon in the Santa Monica Mountains (Yerkes and Campbell, 1979)
comprises a sequence of siltstone, sandstone, and conglomeratic
sandstone which represents a shallow-marine environment (neritic)
with a westward-flowing sediment dispersal system (Howell, 1974).
The contact with the overlying Sespe Formation is conformable
(Howell, 1974; Yerkes and Campbell, 1979).
SUBSURFACE STRATIGRAPHY

Simi Valley

Upper Cretaceous strata are poorly represented in the subsurface of the Simi Valley area. Benthic foraminifer data indicate that the Pacific Western Marr 1 well in the Simi Valley reached the Cretaceous (Section A-A', Plate IIb). Farther to the east, the Getty Joughin 1 and Standard Frew 1-1 wells penetrate up to 2,700 feet of Cretaceous strata (Section A-A', Plate IIc). Electric-log characteristics and lithologic descriptions of the Cretaceous in these wells suggest a sequence of sandstone and mudstone similar to exposures in the Simi Hills, and similar to descriptions of electric logs in the Horse Meadows oil field which are correlated to the Chatsworth Formation (Link, 1981).

The pre-Santa Susana Paleocene is cut by several wells in and near the Simi Valley (Section A-A', Plates IIb, IIc), but the Simi Conglomerate cannot be differentiated as a separate member in the subsurface. Conglomerate is common in these wells, and at least the upper part of the sequence contains benthic foraminifers.

An unconformity with considerable topographic relief between the Cretaceous and overlying Tertiary strata is documented in the subsurface east of the line where the pre-Santa Susana Tertiary strata and Upper Cretaceous strata are overlapped by the Santa Susana Formation (Section A-A', Plate IIc). Approximately 450 feet of pre-Santa Susana Paleocene strata are present in the Getty Joughin 1 well, but farther east, Santa Susana conglomerate
rests directly on Cretaceous strata in the Frew 1-1 well. This subsurface relation suggests that the Paleocene conglomerate exposures to the south in Blind Canyon, east of Brown's Canyon, and in the Chatsworth Reservoir area (Fig. 1) are the Santa Susana conglomerate.

Subsurface data in the southwest Simi Valley (Section B-B', Plates IIIa, IIIb) are not adequate to map Zinsmeister's (1974) outcropping sandstone tongues within the Santa Susana Formation. However, the sandstone tongues are probably present in the Regent Runkle 1 well, but they are absent in the C. A. Palmer Brandeis 1 and Pamoan Hot Rod Flannagan 1 wells to the east, documenting an eastward change of the Santa Susana to a finer-grained facies in the subsurface as well as on the surface (Section B-B', Plate IIIb).

Thick wedge-shaped sandstone lenses are again present in the Santa Susana Formation in Union Las Llajas Corehole 1 through Standard Frew 1-1 wells (Section A-A', Plate IIc). These northeastern sandstone lenses as well as Zinsmeister's (1974) sandstone tongues to the southwest (Section B-B', Plates IIIa, IIIb) may chart cycles of submarine fan development, abandonment, and rejuvenation during Santa Susana deposition in a slope environment.

Lithologic descriptions and electric-log characteristics of the Llajas Formation west of the M. H. Marr Marr Ranch 20 well (Section A-A', Plates IIa, IIb) indicate predominant sand and gravel deposition in the lower part of the section changing to mostly silt with minor sand deposition in the upper part. Squires
(1981) documented this same relationship in the type section at Chivo Canyon (Plate IIb, Squires' A section) where the sequence changes upsection from a shallow marine to an outer shelf or slope depositional environment.

West of the type Llajas in Chivo Canyon, the sequence grades to predominantly siltstone as far west as the Macson Strathearn 1 well (Section A-A', Plates IIa, IIb). A north-south transect of the Simi Valley (Section C-C', Plate IV) shows that the Llajas Formation is predominantly siltstone in the southern part of the Simi Valley as well as in the northern part.

West of the Macson Strathearn 1 well (Section A-A', Plate IIa), thick sandstone lenses are interbedded with sandy shale in the Hancock Strathearn 16-6 through Marathon Vail 1 wells. This same stratigraphic relationship is documented to the south (Section B-B', Plate IIIa) in Runkle Canyon and the Mayo Montgomery 1 well, and westward to the Intex McCrea 1 well. Section D-D' (Plate V), comprising the Intex McCrea 1, Marathon Vail 1, and Union Simi 1-35 wells, shows that these sandstone lenses in the Llajas are common west and southwest of the Simi Valley.

Benthic foraminifers found in the Shell Strathearn 1 well (Ross, 1952) (Section A-A', Plate IIa) and in the Havenstrite Tapo 1 well (Section C-C', Plate IV) indicate deposition of the Llajas at neritic depths in the lower part of the formation, and at bathyal depths in the upper part of the formation. This is similar to the depositional sequence at the type section, as described by Squires (1981) (Section A-A', Plate IIb).
Northwestern San Fernando Valley

The Cretaceous strata in the lower part of the Sun Porter Estate 81-16 well and, to a lesser extent, in the lower part of the Porter Sesnon Horse Meadows 2-47 well (Sections G-G', H-H', Plates VIII, IXa) are mainly fine-grained siltstone, in contrast to the coarser grained, sandstone-rich Cretaceous sequence of the Aliso Canyon oil field (Section E-E', Plate VI) and the Simi Hills. This change of facies eastward suggests that the Cretaceous of the San Fernando Valley was east of the main Cretaceous Chatsworth fan. Cretaceous strata in the Sun Porter Estate 81-16 well (Plates VIII, IX) contain foraminifers of the "F-zone" and possibly the "G-Zone" of Goudkoff (1945).

The disconformable contact between the Cretaceous and overlying Tertiary in the vicinity of the type section at Black Canyon in the Simi Hills changes to an angular unconformity in the northwestern San Fernando Valley, as documented in the hanging-wall block of the Frew fault in the Aliso Canyon oil field (Fig. 4, Section E-E', Plate VI) and in the Horse Meadows oil field (Section F-F', Plate VII). Because the Santa Susana Formation rests directly upon the Cretaceous in both these oil fields, the age of tilting of the Cretaceous can be dated only as pre-Santa Susana. In section F-F' (Plate VII) as well as sections G-G' and H-H' (Plates VIII, IX), the pre-Santa Susana Tertiary is missing, and there is only one possible occurrence of the Santa Susana conglomerate (Section G-G', Plate VIII, Porter Sesnon
Quarry 78-4). Otherwise, gray claystone and siltstone of the Santa Susana Formation overlap the pre-Santa Susana Tertiary and rest directly on Cretaceous turbidites (Lant, 1977; Shields, 1977). The blue-gray siltstone and claystone of the Santa Susana Formation in the northeastern Simi Valley and northwestern San Fernando Valley (Plates VIII, IX) change to a sandier lithology to the northeast in the Exxon Marquis 1, Gulf Ward 1, and Continental Phillips 1 wells (Plate IXb), and Frew 1-1 through Porter Sesnon Sesnon Fee 7 wells (Plates VI and VIII).

Disconformably(?) above the Santa Susana Formation in section H-H' (Plate IXb), the Llajas basal conglomerate thickens markedly to the southwest, especially in the Arco Pertusati 1 and Shell Schonfeld 1 wells. The overlying Llajas Formation is finer grained than that found in the Simi Valley area with the exception of the Scope Miller-Sanger 1 well, which contains a sequence dominated by sandstone.

The Llajas Formation in the subsurface of northwestern San Fernando Valley is overlain successively by nonmarine sandstone, marine siltstone, and middle Miocene Topanga basalt (Shields, 1977). Because of the close stratigraphic proximity to the middle Topanga basalt and the fact that other Topanga outcrops interbedded with Miocene volcanic rocks in the San Fernando Valley are nonmarine (Oakeshott, 1958), the nonmarine sequence is considered by Shields (1977) to be correlative with the nonmarine part of the lower Topanga Formation in the Santa Monica Mountains (Durrell, 1954; Campbell and others, 1966) rather than the Sespe Formation.
Figure 4. Location map of the Frew and Santa Susana faults. After Lant (1977), Shields (1977), and Yeats, Butler & Schlueter (1977).
Santa Susana Mountains

Section I-I' (Plate X) in the Santa Susana Mountains, is parallel to the Frew fault on the footwall side (Fig. 4). The similarity of sandstone lithology of the Llajas Formation in this section and section A-A' (Plate IIc), which is also parallel to the Frew fault on the hanging-wall side, suggests that there has not been large-scale lateral displacement on the Frew fault.

Newhall

A thick sequence of Paleocene and Eocene strata is present in the Continental Phillips 1 well (Section H-H', Plate IXb). The lowermost conglomerate was previously described as the Simi Conglomerate (Nelligan, 1978). However, the presence of foraminifers equivalent to the "D" zone of Laiming (1939), the overlapping relationship of the Santa Susana Formation to the southwest (Sections A-A', E-E', Plates IIc, VI), and the lack of evidence for "Martinez" or Laiming "E" zone faunas suggest that the conglomerate is part of the basal Santa Susana Formation. Directly above the Santa Susana conglomerate, the dominant lithologies are siltstone and claystone. This part of the section is like the Santa Susana in those wells southwest of Exxon Marquis 1 in section H-H' (Plate IX) or the Getty Frew 1-1 well in sections A-A' and E-E' (Plates IIc, VI). The intermixing of claystone, siltstone, and conglomerate in the upper part of the Santa Susana suggests an influx of coarser-grained material from a nearby source.
Above the Santa Susana Formation, the Llajas Formation consists of siltstone with minor sandstone. This is a relatively fine-grained sequence as compared with the type Llajas in the Simi Valley. However, the data from the Phillips 1 well and the Elsmere Canyon outcrop suggest that these strata are related more closely to the Simi Valley sequence than either the San Francisquito Formation or the Paleogene of the Topa Topa Mountains.

Oak Ridge

Approximately 2,000 feet of Upper Cretaceous sandstone occur in the Shell Dryden 2 well on Oak Ridge (Section J-J', Plate XIa). Sandstone core descriptions for the Cretaceous are similar to the sequence which crops out in the Simi Valley. This suggests that the Dryden 2 well penetrated part of the Chatsworth fan.

Above the Cretaceous, the entire pre-Llajas Tertiary is overlapped westward across Oak Ridge by the Llajas Formation. The correlation of the pre-Llajas strata in the Union Torrey 92 well (Section J-J', Plate XIb) is problematic; these strata may be correlative to the Santa Susana Formation or to the pre-Santa Susana Tertiary. Faunal evidence does not preclude a Cretaceous age for the lowest part of the section in the well. The middle Eocene age of the Llajas basal conglomerate in the Union Torrey 92 well is suggested by the presence of an algal limestone which possibly is correlative to the middle Eocene Sierra Blanca Limestone found in the Santa Ynez Mountains (Johnson, 1968; Howell, 1974). Middle Eocene fauna and conglomeratic lithology suggest the presence of
the Liajas basal conglomerate in the Shell Dryden 2 well (Plate XIa). A sharp lithologic change to gray sandstone, which continues downhole through the appearance of a definite Cretaceous fauna, suggests that the Liajas conglomerate rests unconformably on Upper Cretaceous strata in the Dryden 2 well.

Neritic paleobathymetry in the Texaco Shells E-7 and E-8 wells (Section J-J', Plate XIa), based upon benthic foraminifers, may chart the regression found in the upper Liajas Formation at the type section (Squires, 1981). Brackish-water shale described in the Union C & H 10 well further supports neritic depths of deposition and may indicate that paleogeography during late Liajas time included an estuarine environment on part of Oak Ridge. The Liajas thickens from east to west across Oak Ridge from approximately 2,800 feet as documented in the Havenstrite Tapo 1, to approximately 3,800 feet in the Shell Dryden 2 (Plate XI).

**Oxnard Plain**

Cretaceous sandstone, similar in description and electric-log character to that in the northwestern San Fernando Valley is encountered in the bottom 900 feet of the Sun Ferrell 1 well (Section K-K', Plate XIIc). Farther southwest, Cretaceous strata may also occur in the Texaco Capital-Oxnard 1 and Lloyd Livingston 4 wells (Plate XIIa, XIIb). These sandstones may be part of the same depositional system that deposited Cretaceous strata in the Simi Hills and Santa Monica Mountains. However, none of these sequences is confirmed as Cretaceous on the basis of fossils.
The sandy pre-Llajas Tertiary strata beneath the Oxnard Plain are similar lithologically to the pre-Santa Susana marine sequence in the southwestern Simi Hills (Section B-B', Plate III). However, the identity of this sequence is questionable without better biostratigraphic zonation; these strata may be part of the Santa Susana Formation.

The Llajas Formation of the Oxnard Plain was apparently deposited in upper bathyal to upper neritic water depths as indicated by paleobathymetry, abundance of sandstone and siltstone, and abundant worm impressions and shell fragments (Plate XII).
DISCUSSION AND CONCLUSIONS

The Cretaceous marine sandstone that forms the Chatsworth deep-sea sand fan of Link (1981), Colburn (1981), and Colburn, West, and Carey (1981), is inferred by these workers to reach eastward at least as far as the eastern extent of the Horse Meadows oil field, west as far as Thousand Oaks in the Simi Hills and Trancas Beach district in the Santa Monica Mountains, and south to the Malibu Coast fault (Colburn, 1981) (Fig. 5). Subsurface data from this study extend the areal distribution of this Cretaceous fan complex northwest to the Shell Dryden 2 well on Oak Ridge near the Bardsdale oil field (Section J-J', Plate XIa) and possibly southwest to the Sun Ferrell 1 well in the Oxnard Plain (Section K-K', Plate XIIc). However, the sequence correlated to the "G-Zone" (?) and most of the "F-Zone" of Goudkoff (1945) in the Sun Porter 81-16 and the Horse Meadows 2-47 wells (Sections G-G', H-H', Plates VIII, IX) is fine grained, indicating the eastern edge of the Chatsworth sand fan lay west of these wells. The east edge of the fan expanded eastward to include those wells later in the Cretaceous. The distribution of Cretaceous surface exposures and those wells which penetrate Cretaceous strata located outside of Colburn's (1981) minimum extent of the Chatsworth deep-sea fan are shown in Figure 5.

Deposition of the Chatsworth fan was followed by uplift and local tilting of at least nine degrees in the Aliso Canyon oil field (Section E-E', Plate VI) and 26 degrees in the Horse Meadows
Figure 5. Distribution of surface Cretaceous rocks (shown as stippled pattern). Also shown are those wells which penetrate Cretaceous strata outside of Colburn's (1981) minimum extent of the Chatsworth deep-sea fan, (after Jennings and Strand, 1969).
oil field (Section F-F', Plate VII) as based upon dipmeter logs, prior to deposition of the Santa Susana Formation (Yeats, 1979). However, it cannot be demonstrated whether the tilting predated deposition of the Simi Conglomerate or postdated deposition of the pre-Santa Susana marine Paleocene strata.

The Simi Conglomerate was derived from an eastern source (Sage, 1973). A distinctive red pisolitic claystone overlies the Simi Conglomerate. It is overlain by a marine Paleocene sandstone sequence in both the western Simi Hills and in Solstice Canyon in the Santa Monica Mountains, suggesting to Yerkes and Campbell (1971), that the Solstice Canyon sequence was once part of the Simi Hills, and was later thrust to the south during the Miocene. Sage (1973) suggested that the red pisolitic claystone overlying the Simi Conglomerate marks a north-northwest-trending paleo-shoreline as illustrated in Figure 6. Also illustrated in Figure 6 is the distribution of Simi Conglomerate outcrop and those wells which most probably contain the Simi Conglomerate.

After deposition of the Simi Conglomerate, eastward transgression resulted in reworking of the upper part of the Simi Conglomerate and deposition of fossiliferous siltstone, sandstone, and conglomeratic sandstone of the pre-Santa Susana Paleocene over the Simi Conglomerate. It is suggested that the seas which deposited the pre-Santa Susana Paleocene strata did not transgress into the northwestern San Fernando Valley area. Minor regression and erosion followed deposition of the pre-Santa Susana Paleocene, creating a local disconformity. The pre-Santa Susana Paleocene
Approximate shoreline from Sage (1973). Based on the distribution of Pisolitic claystone.

Figure 6. Distribution map of the Simi Conglomerate. Paleocurrent data indicated with arrows. Also shown are those wells which may penetrate pre-Santa Susana marine Paleocene strata.
was then overlapped by a major transgression which resulted in deposition of the Santa Susana Formation. Deposition of the Santa Susana conglomerate in Simi Valley and the Aliso Canyon oil field was probably controlled by the availability of the Simi Conglomerate as the major source of clasts. Figure 7 shows schematically the extent of the marine Paleocene strata, Simi Conglomerate, and the westward overlapping of the Santa Susana Formation. The same relationship is proposed for the Santa Monica Mountains. The Solstice Canyon sequence, consisting of a thin Simi Conglomerate, a relatively thick pre-Santa Susana marine sequence, and little or no Santa Susana Formation, would be analogous to the exposures in the western Simi Hills. East of Solstice Canyon, in Carbon and Topanga Canyons, the sequence consists of the Santa Susana Formation lying directly on Cretaceous. This is analogous to the situation in the Horse Meadows and Aliso Canyon oil fields (Sections E-E', F-F', G-G', H-H', Plates VI, VII, VIII, IX).

The distribution of Santa Susana Formation lithologies is shown in Figure 8. Two models are presented to account for the distribution pattern. Model (I) suggests that most of the Simi Valley and northwestern San Fernando Valley were part of a northwest-trending submarine high which was shielded from significant tractive or turbidity current sand deposition during Santa Susana time, and received only fine-grained hemipelagic deposits. Submarine topographic lows in the Santa Susana Mountains to the northeast and in the western Simi Hills to the southwest received basin-plain sands from an east or southeast source. Limited paleocurrent
Figure 7. Extent of pre-Santa Susana marine Paleocene strata and the overlapping of the Santa Susana Formation.
Figure 8. Distribution map of the Santa Susana Formation. Paleocurrent data indicated with arrows. Also shown are two models which may account for the distribution patterns. (I) suggests that currents flowed parallel to a submarine ridge. (II) suggests that sediment was deposited down a slope and into a turbidite trough.
data for the Santa Susana Formation (Janes, 1976) suggest predominantly northwest transport of fine-grained sediments. However, if these fine-grained sediments were deposited on either the distal end of a submarine fan or on a channeled slope area the data may be unreliable as a predominant direction of sediment dispersal. Data which support this model include paleobathymetry evidence based upon benthic foraminifers which suggest a bathyal (often lower bathyal) environment for the entire Santa Susana Formation (M. V. Filewicz, written commun., 1982). An alternate model (II) is deposition of the Santa Susana on a southwest-facing shelf, slope and turbidite trough (Figure 8). Sand channels exposed in Poison Oak and Meier Canyons (R. Squires, written commun., 1982) which may have funneled coarse-grained sediment westward or southwestward down the presumed slope, support this model.

West of the Union Torrey 92 well on Oak Ridge, the Llajas Formation rests directly on Cretaceous strata (Section J-J', Plate XI). The pre-Llajas Tertiary is missing due to either nondeposition on a topographic high or erosion prior to deposition of the Llajas Formation on Oak Ridge, with the latter interpretation more likely.

Regression ended the deposition of the Santa Susana Formation and resulted in a three million year time hiatus, in the early Eocene (M. V. Filewicz, written commun., 1982). This was followed by transgression and deposition of the Llajas Formation. After the deposition of a basal coastal alluvial-fan sequence (Llajas
basal conglomerate of Squires, 1981), mudstone and siltstone were the main detritus deposited in a west- to northwest-trending belt through the northwestern San Fernando Valley and eastern Simi Valley (Fig. 9). To the northeast in the Santa Susana Mountains (Section I-I', Plate X), and southwest in the Oxnard Plain (Section K-K', Plate XII), sandstone was the dominant lithology. A transition zone between sandstone and mudstone lithologies occurs in a belt between the Oxnard Plain and central Simi Valley. In this area thick sandstone lenses occur as interbeds in a sequence which is predominantly siltstone. The overall distribution of Llajas lithologies corresponds roughly to those of the underlying Santa Susana Formation. Two models are presented in Figure 9 to account for the superimposed patterns. The first model (I) suggests that the Llajas was deposited on the same submarine high that may have been present during Santa Susana time. The second model (II) predicts that Llajas deposition was controlled by a "shelf" to turbidite trough topography similar to that which may have controlled Santa Susana sedimentation. Paleobathymetry data based on microfossils from Simi Valley, the Santa Monica Mountains, Oak Ridge, and the Oxnard Plain, suggest that the Llajas was deposited in upper bathyal to upper neritic depths throughout most of the Ventura basin. Thickness differences between the Oxnard Plain (less than 1,000 feet), Simi Valley (2,000 feet), and Oak Ridge (4,000 feet), suggest that the Oxnard Plain may have been located on an offshore high where sediment did not accumulate as quickly as in areas farther east.
Figure 9. Distribution map of the Llajas Formation. Paleocurrent data from the Llajas Conglomerate indicated with arrows; (1) - Howell (1974), (2) - Yeats and others (1974). Also shown are two models which may account for the distribution patterns. (I) suggests that currents flowed parallel to a submarine ridge. (II) suggests that sediment was deposited down a slope and into a turbidite trough.
Clast type and paleocurrent data for the Sespe and Vaqueros Formations (Yeats and others, 1974; McCracken, 1972) suggest that the Paleocene and Eocene sedimentation from east to west and the basin geometry trends of the southern Ventura basin continued until the Miocene, at which time extensional tectonism characterized by volcanism and normal faulting began (Yeats, 1971, 1976). This is in contrast to the reverse faulting that characterizes the basin today (Yeats, 1971).

The Paleogene basin configuration of southern California was altered significantly in the Neogene. Sage (1973) and Howell (1974) attempted palinspastic reconstructions of the Paleocene and Eocene paleogeography of southern California assuming large-scale movement on the Malibu Coast fault system, the San Gabriel fault system, and the San Andreas fault system. These reconstructions indicate that a continuous northwest-trending shoreline was present during the early Tertiary which shed clastics to the west or southwest into the southern Ventura basin.

Howell (1974) suggested that rotation of crustal blocks in southern California was also necessary to account for the present-day configuration of Eocene strata. Based upon paleomagnetic evidence, Kamerling and Luyendyk (1979) suggested that the Santa Monica Mountains and Conejo Hills have rotated 64 to 81 degrees clockwise. To accommodate the rotation, Luyendyk and others (1980) suggested 20 miles of left-lateral offset on the Simi fault. In contrast, Truex (1976) proposed 35 miles of right-lateral offset on a Las Posas-Simi-Frew-Soledad fault system.
as a result of the apparent westward displacement of the Santa Monica Mountains from an original position north of the Santa Ana Mountains.

On the basis of Sespe and Llajas Conglomerate electric-log correlations across the Simi fault, Hanson (1981) showed that there is no evidence to support large-scale lateral offset on this fault. Data from this study further support no large-scale lateral displacement; facies changes within the Llajas Formation cross the Simi fault with no apparent offset (Fig. 8). The similarity of the Elsmere Canyon outcrop and the Continental Phillips 1 well to the Simi Valley and San Fernando Valley data, and the similarity of the Llajas Formation north and south of the Frew fault (Sections A-A', I-I', Plates IIc, X), suggest that there was no large-scale lateral displacement on either the Santa Susana fault or the Frew fault.

The proposed rotation of Cretaceous and Paleogene strata in the southern Ventura basin (Kamerling and Luyendyk, 1979) is shown in Figure 10. Rotated directions of sediment transport for the Cretaceous Chatsworth Fan and Sespe Formation suggest dispersal of sediment westward in the southern Ventura basin. Based upon conglomerate clast compositions, Colburn, West, and Carey (1981) suggested that the Peninsular Ranges served as the main source for the Chatsworth Fan. However, they do not preclude the possibility of a source on the east side of the San Andreas fault. A southeastern source was suggested for the Sespe Formation based upon imbricate clast orientations (Yeats and others, 1979).
Figure 10. Post Paleogene rotation of the southern Ventura basin.
Sage (1973) suggested a northwest-trending shoreline and a northeastern source for the Paleocene of southern California based upon the distribution of a pisolitic claystone, clast compositions, and unrotated paleocurrent data. Rotation of the Paleocene suggests a northern source, with sediment deposited along an east-west oriented shoreline. Sedimentation patterns and paleocurrent trends for the Santa Susana and Llajas Formations are inconclusive as to a predominant direction of sediment transport, but appear to correspond more closely with the Paleocene trends than with the trends of the Cretaceous or Sespe Formation. In summary, consideration of post-Paleogene clockwise rotation results in an eastern source for the Chatsworth fan, comparable to the eastern source for Cretaceous strata west of the Peninsular Ranges. A derivation of the Paleocene shoreline sequence, rich in quartzite clasts, from the north, a source area relatively free of quartzite, is more difficult to imagine than a derivation from the east, if rotation is not assumed.
REFERENCES CITED


Cushman, J., and McMasters, J., 1936, Middle Eocene foraminifera from the Llajas Formation, Ventura County, California: Jour. Paleo., v. 10, no. 6, p. 497-517.


Roth, J. C., 1958, Geology of a portion of the southern Santa Ana Mountains, Orange County: Univ. of California, Los Angeles, unpub. M.A. thesis.


Weber, F. H., in progress, Geology of the N.W. 1/4 and S. 1/3 of the N.E. 1/4 of the Thousand Oaks quadrangle, Ventura County, California, 1:9,600 scale.


## WELLS UTILIZED IN STUDY

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Well Name</th>
<th>Sect.-Township-Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Arco Pertusati 1</td>
<td>20-2N-16W</td>
</tr>
<tr>
<td>2</td>
<td>C.A. Palmer Brandeis 1</td>
<td>7-2N-17W</td>
</tr>
<tr>
<td>3</td>
<td>Carrillo Wiekhorst 1</td>
<td>11-2N-18W</td>
</tr>
<tr>
<td>4</td>
<td>Continental Berylwood 1</td>
<td>18-2N-20W</td>
</tr>
<tr>
<td>5</td>
<td>Continental Howell 2</td>
<td>35-3N-16W</td>
</tr>
<tr>
<td>6</td>
<td>Continental Phillips 1</td>
<td>6-3N-15W</td>
</tr>
<tr>
<td>7</td>
<td>Exxon Berylwood Inv. Co. D-2</td>
<td>19-2N-20W,1</td>
</tr>
<tr>
<td>8</td>
<td>Exxon Marquis 1</td>
<td>26-3N-16W</td>
</tr>
<tr>
<td>9</td>
<td>Franco Western Smith 71A-11</td>
<td>11-2N-19W</td>
</tr>
<tr>
<td>10</td>
<td>Getty Joughin 1</td>
<td>25-3N-17W</td>
</tr>
<tr>
<td>11</td>
<td>Getty Tapo 42</td>
<td>36-3N-18W</td>
</tr>
<tr>
<td>12</td>
<td>Gulf Ward 1</td>
<td>27-3N-16W</td>
</tr>
<tr>
<td>13</td>
<td>Hancock Strathearn 16-6</td>
<td>6-2N-18W</td>
</tr>
<tr>
<td>14</td>
<td>Havenstrite Tapo 1</td>
<td>13-3N-18W</td>
</tr>
<tr>
<td>15</td>
<td>Husky Getty Tapo Ranch 1</td>
<td>25-3N-18W,1</td>
</tr>
<tr>
<td>16</td>
<td>Intex McCrea 1</td>
<td>27-2N-19W,1</td>
</tr>
<tr>
<td>17</td>
<td>Lloyd Livingston 4</td>
<td>31-2N-21W</td>
</tr>
<tr>
<td>18</td>
<td>Lloyd McGrath 2</td>
<td>32-2N-21W</td>
</tr>
<tr>
<td>19</td>
<td>Lloyd McGrath 4</td>
<td>32-2N-21W</td>
</tr>
<tr>
<td>20</td>
<td>Macson Strathearn 1</td>
<td>6-2N-18W</td>
</tr>
<tr>
<td>21</td>
<td>Marathon Vail 1</td>
<td>10-2N-19W,1</td>
</tr>
<tr>
<td>22</td>
<td>Mayo, Luther T., Montgomery 1</td>
<td>21-2N-18W,1</td>
</tr>
<tr>
<td>23</td>
<td>McDonald and Norris Water Co. 1</td>
<td>35-3N-18W</td>
</tr>
<tr>
<td>24</td>
<td>M.H. Marr Marr Ranch A-1</td>
<td>30-3N-17W</td>
</tr>
<tr>
<td>25</td>
<td>M.H. Marr Marr Ranch 17</td>
<td>31-3N-17W</td>
</tr>
<tr>
<td>26</td>
<td>M.H. Marr Marr Ranch 20</td>
<td>30-3N-17W</td>
</tr>
<tr>
<td>27</td>
<td>M.H. Marr Marr Ranch 26</td>
<td>32-3N-17W</td>
</tr>
<tr>
<td>28</td>
<td>National Expl. Binns 67-1</td>
<td>1-2N-17W</td>
</tr>
<tr>
<td>29</td>
<td>Northridge Simco 1</td>
<td>31-3N-17W</td>
</tr>
<tr>
<td>30</td>
<td>Pacific Western Marr 1</td>
<td>36-3N-18W</td>
</tr>
<tr>
<td>31</td>
<td>Pamoan Hot Rod Flannagan 1</td>
<td>6-2N-17W</td>
</tr>
<tr>
<td>32</td>
<td>Pauley BIOW 36</td>
<td>19-3N-16W</td>
</tr>
<tr>
<td>33</td>
<td>Porter Sesnon Greenman Community 52-15</td>
<td>15-2N-16W</td>
</tr>
<tr>
<td>34</td>
<td>Porter Sesnon Horse Meadows 2-47</td>
<td>4-2N-16W</td>
</tr>
<tr>
<td>35</td>
<td>Porter Sesnon Horse Meadows 2A-47</td>
<td>4-2N-16W</td>
</tr>
<tr>
<td>36</td>
<td>Porter Sesnon Horse Meadows 3-49</td>
<td>4-2N-16W</td>
</tr>
<tr>
<td>37</td>
<td>Porter Sesnon Orchard 38-10</td>
<td>10-2N-16W</td>
</tr>
<tr>
<td>38</td>
<td>Porter Sesnon Quarry 78-4</td>
<td>4-2N-16W,1</td>
</tr>
<tr>
<td>39</td>
<td>R. B. Jackson R &amp; G 1</td>
<td>17-3N-18W</td>
</tr>
<tr>
<td>40</td>
<td>Regent Runkle 1</td>
<td>14-3N-21W,1</td>
</tr>
<tr>
<td>41</td>
<td>Scope Miller-Sanger 1</td>
<td>34-2N-17W,1</td>
</tr>
<tr>
<td>42</td>
<td>Shell Dryden 2</td>
<td>7-3N-19W</td>
</tr>
<tr>
<td>43</td>
<td>Shell Schonfeld 1</td>
<td>30-2N-16W,1</td>
</tr>
<tr>
<td>44</td>
<td>Shell South Mtn. and Ojai 21</td>
<td>19-3N-20W</td>
</tr>
<tr>
<td>45</td>
<td>Shell Strathearn 1</td>
<td>6-2N-18W</td>
</tr>
<tr>
<td>Well No.</td>
<td>Well Name</td>
<td>Sect.-Township-Range</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>46</td>
<td>So. Cal. Gas Co. Sesnon Fee 3</td>
<td>33-3N-16W</td>
</tr>
<tr>
<td>47</td>
<td>So. Cal. Gas Co. Sesnon Fee 7</td>
<td>33-3N-16W</td>
</tr>
<tr>
<td>49</td>
<td>Standard Brady Estate 2-1A</td>
<td>13-3N-17W</td>
</tr>
<tr>
<td>50</td>
<td>Standard Frew 1-1</td>
<td>29-3N-16W</td>
</tr>
<tr>
<td>51</td>
<td>Standard Frew 1-5</td>
<td>29-3N-16W</td>
</tr>
<tr>
<td>52</td>
<td>Standard Frew 1-6</td>
<td>29-3N-16W</td>
</tr>
<tr>
<td>53</td>
<td>Standard Lucas 1</td>
<td>1-1N-22W(^1)</td>
</tr>
<tr>
<td>54</td>
<td>Standard Maulhardt Community 101-A</td>
<td>1-1N-22W(^1)</td>
</tr>
<tr>
<td>55</td>
<td>Standard Roosa 2</td>
<td>29-3N-16W</td>
</tr>
<tr>
<td>56</td>
<td>Standard Standard Sesnon 12</td>
<td>29-3N-16W</td>
</tr>
<tr>
<td>57</td>
<td>Sun Drilling Ferrell 1</td>
<td>14-2N-20W(^1)</td>
</tr>
<tr>
<td>58</td>
<td>Sun Oil Greenman Community 72-15</td>
<td>15-2N-16W(^1)</td>
</tr>
<tr>
<td>59</td>
<td>Sun Oil Porter Estate 81-16</td>
<td>16-2N-16W(^1)</td>
</tr>
<tr>
<td>60</td>
<td>Texaco Bannon Silver-K</td>
<td>14-1N-22W(^1)</td>
</tr>
<tr>
<td>61</td>
<td>Texaco Berylwood 2</td>
<td>16-2N-20W(^1)</td>
</tr>
<tr>
<td>62</td>
<td>Texaco Capital-Oxnard 1</td>
<td>5-1N-21W(^1)</td>
</tr>
<tr>
<td>63</td>
<td>Texaco Miketta 1</td>
<td>21-2N-20W(^1)</td>
</tr>
<tr>
<td>64</td>
<td>Texaco Shiells E-7</td>
<td>4-3N-19W</td>
</tr>
<tr>
<td>65</td>
<td>Texaco Shiells E-8</td>
<td>4-3N-19W</td>
</tr>
<tr>
<td>66</td>
<td>Texaco Shiells 165</td>
<td>4-3N-19W</td>
</tr>
<tr>
<td>67</td>
<td>Texaco Shiells 202</td>
<td>4-3N-19W</td>
</tr>
<tr>
<td>68</td>
<td>Texaco-Union N. Richardson Heirs 1</td>
<td>14-3N-21W</td>
</tr>
<tr>
<td>69</td>
<td>Union C &amp; H 10</td>
<td>23-3N-21W</td>
</tr>
<tr>
<td>70</td>
<td>Union Continental Janss 1</td>
<td>22-2N-21W</td>
</tr>
<tr>
<td>71</td>
<td>Union Del Aliso 1-1</td>
<td>19-3N-16W</td>
</tr>
<tr>
<td>72</td>
<td>Union Del Aliso 1-2</td>
<td>19-3N-16W(^1)</td>
</tr>
<tr>
<td>73</td>
<td>Union Horse Meadows 1-46</td>
<td>5-2N-16W</td>
</tr>
<tr>
<td>74</td>
<td>Union Horse Meadows 3-74</td>
<td>3-2N-16W</td>
</tr>
<tr>
<td>75</td>
<td>Union Las Llajas Corehole 1</td>
<td>22-3N-17W</td>
</tr>
<tr>
<td>76</td>
<td>Union Las Llajas 9</td>
<td>22-3N-17W</td>
</tr>
<tr>
<td>77</td>
<td>Union Simi 1-35 O.H.</td>
<td>35-3N-19W(^1)</td>
</tr>
<tr>
<td>78</td>
<td>Union Simi 24</td>
<td>28-3N-17W(^1)</td>
</tr>
<tr>
<td>79</td>
<td>Union Torrey 92</td>
<td>5-3N-18W</td>
</tr>
</tbody>
</table>

\(^1\) Paleocene and Eocene samples available from: California Well Sample Repository, Cal. State Bakersfield, 9001 Stockdale Hwy., 93309, (805) 833-2324, Repository Curator: Mr. Jack Tucker