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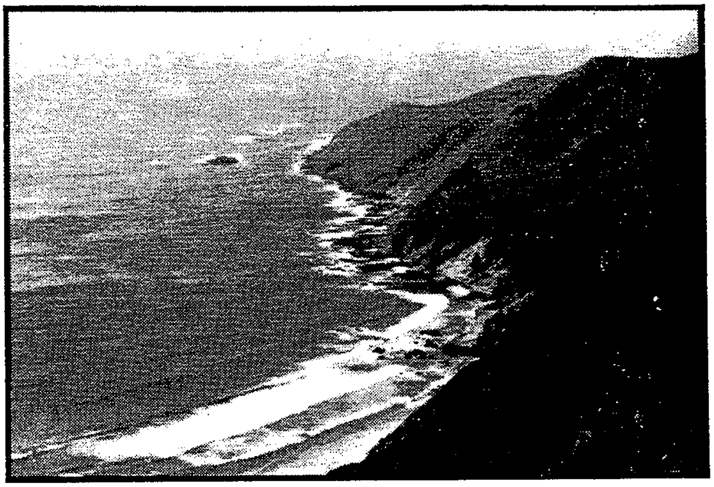

Origin, Maintenance and Land Use of Aeolian Sand Dunes of the Santa Maria Basin, California

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Introduction

The Pleistocene-Holocene sand dunes of the Santa Maria Basin are the largest aeolian sand deposits on the California coast. Individual dune sheets within a particular complex of dunes represent sequential, spatially overlapping aeolian depositional episodes. Geologically younger portions of particular dune sheets lie closer to their source (the beach). The older inland dune deposits are functionally and stratigraphically related to their coastal counterparts. The spatial and temporal pattern of dune emplacement within the Santa Maria Basin reflects the constancy of dune-building forces along this portion of coastal California throughout Quaternary times.

This report contains four sections: Section 1 consolidates geologic, climatic and physiographic information into a summary of the origin and maintenance of dune systems within the Santa Maria Basin. Section 2 documents historical impacts to dune distribution associated with land use changes over the past 155 years. Section 3 discusses the most important ecosystem-level threats to the dune systems and Section 4 identifies areas in need of preservation.

1.0 ORIGIN AND MAINTENANCE OF DUNE SYSTEMS IN THE SANTA MARIA BASIN

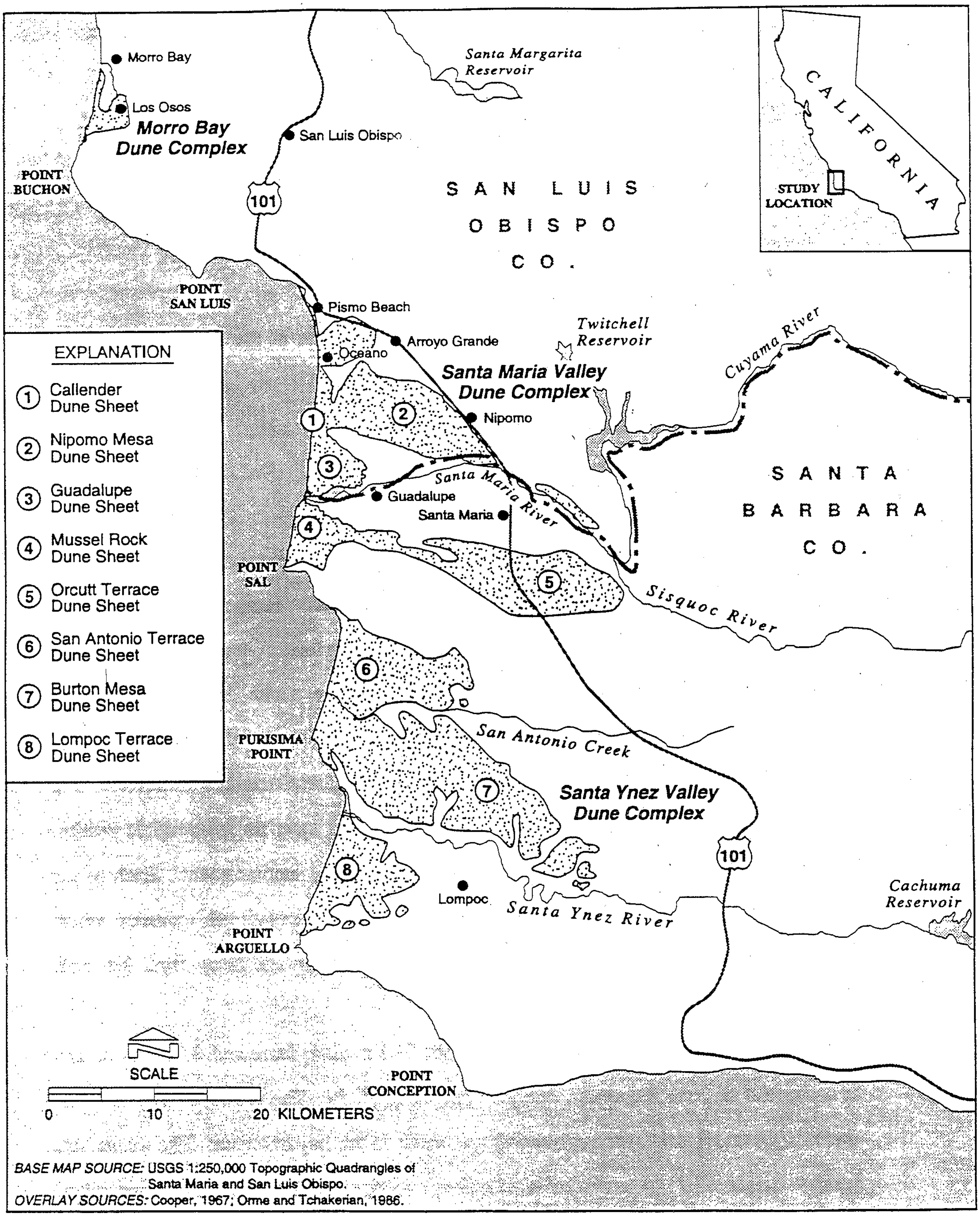
1.1 Description of the area covered by this report

The dune systems discussed in this report are located in the Santa Maria Basin, a northwest-southeast trending synclinal trough located in southwestern San Luis Obispo and adjacent western Santa Barbara County. Various names have been applied to individual sand deposits. The nomenclature of Cooper (1967) and Orme and Tchakerian (1986) will be employed here (Fig. 1).

The coastal and inland dune sheets lying within the geomorphic entity known as the Santa Maria Basin are geographically and geologically interactive aeolian units. The Santa Maria Basin contains three major dune complexes: the Morro Bay Dune Complex, Santa Maria Valley Dune Complex and the Santa Ynez Valley Dune Complex (Fig. 1). The latter two dune complexes are the focus of this report.

The Santa Maria and Santa Ynez Valley Dune Complexes are subdivided into dune sheets (Figs. 1 and 2), however these distinctions have no geomorphic reality. The dune complexes are more properly divisible by age of emplacement. Each of the dune sheets discussed below actually represent several depositional episodes which together form a consistent longitudinal pattern of increasing age away from the coast (Fig. 2).

The Morro Bay Dune Complex extends 14 km alongshore and 8 km inland and is composed of three sequential, aeolian deposits (Fig. 1). The principal feature of the dunes is a curving northward-projecting spit south of the bay entrance. The dunes here reach a height of 35 m and consist of older, stabilized parabolic dunes on the inland edge of the strip and younger, active dunes along the coast which overlie portions of



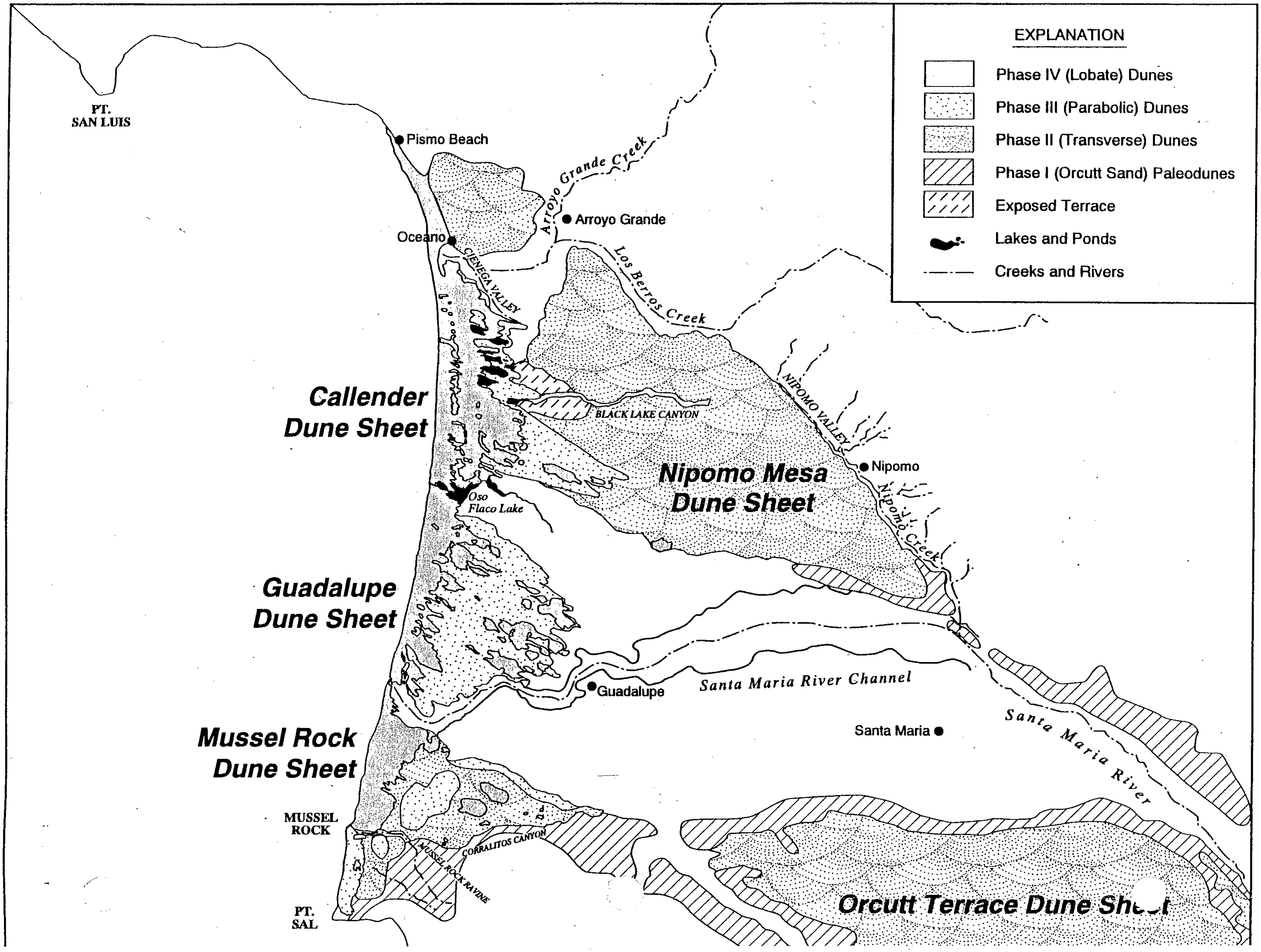
BASE MAP SOURCE: USGS 1:250,000 Topographic Quadrangles of Santa Maria and San Luis Obispo.
OVERLAY SOURCES: Cooper, 1967; Orme and Tchakerian, 1986.

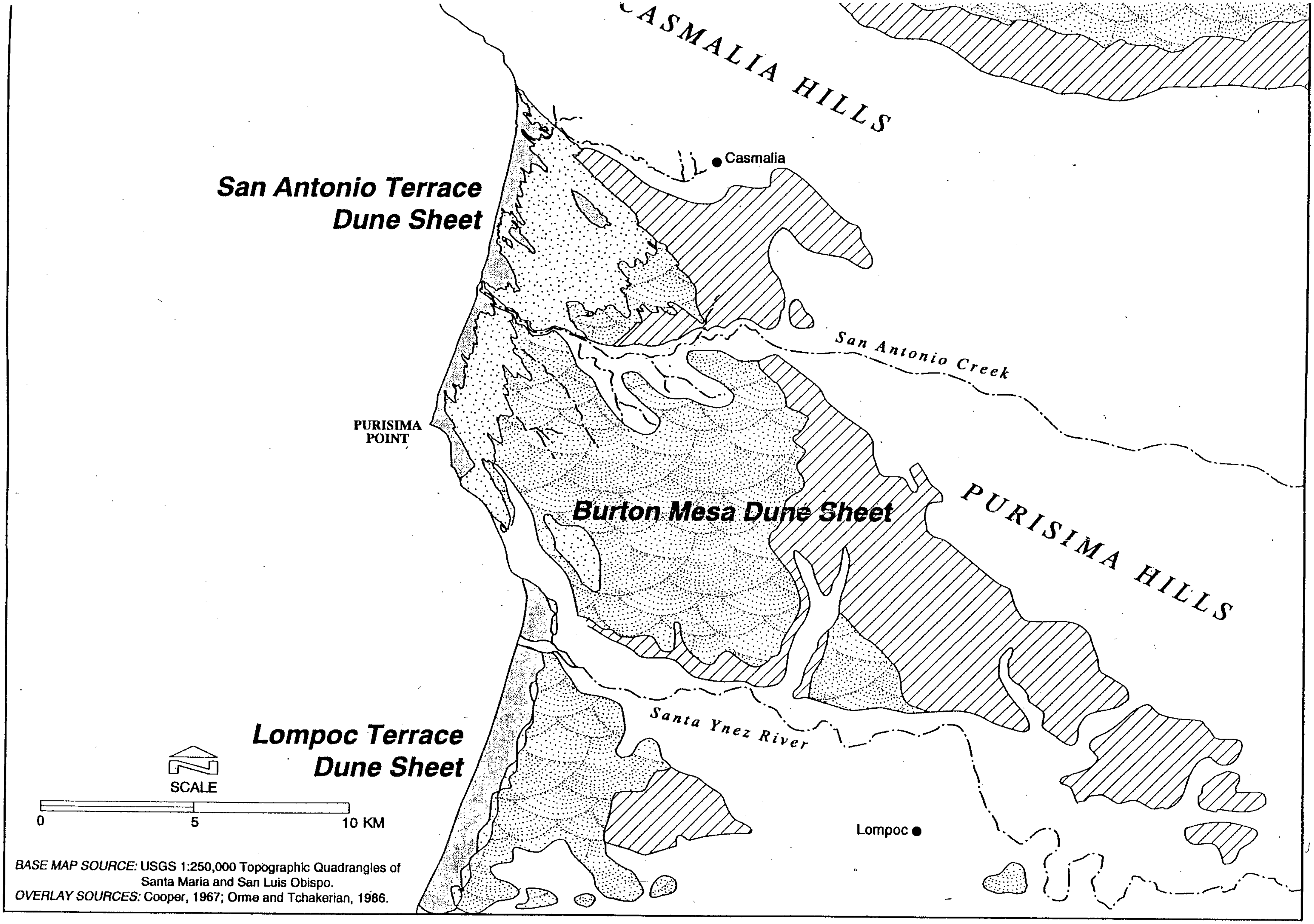
Figure 1
DUNE SYSTEMS OF SOUTHWESTERN SAN LUIS OBISPO AND WESTERN SANTA BARBARA COUNTIES, CALIFORNIA

the older dunes (Cooper, 1967). Beyond the southern end of Morro Bay the coastal strip of dunes have stabilized and are perched on top of a cliff bounding a marine terrace. The dunes extend as far south as the mouth of Islay Creek. North of the bay entrance is a narrow dune belt behind the beach. These dunes contain numerous hillocks approximately 1-2 m high, vegetated by pioneer species such as sand verbena (*Abronia* spp.) and bush lupine (*Lupinus* spp.). Southeast of Morro Bay is a lowland mantled by older dunes, vegetated by a mixture of live oak woodland, chaparral and coastal sage scrub, although the dune sheet is now largely obliterated by residential development. The inner edge of this dune sheet is in contact with the alluvium of Los Osos Creek as well as buried marine terraces below present sea level north of Hazard Canyon. The dune sheet ascends the adjoining slope of the San Luis Range (Irish Hills) to a height of 300 m (Orme, 1990). Cooper (1967) attributed the presence of shallow dry stream channels across this dune sheet as evidence of its great age. It is contemporaneous with the Nipomo Mesa, Orcutt Upland and Burton Mesa dune sheets to the south, however, emplacement of these paleodunes may have involved several depositional episodes (Orme, 1990).

The Santa Maria Valley Dune Complex extends 28 km alongshore and 50 km inland. It is the largest system of coastal dunes in California and contains five distinct dune sheets. The Callender dune sheet contains two Holocene depositional events and includes coastal dunes extending from Pismo Beach south to Oso Flaco Lake (Fig. 2). These dunes cover portions of the alluvial plains of the Cienaga and Santa Maria Valleys and overlie the western edge of Nipomo Mesa. Nipomo Mesa dune sheet is about 75 m above sea level and is a Pleistocene dune deposit lying on top of a fluvial terrace 30 m above the adjoining alluvial plain (Cooper, 1967). The portion of the mesa not concealed by Holocene dunes covers an area of approximately 72 square km and extends over 18 km from the present shoreline (Fig. 2). The Guadalupe dune sheet contains two Holocene deposits that lie entirely on the Santa Maria floodplain and extend from Oso Flaco Lake south to the mouth of the Santa Maria River. The Mussel Rock dune sheet is a series of four, partially overlapping aeolian sand deposits that span the entire temporal sequence of dune emplacement in the Santa Maria Basin (Fig. 2). These deposits extend from the mouth of the Santa Maria River south to Point Sal. They lie partially on the southern edge of the Santa Maria River floodplain as well as on a series of marine terraces extending southward to Point Sal from sea level to approximately 250 m on the adjoining seaward slopes of the Casmalia Hills. The oldest Pleistocene portion of the Mussel Rock dune sheet extends eastward along a fluvial terrace bordering the southern edge of the Santa Maria River Valley to join the oldest portions of the Orcutt Terrace dune sheet (Fig. 2). The Orcutt Terrace dune sheet encompasses two Pleistocene depositional events and is perched atop a fluvial terrace lying 12 m above present sea level (Woodring and Bramlette, 1950; Worts, 1951; Cooper, 1967). Most of the surface deposits on the Orcutt Terrace are late Pleistocene, contemporaneous with the Nipomo Mesa deposits.

The Santa Ynez Valley Dune Complex contains three dune sheets, extending 30 km alongshore and 42 km inland. San Antonio Terrace is a large dune sheet extending from Shuman Canyon, just south of Point Sal, south to Purisima Point. Like the Callender and Guadalupe dune sheets the extant deposits represent two Holocene emplacement events (Fig. 2). However, the San Antonio dune sheet rests mainly on marine terraces, not alluvium (Cooper, 1967). As with the Callender dune sheet, the San Antonio Terrace dune sheet overlies the western edges of an older sand deposit, Burton Mesa. The Burton Mesa dune sheet is the largest exposure of mid-Pleistocene sands in the Santa Maria Basin (Figure 2). It extends from Shuman Canyon in the north, roughly southeast along the southern slopes of the Purisima Hills eastward to a point approximately 35 km from the present shoreline in the Santa Ynez River Valley


EXPLANATION
Phase IV (Lobate) Dunes
Phase III (Parabolic) Dunes
Phase II (Transverse) Dunes
Phase I (Orcutt Sand) Paleodunes
Exposed Terrace
Lakes and Ponds
Creeks and Rivers
PT. SAN LUIS
Pismo Beach
Arroyo Grande Creek
Arroyo Grande
Oceano
Los Berros Creek
CIENEGA VALLEY
Callender Dune Sheet
BLACK LAKE CANYON
NIPOMO VALLEY
Nipomo
Nipomo Mesa Dune Sheet
Nipomo Creek
Oso Flaco Lake
Guadalupe Dune Sheet
Guadalupe
Santa Maria River Channel
Santa Maria
Santa Maria River
Mussel Rock Dune Sheet
MUSSEL ROCK
CORRALITOS CANYON
MUSSEL ROCK RAVINE
PT. SAL
Orcutt Terrace Dune Sheet



BASE MAP SOURCE: USGS 1:250,000 Topographic Quadrangles of Santa Maria and San Luis Obispo.
OVERLAY SOURCES: Cooper, 1967; Orme and Tchakerian, 1986.

Figure 2
COMPOSITE DISTRIBUTION OF DUNE SHEETS IN THE SANTA MARIA AND SANTA YNEZ RIVER VALLEYS

(Figs. 1 and 2). The Lompoc Terrace dune sheet, like the Mussel Rock dune sheet, encompasses four spatially overlapping, sequential dune deposits (Cooper, 1967; Orme and Tchakerian, 1986). The Lompoc Valley, an alluvial plain formed by the Santa Ynez River, separates this dune sheet from the San Antonio Terrace and Burton Mesa, although dune emplacement at both locations was contemporaneous (Fig. 2). This dune sheet extends from the mouth of the Santa Ynez River southward to just north of Point Arguello and eastward to a point approximately 12 km from the present shoreline (Figs. 1 and 2). The oldest, Pleistocene portions of the dune sheet extend upslope on the northwestern edges of the Santa Ynez Mountain Range to a height of at least 200 m (Cooper, 1967).

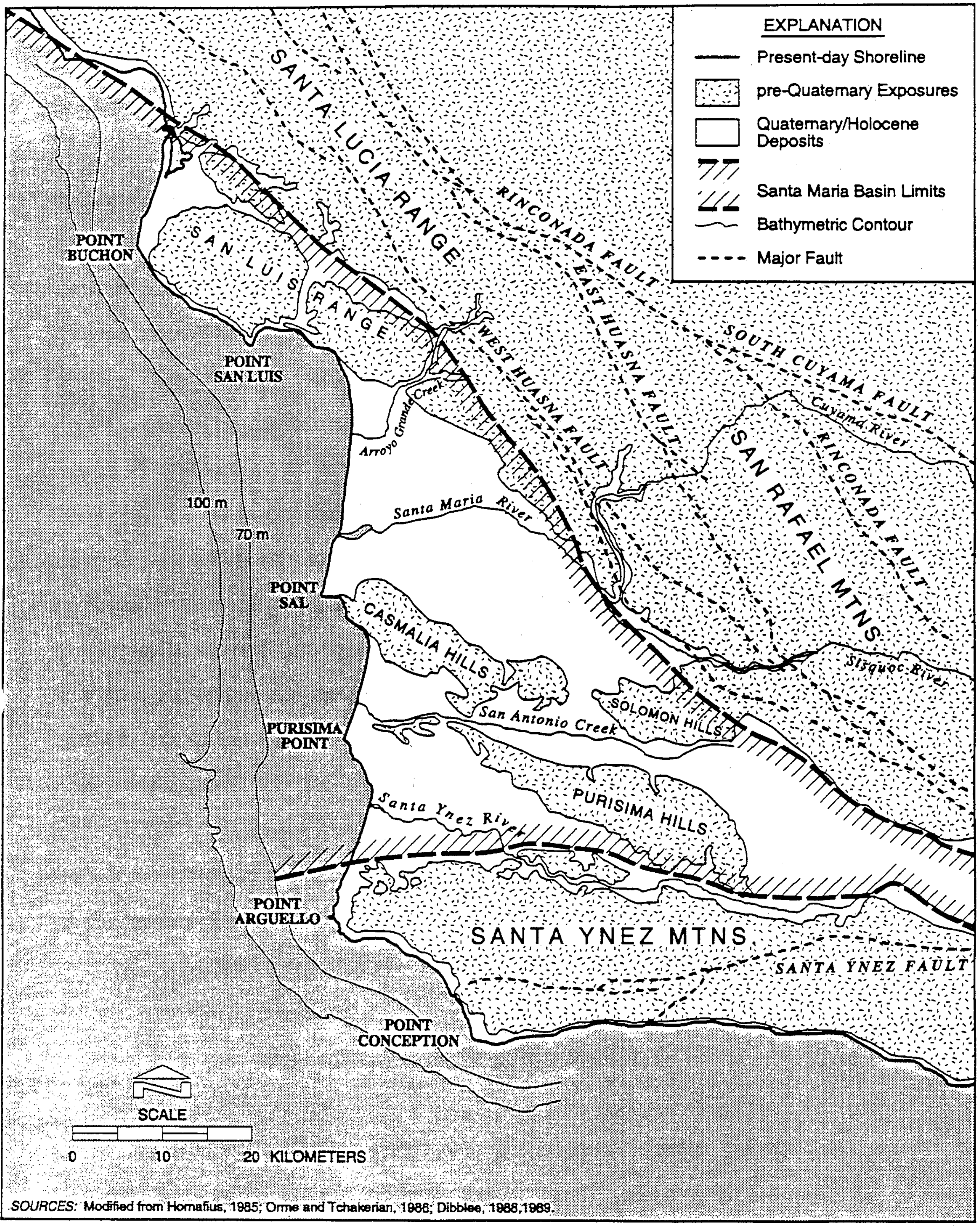
1.2 Origin and evolution of the Santa Maria Basin

Along the western coast of upper and lower California between 28° and 38°N. recurring surface sand deposits are found at six localized, highly disjunct locations, coincident with subsiding basins: Monterey Bay (Salinas Basin), Santa Maria Valley (Santa Maria Basin), Ventura-Oxnard Plain (Ventura Basin), Santa Monica Bay (Los Angeles Basin), San Quintin Bay (San Quintin Basin) and Vizcaino Bay (Vizcaino Basin) (Cooper, 1967; Orme and Tchakerian, 1986). The latter two locations lie within Baja California, Mexico. Small aeolian sand deposits are found between these basins but these are restricted to protruding headlands which interrupt the prevailing northwest winds.

Probably the single most important factor in recurrent dune emplacement at these coastal locations is the tectonic development of a subsiding basin which provides catchment for repeated aeolian sand deposition. The dune complexes discussed here lie within the Santa Maria Basin, a synclinal trough with a generalized northwest-southeast axis (Fig. 3). This basin began its evolution during the mid-Miocene (10 to 15 million years ago) when extensional tectonic forces associated with the onset of clockwise rotation of the Santa Ynez Mountain Range away from the Santa Lucia Range produced a V-shaped gap at the intersection of the NW-trending Hosgri, Nacimiento and Huasna Faults and the presently EW-trending Santa Ynez River Fault (Hornafius, 1985; Luyendyk, et al., 1980). Elongation of the basin produced NW-trending crustal "slivers" separated by right-lateral strike-slip faults within the basin (Hornafius, 1985).

The basin became a locus for subsequent marine deposition. The Monterey (middle to late Miocene), Sisquoc (late Miocene to mid-Pliocene), Foxen (middle to late Pliocene) and Careaga (late Pliocene) Formations underlie later deposits throughout the Santa Maria Basin (Woodring and Bramlette, 1950; Dibblee, 1988, 1989).

Rotation of the Santa Ynez Range slowed or stopped in the late Miocene and then resumed at a rapid rate in the Plio-Pleistocene (1.5 to 3 million years ago) (Hornafius, 1985). Initial rotation of the range produced crustal elongation; subsequent rotation of the block during the late Pliocene and Pleistocene, compressed and uplifted the crustal "slivers" within the basin (Woodring and Bramlette, 1950; Hornafius, 1985). The non-marine, fluvially deposited Paso Robles Formation (late Pliocene-early Pleistocene) was deposited after basinal emergence. Continuing Pleistocene rotation of the Santa Ynez Range further compressed the basin to produce a radiating fold pattern, emanating from the SE corner of the basin along the right-lateral strike-slip faults (Hornafius, 1985). Compression, deformation and uplift of these folds during the early to mid-Pleistocene (1 to 2 million years ago) produced the present-day NW-SE trending, anticlinal San Luis Range as well as the Casmalia, Solomon and Purisima Hills and other structural features of the basin (Fig. 3; Woodring and Bramlette, 1950). Non-synchronized rates of uplift of portions of the Santa Maria Basin continued during late Pleistocene times, at apparently disparate rates of uplift (e.g., a series of



SOURCES: Modified from Hornafius, 1985; Orme and Tchakerian, 1986; Dibblee, 1988,1989.

Figure 3
QUATERNARY AND PRE-QUATERNARY EXPOSURES WITHIN AND ADJACENT TO THE SANTA MARIA BASIN

nine Late Pleistocene marine terraces occur on the southwest flanks of the Casmalia Hills (Clark, 1990, in Orme, 1992).

Transient and local episodes of basinal subsidence occurring throughout late Tertiary and Quaternary times have maintained suitable conditions for recurring coastal dune development (Orme and Tchakerian, 1986). In contrast, adjacent uplifted areas only have thin and poorly developed aeolian sand deposits (e.g., aeolian sand deposits at Point Piedras Blancas and Point Conception).

The present-day topography of the study area consists of a series of northwest-southeast-trending ridges and valleys formed by folded and faulted marine sediments of Tertiary and Cretaceous age (Fig. 3). Near the shore, the ridges of the San Luis Range (Irish Hills), Casmalia Hills, Purisima Hills and the Santa Ynez Mountains form the major headlands of Point Buchon, Point San Luis, Point Sal, Purisima Point, Point Arguello and Point Conception, respectively (Figs. 1 and 3). The coastal portions of the ridges do not exceed elevations of 500 to 2,000 feet; the valleys are wide with floors near sea level. The two principal valleys, the Santa Ynez and the Santa Maria, were cut well below present sea level during past glacial maxima. The present streams meander on a depositional floodplain of stream sands and gravels up to 1000 m thick (Woodring and Bramlette, 1950; Worts, 1951; Fig. 3). The coastal portions of the two valleys are boxed by fields of sand dunes which, due to the prevailing onshore winds, are actively migrating inland (Bowen and Inman, 1966; Cooper, 1967).

1.3 Emplacement of individual dune sheets

Specific tectonic, climatic and topographic conditions are involved in the formation of dune sheets. Three important factors govern the localized, recurrent creation and persistence of coastal sand deposits in the Santa Maria Basin. These are:

the tectonic behavior of the coast during Quaternary time; an abundant sand supply, and; effective offshore winds (Orme and Tchakerian, 1986). A description of the relationship between dune topography, sediment budgets and wind regimes is provided in Section 1.4.3.

Cooper's important monograph on the coastal dune systems of California was primarily a description of the dune masses. Lacking geochronological controls for emplacement of aeolian sands and related deposits, he divided the depositional history of the dunes into two stages: pre-Flandrian and Flandrian. The latter age corresponds to events that took place during and after the final eustatic sea level rise, i.e., less than 6,000 years ago. This temporal dichotomy was based on the stratigraphy, surface morphology and vegetational development of individual dune sheets.

Using geomorphic, stratigraphic and radiocarbon dating techniques on the Morro Bay Complex and the Mussel Rock Dune Sheet, Orme and Tchakerian (1986) and Orme (1980, 1988, 1990, 1992), presented an absolute time-scale for late Pleistocene fluvial deposition associated with or followed by several aeolian dune-building episodes. These results appear to correlate with aeolian deposition events studied elsewhere in the Santa Maria Basin (e.g., Johnson, 1983). It now appears that the three major dune complexes of the Santa Maria Basin are composed of multiple depositional episodes or phases of dune emplacement. These phases represent four sequences of dune formation in the Santa Maria Basin, ranging in age from at least mid-Pleistocene time to the present (Fig. 2 and Figs. 4,5,6 and 7).

This report follows the terminology used by Orme and Tchakerian (1986) in describing phases of dune emplacement in the Santa Maria Basin. Their terminology relates to Cooper's (1967) descriptions as follows:

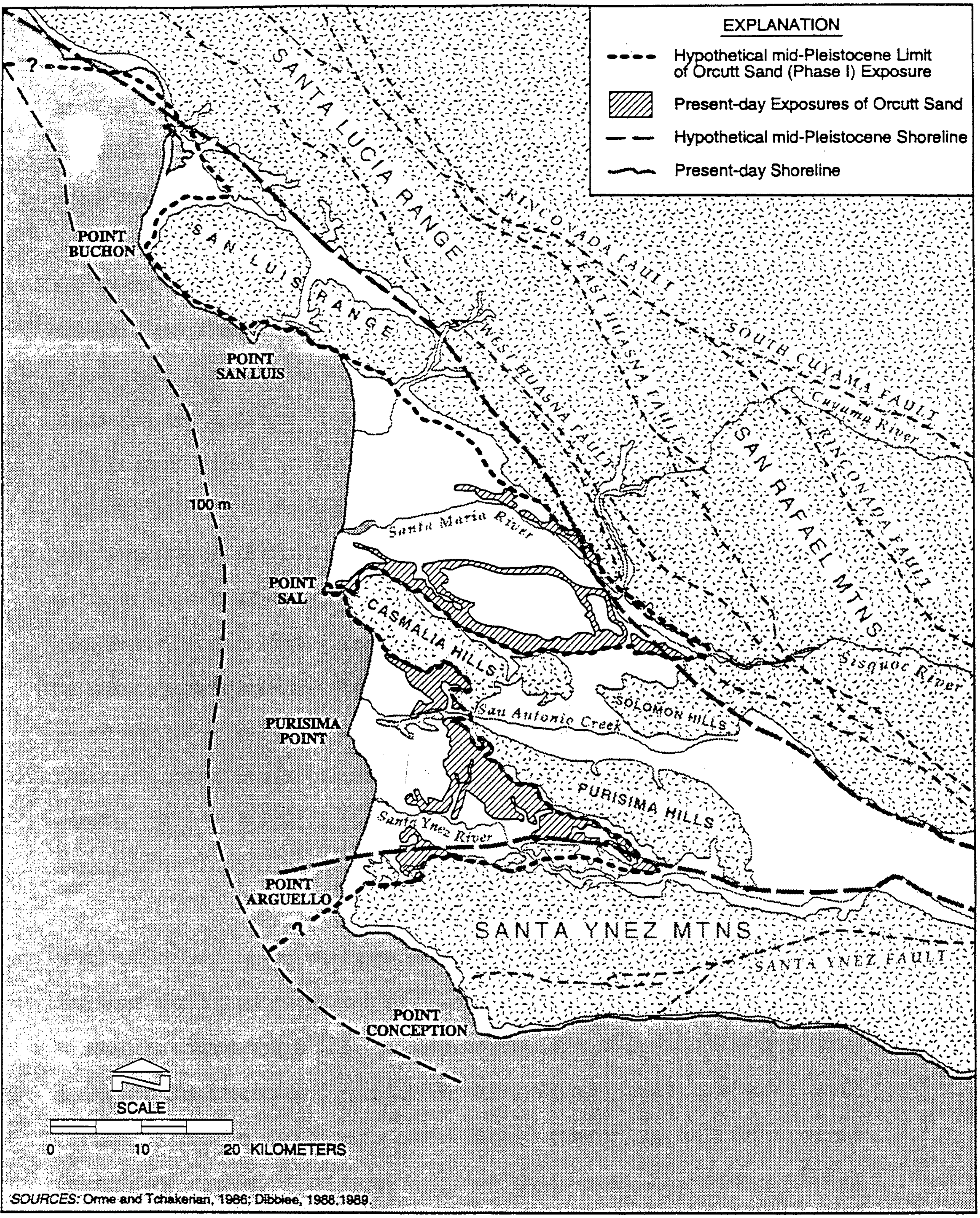
Age	Cooper (1967)	Orme and Tchakerian (1986)
mid-Pleistocene (25,000-80,000+ yrs BP)	pre-Flandrian	Phase I
late Pleistocene (6,000 - 25,000 yrs BP)	pre-Flandrian	Phase II
Holocene (2,000-6,000 yrs BP)	Flandrian, Episode I	Phase III
Holocene (0 - 2,000 yrs BP)	Flandrian, Episode II	Phase IV

The oldest dunes (Phase I paleodunes of Orme and Tchakerian, 1986) are highly modified deposits lying on emergent marine terraces or in deep subsiding basins. Late Pleistocene and early Holocene paleodunes (Phase II of Orme and Tchakerian, 1986 and Episode I pre-Flandrian dunes of Cooper, 1967) mantle the larger coastal lowlands, descending below present sea level at the coast. Late Holocene deposits (Phase III of Orme and Tchakerian, 1986 and Episode II Flandrian of Cooper, 1967), include surface aeolian sands laid down during the present interglacial (2,000 to 6,000 years before present), as well as active younger Flandrian dunes (Phase IV of Orme and Tchakerian, 1986), found along the present shoreline (Figs. 4-7).

1.3.1 Phase I: Deposition of Orcutt Sand

Figures 2 and 4 shows the present-day and hypothetical Pleistocene distribution of the aeolian and fluvial sand and gravel deposits known as Orcutt Sand. These deposits underlie the Nipomo Mesa, Orcutt Upland, Mussel Rock, Burton Mesa dune sheets and portions of the Lompoc Terrace dune sheet (Fig. 2). Woodring and Bramlette (1950) regarded the Orcutt formation as the oldest, most extensive terrace deposit in the area and suggest that the upper portion may include some windblown material. Muehlberger (1955) studied the vertical distribution of sediments in the Santa Maria lowlands and agreed with Worts (1951) and Woodring and Bramlette (1950) that the Orcutt Formation lies on top of older sediments (the Paso Robles Formation) and is composed of sand and gravel at its lower depths and sand in the upper portions (Worts, 1951). Cooper (1967) concluded that terrace deposits overlie the Orcutt, with aeolian sands overlying both deposits. His description of the Orcutt Terrace is as follows: "...on the south side of the Santa Maria Valley is an isolated body of ancient dunes, extensive but thin,. with some small outliers. The principal mass is 10 km long and 5 km wide...[it] is confined to the terrace and separated from the present floodplain by a low bluff, [and] must be considered a sheet of river-valley dunes of pre-Flandrian age." Subsequent work by Orme and Tchakerian (1986) and Orme (1992), established that the Orcutt Sand is actually a complex of aeolian and fluvial sediments comprising two distinct origins: strongly indurated aeolian sand deposits (Phase I dissected paleodunes) blown in at least 60,000 to 80,000 years before present (BP) and fluvial deposits of sand and gravels (= the Orcutt Sand of Woodring and Bramlette, 1950; the Orcutt Formation of Worts, 1951; and the Qf1 to Qf3 fluvial deposits of Orme, 1992), laid down on top of the these aeolian deposits between 25,000 to 32,000 years BP. Johnson (1983) concluded that the aeolian, upper portions of the Orcutt Sand on the Burton Mesa dune sheet may be more than 200,000 years old.

Surface exposures of Phase I paleodunes appear to be confined to the Santa Maria River Valley and Santa Ynez River Valley portions of the Santa Maria Basin and occur up to 42 km inland from the present shoreline. The largest surface exposure of Phase I paleodunes is the Burton Mesa dune sheet, lying along the southern flank of the Purisima Hills (Fig. 4). However, these aeolian deposits may once have blanketed virtually the entire basin, from the foot of the San Rafael and Santa Lucia Mountains to the ocean and may have been partly eroded from the shoreline portions of the basin



SOURCES: Orme and Tchakerian, 1986; Dibblee, 1988,1989.

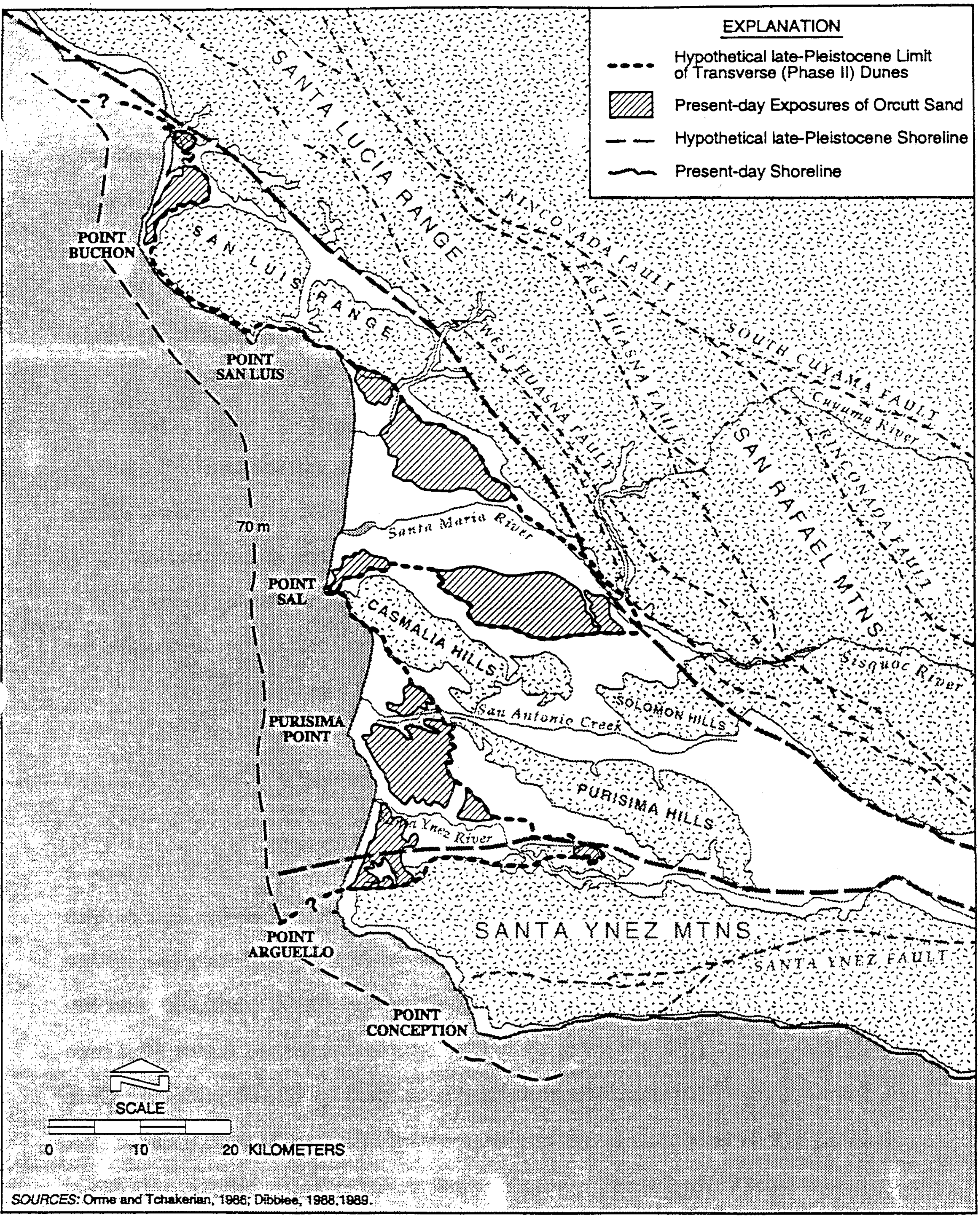
Figure 4
DISTRIBUTION OF MID-PLEISTOCENE ORCUTT SAND (PHASE I)
PALEODUNES IN THE SANTA MARIA BASIN

following uplift of the Casmalia Hills and San Luis Range (Woodring and Bramlette, 1950; Orme and Tchakerian, 1986; Fig. 4). At maximum sea level regression the shoreline was several km west of its present location (Cooper, 1967). Figure 4 shows an hypothetical relative position of the paleoshoreline during Phase 1 sand deposition. The Santa Maria River and other watercourses, prograding across the emerging continental shelf, transported and reworked sediments stranded on emerging marine terraces and supplied abundant sand for dune construction along the coast.

Phase I dunes are old enough to have developed a soil profile, classified as Tangair and Narlon soils (Shipman, 1972; 1981). Subsurface soils are typically indurated by iron oxides however, surface exposures are commonly composed of loose sand. These deposits are characterized by a higher proportion of fine particles relative to younger deposits, indicating prolonged post-depositional weathering (Cooper, 1967; Orme and Tchakerian, 1986). Throughout the area, Phase I dune deposits are contiguous with and underlie Phase II deposits (compare Figs. 4 and 5).

1.3.2. Phase II: Deposition of transverse paleodunes

These are the pre-Flandrian dunes described by Cooper (1967). Figure 5 illustrates the extensive present-day surface exposures of Phase II aeolian sand deposits in the Santa Maria Basin. Orme and Tchakerian (1986) concluded that these deposits overlie Phase I dune deposits and were deposited between 10,000 and 25,000 years BP, although Johnson (1983), working on the San Antonio Terrace and Burton Mesa dune sheets, concluded that these formations may be as much as 125,000 years old. Orme (1992) has demonstrated on geomorphic, pedologic and stratigraphic grounds, that Phase I and II dunes probably represent several aeolian events interspersed with fluvial deposition. Phase II dune surfaces are characterized by a subdued transverse dune



SOURCES: Orme and Tchakerian, 1986; Dibblee, 1988,1989.

Figure 5
DISTRIBUTION OF LATE-PLEISTOCENE TRANSVERSE (PHASE II) DUNES IN THE SANTA MARIA BASIN

morphology (i.e., dune ridges parallel to the prevailing wind direction), which indicate sand was deposited during periods of relative sea level regression and abundant sand budgets. Sea levels fell rapidly during the last glacial maximum approximately 18,000 years BP, exposing huge amounts of sediment for subsequent aeolian transport onshore. Figure 5 shows potential sea levels coincident with the 70 m bathymetric contour, although sea levels may have been 100 m below the present shoreline.

Phase II dunes are the most extensive surface dunes in the Santa Maria Basin and comprise the bulk of the dunes found in the Morro Bay Dune Complex and the Nipomo Mesa, Orcutt Upland, Burton Mesa and Lompoc Terrace dune sheets (Fig. 5). They mantle Phase I dunes, but disappear beneath Phase III sand deposits toward the coast (Fig. 2).

Phase II dunes are composed of poorly consolidated to unconsolidated red to yellow sands with a clay-enriched B-horizon profile. The substratum is generally a dense, cemented sand layer (Shipman, 1972). Particle size analysis demonstrates that like Phase I dunes, Phase II substrates also have significantly higher proportions of fines relative to more recent aeolian deposits which forms a denser soil relative to younger dunes (Cooper, 1967; Orme and Tchakerian, 1986; L.E. Hunt, pers. obs.).

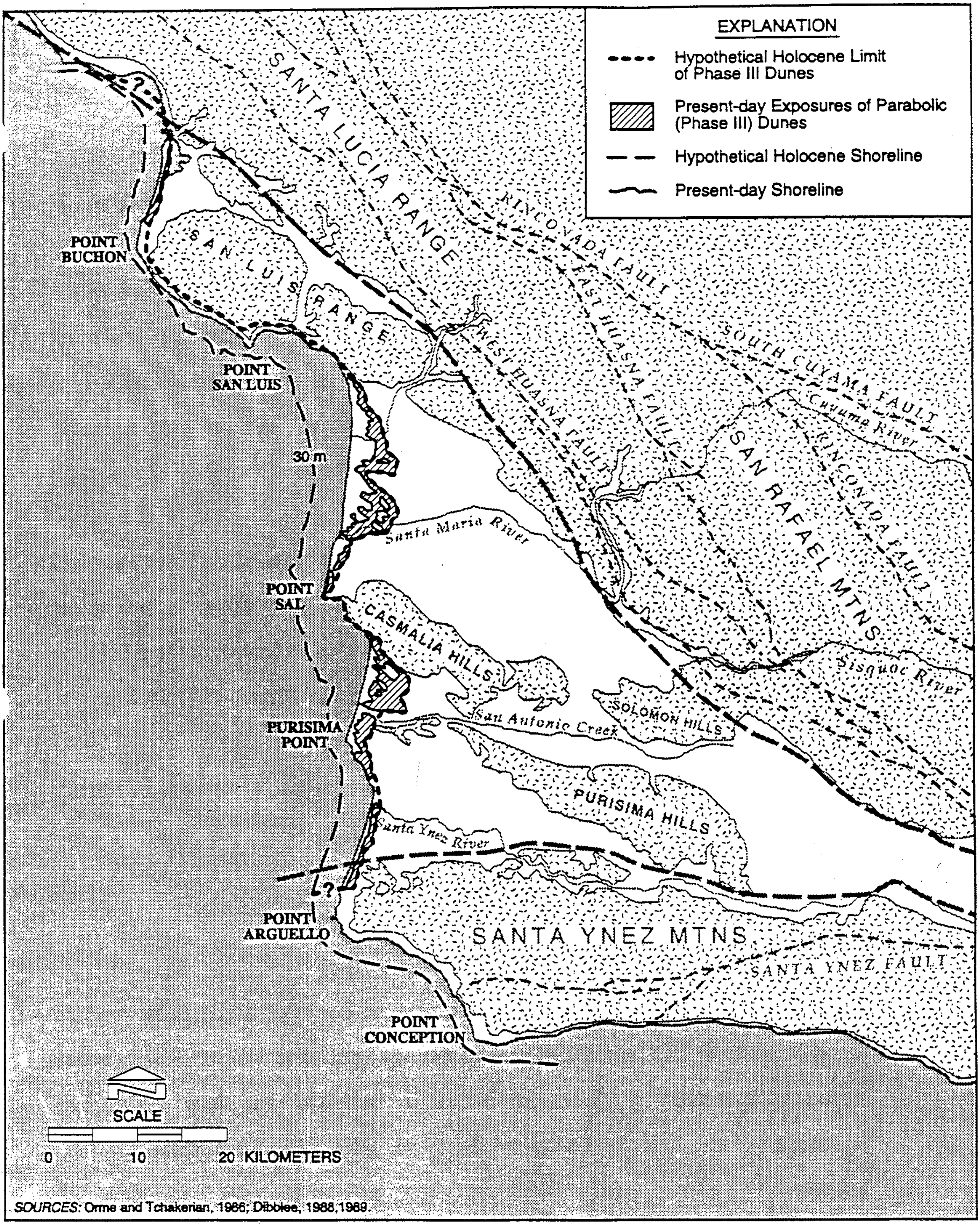
The natural vegetation of Phase II dunes is quite different from that found on depositionally younger dune sheets. Live oak woodland, chaparral and coastal sage scrub are the dominant vegetation types with *Adenostoma* as a dominant shrub and *Ceanothus* and *Arctostaphylos* as dominant woody elements. Live oak (*Quercus*) is present in scattered clumps. Wells (1962) pointed out that many of the clumps of live oak sprouts in the fire-dominated chaparral on Nipomo Mesa are spaced at the normal interval for a closed-canopy forest, indicating a very long period of stability.

1.3.3. Phase III: Deposition of parabolic dunes

Phase III dunes are were deposited between 2,000 and 6,000 years BP at a time of rising sea levels, coincident with a warm-dry period between 2,300 and 7,800 years BP (Orme and Tchakerian, 1986). These deposits are the Episode I Flandrian dunes of Cooper (1967), formed in association with the final alluviation of the Santa Maria Valley and the tributary valley of Arroyo Grande Creek. Alluviation of the Santa Maria and Arroyo Grande valleys has kept pace with rising sea levels (Cooper, 1967). Phase III dunes mantle Phase II deposits, however their areal extent is much reduced and they extend only about 7 km inland from the present shoreline. These dunes form the present-day, inland portions of the Callender, Guadalupe and Mussel Rock dune sheets, as well as most of the San Antonio Terrace dune sheet (Fig. 6).

Phase III dune surfaces are characterized by parabolic ridges, indicating deposition during and after periods of relative sea level rise and reduced sand budgets. Some of these ridges rise more than 60 m above sea level between Pismo Beach and the Santa Maria River. Section 1.4.3 discusses the formation of these dune structures. Despite the absence of reliable dating methods for this dune phase on the Mussel Rock dune sheet (Orme, 1992), these dunes are morphologically similar to parabolic dunes whose inland "noses" had stabilized at least 3,000 to 4,200 years BP along the coast south of Morro Bay (Orme, 1990).

Phase III dune soils are typically grey to white loose sand stabilized in most places by dune scrub vegetation (Shipman, 1972, 1981).



SOURCES: Orme and Tchakerian, 1986; Dibblee, 1988,1989.

Figure 6
DISTRIBUTION OF HOLOCENE PARABOLIC (PHASE III)
DUNES IN THE SANTA MARIA BASIN

1.3.4. Phase IV: Deposition of lobate dunes

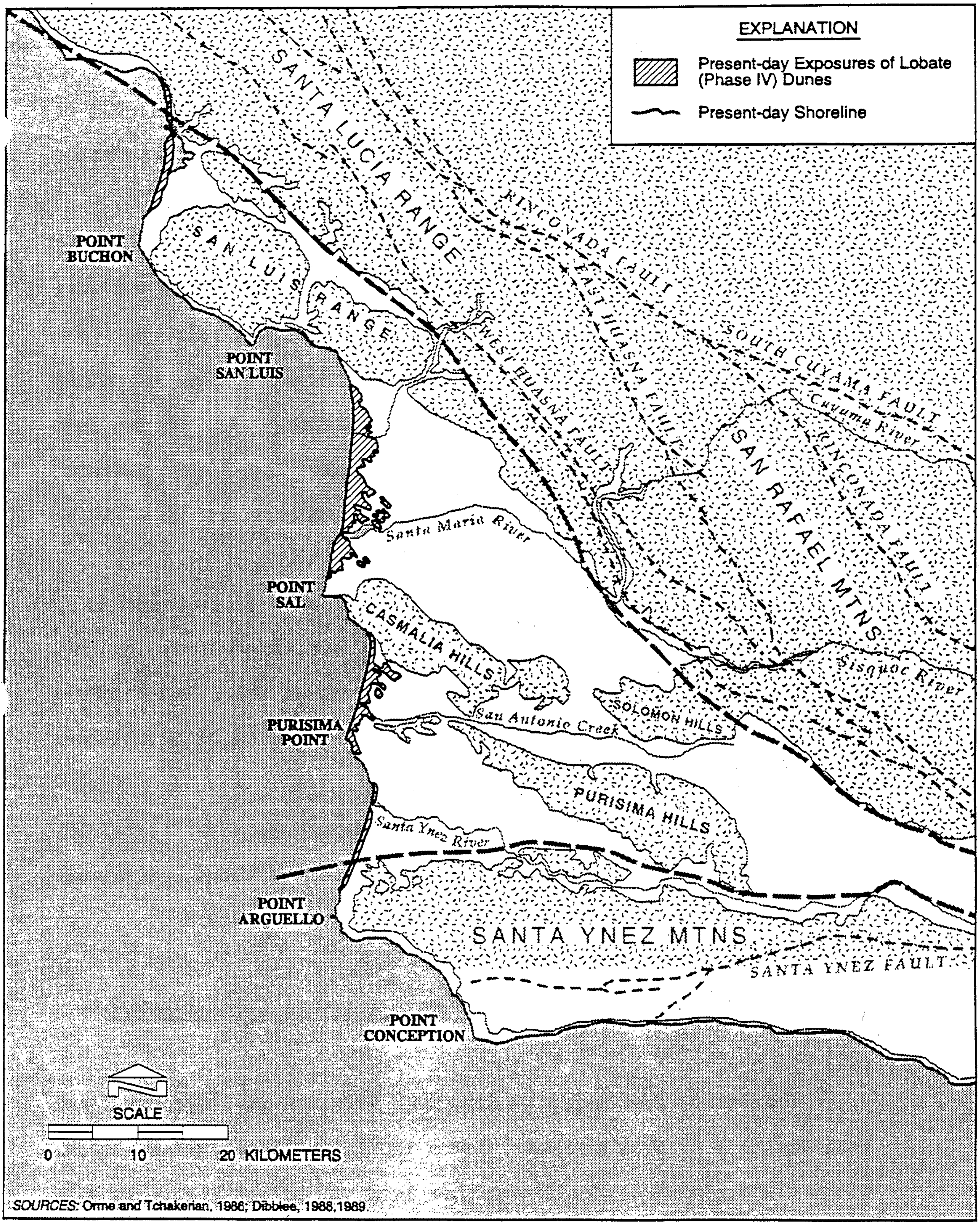
Phase IV dunes are the most recently deposited dunes and occur directly inland from the present shoreline along much of the Santa Maria Basin (Fig. 7). Deposition of these dunes began about 2,000 years BP, during the period of relatively stable sea level. Deposition continues to the present. These dunes overlie Phase III deposits and are characterized by a lobate surface topography, with pioneer dune plants such as sand verbena (*Abronia* spp.) forming the nuclei for these lobate structures (Cooper, 1967; Orme, 1990; 1992). Aeolian transport of sand is ongoing and these dunes are actively migrating inland.

Imbedded within Phase III deposits throughout the Santa Maria Basin are small areas of Phase IV dunes (Fig. 7). The lobate surface topography of these dunes indicate renewed aeolian activity, possibly from removal of vegetative cover from more stabilized dunes as a result of natural or human-induced fires (Orme, 1990; 1992).

1.4. Transport and climatic conditions responsible for the creation and persistence of the Santa Maria Basin dunes

1.4.1. Fluvial transport processes

During Quaternary times, the coastal zone of the Santa Maria Basin received abundant clastic debris from the erosion of recently uplifted or still tectonically active mountains underlain by quartz-rich Mesozoic batholiths and later sedimentary formations (Worts, 1951; Woodring and Bramlette, 1950). The Santa Maria, Cuyama, Sisquoc and Santa Ynez Rivers transported erosive material from the Santa Lucia, San Rafael and Santa Ynez Mountains to the coast for dune construction (Fig. 8). During



SOURCES: Orme and Tchakerian, 1986; Dibblee, 1988,1989.

Figure 7
DISTRIBUTION OF LOBATE (PHASE IV) DUNES
IN THE SANTA MARIA BASIN

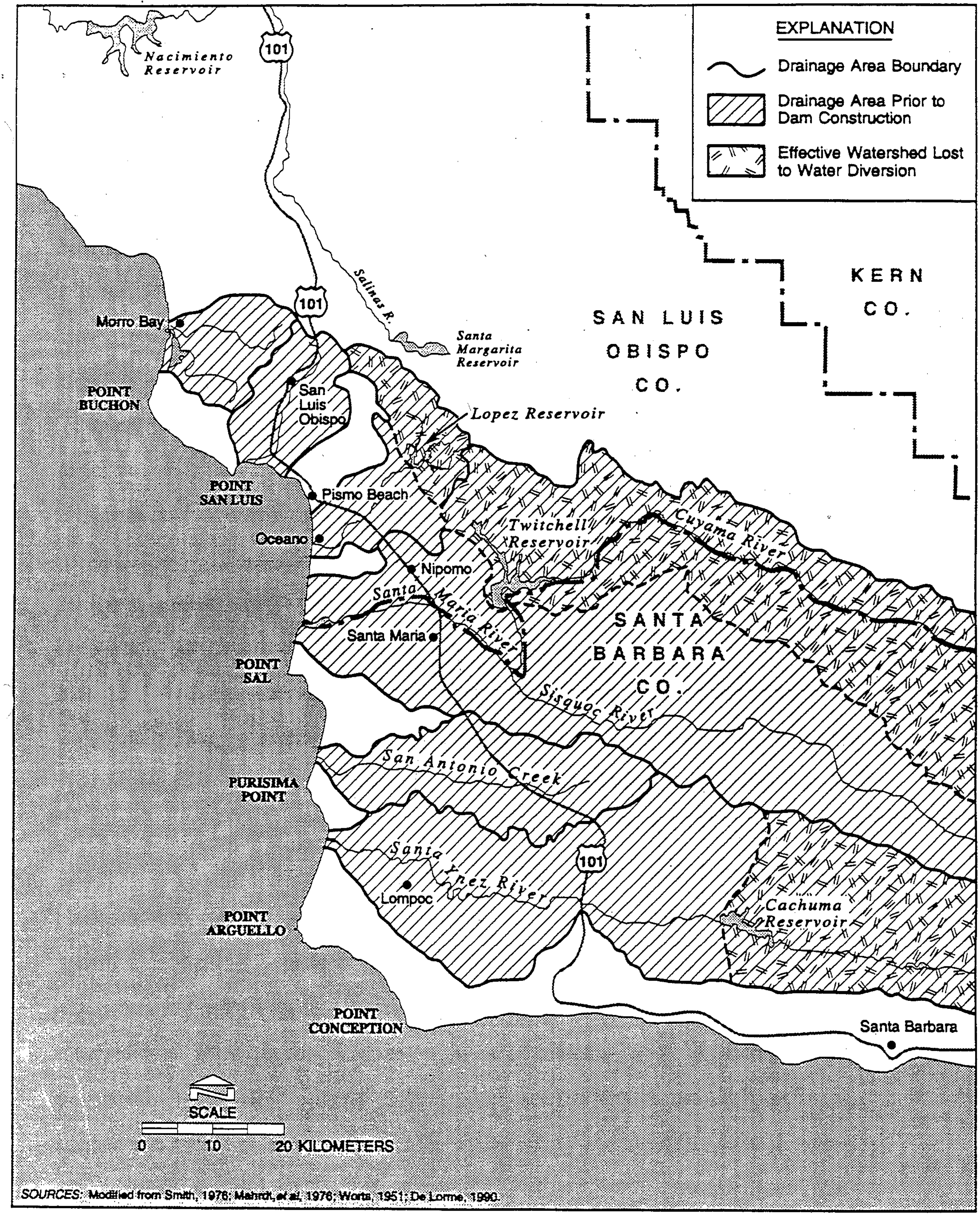
mesic periods of the Quaternary, these watercourses carried immense volumes of sediment. Transition from a cool, mesic to a warm, xeric climate (associated with the present interglacial period), decreased fluvially transported sediment volumes.

The Santa Maria River (including the Cuyama and Sisquoc Rivers) and the Santa Ynez River watersheds are the primary sources of beach sand in the basin (Zeller, 1962; Bowen and Inman, 1966; Cooper, 1967). Historically, the Santa Maria and Santa Ynez Rivers drained an area of 1,843 and 900 square miles, respectively (Fig. 8). Despite the larger drainage area, sediment discharge rates from the Santa Maria River are usually lower than rates from the Santa Ynez River because the former traverses an extensive depositional floodplain before entering the ocean (Fig.8; Johnson, 1959).

Smaller amounts of sediment originate from erosion of the continental shelf, outfall from coastal streams, such as San Luis Obispo Creek, Arroyo Grande Creek and San Antonio Creek, and cliff erosion of dune deposits around Mussel Rock and Point Sal. These secondary sources can be significant. For example, the Orcutt sandstones at Point Sal and between Surf and Point Arguello contains over 80% quartz of sand-size (Woodring and Bramlette, 1950). Bowen and Inman (1966) and Cooper (1967) estimate that cliff erosion of the Orcutt sandstones from north of Mussel Point to south of Point Sal yields about 40,000 cubic yards of sand per year to the beaches.

1.4.2. Littoral transport processes and the formation of receptive shorelines

The extensive dune fields in the Santa Maria Basin represent a huge loss of sand from the beach by wind transport. Bowen and Inman (1966) estimated aeolian transport of sand on the beaches between Pismo Beach and the Santa Maria River to be approximately 38,000 cubic meters/year, however Mulligan (1985) states that sand loss



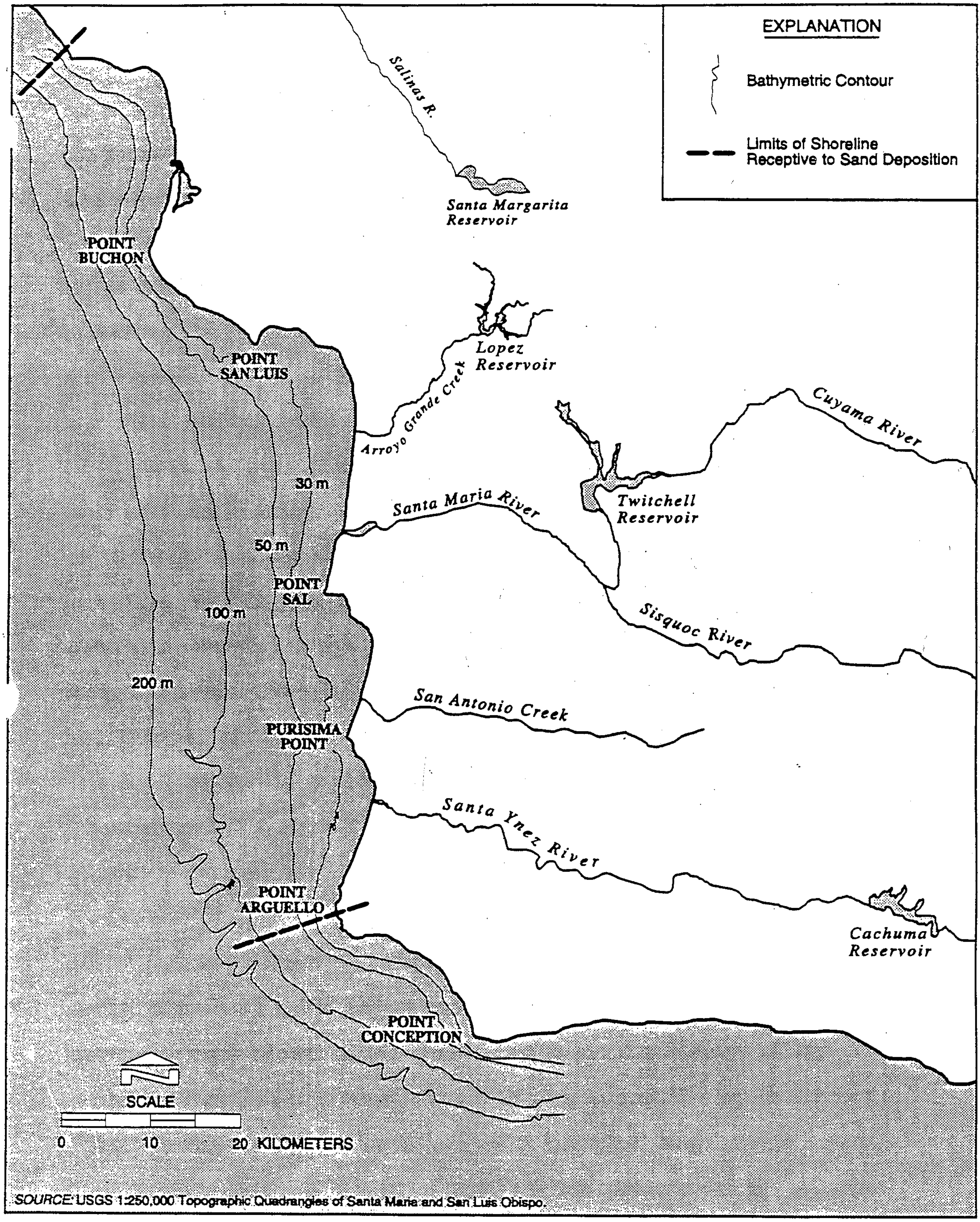
SOURCES: Modified from Smith, 1976; Mahrdt, et al, 1976; Worts, 1951; De Lorme, 1990.

Figure 8
MAJOR DRAINAGE AREAS CONTRIBUTIVE TO THE DUNE SYSTEMS OF WESTERN SAN LUIS OBISPO AND SANTA BARBARA COUNTIES

rates are probably closer to 300,000 cubic meters/year. These numbers demonstrate that large volumes of sand must enter the littoral zone in order to prevent depletion of the coastal dune masses.

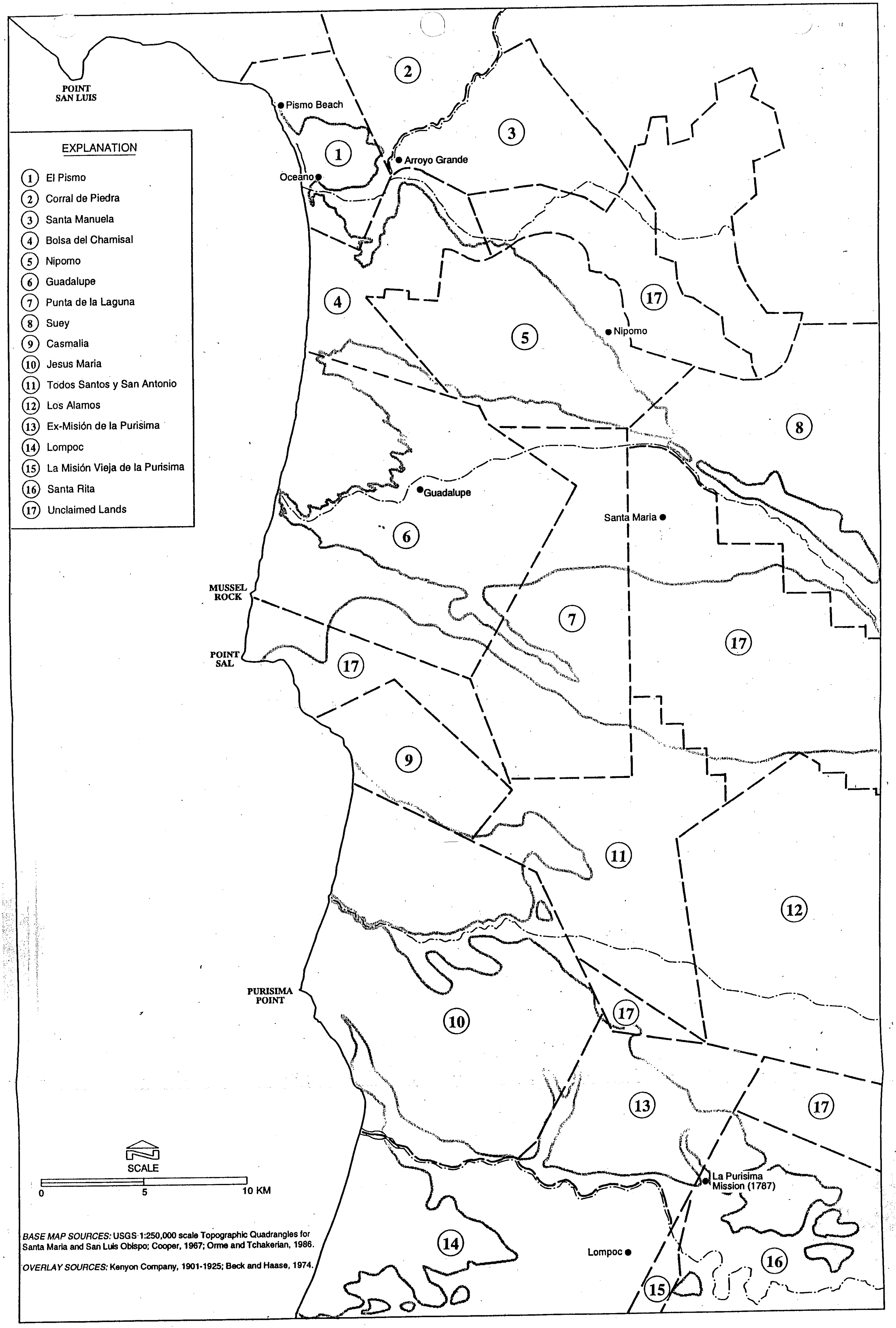
Clastic debris carried by the rivers and streams within the basin is deposited onto the continental shelf and borderland where it is further distributed, generally southward, by waves and currents. The continental shelf has a width of approximately 8 to 25 kilometers between the 200-meter bathymetric contour and the shoreline adjacent to the Santa Maria Basin. The 200-meter bathymetric contour generally represents the seaward base of the continental shelf. Although the shelf is narrow north of Point Conception, relative to south of this point, it is considerably wider and has a lower slope in the region of the Santa Maria Basin. For example, the 200-meter contour lies about 8-10 km offshore of Point Conception and Point Buchon compared to about 23 km offshore from the mouth of the Santa Maria River (Fig. 9). Subsidence and eustatic sea level fluctuations associated with glacial events periodically exposed large nearshore areas of this portion of the shelf to direct onshore wind action. This material was driven upslope by subsequent marine transgressions (Cooper, 1967; Orme, 1992).

Marine swells are usually the major dynamic factor governing the direction of net movement of littoral sand. Swell is wind-generated waves that have moved outside their area of generation, usually as a product of oceanic storms. They may travel many hundreds of miles before reaching a continental margin. Silvester (1960) modelled the effect of persistent swell generated at an angle toward a straight sandy coastline with rocky headlands on coastal erosion patterns (Fig. 10a,b). His model allowed no upcoast sand replenishment. Eroded sediment moved offshore as well as downcoast (longshore transport). The swell was generated until an "equilibrium shape" in the upcoast bay was attained and no further sediment movement occurred in the bay (Fig.



SOURCE: USGS 1:250,000 Topographic Quadrangles of Santa Maria and San Luis Obispo.

Figure 9
BATHYMETRIC PROFILE OF CONTINENTAL SHELF ADJACENT TO THE SANTA MARIA BASIN



BASE MAP SOURCES: USGS 1:250,000 scale Topographic Quadrangles for Santa Maria and San Luis Obispo; Cooper, 1967; Orme and Tchakerian, 1986.

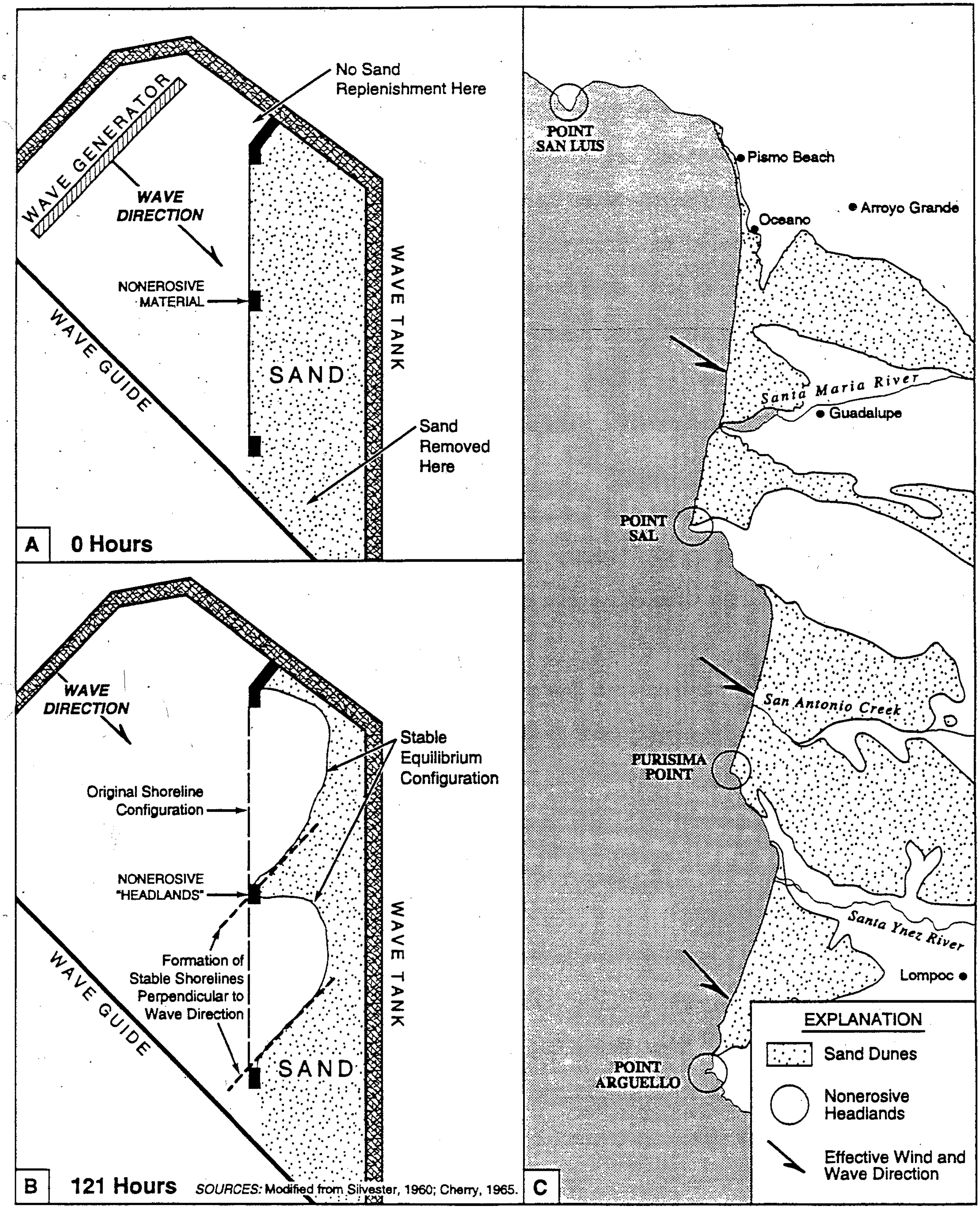
OVERLAY SOURCES: Kenyon Company, 1901-1925; Beck and Haase, 1974.

Figure 11
LAND USE IN THE SANTA MARIA BASIN BETWEEN 1837 AND 1846

10B). The beach in the bay leeward of a headland attained a position parallel to the strongly refracted low-energy wave fronts that arrived in the bay. The characteristic concave shape of the bay in the lee of the headland tended to become more pronounced as the rate of sand supply decreased. Silvester called the condition which exists when the refracted fronts of the predominant swell break essentially parallel to the equilibrium beaches, as a stable equilibrium condition. Note that the straight section of the stable beach is parallel to the deep-water wave fronts, as they were refracted very little. However, the curved portion of the bay was sculpted by swell which was diffracted around the upcoast headland and refracted inside the bay (Fig. 10B).

The equilibrium condition in Silvester's model was attained with no upcoast sand supply (a stable equilibrium). If sand has been suppled continually from the upcoast, as is the case with the Santa Maria Basin shoreline, then the equilibrium beaches in his model would have been oriented at an angle to the predominant swell. Consequently, the refracted fronts of the predominant swell would break at an angle to the beaches, set up littoral currents and continually transport the incoming sand downcoast (the "dynamic equilibrium" condition described by Cherry, 1965). Silvester (1960), concluded that swell, rather than storm waves, is the major dynamic factor that controls the long-term patterns of littoral sand transport and therefore governs the orientation of sand accumulations along a coastline.

Longshore sediment transport is an important component of dune construction. Waves traveling over a sand bed exert stress on the bed, which if sufficiently intense, will produce a to-and-fro motion of sand (Cherry, 1965). Once in suspension, any net longshore energy will transport sediment in a down-wave direction (Inman and Bowen, 1963). The continental shelf in the region from Pismo Beach to San Antonio Creek is relatively flat and gradually steepens south to Point Conception, becoming much steeper east of this point. The shoreline configuration in this region is strongly



SOURCES: Modified from Silvester, 1960; Cherry, 1965.

Figure 10
SIMULATED (A,B) AND ACTUAL (C) SHORELINE CONFIGURATIONS

reflected by the 10 m bathymetric contour (USGS, 1979, 1989), less so by the 30 m and 50 m contours and not at all by the 100 m contour (Fig. 9). Consequently, the nearshore environment between the shoreline and the 30 meter bathymetric contour is the most effective littoral transport zone (Zeller, 1962). Waves moving over the nearshore portions of the shelf supply the energy to set the sand in motion. In the surf zone the longshore currents usually flow to the south, although this trend may be reversed during the winter months (Inman, 1953; Bowen and Inman, 1966). Along the southern California coast there is a seasonal migration of sand between the beaches and deeper water in response to the seasonal changes in wave height, period and direction of approach. In general the beaches build seaward during the small waves of summer and are cut back by high winter storm waves. Bottom surveys indicate that most of the seasonal offshore-onshore interchange of sand occurs in depths less than 10 m (Inman, 1953).

Where an open coast has prominent rocky headlands and a relatively even shallow-water topography (as in the Santa Maria Basin), the coastline beach will form a characteristic concave bay in the lee of each headland. The beach immediately upcoast from a headland will be oriented approximately parallel to the predominant deep-water swell (Fig. 10C), as the swell is refracted very little (Silvester, 1960; Cherry, 1965). This beach alignment acts to reduce the ratio between the net longshore wave power and the total long-shore wave power, and hence reduces the longshore transport of sediment (Zeller, 1962; Cherry, 1965; Bowen and Inman, 1966). The most receptive shorelines in the Santa Maria Basin occur where the shoreline orientation changes gradually from a south to a southwest alignment as one proceeds downcoast. In such instances the beach maintains a fairly straight or slightly concave south or southwesterly trend until it changes direction abruptly downcoast from a headland. Several such coastline configurations occur between Point Buchon and Point Arguello.

The most noticeable features of the coastline are the three long, nearly straight beaches, facing west-northwest between Pismo Beach and Point Arguello (Fig. 10C).

Three headlands of resistant rock, Point Sal, Purisima Point and Point Arguello, act as natural groins causing the beaches to align nearly perpendicular to the principal direction of wave approach. Littoral current energy is strongest directly east of Point San Luis because of the large angle of wave attack in this region (See Figure 13 in Zeller, 1962 for refraction diagram of this portion of the coast). When the shoreline changes alignment southward from San Luis Bay and becomes parallel to the wave crest at the breaker line, the strength of the littoral currents diminish to a point where sediment can no longer be effectively moved. Sediment accumulates upcoast from the next downcoast headland and is redistributed by direct wave action (Cherry, 1965).

Because sand supply is intermittent along the coast of the Santa Maria Basin, an extreme form of dynamic equilibrium may be established. The temporally variable input of sediments to the coast by watercourses in the basin results in a variable orientation of the straight portions of the coastlines within the concave bays. When there is abundant sand supply to the coast, such as following storm events, beach alignment may shift slightly counterclockwise, assuming a more northerly orientation. During periods of low supply, dynamic equilibrium conditions will restore beach alignment to its original angle. The typical orientation of the shoreline north of Point Sal is N 13·E (Zeller, 1962; Cooper 1967).

The efficacy of littoral processes in sand movement was demonstrated by Bowen and Inman (1966), who showed that the spatial dispersion of marked sand samples assumed a Gaussian distribution due to littoral transport processes. The center of the distribution was about 70 yards south of its initial position and marked sand was distributed as far as two miles on either side of the release point after one year.

1.4.3. Aeolian transport processes and dune formation

Beach characteristics largely determine where dune masses form. Dunes are frequently found at or near the southern end of beaches where the local alignment of the shore changes towards the south or southwest. This fact indicates a decrease in the rate of littoral sand drift as the shoreline becomes almost parallel to the breakers. The sand that cannot be transported any farther downcoast by wave and current energy tends to accumulate at the prominent headlands of Point Buchon, Point Sal, Purisima Point and Point Arguello. These accumulations are then subject to aeolian transport inland and dunes form directly behind these beaches (Fig. 10C). The sand is predominantly quartz with some feldspar and small quantities of heavy minerals and rock fragments. Virtually no calcareous material is present (Zeller, 1962; Trask, 1952).

Sand supplied to coastal dunes comes from flats and banks exposed at low water and from the dry inland margins of the beach. The sand moves inland in the direction of the principal winds. Dunes are built only where onshore winds are more vigorous than offshore winds, unless there is enough vegetation to prevent offshore winds from removing the sand. Bowen and Inman (1966) estimated from the annual wind regime that sand was returned to the beach by offshore winds at a rate of about 5% of the inshore transport rate. In order that sand may move inland the back beach must be sufficiently low or of gradual slope so that sand-carrying winds are not obstructed. A low back beach is a common feature of all principal dune masses of the Santa Maria Basin (Cooper, 1967). At some headlands, where the back beach is sufficiently low, sand moves over the headland and may reenter the ocean downcoast (e.g., Point Piedras Blancas and Point Conception). Whenever the wind velocity is reduced sufficiently, the transported sand will be deposited. A cliff, bush, rock, or sand mass are examples of common obstructions frequently encountered by the wind. Onshore movement of sand north of the Santa Maria River is supplied to the dunes between Pismo Beach and Mussel Rock. The sand can be assumed to migrate initially only to the first dune inland from the beach where it moves up the windward face of the dune (deflation), avalanches down the lee (or slip) face, and is buried within the advancing dune (inflation). It will be released again when the dune advances its own length. With measured rates of advance on the order of 2 feet/year, this may be many years (Bowen and Inman, 1966). San Antonio Terrace dune sheet and other coastal dunes between Point Sal and Point Arguello are not continuous, but broken and vegetated ridges with channels between them through which the sand may blow inland for some distance (Cooper, 1967). This is also true for the area around Surf, although the dune field is not as extensive (Fig. 2). The decrease in size of the inland basins south of the Santa Maria Valley (a factor bearing on the development of a strong sea breeze regime), also suggests that average wind velocities are reduced south of Point Sal (Bowen and Inman, 1966; Cooper, 1967). South of Point Arguello sand movement is confined to the beach with no losses to dunes, except one small dune near Point Conception (Bowen and Inman, 1966).

Sediment budgets and wind velocity largely determine the surface topography of dunes. Variation in these parameters may be long-term, seasonal or simply a function of distance from the source (shoreline) and relationship to other topographic features such as basins and hills. During periods of high wind regimes and/or elevated sediment budgets, lobate or dome-shaped dunes tend to form. Early colonizing plant species frequently form the nuclei for these isolated hillocks (Cooper, 1967). As sediment budgets and/or winds decrease, dune topography changes from dome-shaped to transverse to barchan (reverse parabolic) to parabolic dune structures (McKee, 1983). Within the Santa Maria Basin, lobate dunes tend to form immediately adjacent to the shoreline, close to sediment sources and elevated wind regimes. Transverse and parabolic dunes in the basin are characteristic of Phase II and Phase III dune-building episodes, respectively (Cooper, 1967; Orme and Tchakerian, 1986). Their surface topography indicates periods of enhanced sediment budgets coincident with marine regressions, followed by later declines in sediment supplies as sea levels rose during the Late Pleistocene-Holocene. These dunes are generally well stabilized by dune scrub vegetation. Cooper (1967) offers an hypothetical account of the original and development of parabolic dune structures. The dune scrub vegetation characteristic of this portion of the California coast is sufficiently dense to stop massive sand movement by not effective enough to prevent changes in detail. The characteristic dune form associated with stabilization is an elongate parabola. "The greatest effectiveness in invasion of older masses or new territory, determined by the "effective wind," is straight ahead; burial of vegetation is easy at the front of the mass. A trough develops behind the advancing front, which becomes a path of a concentrated forward air current. Drag due to the containing walls retards air velocity along the sides, deflecting the flow lines to right and left. Sand is dropped, building lateral ridges. As the active mass moves on, these, and the floor of the trough as well, are occupied by vegetation and gradually stabilized. Loss of material left behind in the flanking ridges, not fully compensated by what is picked up from older deposits, results in decrease in the mass of mobile sand. The trough narrows; movement ceases when the lateral ridges meet." (Cooper, 1967, p. 85).

Aeolian transport of sand from the coast appears to be especially effective during summer afternoons when inland temperatures rise, producing convection currents which draw sea winds onshore. These breezes often exceed threshold levels for sand transport (Mulligan, 1985). Cooper (1967) reports the effective wind direction, i.e., a mean value derived from the measured long axes of linear and parabolic dunes, to be between 300· and 321·, averaging 312·NNW. Inman and Bowen (1966) report that the principal wind direction in all seasons was from 320·NNW (Fig. 10C).

2.0 HISTORICAL LAND USE CHANGES IN THE SANTA MARIA BASIN

The following discussion and associated figures are based on materials examined in the archives of the Map and Imagery Library at the University of California-Santa Barbara and the Santa Barbara County Historical Society Museum in Santa Barbara. Maps and aerial photographs used in preparing this portion of the report are listed in Appendices A and B.

2.1 Pre-European conditions

Aboriginal peoples were responsible for the first human-induced changes to the dune complexes within the Santa Maria Basin. Orme (1990) has identified an extensive charcoal seam in dune cross-sections at Morro Bay, about 1730 years old. Whether this fire was caused by lightning or aboriginal peoples is uncertain, but correlated with this large-scale removal of vegetation is destabilization of the dunes, which resulted in a renewed phase of parabolic dune-building activity. There are other examples of dune reactivation attributable to natural or human-induced fire in the Santa Maria Basin. Crespi (1769) described extensive burned areas around present-day Pismo Beach, as apparently caused by Chumash Indians.

2.2 Spanish exploration and settlement, late 18th century to mid-19th century

More intensive and wide-ranging land use changes came with Spanish exploration and settlement of the Santa Maria Basin. The first Spanish expedition to traverse the Santa Maria Basin was led by Gaspar de Portola and Father Juan Crespi in 1769. While onroute from San Diego to Monterey, their party used a coastal route.

From Point Conception the explorers stayed close to the ocean past Point Arguello. Near Point Sal, however, they turned inland to avoid the sand dunes. They headed back towards the beach south of Oso Flaco Lake, camped around the lake, then proceeded north between the dune lakes and the beach, crossed the dunes near the mouth of Arroyo Grande Creek and continued north along the beach.

Soon after initial exploration of the Basin, missions were established which initiated the agricultural history of the area. The pattern of establishment however, appears to show that the Santa Maria and Santa Ynez Valleys were less attractive than other areas to the north and south. Undoubtedly the dune complexes of the Basin figured prominently in early settlers' evaluation of the area. The Santa Maria Valley in the 1840's was characterized as, "...a sandy waste so undesirable that early settlers rejected the land, even for free.", and, "[the valley] went begging for takers." (Storke, in Brantingham, 1991). The constant northwest winds were considered a serious detriment to settlement of the Lompoc and Santa Maria Valleys and vicinity, thus other inland valleys such as Los Alamos Valley were settled first (Thompson and West, 1883). Mission San Luis Obispo de Tolosa was the first mission to be established in the region, in 1772. La Purisima Mission was founded fifteen years later, in 1787, and Mission Santa Ynez followed in 1804. Cattle were allowed to roam freely over Mission lands, but cultivation was limited to the immediate vicinity of the Mission. The brush-covered sand hills of the region were unsuited to the agricultural practices of the day. In the 1830's, "...only Indians and Mexicans [were] farming, and then only on arroyos and bottom lands, for anyone who would have attempted cultivation without irrigation would have been laughed at." (Thompson and West, 1883, p. 282).

The dune systems were subjected to relatively light livestock grazing in the period between the establishment of the missions and the land grants. In the late 1830's and continuing into the late 1840's, the Santa Maria and Santa Ynez Valleys were divided into land grants (Fig. 11). Coastal portions of the Santa Maria Basin were the first to be claimed. The coastal dunes between modern Pismo Beach and Point Arguello fell largely within five land grants: Pismo (1840), Bolsa del Chamisal (1837), Guadalupe (1837), Casmalia (1840), Jesus Maria (1837) and Lompoc (1837). Inland dune systems fell within the Nipoma (1837), Punta de la Laguna (1845), Todos Santos y San Antonio (1844), Santa Rita (1845) and ex-Mision de la Purisma (1845) land grants. Large portions of the Orcutt Upland, Mussel Rock Dune Sheet and Burton Mesa fell within unclaimed government lands (Fig. 11).

With the issuance of land grants, settlement of the Basin continued and rates of land use conversion within and adjacent to the dune systems intensified. Livestock grazing continued to be the principal land use on the ranchos, however grazing pressures were greatly increased from pre-land grant days. For example, soon after its establishment in 1840, the Pismo Rancho was supporting 1,000 head of cattle and by the late 1870's, the Todos Santos Rancho and the Punta de la Laguna Ranchos combined, grazed over 9,000 sheep and 1700 cattle on their lands (Thompson and West, 1883). Much of this land included the basin dune systems (Fig. 11).

2.3 American settlement of the basin, mid- to late 19th century.

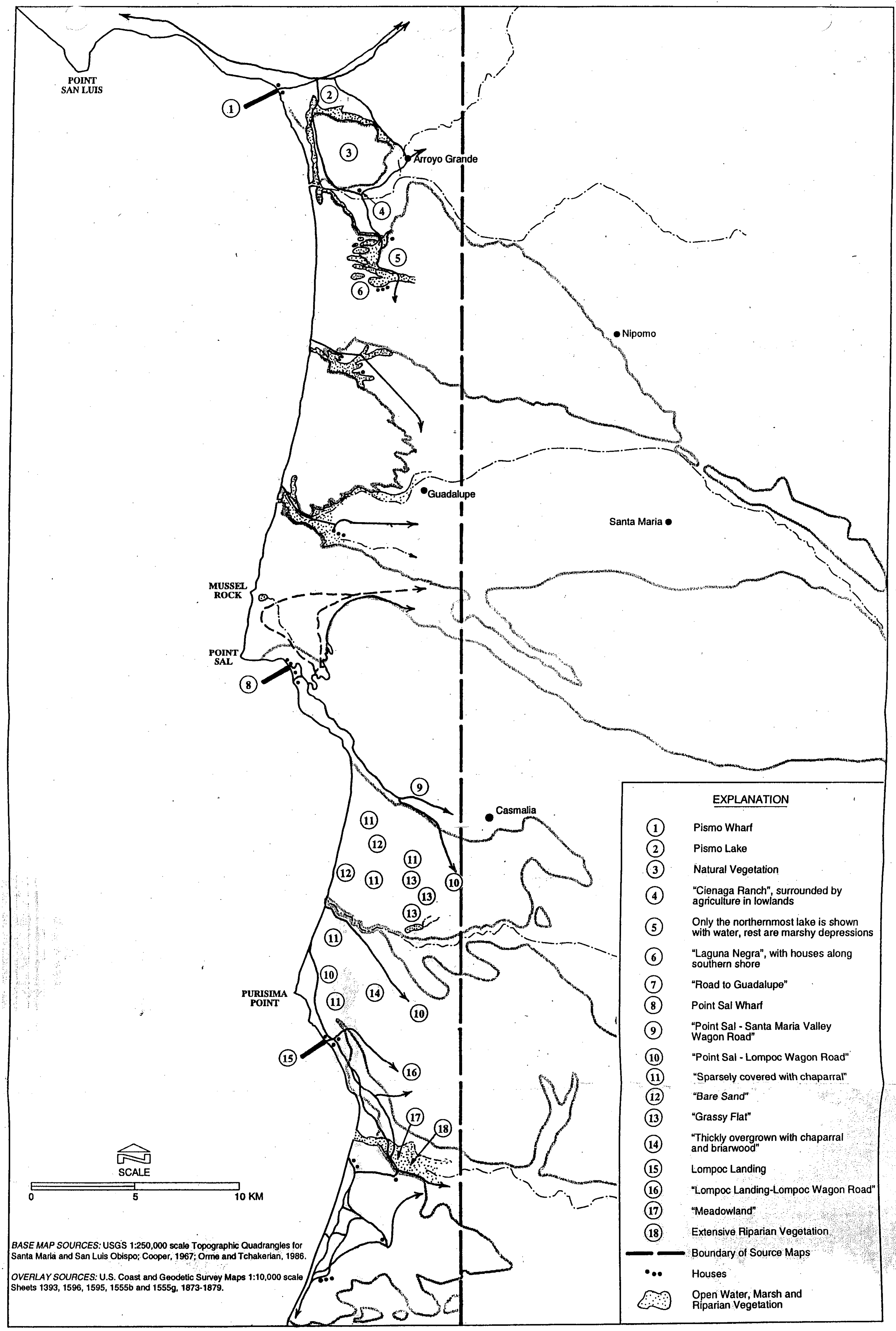
Figure 12 depicts coastal features as portrayed on area maps drawn between 1873 and 1879. The U.S. Coast and Geodetic Survey, on which Fig. 12 is based, only mapped a 2-3 km coastal strip. A prominent feature of Fig. 12 are the numerous and extensive wetlands associated with the coastal dune sheets. Landward migration of transverse and parabolic dunes frequently impounded coastal drainages, creating isolated marshes and/or lakes. According to Thompson and West (1883), in the 1830's, "...there was no well-defined river channel [in the lower Lompoc Valley], the water spreading out in the lower part of the valley into a laguna..." (p. 282). The coastal dune systems of the Santa Maria Valley, contained numerous dune lakes (Fig. 12). A large lake (later named Pismo Lake) formed in a low-lying area at the confluence of several minor watercourses. This lake emptied into a large marsh lying along the inland side of an extensive barrier beach. The marsh extended southward to join Arroyo Grande Creek at the west edge of the Cienaga Valley. The confluence of these drainages formed a wide outlet to the ocean and isolated the barrier beach from the dunes south of Arroyo Grande Creek. An unusual feature of the southern end of Cienaga Valley are numerous lakes of various sizes, either lying within or bounded by parabolic dunes. The lakes are a surface manifestation of groundwater flowing through the gravels of the lower Cienaga Valley (Cooper, 1967). There are ten depressions capable of retaining water is wet years however, the number of lakes varies depending on the amount of precipitation and groundwater extraction. Most of these lakes do not exceed 2-3 m deep and occasionally dry up. The U.S. Coastal and Geodetic Survey of 1873-1879 portrays only two of the lakes as "lagunas", the remainder are marshy depressions (Fig. 12). Note the relative size of "Laguna Negra" [=Black Lake] and its connection to an extensive marsh along its northern edge (Fig. 12). Cooper (1967) notes that in the 1930's and 1940's, a private hunting club maintained the level of the lakes, especially in the dry season, by pumping water from drainage ditches in adjacent reclaimed farmland.

Marshes and lagoons were also found in the vicinity of Oso Flaco Lake, which prior to the 1860's, was the outlet for the Santa Maria River (Muehlberger, 1955). The mouths of the Santa Maria River and Santa Ynez Rivers, as well as other small drainages, such as Schuman Canyon and San Antonio Creek also supported marshes and lagoons (Fig. 12). Some of the dune system lagoons were extensive. "There is at the point [vicinity of Point Sal] a laguna approximately 3 miles long, which covers an area of about 3,000 acres. It is a great resort of geese and ducks,...Large numbers are shot for feathers." (Thompson and West, 1883, p. 298). This description probably pertains to Guadalupe Lake, a large, shallow lagoon with two arms, formed between the fingers of the southwest edge of the Orcutt Upland, near present-day Betteravia (Fig. 13).

The earliest roads in the area were trails connecting the missions. These trails roughly followed the earlier exploration routes. By the early 1870's several roads were established within the coastal dunes north of the Cienaga Valley, Mussel Rock dune sheet, San Antonio Terrace and the Lompoc Terrace. The coastal roads took advantage of natural breaks in the dunes or, when required, traversed the dunes as the shortest route from wharves. Wharves were constructed at present-day Pismo Beach as well as immediately south of Point Sal and Purisima Points in the early to mid-1870's in response to the need to export cereal crops and import building materials for the expanding communities (Fig. 12). A road was constructed between the Point Sal wharf and Guadalupe, through portions of the Mussel Rock dune sheet in 1872 (Thompson and West, 1883). In the same year a road between the Point Sal wharf and Lompoc was constructed. Several of these roads persist today. For example, the road leading southeast from the Point Sal wharf in Figure 12 splits into two branches, the north branch is the present Casmalia-Point Sal Road and the southeasterly branch follows portions of the present-day El Rancho Road and Lompoc-Casmalia Road. The roads heading east across the Mussel Rock dune sheet converge to roughly follow the present-day Corralitos Canyon-Brown Roads.

Settlement of *sobrante*, or "leftover" lands (Fig. 11) outside the ranchos increased after the Civil War. The drought of 1862-64 also contributed to the subsequent subdivision of rancho lands. American settlers began occupying portions of the Santa Maria Valley near present-day Santa Maria about 1865. Squatters began occupying portions of the Punta de la Laguna Rancho in 1869 (Thompson and West, 1883). By the early to mid-1870's, the towns of Guadalupe (1872), Central City [= Santa Maria] (1876) and Lompoc (1874), were established. Further impetus for settlement was provided by the introduction of dry farming techniques for cereal and other crops (e.g., wheat, barley, rye, hemp) and the sale and/or subdivision of the ranchos by the original owners or developers. Subsequent land-use conversion from grazing to agriculture was rapid. Clearing of natural vegetation began first in the bottom lands and the land use was converted from grazing land to agriculture. By the early 1870's, extensive portions of the Cienaga Valley, Nipomo Valley, Santa Maria River Valley, San Antonio Creek/Los Alamos Valley and the Santa Ynez River Valley were under cultivation (Fig. 12). The dune systems were, for the most part, still open space and used as grazing land, however, portions of the Mussel Rock dune sheet and Lompoc Terrace were dry-farmed for cereal crops in the early 1870's (Fig. 12). Once the towns of Lompoc, Guadalupe and Central City were established, roads connecting them to each other and to other established communities such as San Luis Obispo, Los Alamos and Santa Barbara, were built. In late 1874 a county road was built through Purisima Canyon, over a portion of Burton Mesa, connecting Lompoc with La Graciosa (a stagecoach stop between Los Alamos and San Luis Obispo) (Thompson and West, 1883). Present-day Rucker Road, Harris Grade and Highway 1 follow parts of this road.

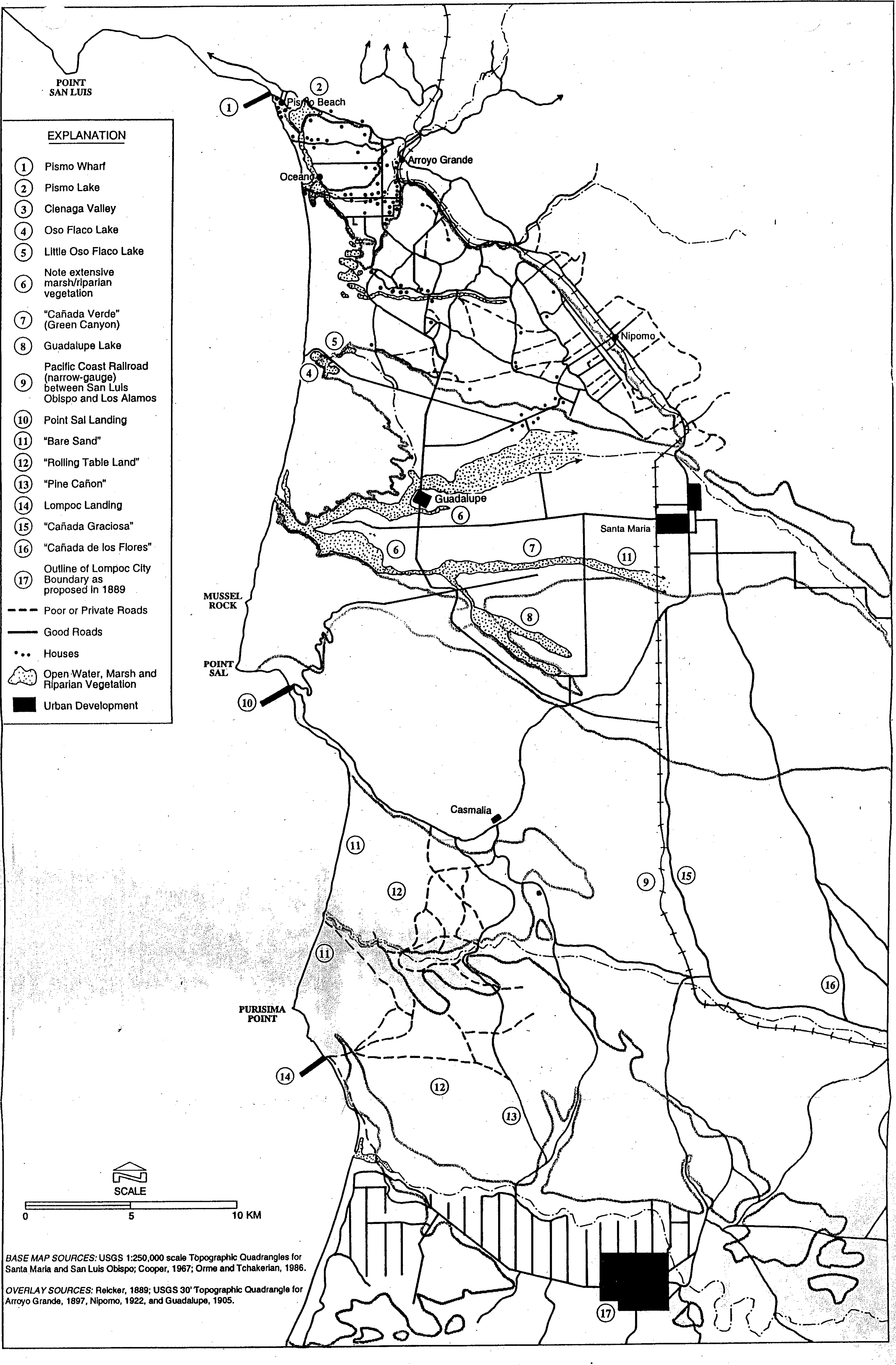
The period between 1875 and 1900 witnessed perhaps the fastest conversion of open space to agricultural and urban land in the basin than any other period. Two processes greatly accelerated development: subdivision of the ranchos and completion of railroad lines through the basin. The El Pismo Rancho was subdivided for sale in 1882; portions of the Nipoma Rancho in 1886. The narrow gauge Pacific Coast Railroad line was completed between Port Harford and Los Olivos in the early to mid-



BASE MAP SOURCES: USGS 1:250,000 scale Topographic Quadrangles for Santa Maria and San Luis Obispo; Cooper, 1967; Orme and Tchakerian, 1986.

OVERLAY SOURCES: U.S. Coast and Geodetic Survey Maps 1:10,000 scale Sheets 1393, 1596, 1595, 1555b and 1555g, 1873-1879.

Figure 12
LAND USE ALONG COASTAL PORTIONS OF THE SANTA MARIA BASIN BETWEEN 1873 AND 1879



BASE MAP SOURCES: USGS 1:250,000 scale Topographic Quadrangles for Santa Maria and San Luis Obispo; Cooper, 1967; Orme and Tchakerian, 1986.

OVERLAY SOURCES: Reicker, 1889; USGS 30' Topographic Quadrangle for Arroyo Grande, 1897, Nipomo, 1922, and Guadalupe, 1905.

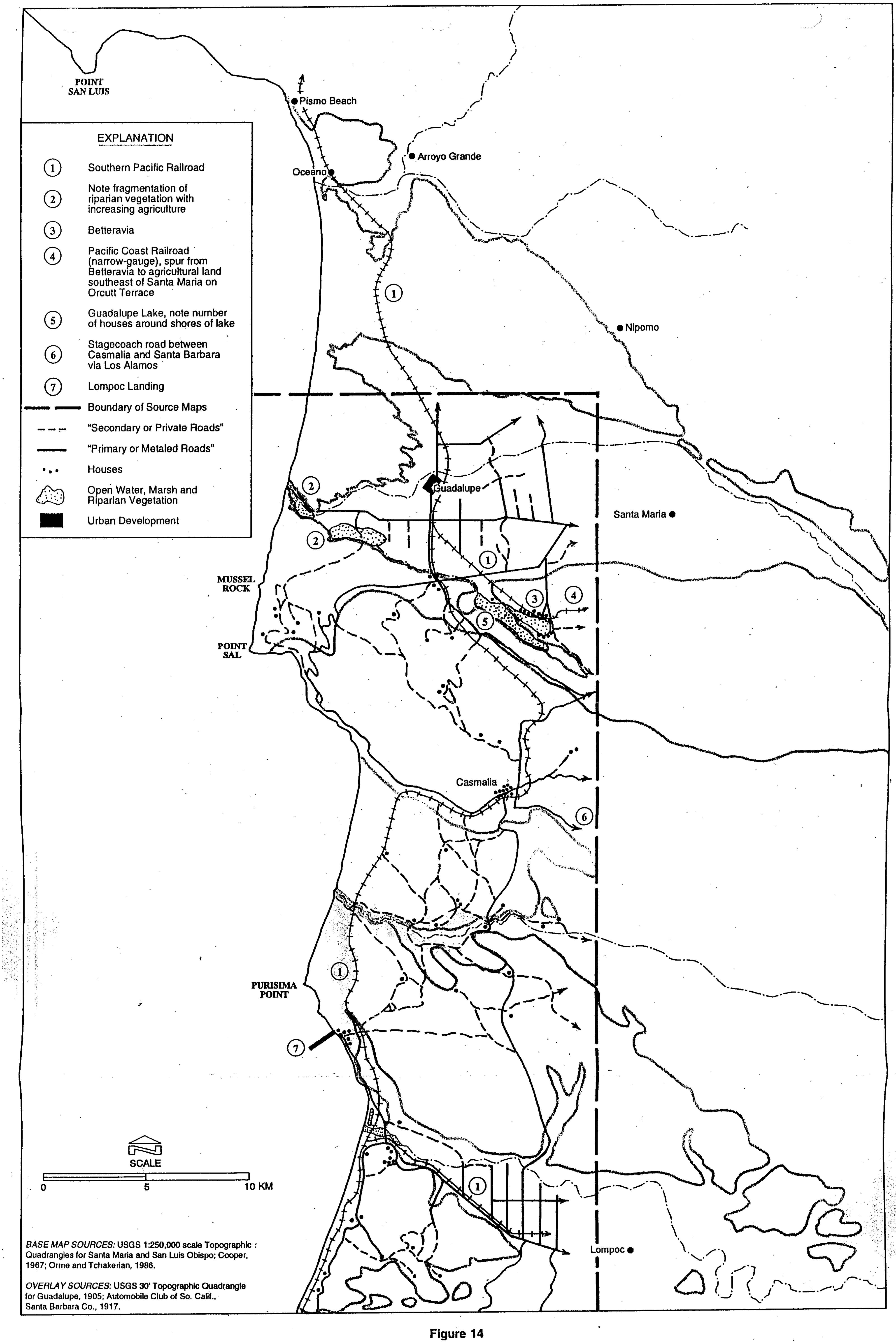
Figure 13
LAND USE IN THE SANTA MARIA BASIN ca. 1889

1880's and served as the major transportation link from this time until completion of the Southern Pacific Railroad route in 1901 (Fig. 13). With the exception of the Orcutt Terrace, this narrow gauge railroad largely avoided the dune sheets. It followed a route along the eastern base of Nipomo Mesa, parallel to present-day Thompson Avenue (Fig. 13).

The Southern Pacific Railroad route was the second large-scale disturbance to the coastal dune systems following establishment of grazing practices on the ranchos. The present-day railroad route still follows the original survey. This route entered the basin in early 1895, when tracks were laid between San Luis Obispo and Oceano (Fig. 14). The marshes backing the barrier dunes south of Pismo were drained and the route followed this low-lying area across the Cienaga Valley. From this point the railroad turned south and ran along the boundary between the Callender dune sheet and the western edge of the Nipomo Mesa dune sheet on its way towards Guadalupe. After leaving the Callender dune sheet the route traversed a portion of the Santa Maria River floodplain. By late 1895 the railroad bridge over the Santa Maria River was completed and tracks were laid to Guadalupe. By early 1896, the tracks had reached Casmalia by traversing the extreme eastern portions of the Mussel Rock dune sheet and ascended the Casmalia Hills via Shuman Canyon. From Casmalia a stagecoach line continued southeastward to Los Alamos and Santa Barbara (Fig. 14).

The coastal dune sheets of the southern half of the Basin were directly impacted by the railroad. By late 1896 tracks were laid across Phase III and IV dunes of the San Antonio Terrace southward to the Santa Ynez River apparently because this route was easier than following the wagon roads between Lompoc and Casmalia or between Lompoc and Santa Maria. The railroad bridge over the Santa Ynez River was completed in 1897 and the railroad terminated at Surf, approximately 2 kilometers south of the Santa Ynez River. From the Santa Ynez River south to Point Arguello, the railroad was built across Phase IV dunes at the seaward base of Lompoc Terrace (Fig. 14). The route between Surf and Santa Barbara was not completed until 1901 (Nicholson, 1980).

Note the size of Lompoc relative to Santa Maria in Figure 13--a trend that was not reversed until many years later. Agricultural development in the Lompoc Valley outstripped that of the Santa Maria Valley in the latter quarter of the 19th century. Conversion of portions of the dune systems for agriculture continued, especially at the northern and southern edges of the Basin. Between the late 1870's and late 1890's, extensive portions of the Phase II dunes north of Cienaga Valley, as well as Phase II dunes on the Nipomo Mesa and Lompoc Terrace were under cultivation (Fig. 13). The most extensively disturbed portions were the paleodunes on Nipomo Mesa. Figure 13 shows the location of houses and major roads on the mesa in 1897. The town of Nipomo, expanding around the former headquarters of the Nipoma Rancho, appears to be the focus for development on the mesa. Cienaga Valley, at the northwest corner of Nipomo Mesa, and the dune system to the north of the valley are heavily settled. By 1878, Arroyo Grande was described as a "...thriving place with 12-15 houses...", and a number of commercial establishments (Thompson and West, 1883). The town of Oceano was founded in 1893 and recreational beach development began in the dunes adjacent to Oceano and at Pismo Beach in the mid-1890's. By 1897 the Cienaga Valley was almost completely under cultivation while the dune sheet to the north appears to be in the early stages of conversion from open space to agriculture (Fig. 13). The introduction of irrigation from the development of artesian wells also had been introduced to the Santa Maria and Lompoc Valleys by 1897 (Smith, et al., 1976). Agriculture spread on the Lompoc Terrace, becoming more organized as shown by the pattern of road development. Small amounts of farming continued on the older portions of the dune sheets north of San Antonio Creek, but increases in the number of



BASE MAP SOURCES: USGS 1:250,000 scale Topographic Quadrangles for Santa Maria and San Luis Obispo; Cooper, 1967; Orme and Tchakerian, 1986.

OVERLAY SOURCES: USGS 30' Topographic Quadrangle for Guadalupe, 1905; Automobile Club of So. Calif., Santa Barbara Co., 1917.

Figure 14
LAND USE ALONG COASTAL PORTIONS OF THE SANTA MARIA BASIN IN 1905

roads in this area shown in Figure 13 relative to Figure 12, primarily reflect alternate routes to and from Lompoc, Casmalia, Guadalupe and the wharves at Point Sal and Lompoc Landing. Maps produced in 1889 show areas of bare sand on the San Antonio Terrace and characterize the inland portions of this dune sheet and the adjoining Burton Mesa as "rolling table land", devoid of agriculture (Fig. 13). Impacts to the Orcutt Upland appear to be limited to transportation corridors, although this dune sheet was undoubtedly grazed at this time. The aforementioned road from Lompoc to La Graciosa was extended to connect Central City (name switched to Santa Maria in 1882). The Pacific Coast Railroad followed a route adjacent and parallel to this road. Highway 1 now follows parts of this route. Another important road leads out of Santa Maria, southeast across the Orcutt Terrace, through Solomon Canyon and Canada de los Flores, to connect with the La Graciosa to Los Alamos Road. Present-day Highway 101 roughly follows this route. Other roads and tracks along the east edge of the Orcutt Terrace follow old grant boundaries in Figure 13. The number of roads and houses around Guadalupe Lake and the west edge of the Orcutt Terrace in Figure 13 forecasts a locus for future development and probably indicated agricultural conversion of the dunes in this area by the late 19th century.

It is significant that the Callender dune sheet, including the "dune lakes" at the south end of Cienaga Valley, the Guadalupe dune sheet, and seaward portions of the Mussel Rock and San Antonio Terrace dune sheets, remained largely open space in the latter parts of the 19th century. This pattern of development coincides closely with the spatial distribution of Phase III and Phase IV dunes. Settlers apparently found large portions of these dune sheets unsuitable for cultivating even cereal crops. These areas were used as grazing land.

2.4 Land use changes between 1900 and 1980

The relative age and vegetational development of individual dune sheets had a major influence on patterns of urban and agricultural development in the Santa Maria Basin between 1840 and 1900. Agricultural conversion of the land from open space or grazing land first concentrated on portions of the basin most suited to farming, namely the bottom lands close to watercourses. The dune systems were used largely for grazing. With the introduction of dry farming techniques, cereal crops could be grown on the dune systems proper, but only on the stabilized, older, inland dune sheets (Phase I and II dunes) that were old enough to have developed a soil horizon. The geologically younger dune masses closer to the coast were left as grazing land.

An important turning point in land use in the early 20th Century was a transition to more intensive agricultural and urban development as well as the appearance of industrial, military and recreational land uses. This type of growth was not so constrained by the presence of dune sheets within the Basin.

Figure 14 shows major transportation routes and some urban development in a portion of the western half of the basin south of the Santa Maria River, as shown on 1905 maps. Note the increase in the number of houses and roads around Guadalupe Lake, caused by the establishment of Betteravia (a stockyard/feedlot and sugarbeet refinery) as well as a spur of the Southern Pacific Railroad connecting the Pacific Coast Railroad with the main line. Several dwellings occur throughout inland portions of the Mussel Rock Dune Sheet, San Antonio Terrace, Burton Mesa and Lompoc Terrace, although the number of roads have not increased from that shown in Figure 13.

Oil and related development occurred around the turn of the century. Asphaltum was mined in the Purisima Hills and Casmalia Hills in the late 1890's (Woodring and Bramlette, 1950). The latter activity disrupted portions of the extreme east edge of the Phase I dunes of the Mussel Rock Dune Sheet, near the Waldorf siding on the Southern Pacific Railroad tracks. Oil was discovered near the turn of the century in the Graciosa Ridge area of the Solomon Hills. This led to development of the Orcutt Oil Field. The Casmalia Oil Field was developed about 10-15 years later (Woodring and Bramlette, 1950; Worts, 1951). Development of these production fields disturbed only small portions of the Orcutt Terrace west, south and east of the town of Orcutt. About the same time the Lompoc Oil Field was discovered in the Purisima Hills north of Lompoc and in 1934-1936, the Santa Maria Valley Oil Field was discovered (Woodring and Bramlette, 1950). The development of these two oil fields disturbed extensive portions of the Phase I and II dunes on the eastern portions of Burton Mesa and north-central Orcutt Terrace. The Guadalupe Oil Field was developed in 1948 on large portions of Phase III and Phase IV dunes of the Guadalupe Dune Sheet, resulting in reactivation of stabilized Phase III dunes.

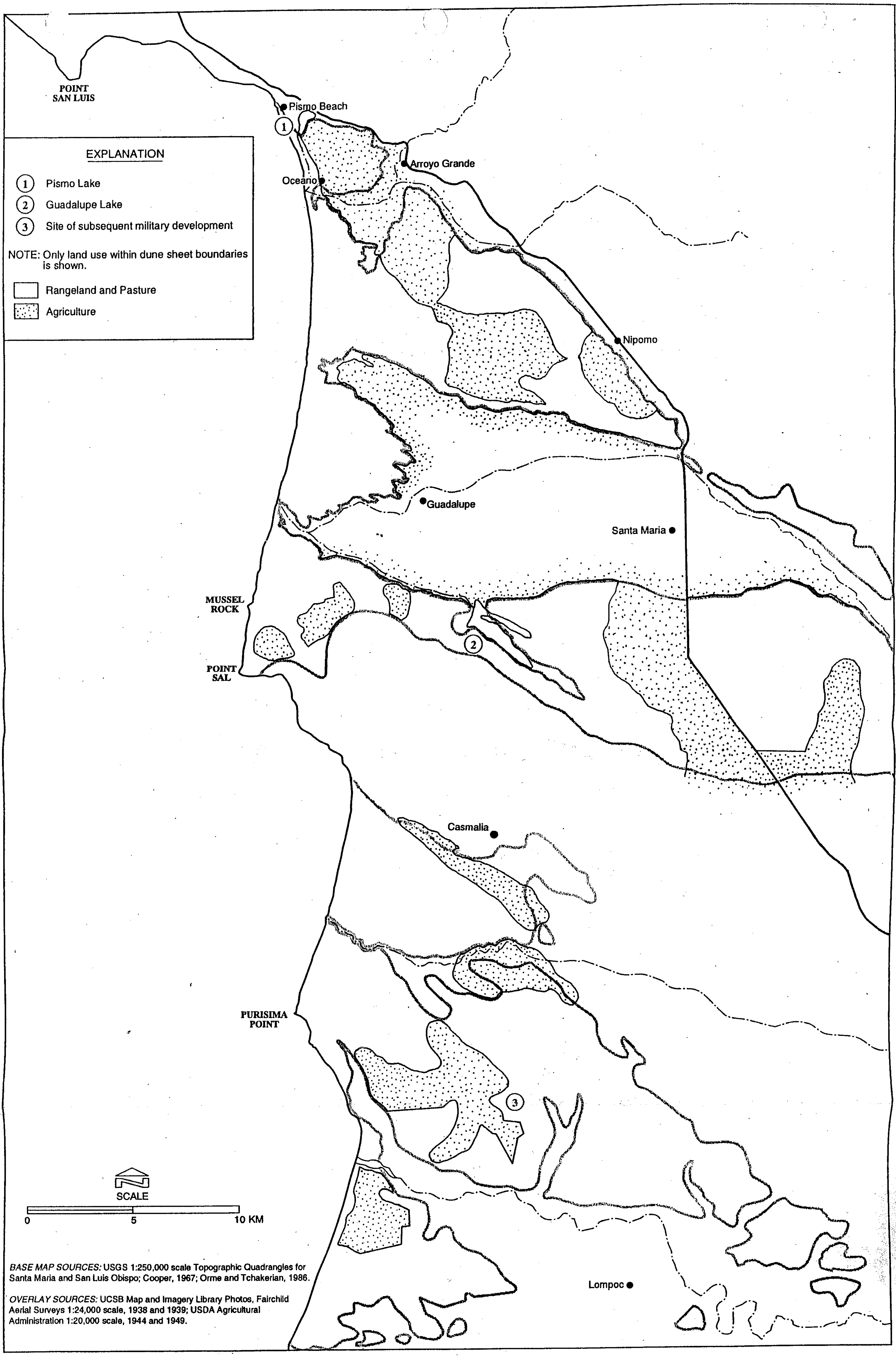
Figure 15 shows major patterns of land use in the basin as observed from aerial photographs flown between 1938 and 1939. This figure only depicts land use within the boundaries of the dune sheets within the basin. By the late 1930's Phase II dunes on Nipomo Mesa and north of Cienaga Valley had been almost completely converted to agricultural and residential use. Photos show large, forested areas, especially along the west end of Nipomo mesa which are remnants of extensive eucalyptus plantations planted around the turn of the century. The Callender and Guadalupe dune sheets were still largely untouched, with the exception of oil field development on the Phase III portions of the latter sheet. Portions of Phase I and II dunes on the Mussel Rock Dune Sheet were actively being farmed. The Orcutt Terrace was extensively disturbed by low density oil field development. The photos show the production fields with relatively widely spaced wells and connector roads with undisturbed dune vegetation between these features. Much of the rangeland category depicted in Figure 15 for the

Orcutt Terrace has some degree of oil development. Extensive portions of the Orcutt Terrace, primarily west of Highway 101 and along the south-central edge of the Terrace are also under cultivation. The Phase III and IV dunes of the San Antonio Terrace remain largely undisturbed, with agriculture restricted to Phase I (Burton Mesa) portions of the dune sheets north of San Antonio Creek. Phase II dunes on Burton Mesa south of San Antonio Creek were extensively cultivated. This site becomes a locus for future development. The remainder of Phase I and II dunes on the Burton Mesa were still primarily used as rangeland. Large portions of the Phase II dunes on the northern Lompoc Terrace were also under agriculture (Fig. 15).

The "dune lakes" if the Callender dune sheet appear to have shrunk in the 1938-39 aerial photos relative to earlier representations. Most of the intervening marsh land has been drained. Arroyo Grande Creek in Cienaga Valley and Canada Verde (Green Canyon) along the northern edge of the Orcutt Terrace and Mussel Rock dune sheet, are channelized. Extensive wetlands associated with the lower Santa Maria River (Figs. 13 and 14) have been eliminated and replaced by agriculture.

Establishment and expansion of military facilities during World War II had a major impact on the dune systems of the Basin, especially those associated with the Lompoc Valley (Fig. 16). A comparison of aerial photographs from 1938-1939 versus 1944-1949 shows the following changes:

1) Expansion of agriculture (primarily irrigated row crops) on previous rangeland, pasturage and eucalyptus plantations on Nipomo Mesa.
2) Agriculture conversion of the Mussel Rock dune sheet has stabilized.
3) Large-scale expansion of existing oil fields in the Santa Maria Valley, especially the Casmalia, Orcutt, and Santa Maria Oil Fields. Most of the production fields developed between 1900 were still present in 1944-1949 and are depicted in



BASE MAP SOURCES: USGS 1:250,000 scale Topographic Quadrangles for Santa Maria and San Luis Obispo; Cooper, 1967; Orme and Tchakerian, 1986.

OVERLAY SOURCES: UCSB Map and Imagery Library Photos, Fairchild Aerial Surveys 1:24,000 scale, 1938 and 1939; USDA Agricultural Administration 1:20,000 scale, 1944 and 1949.

Figure 15
LAND USE ON DUNE SHEETS IN THE SANTA MARIA BASIN BETWEEN 1938 AND 1939

Figure 16. The Orcutt Terrace dune sheet experienced expansion of oil production and transportation facilities on previous rangeland.

4) Large-scale expansion of agricultural activities, especially in the bottom lands of the Santa Maria Valley.
5) Construction of the Santa Maria Airfield on agricultural land on the Orcutt Terrace immediately west of Highway 101.
6) Conversion of agricultural land for military purposes on Phase II dunes of the Burton Mesa and adjacent Phase III portions of the San Antonio Terrace north and south of San Antonio Creek. Military development is spatially coincident with previous agricultural land on the Burton Mesa south of San Antonio Creek, within the boundaries of the newly created Camp Cooke. None of the major military installations shown in Figure 16 within Camp Cooke, are found on the 1938-39 aerial photos. These facilities were constructed in the early 1940's.
7) Extensive conversion of agricultural land on Phase I dunes along San Antonio Creek and Schuman Canyon for military purposes; small buildings and many more roads in these areas. Many of these roads are expanded versions of earlier roads.
8) Expansion of agricultural land on the Lompoc Terrace, including disturbance of rangeland along the southern and eastern portions of the Terrace by numerous military roads.

Other important land use changes portrayed in Figure 16 relative to earlier maps include:

- elimination of the southern arm of Guadalupe Lake and shrinkage of the north arm of the lake; construction of secondary road across north arm;

elimination of lake appears to be due to increased groundwater pumping for agriculture rather than direct land conversion; Highway 1 appears to traverse the long axis of former southern arm of the lake; expansion of the industrial/agricultural operations around Betteravia, including creation of several small ponds; large portions of rangeland along this portion of the Orcutt Terrace converted to agriculture;

- land between the Santa Maria Airfield and town of Orcutt (Orcutt Terrace) is primarily rangeland, but is heavily dissected by primary and secondary roads;
- north edge of Orcutt Terrace east of Highway 101 is primarily agriculture; along the northwest edge and south-central portions of the Terrace west of 101, land use is primarily rangeland with intensive oil field development.

Figure 17 shows land use and major transportation corridors within the basin between 1971 and 1976. The large number of secondary and private roads in the basin prevents these features and complete coverage of land use patterns depicted on the same figure. Land use patterns established in the late 1930's and 1940's have expanded and intensified. A 1959 USGS topographic quadrangle shows that most or all of the secondary roads observed on the Burton Mesa and Lompoc Terrace portions of Camp Cooke in the 1940's appear to have been abandoned or are rarely used. Only the major roads depicted on 1946 maps are still in use.

By the late 1970's, Phase II dunes north of Cienaga Valley are almost completely obliterated by urban/industrial development. Only small portions of the dunes are still farmed. The Callender dune sheet remains largely undisturbed. Several large areas of agricultural land on Nipomo Mesa have reverted back to rangeland and present-day field observations of these fallow areas show they are vegetated primarily

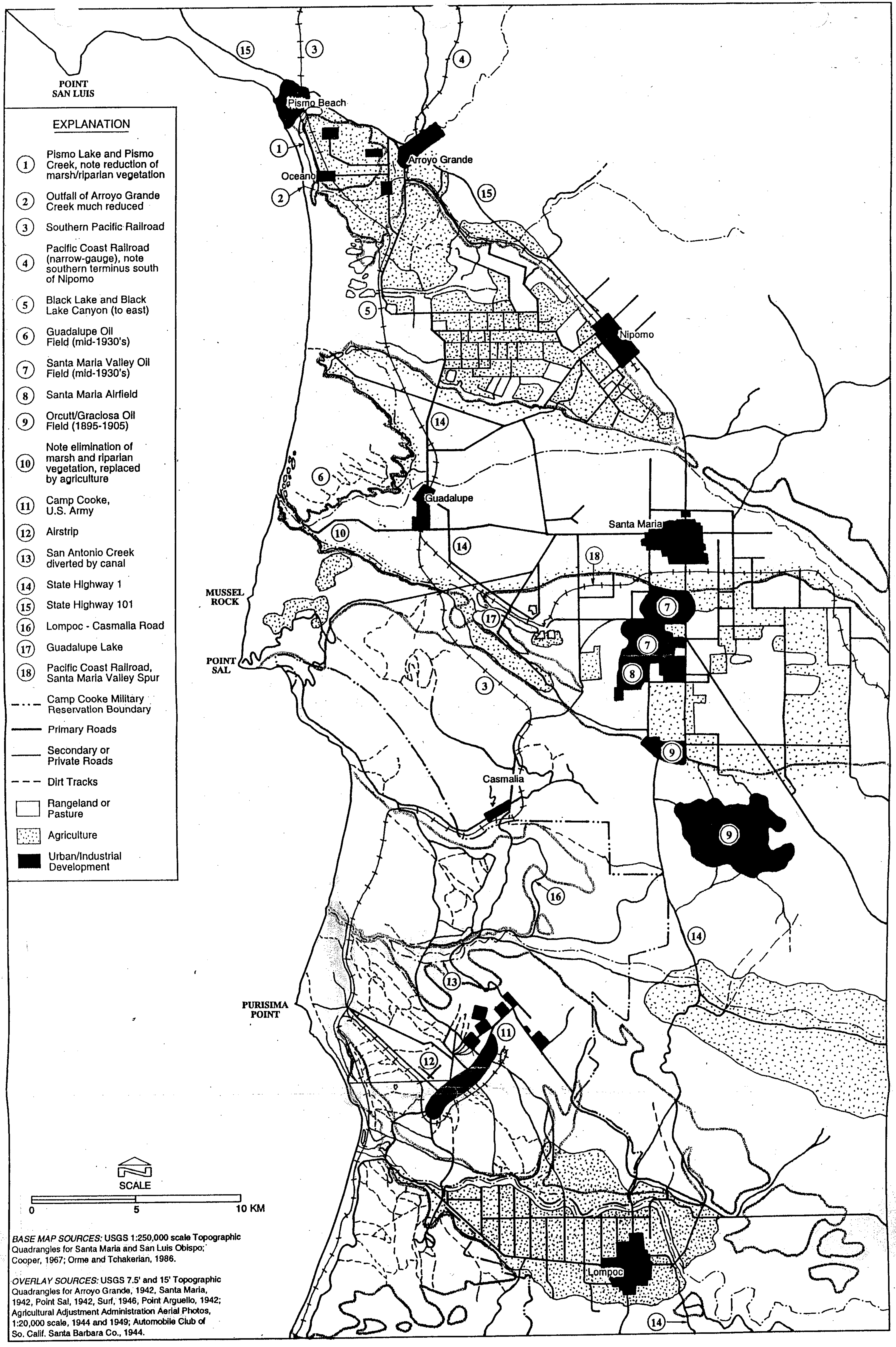


Figure 16
LAND USE IN THE SANTA MARIA BASIN BETWEEN 1942 AND 1949

with a mixture of non-native, invasive annual grasses and early colonizing native shrubs such as bush lupine (*Lupinus* spp.). Forested land along the northern and northeastern portions of the mesa is primarily oak woodland. Most of the old eucalyptus plantations along the central and southern portions of the mesa have been reduced to windrows along property lines and the intervening land is under cultivation (Fig. 17).

The Guadalupe Dune Sheet is largely intact except for sand mining and continuing oil development along the southeastern and southwestern portions of the dune sheet. Following the initial discovery of the oil field in the late 1940's, subsequent development stabilized at a low level. Renewed activity occurred in the late 1970's following deregulation of the industry (Envicom Corp., 1980) and these operations continue today.

Much of the agricultural land on the Mussel Rock dune sheet appears to be abandoned by the late 1970's, however a large agricultural area is still being worked on Phase II dunes bordering the north edge of Corralitos Canyon. This appears to be a resumption and expansion of activities dating back at least to the 1930's (compare Figs. 15 and 17).

Camp Cooke, an army installation established in 1941, was transferred to the Air Force in 1957 and the portions of the base north of the Santa Ynez River were named Camp Cooke Air Force Base. Portions of the base south of the Santa Ynez River were called Point Arguello Naval Missile Facility. In 1964 the two parts were united under the name Vandenberg Air Force Base. Most of the dunes north of San Antonio Creek within the boundaries of Vandenberg Air Force Base have reverted to rangeland by the 1970's. The decrease in density of roads throughout the base as portrayed on Figures 16 versus Figure 17 is an artifact of depicting only the major roads on the latter map. However, many of the secondary roads apparent in the 1940's appear to be abandoned at later dates. Military installations on Burton Mesa south of San Antonio Creek have been expanded. A significant development is the expansion of residential housing just outside VAFB boundaries on Phase I dunes along the eastern end of Burton Mesa. These are the communities of Vandenberg Village and Mission Hills (Fig. 17).

Agricultural operations on Phase II dunes on the Lompoc Terrace has largely disappeared by the 1970's and appears to be replaced by low-density military development.

The urban centers of Lompoc and especially Santa Maria increased significantly between the late 1940's and late 1970's. Santa Maria has expanded primarily across the northern and central portions of the Orcutt Terrace, west and east of Highway 101. Much of the remaining rangeland along the eastern third of the Orcutt Terrace, especially east of Telephone Road, has been converted to agriculture. The only extensive open space remaining on the terrace in the 1970's was the south-central portions, primarily east of Highway 101 to Telephone Road and north of Clark Avenue to Betteravia Road. Small, highly fragmented patches of rangeland continue to exist north of Highway 1 along the south western portions of the Orcutt Terrace. Much of the existing rangeland appears to be devoid of its original dune-scrub vegetation (Fig. 17). Guadalupe Lake has disappeared in aerial photos, but the north arm is shown as an intermittent feature on maps.

2.5 Current land use patterns

Land use changes begun in the 1850's and established by the late 19th century have determined the patterns of dune habitat conversion observed today throughout the Santa Maria Basin. Phase I and II dunes were early targets for destruction because they

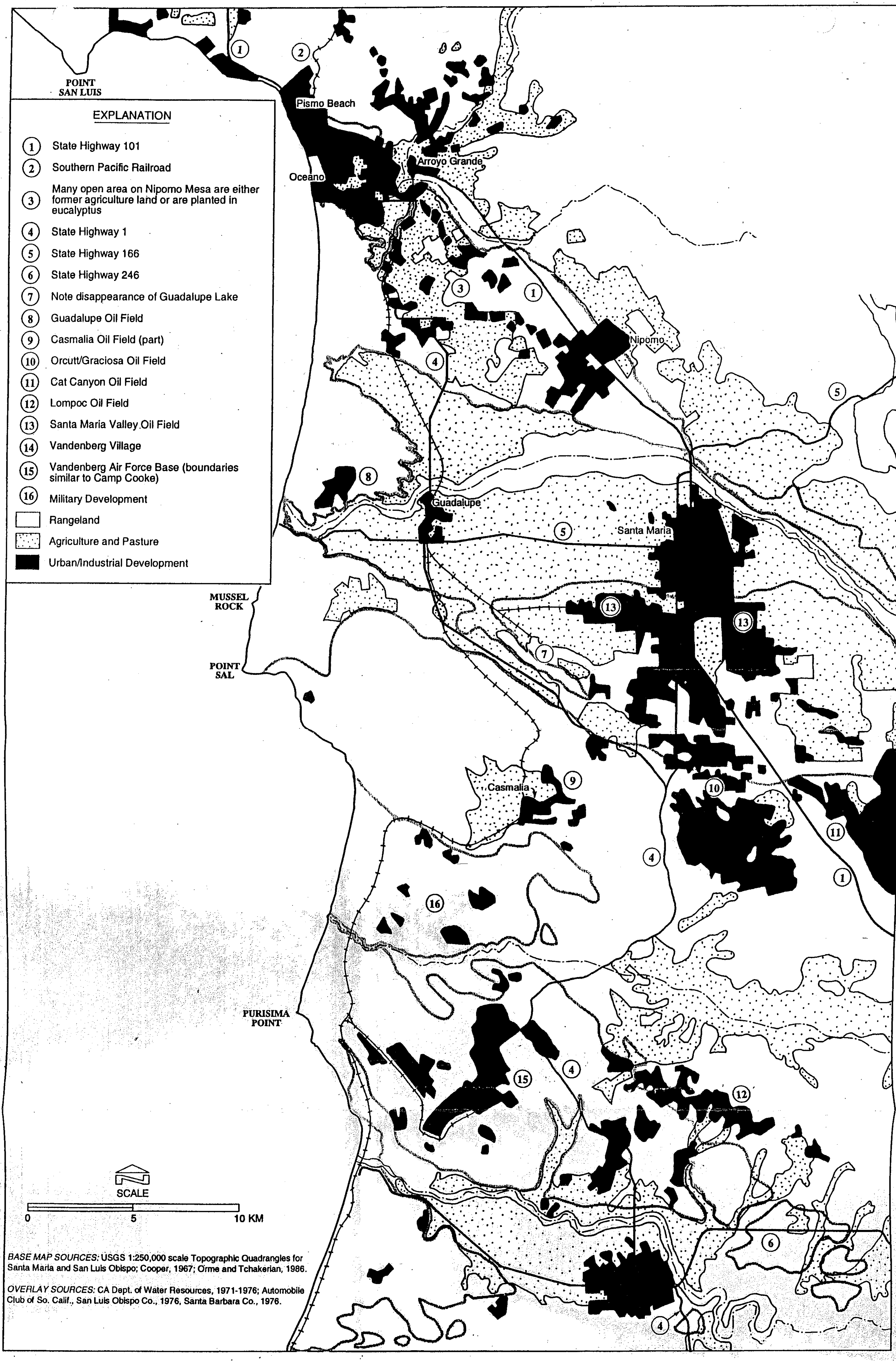


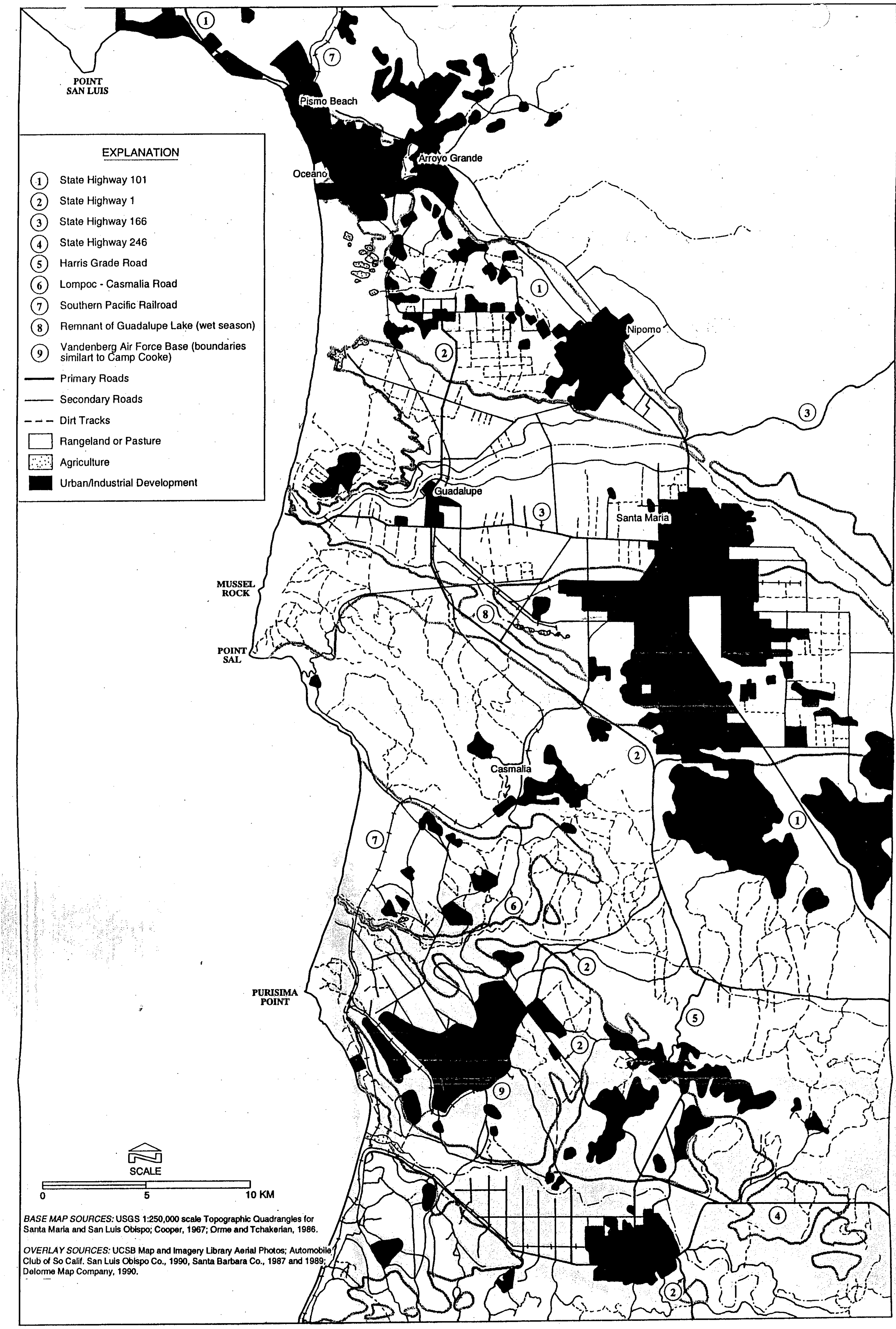
Figure 17
LAND USE IN THE SANTA MARIA BASIN BETWEEN 1971 AND 1976

possessed a soil horizon suitable for farming. Agricultural land was subsequently converted to residential/industrial uses. Figure 18 shows important land use patterns in the basin as well as primary and secondary roadways as they appeared in 1990. Large-scale agricultural expansion slowed by the late 1970's. Agricultural land near urban centers appears to have undergone a net areal reduction by the early 1990's due to conversion of agricultural land to urban/industrial purposes. The general pattern of present-day development continues to intensify around previously established loci.

The only dune systems that remain largely intact are the Callender, Guadalupe and San Antonio Terrace dune sheets. Fragments of the Mussel Rock, Burton Mesa and Lompoc Terrace dune sheets are also relatively undisturbed. Phase I and II dunes of the Orcutt Terrace and Nipomo Mesa were reduced to small, highly fragmented remnants by the early 1990's (Fig. 18).

The destruction of Pleistocene dunes in the Santa Maria Valley has been especially extensive. Phase I and II dune sheets in the Santa Maria Valley have received practically no protection from land conversion. Holocene (Phase III and IV) dunes have been protected only because these areas were deemed unsuitable for 19th century agricultural development. Consequently, Phase I and II dunes have been largely obliterated by agricultural and urban development. A recent development is the conversion of grazing land to row crops on the Orcutt Terrace west of Highway 101.

The situation in the southern half of the Santa Maria Basin is somewhat different. Phase I and II dunes on the Burton Mesa and Lompoc Terrace dune sheets have also been disturbed by land conversion, but to a lesser degree than the Santa Maria Valley. The dune systems within Vandenberg Air Force Base represent the largest and most diverse assemblage of dune phases currently found in the Santa Maria Basin. All four phases of dune emplacement can be found within the boundaries of the Base however, Phase I dunes are not extensive here and have been significantly disturbed (Fig. 2). Large portions of the Phase II and III dunes on the San Antonio Terrace, Burton Mesa and Lompoc Terrace are subject to military development.



BASE MAP SOURCES: USGS 1:250,000 scale Topographic Quadrangles for Santa Maria and San Luis Obispo; Cooper, 1967; Orme and Tchakerian, 1986.

OVERLAY SOURCES: UCSB Map and Imagery Library Aerial Photos; Automobile Club of So Calif. San Luis Obispo Co., 1990, Santa Barbara Co., 1987 and 1989; Delorme Map Company, 1990.

Figure 18
LAND USE IN THE SANTA MARIA BASIN BETWEEN 1989 AND 1990

3.0 REGIONAL THREATS TO THE DUNE SYSTEMS

3.1 Changes in sediment budgets

Human-induced reductions in the amount of sand reaching the ocean from these watercourses is a serious threat to the continued existence of the coastal dune systems. Surface mining of sediments within the streambeds in the basin and the construction of dams on basin watersheds are the most important factors affecting rates of fluvial sediment transport. Disruption of the natural longshore sediment transport processes due to human activities outside the limits of the Santa Maria Basin began to affect sediment budgets within the basin in the middle part of this century. These activities included the construction of groins and breakwaters along the coast.

Between the late 1940's and the late 1970's large-scale, human-induced changes in the sediment budgets that control the creation and maintenance of the dunes included sand mining in the dry watercourses of the basin, extensive groundwater pumping and the construction of dams.

Mining of river sands during the ten year period between 1945-55 (prior to dam construction), averaged 43,000 cubic yards/year from the Santa Maria River and 11,000 cubic yards/year from the Santa Ynez River. These quantities represented a significant proportion of the estimated annual sediment yield of these watercourses at the time (Johnson, 1959).

Dams were constructed on the Cuyama and Santa Ynez Rivers as well as smaller watercourses such as Arroyo Grande Creek. Extensive groundwater pumping and surface water diversion for agricultural, municipal and flood control purposes, significantly reduced or eliminated major sources of sediment contributive to the coastal dunes of the basin. The Vaquero Dam on the Cuyama River (built in 1957) and the Bradbury Dam on the Santa Ynez River (built in 1953), reduced the effective drainage basins of these watersheds by 66% and 48%, respectively (Fig. 8; Judge, 1970). Currently most of the sediment load carried by the Santa Maria River comes from the Sisquoc River (Fig. 8). Prior to regulation by dams, the Santa Maria and Santa Ynez Rivers taken together, drained approximately 80 percent of the Santa Maria Basin, including the most actively eroding portions which are the greatest sources of sediments to the ocean. Much of the present drainage area of the Santa Ynez River now consists of floodplain and a rather small area of active erosion (Johnson, 1959; Bowen and Inman, 1966).

3.2 Exotic Invasive plants

The significance of biological invasions as a causative agent in species extinctions has only recently been appreciated (Mooney and Drake, 1986; Coblentz, 1990). An insidious threat to the viability of the native scrub/shrub habitats of the dune systems in the Santa Maria Basin are invasions by exotic plant species. Several species of invasive exotics are well-established in all of the extant dune systems within the Basin. The most extensive are: Hottentot Fig (*Carpobrotus edulis*), Common Ice Plant (*Mesembryanthemum crystallinum*), Veldt Grass (*Ehrharta calycina*) and Pampas Grass (*Cortaderia jubata*), European Beach Grass (*Ammophila arenaria*) and Conicosia (*Conicosia pugioniformis*) (D'Antonio, 1990; Earth Technology Corporation, 1992). These species are particularly suited to colonizing disturbed and early successional habitats.

Invasion by Ice Plant and introduced grasses, especially Veldt Grass and Beach Grass, is a serious threat to the native plants and certain animals inhabiting the dune systems on Vandenberg AFB (Schmalzer and Hinkle, 1987; D'Antonio, 1990; Earth Technology Corporation, 1992). Land use changes associated with agriculture, grazing and abandonment of agricultural land, in the Basin, documented in the previous section, selects for alien grass invasion. These grasses were also planted over large areas dunes within Vandenberg Air Force Base to stabilize the dunes and control erosion. These species will eventually convert dune scrub habitats to dune grassland habitats. Once incorporated with into the grass/fire cycle, these invasions alter or arrest plant succession, leading to important changes in regional population, species and landscape diversity (D'Antonio and Vitousek, 1992).

Ice Plant, Veldt Grass and European Beach Grass are especially well-established on VAFB. These species alter microclimatic processes such as insolation, soil surface temperatures and nutrient and soil moisture relations. They can also affect dunes at larger-scale levels through geomorphological alterations. For example, where European Beach Grass is established dunes tend to be taller and steeper than those formed by native species because its ability to bind sand is greater than that of native species (Barbour and Johnson, 1977; Slobodchikoff and Doyen, 1977).

Ground coverage by alien grasses, especially Veldt Grass, increased dramatically across portions of the San Antonio Terrace between 1988 and 1993 (L.E. Hunt, pers. obs.). In many places, what was once a dune shrub community with widely separated shrubs and an understory of forbs, is now a shrub-grassland community with very little open space. Certain portions of the San Antonio Terrace currently exceed 15-20% cover by Veldt Grass alone (Earth Technology Corporation, 1992). A direct consequence of alien grass invasion is elimination of localized populations of unique animal species, such as endemic sand dune-dwelling arthropods (Slobodchikoff and Doyen, 1977) and the Silvery Legless Lizard (*Anniella pulchra pulchra*), due to physical and thermal changes in the substrate (L.E. Hunt, unpub. data). The latter species is a unique constituent of the regional fauna, being the only limbless lizard in the western United States. The dunes systems in the Santa Maria

Basin, especially the dune phases occurring within Vandenberg Air Force Base, provide the most extensive habitat for this species within its geographic range. On the San Antonio Terrace, these lizards tend to concentrate beneath shrubs that form a dense leaf litter. The presence or absence of leaf litter is a fundamental factor governing the local distribution of this lizard. Leaf litter decreases soil surface temperatures, retains soil moisture and provides the substrate for the arthropods that these lizards feed upon. Introduced grasses tend to grow most densely beneath native shrubs, eventually eliminating the native shrub leaf litter, elevating soil temperature regimes and inhibiting germination of native shrub seeds and seedlings. Changes in substrate temperature, moisture and subsurface root densities, as a result of grass invasion, will eventually reduce or eliminate legless lizard populations in these dunes (L.E. Hunt, unpub. data).

Efforts have been directed at controlling exotic invasives such as Ice Plant and Veldt Grass on portions of the San Antonio Terrace (Schmalzer and Hinkle, 1987; Earth Technology Corporation, 1992). Effective control of *Carpobrotus* has been achieved through the use of systemic herbicides, coupled with burning of the dead plants and restoration of the sites with native shrub species. However, invasive grasses are more difficult to control because of their habit of growing beneath shrubs. Additional experimental treatments for controlling grasses, similar to those conducted for Ice Plant, are essential if retaining the habitat and wildlife values of the remaining protected dune systems is a priority.

4.0 OPPORTUNITIES FOR FUTURE PRESERVATION

The Santa Maria Basin has the unique distinction of possessing the largest aeolian sand deposits in California however, most of the inland dune sheets will be lost completely unless protected from future agricultural and urban development. The coastal dune sheets remain relatively undisturbed because of their unsuitability for other purposes, especially agriculture. The latter activity appears to forecast subsequent residential development. The inland (and thus older) dune sheets, as well as the host of sensitive plants and animals that inhabit them, are in critical need of protection. A guiding principle in future protection of Basin dune sheets should be preservation of **contiguous** examples of each of the dune phases in both the Santa Maria and Santa Ynez River Valleys. Relatively small portions of the dune sheets currently receive protection from land conversion. Private vs. public land ownership will determine the future of the remaining dune sheets in the Santa Maria Basin.

Phase I dunes are the most degraded and least protected dune formations in the Santa Maria Basin (compare Fig. 2 and Fig. 18). The formerly extensive surface deposits within the Santa Maria Valley have been largely obliterated by residential and agricultural development. Extensive areas of Burton Mesa are privately owned and subject to residential, grazing and oil field development. Minor portions of this formation currently receive protection within the boundaries of La Purisima State Historical Park and the northeastern corner of Vandenberg Air Force Base however, the latter site is subject to military development. Approximately 5,125 acres of Phase I dunes on Burton Mesa was deeded to the State of California by Unocal Oil Company in July, 1991. The State Lands Commission administers the property and is currently formulating a plan for long-term management of the natural resources of the parcel, including a recreational component (Odion, et al., 1993).

Phase II dunes in the Santa Maria Basin are largely unprotected. Small portions of Morro Bay and Mussel Rock Phase II dunes are administered by the California Department of Parks and Recreation. Large portions of the Nipomo Mesa, Orcutt Terrace and Phase II Burton Mesa dune sheets have been permanently lost. Nipomo Mesa north of Willow Road still contains relatively undisturbed scrub and dune oak woodland habitat on Phase II dunes. This habitat should be protected. Phase II dunes on this sheet currently receive no protection outside of the tiny Nipomo Regional County Park. Orcutt Terrace west of Highway 101 has been largely obliterated by urban and agricultural development. The only remaining patches of natural vegetation west of Highway 101 occur in the vicinity of Betteravia. Larger areas of relatively undisturbed Phase II dunes still occur east of Highway 101, in a rectangular area bounded on the south by Clark Avenue and on the east by Telephone Road. These are remnants of the Santa Maria Valley Oil Field. Large portions of privately-owned land immediately north of Clark Avenue have been grazed to the point where the natural dune-scrub vegetation has been replaced by non-native annual grasses and forbs. Natural dune scrub vegetation is still found on oil company lease sites, where they are afforded temporary protection from permanent destruction by agriculture and/or urban development. Without permanent protection, agricultural and urban development will destroy the remaining patches of relatively undisturbed Phase I and II dunes in the Santa Maria Valley. The aforementioned areas on Nipomo Mesa and Orcutt Terrace should be targeted for acquisition in order to preserve high-quality representatives of each of the dune phases in the Santa Maria Valley. Land currently occupied by oil field should be protected because of its relatively undisturbed dune scrub habitats. If these areas are not protected when oil lease options expire, the oldest dune sheets in the Santa Maria Valley will be permanently lost.

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This list contains literature cited in the text as well as additional references on the dune systems of the Santa Maria Basin.

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Appendix A. Inventory of reference maps

The following maps were used to prepare this report. This material is stored in the archives of the University of California-Santa Barbara Map and Imagery Library and the Santa Barbara Historical Society Museum.

Automobile Club of Southern California. 1917. Automobile road map for Santa Barbara County, California; single sheet, laminated.

Automobile Club of Southern California. 1942, 1944, 1952, 1976, 1987. Maps of Santa Barbara County, California, scale 1:200,000.

Beck, W.A. and Y.D. Haase. 1974. Historical atlas of California. Univ. Oklahoma Press, Norman.

Blackburn, O.V. 1934. Official map of Santa Barbara County, Los Angeles; original color map cut into 4 sheets and laminated.

California Department of Water Resources, Land Use Series of California. California Land Use Maps, 1977 and 1985; scale: 1:24,000, registered to overlay 7.5' USGS topographic quadrangles:

- Morro Bay North
- Morro Bay South
- Port San Luis
- Pis Beach
- Arroyo Grande
- Oceano
- Nipomo
- Point Sal
- Guadalupe
- Santa Maria
- Twitchell Dam
- Casmalia
- Orcutt
- Sisquoc
- Surf
- Lompoc
- Los Alamos
- Point Arguello

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Department of Public Works, Division of Highways. 1937. Rural post roads of Santa Barbara County, California; 5 large sheets.

Dibblee, T.W., Jr. 1988. Geologic map of the Tranquillon Mtn. and Point Arguello Quadrangles, Santa Barbara County, California (1:24,000 scale). Dibblee Geol.

Found. Map DF-19. Publ. in coop. with Calif. Dept. Conserv., Div. of Mines, and U.S. Geol. Surv.

Dibblee, T.W., Jr. 1988. Geologic map of the Lompoc and Surf Quadrangles, Santa Barbara County, California (1:24,000 scale). Dibblee Geol. Found. Map DF-20. Publ. in coop. with Calif. Dept. Conserv., Div. of Mines, and U.S. Geol. Surv.

Dibblee, T.W., Jr. 1989. Geologic map of the Casmalia and Orcutt Quadrangles, Santa Barbara County, California (1:24,000 scale). Dibblee Geol. Found. Map DF-24. Publ. in coop. with Calif. Dept. Conserv., Div. of Mines, and U.S. Geol. Surv.

Dibblee, T.W., Jr. 1989. Geologic map of the Point Sal and Guadalupe Quadrangles, Santa Barbara County, California (1:24,000 scale). Dibblee Geol. Found. Map DF-25. Publ. in coop. with Calif. Dept. Conserv., Div. of Mines, and U.S. Geol. Surv.

Kenyon Company. ca. 1900-1920. Map of Santa Barbara County, California, showing Mexican Land Grant boundaries and urban features, drawn, engraved and printed by The Kenyon Company, Des Moines, Iowa; single sheet, laminated.

Riecker, Huber and Mench, Civil Engineers. 1889. Map of the County of Santa Barbara, California; drawn by Paul Riecker; original color map cut into 4 sheets and laminated, also black and white copy shot on 8 sheets.

United States Coast and Geodetic Survey, series of six sheets; all maps 1:10,000 scale:

- No. 1520b - vicinity of Point Arguello (1877)
- No. 1555g - vicinity of Arroyo Hondo to Lompoc Landing (1879)
- No. 1555b - from Lompoc Landing to Shuman's Canon, California (1879)
- No. 1595 - from Shuman's Canon to Santa Maria River and vicinity including Point Sal, north of Point Conception (1879)
- No. 1596 - Santa Maria River northwest to Arroyo Grande (1879)
- No. 1393 - southward, San Luis Obispo Bay, south point to Arroyo Grande (1873, 1874)

United States Geological Survey 7.5' topographic quadrangles, 1:24,000 scale

- Morro Bay North (1965)
- Pismo Beach (1965)
- Arroyo Grande (1965, photorevised 1978)
- Oceano (1965, photorevised 1979)
- Nipomo (1965)
- Point Sal (1958)
- Guadalupe (1947; 1959, photorevised 1974)
- Santa Maria (1959; photorevised 1967 and 1974)
- Twitchell Dam (1959, photorevised 1982)
- Casmalia (1959, photorevised 1974)
- Orcutt (1959, photorevised 1974)
- Sisquoc (1959)

- Surf (1946; 1959)
- Lompoc (1959, photorevised 1974)
- Los Alamos (1959, photorevised 1974)
- Point Arguello (1959)

United States Geological Survey, 15' topographical quadrangles; 1:62,500 scale

- Port Harford [San Luis] (1897)
- Arroyo Grande (1897; 1942; 1959)
- Nipomo (1922)
- Cayucos (1897)
- Point Sal (1942; 1947; 1959)
- Santa Maria (1942; 1959)
- Point Arguello (1947; 1959)
- Lompoc (1947; 1959)

United States Geological Survey, 30' x 60' topographical quadrangle; 1: 100,000 scale

- Santa Maria (1982)
- San Luis Obispo (1982)

United States Geological Survey, 30' topographical quadrangle; 1:125,000 scale

- Guadalupe (1905)

United States Geological Survey, 1 x 2 degree topographical/bathymetric quadrangle; 1: 250,000 scale

- Santa Maria (1989)
- San Luis Obispo (1989)

Reference aerial photographs, including an inventory of photos in he UC-Santa Barbara Map and Imagery Library collection

otos of the Santa Maria Basin in the University of California Map Library archives. All photos listed below are less than 1:50,000 ne MIL also has substantial holdings of > 1:50,000 scale aerial photos, DSAT and Thematic Mapper imagery of the Santa Maria Basin). Photos rom the late 1930's and early 1940's are from Fairchild Aerial Surveys, Inc. However, earlier photos of coastal Santa Maria Basin, such as many of those used by Cooper (1967), date from the mid-1920's to the late 1930's and are housed in the Fairchild Collection at Whittier College, Los Angeles County. NOTE: asterisks (*) denote materials specifically used in preparing this report.

1. Photos from assorted sources.

A. Santa Barbara County.

Lompoc Valley - black and white photos:

- 1938 (1:24,000) C-4950, Fairchild Aerial Surveys for USDA (*)
- 1943-44 (1:20,000) BTM-1943 (*)
- 1954 (1:20,000) BTM-1954 (*)
- 1956 (1:9,600 and 12,000) HA-AN (*)
- 1960 (1:20,000) HA-JT, (includes partial VAFB and San Antonio Creek)
- 1961 (1:20,000) BTM-1961
- 1963 (1:4,800) HA-SI, (western end of Lompoc Valley)
- 1966 (1:12,000) HB-GU
- 1966 (1:24,000) HB-HU
- 1967 (1:20,000) BTM-1967
- 1968 (1:12,000) HB-LH
- 1974 (1:14,400) AF 74-9 (*)
- 1975 (1:36,000) AMI-SB-75 (*)
- 1978 (1:40,000) USDA-40-06083 (*)
- 1982-83 (1:24,000) USDA-Firescope-III, bw

Lompoc Valley - color or color infra-red photos.

- 1978 (1:40,000) USDA-40-06083, cir (*)
- 1980 (1:40,000) USDA-Firescope, cir
- 1989 (1:24,000) PW-SB-7, c
- 1989 (1:40,000) NAPP, cir
- 1990 (1:32,500) 90-084 acc. # 04029, c, cir (*)
- 1990 (1:32,500) 90-084 acc. # 04030, c (*)
- 1991 (1:32,500) 91-022 acc. # 04158, cir (*)

Santa Maria Valley - black and white photos.

- 1938 (1:24,000) C-4950, Fairchild Aerial Surveys for USDA (*)

- 1943-44 (1:20,000) BTM-1943 (*)
- 1954 (1:20,000) BTM-1954 (*)
- 1956 (1:9,600 and 12,000) HA-AN (*)
- 1960 (1:20,000) HA-JT, (includes partial VAFB and San Antonio Creek)
- 1960 (1:12,000) HA-HQ, HA-JG
- 1961 (1:20,000) BTM-1961
- 1964 (1:12,000) HA-YJ
- 1967 (1:20,000) BTM-1967
- 1968 (1:12,000) HB-KZ
- 1969 (1:12,000) HB-PE
- 1970 (1:12,000) HB-RF
- 1974 (1:14,400) AF 74-9 (*)
- 1975 (1:24,000) AMI-SB-75
- 1978 (1:40,000) USDA-40-06083 (*)
- 1982-83 (1:24,000) USDA-Firescope-III

Santa Maria Valley - color or color infra-red photos.

- 1974 (1:24,000) PW-4419, c
- 1977 (1:24,000) PW-SM2, c
- 1978 (1:40,000) USDA-40-06083, cir (*)
- 1980 (1:40,000) USDA-Firescope, cir
- 1981 (1:24,000) PW-SM3, c
- 1989 (1:24,000) PW-SB-7,c
- 1989 (1:40,000) NAPP, cir
- 1990 (1:32,500) 90-084 acc. # 04025, c, cir (*)
- 1990 (1:32,500) 90-084 acc. # 04029, cir (*)
- 1991 (1:32,500) 91-022 acc. # 04030, cir (*)
- 1991 (1:32,500) 91-022 acc. # 04158, cir (*)

B. San Luis Obispo County.

Arroyo Grande, Five Cities area, Nipomo - black and white.

- 1939 (1:20,000) C-5750 (*)
- 1949 (1:20,000) AXH-1949 (*)
- 1954 (1:24,000) C-20570
- 1957 (1:20,000) AXH-1957
- 1958 (1:9,600) HA-CV
- 1960 (1:12,000) HA-JG
- 1961 (1:12,000) HA-MN
- 1962 (1:12,000) HA-ON
- 1963 (1:12,000) HA-TA
- 1964 (1:12,000) 235V
- 1965 (1:3,000) HB-DS
- 1966 (1:3,000) HB-HH
- 1966 (1:4,800 and 1:24,000) HB-JT
- 1966 (1:6,000 and 1:18,000) HB-HW
- 1966 (1:12,000) 273V
- 1969 (1:40,000 AXH-1969
- 1970 (1:12,000) HB-QV

- 1971 (1:24,000) HB-SM
- 1971 (1:24,000) AN-AW
- 1972 (1:31,680) HB-UU
- 1973 (1:12,000) HB-VL (*)
- 1974 (1:12,000) PW-SLO3 (*)
- 1977 (1:32,500) 77-009, acc. # 02464
- 1978 (1:40,000) USDA-40-06079
- 1985 and 1986 (1:31,680) WAC-85CA

Arroyo Grande, Five Cities area, Nipomo - color and color infra--red photos.

- 1975 (1:32,500) 75-074, acc. # 02121, cir
- 1981 (1:12,000 and 1:24,000) PW-SM3, c
- 1982 (1:35,000) NOS-82-EC, c
- 1989 (1:40,000) NAPP, cir
- 1990 (1:32,500) acc. # 04025, cir
- 1990 (1:32,500) acc. # 04029, cir
- 1990 (1:32,500) acc. # 04030, c

Morro Bay and vicinity - black and white photos.

- 1949 (1:20,000) AXH-1949
- 1954 (1:24,000) C-20570
- 1957 (1:20,000) AXH-1957
- 1959 (1:12,000) HA-GI
- 1964 (1:12,000) 235V
- 1965 (1:9,600) HB-AU
- 1969 (1:40,000) AXH-1969
- 1969 (1:6,000) HB-NZ
- 1972 (1:12,300) HB-TN
- 1972 (1:25,440) HB-US
- 1973 (1:24,000) PW-SLO2
- 1977 (1:32,500) 77-007, acc. # 02461
- 1978 (1:40,000) USDA-40-06079 (*)
- 1985 and 1986 (1:31,680) WAC-85CA

Morro Bay and vicinity - color and color infra-red photos.

- 1975 (1:32,500) 75-074, acc. # 02121, cir
- 1977 (1:32,500) 77-007, acc. # 02460, c
- 1982 (1:35,000) NOS-82-EC, c
- 1990 (1:32,500) 90-084, acc. # 04029, cir (*)
- 1990 (1:32,500) 90-084, acc. # 04030, c (*)
- 1991 (1:32,500) 92-016, acc. # 04369, cir

2. Mark Hurd collection of aerial photos, taken between 1956 and 1973; scales vary from 1:1,440 to 1:24,000, with one large-scale set of photos shot at 1:80,000.

A. Santa Barbara County, color photos.

- 1968 (BP), Lompoc Valley and vicinity
- 1969 (AL), Vandenberg Village, VAFB
- 1975 (BN), Clark Avenue, Orcutt (*)
- 1975 (BP), Orcutt to Santa Maria (*)

B. Santa Barbara County, black and white photos.

- 1956 HA-AN, Lompoc to Santa Maria (*)
- 1958 HA-CN, Santa Maria (*)
- 1958 HA-CX, HA-CY, Lompoc
- 1958 HA-DG, Lompoc area
- 1958 DQ, Santa Maria Airport (*)
- 1959 DS, Lompoc area
- 1959 HA-EA, City of Lompoc
- 1959 HA-EY, Miguelito Road, Lompoc
- 1959 HA-GC, Lompoc
- 1960 HA-HQ, Santa Maria
- 1960 HA-JG, Santa Maria to Pismo Beach
- 1960 HA-JI, Santa Maria
- 1960 HA-JT, San Antonio Creek
- 1960 HA-KE, Orcutt
- 1961 HA-KN, Lompoc
- 1961 HA-LF, Santa Maria, along Highway 101
- 1961 HA-MB, Lompoc
- 1961 HA-MM, Santa Maria
- 1962 HA-NE, Lompoc
- 1962 HA-PA, Orcutt
- 1962 HA-PI, Orcutt to Santa Maria along Highway 101
- 1962 HA-PN, HA-PO Vandenberg Air Force Base
- 1962 HA-PT, Lompoc to Santa Maria
- 1962 HA-OC, Morro Bay to Santa Maria
- 1962 HA-QT, Santa Maria to Montecito along Highway 101
- 1962 HA-QY, Santa Maria
- 1963 HA-RS, Lompoc
- 1963 HA-SB, Lompoc
- 1963 HA-SI, western portion of Lompoc Valley
- 1963 HA-SU, Lompoc
- 1963 HA-SY, Santa Maria
- 1963 HA-TF, Santa Maria
- 1963 HA-TO, Lompoc
- 1963 HA-UF, Northeast Lompoc
- 1963 HA-VG, Vandenberg Village to Morro Bay
- 1963 HA-UG, Santa Maria
- 1963 HA-US, Rice Ranch, near Orcutt
- 1963 HA-VF, Lompoc to Santa Maria
- 1963 HA-VO, Lompoc
- 1963 HA-WB, Santa Maria
- 1964,1965 HA-WZ, Sisquoc and Santa Maria area
- 1964 HA-XD, Santa Maria to Lake Cachuma

- 1964 HA-XO, Lompoc mines
- 1964 HA-YP, Santa Maria
- 1964 HA-ZI, between Lompoc and Buellton
- 1964,1965 HB-AR, Miguelito Canyon, Lompoc
- 1965 HB-AY, Lompoc drainage channel
- 1965 HB-BF, Lompoc mines
- 1965 HB-FY, Santa Maria, Broadway at Lakeview
- 1965 HB-GH, Santa Maria
- 1965 HB-FS, Fugler Point to Sisquoc Ranch
- 1966 HB-GU, Vandenberg Village to Lompoc
- 1966 HB-HL, Orcutt to Highway 101
- 1966 HB-HU, Lompoc and vicinity
- 1966 HB-HV, Santa Maria and Orcutt
- 1966 HB-ID, Betteravia to Santa Maria (*)
- 1966 HB-JK, Santa Maria Valley
- 1968 HB-KZ, Orcutt and Santa Maria area
- 1968 HB-LH, Lompoc to Santa Rosa Valley
- 1968 HB-LJ, Santa Maria area
- 1968 HB-LF, beach west of Guadalupe (*)
- 1968 HB-LA, Santa Maria River near Guadalupe (*)
- 1969 HB-NW, Santa Maria Refinery, north of Guadalupe (*)
- 1969 HB-NH, Santa Ynez and Sisquoc Rivers
- 1969 HB-OL, Lompoc to the ocean, along Santa Ynez River (*)
- 1969 HB-OR, San Antonio Creek (*)
- 1969 HB-PE, Santa Maria and Orcutt (*)
- 1969 HB-PR, south of Lompoc to Los Alamos
- 1969 HB-PW, Sisquoc River at Sisquoc
- 1969 HB-QH, west of Lompoc
- 1970 HB-RB, feeder pens between Santa Maria and Guadalupe (*)
- 1970 HB-RF, vicinity of Santa Maria
- 1970 HB-RR, Sisquoc River at Sisquoc
- 1971 HB-SZ, South end of Santa Maria Airport
- 1971 HB-ST, Santa Maria River from Santa Maria to Guadalupe
- 1972 HB-UR, Los Angeles Basin to San Luis Obispo [shot at 1:80,000] (*)
- 1972 HB-TJ, trailer park south of Santa Maria
- 1972 HB-VC, VAFB main gate to Lompoc Village along Lompoc-Casmalia Road (*)
- 1973 HB-VM, Santa Maria (*)
- 1973 HB-VQ, Orcutt (*)
- 1973 HB-VT, Santa Maria Airport (*)
- 1973 HB-VV, Airox Mine at Shuman
- 1973 HB-WK, Orcutt (*)
- 1973 HB-WX, Santa Maria (*)
- 1973 HB-VU, sand dunes west of Guadalupe and town of Guadalupe (*)

C. San Luis Obispo County, color photos.

- 1970 (AP), Pismo Beach (#3), Oceano (#6), Black Lake Canyon (#7)

D. San Luis Obispo County, black and white photos.

- 1958 HA-CV, Pismo Beach
- 1959 HA-GG, Pismo Beach
- 1959 HA-GI, Morro Bay to San Luis Obispo
- 1960 HA-JG, Santa Maria to Pismo Beach (*)
- 1960 HD, Pismo Beach
- 1960 HE, Grover City
- 1961 HA-MN, Morro Bay
- 1962 HA-NO, Pismo Beach Park
- 1962 HA-NZ, Grover City
- 1962 HA-OC, Morro Bay to Santa Maria
- 1962 HA-ON, Pismo Beach area
- 1963 HA-TA, Arroyo Grande
- 1963 HA-TL, Arroyo Grande
- 1963 HA-VG, Vandenberg Village to Morro Bay
- 1964 HA-XG, Pismo Beach
- 1964 HA-YN, Morro Bay to Cambria
- 1965 HB-AX, Morro Bay highway
- 1965 HB-CQ, HB-DS Nipomo
- 1966 HB-HO, Oso Flaco Lake (*)
- 1966 HB-HW, Grover City and Arroyo Grande
- 1966 HB-GO, near Oceano, Dune Lakes and Pismo Beach (*)
- 1966 HB-JT, Arroyo Grande to Pismo Beach
- 1968 HB-LF, beach west of Guadalupe (*)
- 1968 HB-LA, Santa Maria River near Guadalupe (*)
- 1969 HB-NW, Santa Maria Refinery, north of Guadalupe (*)
- 1969 HB-NZ, Morro Bay to Toro Creek
- 1969 HB-PS, Morro Creek
- 1970 HB-QV, Arroyo Grande
- 1970 HB-RI, north of Nipomo (*)
- 1970 HB-RK, Black Lake Golf Course, Nipomo Mesa (*)
- 1971 HB-ST, Santa Maria River from Santa Maria to Guadalupe
- 1972 HB-TN, HB-TO Morro Bay
- 1972 HB-UA, City of Pismo Beach
- 1972 HB-UR, Los Angeles Basin to San Luis Obispo [shot at 1:80,000] (*)
- 1972 HB-US, Morro Bay
- 1972 HB-UU, Grover City and Pismo Beach
- 1972 HB-UV, Shell Beach
- 1973 HB-VL, Grover City and Pismo Beach (*)
- 1973 HB-VU, sand dunes west of Guadalupe and town of Guadalupe (*)

Appendix C. Additional potential sources for historical information and aerial photographs

These sources were not used in preparing this report but may contain additional historical information such as maps and aerial photographs that relate to the Santa Maria Basin.

- Santa Maria Valley Historical Society Museum, Santa Maria
- Lompoc Valley Historical Society
- San Luis Obispo County Historical Society Museum, San Luis Obispo
- Spence Collection (aerial photographs), Univ. California-Los Angeles
- Fairchild Collection (aerial photographs), Whittier College, Los Angeles County
- Vandenberg Air Force Base Audio-Visual Department Archives (aerial photographs)
- University of California-Berkeley Bancroft Library and Map and Imagery Library
- San Luis Obispo County Planning Department (aerial photographs of the Callender, Guadalupe and Mussel Rock Dune Sheets, shot in 1979, as stated in Envicom Corp., 1980)
- Santa Barbara County Planning Department (aerial photographs of the Callender, Guadalupe and Mussel Rock Dune Sheets, shot in 1979, as stated in Envicom Corp., 1980)
- California Department of Transportation (aerial photographs of roadways and adjacent areas)