II. GEOLOGY

The Arroyo Grande-Nipomo Mesa study area lies within a west-northwest-trending region of the southern central coastal area of California that forms a structural and geomorphic transition between the adjoining north-northwest-trending Coast Ranges Geomorphic Province to the northeast and the west-trending Transverse Ranges Geomorphic Province to the south (Figure 2). Nitchman (1988) and Namson and Davis (1990) have described this area as an active fold and thrust belt.

This region developed as the result of two temporally distinct tectonic regimes that operated during Cenozoic[1] time: (1) a late Oligocene to late Miocene phase characterized by right lateral strike-slip faulting, with concurrent subsidence of fault-bounded blocks forming marine depositional basins (Hall, 1978a, 1981; Blake et al., 1978; Stanley and Surdam, 1984), followed by late Miocene to early Pliocene continued strike-slip faulting, but with shortening between faults forming large-scale folds (Hall, 1978a, 1981; Stanley and Surdam, 1984); and (2) late Pliocene to Holocene north-northeast crustal shortening accommodated by displacement along a new generation of parallel west-northwest-striking reverse and thrust faults and local folding, and by uplift, subsidence, or tilting of intervening crustal blocks (Nitchman, 1988; Clark et al., 1994; Vittori et al., 1994; Lettis et al., 1994).[2]

Three geologic depositional basins--Pismo, Santa Maria, and Huasna Basins--created by these tectonic regimes underlie the study area (Figure 2). These basins contain thick, mostly marine sedimentary Tertiary deposits that unconformably lie on a basement of Jurassic (?)-Cretaceous Complex.

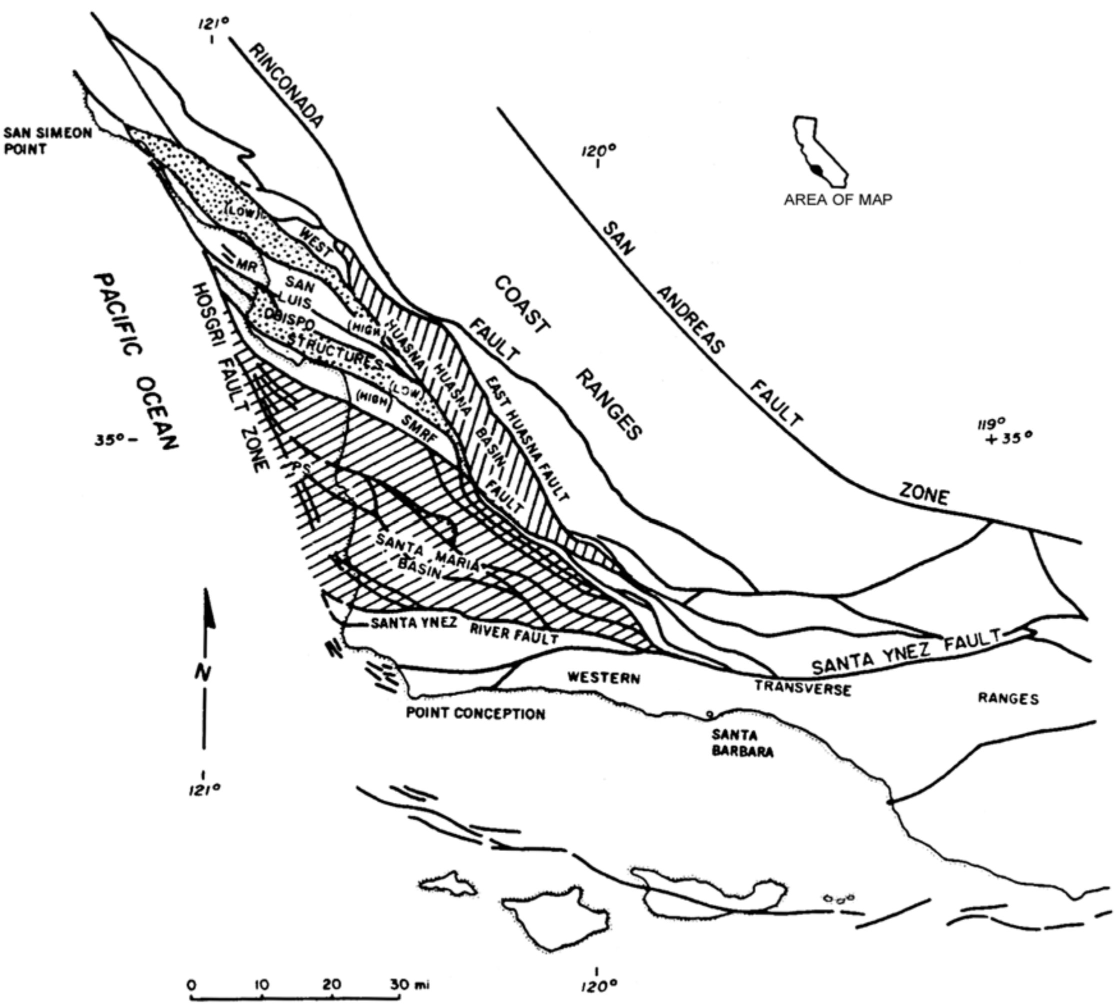
The triangularly shaped Santa Maria Basin opens toward the west and extends offshore to the Hosgri fault zone. The basin is bounded on the north by the San Rafael Mountains and is in contact with the mountains along the largely concealed system of the Santa Maria River-Foxen Canyon-Little Pine faults.[3] On the south, the basin is bounded by the Santa Ynez Mountains of the Transverse Ranges and is in contact with the mountains along the Santa Ynez River fault. The study area overlies only the portion of the basin within San Luis Obispo County.

[1] Geologic Time Scale is included in Appendix C.

[2] Luyendyk et al., 1980 and Hornafius, 1985 have alternatively explained basin development by localized extension resulting from Miocene and Pliocene clockwise rotation of the Transverse Ranges.

[3] The Foxen Canyon-Little Pine faults are in Santa Barbara County, outside the study area.

FIGURE 2 - GENERALIZED GEOLOGIC MAP OF THE SOUTHWESTERN COAST RANGES AND THE WESTERN TRANSVERSE RANGES, CALIFORNIA



Modified from Hall (1981). Figure depicts three structural regions: (1) San Luis Obispo structures, Pismo Basin (stippled pattern and intervening blank areas), consisting of horst-graben-like pull-apart structures between faults; (2) Huasna Basin (vertically ruled pattern), a pull-apart structure; and (3) Santa Maria Basin (diagonally ruled pattern), a pull-apart structure. Abbreviations are Morro Rock (MR), Point Sal (PS), and Santa Maria River Fault (SMRF).

The Pismo Basin, smaller than the Santa Maria, is flanked by strike-slip faults and trends west-northwest. The basin is bounded on the northeast by the West Huasna fault zone and on the southwest by the Santa Maria River fault (Hall, 1981; Heasler and Surdam, 1984; Stanley and Surdam, 1984). The basin extends west offshore to the Hosgri fault zone (Heasler and Surdam, 1984; Kablanow and Surdam, 1984; Clark et al., 1994). The study area overlies the southern portion of the basin.

The Huasna Basin lies between the West Huasna fault zone on the west and the East Huasna fault zone on the east (outside the study area) (Hall and Corbato, 1967; Heasler and Surdam, 1984; Kablanow and Surdam, 1984). The Huasna Basin underlies only three percent of the study area at the upper watershed of Tar Spring Creek and east of the West Huasna fault zone.

Rock Types

Rocks in the study area are predominantly marine sediments and pyroclastics, which range in age from Jurassic (?) to Holocene. The lithologic units are grouped into three categories: (1) basement complex, (2) volcanic rocks, and (3) sedimentary rocks. A generalized geologic map (Plate 2) depicts the geographic extent of the different exposed sediments and rocks. Three cross-sections (Plates 3-5) were constructed for this study from water well and oil well lithologs and electric logs (locations shown on Plate 2). Figure 3 presents a stratigraphic column of the Jurassic through Pleistocene formations found in each of the three geologic basins.

Basement Complex

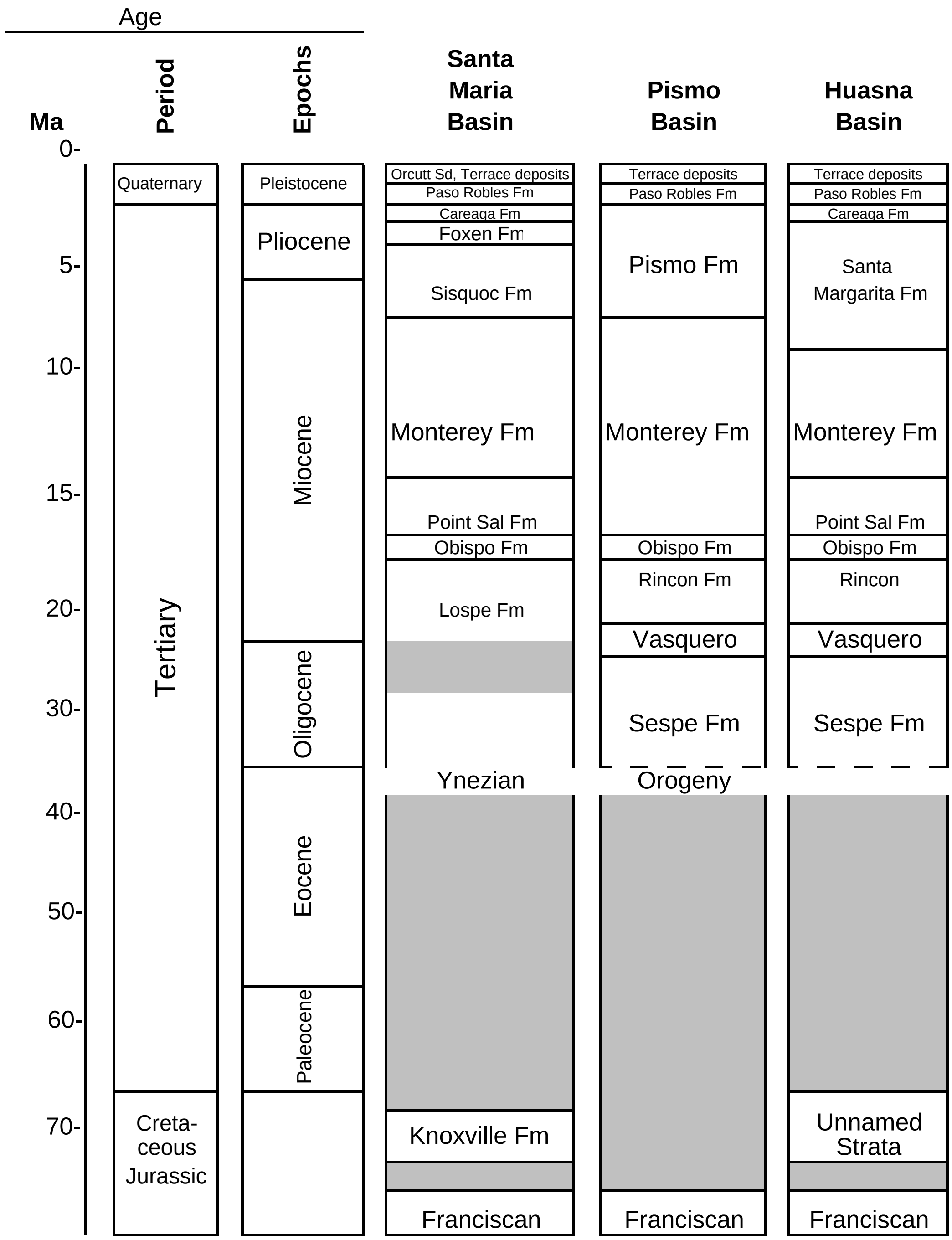
The oldest rocks found in the study area are those referred to as basement complex. These rocks include the Jurassic (?) Franciscan and Knoxville Formations and unnamed Cretaceous strata. The basement complex unconformably underlies the younger Tertiary and Quaternary deposits. Outcrops are found along an area between the West Huasna and Edna faults near Lopez Reservoir, along Los Berros Creek, and in the southern end of the Nipomo Valley near the junction of Highways 101 and 166. These rocks are grouped with Tertiary formations and shown as “TuKJf” on Plate 2.

The Franciscan Complex is notable for its vast extent throughout the Coast Ranges of California and its enigmatic character. The complex is a heterogeneous assemblage of both marine and continental metasedimentary materials. The predominant rock is graywacke, but shale, altered mafic volcanic rock, chert, and minor limestone are also present (Woodring and Bramlette, 1950; Worts, 1951; Hall and Corbato, 1967; Hall, 1973; Hanson, et al., 1994).

Volcanic Rocks

Early Miocene volcanic and pyroclastic rocks in the study area comprise: (1) tuff, altered tuff,

FIGURE 3 - STRATIGRAPHIC CORRELATION DIAGRAM*



*Stratigraphy shown is through only Pleistocene epoch. Diagram modified from Namson and Davis, 1990; Santa Maria Basin (Namson and Davis, 1990; Stanley and Surdam, 1984), Pismo Basin (Stanley and Surdam, 1984; Hall, 1973), and Huasna Basin (Hall and Corbato, 1967) and tuffaceous breccia of the Lospe Formation, (2) tuff and diabase within the Rincon Shale, and (3) tuffs of the largely pyroclastic Obispo Formation. The entire Tertiary volcanic wedge is nearly coincident with the West Huasna fault zone, Santa Maria River fault, and associated fault zones in the San Luis Obispo region (Hall, 1981). Within the study area, the pyroclastic Obispo Formation is exposed along the north side of Highway 101 near Picacho Hill and the northern and eastern highlands that flank the Nipomo Valley.

The Obispo Formation is an important source of water supply in the study area. Hall and Corbato (1967) and Hall (1973) reported the formation consists of resistant silicified or zeolotized tuff and fine- to coarse-grained crystalline tuff, interbedded with basaltic and andesitic lavas, calcareous siltstone or claystone and mudstone. Locally, the tuff is cut by dikes or sills. The interbedded lavas, dikes, and sills are black or dark green and contain as much as 40 percent montmorillonite[4] clay. The ashy matrix of the coarse-grained tuff is commonly altered to montmorillonite clay.

On the lithologs of well completion reports,[5] the Obispo Formation is described as either volcanic sandstone, volcanic shale--often black or gray--or volcanic rock, hard or soft, fractured or broken, with interbeds of hard or soft shale--often black--or clay, and sometimes with crystals of quartz and pyrite.

Sedimentary Rocks

The Santa Maria, Pismo, and Huasna Basins are largely filled with thick accumulations of mostly marine consolidated to unconsolidated sedimentary rocks of Cenozoic age.

The Oligocene through middle Pliocene undifferentiated consolidated sedimentary deposits include: coarse-grained nonmarine redbeds and poorly to well-consolidated, unlaminated to well-laminated, fine- to coarse-grained marine sandstones, siltstones, and mudstones; cherty, diatomaceous, and siliceous shales; dolomite; and diatomite. These deposits include the Monterey Formation, from which significant amounts of petroleum products are produced.

The consolidated Miocene Monterey Formation is an important water supply source in the study area. Hall and Corbato (1967) and Hall (1973) described the formation as consisting of silicified siltstone, claystone, and sandstone, well-bedded claystone or cherty or porcelaneous shale, and some dolomitic shale. The upper part of the formation grades into generally softer, less resistant siltstone and sandstone, with local claystone beds. The formation is commonly fractured and sheared. On the lithologs of well completion reports, the Monterey Formation is described as hard or soft Monterey shale or shale, usually fractured, with some clay.

Santa Margarita Formation. This late Miocene-Pliocene marine formation is found in the

[4]Montmorillonite clays are characterized by swelling in water and extreme colloidal behavior.
[5]Before 1991, these reports were called "Water Well Drillers Report."

Huasna Basin. The formation is a distinctive white-weathering massive bedded, poorly to moderately consolidated, coarse-grained arkosic sandstone and siltstone, with some siliceous claystone and diatomite (Hall and Corbato, 1967).

Pismo Formation. The Pismo Formation of the Pismo Basin consists of marine claystone, sandstone, or siltstone, poorly to moderately well consolidated, and friable nonbituminous and bituminous arkosic or quartz sandstone with some conglomerate, diatomite, dolomitic sandstone, and fossils (Hall, 1973; Stanley and Surdam, 1984; Nitchman, 1988; Hanson et al., 1994). The formation is made up of three depositional sequences of relatively conformable successions of genetically related strata bound by unconformities (Stanley and Surdam, 1984). Hall and Surdam (1967) divided the formation into five members: late Miocene-early Pliocene Miguelito--interbedded diatomaceous claystone and siltstone; late Miocene-early Pliocene Edna--bituminous and nonbituminous sandstone and minor conglomerate beds; late Pliocene Gragg--sandstone and conglomerate; late Pliocene Bellview--sandstone and mudstone; and late Pliocene Squire--sandstone and interbeds of silts and clays (Hall, 1973). Hall (1973) reported a maximum of 550 feet of the Squire Member in the Pismo Basin.

In the study area, extensive exposures of the Pismo Formation occur north of the Wilmar Avenue fault (Plate 2). The Squire Member also occurs at depth between the Santa Maria River fault and the Wilmar Avenue fault in the Pismo Basin (Plates 3-5). The Squire Member is about 550 feet thick under Tri-Cities Mesa and thins to about 50 feet southeasterly along the block between the Santa Maria River and Wilmar Avenue faults.

Plate 2 shows the Squire Member of the Pismo Formation as mapped by Hall (1973). However, Nitchman (1988) remapped part of the surface geology of the eastern San Luis Range. Nitchman differs in his separation of the Squire and Edna Members. He interprets the Squire Member to have been deposited as a thin veneer (up to about 100 feet thick) across the entire San Luis Range from Pismo Beach to Edna Valley, resulting in limited outcrops of the member as opposed to the extensively mapped exposure of Hall. Hall's 1973 Map Sheet 24 includes the statement: "No clear lithologic distinction between Edna and Squire Members in this area." This statement is included on Plate 2 of this study. Water well drillers' lithologic descriptions for wells drilled in the area mapped as the Edna Member by Hall (1973) are frequently similar to those of wells drilled in the area mapped as the Squire Member, making differentiation of the members inaccurate with these data alone. It is beyond the scope of this study to determine the exact extent of the Squire Member.

The Pismo Formation and in particular, the Squire Member, is an important source of groundwater in the study area. As described on the lithologs of well completion reports, the Squire Member generally consists of coarse- to fine-grained gray to blue to greenish sand with some gravel, interbedded by discontinuous beds of gray silt and clay, with sea shells being common. Nitchman (1988) attributed the distinctive greenish tint to the glauconite content. The Squire Member tends to be poorly consolidated in the upper part, becoming increasingly consolidated with depth. Hall (1973) noted that fracturing is common.

Careaga Formation. The late Pliocene shallow-water marine Careaga Formation of the Santa Maria Basin within the study area is typically described on the lithologs of well completion reports as unconsolidated to well consolidated, coarse- to fine-grained, blue to bluish-gray, white, gray, green, yellow, or brown to yellowish-brown sand, gravel, silty sand, silt, and clay. Sea shells or shell fragments in clays, sometimes in sands or gravels, are locally common, but the distinctive sand dollar fossils (*Dendraste, sp*.), reported in outcrops of the formation south of the study area (Dibblee, 1950; Woodring and Bramlette, 1950), were not identified on the lithologs. Occasional mention was made of Monterey shale chips. Where the formation was found to lie on the Sisquoc Formation, sands were described as black or dark brown and tarry. Within the study area, the Careaga Formation occurs only at depth. The formation is about 150 feet thick south of the Santa Maria River fault under Nipomo Mesa (Plate 5) and progressively thickens to about 700 feet toward the southwest part of the study area, along the Santa Maria River (Plate 4).

Paso Robles Formation. The Pliocene-Pleistocene (?) Paso Robles Formation[6] was deposited under a variety of conditions, ranging from fluvial and estuarine-lagoonal in inland areas to nearshore marine at the coast. Consequently, the formation exhibits a wide range of lithologic character and texture.

As described on the lithologs of well completion reports, the formation typically consists of unconsolidated to poorly consolidated to sometimes cemented beds or lenses of gray, brown, tan, white, blue, green, or yellow, coarse- to fine-grained gravel and clay, sand and clay, shale gravel, silt, clay, silty clay, and sandy clay, with some lenses of gravel and sand. The shale gravel is usually porcelaneous pebbles from the Monterey Formation. The nearshore marine deposits can be fossiliferous near the base of the formation.

In the Santa Maria Basin, the Paso Robles Formation lies conformably upon the Careaga Formation; where the Careaga Formation is absent, the formation lies unconformably upon undifferentiated Tertiary rocks or basement complex. In the Pismo Basin, the Paso Robles Formation lies unconformably upon rocks of late Pliocene age or upon many of the older rock units in the area (Hall, 1973).

Where the Paso Robles Formation overlies the Careaga Formation or the Squire Member of the Pismo Formation, the contact is often difficult to distinguish on the basis of borehole litholog descriptions. Woodring and Bramlette (1950) identified the base of the Paso Robles Formation by the occurrence of characteristic, but discontinuous, 50- to 100-foot beds of clay and freshwater limestone; where these were absent, they used conglomerate as the base, but considered the base not well controlled; and, where there was neither clay nor conglomerate, they considered the base doubtful and arbitrary. The criteria for identifying the base established by Woodring and Bramlette (1950) was used in this study, along with cross-sections and reports by

[6]The type region of the Paso Robles Formation is in the Salinas Valley. The usage of the formation name has been extended to nonmarine rocks of the same general stratigraphic position in the Santa Maria Basin by Woodring and Bramlette (1950) and to rocks in the Arroyo Grande 15' Quadrangle by Hall (1973).

Worts (1951), California Department of Water Resources (1958, 1970), Cleath & Associates (1996a), and Hanson et al. (1994).

Thickness of the formation within the study area varies considerably between the Pismo Basin and the Santa Maria Basin and within the basins themselves. In the Pismo Basin, the formation ranges from about 40 feet near Pismo Creek to about 250 feet near Arroyo Grande Creek and the Santa Maria River fault (Plate 3). In the Santa Maria Basin, the formation progressively thickens from about 200 feet along the northwestern margin of the basin (Plate 5) to about 700 feet at the Santa Maria River (Plate 4).

Individual beds in the Paso Robles Formation are laterally discontinuous and difficult to correlate between wells. Worts (1951, p. 32) commented that "The logs show that, . . . there is no correlation possible between beds from place to place in the formation, and that the deposits are lenticular." The abrupt lateral discontinuity of the beds within the formation is typical of sediments deposited in a coastal environment under conditions of rising and falling sea levels (Swift and Palmer, 1978).

Using both lithologs and electric logs of water and oil wells, the Department (1970, cross-sections A-A′ through D-D′) identified fairly continuous clayey silt to silty clay beds within the Paso Robles Formation along the coast and inland. The coastal cross-section A-A′ (Plate 3) prepared for this study includes the correlations from the 1970 investigation.

Orcutt Formation. Worts (1951) reported that the late Pleistocene, essentially nonmarine, Orcutt Formation may be present beneath the Santa Maria Valley within the study area, where the lower member of the alluvium is missing. Based on the lithologs of the well completion reports, Worts (1951) describes the formation as consisting of an upper fine-grained sand member and a lower coarse-grained member. The upper member consists of loosely compacted, massive, medium-grained, reddish-brown sand, with lenses of clay; the lower member consists of loosely compacted, coarse, gray to white gravel and sand. Where exposed, the thickness of the formation is about 100 feet (Hall, 1978b).

Older Alluvium and Terrace Deposits. Middle to late Pleistocene older alluvium is found on the floor of Nipomo Valley, lying unconformably upon undifferentiated Tertiary rocks, Miocene Obispo pyroclastics, or basement complex. The older alluvium consists primarily of brown to reddish-brown, red, yellow, and gray gravel, boulders, sand, and other coarse detrital material of local origin imbedded in a dense matrix of silt and clay, intermixed to varying degrees, crudely stratified, poorly consolidated, only locally cemented. Thickness of these deposits ranges from about 10 to 90 feet.

Middle to late Pleistocene terrace deposits consist of unconsolidated boulders, cobbles, pebbles, sand, silt, and clay. These deposits are remnants of abandoned marine wave-cut platforms or older fluvial deposits, subsequently uplifted and preserved as terraces. Marine terrace deposits are one foot to 15 feet thick (Hall, 1973), well to moderately sorted, typically subrounded to rounded, and consist of Franciscan Complex, Obispo, Monterey, and Pismo Formation lithologies (Hanson et al., 1994). Marine terraces are exposed along the coast at Pismo Beach and buried beneath a thick mantle of sand dunes and alluvium in the Arroyo Grande and Nipomo Mesa areas of the San Luis Range. Uplifted fluvial terrace deposits are preserved along the north side of Arroyo Grande Creek.

Holocene Alluvium. Alluvium underlies the floor of Arroyo Grande Plain and the valley bottoms of Arroyo Grande and Pismo Creeks, extending in tongues up the valleys of their tributaries and the floor of Santa Maria Plain. It consists of unconsolidated, poorly bedded, poorly sorted to sorted sand, gravel, silt, and clay, with cobbles and boulders.

Worts (1951) divided the alluvium of the Santa Maria Valley into an upper fine-grained member and a lower coarse-grained member. He also considered the lower member to be missing from the Oso Flaco District[7] of the Santa Maria Plain that is within San Luis Obispo County. The Department (1970) divided the alluvium of the Pismo Creek area and the Arroyo Grande Creek and Plain into upper fine-grained and lower coarse-grained zones. However, for this investigation, the alluvium is considered a single unit.

In the Pismo Basin, the alluvium overlies the Paso Robles Formation on the Arroyo Grande Plain, and it overlies older sedimentary or basement complex along Arroyo Grande Valley and Pismo Creek and their tributaries. The alluvium on the Arroyo Grande Plain ranges from about 130 feet thick near the confluence of Los Berros Creek with Arroyo Grande Creek to about 40 feet at the coast. Near Pismo Beach, the alluvium at the coast is about 50 feet thick. In Arroyo Grande Valley, a geophysical survey conducted by Goss and Reed (1969, p. 72) found the thickness of the alluvium normally ranged between 75 and 100 feet, with a maximum thickness of about 175 feet just above the confluence of Tar Spring and Arroyo Grande Creeks. Along tributaries of Arroyo Grande Creek, the alluvium ranges from a thickness of about 80 feet to a thin veneer in the upper reaches.

In the Huasna Basin along upper Tar Spring Creek, the alluvium, which overlies the Santa Margarita Formation, was found to be about 80 feet thick.

In the Santa Maria Basin, alluvium overlies the Orcutt Formation, if present, or the Paso Robles Formation throughout most of the Santa Maria Plain. The alluvium was found to be about 130 feet thick near Highway 101 at the county line, gradually thickening toward the coast where, along the Santa Maria River, it is about 230 feet thick. However, in the Oso Flaco District, the absence of Worts's lower member results in thinning of the alluvial deposits to about 60 feet at Oso Flaco Lake, a former outlet of the Santa Maria River. The only alluvium found in Nipomo Mesa is in Black Lake Canyon, where it is about 30 feet thick.

[7] Oso Flaco District is local nomenclature for the northern wedge-shaped part of the alluvial plain of the Santa Maria Valley lying northwest of the Santa Maria River in San Luis Obispo County (Worts, 1951, p. 19).

Clay beds within the alluvium were found to range in thickness from one foot to 30 feet in the Arroyo Grande Plain and from one foot to 170 feet (as reported on the litholog of well completion reports) in the Santa Maria Plain. As with the Paso Robles Formation, the individual beds in the alluvium are laterally discontinuous and difficult to correlate between wells. In 1951, Worts noted that individual clay beds within the alluvium are relatively extensive, especially near the surface. However, he also reported: “from the data at hand it cannot be definitively concluded that individual clay beds extend as one continuous unit entirely across the west end of the valley” (1951, p. 38).

Using both lithologs and electric logs of water and oil wells, the Department (1970, cross-sections A-A′ through D-D′) identified fairly continuous clayey silt to silty clay beds within the alluvium along the coast and inland. The coastal cross-section prepared for this study as cross-section A-A′ (Plate 3) includes the correlations from the 1970 investigation.

Dune Sand. Both late Pleistocene and Holocene eolian-deposited dune sand is within the study area (Plate 2). The older dune sands form Tri-Cities Mesa and Nipomo Mesa and may range in age from 40,000 to 120,000 years (The Morro Group, 1990). Holocene dune sands occur along a coastal belt up to about 1 3/4 miles from Pismo Beach south into Santa Barbara County. The dune sands overlie either alluvium or the Paso Robles Formation.

The Nipomo Mesa triangular lobe of older dune sands is more than four miles wide and extends inland more than 12 miles to a little east of Highway 101. The dunes hardly resemble dunes, but are a disorganized assemblage of rounded hillocks and hollows.

The dune sands consist of coarse- to fine-grained, well-rounded, massive sand with some silt and clay. The sands are largely quartz and are loosely to slightly compacted. The older dune sands are anchored by vegetation and have a well-developed soil mantle. Also, iron oxides may locally cement the dune surface into a crust and stain the sand dark reddish-brown. Lithologs of water wells indicate that the dune sands may contain perching layers of clay.

The older dunes have a maximum thickness of about 60 feet on the Tri-Cities Mesa and about 300 feet near the southern edge of Nipomo Mesa. The younger dunes along the coast are generally less than 50 feet thick, but may reach about 100 feet thick.

Structure

As mentioned at the beginning of the chapter, the region within which the study area lies is structurally and geomorphically distinct from surrounding areas in southern central coastal California. The period of deformation has been so recent that the current topography reflects the structure. The dominant structural features in the region are the Santa Maria Valley, Pismo, and

Huasna synclines, west-northwest-trending neotectonic[8] San Luis/Pismo and Santa Maria Valley structural blocks, and a series of faults.

Synclines

The Santa Maria Valley syncline is an asymmetrical fold that developed within the northern part of the Santa Maria Basin. The syncline is evident only from subsurface data. The northern limb of the syncline, which lies within the study area, is a gentle subsurface fold and is bounded by the Santa Maria River fault. The axial trace of the syncline lies about six miles south of the county line, not along the middle of Santa Maria Valley. The Santa Maria syncline and its margins are cut by numerous faults of middle and late Cenozoic age.

The Pismo syncline is the dominant structural element of the San Luis Range. Field evidence gathered by Nitchman (1988) indicates that the syncline is an open, doubly plunging syncline composed of numerous small folds and subparallel axial traces. The syncline is bounded on the northeast and southwest by the inactive Edna and San Miguelito faults that juxtapose Mesozoic basement rocks against Tertiary strata within the syncline (Hall, 1973; Hall et al., 1979; Nitchman, 1988). The syncline is exposed as a result of uplift associated with the San Luis/Pismo structural block during late Quaternary times.

The Huasna syncline is a pair of doubly plunging en echelon synclines with an associated anticline; subsidiary folds are along the limbs of the larger fold (Hall and Corbato, 1967). The syncline is bounded on the west by the West Huasna fault and on the east by the East Huasna fault (outside the study area). A small portion of the western limb is within the study area.

Structural Blocks

The most significant neotectonic structural features in the area are the San Luis/Pismo and Santa Maria Valley structural blocks (Figure 4 and Plate 2). The structural blocks were defined on the basis of relative differences in uplift/subsidence rates, surface morphology, separation by zones of reverse faulting, and termination against the more northerly-trending Hosgri fault zone (Weber et al., 1987). Topographic uplands and lowlands coincide with the structural blocks.

The San Luis/Pismo block consists of the San Luis Range, including the Pismo syncline, and associated boundary and internal faults. The block is undergoing uplift as a relatively rigid crustal block with little or no internal deformation (Pacific Gas and Electric Company, 1988; Lettis et al., 1994). The block is bordered on the southwest by a diffuse zone of late Quaternary west-northwest-trending, northeast-dipping reverse faults (Wilmar Avenue and Oceano faults) and monoclines that separate it from the subsiding Santa Maria Valley structural block. The northeast side of the block is bounded by the west-northwest-trending, southwest-dipping

[8]Post Miocene structures

FIGURE 4 - MAP OF STRUCTURAL BLOCKS IN THE SOUTH-CENTRAL CALIFORNIA COAST REGION

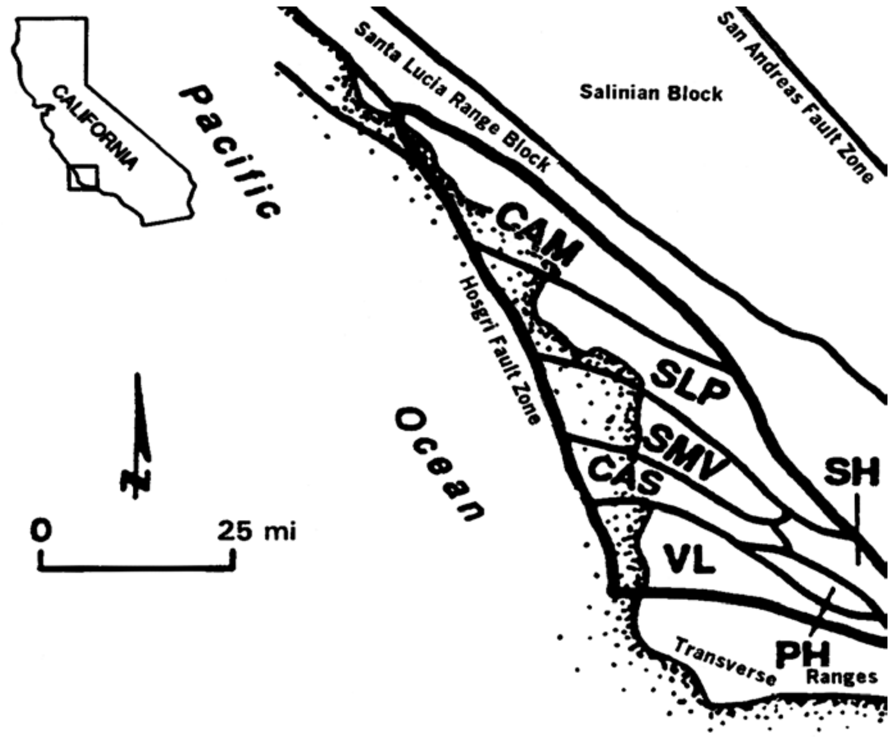


Figure simplified from Lettis, et al., 1994. Abbreviations are: CAM = Cambria block, SLP = San Luis/Pismo block, SMV = Santa Maria Valley block, CAS = Casmalia block, VL = Vandenberg/Lompoc block, PH = Purisima Hills block, SH = Solomon Hills block.

comparatively discrete Los Osos fault zone (Hall et al., 1979; Mezger et al., 1987; Nitchman, 1988; Nitchman and Slemmons, 1994). On the west, the block is bordered by the Hosgri fault zone and on the southeast, by the West Huasna fault zone. Both Pismo and Arroyo Grande Creeks established their channels prior to uplift of the block (Lettis and Hall, 1994).

The Santa Maria Valley structural block, with its substantial Quaternary sediments and lack of emergent marine terraces, has been either a subsiding or static block since at least middle Pleistocene (Lettis et al., 1994). Within the Santa Maria structural block, convergence and crustal shortening resulted in the deformation of Tertiary and Quaternary deposits and, in late Quaternary, tilting of the structural block, subsidence, and continued sedimentation derived from adjacent uplifted structural blocks (Nitchman, 1988; Lettis et al., 1994). The block is bounded on the northeast by the San Luis/Pismo block. On the west, the block is bordered by the Hosgri fault zone and on the south, the block is bounded by the blocks shown on Figure 4.

Faults

Faults within the study area generally strike west-northwest and often intersect the coast at acute angles, extending offshore. Within the study area, two types of faults share this trend: (1) largely inactive, right strike-slip faults; and (2) potentially active reverse and thrust faults. Locations of the faults within the study area are shown on Plate 2.

Santa Maria River Fault. Hall (1978a, 1981, 1982) proposed the existence of the Santa Maria River fault to explain (1) the southward truncation of a thick section of early Miocene pyroclastics and tuffaceous siltstone or claystone, (2) the northward truncation of late Miocene and early Pliocene diatomaceous mudstone and siltstone associated with the Santa Maria Basin, (3) an up to the northeast vertical offset of Franciscan basement, and (4) other stratigraphic contrasts evident from subsurface data.[9] The fault appears to have played a major role in the formation of the Santa Maria Basin (Hall, 1978a, 1981, 1982). Hall (1982) mapped the subsurface location of the fault. The fault is shown at the surface only near Suey Ranch in Santa Barbara County by Dibblee (1994). The youngest fault activity along this fault may have occurred as recently as late Quaternary (Buchanan-Banks, et al., 1978; Hall, 1978a; and U. S. Geological Survey, 1981).

The fault trends west-northwest across the study area, extending offshore near Oceano and merging with the offshore north-striking Hosgri fault zone. At the coast, the location of the fault is constrained by its intersection with the Madonna Construction Company's Oceano 1 oil well at a depth of 1,000 feet (cross-section A-A′, Plate 3). Between Highway 1 and about one mile east of Zenon Way, the fault is constrained by water wells showing significant differences in water levels (Chapter V). To the southeast, from near the head of Black Lake Canyon to near Division Street, Hanson, et al. (1994) postulated a zone of subsurface steps or warps in the top of the bedrock, rather than a single fault. From the coast to its exposure at Suey Ranch, the fault is constrained by significant lithologic differences on opposite sides of the fault. Pismo Basin stratigraphy is displayed northeast of the fault and Santa Maria Basin stratigraphy is displayed southwest of the fault (discussed earlier in this chapter).

Cross-section A-A′ (Plate 3) shows the Santa Maria River fault coinciding with the Oceano fault at the coast and about 90 feet of vertical offset of the base of the Squire Member/Pismo Formation and the base of the Careaga Formation. The section also shows the juxtaposition of Franciscan basement rocks against the Careaga Formation and undifferentiated Tertiary sediments of the Santa Maria Basin. It is not known how much, if any, of the offset across the faults may be attributed to activity of the Santa Maria River fault. Cross-section B-B′ (Plate 4) shows vertical offset of about 250 feet of the base of the Squire Member/Pismo Formation and

[9] The Santa Maria River fault is coincident with Namson and Davis's (1990) Point San Luis anticline. They interpreted a large Franciscan cored structural high along the northeast margin of the Santa Maria Basin as a regional anticline associated with a ramp in a south-verging blind thrust at depth.

the base of the Careaga Formation and Franciscan Complex (?) juxtaposed to the Careaga Formation. Cross-section C-C′ (Plate 5) shows vertical offset of about 180 feet of the base of the Squire Member/Pismo Formation and the base of the Careaga Formation and the juxtaposition of the Knoxville Formation (?) to the Careaga Formation.

West Huasna Fault Zone. This major northwest-trending fault zone transects the northeastern edge of the study area, crossing the Arroyo Grande Valley approximately a mile downstream from Lopez Dam and bounding Pismo and Huasna Basins. Hall (1973) found the fault zone to consist of low- to high-angle reverse faults cut by a younger set of nearly vertical faults. Because of the complexity and differing styles of faulting observed within the fault zone, the predominant sense of displacement is obscured, and movement along the fault zone, as inferred from late Tertiary tectonic conditions and other indirect evidence, is believed to be largely right strike-slip in nature (Nitchman, 1988). Buchanan-Banks et al. (1978) reported that the fault is believed to offset late Pleistocene deposits locally.

Edna Fault. The west-northwest-trending Edna fault zone forms the northern boundary of the Pismo syncline (Hall, 1973). Nitchman (1988) defined it as a high-angle right strike-slip fault that juxtaposes Miocene and Pliocene strata against Franciscan basement rocks. Lettis et al. (1994) interpreted the fault as a zone of high-angle, down-to-the-southwest normal faulting. The Edna fault is considered by Lettis and Hall (1994) to be the southwestern part of the Los Osos fault zone. Hall (1973) stated that the Edna fault cuts late Pliocene and Pleistocene strata. Detailed bedrock mapping and trenching conducted by Lettis et al. (1994) confirmed that the Edna fault has had no late Quaternary movement.

Pismo Fault. Hall (1973) interpreted the fault as a west-northwest trending, high-angle fault with predominantly right, normal strike-slip displacement, juxtaposing Miocene and Pliocene volcanic and sedimentary rocks against Franciscan basement rocks on the southwest. The fault bounds the southwestern margin of the Pismo syncline. It has not been active during the late Quaternary (Lettis et al., 1994). In 1978 and 1981, Hall showed the Pismo fault as the southern extent of the San Miguelito fault. Nitchman (1988) also interpreted the Pismo fault, as mapped by Hall in 1973, as the possible southern extent of the San Miguelito fault.

Wilmar Avenue Fault. The west-northwest-striking, northeast-dipping late Quaternary reverse Wilmar Avenue fault was investigated and described by Nitchman (1988). The fault is exposed only at a sea cliff in Pismo Beach and extends at least to Arroyo Grande. The range front fault is characterized by two distinct structural segments: a western segment that exhibits block uplift with little tilting or folding and an eastern segment that forms a monoclinal fold in the upper Pliocene strata (Nitchman, 1988). The fault extends offshore, veering slightly to the west for at least three miles (Nitchman, 1988; Pacific Gas and Electric Company, 1988; Lettis et al., 1994).

Cross-section A-A′ (Plate 3) intersects the western segment of the fault, and cross-section B-B′ (Plate 4) intersects the eastern segment.

The fault may extend south of Arroyo Grande along the front of the San Luis Range and the northeast margin of Nipomo Mesa to the northern part of Santa Maria Valley, where it may truncate against the Santa Maria River fault. Along this segment, the fault is inferred by the alignment of subtle geomorphic and geologic features, including a straight segment of Nipomo Creek. Cross-section C-C′ (Plate 5) illustrates the juxtaposition of the Miocene Monterey Formation with the Paso Robles Formation and Squire Member/Pismo Formation across this postulated extension of the Wilmar Avenue fault.

Oceano Fault. The northwest-trending, northeast-dipping late Quaternary reverse Oceano fault underlies Nipomo Mesa and extends offshore south of Oceano. Within the onshore segment, the fault is not geomorphically expressed because of the relatively thick alluvial and eolian cover. The fault was first recognized by the Department in a 1970 cross-section (A-A′) along the coast, and later by Pacific Gas and Electric Company (1988) based on interpretation of onshore and offshore seismic reflection and oil well data. It displaces Franciscan Complex basement and overlying Tertiary strata. A southeasterly decrease in vertical separation suggests that the fault probably dies out in the northern Santa Maria Valley near the Santa Maria River (Lettis et al., 1994). The fault may have been active in the past 500,000 years (Pacific Gas and Electric Company, 1988).

Cross-sections B-B′ and C-C′ illustrate the vertical displacement across the Oceano fault, which offsets the base of the Careaga Formation about 200 feet (Plate 4) and about 250 feet (Plate 5) across the fault under central Nipomo Mesa. The vertical separation of the upper contact of the Franciscan Complex is about 500 feet across the fault. At the coast, the Oceano fault coincides with the Santa Maria River fault. As noted earlier, how much of the about 90 feet of vertical offset that can be attributed solely to activity of the Oceano fault is not known.

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