OAK RIDGE FAULT, VENTURA BASIN, CALIFORNIA;

SLIP RATES AND LATE QUATERNARY HISTORY

GRANT 14-08-0001-G1194

Robert S. Yeats, Principal Investigator

Department of Geology

Oregon State University

Corvallis, OR 97331-5506

Research Element I

Program Objective T-4

Administrative Contracting Officer: Teresa F. Brooks

Project Officer: Elaine R. Padovani

August 30, 1988

Open-File Report 89-343

TABLE OF CONTENTS

PREFACE

Part 1 of this report describes the geology of the Oak Ridge fault zone and includes a geologic map, a structure contour map of the fault, and a structure contour map of a marker horizon approximately 1 Ma in age, all to a scale of 1:48,000. Also included are 9 structural cross sections, 8 of which cross the fault, and a geological history of the fault since the Miocene. The report concludes with a discussion of neotectonics and tectonic geomorphology of the fault, including trenching investigations at Montalvo mounds and Bardsdale Cemetery. An appendix, with its own set of references, is titled "Age estimates of Saticoy and Montalvo mound soils" and is written by Thomas K. Rockwell of San Diego State University.

Part 2 documents the late Quaternary slip rate on the fault and considers the fault recurrence interval in light of comparable reverse-fault earthquakes for which slip is known. This report concludes that a destructive earthquake may strike the lower Santa Clara Valley in the near future.

OAK RIDGE FAULT, VENTURA BASIN, CALIFORNIA

Robert S. Yeats
Department of Geology
Oregon State University
Corvallis, OR 97331-5506

ABSTRACT

The Oak Ridge fault is the longest south-dipping Quaternary reverse fault in the western Transverse Ranges, extending from the Santa Susana Mountains westward along the south side of the Santa Clara Valley into the Santa Barbara Channel. It also has the largest late Cenozoic displacement of any south-dipping fault in this region. The fault began as a normal fault annular to Miocene volcanics in the western Santa Monica Mountains. Pliocene and early Pleistocene displacement is documented by a thickness of strata in the footwall block in the Santa Clara Valley greater than that in the hanging-wall block on the south side of Oak Ridge. Displacement rates increased from west to east and from older to younger, with highest rates in the middle Pleistocene. In the last 0.4-0.2 Ma, uplift of Oak Ridge has accompanied reverse slip on the Oak Ridge fault at rates of 5.9 to 12.5 mm/yr except near the coast and offshore, where uplift has been zero. The fault is divided into five segments. (1) a west-trending coastal and offshore segment where both sides are today at maximum burial, (2) a northeast-trending, steeply-dipping, oblique-slip segment that marks the west end of uplift of Oak Ridge, (3) an east-trending dip-slip segment marked by tectonic topography east of Santa Paula, (4) a dip-slip, lobate segment from Balcom Canyon to Wiley Canyon, and (5) an eastern segment where the fault divides into several splays and dies out. Both the Santa Clara syncline and Oak Ridge anticline are en echelon, left-stepping along the west half of the fault. The Montalvo mounds, pressure ridges within the coastal segment, contain tilted and faulted sediments probably younger than 30,000 years. An alluvial fan near Bardsdale with sediments 2,000 years old at its surface is deformed by a scarp reflecting normal faulting of 1.7 to 2.1 m and broad warping with vertical separation of 5 m, possibly reflecting a buried reverse fault related to folding of the Oak Ridge anticline. The lack of evidence for fault creep and the apparent entrainment of sediments along fault planes in the Montalvo mounds and at Bardsdale suggest that fault displacement accompanies earthquakes.

OAK RIDGE FAULT, VENTURA BASIN, CALIFORNIA

Introduction

The Oak Ridge fault is the southern boundary of the deep Ventura trough from the Santa Barbara Channel east to the Santa Susana Mountains, a distance greater than 100 km. It is longer, and it has greater displacement than any other south-dipping reverse fault in the western Transverse Ranges. In plan, it is shaped like a broad, open S, convex to the south offshore and convex to the north onshore (Figure 1; Yeats, 1976). The strike is northeast from Montalvo to South Mountain and east-northeast from South Mountain to Wiley Canyon. At Wiley Canyon, it splits into two strands. The north strand continues east-northeast along the south side of the Santa Clara River and ends at the eastern end of the deep Ventura trough. The south strand continues east-southeast into the Santa Susana Mountains where it is overridden by the Santa Susana fault (Yeats, 1979; 1987a).

The western part of the Oak Ridge fault has no topographic expression due to the absence of uplift; the fault is marked by two blocks that subsided at different rates. 13 km east of the coastline, the hanging wall of the fault has topographic expression as Oak Ridge formed by uplift in late Quaternary time. The footwall block is tilted toward the fault such that the greatest subsidence occurred close to the fault. Santa Clara River follows the axis of this downfaulted block and is so close to the fault that for a considerable distance, the main channel is on the hanging-wall side. Accordingly, exposures of the youngest trace of the fault are rare.

In contrast, most of the other large-displacement reverse faults of the western Transverse Ranges dip north. These include the Malibu Coast, Red Mountain, San Cayetano, Santa Susana, and Sierra Madre faults. The Red Mountain, San Cayetano, and Santa Susana faults form part of a single, discontinuous, segmented fault system that trends slightly north of west. The Red Mountain and San Cayetano faults form the northern boundary of the deep Ventura trough, and the trough ends at the east end of the San Cayetano fault, close to the east end of the north strand of the Oak Ridge fault.

Earthquakes have occurred on the Oak Ridge fault offshore (Lee and Vedder, 1973; Yerkes and Lee, 1979), but there is no historical or instrumental seismicity associated with the fault onshore. However, the fault produces pressure ridges near the coast (Yeats and others, 1981; Hall, 1982), and it cuts a landslide and Holocene alluvial fan deposits east of Santa Paula, so it is considered as potentially active. The lack of tectonic geomorphic expression of the fault is due to the presence of the Santa Clara River along most of the length of the fault together with massive landslides on Oak Ridge. The fault was also active during deposition of the Pliocene-Pleistocene trough sequence, and there is indirect evidence of an ancestral normal fault in the middle Miocene.

Two petroleum-producing trends are related to the onshore Oak Ridge fault. In the hanging-wall block, the West Montalvo, El Rio, South Mountain, West Mountain, Bardsdale, Shiells Canyon, Chaffee Canyon, and Torrey Canyon fields produce oil mainly from the nonmarine Sespe Formation of Eocene and Oligocene age and the underlying marine Eocene Llajas Formation. Farther east, the Oakridge field produces oil from the marine Vaqueros Formation of Oligocene-early Miocene age. Lower Pliocene turbidite sandstones produce oil in the McGrath pool of the West Montalvo oil field (Cross Section A-A', Plate V). In the footwall, petroleum is produced from Pliocene and early Pleistocene turbidite sandstones in the Saticoy field and the Bridge pool of the South Mountain field, and from Pleistocene gravels in the Bardsdale and Shiells Canyon fields.

My work on the Oak Ridge fault began as a well-site geologist in the Saticoy field in 1957 and continued as a production geologist for Shell Oil Company from 1959 to 1964. I continued work on the onshore part of the fault from 1972 to the present, aided by graduate students at Ohio University (Ricketts and Whaley, 1975; Rieser, 1976; Blackie and Yeats, 1976; Cemen, 1977) and at Oregon State University (Huftile, 1988). All onshore wells containing information on the fault were examined. Surface mapping was done by K. R. Whaley east of Shiells Canyon oil field, G. J. Huftile at Wiley Canyon, R. B. Rieser from Shiells Canyon to Balcom Canyon, and by R. S. Yeats from Balcom Canyon to the coast. This mapping is summarized in Plate I. Multichannel seismic lines offshore within 9 km of the coastline were also examined.

This paper summarizes my research and that of my students and addresses the following topics: (1) tectonic evolution of the fault from middle Miocene to the present, and (2) evidence for active tectonics. Slip rates are described by Yeats (1988), and slip vectors by Yeats and others (1988).

Acknowledgments

I am indebted to my Shell colleagues Sieg Hamann, Bert Mull, Dave Pontius, and the late James Carleton (Jim) Taylor for including me in their stimulating discussions during development of the Saticoy field, and this paper is dedicated to Jim Taylor. Ed Hall, Ed Keller, Tom Rockwell, Andrei Sarna-Wojcicki, John Truex, and Bob Yerkes have contributed their ideas through the years, and Union Oil Co. of California and Texaco, Inc. provided summer support to my graduate students. John Tinsley visited the Bardsdale Cemetery trench and provided useful insights.Trenching investigations were conducted by John Powell and Dave Gardner, assisted by Russ Van Dissen. The base map for Plates I - IV was provided by Earl Hart of the California Division of Mines and Geology. My own research was supported by NSF Grant GA-36065 followed by U.S. Geological Survey contracts 14-08-0001-15886 and 14-08-0001-G1194, and by Conoco, Inc. The conclusions in this report are my own and are not necessarily endorsed by any organizations funding this research.

Stratigraphy

General statement

The footwall block of the Oak Ridge fault is largely at maximum burial, and no strata older than Pliocene are exposed or reached by wells. The hanging-wall block exposes strata as old as Oligocene Sespe Formation, and at least one well reaches the Cretaceous (Fig. 2).

Pre-Miocene strata

Seedorf (1983) described the pre-Sespe stratigraphy of Oak Ridge and correlated it to sequences in the Simi Hills, Santa Monica Mountains, and adjacent areas. The Shell Dryden 2 well near Bardsdale penetrated 700 m (2300 feet) of Upper Cretaceous sandstone overlain unconformably by basal conglomerate of the Eocene Llajas Formation (Rieser, 1976). The Union Torrey 92 deep-test well at Torrey Canyon oil field penetrated 536 m (1760 feet) of interbedded gray to black calcareous shale and gray, black to green, poorly-sorted pebbly conglomerate grading upward to interbedded gray sandstone and black calcareous shale (Ricketts and Whaley, 1975). Microfossils are of Paleocene or Cretaceous age. The strata are glauconitic at the contact with overlying algal limestone and conglomerate of the Llajas Formation.

The marine Llajas Formation of middle and late Eocene age contains a basal cobble conglomerate overlying older strata with low-angle unconformity (Seedorf, 1983). The conglomerate is associated with algal limestone in the Torrey 92 well and is overlain by strata with middle Eocene foraminifers (Ulatisian Stage of Mallory, 1959). Lithologies include sandstone and gray siltstone, some containing trace fossils ("worm impressions"). Bathyal foraminiferal faunas are found in the middle part of the Llajas, and neritic faunas of late Eocene age (Narizian Stage of Mallory, 1959) occur in the upper part, reflecting the transgressive-regressive cycle documented by Squires(1981) at the Llajas type section in the Simi Hills. Thickness is 750 m (2450 feet) in the Torrey 92 well increasing westward to 1280 m (4200 feet) in the Dryden 2 well.

The Eocene is transitional upsection to the nonmarine Sespe Formation, a redbed sequence including sandstone, varicolored mudstone, and local conglomerate (McCracken, 1972). Vertebrate faunas are of late middle Eocene to late Oligocene age (Lander, 1983), and a tuff bed near the top of the Sespe at South Mountain is dated by K-Ar as 27.8 +/- 0.28 Ma (Mason and Swisher, 1988). Thicknesses on Oak Ridge are 1770-2120 m (5800 to 6950 feet), close to the maximum Sespe thicknesses measured anywhere in the Ventura basin.

Miocene strata

The Miocene south of the Oak Ridge fault consists of three sequences separated by angular unconformities: the lower Miocene Vaqueros Formation, the middle Miocene Topanga Formation and Conejo Volcanics, and the middle and upper Miocene Modelo Formation. At Big Mountain, south of Oak Ridge, the Vaqueros contains microfossils of the Saucesian Stage of Kleinpell (1938) and thus is no older than early Miocene, 23 Ma (Blake, 1983). The Vaqueros lies with angular unconformity on normal-faulted Sespe Formation (Hall and others, 1967; Canter, 1974; Yeats, 1987b). The Topanga Formation and Conejo Volcanics contain middle Miocene foraminifers, predominantly of the Relizian Stage of Kleinpell (1938); these formations overlap the Vaqueros to rest directly on Sespe Formation. The Conejo Volcanics include andesite and basalt flows and volcaniclastic rocks dated by potassium-argon as 15.5 +/- 0.8 to 13.9 +/- 0.4 Ma (Turner and Campbell, 1979; Williams, 1983). The Conejo Volcanics flowed northward from eruptive centers in the western Santa Monica Mountains, and they now lens out south of the middle Miocene outcrop on the south side of Oak Ridge (Figure 3) providing evidence that Oak Ridge existed as a topographic feature during the middle Miocene (Yeats, 1987b). The feather edge of the volcanics is exposed only in the Big Mountain area south of Oak Ridge. In the subsurface of Oxnard Plain, the Conejo Volcanics are overlain with angular unconformity by Modelo Formation, which consists of a basal sandstone of late middle Miocene age (microfossils of the Luisian Stage of Kleinpell, 1938) overlain predominantly by organic shale, siliceous shale, chert, dolomite, limestone, thin-bedded sandstone, and silver-gray ash of middle and late Miocene age (Luisian and Mohnian Stages) (Yeats, 1983a). Zircon from an ash bed in the Modelo Formation at Balcom Canyon gave an age of 8.3 +/- 0.8 Ma (Obradovich and Naeser, 1981). The relatively thin Modelo of Oak Ridge and adjacent areas to the south is in contrast to thick turbidite-bearing Modelo in the Santa Susana Mountains and east Ventura basin.

Miocene formations on Oak Ridge are poorly exposed due to extensive landslides, and the Conejo Volcanics are not present there to distinguish in the field between Vaqueros sandstone and basal Modelo sandstone. Furthermore, the unconformities that are angular south of Oak Ridge are disconformities at Oak Ridge, making more difficult the separation of various Miocene sandstones in the field. Accordingly, the Miocene sandstones are mapped together. A sill of hornblende andesite at South Mountain occurs at a higher stratigraphic level than the Conejo Volcanics and is therefore younger (Yeats, 1964). The combined Miocene sandstone sequence is thinnest at West Montalvo, South Mountain, Bardsdale, Shiells Canyon, and Torrey Canyon oil fields, 185-230 m (600-750 feet), and thickest in areas between the major oil fields, Balcom Canyon and Wiley Canyon, 670-715 m (2200-2350 feet). This suggests that individual structures localizing these oil fields were in existence in middle Miocene time. At Shiells Canyon, Edwards (1971) was able to map separately the Vaqueros and the basal Modelo sandstone, and he found the Modelo sandstone was only about 18 m (60 feet) thick. Farther east, the basal Modelo sandstone is mapped in the subsurface (Figure 2) where it is as much as 128 m (420 feet) thick. In the Oakridge oil field, the Modelo sandstone overlies the Vaqueros with low-angle unconformity.

The fine-grained portion of the Modelo Formation is exposed on Oak Ridge and is found in the subsurface to the south. Kew (1924) subdivided the Modelo into a lower, more siliceous member and an upper, more clay-rich member, roughly corresponding to sequences with Luisian and Mohnian foraminifers, respectively. The lower member consists of thin-bedded organic shale with interbeds of sandstone, limestone, and chert, and the upper member includes chocolate-brown to white diatomaceous shale, siltstone, and chert. The uppermost Modelo contains a siliceous fauna that is not age-diagnostic. Thicknesses of the Modelo are 150 m (500 feet) at Bardsdale oil field, 520 m (1700 feet) at West Montalvo oil field, and 730 m (2400 feet) at Torrey Canyon and Oakridge oil fields.

Wells north of the Oak Ridge fault are not deep enough to penetrate the Miocene. Information on the Miocene there is based on exposures on the north side of the Ventura trough, where the Sespe is overlain by Vaqueros Formation (primarily shallow-marine sandstone), Rincon Shale, and Monterey Formation. These formations also occur in horses along the Oak Ridge fault (Rieser, 1976), indicating that they underlie the Pliocene of the footwall block near the fault. Miocene thicknesses on the north side of the Ventura basin are 450-600 m for the lower Miocene Rincon Shale and 600-780 m for the middle and upper Miocene Monterey Shale (Nagle and Parker, 1971; Schlueter, 1976; Barnard, 1979; Jackson and Yeats, 1982; Huftile, 1988). Because the Ventura trough is post-Miocene in age, these thicknesses probably also apply close to the Oak Ridge fault as well. The Rincon Shale north of the Oak Ridge fault is included in the Vaqueros Formation south of the fault, and the Monterey Shale north of the fault is coeval with the Topanga Formation, Conejo Volcanics, and Modelo Formation south of the fault.

Pliocene and Pleistocene strata

In the western Ventura basin, the Monterey Formation (or locally the Modelo Formation) is overlain by the Sisquoc Formation, and in the eastern Ventura basin, the Modelo Formation is overlain by the Towsley Formation. The Sisquoc is predominantly fine grained, although sandstone turbidites occur on the north side of the Ventura basin and in the D-8 zone of the Ventura Avenue oil field (Yeats, 1983b). The Towsley is predominantly turbidite sandstone and conglomerate alternating with siltstone (Winterer and Durham, 1962; Yeats and others, 1985). Fine-grained Towsley and Sisquoc strata typically include chocolate-brown siltstone in contrast to the siliceous or calcareous, dark brown to black organic shale of the Modelo Formation and the brownish-gray siltstone of the overlying Pliocene Fernando Formation (Yeats, 1976). Thicknesses of Sisquoc are 640 m in the Carpinteria area (Jackson and Yeats, 1982) and 460 m in the upper Ojai valley (Schlueter, 1976). The Towsley is 1200 to 1250 m thick in the westernmost Santa Susana Mountains at the east end of the Oak Ridge fault (Ricketts and Whaley, 1975). The Sisquoc Formation is absent on the hanging-wall block of the Oak Ridge fault except for an area near the coast where fine-grained Sisquoc strata overlying the Modelo are overlapped by Pliocene beds with a Repettian Stage microfauna as described by Natland (1952).

The age of the Sisquoc and Towsley is not completely resolved. The microfauna in these formations have been referred to the Delmontian Stage of Kleinpell (1938), but this is not a true faunal stage (Pierce, 1972; Barron, 1976). Furthermore, part of the lower Towsley has a Mohnian microfauna (Yeats and others, 1985). Radiometric dating of ash beds intercalated with strata of late Miocene to early Pliocene age in the Santa Maria basin and Palos Verdes Hills provides an estimate of 6 Ma for the top of the Mohnian Stage and 4 Ma for the top of the Malaga Mudstone in the Palos Verdes Hills (Obradovich and Naeser, 1981), a formation correlated to the Sisquoc Formation. Barron (1986) shows the top of the Mohnian as time-transgressive, varying from slightly older than 7 Ma to slightly older than 6 Ma. With the Miocene-Pliocene boundary now placed at 5.3 Ma, the Sisquoc is in part Miocene and in part Pliocene in age.

The overlying Pliocene and lower Pleistocene strata of the Fernando Formation are considered as one lithologic sequence (Yeats, 1976; 1977). The basal beds are deep-water siltstone gradational in the footwall block with the

Sisquoc below. These pass upward into abyssal-plain turbidite sandstone alternating with siltstone. These strata are derived primarily from crystalline basement east of the basin and carried down a trough ancestral to the Santa Clara valley (Hsu, 1977; Hsu and others, 1980). Subordinate source areas in the Topatopa Mountains to the north supplied submarine fans with clasts of sedimentary rock, primarily Eocene sandstone, but also including clasts of Monterey Shale. West of Piru, these sandstone turbidites spread out over a broad basin floor that extended from the Oak Ridge fault north across the Ventura Avenue anticline and Canada Larga syncline to the San Cayetano and Red Mountain faults. Upsection, the turbidite sandstones are crowded south against the Oak Ridge fault, reflecting a gentle southward tilting of the basin floor toward the fault. The uppermost turbidites flowed south of Oak Ridge and are most abundant in the Oxnard Plain, suggesting that the main sediment path was down the Happy Camp and Long Canyon synclines south of Oak Ridge rather than the Santa Clara Valley. In the Oxnard Plain, the turbidite sandstones wedge out against Miocene rocks in a buttress submarine unconformity (Yeats, 1965). Locally, a thin veneer of discontinuously-deposited deep-water Fernando siltstone occurs between the Fernando turbidites and the Miocene. Other submarine unconformities developed within the Fernando in the direction of the Santa Monica Mountains and along Oak Ridge in the direction of South Mountain (Figure 4). North of the Oak Ridge fault, turbidites are overlain by a thick mudstone section ("Mudpit shale") with a Pleistocene cold-water fauna correlated to the Santa Barbara Formation, and this is overlain by the Saugus Formation (San Pedro Formation of Weber and others, 1973). The type locality of the Saugus is in the east Ventura basin, but the name "Saugus" has been rather loosely applied to all shallow-marine and nonmarine coarse clastic deposits that predate late Pleistocene deformation in the Ventura basin. As shown by Yeats (1976; 1977), the turbidite sandstone-mudstone facies boundary and the mudstone-Saugus boundary are time-transgressive, older eastward toward Piru and northward toward the outcrop.

During deposition of the Pliocene-Pleistocene sequence, the central Ventura basin was a flat-floored borderland basin with Oak Ridge an intermittently positive submarine feature in its center (Yeats, 1965) and the Santa Monica Mountains and Topatopa Mountains above water on the south and north, respectively. The basin subsided at a slower rate than it was filled, so that the shoreline migrated west to and perhaps beyond its present position. Thicknesses of the Pliocene-Pleistocene sequence in the main basin are enormous: 6 km near the coastline and 7.7 km in the deepest part of the basin between Fillmore and Piru. The Pleistocene sequence in the deepest part of the basin is nearly 5 km thick (Yeats, 1977), the thickest Quaternary sequence in the world.

The Fernando Formation is divided by Natland (1952) into four microfaunal stages based on benthic foraminifers. These are, from oldest to youngest, the Repettian, Venturian, Wheelerian, and Hallian. The benthic foram zones, at least those up to the middle Wheelerian, approach time lines within the main Ventura trough and the Oxnard Plain because they are parallel to electric-log markers and ash beds. This is probably because these areas occupy a single paleoecological niche, the abyssal plain. Across bathymetric strike, the zones cross time lines in comparison with pelagic microfaunal assemblages (Ingle, 1967), indicating that the faunal assemblages are controlled by environmental stresses in addition to age. The high latitude and the provincial nature of the faunas make it difficult to correlate the Ventura basin sequence to the tropical open-ocean time scale (Ingle, 1973).

However, the Pliocene-Pleistocene sequence has been age-calibrated by tephrachronology, magnetostratigraphy, and radiometric dating. Zircons in an ash bed in Repettian strata in the Palos Verdes Hills were fission-track dated at 3.4 +/- 0.3 Ma (Obradovich and Naeser, 1981), suggesting an age of the Repettian-Sisquoc boundary of about 4 Ma (assuming the tops of the Sisquoc Formation and Malaga Mudstone are time-correlative). On Oak Ridge west of South Mountain, Sarna-Wojcicki and others (1984; 1987) reported the Huckleberry Ridge ash, 2.01 Ma in age, in Fernando strata that are younger than Repettian on the basis of field and subsurface relations. Zircons in the Bailey ash, between Horizons 4 and 5 of Yeats (1983) and Blackie and Yeats (1976) were fission-track dated at 1.2 +/- 0.2 Ma (Izett and others, 1974; Izett, 1981). Blackie and Yeats (1976), using magnetic stratigraphy, recognized the Olduvai event below and the Jaramillo event above the Bailey ash horizon in the Saticoy field. Other ash beds in the upper Fernando Formation and lowermost Saugus Formation at the Ventura Avenue anticline (Sarna-Wojcicki and others, 1984; 1987) and the identification of the Brunhes-Matuyama chron boundary there (Liddicoat and Opdyke, 1981) permit the dating of the base of the Saugus there at about 0.65 Ma (Yeats, 1988). Amino acid racemization age estimates in shells in the Saugus Formation show that the top of the Saugus is about 0.2 Ma (Lajoie and others, 1982), although K. R. Lajoie (pers. comm. 1987) indicates that an age as old as 0.4 Ma is permitted by his data. A magnetostratigraphic section in the east Ventura basin, calibrated by the presence of the dated Bishop tuff, indicates that the top of the Saugus there is about 0.4 Ma (Levi and others, 1986).

Late Quaternary sediments

The shift from deposition to erosion accompanying major folding and faulting from 0.2 Ma to the present results in poor preservation of the late Quaternary geological record. During this time, Oak Ridge, South Mountain, and the Ventura Hills north of the lower Santa Clara River were uplifted, and the shoreline migrated westward and eastward in response to Pleistocene eustatic sealevel changes. Sediments include fluvial deposits of the Santa Clara River and of major side streams, including Piru, Sespe, and Santa Paula Creeks and the Ventura River, alluvial-fan deposits from smaller side drainages into the Santa Clara River, landslide deposits, especially on Oak Ridge, and estuarine, beach, and eolian deposits along the coast (Cleveland, 1973; McCoy and Sarna-Wojcicki, 1978; Greene and others, 1978). The thickness of post-0.2 Ma gravels cannot be determined in the footwall block between Santa Paula and Piru because the Saugus there is nearly flat-lying, and Saugus gravels are similar to overlying late Quaternary gravels of the Santa Clara River. However, where Santa Clara River deposits locally overlie beds strongly deformed along the Oak Ridge fault or south-dipping strata on the north flank of the Santa Clara syncline, the river gravels rest with angular unconformity on these deformed strata, and the thickness of the river gravels can be determined.

In the lower Santa Clara Valley and the adjacent Oxnard Plain, the Saugus Formation is overlain unconformably by as much as 400 meters of alluvial deposits that have been subdivided into older alluvium and younger alluvium (State Water Resources Board, 1953, 1956; Geotechnical Consultants, 1972). The older alluvium includes coarse-grained sand and gravel described as the Mugu aquifer in the Oxnard Plain. The Mugu aquifer is correlated with difficulty across the Oak Ridge fault to gravels that are thickest near the present Santa Clara River and thinner northward toward the foothills. The basal sand and gravel unit is overlain by clay and silty clay with only minor amounts of sand and gravel (Geotechnical Consultants, 1972). Foraminifers from this fine-grained unit are similar to those found in place in the Fernando Formation, leading Quick (1973; 1981) to propose a near-surface fault within the lower Santa Clara Valley. It seems more likely that the fine-grained unit, together with its microfossils, is derived from the Pico Formation of the Ventura Hills and Oak Ridge, both of which began to be strongly uplifted about 200,000 years ago. The younger alluvium includes the Oxnard aquifer which is correlated from the Oxnard Plain across the Oak Ridge fault into the lower Santa Clara Valley. The alluvial sequence is 120 to 165 meters thick near the coast and somewhat thinner near the west end of Oak Ridge. Farther east, in the City of Santa Paula, 390 m of gravels overlie steeply-dipping Saugus Formation in the Union SPS 1 well, drilled close to the Oak Ridge fault in the footwall block. Farther east, the thickness of post-Saugus sediments cannot be determined because the Saugus is nearly flat-lying, but the post-Saugus sediments are probably at least as thick as they are at Santa Paula. In the hanging-wall block of the Oak Ridge fault at Bardsdale, 40-50 meters of river gravel and alluvial-fan deposits overlie Sespe Formation. In the lower Santa Clara Valley, alluvial-fan deposits from 4 m below the surface of Harmon Fan contain vertebrates which gave four amino-acid racemization dates ranging from 5700 to 6300 yrs (Egner and others, 1974). Rodent bones at 3.5-4 m below the surface near the fan head were dated as 6000 yrs (Sarna-Wojcicki and others, 1976).

Putnam (1942) recognized the Sulphur Mountain surface as postdating the mid-Pleistocene orogeny, but this surface has not been dated. Lajoie and others (1982), using amino-acid racemization of shells at the base of deformed marine terrace deposits, dated the Ventura terrace at 85 to 105 ka, the Punta Gorda terrace at 40 to 60 ka, and the Sea Cliff terrace at 1.8-5.8 ka. The Punta Gorda terrace is also dated by the U-series method (Kaufman and others, 1971), and the Sea Cliff terrace is also dated by the radiocarbon method. The Oak View fluvial terrace of the Ventura River provided radiocarbon dates of 39.4 +/- 2.6 and 36.6 +/- 1.1 ka (Rockwell and others, 1984). McCoy and Sarna-Wojcicki (1978) pointed out that latest Pleistocene surfaces are marked by a prominent B horizon in soils developed on their surfaces, whereas Holocene surfaces lack a prominent B horizon. At two small pressure ridges near Montalvo, latest Pleistocene deposits with a prominent soil directly overlie the Saugus Formation, and the thick alluvial sequence of surrounding lowlands is not present (Hall, 1982).

The Santa Clara River now reaches the coast near the Oak Ridge fault, in the hanging-wall block, but this was not always the case. The Mugu and Hueneme submarine canyons were cut by currents laden with sediments originating in the Santa Clara River; these sediments were carried south by longshore currents to these submarine canyons (Greene and others, 1978). At various times in the late Quaternary, the Santa Clara River cut southward across the Oxnard Plain to feed directly into the Mugu and Hueneme canyons. Greene and others (1978) showed that the Mugu aquifer and other upper Pleistocene sediments crop out on the walls of these submarine canyons.

Structure

General statement

The structural history of the Oak Ridge fault system can be divided into three stages: (1) Miocene normal faulting accompanying extension and volcanism, (2) Pliocene-middle Pleistocene faulting accompanying filling of the Ventura trough, and (3) late Quaternary faulting. Because pre-Pliocene rocks in the Ventura trough are too deeply buried to be reached by drilling, evidence for Miocene tectonics is limited to the hanging-wall block of the Oak Ridge fault. Pliocene-early Pleistocene deformation is best studied west of Oak Ridge, where both hanging-wall and footwall blocks are at maximum burial, but indirect evidence of deformation all along the fault is obtained by comparing thicknesses and facies of sequences of this age in the hanging-wall and footwall blocks. Late Quaternary deformation is best studied by examination of wells drilled adjacent to and through the fault zone.

Miocene normal faulting

The Sespe Formation is cut by normal faults in the West Montalvo, West Mountain, South Mountain, Bardsdale, and Shiells Canyon oil fields on Oak Ridge as well as fields farther south in the Oxnard Plain (Yeats, 1987b). At Big Mountain oil field, south of Torrey Canyon, the Sespe underwent normal faulting prior to deposition of the Vaqueros Formation (Hall and others, 1967; Canter, 1974). At South Mountain oil field, there was an early episode of normal faulting that cuts the Sespe but not the overlying Miocene sandstone and a later episode that cuts the Modelo but not the Fernando (Yeats, 1965; 1987b). These normal faults occur in conjugate sets, indicating that the maximum compressive stress is the load stress (σ_1), approximately perpendicular to bedding of the overlying, moderately-dipping Fernando Formation. This relationship becomes evident by comparing a structure contour map of a Sespe horizon with a form-line structure contour map of the same horizon constructed perpendicular to dipping Fernando bedding rather than to the horizontal (Figure 5). The form-line map shows that the conjugate faults are accompanied by broad folding of the Sespe into brachyanticlines with their axes parallel to local 2. The oil accumulations at South Mountain and West Mountain oil fields are more closely related in space to these restored brachyanticlines than to present-day structure; the southern end of the South Mountain field extends almost to the axis of the present-day Long Canyon syncline, but does not extend very far down the east plunge of the South Mountain anticline toward Balcom Canyon.

The Colonia pool of the West Montalvo oil field is presently the most deeply buried Sespe oil reservoir south of the Oak Ridge fault, but this is principally due to burial by post-Miocene strata. The Sespe is overlain directly by Modelo Formation, with older Miocene formations (Conejo, Topanga, Vaqueros) absent. The basal transgressive Modelo sandstone lenses out around the Colonia structure such that in the center of the field, fine-grained Modelo rests directly on Sespe. This indicates that the Colonia producing structure was topographically high at the beginning of Modelo deposition. The parallelism of Modelo sandstone isopachs to east-west normal faults cutting Sespe Formation (Figure 3) suggests that the topography was tectonically controlled.

It has already been noted that lava flows of the Conejo Volcanics lens out northward against the south side of Oak Ridge, coming closest to the Oak Ridge fault at Balcom Canyon and El Rio oil field, east and west, respectively, of South Mountain oil field (Figure 3). This suggests that Oak Ridge was a tectonically-controlled topographic feature in middle Miocene time. Because this Miocene ridge is parallel to the post-Miocene Oak Ridge fault, it is proposed that the Oak Ridge fault had a Miocene normal-fault ancestor, and the convex-north trace of the ancestral fault was controlled by stresses related to volcanic centers in the western Santa Monica Mountains (Campbell and Yerkes, 1976; Jakes, 1979), formed in part by caldera collapse (Yeats, 1987b). Except for South Mountain, the conjugate fault systems in Oak Ridge oil fields show an orientation of 2, the intermediate principal stress, parallel to the convex-north fault trace, indicating that extension was horizontal and perpendicular to the fault.

Pliocene and Pleistocene deformation during filling of the Ventura trough

During the Pliocene and much of the Pleistocene, both sides of the Oak Ridge fault subsided and received sediments, but the north side subsided more and thus received a greater thickness of sediments. However, the water depth at the time of deposition was the same for strata of any given age on both sides of the fault, as based on benthic foraminifera, and there are no scarp-derived breccias adjacent to the fault on the downthrown side. This indicates that the fault had little or no topographic expression on the sea floor. Unconformities developed within the sequence in the direction of Oak Ridge (Figure 4), but these appear to express only a temporary change from sediment accumulation to sediment bypassing or even submarine erosion (Yeats, 1965).

It is difficult to imagine a mechanism in which basin narrowing accompanied by reverse faulting could occur without uplift of the hanging-wall block. Namson (1987) retrodeformed (balanced) a cross section based on data near the Oak Ridge fault from Yeats (1979b, in part reproduced as Cross Section B-B', Plate V) and found that the bedding intersects the fault in such a way that the fault would have to be normal when the bedding was horizontal. Based on this relationship, he proposed that the Oak Ridge fault was originally a north-dipping normal fault that underwent displacement during deposition of the Sisquoc Formation and much of the Fernando Formation, perhaps into early Pleistocene time. Anticlinal folding occurred later, rotating the fault into its present orientation as a reverse fault. The normal-fault hypothesis would explain the lack of uplift during the Pliocene, because the basin would have been undergoing extension at that time.

On the other hand, reverse faulting during the depositional phase is clearly documented for the Taylor thrust set in the Ventura Avenue oil field, where thin-skinned thrusting occurred 1.3 to 0.65 Ma (Yeats, 1983b). Folding occurred in the Carpinteria basin prior to Santa Barbara (marine early Pleistocene) deposition (Jackson and Yeats, 1982), and folding occurred prior to Saugus deposition on the south side of the Santa Susana Mountains (Yeats, 1979a; 1987), in the Santa Clara Valley east of Piru (Yeats et al., 1985), and in the Upper Ojai Valley (Huftile, 1988). This indicates that some contractile deformation occurred during the depositional phase, as early as 1.3 Ma, long before the end of Saugus deposition at 0.4-0.2 Ma. Namson's proposal does not consider the possibility of bedding slip accompanying folding on the south limb of the Santa Clara syncline, which could result in the present geometric relationship along a fault that was reverse at the time of deposition. This problem will be discussed in greater detail in a separate paper.

Because any given Pliocene or Pleistocene horizon was deposited in the same depth of water on both sides of the fault, the vertical separation of this horizon is a measure of the vertical component of movement on the Oak Ridge fault since that horizon was deposited. For vertical separation, I measure the vertical distance between the horizon in the crest of the Oak Ridge anticline and the trough of the adjacent Santa Clara syncline, thereby including folding related to the fault as well as separation across the fault itself (for further discussion, see Yeats, 1988). The difference in thickness of a given stratigraphic interval in the upthrown and downthrown block can be used to determine the vertical separation rate of that interval. Rates are based on the following age assumptions: Repetto-Sisquoc contact, 4 Ma; top of Repetto, 3 Ma; microfaunal horizon 5, 1 Ma; base of Saugus near the coast, 0.65 Ma; top of Saugus, 0.2 Ma (see discussion under Stratigraphy giving evidence for ages of horizons).

Vertical separation rates are shown in Figure 6a. Two trends are apparent: an increase in separation rates for the last 4 m.y., and an increase in rates from west to east. Rates for the Repetto member of the Fernando Formation are 0.5 to 1.1 mm/yr, for the remainder of the Fernando Formation (Pico member), 0.6 to 2.3 mm/yr, and for the Saugus, 1.4 to 7.5 mm/yr.

Post-Saugus deformation

Vertical separation rates for the time after the end of Saugus deposition are 0 (in the coastal plain west of Oak Ridge) to more than 11 mm/yr from South Mountain eastward, assuming that the top of the Saugus is 0.2 Ma and the flat-lying gravels in the Union SPS 1 well near Santa Paula (Cross Section C-C', Plate V) are younger than Saugus. Yeats and others (1988) propose that the Saugus is not uplifted in the hanging-wall block of the Oak Ridge fault west of Oak Ridge because the displacement is transferred from the Oak Ridge fault to a decollement in Miocene shale, called by them the Sisar decollement. Yeats (1988) shows that the vertical separation rate at South Mountain could be as low as 5.6 mm/yr if the top of the Saugus is as old as 0.4 Ma.

Oak Ridge itself is underlain by a series of left-stepping anticlines, most of which bring Sespe Formation to the surface. Many of the faults in the core of the anticline at South Mountain have normal separation; these formed during the Miocene (Figure 5; Yeats, 1987). Those with reverse separation are assumed to be Quaternary, although they do not cut Quaternary deposits. The left-stepping anticlines west of South Mountain (Plate I) have no expression in the deformation of microfaunal horizon 5 (Plate III), which shows a homoclinal dip to the SSE. The structural depression at Balcom Canyon between the anticlines to the west at South Mountain and to the east at Bardsdale is not expressed in deformation of the Bailey ash (Plate I); this depression is the only place where Repettian strata are exposed on the south side of Oak Ridge. These relations suggest that the culminations and depressions along the Oak Ridge anticline, together with the left steps, predate the anticline itself, which is almost entirely post-Saugus.

The Santa Clara syncline is also stepped to the left on the west side of Oak Ridge such that at one locality at the west end of Oak Ridge, there is no south flank of the syncline. East of Balcom Canyon, the syncline also lacks a south flank (Cross Section E-E'), but this area separates a more simple, asymmetric syncline to the west from a more complex folded structure to the east. West of Piru, these structures formed prior to the end of Saugus deposition, but in the east Ventura basin, the Saugus is involved in these folds as well (Yeats and others, 1985). Folding of the syncline at the east end of the Oak Ridge fault clearly predates faulting; Cross Sections F-F' and G-G' show the Oak Ridge fault cutting across already-folded strata.

Well data provide structural control on the Oak Ridge fault to depths as great as 4 km (Plate II). The fault may be subdivided into several segments: (1) coastal segment, (2) oblique-slip segment from Saticoy to Santa Paula, (3) dip-slip segment from Santa Paula to Balcom Canyon, (4) dip-slip, lobate segment from Balcom Canyon to Wiley Canyon, and (5) eastern segment, where the fault divides into several splays and dies out.

The coastal segment is at maximum burial on both hanging-wall and footwall sides; there has been virtually no displacement since the end of Saugus deposition. However, near Montalvo, there are two left-stepping pressure ridges in which Saugus and post-Saugus sediments are deformed; these are described below in the Neotectonics section. This segment trends westward for a considerable distance offshore, where it is difficult to describe because of the lack of well control on the fault itself. The fault zone is very thin and is mapped as a zone of erratic dips where no electric-log correlation is possible in the otherwise easily correlatable Fernando turbidite sandstones and mudstones. The fault cuts Fernando Formation but dies out in the upper Fernando and does not cut Saugus. At the east end of this segment, the fault does not cut Fernando at all; the Fernando is folded into a steep monoclinal flexure above a blind fault beneath well control (see cross sections in Yeats and others, 1981). The Montalvo normal fault (Cross Section A-A'; Plates II and III) diverges southwest from the Oak Ridge and cuts the entire Saugus; thicker Saugus in the downthrown block indicates that the Montalvo fault is a growth fault. The normal separation is difficult to explain in an otherwise contractile regime. The fault may have a left-lateral strike-slip component with the slip vector trending more easterly than the strike of the fault.

In the oblique-slip segment between Saticoy and Santa Paula, the Oak Ridge fault dips as steeply as 80 degrees southeast. Unlike the coastal segment, the fault cuts Saugus and would probably be expressed at the surface by a scarp, but the Santa Clara River flows down the surface trace of the fault and is in part located in the hanging-wall block; thus the fault has no surface expression. The footwall block contains the Saticoy oil field, which produces oil from upturned Fernando turbidite sandstones lensing out against the South

Mountain seaknoll of Yeats (1965). The Oak Ridge fault cuts obliquely across the seaknoll and displaces it 3.5 km left-laterally and 3.75 km vertically at the Horizon 5 level, giving a net slip of 5.2 km (Yeats, 1976). A frontal fault within the Saticoy field parallel to the Oak Ridge fault has displaced the turbidite reservoirs and their oil-water contacts left-laterally, indicating that oil accumulation predated the youngest movement on the fault (Yeats and Taylor, in prep.). In this segment, the post-Saugus displacement increases northeastward from zero to its maximum figure of 2375 to 2490 m at South Mountain (Yeats, 1988). The fault zone itself consists predominantly of highly fractured Monterey Shale, although upturned Fernando turbidites close to the fault are also highly fractured and cemented with calcite (Friedman, 1969). At the west end of Oak Ridge, the Lloyd-Butler reverse fault with north side up diverges from the Oak Ridge fault and extends eastward parallel to the southern range front. The Lloyd-Butler fault cuts Fernando but not Saugus, and thus it is not exposed at the surface.

This segment grades into the dip-slip segment between Santa Paula and Balcom Canyon as the strike of the fault curves from northeast to east-southeast. The dip of the fault decreases eastward from 80 degrees to 64 degrees. This segment contains the eastern end of oil production from Fernando turbidites, referred to as the Bridge pool of the South Mountain oil field, although it is continuous with the Saticoy field. Casings of oil wells crossing the fault are not deformed at the fault, indicating no aseismic slip since these wells were drilled in the mid-1950's. The Santa Clara River flows in the hanging-wall block at the City of Santa Paula, but upstream to the east, the river is farther from the foot of Oak Ridge, and the surface trace of the Oak Ridge fault is expressed by tectonic topography. Balcom Canyon itself is marked by the sharpest change in strike along the entire fault. The range-front fault extends into the range and dies out, and a more northerly fault strikes north along the range front and curves eastward toward Bardsdale. South of the crest of South Mountain, the north-dipping South Mountain thrust is not in contact with strata younger than the Modelo Formation, which it cuts. However, the thrust appears to be folded as part of the Oak Ridge anticline, indicating that it predates folding (see cross section in Yeats, 1988).

In the east-striking segment from Balcom Canyon to Wiley Canyon, the fault dips 64 to 77 degrees south at depth, but shallower than 1 to 2 km below sea level, the fault is strongly lobate (Rieser, 1976; Cross Sections E-E' and F-F', and Plate II). The lobate portion of the fault is also highly irregular in strike and dip, and locally, in the Shiells Canyon oil field, the fault dips west. Saugus Formation beneath the fault comprises an oil-producing zone in the Bardsdale and Shiells Canyon oil fields. Casings of oil wells crossing the Oak Ridge fault are not deformed at the fault, indicating that the fault has not moved aseismically since these wells were drilled in the late 1940's and 1950's. The thickness of the fault zone varies from a few meters to more than 300 meters in the lobate section at Shiells Canyon. The fault zone contains horses of marine Eocene, Sespe, Vaqueros, lower Miocene Rincon Shale, Monterey Shale, Repetto and Pico members of the Fernando Formation, and Saugus, and it is characterized by slickensides, gouge, cataclastic sandstone, secondary calcite, and highly variable core dips. Underneath the Oak Ridge fault is a frontal fault, the Basolo fault of Rieser (1976) which brings Fernando Formation over Saugus (Cross Sections D-D' and E-E'). The Basolo fault is truncated by the Oak Ridge fault and is probably older. In this segment, the lobate Oak Ridge fault comes to the surface in the Santa Clara Valley, far to the north of the range front, and its subcrop against Santa Clara River gravels is poorly constrained by well data (Plate II).

In the eastern segment, the Oak Ridge fault divides into the south, middle, and north strands (Ricketts and Whaley, 1975; Plates I and II; Cross Section G-G'). At Torrey Canyon oil field, the south strand brings Miocene to Cretaceous(?) strata on the south side into contact with Modelo Formation and younger strata on the north. The south strand steepens eastward to vertical and to a north dip with normal separation. Farther east, on the north side of the Oakridge oil field, the south strand is overridden by the Santa Susana fault (Yeats, 1987a). The middle strand appears to be a splay of the south strand, and it, too, changes eastward from a south dip to a north dip. This change in dip is interpreted as broad southward tilting accompanying south-verging thrusting on the Santa Susana fault. In the Upper Ojai Valley, the Sisar fault changes eastward from a south-dipping reverse fault to a north-dipping normal fault as the San Cayetano fault is approached (Huftile, 1988), a situation comparable to the Oak Ridge-Santa Susana relationship.

The north strand diverges from the Oak Ridge fault west of the point where the south strand has a vertical dip (Plate II), and it reaches the Santa Clara Valley and dies out as a reverse fault, suggesting that it is younger than the south and middle strands. Further north, the Camulos fault comprises the range-front fault of the northwest side of the Santa Susana Mountains, and it may offset late Quaternary alluvial deposits (note map relations in Plate I). Yeats and others (1985) mapped the Camulos fault as the north strand of the Oak Ridge fault. Farther east, the Camulos fault dies out, close to the place where the San Cayetano fault dies out. Both the north strand and the Camulos fault cut across already-folded Fernando and Saugus Formations.

Neotectonics

Although the Oak Ridge fault east of Saticoy is considered as active with slip rates of 5.9 to 12.5 mm/yr (Yeats, 1988), it produces relatively few geomorphic features related to ground rupture, largely because the Santa Clara River follows the fault trace for most of its length. Nonetheless, several features along the fault trace give evidence of late Quaternary deformation. These are as follows: (1) Montalvo Mounds, (2) Balcom Canyon fault scarps, (3) Bardsdale Cemetery fault scarp, and (4) Camulos scarp. The Montalvo, Bardsdale, and Camulos relations are described below, followed by a discussion of Oak Ridge uplift history and drainage evolution.

Montalvo Mounds

The community of Montalvo is flanked on east and west by two en echelon, stepped-right west-northwest-trending pressure ridges (Plate I). A possible third pressure ridge north of the intersection of Bristol Road and Telephone Road (cf. Plate I) is suggested due to an anomalous deflection of the 220- and 240-foot contours on the southeast side of Harmon fan, but this could not be confirmed in the field, and it is not discussed further. This report on the other two mounds is an update of Hall (1982), based on additional mapping by

Edward A. Hall, John Powell, Russell Van Dissen, and Robert S. Yeats and an unpublished summary by Russell Van Dissen.

The eastern (Victoria Street) mound is 1100 m long, 300 m wide, and strikes N 70 W. Its appearance on the 1951 Saticoy 7 1/2 minute quadrangle, used for the base map for Plates I-IV, shows that much of its southeastern portion was removed prior to 1951 by quarrying for sand and gravel. Most of the western half has now been quarried since the topographic map was surveyed. According to Hall (1982), this quarrying has exposed, in the core of an anticline, a yellow-brown silty claystone at least 12 m thick containing charcoal that is beyond the range of radiocarbon dating. The claystone is overlain by loosely-consolidated sand and cobble gravel with interbeds of gray to tan siltstone. This sequence is similar to modern sediments of the Santa Clara River, and it is correlated to the Saugus Formation. Unconformably overlying the Saugus is a dirty brown, poorly-sorted sand and gravel with interbeds of silt similar to sediments transported from the north (Hall, 1982) by streams on the Harmon alluvial fan. The unconformity is most prominent on the south side of the anticline where Saugus Formation dipping 48 degrees SW is overlain by sand and gravel dipping 11 to 36 degrees SW. The unconformity is observed on the north side as well, but it is less angular. The axial region of the anticline is cut by two reverse faults, both with south side up and 12 to 15 m stratigraphic separation. The southerly fault strikes N 67-75E and dips 56-57 degrees south, and the northerly fault strikes N80E to N74W and dips 42-48 degrees south. The southerly fault cuts the sequence overlying the unconformity with separation of about 3 m. The anticlinal axis trends N60W and plunges 10-15 degrees NW. For a map and cross section of this mound, see Hall (1982).

The western (Knoll Drive) mound strikes N50W and is 600 m long and 250 m wide. A geologic map by Hall (1982) has been updated on the basis of additional excavations south and west of Knoll Drive and is shown as Figure 7. As described by Hall (1982), the oldest rocks are loosely consolidated gray sand and gravel with interbeds of yellow-brown to reddish-brown sandy clay similar to the older sequence at the Victoria Street mound and correlated to the Saugus Formation; 7 meters of section was excavated at the Knoll Drive mound. The Saugus is overlain with angular unconformity by brown to gray-brown ssndy gravel and very dark-brown, silty, fine-grained sand and gravel. These units are thickest at the southwest edge of the Union Oil building excavation. A fault within the Saugus strikes N2E and dips 70-75 degrees E, but does not cut the above-mentioned unconformity at the base (Figure 8). Injected sand, clay, and gravel along the fault plane suggests that fault movement was coseismic. Farther west in the excavation, two normal faults have attitudes of N5W 75-78 degrees E. These faults cut the unconformity at the top of the Saugus but not the younger very dark-brown gravel. Both faults show west side up with a total separation of 3.5-4.5 m.

Excavations at the G. L. Center (Figure 7) reveal light gray Saugus sand and gravel overlain by yellow-brown and green clay which is itself unconformably overlain by black clay. Foundation borings north of the mound penetrated brown silt; the brown gravel of the Union excavation is missing. Excavations for a building site at the northwest corner of Sperry Avenue and Colt Street (Figure 9) revealed numerous small faults, some of which extend to, but not across the surface soil. The older light-brown soil (Unit A of Figure 9) is tilted along with still older coarser-grained sediments. This soil is overlain and truncated by brown to black clayey soil (Unit B of Figure 9).

The map, Figure 7, shows that the anticline curves from N70W in the south to N20W in the north. The post-Saugus sediments are finer grained on the northeast side, suggesting to Hall (1982) that uplift of the mound may have interrupted drainage from Harmon fan to the north, producing a lake or marsh. The mounds have no expression at depth in wells, as illustrated in Plate III and Cross Section B-B'. They are believed to be pressure ridges accompanying minor left slip on the Oak Ridge fault at depth. The local stress field accompanying left slip would suggest that east-trending faults would have reverse displacement, as observed in the Victoria Street mound, and north-trending faults would have normal displacement, as observed on the Knoll Drive mound.

An air-photo lineation close to the Oak Ridge fault at the Saticoy Country Club mapped by Sarna-Wojcicki and others (1976) was trenched, but no fault was found. However, an <u>in situ</u> burn zone in this trench yielded a radiocarbon age of 30,300 +/- 750 years (T. K. Rockwell, pers. comm., 1987). Soil developed in the overlying alluvium is consistent with this date and is similar to soils in the sediments unconformably overlying the Saugus in the Victoria Street mound. If this correlation is accepted, the younger, less-tilted sediments at Victoria Street have been deformed in the last 30,000 years.

<u>Balcom Canyon fault scarps</u>

East of Santa Paula, the Santa Clara River channel is well to the north of the Oak Ridge range front, and fault topography is developed along the range front as far east as the mouth of Balcom Canyon (Plate I). An alluvial fan, called here the Balcom fan, spreads out from the mouth of Balcom Canyon, and this may have contributed to the more northerly position of the Santa Clara River channel, because Balcom Canyon contains the largest north-flowing drainage on Oak Ridge. The north side of Oak Ridge contains massive landslides, one of which has covered part of the west end of the fan. This landslide is cut by the Oak Ridge fault. Farther east, the range front is sharply linear and stepped right from the fault trace in the landslide. A stereopair of the faulted landslide and linear range front is presented by Yeats and others (1982).The surface position of the fault in comparison with its position in wells (Plate II) indicates that the fault is not lobate in this segment. The range front is linear as far east as the fault segment boundary at Balcom Canyon, where the fault and the range front turn sharply north.

<u>Bardsdale Cemetery trench</u>

East of Balcom Canyon, well data show that the Oak Ridge fault projects to the surface 1 to 1.5 km north of the foot of Oak Ridge (Rieser, 1976; Plate II). The range front is abrupt and scalloped; it was cut by the Santa Clara River at a time when it flowed south of its present channel (Figure 10a). Water wells in the area such as Well 3N/20W/11A1 illustrated in Figure 10a, penetrate a gravel above the top of the Sespe that is interpreted as Santa Clara River gravel. Following northward migration of the channel, the surface was covered by coalescing alluvial fans (Bardsdale and Grimes fans) formed by streams draining Oak Ridge. Fan slope angles decrease from 4 degrees at the range front to 0.5 degrees downslope. At the north edge of the Bardsdale Cemetery, near the south end of Sespe Street, the Bardsdale surface is interrupted by a broad, north-facing scarp with slopes as high as 8 degrees. The scarp trends N60E, parallel to structure contours of the subjacent Oak Ridge fault, and can be traced for 1200 meters. A stereopair of this scarp is presented by Yeats and others (1982). Vertical surface offset across this scarp is 5 m (Figure 11).

A backhoe trench was excavated across this scarp on the west side of Sespe Street by Staal, Gardner, & Dunne, Inc. and logged by John Powell, David Gardner, and Russell Van Dissen. The trench (Figure 11) revealed alluvial-fan deposits derived from Modelo (in some cases burned brick red), Vaqueros, and Sespe strata similar to exposures on the north flank of Oak Ridge. These sediments are in contrast to Santa Clara River gravels which are far-derived and include well-rounded clasts of crystalline rocks. The fan deposits include silty sand with gravel, and sand and gravel channel deposits with variable amounts of cobbles and isolated boulders. Soils appear to be Holocene on the basis of an A/Cox profile development similar to other late Holocene soils in the Ventura basin (Rockwell and others, 1984b; T. K. Rockwell, pers. comm., 1986); this is confirmed by a radiocarbon date of 2010 +/- 145 yrs based on charcoal in faulted sediments in the trench (T. K. Rockwell, pers. comm., 1986).

The fan deposits are cut by a normal fault striking N70E and dipping 60-65 degrees north. Four distinctive contacts are recognized on both sides of the fault and are labeled (1), (2), (3), and (4) on Figure 11. Contacts (1) and (2) are displaced 1.7 m, and Contacts (3) and (4) are displaced 2.1 m, weakly suggesting that (3) and (4) underwent a displacement of 0.4 m prior to deposition of (2). This difference can be seen on the trench log as a greater thickness of the beds between (2) and (3) in the downthrown block. However, these units vary considerably in thickness in the trench, and the thickness difference between (2) and (3) may represent juxtaposition by oblique-slip rather than dip-slip faulting. Trench evidence does not preclude the fault being formed in a single event.

A dark brown, clay-rich zone 2-4 cm thick in the deepest excavation of the fault appears to be fault gouge; shallower excavations of the fault lack gouge. Flat clasts of gravel tend to be aligned in the fault plane at shallower excavations. Silty, dark brown, very-fine-grained to medium-grained sand similar to the unit above contact (1) is entrained in the upper 3 m of fault excavation, suggesting that faulting was coseismic. The fault is overlain by unfaulted sand and gravel and dark-brown silty sand.

The vertical component of dip separation of contacts (3) and (4) is 1.7 m, considerably less than the vertical surface offset across the scarp of 5 m. This indicates that only a third of the offset across the scarp is accommodated at the near-surface fault. How was the rest of the offset formed? Evidence bearing on this problem includes (1) the Oak Ridge fault at depth is characterized by reverse slip at comparatively high rates (Yeats, 1988), and (2) the maximum scarp slope angle is only 8 degrees, despite the fact that the scarp is undissected, and deformed sediments are late Holocene in age. This means that the low angle of the scarp slope does not indicate a great age for the scarp. I suggest that the scarp was formed by a lower angle reverse fault that is too deep to be reached by the trench (Figure 10b), and the normal fault in the trench was formed by bending moment in the convex part of the fan sequence as it warped over the buried reverse fault. Neither of the above-mentioned faults is the Oak Ridge fault, as Figure 10a shows, and they are more likely related to folding of the Oak Ridge anticline accompanying faulting. Similar features were trenched along the Dunstan fault, New Zealand (Beanland and others, 1986).

The normal fault is overlain by unfaulted sediments that are warped to show the full 5 meters of vertical separation across the scarp, indicating that at least two events deformed sediments in the trench in the last 2000 years, one forming the normal fault and possibly some of the broad warping, and the other forming the rest of the broad warping, presumably as the proposed buried reverse fault formed. Because the vertical surface offset of the scarp is three times that on the normal fault, and the offset of contacts (3) and (4) is greater than that of contacts (1) and (2), there could have been three events in the last 2000 years.

Camulos scarp

South of Piru, alluvial deposits north of the range front on both sides of Torrey Road have a linear boundary with Santa Clara River channel deposits; this boundary is marked by the 640-foot contour east of Torrey Road. This lineament lies at the surface projection of the Camulos fault as based on well data. It could be related to faulting, but it could also be a terrace riser formed entirely by the Santa Clara River. Farther east, the Santa Clara River cuts into the hanging-wall block of the Camulos fault, and no fault-related surface features are preserved.

Uplift history of Oak Ridge

Figure 6B is a longitudinal profile of maximum altitudes on Oak Ridge, and a comparison with Figure 6A shows that these altitudes are related to post-Saugus uplift of the hanging-wall block of the Oak Ridge fault. West of Oak Ridge, post-Saugus uplift is zero, but the west end of uplifted Saugus is nearly 3 km west of the prow of Oak Ridge because the Santa Clara River has eroded this western end at times when the river flowed south across Oxnard Plain. The ridge has a saddle at Balcom Canyon, which may reflect the structural depression that exists there; however, this structural depression is not evident in dips of the Fernando and Saugus on the south side of Oak Ridge. More likely, the high point at South Mountain reflects the resistance to erosion of a sill of hornblende andesite that crops out near the summit.

The Oak Ridge drainage divide is plotted on Plate IV. Comparison with the geologic map, Plate I, shows that the drainage divide is everywhere south of the Oak Ridge anticlinal axis. The anticlinal axis is far down the north side of Oak Ridge, locally near its base. For the most part, the drainage divide is within the Fernando Formation, and south of Fillmore, it is in Saugus. Locally, however, the drainage divide is in the Modelo, and these changes in position from Fernando to Modelo are abrupt, giving the map of the divide a serrate pattern. The northerly position of the drainage divide at South Mountain appears to be related to the resistant ledge of andesite; to the east in Balcom Canyon and to the west at the west end of Oak Ridge, the andesite is not present, and the drainage divide farther south, in the Fernando. This is evidence that the drainage divide was previously much farther north and has migrated southward as Oak Ridge was uplifted.

Alluvial fans are common on the southwest side of Oak Ridge, and most of these are entrenched. These fans were studied by Russell Van Dissen with the objective of determining if older fans are tilted southward more than younger ones. Age determinations on geomorphic surfaces are based on profile descriptions by Edwards and others (1970) calibrated for the Ventura basin by Rockwell and others (1984b). Thus calibrated, the Chesterton (abrauptic durixeralf) and Huerhuero (haplic natrixeralf) soils of Edwards and others (1970) are 25-40 ka in age, and the Rincon, Zamora, and Azule mollic haploxeralf soils are 12-30 ka in age. Other soils are 5 ka and younger.

Longitudinal profiles of alluvial fans west of Fox Canyon (south of South Mountain) show that most surfaces older than 12 ka do not extend far upvalley but are found downstream of the range front as dissected alluvial fans. A single profile with a Huerhuero soil has a maximum slope angle of 8.8 degrees compared with a lower fan with a young soil in the same valley with a maximum slope of 6.6 degrees. At the head of the valley, the older surface is 40 m higher than the younger one, although at the range front, both surfaces have the same altitude and slope. For most of the valleys, the older fans have been removed by dissection, and this period of dissection was followed by valley infilling upstream of the range front. The younger valley fill is now being entrenched by the modern streams. The relations between the older and younger fan surfaces could be explained by uplift and southward tilting of Oak Ridge, but other factors such as climate cannot be excluded.

Conclusions

The Oak Ridge fault probably began as a middle Miocene normal fault annular to volcanic centers in the western Santa Monica Mountains, and this served as a zone of weakness to localize Pliocene and Quaternary activity. Different thicknesses of Fernando Formation north and south of the fault give evidence of Pliocene faulting accompanying subsidence of both blocks at different rates. This faulting took place at higher rates at Oak Ridge itself than it did near the coast and offshore, and displacement rates are greater for younger strata and are highest for the Pleistocene Saugus Formation. Strong uplift of the hanging-wall block at Oak Ridge began only in the late Pleistocene, 0.4-0.2 Ma. Near the coast, the hanging-wall block was not uplifted, and the only evidence of young deformation is the Montalvo mounds, pressure ridges accompanying strike-slip faulting of small displacement.

The Oak Ridge fault is poorly expressed in tectonic-geomorphic features, largely because the Santa Clara River covers most of the fault trace. However, where the Santa Clara River is well to the north of the fault trace, landslides and alluvial fans are observed to be deformed. The Bardsdale alluvial fan, radiocarbon dated as 2000 years, is offset 5 meters by a broad warp possibly masking a buried reverse fault and 1.7 meters by a normal fault exposed in a trench, giving evidence of two and possibly three faulting events in the last 2000 years. In the Montalvo mounds, alluvial fan materials as old as 30,000 years are tilted. On the basis of these relations and on the slip rate of 5.9 to 12.5 mm/yr at Oak Ridge, the Oak Ridge fault is considered active. Casings of oil wells drilled across the fault in the last 30-40 years are not damaged at the fault, indicating no aseismic slip during that time. Faults at Knoll Drive and Bardsdale Cemetery entrain soft sediments from below, suggesting that faulting was coseismic.

REFERENCES CITED

Barnard, M. P., 1979, Generalized stratigraphic column for the Santa Ana Valley, Matilija quadrangle, Ventura County, California, in Bell, G. and Berger, D., eds., Geology of the Lake Casitas area, Ventura County, California, Field Trip Guidebook, 1979: Pacific Section, American Association of Petroleum Geologists.

Barron, J. A., 1976, Marine diatom and silicoflagellate biostratigraphy of the type Delmontian Stage and the type Bolivina obliqua Zone, California: Journal of Research, U. S. Geological Survey, v. 4, no. 3, p. 339-351.

Barron, J. A., 1986, Updated diatom biostratigraphy for the Monterey Formation of California, in Casey, R. E. and Barron, J. A., eds., Siliceous microfossils and microplankton of the Monterey Formation and modern analogs: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 45, p. 105-119.

Beanland, S., Berryman, K. R., Hull, A. G., and Wood, P. R., 1986, Late Quaternary deformation at the Dunstan fault, Central Otago, New Zealand, in Reilly, W. I. and Harford, B. E., eds., Recent Crustal Movements of the Pacific Region: Royal Society of New Zealand Bulletin 24, p. 293-306.

Blake, G. H., 1983, Benthic foraminiferal paleoecology and biostratigraphy of the Vaqueros Formation, Big Mountain area, Ventura County, California, in Squires, R. L. and Filewicz, M. V., eds., Cenozoic geology of the Simi Valley area, southern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 173-181.

Campbell, R. H., and Yerkes, R. F., 1976, Cenozoic evolution of the Los Angeles basin area--relation to plate tectonics: Pacific Section, American Association of Petroleum Geologists Miscellaneous Publication 24, p. 541-558.

Canter, N. W., 1974, Paleogeology and paleogeography of the Big Mountain area, Santa Susans, Moorpark, and Simi quadrangles, Ventura County, California: Athens, Ohio University MS thesis, 58 p.

Cemen, I., 1977, Geology of the Sespe-Piru Creek area, Ventura County, California: Athens, Ohio University MS thesis, 69 p.

Cleveland, G. B., 1973, Late Quaternary sedimentation, in Weber, F. H., Jr., Cleveland, G. B., Kahle, J. E., Kiessling, E. F., Miller, R. V., Mills, M. F., Morton, D. M., and Cilweck, B. A., Geology and mineral resources study of southern Ventura County, California: California Division of Mines and Geology Preliminary Report 14, p. 28-39.

Edwards, D. R., Rabey, D. F., and Kover, R. W., 1970, Soil survey of Ventura area, California: Soil Conservation Service, U. S. Department of Agriculture, 148 p.

Edwards, L. N., 1971, Geology of the Vaqueros and Rincon Formations, Santa Barbara embayment, California: Santa Barbara, University of California Ph.D.

thesis, 240 p.

Egner, D. E., Lynn, R. J., and Guzman, R., 1974, Geologic-seismic investigation, proposed governmnet center, County of Ventura, California; unpub. report, Fugro Inc., Project 73-091-EG, Long Beach, Calif., 21 p.

Friedman, M., 1969, Structural analysis of fractures in cores from Saticoy field, Ventura County, California: American Association of Petroleum Geologists Bulletin, v. 53, p. 367-389.

Geotechnical Consultants, Inc., 1972, Hydrogeologic investigation of the Mound Ground Water Basin, for the City of San Buenaventura, California: Job V2067, 59 p.

Greene, H. G., Wolf, S. C., and Blom, K. G., 1978, The marine geology of the eastern Santa Barbara Channel with particular emphasis on the ground water basins offshore from the Oxnard Plain, southern California: U. S. Geological Survey Open-File Report 78-305, 104 p.

Hall, E. A., 1982, Geological observations on the Montalvo mounds, Ventura area, California, in Cooper, J. D., compiler, Neotectonics in southern California, Guidebook prepared for the 78th Annual Meeting of the Cordilleran Section of the Geological Society of America, Anaheim, California, April 19021, 1982, p. 53-57.

Hall, E. A., Durrie, J., and Saunders, J., 1967, Field trip, morning section, Big Mountain oil field: Pacific Section, American Association of Petroleum Geologists, 10 p.

Hsu, K. J., 1977, Studies of Ventura field, California: I: Facies geometry and genesis of lower Pliocene turbidites: American Association of Petroleum Geologists Bulletin, v. 61, p. 137-168.

Hsu, K. J., Kelts, K., and Valentine, J. W., 1980, Resedimented facies in Ventura basin, California, and model of longitudinal transport of turbidity currents: American Association of Petroleum Geologists Bulletin, v. 64, p. 1034-1051.

Huftile, G. J., 1988, Geology of the Upper Ojai Valley and Chaffee Canyon areas, Ventura County, California: Corvallis, Oregon State University MS thesis, 103 p.

Ingle, J. C., 1967, Foraminiferal biofacies variation and the Miocene-Pliocene boundary in southern California: Bulletin of American Paleontology, v. 52, no. 236, p. 217-394.

Ingle, J. C., 1973, Summary comments on Neogene biostratigraphy, physical stratigraphy, and paleo-eceanography in the marginal northeastern Pacific Ocean, in Kulm, L. D., von Huene, R., and others, Initial Reports of the Deep Sea Drilling Project, v. 18, Washington D. C. (U. S. Government Printing Office), p. 949-960.

Izett, G. A., 1981, Volcanic ash beds: Recorders of upper Cenozoic silicic pyroclastic volcanism in the western United States: Journal of Geophysical Research, v. 86, p. 10,200-10,222.
Izett, G. A., Naeser, C. W., and Obradovich, J. D., 1974, Fission-track age of zircon from an ash bed in the Pico Formation (Pliocene-Pleistocene) near Ventura, California: Geological Society of America Abstracts with Programs, v. 6, p. 197.

Jackson, P. A. and Yeats, R. S., 1982, Structural evolution of Carpinteria basin, western Transverse Ranges, California: American Association of Petroleum Geologists Bulletin, v. 66, p. 805-829.

Jakes, M. C., 1979, Surface and subsurface geology of the Camarillo and Las Posas Hills area, Ventura County, California: Corvallis, Oregon State University MS thesis, 105 p.

Kaufman, A., Broecker, W. S., Ku, T. L., and Thurber, D. L., 1971, The status of U-series methods of mollusk dating: Geochimica et Cosmochimica Acta, v. 35, p. 1155-1183.

Kew, W. S. W., 1924, Geology and oil resources of part of Los Angeles and Ventura Counties, California: U. S. Geological Survey Bulletin 753, 202 p.

Kleinpell, R. M., 1938, Miocene stratigraphy of California: Tulsa, Oklahoma, American Association of Petroleum Geologists, 450 p.

Lajoie, K. R., Sarna-Wojcicki, A. M., and Yerkes, R. F., 1982, Quaternary chronology and rates of crustal deformation in the Ventura area, California, in Cooper, J. D., compiler, Neotectonics in southern California: Guidebook prepared for the 78th Annual Meeting of the Cordilleran Section of the Geological Society of America, Anaheim, California, April 19-21, 1982, p. 43-51.

Lander, E. B., 1983, Continental vertebrate faunas from the upper member of the Sespe Formation, Simi Valley, California, and the terminal Eocene event, in Squires, R. L., and Filewicz, M. V., eds., Cenozoic geology of the Simi Valley area, southern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 142-153.

Lee, W. H. K., and Vedder, J. G., 1973, Recent earthquake activity in the Santa Barbara Channel region: Seismological Society of America Bulletin, v. 63, p. 1757-1773.

Levi, S., Schultz, D. L., Yeats, R. S., Stitt, L. T., and Sarna-Wojcicki, A. M., 1986, Magnetostratigraphy and paleomagnetism of the Saugus Formation near Castaic, Los Angeles County, in Ehlig, P. L., compiler, Neotectonics and Faulting in Southern California: Guidebook and volume prepared for the 82nd Annual Meeting of the Cordilleran Section of the Geological Society of America, Los Angeles, California, March 25-28, 1986, p. 103-108.

Liddicoat, J. C., and Opdyke, N. D., 1981, Magnetostratigraphy of sediments in the Atlantic Coastal Plain and Pacific Coast of the United States as an aid for dating tectonic deformation: Technical Report Summary, Contract 14-08-0001-18377, U. S. Geological Survey, Menlo Park, California.

Mallory, V. S., 1959, Lower Tertiary biostratigraphy of the California Coast Ranges: Tulsa, Oklahoma, American Association of Petroleum Geologists, 416 p.

Mason, M. A., and Swisher, C. C., 1988, New evidence for the Arikareean age of the South Mountain local fauna, Ventura County, California and its relationship to marine geochronology: Geological Society of America Abstracts with Programs, v. 20, p. 211.

McCoy, G., and Sarna-Wojcicki, A. M., 1978, Preliminary map showing surficial materials of the Ventura-Oxnard Plain area, California: U. S. Geological Survey Open-File Report 78-1065, map scale 1:125,000.

McCracken, W. A., 1972, Paleocurrents and petrology of Sespe sandstones and conglomerates, Ventura basin, California: Stanford, California, Stanford University Ph.D. thesis, 183 p.

Nagle, H. E., and Parker, E. S., 1971, Future oil and gas potential of onshore Ventura basin, California, in Cram, I. H., ed., Future petroleum provinces of the United States--their geology and potential: Tulsa, Oklahoma, American Association of Petroleum Geologists Memoir 15, v. 1, p. 254-297.

Namson, J., 1987, Structural transect through the Ventura basin and western Transverse Ranges, in Davis, T. L., and Namson, J. S., eds., Structural evolution of the western Transverse Ranges: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 48A, p. 29-41.

Natland, M. L., 1952, Pleistocene and Pliocene stratigrphy of southern California: Los Angeles, University of California Ph.D. thesis, 165 p.

Obradovich, J. D., and Naeser, C. W., 1981, Geochronology bearing on the age of the Monterey Formation and siliceous rocks in California, in Garrison, R. E., Douglas, R. G., Pisciotto, K. E., Isaacs, C. M., and Ingle, J. C., eds., The Monterey Formation and related siliceous rocks of California: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 87-95.

Pierce, R. L., 1972, Revaluation of the late Miocene biostratigraphy of California: Summary evidence, in The Proceedings of the Pacific Coast Miocene Biostratigraphic Symposium: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 334-340.

Putnam, W. C., 1942, Geomorphology of the Ventura region, California: Geological Society of America Bulletin, v. 53, p. 691-754.

Quick, G. L., 1973, Preliminary microzonation for surface faulting in the Ventura, California area, in Moran, D. E., Slosson, J. E., Stone, R. O., and Yelverton, C. A., eds., Geology, seismicity, and environmental impact: Association of Engineering Geologists Special Publication, p. 257-262.

Quick, G. L., 1981, The alleged Ventura fault in historical perspective, in

Quick, G. and Slade, R., field trip chairmen, Field trip guidebook to selected features in the Ventura and Santa Barbara County areas: Southern California Section, Association of Engineering Geologists Annual Field Trip, 6 p.

Ricketts, E. W., and Whaley, K. R., 1975, Structure and stratigraphy of the Oak Ridge fault-Santa Susana fault intersection, Ventura basin, California: Athens, Ohio University MS thesis, 109 p.

Rieser, R. B., 1976, Structural study of the Oak Ridge fault between South Mountain and Wiley Canyon, Ventura County, California: Athens, Ohio University MS thesis, 93 p.

Rockwell, T. K., Keller, E. A., Clark, M. N., and Johnson, D. L., 1984a, Chronology and rates of faulting of Ventura River terraces, California; Geological Society of America Bulletin, v. 95, p. 1466-1474.

Rockwell, T. K., Keller, E. A., and Johnson, D. L., 1984b, Tectonic geomorphology of alluvial fans and mountain fronts near Ventura, California, in Morisawa, M., and Hack, J. T., eds., Tectonic geomorphology: The Binghamton Symposium on Geomorphology, International Series, no. 15, p. 183-207.

Sarna-Wojcicki, A. M., Williams, K. M., and Yerkes, R. F., 1976, Geology of the Ventura fault, Ventura County, California: U. S. Geological Survey Miscellaneous Field Studies Map MF-781, 3 sheets, scale 1:6000.

Sarna-Wojcicki, A. M., Bowman, H. R., Meyer, C. E., Russell, P. C., Woodward, M. J., McCoy, G., Rowe, J. J., Baedecker, P. A., Asaro, F., and Michael, H., 1984, Chemical analyses, correlations, and ages of upper Pliocene and Pleistocene ash layers of east-central and southern California: U. S. Geological Survey Professional Paper 1293, 40 p.

Sarna-Wojcicki, A. M., Morrison, S. D., Meyer, C. E., and Hillhouse, J. W., 1987, Correlation of upper Cenozoic tephra layers between sediments of the western United States and eastern Pacific Ocean and comparison with biostratigraphic and magnetostratigraphic ages data: Geological Society of America Bulletin, v. 98, p. 207-223.

Schlueter, J. C., 1976, Geology of the upper Ojai-Timber Canyon area, Ventura County, California: Athens, Ohio University MS thesis, 75 p.

Seedorf, D. C., 1983, Upper Cretaceous through Eocene subsurface stratigraphy, Simi Valley and adjacent regions, California, in Squires, R. L., and Filewicz, M. V., eds., Cenozoic geology of the Simi Valley area, southern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 109-128.

Squires, R. L., 1981, Transitional alluvial to marine sequence: The Eocene Llajas Formation, southern California: Journal of Sedimentary Petrology, v. 51, p. 923-938.

State Water Resources Board, California, 1953, revised 1956, Ventura County Investigation: Bulletin 12, 2 volumes.

Turner, D. L., and Campbell, R. H., 1979, Age of the Conejo Volcanics: U. S. Geological Survey Bulletin 1457-E, p. E18-E22.

Weber, F. H., Jr., Cleveland, G. B., Kahle, J. F., Kiessling, E. F., Miller, R. V., Mills, M. F., Morton, D. M., and Cilweck, B. A., 1973, Geology and mineral resources study of southern Ventura County, California: California Division of Mines and Geology Preliminary Report 14, 102 p., geological map scale 1:48,000.

Williams, R. E., 1983, Miocene volcanism in the central Conejo Hills and western Simi Valley, Ventura County, California, in Squires, R. L., and Filewicz, M. V., eds., Cenozoic geology of the Simi Valley area, southern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 183-190.

Winterer, E. L., and Durham, D. L., 1962, Geology of southeastern Ventura basin, Los Angeles County, California: U. S. Geological Survey Professional Paper 334-H, p. 275-366.

Yeats, R. S., 1964, Andesite sill at South Mountain oil field, Ventura County, California: Geological Society of America Special Paper 76, p. 233.

Yeats, R. S., 1965, Pliocene seaknoll at South Mountain, Ventura basin, California: American Association of Petroleum Geologists Bulletin, v. 49, p. 526-546.

Yeats, R. S., 1976, Neogene tectonics of the central Ventura basin, California, in Fritsche, A. E., Ter Best, H., Jr., and Wornardt, W. W., eds., The Neogene Symposium: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 19-32.

Yeats, R. S., 1977, High rates of vertical crustal movement near Ventura, California: Science, v. 196, p. 295-298.

Yeats, R. S., 1979a, Stratigraphy and paleogeography of the Santa Susana fault zone, Transverse Ranges, California, in Armentrout, J. M., Cole, M. R., and Ter Best, H., Jr., eds., Cenozoic paleogeography of the western United States: Pacific Section, Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 3, p. 191-204.

Yeats, R. S., 1979b, Neotectonics of the Ventura Avenue anticline: Semi-annual technical report, Contract 14-08-0001-17730, U. S. Geological Survey, Menlo Park, California, 24 p.

Yeats, R. S., 1983a, Heavy oil accumulations in the Oxnard field, Ventura basin, California, in Isaacs, C. M., and Garrison, R. E., eds., Petroleum generation and occurrence in the Miocene Monterey Formation, California: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 85-98.

Yeats, R. S., 1983b, Large-scale Quaternary detachments in Ventura basin, southern California: Journal of Geophysical Research, v. 88, no. B1, p. 569-

583.

Yeats, R. S., 1987a, Late Cenozoic structure of the Santa Susana fault zone: U. S. Geological Survey Professional Paper 1339, p. 137-160.

Yeats, R. S., 1987b, Changing tectonic styles in Cenozoic basins of southern California, in Ingersoll, R. V., and Ernst, W. G., eds., Cenozoic basin development of coastal California: Rubey Vol. VI, Prentice-Hall, Inc., Englewood Cliffs, N. J., p. 284-298.

Yeats, R. S., 1988, Late Quaternary slip rates on the Oak Ridge fault, Transverse Ranges, California: Implications for seismic risk: Journal of Geophysical Research, in press.

Yeats, R. S., Clark, M. N., Keller, E. A., and Rockwell, T. K., 1981, Active fault hazard in southern California: Ground rupture versus seismic shaking: Geological Society of America Bulletin, v. 92, part 1, p. 189-196.

Yeats, R. S., Keller, E. A., Rockwell, T. K., Lajoie, K. R., Sarna-Wojcicki, A. M., and Yerkes, R. F., 1982, Field trip number 3: Neotectonics of the Ventura basin--road log, in Cooper, J. D., compiler, Neotectonics in southern California: Guidebook prepared for the 78th Annual Meeting of the Cordilleran Section of the Geological Society of America, Anaheim, California, April 19-21, 1982, p. 61-76.

Yeats, R. S., McDougall, J. W., and Stitt, L. T., 1985, Cenozoic structure of the Val Verde 7 1/2-minute Quadrangle and south half of the Whitaker Peak 7 1/2-minute Quadrangle, California: U. S. Geological Survey Open-File Report No. 85-587, 23 p., 4 plates.

Yeats, R. S., Huftile, G. J., and Grigsby, F. B., 1988, Oak Ridge fault, Ventura fold belt, and the Sisar decollement, Ventura basin, California: Geology, in press.

Yeats, R. S., and Taylor, J. C., in prep., The Saticoy oil field, Ventura basin, California, in Beaumont, E. A., and Foster, N. H., eds., Atlas of Petroleum Geology: Tulsa, Oklahoma, American Association of Petroleum Geologists.

Yerkes, R. F., and Lee, W. H. K., 1979, Maps showing faults and fault activity and epicenters, focal depths, and focal mechanisms for 1970-75 earthquakes, western Transverse Ranges, California: U. S. Geological Survey Miscellaneous Field Studies Map MF 1032, scale 1:250,000, 2 sheets.