UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GEOLOGY AND PALEONTOLOGY OF THE TESLA FORMATION, ALAMEDA AND SAN JOAQUIN COUNTIES, CENTRAL CALIFORNIA

By

C. K. THROCKMORTON

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[1] U.S. Geological Survey, Denver, Colorado

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GEOLOGY AND PALEONTOLOGY OF THE TESLA FORMATION, ALAMEDA AND SAN JUAQUIN COUNTIES, CENTRAL CALIFORNIA

By

C.K. Throckmorton

ABSTRACT

The Tesla area, which includes the type section of the Tesla Formation, encompasses about 30 km^2 in the eastern part of the central Diablo Range. The geology of the Tesla area is typical of the Coast Ranges of California. Rock formations ranging in age from Jurassic to upper Miocene are involved in a complex of folds and faults. Three major faults divide the Tesla area into four structural blocks which differ in their style and complexity of structural deformation. All three faults were active during the Neogene, but have shown no Holocene activity. The oldest rocks, the Jurassic and Cretaceous Franciscan assemblage, consist primarily of graywackes, shales, and cherts and are faulted against mudstones and shales of the upper Jurassic Knoxville and Cretaceous Panoche Formations. Overlying and in fault contact with the Knoxville are marine shales, sandstones, and siltstones of the Panoche, which is conformably overlain by marine shales and sandstones of the upper Cretaceous Moreno Formation. Overlying the Moreno are sandstones of the middle Eocene, Paleocene?, and possibly upper Cretaceous Tesla Formation, the focus of this study. The Miocene Cierbo Sandstone unconformably overlies the Tesla and locally the formations are in fault contact. Non-marine sandstones and siltstones of the upper Miocene Neroly Formation overlie the Cierbo.

The 675-m thick Tesla is divided into lower and upper sandstone members, and two lithologic facies are recognizable within each member. The lower sandstone member consists mostly of paralic facies rocks with a tongue of shallow-marine facies occurring near the top of the member. The upper sandstone member consists mostly of a middle shoreface facies. A paralic facies is also recognizable in the uppermost part of the upper sandstone member. Faunal and sedimentological evidence indicates that the paralic facies strata were deposited in brackish water or marine waters near a fresh-water influx. Possible specific environments include: delta topset, delta front, bay, estuarine, lagoonal, upper shoreface, and fluvial. Lithology and molluscan faunas suggest deposition of the shallow-marine facies on the outer edge of a delta. Deposition of the middle shoreface facies strata occurred on a shallow-marine shelf. When the Tesla strata are regarded as a whole, it is clear that deposition occurred in different environments marginal to a land mass, and resulted in both paralic and normal marine deposits.

Molluscan faunas from the basal part of the Tesla (paralic facies) are suggestive of a Late Cretaceous or Paleocene age. Mollusks from the shallow-marine facies in the lower sandstone member suggest a "Capay" (early Eocene) or "Domengine" age (late early Eocene through early middle Eocene), and (possibly) "Meganos" (late Paleocene to early Eocene) age. Mollusks from the upper sandstone member (middle shoreface facies) indicate a late early Eocene

through early middle Eocene ("Domengine") age. Mollusks from the paralic facies in the uppermost part of the upper sandstone member are "Domengine" to (possibly) late Eocene age.

INTRODUCTION

The Tesla area is located in Alameda and San Joaquin counties, between the cities of Livermore and Tracy (fig. 1). The area encompasses about 30 km^2 in the eastern part of the central Diablo Range, on the western edge of the San Joaquin Valley, California. Exposures of the Tesla are generally poor; soil and landslides cover much of the formation. Bedding is fairly well exposed in the lower half of the section measured along Tesla Road, but even here exposures are limited to 2-10 m along strike. The upper half of the measured section at Tesla Road is mostly covered by landslides. A road leading into the Tesla mine provides the best exposures in the Corral Hollow reference section. Above the Tesla mine, strata are traceable for tens of meters along strike. A 6-m-thick white sandstone bed in these strata is traceable for 0.5 km to the west and 0.5 km to the east, almost to Tesla Road. State Highway 50 provides access to Tesla Road, which bisects the Tesla area and provides in its roadcuts many of the best rock exposures in the area.

The Tesla Formation and the Tesla area derive their names from the abandoned mining town of Tesla, located in the southwestern part of the mapped area (pl. 1). This area provides the best exposures of the Tesla Formation, which can be traced as a band for about 8 km along Corral Hollow. Mapping was done on a 1:12,000 scale enlargement of part of the Midway, California 7.5 minute U.S. Geological Survey topographic map. Aerial photographs were used to augment field mapping. Thin sections were examined to provide lithologic details of the formations.

Previous Work

Until Huey's work (1940, 1948), little work had been done in the Tesla area. Whitney (1865) briefly discussed the area in his monograph on California; other workers, including Turner (1891, 1898) and Weaver (1909) studied the upper Tertiary formations north of Corral Hollow. Anderson and Pack (1915), in their study of the oil resources of the northwestern San Joaquin Valley, published a geologic sketch map of the region and described the formations present. Vickery (1925a, 1925b) presented a structural analysis of the Livermore region, including the Tesla area. Publications by Clark (1935) and Taff (1935) dealt with large tracts of the Diablo Range, and only incidentally made reference to the Tesla area. Huey (1948) provided the first detailed study of the Tesla Formation in the Tesla area. Stewart (1949) and Morris (1962) correlated the Tesla Formation in the Tesla area with other California Tertiary strata. Collins (1950) mapped the Tesla Formation in the Orestimba quadrangle, about 65 km southeast of Tesla (fig. 1). Briggs (1953) recognized Tesla(?) Formation in the Laguna Seca area, about 130 km southeast of Tesla (fig. 1). Raymond (1970, 1973), Herd and Helley (1977), and Herd (1977) mapped active faults whose traces extend close to the boundaries of the study area. Dibblee (1980; Dibblee and Darrow, 1981) prepared a reconnaissance geologic map of the Midway quadrangle. Nilsen (1972) published a reconnaissance landslide map that covers the western part of the study area.

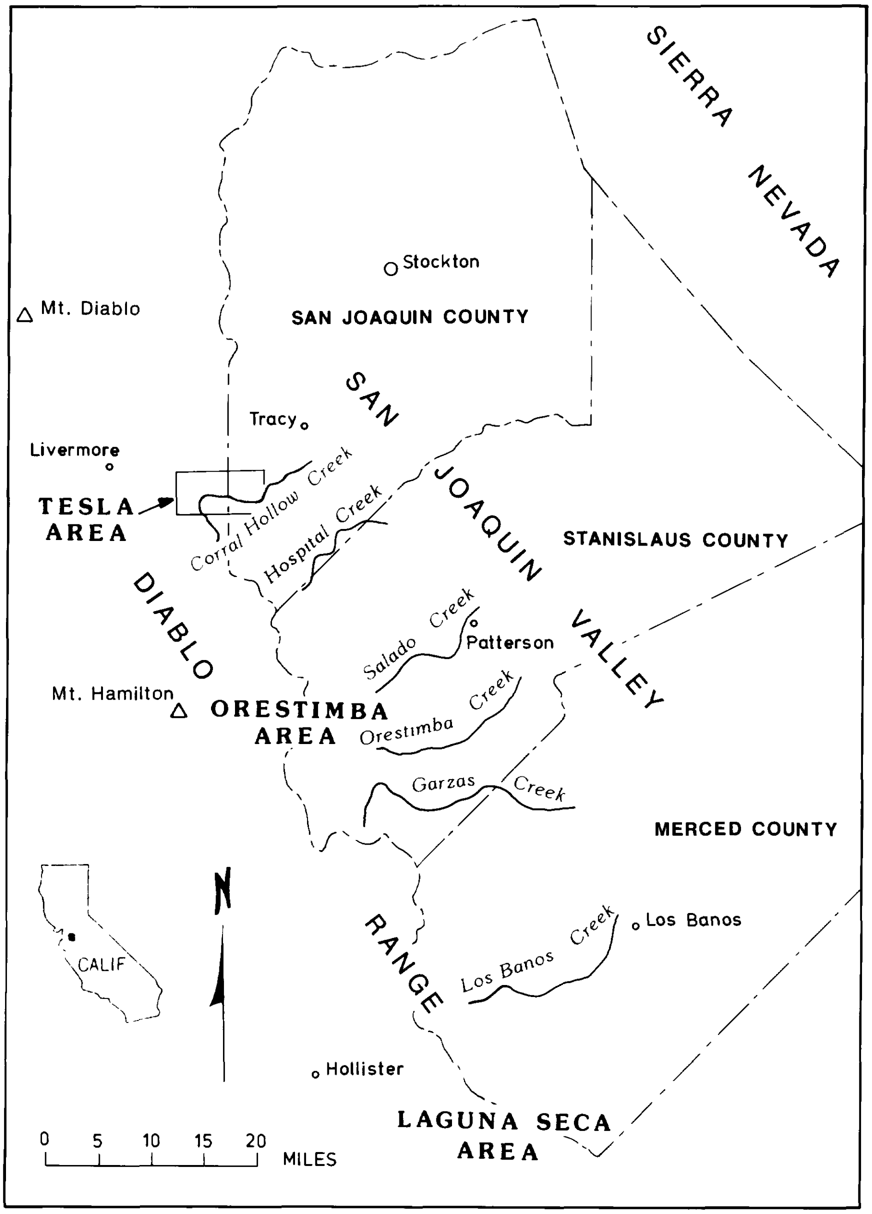


Figure 1. Location map of the Tesla area, central California (modified from Bishop, 1970).

STRATIGRAPHY

Introduction

Although the present study centers on the paleontology and stratigraphy of the Tesla Formation, superjacent and subjacent strata were studied in order to determine the local depositional and structural setting through time and the role of the Tesla Formation in the geologic history of the area. The formations present in the study area range in age from Jurassic to Holocene, and consist of predominantly sedimentary rocks of marine origin. A generalized columnar section is presented in figure 2.

Franciscan Assemblage

The structurally lowest rocks in the study area belong to the Franciscan assemblage, which is in fault contact with rocks of the coeval (in part) Great Valley sequence. Early stratigraphic studies (Lawson, 1895; Taliaferro, 1943) failed to recognize that the Franciscan is not a formation (sensu stricto), but rather a series of sedimentary and volcanic units of varying age tectonically juxtaposed and commonly separated by melange zones. Throughout the Coast Ranges, the Franciscan consists predominantly of graywacke and smaller volumes of shale, mudstone, greenstone, chert, and minor limestone (Bailey and others, 1964). Much of the Franciscan is melange consisting of sheared mudstone and interbedded graywacke which contain blocks of altered mafic volcanic rocks, chert, and metamorphic rocks, including high grade rocks of the blueschist and eclogite facies.

Franciscan rocks are exposed in the southern part of the study area (pl. 1) and extend for tens of kilometers to the west and hundreds of kilometers to the south in the Diablo Range. In the study area, the Tesla fault separates the Franciscan from the Upper Jurassic Knoxville and Cretaceous Panoche Formations. Minimum thickness of the Franciscan in the study area is 800 m. The base of the Franciscan is not exposed.

Graywacke is the predominant Franciscan lithology, while poorly exposed mudstone and shale are subordinate. Chert is common, and blueschist knockers are rare. The graywacke is characteristically gray, medium grained, massive, and dense. Weathered colors vary from gray-brown to brown. Shale partings are rarely present, defining the bedding. Quartz is the dominant mineral. Feldspar is common to abundant. Mafic grains, including magnetite, biotite, and hornblende, vary between about 1 percent and about 5 percent of the grains. Chert, quartz, and shale(?) rock fragments comprise several percent of the rock.

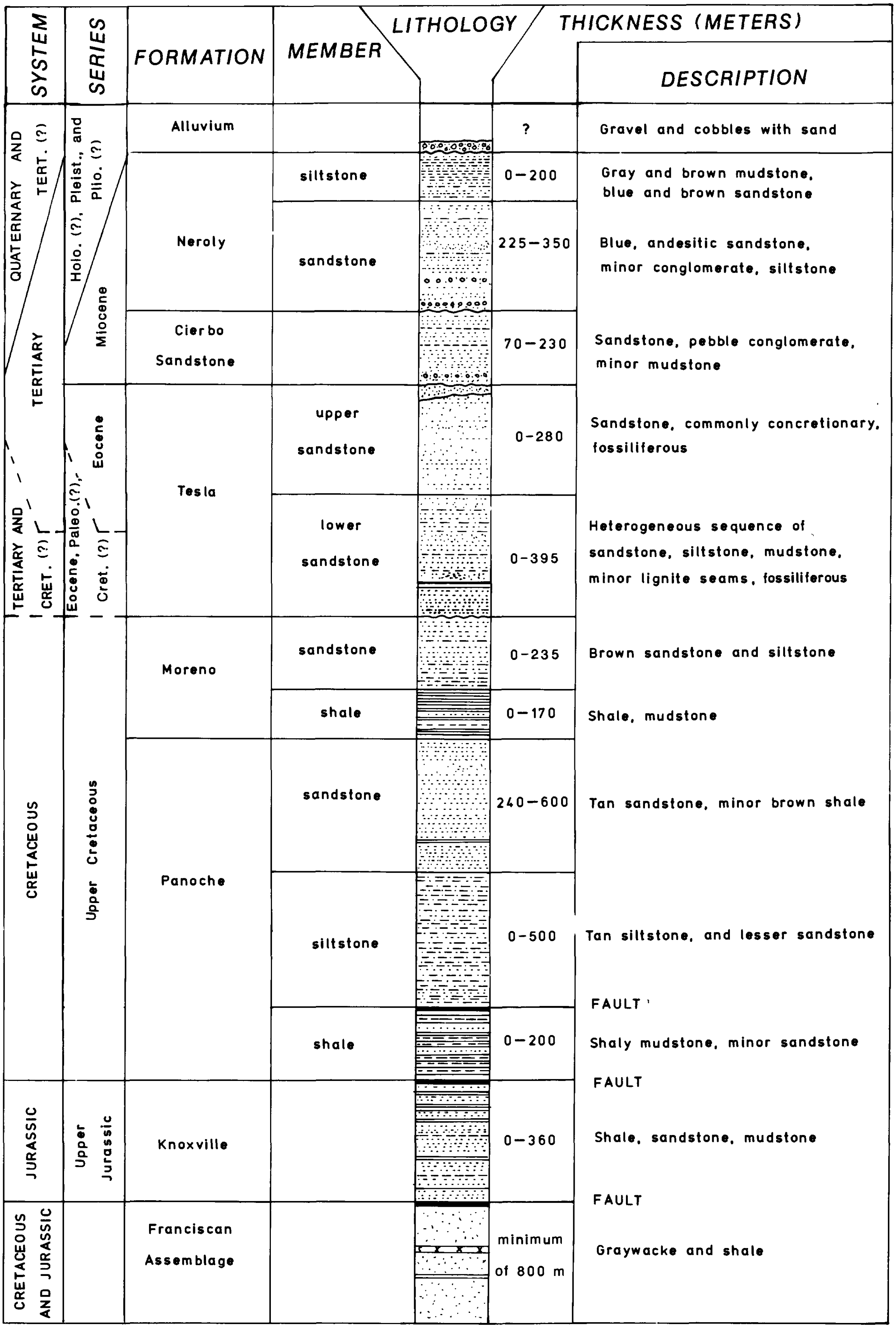


Figure 2. Composite stratigraphic column of the Tesla area.

Thinly bedded, dark green and brown shale and mudstone commonly occur in thick sequences. Thin shale beds are also interbedded with graywacke and chert. Red, green, dark brown, and white resistant chert lenses and thin beds are easily traceable. Sequences of chert beds up to 10 m thick are common throughout the formation.

Fauna and Age

The overall age of Franciscan strata ranges from Late Jurassic to Eocene (Blake and Jones, 1974; Evitt and Pierce, 1975). The author found Cretaceous foraminifers in the Franciscan at locality 513, indicating that some Franciscan strata in the Tesla area are Cretaceous. The age of the Franciscan is interpreted, however, to be Jurassic and Cretaceous, the age of adjacent Franciscan rocks mapped by Herd (1977) in Alameda County. Radiolarian tests were observed in chert beds in the Tesla area. Analysis of these faunas may provide further age refinement of the Franciscan in the Tesla area.

Environment of Deposition

Franciscan sediments are commonly accepted to be deep-sea fan turbidites and pelagic sediments that were deposited in an oceanic trench overlying a subduction zone, and bordering the North American continent on the west (Bailey and others, 1964; Blake and Jones, 1974).

Knoxville Formation

In the Tesla area, the Jurassic Knoxville Formation (White, 1885; Bailey and others, 1964) is faulted against and structurally overlies the Franciscan. It occurs as fault-bounded strips between Franciscan rocks and the Cretaceous Panoche Formation, and attains a maximum thickness of 360 m. The Knoxville strata exposed in the Tesla area consist of dark gray mudstone and shale, and light gray and tan, thin-bedded sandstone.

Elsewhere in the Coast Ranges, the Knoxville strata include shale, thick-bedded sandstone, massive lenticular conglomerate, and locally, pebbly mudstone, chert, and volcanic rock (Bailey and others, 1964). Previous workers (Anderson and Pack, 1915; Huey, 1948) included the Knoxville rocks of the Tesla area in Cretaceous formations. The strata are assigned in this report, to the Knoxville Formation on the basis of similar lithology, stratigraphic position, and age.

A tabular body of porphyritic andesite(?) is exposed near the contact with the Franciscan at Corral Hollow. The contacts with the sedimentary rocks above and below are not sufficiently well-exposed to indicate the exact nature of the igneous body, but its trend parallels the strike of the sedimentary rocks, suggesting that it is a sill or flow. The andesite(?) present at Corral Hollow can only be traced for 10 m along strike, but small exposures were found in several places in the study area, and aided in the delineation of the Knoxville strata.

Fauna and Age

The Knoxville ranges in age from late Kimmeridgian to late Tithonian (Imlay, 1980). Maddock (1964) described Portlandian Knoxville rocks from an area about 25 km southeast of the study area. These strata yielded the Late Jurassic fossil Buchia piochii. Limestone concretions collected by the author from Knoxville mudstone in the study area (loc. UCB D-8160) yielded the Tithonian fossils Phylloceras sp. and Buchia elderensis (David Jones, U.S. Geological Survey, oral commun., 1980).

Environment of Deposition

Knoxville strata were deposited on oceanic crust (Bailey and others, 1970; Blake and Jones, 1978) in the arc-trench gap, between the trench receiving coeval Franciscan sediments and the magmatic arc of the ancestral Sierra Nevada (Blake and Jones, 1978). Data primarily from exposures in the Sacramento Valley indicate that the Knoxville rocks are deep-water turbidites deposited by westerly directed currents on submarine fans in a slope environment (Ingersoll, 1978; Dickinson and Ingersoll, 1978) and lesser pelagic sediments.

Panoche Formation

The Cretaceous Panoche Formation was named by Anderson and Pack (1915), who designated the type locality in the Panoche Hills, 120 km southeast of the study area. As originally mapped along the west side of the San Joaquin Valley, the Panoche in part included strata now assigned to the Upper Jurassic Knoxville Formation. The Panoche has been divided into lithologic units by several workers. Huey (1948), citing significant age and lithologic differences, assigned the lowest Panoche rocks to a separate formation, the Lower Cretaceous Horsetown. Maddock (1964) described distinctive strata 25 km south-southeast of Corral Hollow, in the Mt. Boardman quadrangle, that are probably correlative with Huey's Horsetown. He named the unit the Adobe Flat Shale Member. Bishop (1970) divided the Panoche about 30 km southeast of Tesla into seven informal and formal lithostratigraphic units, retaining the Maddock's Adobe Flat Shale Member at the base of the Panoche, and divided the upper part into six informal units. Bishop could not extend his seven-fold division scheme beyond Ingram Creek, about 25 km southeast of the Tesla area. From Ingram Creek to Hospital Creek, Bishop was only able to divide the Panoche into an upper unit and a lower, the Adobe Flat Shale Member, thus illustrating the lateral variation of the formation.

In the Tesla area, three informal members of the Panoche are recognizable; the lowest consists primarily of mudstone and shale and is correlative to the Adobe Flat Shale Member of Maddock (1964); the middle member consists of fine-grained siltstone and lesser sandstone; the upper member is predominantly medium-grained sandstone (fig. 2).

Shale Member

The shale member of the Panoche Formation consists of thin beds of hard, dark gray and black, nodular shaly mudstone, and minor, soft green and dark brown mudstone and shale, and minor, thin-bedded fine-grained sandstone. Calcareous concretions occur locally. Thickness of this member ranges from 0-200 m. Although exposures are poor, field relationships suggest that the shale member strata occur in narrow fault bounded blocks.

Siltstone Member

Structurally overlying the shale member of the Panoche Formation, is a sequence of predominantly tan, sandy siltstone, and lesser fine-grained tan arkosic sandstone. Bedding is characteristically thin. The base of the member is faulted against Franciscan rocks, the Knoxville, and the shale member of the Panoche Formation. The contact with the overlying sandstone member is depositional, conformable, and gradational. Thickness of this member ranges from 0-500 m.

Sandstone Member

The sandstone member of the Panoche Formation consists of thin to thick-bedded, moderately well sorted, indurated, tan medium-grained sandstone and lesser tan fine-grained sandstone, tan to black siltstone, and dark brown shale. Flame structures, convolute bedding, and rip-up clasts occur in outcrops in Corral Hollow.

As noted above, the contact with the siltstone member is depositional and conformable. In the exposures south of Corral Hollow, the sandstone member is conformably overlain by the Moreno Formation; north of Corral Hollow, the Panoche Formation is unconformably overlain by strata of the Miocene Cierbo Sandstone. The sandstone member of the Panoche Formation is about 600-m-thick in the west, but thins eastward to about 240 m.

Fauna and Age

Goudkoff (1945) has shown from foraminiferal data that the top of the Panoche Formation becomes progressively younger to the south; the age is late Campanian between Los Banos Creek and Mt. Diablo, early Maastrichtian in the Ortigalita Peak Quadrangle, and middle Maastrichtian in the Panoche Hills.

Along Hospital Creek and Del Puerto Creek, 15 and 30 km southeast of the Tesla area, respectively, Bishop (1970) considered the Adobe Flat Shale Member (equivalent to the author's shale member) to be of Albian to Turonian age based on the occurrence of *Inoceramus labiatus*, and *Cibicides stephensoni*; Lower Cretaceous (probably Albian) dinoflagellates and the Lower Cretaceous (Albian) ammonites *Beudanticeras (Brewericeras) hulenense* (Anderson) and *Leconteites* cf. *L. lecontei* (Anderson). The member overlying the Adobe Flat Shale Member contains Cretaceous mollusks which are characteristic of the Santonian Stage, and probably range from Coniacian to Santonian, but may range from upper Turonian into the lower Campanian (Bishop, 1970). The upper members in the area are Campanian (Bishop, 1970), based on the occurrence of *Planulina constricta* which is restricted to the Campanian, *Baculites inornatus* characteristic of the upper Campanian, and *Baculites chicoensis* which is characteristic of the lower Campanian.

Huey (1948) reported several Early Cretaceous fossils from his Horsetown Formation (shale member of the Panoche Formation of this report) at a locality in Corral Hollow. During the present study, the author found foraminifers at loc. 518B that can only be determined to be Late Cretaceous (early Campanian or older, F-1 zone or older).

Outside of the present study area, but within 12 km of Tesla, Huey (1948) reported numerous mollusks from three localities in the Panoche. These mollusks were considered to be Cenomanian and early and late Senonian. Popenoe and others (1960), on the basis of Huey's (1948) finding of the ammonite *Metaplacenticeras*, considered the age of the upper part of the Panoche, corresponding to the author's sandstone member, to be late Campanian. Popenoe and others (1960) also cite Matsumoto (1959) who found the late Campanian to Maastrichtian *Baculites rex* near the top of the Panoche several kilometers west of the Tesla area. Thus, a late Campanian to Maastrichtian age is suggested for the sandstone member in the Tesla area.

Environment of Deposition

Detailed work by Bishop (1970) on the Panoche exposed between 11 and 40 km southeast of the study area indicates that its upper (Coniacian to Campanian) part consists of interbedded deep sea turbidites and pelagic sediments. Foraminifers from the shale member at loc. 518B indicate outer neritic to upper bathyal depths.

Moreno Formation

Conformably overlying the Panoche Formation are marine shale and sandstone of the Moreno Formation, which has been geographically extended into the Tesla area (Throckmorton, 1988). The type locality of the Moreno (Anderson and Pack, 1915) was designated in the Diablo Range about 120 km southwest of the study area in the Panoche Hills. Anderson and Pack recognized two members, a lower shale member, and an upper sandstone member. Attempts have been made to subdivide the Moreno into several more members: in the type area (Payne, 1951); in the Laguna Seca Hills (Briggs, 1953); and in the area near Del Puerto Creek (Bishop, 1970). These attempts were only locally successful (Bishop, 1970). Abrupt lateral changes in the strata in these areas prevented a consistent division other than into a lower shale member and an upper sandstone member. Anderson (1943, 1958), working in the eastern Diablo Range, named the sandstone unit above the Moreno shale the Garzas member. Taliaferro (1943), considered the Garzas member of Anderson (1943, 1958) as the upper member of the Moreno Formation.

In a paper read at the October 16, 1941 meeting of the Pacific section of the American Association of Petroleum Geologists (A.S. Huey and J.W. Daly, 1941, "A discussion of part of the Upper Cretaceous along the west border of the San Joaquin Valley"), Huey and Daly proposed that the Moreno Formation be redefined on the basis that the Moreno Formation, as originally defined in the type area (Anderson and Pack, 1915), did not include strata mapped as Moreno by Anderson and Pack in other areas along the west side of the San Joaquin Valley.

Huey and Daly (1941) suggested abandoning the term Moreno and replacing it with the term Moreno Grande, implying expanded Moreno. This solution would change the concept of the Moreno as it was conceived in the type area. The North American Code of Stratigraphic Nomenclature dictates that a formation name be a combination of a geographic name and a lithologic term describing the dominant lithology of the formation. The concept of an expanded Moreno (larger than the type) fails to communicate how it (Moreno Grande) is different from the type, and therefore fails as a communicative device for recognizing Moreno Grande strata in the field. The name Moreno Grande is, therefore, unacceptable. The present report retains the term Moreno Formation as originally defined.

Divisions of the Moreno recognized in the Tesla area include a lower shale member, and an overlying sandstone member. The sandstone member is lithologically similar to the Garzas member of Bishop (1970) of the Moreno Formation, who mapped the Garzas member in the Diablo Range about 35 km to the southeast of the Tesla area.

In the Tesla area, the shale member occurs as a poorly exposed but apparently continuous band across the mapped area, while the sandstone member of the Moreno Formation occurs discontinuously across the area.

Shale Member of the Moreno Formation

The 170-m-thick shale member of the Moreno Formation conformably overlies the sandstone member of the Panoche Formation. The contact is nowhere well-exposed, but is marked by a pronounced swale and subdued topography that is developed above the shale and mudstone comprising nearly all of this member. The shale is chocolate brown to purplish brown and is commonly laminated. Surface exposures are weathered light gray. Foraminifers are common constituents but are poorly preserved in surface samples. Brown mudstone is a minor constituent. Rare, thin limestone and gray to cream, siliceous shale layers occur near the top of the shale member. Thin sandstone layers occur locally.

Sandstone Member of the Moreno Formation

The sandstone member conformably overlies the shale member of the Moreno Formation. The thickness of the member ranges from 0-235 m. Exposures are generally poor, but appear to grade upward from siltstone, sandy siltstone, and fine-grained sandstone, to fine- and medium-grained sandstone. The sandstones are quartzose, and contain several percent plagioclase, potassium feldspar, and volcanic and quartzose rock fragments. Altered and fresh biotite and carbonaceous plant fragments are abundant in some beds. Macrofossils are uncommon.

Cretaceous fossils were found during the present investigation in sandstone that Huey (1948) assigned to the basal part of the Tesla Formation. At UCB loc. D-8146, near the Tesla site (pl. 1), the author collected the Cretaceous pelecypod Acila (Truncacila) demessa from the base of a 115 m sequence of fine- to medium-grained sandstone. These sandstones are indistinguishable from the underlying sandstones of the sandstone member, and overlie these beds gradationally. In the Tesla area the marine depositional environments of the Moreno Formation reflect a continued shallowing of the site of Moreno deposition through time, from deeper water shales, (shale member) to shallower water siltstones and very fine-grained sandstones (lower part of the sandstone member). The uppermost beds of the sandstone member (mapped previously as Tesla by Huey) demonstrate further shallowing from shallow-water fine-grained sandstones to very shallow medium-grained sandstones. A significant environmental change is indicated, however, by the overlying beds mapped here as the Tesla Formation; these are of deltaic or fluvial-deltaic origin. Thus, on the basis of similar lithology and depositional environment, these strata (previously mapped as Moreno Grande Formation and basal Tesla Formation by Huey) were stratigraphically restricted from the Tesla Formation and reassigned to the sandstone member of the Moreno Formation (Throckmorton, 1988).

To the east, at UCB loc. D-8171, sandstones identical to the sandstone of UCB loc. D-8146 contain the Cretaceous ammonite _Diplomoceras_ cf. _D_. _notabile_ and _Acila_ (_Truncacila_) _demessa_. These sandstones were also mapped as part of the Tesla Formation by Huey. On the basis of similar lithologies and depositional environments, these sandstones at UCB loc. D-8171 are also assigned to the sandstone member of the Moreno Formation.

Fauna and Age

The overall age range of the Moreno Formation has been established by fossil evidence from numerous areas, however, the formation is time-transgressive, and is progressivly younger towards the south (Payne, 1962; Bishop, 1970). Payne (1951) determined that the Moreno in the area between Los Banos and Coalinga is Late Cretaceous and early Paleocene in age. Bishop (1970), discussing the Moreno exposed between Salado Creek and Hospital Creek, cited fossil evidence for a Maastrichtian age for his Garzas member exposed there and a Campanian to Maastrichtian overall age for the Moreno. In the Tesla area, Huey's (1948) microfossil data indicate an early Maastrichtian age for the shale member, while macrofossils indicate a Late Cretaceous age for the sandstone member.

Foraminifers collected by the author indicate that the shale member is Campanian (E zone) to Maastrichtian, (D-2 zone) in age. Nannoplankton from a locality in the shale member indicate a Late Cretaceous, probably Campanian to Maastrichtian age (possible _T_. _trifidus_ - _L_. _quadratus_ zone). The mollusk _Acila_ (_Truncacila_) _demessa_ was found at a locality in the sandstone member, suggesting a Campanian age.

Environment of Deposition

Foraminifers from the lower Moreno shales in the Diablo Range about 90-130 km southeast of Tesla indicate that the shales were deposited at neritic to bathyal depths. Foraminifers from the upper Moreno shales indicate deposition in a neritic environment, on a slope flanking a deep marine basin (Payne, 1962). Sandstones in the Moreno are the result of turbidite deposition in channels cut into the slope (Ingersoll, 1978).

Sandstones of the Garzas member in the Quinto creek area, 55 km southeast of Tesla, are nearshore, shallow water turbidites; however, 30 km to the northwest in the Del Puerto area, the Garzas turbidites were deposited in deeper water (Bishop, 1970).

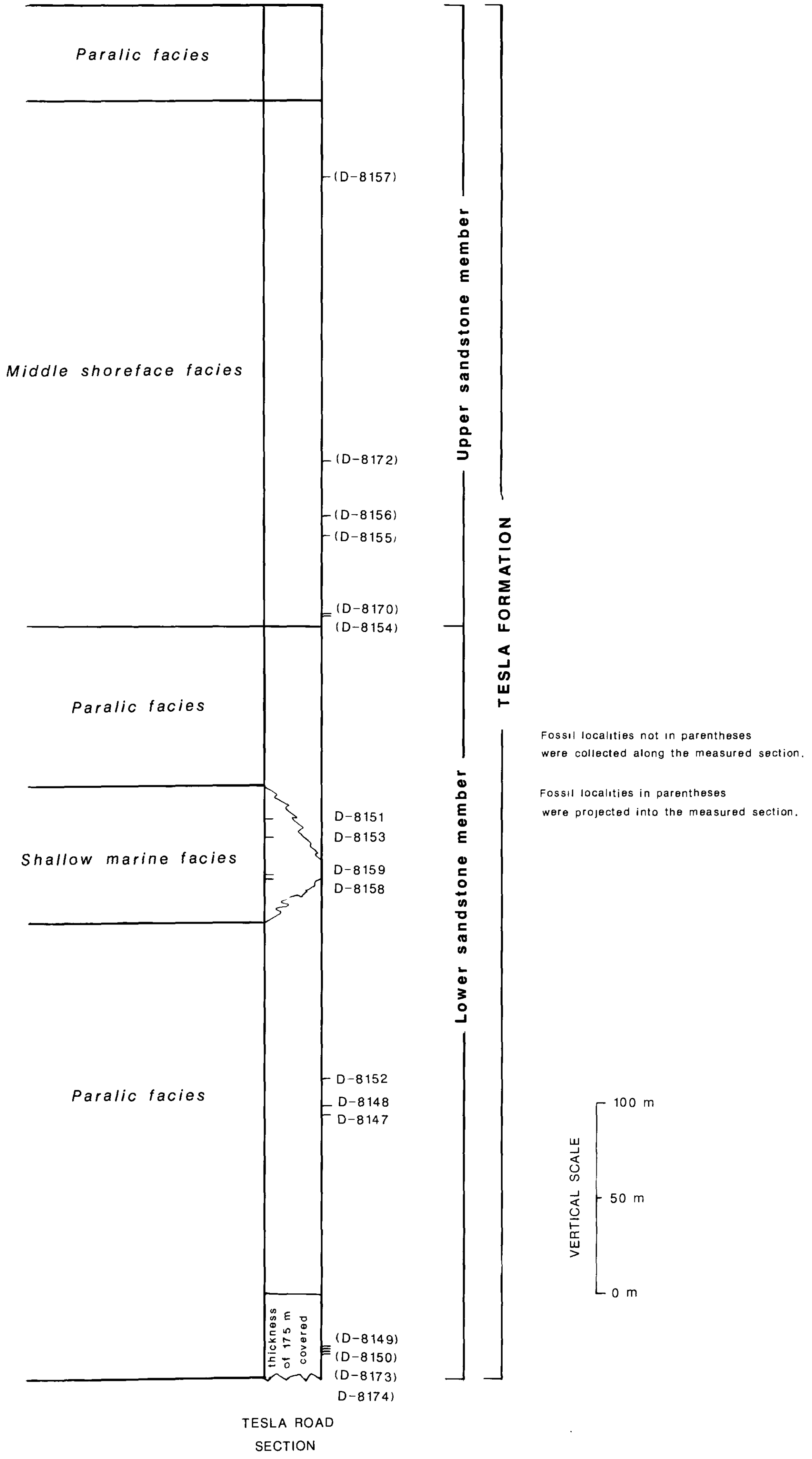
In the Tesla area, an extensive radiolarian fauna found in the shale member indicates marine deposition in cold water (Huey, 1948). Foraminifers found by the author at localities in the shale member indicate upper to middle bathyal, and possibly outer neritic depths (locs. 501A, 581). Foraminifers from the middle part of the sandstone member indicate deposition at upper bathyal depths (loc. 903). Shallow-water marine mollusks from the upper part of the sandstone member indicate marine shelf conditions, and crossbedded sandstones near the top of the sandstone member suggest marine deposition on the inner shelf of a marine basin.

Tesla Formation

In the Tesla area, Anderson and Pack (1915) mapped the strata comprising the Tesla Formation as the Eocene Tejon Formation. Huey (1937) proposed the name Tesla and first published the name in 1948, suggesting the type area be designated in the vicinity of the defunct mining town of Tesla (pl. 1). Although Huey (1948) did not designate a type section or locality for the Tesla Formation, Bartow and others (1985) referred to the type locality as occurring in the Tesla area. The most representative exposures of the Tesla are Huey's (1948) paced section along Tesla Road, designated as the type section (Throckmorton, 1988). Approximately 175 m of lowermost Tesla strata are not exposed at Tesla Road, but are exposed to the south and east of the Tesla Road type section. The designated Corral Hollow reference section (Throckmorton, 1988) is located 1 km to the west of the type section. Because the Tesla strata thin to the west of the type section, only about 60 m of the lowest part of the Tesla Formation occur at the Corral Hollow reference section, where the Tesla-Moreno contact is exposed.

The Tesla Formation consists predominantly of arkosic, quartzose sandstones, interbedded with siltstones, mudstones, and carbonaceous shales. Carbonaceous material and plant fragments are common in most of the siltstones and sandstones. Glauconite commonly occurs as pellets in the sandstones. Two informal members are recognized in the Tesla area (figs. 2 and 4). A sequence of white, gray, or brown sandstones, interbedded with siltstones, carbonaceous shales, mudstones, and lignite seams comprise the 395-m-thick lower sandstone member. Low-grade coal was mined in the 1860's from a 1.75 m coal seam (Whitney, 1865) which occurred in the lower sandstone member. The seam was lenticular and is no longer exposed at the surface. Brackish and shallow-water marine faunas occur in sandstone, siltstone, and mudstone beds in this member. Gray and brown sandstones and minor, gray and brown siltstones containing shallow-water marine faunas comprise most of the 280-m-thick upper sandstone member (fig. 3). At the top of the upper sandstone member are white and brown sandstones which are similar to the brackish-water sandstones of the lower member. Stewart (1949) reported *Cuneocorbula* cf. *C. torreyensis*, the fresh-water gastropod ?*Viviparus*, and ?*Elimia* from these these uppermost Tesla strata. The presence of *Viviparus* suggests deposition in a fluvial or deltaic environment, as were the strata belonging to the paralic facies in the lower sandstone member.

Figure 3. Tesla Formation at Tesla site. Brown, gray and white strata in foreground belong to the lower sandstone member. Strata in the distance belong to the upper sandstone member. Mine tailings are in the lower right foreground.



Fossil localities not in parentheses were collected along the measured section.

Fossil localities in parentheses were projected into the measured section.

Figure 4. Facies recognized in the Tesla Formation in the Tesla area and stratigraphic position of Tesla macrofossil localities.

The Tesla Formation overlies the Upper Cretaceous Moreno Formation. Where the Tesla Formation overlies the sandstone member of the Moreno Formation, the contact may be conformable, however, where Tesla strata overlie the shale member of the Moreno Formation, an unconformable contact is indicated. The absence of the sandstone member of the Moreno Formation implies non-deposition or erosion prior to the deposition of the Tesla. Within the 395-m-thick lower sandstone member are disconformities of unknown magnitude. The 280-m-thick upper sandstone member conformably overlies the lower sandstone member. The thickness of the upper sandstone member ranges from less than 110 m to 280 m. The range appears to be the result of erosion prior to deposition of the brackish water sandstones near the top of this member. The Tesla Formation is in fault contact with the overlying Cierbo Sandstone at Tesla Road. However, to the west the contact may be depositional, as mapped by Huey (1948) and Dibblee (1980). Within the study area, the maximum thickness of the Tesla Formation is 675 m.

Mapping and measurement of two stratigraphic sections provided stratigraphic and facies relationships of the Tesla Formation (pls. 1 and 2). Tesla strata exhibit rapid vertical lithologic variability, necessitating simplifying the columns by reducing the detail that is actually present.

Lithology

The major rock types occurring in the Tesla are discussed below.

Siltstones, Carbonaceous Shales, and Mudstones

Tesla siltstones are generally moderately sorted and range in color from gray to brown. Some siltstones are structureless; others exhibit foliation defined by alignment of platy micas and carbonaceous plant fragments. Quartz is the predominant mineral; biotite, white mica, and plagioclase are also abundant. Carbonaceous material is a common constituent and is abundant in some siltstones. Mudstone and shale are too fine-grained to microscopically determine the minerals present except for silt-size quartz, biotite, and white mica. Carbonaceous material is ubiquitous.

Sandstones

Tesla sandstones range in color from brown to gray to white; a characteristic clastic grain assemblage or cement influences the color of the sandstones.

The brown sandstones are quartose, and generally contain common to abundant plagioclase, biotite, and potassium feldspars. Volcanic rock fragments, and glauconite are commonly present, each in trace amounts to about 2 percent of the rock. Fragments of carbonaceous plant material are common, and in some rocks are abundant. Some sandstones are arkosic, containing about 10-20 percent feldspar. Most of the brown sandstones are poorly cemented by limonite; some sandstone beds and concretionary sandstones are cemented by calcite. A brownish clay matrix is present in some of the more poorly sorted sandstones. The textures of the brown sandstones are variable and gradational. Grain size varies from fine to medium sand, and rarely coarse sand; sorting ranges from poor to good. Grains, except for glauconite, which occurs as pellets, are predominantly angular to subangular.

The gray sandstones have similar clastic grain assemblages and rock textures to the brown sandstones, and differ from the brown sandstones primarily by the absence of abundant limonite cement. Light-gray sandstones have lower percentages of mafic grains and organic material than the brown sandstones.

The white sandstones are conspicuous, but not abundant. Low mafic mineral content (less than about 5 percent) and the presence of the white clay mineral anauxite appear to be the cause of the white color. Anauxite was identified in the white Tesla sandstones by Allen (1941) and Morris (1962). Some white sandstones do not contain anauxite, but are white because of the low mafic, high quartz and feldspar clastic constituents. These sandstones grade into gray sandstones with an increase in the percentage of mafic grains and (or) a decrease in the amount of anauxite.

The white sandstones are fine-to medium-grained, poorly to moderately sorted, and massive to finely crossbedded. Angular quartz dominates; plagioclase and potassium feldspar are common constituents; biotite and quartzose sedimentary and volcanic rock fragments are present. A white clay matrix is generally, but not everywhere present. Calcite cements some of the white sandstones.

Provenance

A detailed mineralogic study is beyond the scope of this report. Detailed mineralogic studies of the Tesla rocks were, however, made by Allen (1941) and Morris (1962). The results of Allen's work, which were confirmed by Morris, are summarized below, and are the basis for determining the provenance of the Tesla rocks.

Allen (1941) concluded that the source area for most Tesla sediments was the Sierra Nevada, to the east, but that a secondary Franciscan source lay to the west. The evidence for the Sierran source is the granitic detritus that is abundant in the Tesla rocks. The presence of andalusite in some Tesla rocks is the most diagnostic feature, as it is not known to occur in the Coast Ranges, but commonly occurs in the metamorphic rocks of the Sierra Nevada. Lateritic clays that formed in the warm moist climate of the ancestral Sierra Nevada contributed anauxite to the white Tesla sands. Sparse glaucophane and sparse albite suggest a secondary Franciscan source.

Environments of Deposition

The Tesla Formation is divisible into three facies on the basis of combined stratigraphic and faunal characteristics. Each facies is characterized by a consistent internal lithologic variability (pl. 2). Within each facies, lithologic and paleontologic features of individual strata and the successions of different strata provide evidence for interpreting the depositional environments. Strata of the lower sandstone member are recognizable as a paralic facies; a paralic facies also occurs in the uppermost part of the upper sandstone member. A shallow-marine facies is distinguishable as a tongue within the lower member. A middle shoreface facies comprises all but the uppermost part of the upper sandstone member.

Paralic Facies (lower sandstone member)

Sedimentary and fossil evidence from the paralic facies in the lower sandstone member indicate that deposition occurred primarily in a marginal marine environment in and near a delta. Within this facies, Tesla strata exhibit features common to deltaic and related environments including: rapid vertical and lateral lithologic variability, abundant plant debris, lignite beds, and highly micaceous rocks. Fossil evidence further supports deltaic deposition. The uncommon molluscan faunas have a low diversity and indicate brackish water deposition and also a mixing of brackish water and marine faunas. Transport of these fossils was minimal, and deposition of the assemblages occurred either (1) in the brackish water part of a delta, (2) in a nearby brackish environment such as an estuary, lagoon, or bay, or (3) in normal marine waters adjacent to these brackish water environments. The burrows of soft-bodied organisms, common in parts of deltas, are abundant at some stratigraphic horizons. Leaves of terrestrial plants occur at several localities. Such occurrences are common in deltaic environments.

Fossils, sedimentary structures, and other stratigraphic features permit a refinement of the environmental conclusions made above. Deposition in specific subenvironments within or adjacent to a delta are suggested by the below-listed, four different recurring associations in the paralic facies of the lower sandstone member. An association in this report is defined as a sequence(s) of interbedded rocks of different lithologies. Vertical lithologic variability is so great that these associations are in themselves generalizations of the lithologic columns as shown in plate 2.

Burrowed sandstone-siltstone-mudstone association--Sets of interbedded gray or brown sandstone, siltstone, and silty mudstone beds in this association contain abundant plant detritus and abundant biotite. This heterogeneous association contains coarse-grained sandstones, rare intraformational clasts (fig. 5), common burrows, and lacks a shelled macrofauna. These features suggest deposition in a delta front or delta topset environment (Dott, 1964; Reineck and Singh, 1975).

Organic-rich siltstone-mudstone-lignite association--Interbedded sequences of predominantly dark brown, carbonaceous siltstone, mudstone, and thin beds and lenses of lignite occur in this association. Thin veins of secondary gypsum have formed from the weathering of pyrite that was once present in the mudstone and lignite seams. Leaves and other plant fragments are present in the mudstone. These features suggest deposition in a lagoonal or estuarine environment, probably at the margins of a delta complex.

Fossiliferous gray and brown sandstone-siltstone association--Sandstone beds in the lower part of the paralic facies contain sedimentary structures that suggest deposition in very shallow water, possibly in upper shoreface environment. Structures in this association commonly found in an upper shoreface environments (Harms, 1975) include small-scale trough crossbeds, planar crossbeds, sigmoidal crossbeds, ripple laminations, cross laminations, and convolute bedding (figs. 6, 7, 8). Other features present in some sandstone beds include pebbly zones, intraformational mudstone clasts, and laminae defined by biotite- and magnetite-rich segregations. These features suggest a relatively high energy environment, affected by opposing water currents, such as might occur in a swash zone or tidal channel. Magnetite and

Figure 5. Platy mudstone chips in sandstone of the burrowed sandstone-siltstone-mudstone association (paralic facies). Stratigraphic top is at top of photo. Note circular burrows (parallel to bedding) at left bottom.

Figure 6. Crossbedded sandstone in the fossiliferous gray and brown sandstone-siltstone association (paralic facies). Dark laminae are biotite- and organic-rich. Stratigraphic top is to left.

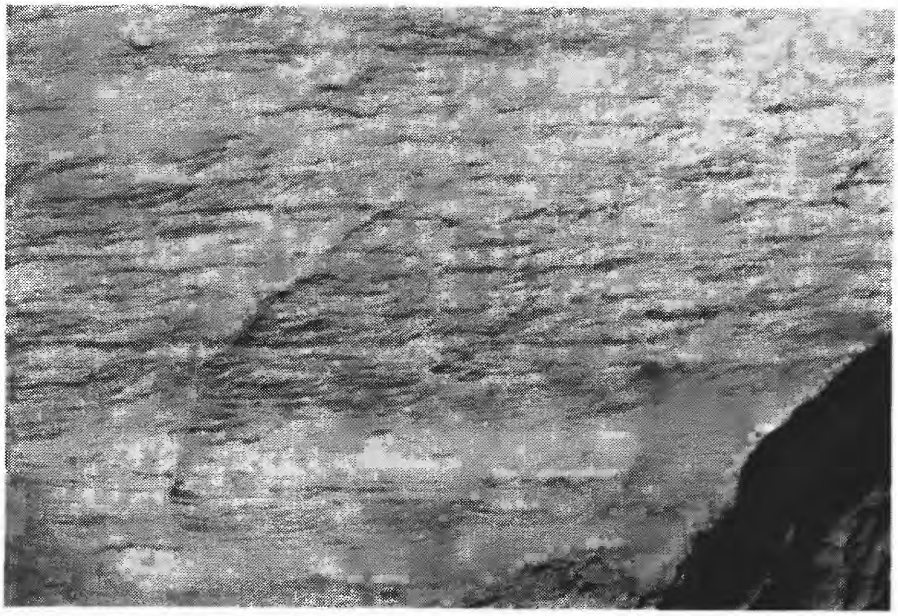


Figure 7. Ripple laminations in sandstone within the fossiliferous gray and brown sandstone-siltstone association (paralic facies). Stratigraphic top is to the left. Thickness of strata in photo is approximately 0.5 m.

Figure 8. Laminated and crossbedded sandstone within the fossiliferous gray and brown sandstone-siltstone association (paralic facies). Cross-sets indicate opposing current directions. Younger strata are to the left. Dark sandstone is organic rich.

biotite might have been concentrated by the constant winnowing of waves and currents occurring near a shoreline. These sandstone beds were probably deposited near a delta, as they are organic rich and biotite-rich, features common to deltas (Shepard, 1964; Dott, 1964).

One fossil assemblage (UCB loc. D-8150) found in this association suggests a mixing of a brackish water community with a normal marine community. The brackish water mollusk,?*Diodus tenuis* and a potamidid found at this locality suggest brackish water estuarine, bay, or deltaic environments. Fossils found in this assemblage that are tolerant of normal marine waters are *Corbula*, ?*Pteroluter* n. sp., an indeterminate mactrid, and an indeterminate buccinid. These fossils may have washed in from nearshore marine environments with flood tides or waves, or floods may have transported the brackish water fauna seaward into a normal marine environment.

All other fossil assemblages in this association consist of brackish water mollusks or mollusks that are tolerant of brackish water condition. These assemblages have a low faunal diversity and are dominated by the infaunal suspension-feeders *Corbula* sp., *Corbula* n. sp. aff. *C. pozo*, *Corbicula* sp., and *Diodus tenuis*. The predominance of suspension feeders in these assemblages suggests that the organisms lived in a moderately turbid environment such as near the margins of a brackish water bay, or in a delta.

In summary, the fossiliferous sandstone-siltstone association was deposited in a nearshore environment: in a brackish water bay, the brackish water part of a delta, or in a marine environment adjacent to these areas.

White sandstone-brown and gray sandstone-siltstone-lignitic mudstone association--Within the paralic facies are strata that form four repeated cycles of fining-upward sets of white sandstone, brown and gray sandstone, siltstone or mudstone, and lignitic mudstone. A low angle unconformity separates the lowest bed of each set from the underlying strata (fig. 9). Shallow channels several centimeters deep occur at some horizons (fig. 10).

White sandstone beds occur at the base of each set. Some are crossbedded, pebbly, and laminated, and biotite-rich and grade upward from coarse- to medium-grained, and then to fine-grained sandstone. Some grade to brown sandstone. Lignite seams and thin interbeds of organic-rich siltstones are common. No fossils other than plant fragments were found.

Purplish-brown weathering siltstones overlie the white sandstone in places. Gypsum occurs as fracture fillings in some beds. When present, mudstone, with or without plant fragments and intercalated lignite seams, forms the top of each set.

Stratigraphic evidence suggests, as one possibility, a fluvial environment of deposition for this association. The strata contain features comparable to modern floodplain sequences such as those described by Allen (1964, 1970) and Walker (1975), and include: fining-upward sequences of sandstones, siltstones, and mudstones; lignite seams or lignitic mudstones at

Figure 9. Slight angular unconformity between younger white sandstone (right) and shaly mudstone in the white sandstone-brown and gray sandstone-siltstone-lignitic mudstone association (paralic facies). Note lignite streaks in white sandstone.

Figure 10. Tesla paralic facies strata exposed near Tesla site (white sandstone-brown and gray sandstone-siltstone-lignitic mudstone association). Uppermost bed (youngest) is pebbly siltstone (note irregular basal contact). Middle bed is white sandstone; lower bed is siltstone. Thin ledges in siltstone are heavily cemented by limonite.

the top of some fining-upward cycles; and crossbedded sandstones. Herringbone crossbedding is present in some sandstones. In this fluvial model, the sandstone of this association represents lateral accretion channel deposits, while the finer-grained beds represent vertical accretion overbank and oxbow lake deposits.

Another possibility is a deltaic environment. As discussed above, successive sandstone beds contain crossbeds indicating opposing current directions. Deposition of these beds may have occurred under dual fluvial-tidal or fluvial-marine current influence. One environment subject to these currents is a distributary channel in the high constructional parts of a delta. Fining upward sequences, like those in this association, occur in delta distributary channels (Donaldson and others, 1970). Brown sandstone and siltstone in this association have variable lithologies and clastic grain assemblages containing common biotite, features common to deltaic environments. The glauconite in the brown sandstones suggests that the beds are of marine origin rather than fluvial origin. Thus, the white sandstone, brown sandstone, and siltstone beds may have accumulated in a delta. However, mudstones and lignitic mudstones at the top of some sets are more likely to have formed in a swamp or lagoon than on the delta, suggesting that the delta migrated laterally, allowing a swamp or lagoon to develop where deltaic deposits were once laid down.

In summary, the white sandstone in this association may have originated in a fluvial or deltaic environment. The brown sandstones and siltstones were probably formed in a deltaic environment, the lignitic mudstones probably formed in a coastal swamp environment.

Paralic Facies (upper sandstone member)

Near the top of the upper sandstone member is a poorly exposed white sandstone similar to the white sandstones found in the paralic facies of the lower sandstone member. Although no fossils were found in these uppermost Tesla strata during this study, Stewart (1949) reported *Cuneocorbula* cf. *C. torreyensis*, ?*Elimia* and the fresh-water gastroppod ?*Viviparous* from a white sandstone in this facies. The presence of the Eocene genus *Cuneocorbula* indicates these beds belong to the Tesla Formation and not to the overlying Miocene Cierbo Sandstone. The presence of the fresh-water gastropod ?*Viviparous* suggests deposition in a fluvial or deltaic environment, as were strata belonging to the paralic facies in the lower sandstone member.

Summary of paralic facies.--Paralic facies strata were deposited in nearshore marine, paralic, and possibly fresh water environments. Possible specific environments include: delta topsets, delta front, bay, estuarine, lagoonal, upper shoreface, and fluvial. Depositional conditions fluctuated rapidly during deposition of this facies. Lateral lithologic changes indicate adjacent contemporaneous environments, while vertical changes indicate rapid environmental changes through time, caused by lateral migration of environments, and, possibly, by eustatic sea level changes.

Shallow-marine Facies

Lithologic characteristics of the shallow-marine facies strata differ little from some of the paralic facies strata and are compatible with deposits of deltaic origin. These sandstones, siltstones, and mudstones contain plant material and moderate amounts of biotite and glauconite. Fossil assemblages, containing the genera Acila, Nuculana, Periploma, ?Pitar, and Turritella (UCB locs. D-8158, D-8159, D-8153, and D-8151), found in fine-grained lithologies from these beds are suggestive of deposition in a nearshore shallow-marine environment below wave base; in calm or moderately calm waters, such as the seaward margin of a delta; or a calm nearshore marine environment adjacent to a delta. Strata of this facies are laterally equivalent to sandstone, siltstone, mudstone, and lignite beds of the paralic facies.

Middle Shoreface Facies

Strata of the middle shoreface facies were deposited across the entire area including both the Corral Hollow and Tesla Road measured sections (pl. 2, fig. 4). These strata vary little, and are predominantly buff-colored, medium and fine-grained sandstones containing rare to abundant plant material and moderate amounts of biotite and glauconite.

Macrofauna from this facies (UCB locs. D-8154, D-8170, D-8155, D-8156, D-8172 and D-8157) suggest deposition in the inner sublittoral zone, on a shallow-marine shelf. Variations in the composition of fossil assemblages with lithology suggest that conditions varied slightly at different horizons. The muddy siltstone substrate and distinctive fauna at UCB loc. D-8172 indicate lower energy conditions and/or possibly deeper water shelf conditions than the sandstones.

UCB loc. D-8157 contains a diverse fauna dominated by the infaunal suspension-feeders Glycymeris sp. and Turritella merriami (here inferred to be suspension-feeding). Detritus feeders and predators are rare. Assemblages from UCB locs. D-8154, D-8170, D-8155, and D-8156 are dominated by the infaunal suspension-feeder Spisula sp., and the infaunal deposit-feeders Nuculana or Nucula. These feeding types and inferred substrate niches are similar to those of several offshore communities (Scott, 1976, 1978), however, by considering the substrate type (sand), feeding habits, and the uniform lithology of this facies, all assemblages in this facies appear to represent marine shelf communities from the middle shoreface.

Summary of Tesla Facies

When the Tesla strata are regarded as a whole, it is clear that deposition occurred in different environments marginal to a land mass, and resulted in both paralic and normal marine deposits.

Except for some strata of possible fluvial origin, Tesla rocks may all be characterized as deltaic and marginal marine deposits. The paralic facies was deposited in paralic environments possibly including delta, bay, estuary, swamp, and lagoon. The shallow-marine facies accumulated in a shallow marine environment, possibly at the outer edge of a delta, or on a shallow shelf near a delta. The middle shoreface facies was deposited on the middle shoreface of a shallow marine shelf. The change from paralic conditions in the lower sandstone member to normal marine conditions in the upper sandstone member is interpreted to be the result of a marine transgression. The paralic facies near the top of the upper sandstone member represents a marine regression and a return to depositional conditions similar to those in lower paralic facies.

Age of the Tesla Formation

The Tertiary sequence of California has been divided into numerous chronostratigraphic units based on stratigraphic limits of mollusks. The molluscan stages of Clark and Vokes (1936) were developed from the zones of Dickerson (1913, 1914, 1916), the groups of Clark's (1918, 1921), and the horizons of Clark (1926). Weaver and others (1944) incorporated, with slight modification, Clark's and Vokes' "stages" in their chronostratigraphic classification of marine formations of western North America. Clark and Vokes' (1936) "stages" are placed within quotation marks to indicate their informal usage, and to distinguish them from the formations having the same names. From oldest to youngest, the Eocene molluscan stages are informally designated the "Meganos", "Capay", "Domengine", "Transition", and "Tejon". The stratigraphic names, Martinez, Meganos, Capay, Domengine, and Tejon have been applied to both lower Tertiary formations and stages. Their use as both time-stratigraphic and litho-stratigraphic units has resulted in much confusion, and new names should replace these stage names.

Givens (1974) restricted the "Capay stage" of Clark and Vokes by placing their upper faunal zone of the Capay stage" into the "Domengine stage". Saul (1983) and Squires (1984) regarded the "Capay" stage as early Eocene and the "Domengine" stage as late early through early middle Eocene. This report follows the age designations of Saul (1983) and Squires (1984).

Huey (1948) and Stewart (1949) assigned the upper part of the Tesla Formation in the Tesla area to the middle Eocene (now considered lower Eocene) "Capay" stage based on the occurrence of *Turritella merriami*. Huey reported no age-diagnostic fossils from the lower part of the Tesla Formation in the Tesla area. In the Orestimba area. Stewart and others (1944) mapped strata lithologically similar to strata of the lower part of the Tesla in the Tesla area as Martinez(?) Formation. These strata were subsequently assigned to the Tesla(?) Formation by Stewart (1949). These strata contain the brackish water mollusks "*Placunanomia*" cf. *inornata*, *Diodus tenuis*, and "*Psammobia*" *cylindrica* (Stewart and others, 1944). Because *P. cylindrica* is considered a Paleocene species, Stewart and others (1944) inferred that the lower part of their Martinez(?) Formation in the Orestimba area is Paleocene in age. By analogy, Huey (1948) speculated that the lower part of the Tesla area in the Tesla area may also be Paleocene in age. Stewart (1949) stated that the lower part of the Tesla in the Tesla area, by virtue of its stratigraphic position, may be as old as Late Cretaceous.

Huey (1948) considered *Turritella merriami* to be an index fossil of the middle Eocene (now considered lower Eocene) "Capay" stage; however, Givens and Kennedy (1979) disputed *T. merriami*'s restricted age assignment and stated that *T. merriami* ranges from the "Capay" into the "Domengine." Weaver (1953) reported *T. merriami* from the Muir Sandstone, supporting Givens and Kennedy (1979). At a locality near the top of the Muir Sandstone, Weaver reported the occurrence of *Turritella uvasana aedificata*, which is restricted to the "Domengine" stage (Merriam, 1941; Keen and Bentson, 1944). At localities in the Muir Sandstone stratigraphically lower than strata containing *T. merriami*, Weaver (1953) reported the occurrence of Phalium (Semicassis) *tuberculiformis* [= *Galeodea tuberculiformis*] which was considered by Clark and Vokes (1936) and Vokes (1939) to be restricted to the "Domengine." However, Squires (1984, 1987) stated that *P.* (*S.*) *tuberculiformis* occurs in the "Domengine" through "Transition" stages, and possibly ranges into the "Capay". The occurrence of *P.* (*S.*) *tuberculiformis* stratigraphically below the "Domengine" *T. uvasana aedificata* indicates that *P.* (*S.*) *tuberculiformis* in the Muir Sandstone is also "Domengine" in age. The occurrence of *T. merriami* above strata containing *P.* (*S.*) *tuberculiformis*, and below strata containing *T. uvasana aedificata*, confirms a "Domengine" age for *T. merriami* in the Muir Sandstone.

The published range of several species found in the upper sandstone member of the Tesla Formation during the present study are shown in figure 11. *Conus caleocius* found in lower part of the upper sandstone member establishes a "Domengine," (late early through early middle Eocene age) for the upper part of the Tesla Formation in the Tesla area. *C. caleocius* has also been found in "Domengine" strata from Simi Valley, southern California through central California (Vokes, 1939; Squires, 1984, 1987). *Turritella merriami* occurs in two assemblages in the upper sandstone member, from the upper part of the middle shoreface facies and from the lower part of the middle shoreface facies (with *C. caleocius*). Since *T. merriami* ranges from the "Capay" through the "Domengine," and *C. caleocius* is "Domengine" in age, the middle shoreface facies is "Domengine" in age.

Molopophorous californicus has been reported only from two localities in "Division D" of the Meganos Formation of Clark and Woodford (1927) (Keen and Bentson, 1944). These beds are now assigned to the "Capay stage" (Fischer, 1979). *M. californicus* is present in the upper sandstone member of the Tesla in the Tesla area, in two assemblages in the middle shoreface facies, above the strata containing *C. caleocius*. Thus, the occurrence of *M. californicus* in the upper sandstone member of the Tesla is regarded as the first in rocks younger than "Capay."

The Eocene genus *Cuneocorbula* was reported by Stewart (1949) from strata in the paralic facies in the uppermost part of the Tesla Formation. The presence of *Cuneocorbula* and the "Domengine" age of the underlying middle shoreface facies strata bracket the age of this strata at "Domengine" to late Eocene.

Turritella buwaldana is found in assemblages near the top of the lower sandstone member, in the shallow-marine facies. *Turritella buwaldana* ranges in age from "Capay" through "Tejon" and possibly extends into the "Meganos" (Squires, in press). The occurrence of *T. buwaldana* in strata below the "Domengine" middle shoreface facies restricts the age of these strata to "Capay" (early Eocene) through "Domengine" (late early Eocene through early middle Eocene), and possibly "Meganos" (late Paleocene to early Eocene).

Strata from the lowermost part of the Tesla Formation have produced no age-diagnostic fossils; therefore, the definitive age of Tesla strata below the shallow-marine facies has not been established. However, the assemblage collected at UCB loc. D-8150 near the base of the Tesla, bears a striking resemblance to the assemblage from UCLA loc. 3774, collected from the Pozo District, San Luis Obispo County (LouElla Saul, Los Angeles County Natural History Museum, written commun., 1981), which is interpreted to be early Maastrichtian in age. UCB loc. 3774 contains *Corbula pozo*, *Diodus* n. sp., *Anomia* cf. *A. jalama*, and ?*Terebralia juliana*. The fauna from UCB loc. D-8150 includes *Anomia* sp., *Corbula* n. sp. aff. *C. pozo*, ?*Diodus tenuis*, ?*Pteroluter* n. sp., an indeterminate mactrid and an indeterminate potamidid (table 1). In addition, *Anomia* sp., *Corbula* n. sp. aff. *C. pozo*, *Diodus tenuis*, and a potamidid occur in several assemblages in the lower 215 m of the Tesla Formation. The similar fauna suggests a possible Late Cretaceous (Maastrichtian) age for the basal part of the Tesla in the Tesla area, however, ?*Pteroluter* n. sp., also found in the assemblage from UCB loc. D-8150 possesses a ligament unlike any found in the Tertiary or Maastrichtian, but like those found commonly in the Cenomanian to Campanian. The indeterminate mactrid from the Tesla Formation resembles the Late Cretaceous *Cymbophora* (LouElla Saul, written commun., 1981).

Scant evidence suggests a possible Paleocene age (rather than a possible Late Cretaceous age) for UCB loc. D-8150. A gastropod resembling *Tornatellaea pinguis* occurs at this locality also. If it is *T. pinguis*, it suggests a middle(?) Paleocene age (LouElla Saul, written commun., 1981).

The stratigraphic position of the lower part of the lower sandstone member of the Tesla permits its age range to extend possibly from the Late Cretaceous to the early middle Eocene. If the lower part of the Tesla Formation is Cretaceous in age, then approximately 20 million years is represented by only 315 m of Tesla strata (occurring below UCB loc. D-8158; fig. 4, pl. 2). This seems unlikely, however, the Tesla-Moreno contact appears to be conformable at the Corral Hollow measured section, where the Tesla Formation overlies the Upper Cretaceous sandstone member of the Moreno.

Age of the Tesla(?) Formation in the Laguna Seca Area and the Tesla Formation in the Orestimba Area

The Tesla and Tesla(?) Formation strata crop out in two areas southeast of the Tesla area, in the Laguna Seca area and in the Orestimba area (fig. 1). The Tesla Formation has not been reported from areas south of Laguna Seca or north of the Tesla area. Exposures of the Tesla Formation in the Tesla and Orestimba areas, and the Tesla(?) Formation in the Laguna Seca area are discontinuous, and correlation of strata between these areas is not definite.

In the Laguna Seca area, the Tesla(?) Formation overlies the Paleocene and lower Eocene(?) Laguna Seca Formation of Payne (1951), and underlies the middle Eocene Kreyenhagen Formation of Briggs (1953), and thus, may range in age from late Paleocene to early or middle Eocene. The Tesla(?) strata in this area include white, clayey (anauxitic?), quartzose sandstone, kaolinitic clay, brown shale, and pebble conglomerate (Briggs, 1953). No fossils other than fragmental leaf impressions have been reported from the Tesla(?) in the Laguna Seca area (Briggs, 1953).

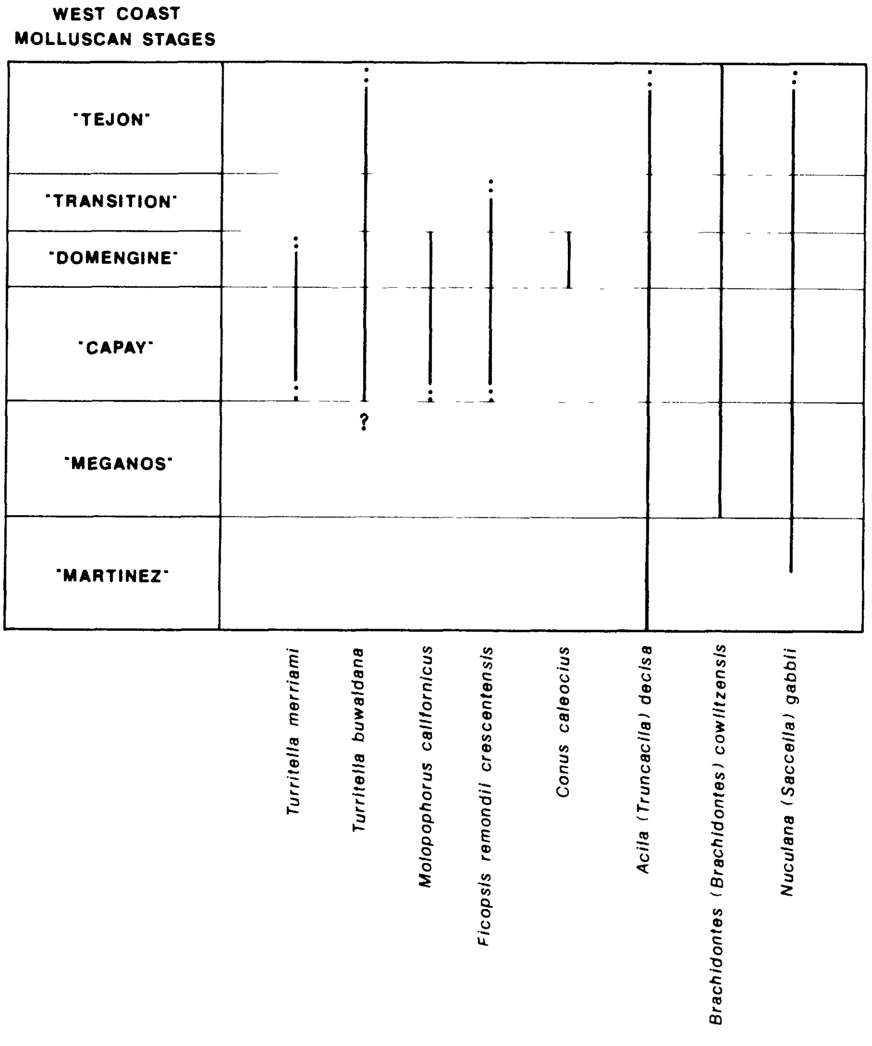


Figure 11. Ranges of fossils from the upper sandstone member of the Tesla Formation. Data from Givens (1974), and Squires (1984, 1987).

Table 1. Mollusks from the Tesla Formation in the Tesla area.

	Upper sandstone member						Lower sandstone member										
	Middle shoreface facies						Shallow marine facies				Paralic facies						
UCB LOC. NO.	D–8157	D–8172	D–8156	D–8155	D–8170	D–8154	D–8151	D–8153	D–8159	D–8158	D–8152	D–8148	D–8147	D–8149	D–8150	D–8173	D–8174
Mollusca																	
Bivalvia																	
Acanthocardia (Schedocardia) cf. A. brewerii (Gabb)	●	●															
Acila (Truncacila) decisa (Conrad)		●					●										
Anomia sp.	●										●	●	●	●	●	●	
Brachidontes (Brachidontes) cowlitzensis (Weaver and Palmer)	●																
Callista (Costacallista) hornii vokesi? Squires											●						
carditid (indeterminate)							●										
Corbicula sp.																●	
? Corbicula sp.											●	●					●
Corbula n. sp. aff. C. pozo Dailey and Popenoe												●	●	●	●	●	●
Corbula sp.											●	●	●	●	●		
? Corbula sp.															●		
Diodus tenuis (Gabb)												●	●	●			
? Diodus tenuis															●		
Glycymeris sp.	●																
mactrid (indeterminate)															●		
Mytilus sp.													●	●		●	●
Nucula sp.			●	●	●												
Nuculana (Saccella) gabbii (Gabb)				●	●		●										
Nuculana (Scaeoleda) sp.	●																
Nuculana sp.	●	●	●			●		●	●								
Periploma sp.							●										
Pitar sp.	●																
? Pitar sp.							●						●				
? Pteroluter n. sp.															●		
Solen sp.	●		●		●	●											
Spisula sp.	●	●	●	●	●												
Tellina n. sp.? aff. Givens T. townsendensis Clark						●											
Tellina sp.			●			●											
Gastropoda																	
Architectonica sp.	●																
buccinid (indeterminate)			●												●		
Calyptraea sp.	●																
Cancellaria sp.			●														
Fusinus sp.	●						●										
Gemmula sp.							●										
Molopophorus californicus Clark and Woodford			●	●													
naticid (indeterminate)	●		●	●		●	●					●					
potamidid (indeterminate)											●	●	●	●	●	●	
Scaphander sp.	●		●				●										
turrid sp.							●										
Turritella buwaldana Dickerson		●					●	●		●							
Turritella buwaldana subsp. coosensis? (Merriam)							●										
Turritella merriami Dickerson	●																
Whitneyella sp.			●			●											
Scaphopoda																	
Dentalium sp.	●	●	●	●	●												

Booth (1950), Collins (1950), and Dibblee (1981, 1982a, 1982b) mapped a nearly continuous belt of Tesla strata in the Orestimba area. The Tesla in this area consists of white, clayey, quartzose sandstone, siltstone, fine-grained sandstone, and clay (Booth, 1950). Booth included in his Tesla Formation fossiliferous, green, glauconitic, marine sandstones that overlie these beds. Stewart and others (1944) mapped these glauconitic sandstones as Domengine(?) Sandstone. Bartow and others (1985) subsequently assigned these sandstones to the Domengine Sandstone. The glauconitic sandstones Booth included in his Tesla Formation contain *Turritella uvasana* and *Turritella buwaldana*. Booth (1950) stated that these fossils are indicative of a "Domengine" age. However, Squires (1984, 1987) has established that *T. buwaldana* ranges from the "Capay" to the "Tejon," and possibly into the "Meganos," (Squires, in press), while *T. uvasana* s.s. is restricted to the "Tejon." Thus, these glauconitic sandstones in the Orestimba area are "Tejon" in age. As discussed in the previous section, the age of the marine sandstones comprising the upper sandstone member of the Tesla Formation in the Tesla area is "Domengine."

Stewart and others (1944) reported *Diodus tenuis*, "*Placunanomia*" cf. *inornata* and "*Psammobia*" *cylindrica*, a Paleocene species, from the lower part of what they termed the Martinez(?) Formation in the Orestimba area. Booth (1950) also reported *P. cylindrica*? from the lower part of his Tesla in this area and, like Stewart, assigned a Paleocene age to these strata. A probable late Paleocene diatom assemblage was collected from a siltstone facies in the lower part of the Tesla in the Orestimba area (Bartow, 1985).

Based on fossil evidence summarized above, the lower part of the Tesla Formation in the Orestimba area is Paleocene in age. *Psammobia cylindrica* was not found in the Tesla area, but faunas similar to the brackish water fossils in the Orestimba area establish a facies equivalence for the lower parts of the Tesla in these areas.

Cierbo Sandstone

The Miocene Cierbo Sandstone unconformably overlies the Tesla Formation, and locally, at Tesla Road near the Corral Hollow fault, the formations are in fault contact. In the northern part of the study area the Cierbo Sandstone unconformably overlies the Panoche Formation, indicating that prior to the deposition of the Cierbo, the Tesla and Moreno Formations were eroded and significant differential uplift occurred within the area.

The Cierbo consists of friable, white quartzose sandstone, white and tan quartz- and chert-pebble sandstone and conglomerate, tan sandstone, and green and brown silty mudstone. A maximum thickness of 230 m is exposed.

Mineral assemblages of Cierbo rocks are similar to those in the Tesla Formation. The abundance of black chert pebbles in the sandstone and conglomerate aids in distinquishing the Cierbo Sandstone from the Tesla Formation. Cierbo sediments were derived both from granitic and metamorphic rocks of the Sierra Nevada and from Franciscan and related rocks of the Coast Ranges (Huey, 1948). A Sierran source is suggested by lithologic similarity to the Tesla white sands. In addition to quartz, both contain kaolinized potassium feldspar and a heavy mineral suite including zircon, andalusite, hypersthene, garnet and hornblende. A Franciscan source is indicated by actinolite, glaucophane, and chert grains in the Cierbo sandstone (Huey, 1948).

Fauna and Age

The age of the Cierbo is late Miocene, based on the occurrence of *Ostrea bourgeoisii* and *Pecten raymondi* (Huey, 1948). The author found *O. bourgeoisii* at loc. 462 and UCB locs. D-8162, D-8169, and D-8163, and *P. raymondi* at UCB loc. D-8163, confirming Huey's age assignment.

Environment of Deposition

The lithology and fossils indicate that most of the Cierbo was deposited in a shallow marine environment. The white sandstone, and pebbly sandstone and conglomerate may have been deposited in a fluvial environment.

Neroly Formation

The upper Miocene Neroly Formation stratigraphically overlies the Cierbo Sandstone. The contact appears to be parallel and conformable near Tesla. However, relationships just north of the study area (Huey, 1948) indicate that the contact is an angular unconformity. Huey concluded that the Cierbo unconformably overlies the Neroly throughout the Altamont quadrangle. He recognized angular unconformities locally. The author did not examine the contact throughout the entire quadrangle and therefore accepts Huey's interpretation that the contact in the study area is unconformable.

The Neroly is divided into a lower sandstone member, 225-350 m thick, and an upper siltstone member, 0-200 m thick. The lower member consists of resistant, blue, medium-to coarse-grained, andesitic sandstone; minor resistant, pebble, and cobble conglomerate; and minor blue andesitic siltstone, white clay, water-lain tuff, brown sandstone, and brown and green siltstone. The upper member consists of gray and brown mudstone, blue and brown sandstone, and minor brown conglomerate. The volcanic detritus of the Neroly was derived from andesites of the Sierra Nevada (Huey, 1948).

Fauna and Age

Although not numerous, fossil horizons in the Neroly have been found. Fossil leaves, wood, and horse teeth have been reported from the Tesla area by Huey (1948). Hugh Wagner, Steven May, and the author visited UCB loc. UCMP V-4613 in the study area in 1979 and made a small collection of fossil mammals from the Neroly sandstone member (pl. 1, Appendix I). Charles A. Repenning of the U.S. Geological Survey identified from this material:

canid, wolf size but not *Canis*
Martinogale sp. aff. *M. alveodens*, a primitive skunk
rodent
Serridentinus sp. aff. *S. productus*, a mastodont proboscidian
antilocaprid, small, cf. *Merycodus*, a pronghorn.

In addition, Dr. Repenning examined the following material, borrowed from the UCB vertebrate collections:

Martinogale sp. aff. *M. alveodens*, a primitive skunk
Eucastor lecontei, a primitive beaver
Copemys sp. near *C. barstowsensis*, a primitive New World mouse.

Dr. Repenning concluded that the fauna is unquestionably Clarendonian in age and suggested that it is about mid-Clarendonian (about 10 m.y.b.p.).

Environment of Deposition

The Neroly fossils indicate that the formation was deposited in a non-marine environment, possibly a floodplain. Fresh-water snails found by the author (UCB locs. D-8166, D-8165, pl. 1, Appendix I) within the lower sandstone member in a tuff and tuffaceous siltstone indicate a fresh-water lake or fluvial environment.

Older Alluvium

Isolated Pleistocene terrace deposits occur along Corral Hollow Creek. The sediments are unconsolidated rounded pebble and cobble gravels in a poorly sorted sand matrix. The clasts are primarily quartz, volcanic rocks, chert, graywacke, and schist.

Alluvium

Holocene ephemeral stream deposits were mapped in the major stream valleys. The alluvium consists of silt- to cobble-size particles and minor boulders and clay-size particles. Franciscan detritus comprises most of the cobbles and pebbles, which include quartz, graywacke, chert, and schist.

Landslides

Much of the area is overlain by landslide deposits which occur in areas underlain by every formation exposed in the Tesla area. The Tertiary formations are more susceptible to sliding than are the Cretaceous and older formations. The landslides were largely mapped from aerial photographs and were recognized by irregular, hummocky topography and often by a scarp in the bedrock and soil on the hillside above the slide. The unaltered appearance of some slides and the eroded and subdued appearance of others indicate that sliding has occurred over an extended period of time.

Mine Tailings

A significant volume of mine tailings was dumped near the mouth of the Tesla mine. They are distinguished by their proximity to the Tesla mine, topographic form, and unconsolidated nature.

STRUCTURE

The study area is structurally complex. Numerous major and minor faults are the primary structural features, but several folds are also important to local structure. Previous workers, including Vickery (1925a, 1925b), Huey (1948), Dibblee (1980), and Dibblee and Darrow (1981), have consistently used the names Carnegie, Corral Hollow, and Tesla for the faults in the study area, but have applied these names to different fault segments. The present writer uses the same fault names, but maps the faults differently from previous workers.

Three major faults divide the study area into four structural blocks, the Carnegie, Corral Hollow, Tesla, and the Franciscan. These blocks differ in their style of structural deformation (fig. 12, pl. 1).

North of the Carnegie fault, within the Carnegie block, the Panoche Formation, Cierbo Sandstone, and Neroly Formation have shallow southeastward dips and occupy the south limb of the broad Patterson Pass anticline (Huey, 1948). In the extreme east part of the study area, the Carnegie block is more complex; a tight, southeast-trending syncline occurs entirely within rocks of the Neroly Formation.

The Corral Hollow block is bounded by the Carnegie fault on the northeast and by the Corral Hollow fault on the south and southwest. Within this block, the Cierbo Sandstone and Neroly Formation dip steeply and form a tight syncline-anticline pair. Both folds are truncated by the Carnegie fault to the east, and by the Corral Hollow fault to the west.

The Tesla block is located between the Corral Hollow and the Tesla faults. Here the strata dip steeply and predominantly to the north and are disrupted by several faults of small to moderate displacement. These faults trend northeast to northwest, and east-west, and do not extend outside the Tesla block. These faults will be discussed in detail in the following section. The Tesla block contains the only exposures of the Tesla Formation in the study area.

Only Franciscan rocks are exposed in the Franciscan block. Unlike strata in the Tesla block, the Franciscan rocks are intensely deformed and in part metamorphosed. Thus, Franciscan deformation and metamorphism must have occurred prior to the juxtaposition of the Franciscan and Tesla blocks.

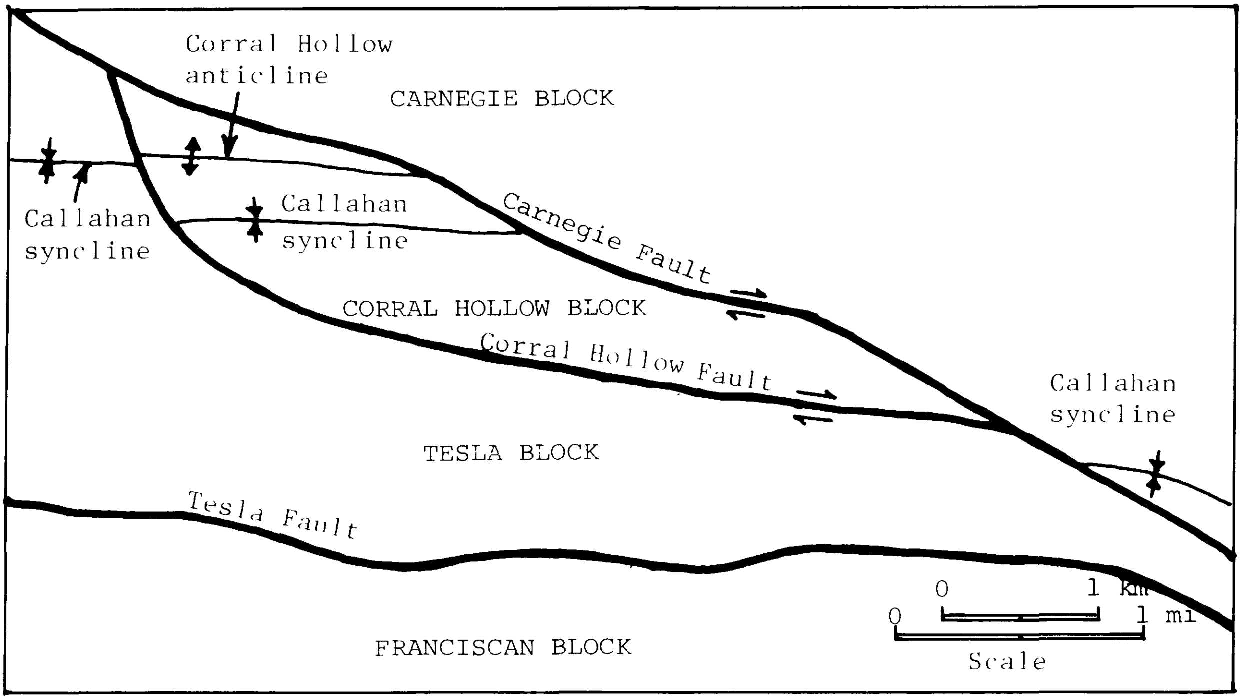


Figure 12. Diagrammatic map of the Tesla area showing structural blocks and fault boundaries.

Faults

Carnegie Fault

The Carnegie fault strikes approximately N65°W and extends across the entire study area (pl. 1). Its trace is relatively straight and undeflected by topographic features, indicating the fault plane is vertical or nearly vertical. The sense of motion on the fault is right-lateral strike-slip, based on the offset of the Callahan syncline (Raymond, 1973). This syncline is designated as the Corral Hollow syncline by Dibblee (1980) and Dibblee and Darrow (1981). As discussed in the section on folds, each segment of the Callahan syncline has the same open style of folding and similar axial trend. The evidence indicating continuity of the two segments is not perfect, however, as the Corral Hollow anticline does not have a corresponding segment north of the Carnegie fault. A possible scenario that may account for this apparent inconsistency is proposed below.

Because the Carnegie syncline and Corral Hollow anticline are bounded by faults and are not continuous from the Carnegie block into the Corral Hollow block, it is unlikely that faulting preceeded folding. However, folding may have been in part synchronous with faulting and may have been the result of the same tectonic forces. The forces may have developed a syncline which, as pressures continued, was broken by the Carnegie fault. As the Corral Hollow block was moved relatively northwestward along the Carnegie fault, the rocks were forced against the Carnegie block which acted as a buttress, applying a southerly directed resistance. The north-directed component of the force causing the strike-slip fault and the south-directed force of resistance may have together caused the formation of the Corral Hollow anticline. Thus, the occurrence of the Corral Hollow anticline does not preclude the former connection of the two segments of the Callahan syncline in the Carnegie and Corral Hollow blocks, and therefore Raymond's (1973) interpretation of strike-slip motion for the Carnegie fault is plausible. The author, for lack of evidence to the contrary, accepts Raymond's interpretation. Strike-slip separation of the Carnegie syncline by motion along the Carnegie fault is a minimum of 5 km.

To the east of the Tesla area the Carnegie fault offsets deposits of the Pliocene Livermore Gravels (Raymond, 1973). However, the Carnegie does not offset Pleistocene terrace deposits or Holocene stream deposits in Corral Hollow, indicating that the most recent motion on the Carnegie was during or after the Pliocene, but prior to the deposition of the Pleistocene terrace gravel.

Corral Hollow Fault

The Corral Hollow fault trace trends east-west in Corral Hollow, (fig. 13, pl. 1) bends sharply northward near the center of sec. 25, T.3S, R.3E, and continues northward where it is terminated by the Carnegie fault. The fault trace is undeflected by topographic irregularities, indicating the fault plane is vertical or nearly vertical.

As discussed in the following section on folds, the segment of the Callahan syncline in the Tesla block has the same open style of folding and similar axial trend as the Callahan segment in the Corral Hollow block, suggesting that the two fold segments were once continuous. The Corral Hollow anticline, adjacent to the Callahan syncline segment in the Corral Hollow block, has no counterpart in the Tesla block. The absence of the anticline in the Tesla block does not preclude former continuity of the Callahan syncline from the Corral Hollow block onto the Tesla block, for the same reasons that explained the absence of a counterpart of the Corral Hollow anticline in the Carnegie block. Thus, the two segments of the Carnegie syncline in the Tesla and Corral Hollow blocks are assumed to have been continuous, but were separated by a distance of 0.6 km by right-slip motion along the Corral Hollow fault. Dibblee (1980) mapped the Corral Hollow fault similarly and also indicated a right-lateral sense of movement. Huey (1948), however, mapped the Corral Hollow fault differently than Dibblee and the author. Huey considered the author's east-west trending fault located in secs. 25 and 26, T.3S, R.3E, to be a segment of the Corral Hollow fault. He recognized this segment as a reverse fault and on this basis interpreted the entire Corral Hollow fault as a reverse fault. This sense of motion is correct for this segment, but the major movement along the Corral Hollow fault (as interpreted by the author) is right-lateral.

The youngest beds offset by the Corral Hollow fault belong to the upper Miocene Neroly Formation, indicating that the latest fault movement occurred after the deposition of the Neroly and before deposition of Holocene alluvium in Corral Hollow.

Tesla Fault

The Tesla fault extends the entire length of the study area and marks the contact between intensely deformed rocks of the Franciscan assemblage south of the fault, and the Cretaceous Great Valley sequence rocks north of the fault. The fault is vertical and trends about N80°W, roughly paralleling a series of faults that have juxtaposed units of the Great Valley sequence.

The Tesla fault roughly parallels the strike of Franciscan strata adjacent to the Tesla fault. This feature, as well as the juxtaposition of the Great Valley sequence against the Franciscan assemblage, led Raymond (1970, 1973) to conclude that the Tesla fault is part of the Coast Range thrust (Bailey and others, 1970). Subduction motion along the Coast Range thrust occurred during the Mesozoic and early Tertiary (Dickinson and others, 1979a). However, the youngest rocks truncated by the Tesla fault belong to the upper Miocene Neroly Formation, indicating that the latest activity of the fault postdates deposition of the Neroly. Raymond (1970, 1973) attributes this age discrepancy and the present near-vertical orientation of the Tesla fault to a reactivation of movement (high angle) along the Coast Range thrust probably at the time of diapirism of the Diablo Range in the late Cenozoic (Ernst, 1970).

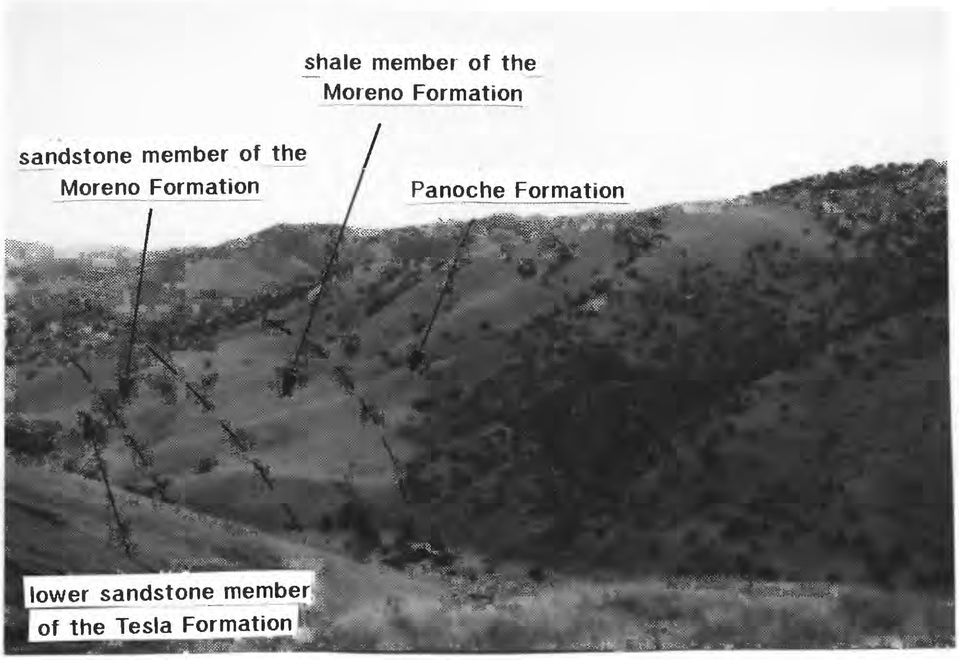


Figure 13. View eastward along Corral Hollow.

Miscellaneous Faults

Numerous, high angle, normal or reverse faults of small to moderate displacement have disrupted the rocks in the study area. Poor exposures generally prevent determining the attitude of the faults, but for many faults the sense of relative motion and approximate displacement can be determined.

The Patterson Pass fault is located within the Carnegie block (pl. 1, fig. 12). It trends northwest and offsets the Cierbo-Neroly contact in sec. 19, T.3S, R.4E. Poor exposures prevented the author from determining the sense of motion on the fault, however Huey (1948) classified the fault displacement as oblique-slip on the basis of slickenside orientation in well cores taken outside of the Tesla area. Movement on the Patterson Pass fault postdates deposition of the Neroly Formation.

An unnamed, high-angle fault marks the contact between the Panoche Formation and the Cierbo Sandstone in NE1/4 sec. 19, T.3S, R.4E (pl. 1). The fault parallels the Patterson Pass fault and is upthrown on the northeast side. The most recent movement along the fault occurred after deposition of the Cierbo, but the magnitude of displacement is unknown.

Faults within the Tesla block can be divided into two groups, a northwest to northeast trending group, and an east-west trending group. The faults that trend northwest to northeast do not extend beyond the Tesla block. These faults have steeply dipping axial planes. The displacement of strata indicates most of these faults are left-lateral strike-slip faults. These left-lateral faults are probably sympathetic faults that occurred as a response to major strike-slip motion along the Corral Hollow and Carnegie faults. The fault in sec. 33, T.3S, R.4E is a north-dipping reverse fault that probably formed in an analogous manner as the Corral Hollow anticline. Potentially, as the Tesla block moved westward and northwestward (relative to the Corral Hollow block along the strike-slip Corral Hollow fault), the north-directed component of the force caused the strike-slip faulting, and the south-directed force of resistance to motion by the Corral Hollow block caused part of the Tesla block adjacent to the Corral Hollow fault to break. The resultant reverse fault is the kind of fault that would be expected in this structural setting.

East-west trending faults that roughly parallel the Tesla fault bound the shale member of the Panoche Formation and the Knoxville Formation on the north (secs. 35, and 36, T.3S, R.3E). The fault planes are nearly vertical and at some places parallel the bedding of adjacent Knoxville and Panoche rocks. These faults have the same characteristics as the Tesla fault, thus, they are probably part of the Coast Range thrust fault system. However, they juxtapose Great Valley series rocks of different ages rather than Franciscan assemblage rocks against the Great Valley sequence.

Relative Ages of Faults

Regionally the Tesla fault is the oldest fault, but as discussed earlier, reactivation of motion during the late Cenozoic along the Coast Range thrust complicates the relative age relationships of the Tesla, Carnegie, and Corral Hollow faults. The Carnegie fault truncates and offsets the Tesla fault in the Cedar Mountain quadrangle, to the southeast of the study area and is therefore younger than the Tesla fault (Raymond, 1973). This age relationship is most likely the same in the Tesla area. The post-Neroly age and same sense of motion of the Corral Hollow and Carnegie faults suggests that these faults are tectonically related and are probably about the same age.

The Tesla, Corral Hollow, and Carnegie faults have all undergone Neogene motion. The majority of the other faults in the Tesla area are probably also the result of Neogene tectonism that produced the strike-slip Carnegie and Corral Hollow faults and uplifted the Diablo Range by reactivating motion along the Tesla fault.

Folds

Folds occur within the Carnegie, Corral Hollow, and Tesla blocks (pl. 1, fig. 12). In addition, strata dipping south to southeastward in the western part of the Carnegie block occupy the south limb of the Patterson Pass anticline (Huey, 1948). The axis of this fold lies north of the study area.

The northwest trending Callahan syncline occurs in the southeast part of the Carnegie block. The rocks exposed along the axis belong solely to the Neroly Formation. The fold is closed and asymmetrical; dips on the southern limb are steep, while those on the northern limb are relatively shallow. The axial trace is gently curved, the trend varying between about N60°W and N85°W. Bedding attitudes indicate that the syncline plunges gently to the southeast. The Callahan syncline is truncated by the Carnegie fault in Corral Hollow.

In the northwest part of the Corral Hollow block, rocks of the Neroly and Cierbo Sandstone form a tight syncline-anticline pair (Callahan and Corral Hollow), respectively. The Corral Hollow anticline is closed and asymmetrical; the south limb is much steeper than the north. The axial trace is relatively straight and trends about N80°W. Although somewhat erratic, bedding attitudes indicate the fold plunges gently southeast. The adjacent Callahan syncline trends approximately east-west and also plunges southeast. The fold is closed and symmetrical. Both the syncline and anticline are truncated by the Corral Hollow and Carnegie faults.

A segment of the closed Callahan syncline trends approximately N75°W in rocks of the Cierbo Sandstone and Neroly Formation in the western part of the Tesla block. The syncline is offset by a north-trending fault and is truncated at its eastern limit by the Corral Hollow fault.

GEOLOGIC HISTORY OF THE TESLA AREA

Numerous depositional and tectonic models have been proposed to explain the depositional and structural history of the Coast Ranges (Atwater, 1970; Bailey and others, 1970; Ernst, 1970; Raymond, 1973; Blake and Jones, 1974, 1978; Clarke and others, 1975; Nilsen and Clarke, 1975; Nilsen, 1977; Dickinson and others, 1979a, 1979b; Ingersoll, 1979). The following summary, which focuses on the central Diablo Range and the north end of the San Joaquin Valley, is largely a synthesis of these earlier workers. Details of Upper Cretaceous and Eocene stratigraphy and structure in the Tesla area are derived primarily from the present study.

The Jurassic to Tertiary Franciscan assemblage and Great Valley sequence (Knoxville, Panoche, and Moreno Formations) were deposited on oceanic crust in a trench and arc-trench gap, respectively, in and above an active subduction zone. The Franciscan rocks were thrust against and under the Great Valley sequence along the subduction zone creating the Coast Range thrust. Thrusting caused local uplifts in the area of the central Coast Range, and the resulting locally emergent parts of the Diablo Range shed detritus into the arc-trench gap, supplying the Great Valley sequence with Franciscan detritus. The primary source of sediment for the Franciscan and Great Valley was the ancestral Sierra Nevada.

The depositional environment of the Great Valley sequence changed through time. The Upper Jurassic Knoxville and Cretaceous Panoche Formations consist of slope deposited turbidites and pelagic sedimentary rocks. Upper Cretaceous shales of the Moreno Formation represent marine slope deposits, while Upper Cretaceous siltstones and sandstones of the sandstone member of the Moreno Formation represent shelf and nearshore marine deposits. Gaps in the record of Jurassic and Cretaceous sedimentation are probably the result of depositional hiatuses and erosion caused by tectonism.

During the early Tertiary, the Great Valley depression was separated into two basins, divided by a structural high called the Stockton arch (Hoots and others, 1954; Repenning, 1961, [fig. 14]). The arch may have been caused by compression resulting from motion along the proto-San Andreas fault. Upper Cretaceous shallow-water deposits of the Moreno Formation indicate that the Stockton arch may have begun to develop as early as the Late Cretaceous. The partially unconformable contact between the Moreno and the overlying, possibly Upper Cretaceous basal part of the Tesla suggests that the Stockton arch may have become a prominent feature by the end of the Late Cretaceous. This timing is consistent with the conclusion of Fischer (1979), who proposed a Late Cretaceous age for uplift of the north side of the Stockton arch in the Sacramento basin.

From possibly the Late Cretaceous into the middle Eocene, the Tesla Formation was deposited in what is now the northern end of the San Joaquin Valley, in a deltaic and shallow marginal-marine environment. The sea into which Tesla sediments were deposited shoaled to the north against the emergent Stockton arch. Tesla sediments were derived partly from this uplift, but the primary source was the Sierra Nevada to the east.

Deposition which occurred possibly during the Late Cretaceous through early middle Eocene (and possibly late Eocene) is represented by only 675 m of Tesla strata, representing two regressive phases and one transgressive phase of deposition. During the regressions, erosion and hiatuses in deposition occurred. The relative thinness of the Tesla Formation, representing such a long time span, suggests numerous hiatuses or fewer hiatuses of long duration.

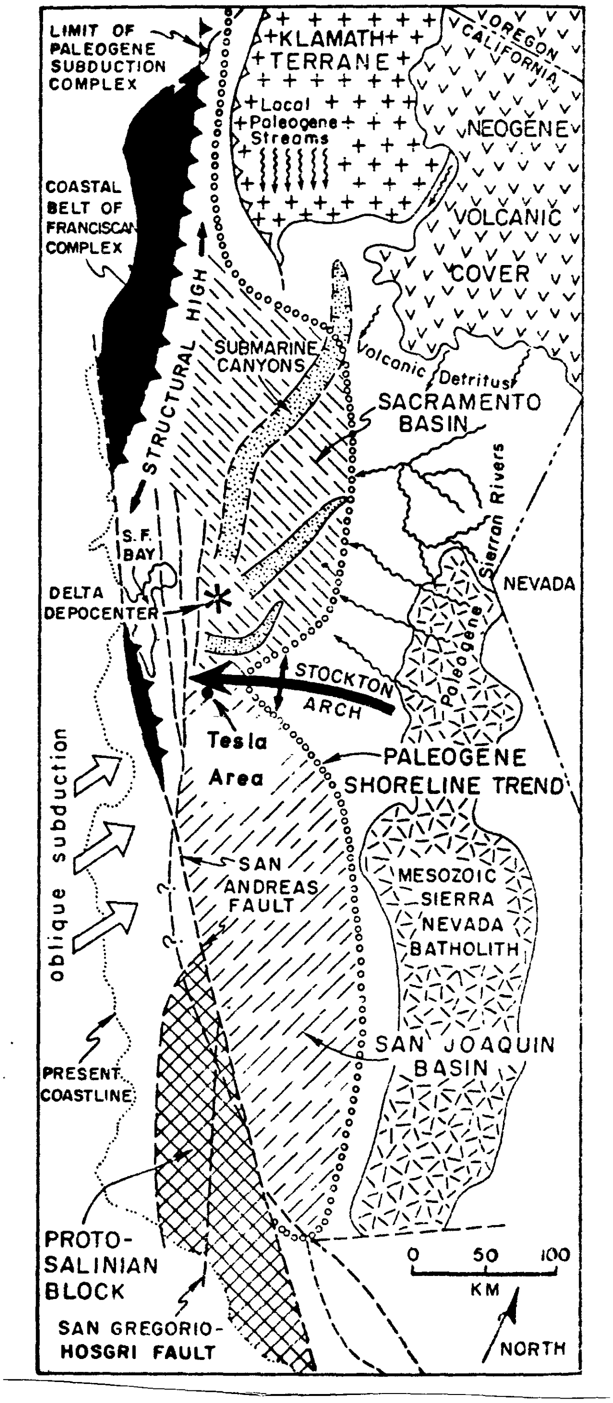


Figure 14. Paleotectonic and paleogeographic sketch map of northern and central California during Paleogene time. Note westward extension of Paleogene shoreline at the Stockton arch. Land was probably also exposed to the west of Corral Hollow, shedding detritus into the Tesla area. (From Dickinson and others, 1979a).

Oligocene and lower Miocene deposits do not occur in the Tesla area. Strata representing this interval may never have been deposited or were eroded prior to late Miocene deposition of the shallow-marine Cierbo Sandstone. The Cierbo unconformably overlies the Tesla Formation and locally, at Tesla Road, the formations are in fault contact. In the northern part of the Tesla area, the Cierbo rests unconformably on the Upper Cretaceous Panoche Formation, indicating that prior to the depopsition of the Cierbo, the Tesla and Moreno Formations were eroded, and significant differential uplift occurred within the area. The Cierbo constitutes the last record of marine deposition in the Tesla area. Late Miocene terrestrial deposition represented by the Neroly Formation followed.

Subduction, which began in the Late Jurassic, ceased in the Neogene, probably during the Miocene. Strike-slip faulting along the San Andreas fault system began at this time. The Carnegie and Corral Hollow faults are probably part of the San Andreas system. Accompanying strike-slip faulting were folding, high-angle faulting, and uplifting of the Diablo Range. Segments of the Coast Range thrust, such as the Tesla fault, were rejuvenated during this period of uplift.

Uplift during the Quaternary caused erosion and disection in the Tesla area, accompanied by alluviation of valleys. Pleistocene alluvial deposits occur in isolated areas, and Holocene alluvium is being deposited along the courses of present day ephemeral streams. Oversteepened hillsides are being modified by landslides.

PALEONTOLOGY OF THE TESLA FORMATION

Introduction

A list of taxa identified from the author's localities Tesla Formation during the present study is presented in table 1. Selected Tesla mollusks are illustrated in plates 3 through 8. Unfortunately, no compendium of fossils collected from the Tesla Formation exists for comparison with the author's material, nor is there an adequate reference collection of fossils from the Tesla. Identifications were made by comparison with published photographs, drawings and descriptions of Pacific Coast Cretaceous and Tertiary mollusks, and by comparison with Pacific Coast Tertiary and Cretaceous specimens, and collections from the Museum of Paleontology, Berkeley. Comparisons were also made with material borrowed from University of California, Los Angeles (UCLA loc. 3774). Identification of taxa proceeded as far as was possible; "identification" is meant here to indicate useful recognition of at least part of a fossil's taxonomic classification (e.g., Spisula sp., mactrid, neogastropod, pelecypod). Full citations for all taxa identified from the author's localities are listed in Appendices I and II, and are not repeated in the text. The author also identified taxa from localities in the study area that were previously collected by other workers. The full citations of these taxa are given only when they are first mentioned in the section on Other Fossils from the Tesla Formation in the type area.

The autoecology of the fossil mollusks is inferred by analogy with modern organisms and, when possible, by analysis of functional morphology. The autoecological information on living and fossil taxa was obtained primarily by a literature search. The following section on Autoecology provides the foundation for the following section on Paleoecology. This section is organized by facies; the paleoecologic interpretation of fossils from each facies is presented at the end of each facies discussion. The synthesis of sedimentological data and the conclusions made in the Paleoecology section supports the reconstruction of the depositional environment of Tesla facies.

Macrofossils were collected from 17 localities in the Tesla Formation (table 1, pl. 1). Seven localities occur along the section measured at Tesla Road (pl. 1). The stratigraphic positions of localities not found along the section (enclosed in parentheses) are projected into the measured section along Tesla Road (pl. 1). Macrofossil and microfossil locality information is provided in Appendices I and II. Mollusks dominate the assemblages with 18 genera of pelecypods, 13 genera of gastropods, and at least one scaphopod genus. Also found were a scleractinian coral (Stephanophyllia sp.), a heart urchin (Schizaster sp.), an elasmobranch (?Myliobatis sp.), and crab claws. More species undoubtedly are present in some assemblages than determined by the author, but poor preservation prevented their identification.

Fossiliferous beds occur throughout the Tesla Formation but are not abundant. They have been collected by the author from both the lower and upper sandstone members, in the paralic, shallow-marine, and middle shoreface facies. Principal mollusk-bearing zones are the lower 215 m of the paralic facies (lower sandstone member), the middle 30 m of the shallow-marine facies (lower sandstone member), and the lower 90 m of the middle shoreface facies (upper sandstone member). Brackish water assemblages in the paralic facies are characterized by a low diversity (fewer than 8 taxa), and high fossil density. Normal marine assemblages in the shallow-marine facies are characterized by moderate diversity (greater than 8 taxa), and low fossil density. Marine assemblages in the middle shoreface facies are characterized by moderate diversity and moderate to high fossil density. All assemblages are dominated by one, two, or three species.

Variation in fossil preservation and induration of host rocks, extreme differences in fossil densities, and poor exposures prevented statistical sampling. Collecting methods were used that were appropriate for each locality, in order to ensure representative sampling of the assemblage. Diagenetic and post-diagenetic processes have altered or removed shell material from most of the assemblages. The majority of the assemblages have no shell material preserved, with only casts and molds remaining. Within the shelled assemblages, fossil preservation ranges from articulated bivalves to disarticulated scattered valves, to highly fragmented shell coquinas. Shells commonly are badly leached and chalky, but are well-preserved in a few assemblages. Preservational details of each assemblage are described in the section on Paleoecology.

Definition of Terms

Because of differences in the concept and usage in the literature of the terms zone, assemblage, and paleocommunity, these terms as used in this report are defined for clarity. The term zone (e.g., first molluscan zone, megafossil zone), is used as an informal biostratigraphic unit indicating "a body of strata unified in a general way by paleontologic features but for which there is insufficient need or insufficient information to justify designation as a formal named unit" (Hedberg, 1961). The term assemblage, is "any group of fossils from a suitable restricted stratigraphic interval and geographic locality" (Fagerstrom, 1964). A paleocommunity refers to "a fossilized community--consisting of all potentially preservable members of a single ancient community" (Kauffman and Scott, 1976).

Autoecology

Bivalvia

Acanthocardia (Schedocardia) cf. A. brewerii

Modern cardiids are shallowly buried infaunal suspension feeders (Stanley, 1970; Black, 1970; McKerrow, 1978). They are moderately rapid to rapid burrowers with short siphons, and live with their posterior margin lying at, or just beneath the sediment surface (Stanley, 1970). *Cardium edule* is a modern vagrant species found on the lower shore of sandy beaches, buried to the depth of its shell (Black, 1970). *Acanthocardia* (*Schedocardia*) cf. *A. brewerii* is inferred to have also had the same life habits as its modern counterparts.

Acila (Truncacila) decisa

Modern species of the subgenus *Truncacila* are restricted to the Pacific and Indian oceans, where they favor, but are not restricted to, a cool temperate habitat. The majority live in temperate waters, between 4.5 and 20°C (Schenck, 1936). *Acila* is not found living in the intertidal zone or at depths in excess of 1470 m; most are found at depths less than 915 m, and therefore live in the sublittoral zone at neritic and bathyal depths (Schenck, 1936). Modern and fossil Acilas are marine. They do not live in estuaries and prefer, but are not restricted to, a mud or fine sand bottom (Schenck, 1936). Most species from the western North American coast live today at depths of 10 to 1,280 m (Keen and Coan, 1974). Acilas are moderately rapid burrowing, deposit feeders (Stanley, 1970). They are siphonless and live shallowly buried (Schenck, 1936).

Acila (Truncacila) *decisa* is inferred to have been a detritus feeder, living infaunally at shallow depths below the substrate surface in the sublittoral zone.

Anomia sp.

Species of *Anomia* on the coast of western North America live intertidally to 45 m, attached to rocks or other shells (Keen and Coan, 1974). Ladd (1951, 1957) collected species living in closed bays and passes on the Texas coast in brackish-water ranging in depth from 1 to 3 m, from substrates ranging from soft mud to mixed shell and muddy sand. *Anomia simplex*, a species studied by Stanley (1970), lives just below the spring low tide level in gravelly coarse sand where it is byssally attached to rocks and shell debris. This species is generally restricted to a shallow subtidal environment where there is moderate current flow (Stanley, 1970). Moore (1969a) stated that species of *Anomia* prefer high-energy shallow shelf environments.

Anomia sp. was found in the study area in fine-grained sandstone and sandy siltstone from the lower part of the Tesla Formation in association with brackish-water mollusks, and in the upper part of the Tesla formation in association with fossils indicative of a normal marine, inner-sublittoral environment. *Anomia* sp. of the present study is inferred to have been epifaunally attached suspension feeder, able to tolerate both brackish and normal marine waters of the nearshore shallow shelf.

Brachidontes (Brachidontes) cowlitzensis

Fossil and modern species of *Brachidontes* are fresh to marine forms. Modern species of *Brachidontes* are epifaunal or semi-epifaunal suspension feeders (Stanley, 1970), living intertidally on hard substrate, attached to rocks by a byssus (Keen and Coan, 1974; Stanley, 1970). Some species live in shallow subtidal settings, inhabiting grass flats (Stanley, 1970). Epifaunal species can be identified from those living infaunally by differences in morphology, including the presence of a pronounced anisomyarian, and triangular shell outline, recurved or hooked shaped shells, and large posterior muscles (Stanley, 1970). *Brachidontes cowlitzensis* has a shape similar to those living epifaunally, and is inferred to have been an epifaunal suspension feeder that lived in an intertidal or subtidal environment.

Callista (Costacallista) hornii vokesi?, Squires, ?Pitar sp., Pitar sp.

The autoecology of *Callista* (*Costacallista*) *hornii vokesi*?, Squires is inferred to be the same as ?*Pitar* sp. and *Pitar* sp.

carditid

Very little ecological information is available for the Carditidae. Modern genera (*Cyclocardia*, *Glans*, *Miodontiscus*, *Milneria*) of Carditidae from the coast of western North America live intertidally to depths of 1,830 m (Keen and Coan, 1974). Members of Carditidae live infaunally; most are free-burrowing, but a few are byssally attached (Stanley, 1970). Because they lack siphons, they must live very shallowly buried. *Cardita floridana*, studied by Stanley (1970), lives infaunally, attached to buried stems of submarine grasses. *C. floridana* inhabits moderately protected intertidal and subtidal grass-covered, muddy sands.

The carditid from the study area is inferred to have lived infaunally in an intertidal or subtidal environment, at very shallow depths, where it was suspension feeding (Carole Hickman, University of California, Berkeley, oral commun., 1981). It may have lived in the substrate byssally-attached or free.

Corbicula sp., Corbicula sp.

Corbicula is a shallow-burrowing suspension feeder, inhabiting Paleogene brackish-water, intertidal, or sublittoral estuarine areas with sand or muddy substrates, where they commonly dominate the infauna (McKerrow, 1978). Modern corbiculids typically occur in brackish to fresh water (Keen, 1958). Moore (1969b) stated that fossil *Corbicula* also occur in normal marine environments. Transport of fossils from brackish-water to marine settings is common, however, and therefore the author does not consider *Corbicula* to be an inhabitant of normal marine environments. *Corbicula* sp. in the present study occurs in fine-grained sandstone, sandy siltstone, and silty mudstone, associated with a potamidid, a gastropod restricted to brackish water. *Corbicula* sp. is therefore inferred to have been living shallowly buried in a brackish-water, intertidal or sublittoral environment of fluctuating salinites.

Corbula n. sp. aff. C. pozo, Corbula sp., ?Corbula sp.

LouElla Saul, Los Angeles County Natural History Museum, identified several specimens sent to her by the author as *Corbula* n. sp. aff. *C. pozo*. *Corbula* sp. may represent more than one species, some of which may be *Corbula* n. sp. aff. *C. pozo*. *?Corbula* sp. was found in an assemblage containing *Corbula* n. sp. aff. *C. pozo*.

Both modern and fossil species of *Corbula* are shallowly buried (just below the surface) suspension feeders (Stanley, 1970, 1972; McKerrow, 1978). Gardner (1957), however, reports that some living species of *Corbula* live epifaunally on the sea floor. Some species of *Corbula*, including *Corbula caribea* are exceedingly sluggish burrowers that secrete byssal threads for stabilization (Stanley, 1970). Living and fossil *Corbula* inhabit a variety of different substrates. Vokes (1945) and McKerrow (1978) state that fossil Corbulas live in nearshore, normal marine environments. However, members of the subgenus *Panamicorbula* inhabit brackish water muds of mangrove swamps in tropical West America (Keen, 1971). *C. caribea* favors a muddy substratum and sheltered subtidal conditions (Gardner, 1957), while recurrent fossil assemblages containing *Corbula* have been found in shelf silts and sands, and glauconitic sandy clays (McKerrow, 1978; Vokes, 1945). Keen and Coan (1974) reported that off the coast of western North America, species of *Corbula* live intertidally to a depth of 75 m; however, *Corbula luteola*, a species living in the San Pedro Channel has been found living at depths of 196-225 m, where it is common (Natland, 1957). *Corbula* n. sp. aff. *C. pozo* occurs in the lower part of the Tesla Formation (paralic facies) with *Diodus tenuis*, *Corbicula* sp., *Mytilus* sp., *Anomia* sp., and a potamidid, in fine-grained sandstones, sandy siltstone, and poorly sorted silty mudstone. These beds are interpreted to be shallow, nearshore, brackish water deposits. *Corbula* n. sp. aff. *C. pozo* is inferred to have been a shallowly buried suspension feeder that was able to tolerate water of less than normal salinity.

Diodus tenuis, ?Diodus tenuis

The genus *Diodus* is represented by two species, *Diodus tenuis* and *Diodus* n. sp. The latter species is reported from UCLA loc. 3774 (USGS loc. M-5025) in the Pozo district, San Luis Obispo County (LouElla Saul, written commun., 1981). Although *D. tenuis* is treated as a valid name by Keen and Benston

(1944), Moore (1969b) places the genus *Diodus* in synonomy under the genus *Polymesoda*. The author chooses to follow Keen and Benston (1944), retaining the name *Diodus tenuis*. *D. tenuis* is a corbiculid and its autecology is therefore inferred from the genus *Corbicula*.

Glycymeris sp.

Glycymerids are indicative of shallow water, normal marine environments (Black, 1970). Modern glycymerids lack siphons and therefore must live very close to the sediment/water interface (Black, 1970). They live shallowly buried, some barely covered by the sediment, often with the posterior end of the shell exposed (Stanley, 1970). Stanley studied *Glycymeris pectinata*, a glycymerid that lives just below mean low tide in gravelly, carbonate sands off the coast of Florida. This species is a shallow-burrowing, non-siphonate suspension feeder that crawls for considerable distances before achieving burial.

Abundant fossil glycymerids are found in recurrent Eocene assemblages of shallow shelf environments at depths of between 10 and 30 m. These ancient glycymerids were also shallowly buried suspension feeders (McKerrow, 1978).

Glycymeris sp. in the study area is a small (averaging 9 mm in length) disc-shaped species. The shell is moderately inflated and the valves have numerous radial ribs. It is inferred to have lived in a shallow water, normal marine environment, where it was living shallowly buried and suspension feeding.

Mactrid

The mactrid found in the study area is interpreted to have had the same life habits as modern mactrids (see discussion of ?*Pteroluter*).

Mytilus sp.

Living and fossil species of *Mytilus* are found in fresh water to normal marine deposits (Moore, 1969a). *Mytilus* from the coast of western North America lives today intertidally to 40m (Keen and Coan, 1974). Living and fossil species of *Mytilus* suspension feed (Stanley, 1970; Black, 1970; McKerrow, 1978). Stanley (1970, 1972) studied the life habits of the modern mussel *Mytilus edulis*, and found that it prefers the intertidal zone, where it is exposed to strong wave action. *M. edulus* attaches to rocks or shells by means of a byssus. This species also occurs in the shallow sublittoral zone, and frequently in muddy estuaries or lagoons in which salinity is lower than that of normal sea water (Black, 1970). Thus, *M. edulis* occurs in normal marine waters in the littoral and shallow sublittoral zones, and in brackish water estuaries.

Mytilus sp. from the study area occurs with mollusks indicative of a brackish-water environment and is inferred to have had the same life habits as *M. edulis*.

Nucula sp.

Nucula from the coast of western North America lives at depths ranging from 10 to 2,000 m (Keen and Coan, 1974). Nearly all nuculaceans live subtidally (Stanley, 1970). Modern and ancient members of the genus *Nucula* are shallow-burrowing infaunal deposit feeders (Stanley, 1970; McKerrow, 1978). Like *Glycymeris*, nuculids have no siphons and therefore must live shallowly buried near the water/sediment interface. Modern *Nucula* burrows slowly and remains relatively sessile once buried (Moore, 1969a). Nuculids show a strong preference for fine-grained substrates where they collect food particles from the sediment with appendages of the labial palps called proboscides (Moore, 1969a). Stanley (1970) studied the life habits of *Nucula proxima* and found it to be a moderately rapid burrower that is seldom found at depths of burial greater than 1 cm. *N. proxima* prefers muddy substrates and sheltered subtidal conditions.

Nuculids may derive part of their food supply from suspension feeding (Stanley, 1970), but because so many of their adaptations are associated with deposit feeding, suspension feeding is certainly only a secondary food-gathering mechanism (Stasek, 1965).

Nucula sp. of the present study occurs with mollusks that live in shallow water, normal marine environments, thus it is inferred that *Nucula* sp. also lived in a shallow water normal marine environment. It lived subtidally, like its ancient and modern counterparts, shallowly buried, where it was deposit feeding.

Nuculana (Saccella) gabbii, Nuculana (Scaeoleda) sp., Nuculana sp.

Species of *Nuculana* from the coast of western North America live today at depths of 5 to 3,660 m (Keen and Coan, 1974). Modern members of the genus *Nuculana* are siphonate deposit feeders (Stanley, 1970; Moore, 1969a) that live shallowly buried (Carole Hickman, oral commun., 1981). Many of the nuculanids' adaptations are associated with deposit feeding (Stasek, 1965). However, Stasek also stated that nuculanids may be suspension feeding as a secondary means of obtaining food. This belief is consistent with Stanley's observation that many shallow water deposit feeders derive part of their food supply from suspension feeding. *Nuculana* is a moderately fast burrower, but remains stationary once buried (Moore, 1969a). Nuculanids show a strong preference for fine-grained substrates (Moore, 1969a).

Nuculana (*Saccella*) *gabbii* in the present study is found in siltstone and sandstone at several localities. Since so many of its adaptations are associated with deposit feeding, it is inferred that this ancient *Nuculana* was a deposit feeder that lived shallowly buried. However, *N.* (*Saccella*) *gabbii*, when it occurs in clean sands, may have supplemented its food supply by suspension feeding.

Periploma sp.

Species of the genus *Periploma* from the coast of western North America live today at depths of 20 to 90 m (Keen and Coan, 1974). Inferences can be made as to the life habits of ancient *Periploma* from the shape and convexity of living *Periploma*, since these characteristics are closely correlative with depth of burrowing (Moore, 1969a). Deeper burrowing bivalves are generally less convex and more elongate. *Periploma* sp. in the present study has an elongate, slightly convex shell; characteristics similar to *Mya* and *Panope*, which are moderately deep burrowing genera.

Stanley (1970) stated that all marine deposit feeders belong only to four shallow water families, the protobranch Nuculidae and Nuculanidae, and the heterodont Semelidae and Tellinidae. Thus, *Periploma* sp. of the present study is inferred to have been a suspension feeder. The internal mold of *Periploma* sp. from the study area indicates that this species was an elongate form; thus, following Moore's interpretation, this species is inferred to have lived at moderate to deep depths within the substrate.

Pitar sp., ?Pitar sp.

Modern species of *Pitar* are suspension feeding, siphonate venerids that live infaunally (Moore, 1969a; McKerrow, 1978). Species from the coast of western North America are found living at depths of 25 to 185 m (Keen and Coan, 1974). *Pitar* is a common constituent of Eocene, shallow sublittoral, sandy clay communities, where they lived shallowly buried (McKerrow, 1978).

Pitar sp. from the study area is interpreted to have lived like its modern and ancient counterparts, as an infaunal, shallowly buried suspension feeder.

?Pteroluter n. sp.

This mactrid was identified by LouElla Saul, Los Angeles County Natural History Museum. After examining several specimens she concluded that ?*Pteroluter* n. sp. "has many characteristics in common with *Pteroluter*, including, no posterior laterals, posteriorly directed beaks, well filled triangular 2b, external ligament on alate nymph, and internal ligament in spoon shaped depression. It differs from *Pteroluter* in having only one anterior lateral in each valve, a condition, however, that could be derived from *Pteroluter* by the elimination of one anterior lateral, thus following a common mactrid trend of hinge concentration."

Members of Mactridae (*Mactra*, *Tresus*, *Raeta*) from the coast of western North America live intertidally to 30 m, in sand (Keen and Coan, 1974). The Mactracea are one of the most highly diversified superfamilies; they display many adaptive features for burrowing in soft substrates (Stanley, 1970). One adaptive feature many mactrids exhibit is a triangular anterior-ventral shell margin, a feature usually associated with a rapid-burrowing habit (Stanley, 1970). Although some mactrids are shallow burrowers (*Spisula*, *Mesodesma*, *Mulinia*, *Rangia*), *Mactra fragilis* is a moderately deep burrower which has a pointed, triangular shell (Stanley, 1970). *M. fragilis* lives intertidally and in shallow subtidal environments, where it appears to be restricted to grassy bottoms and sandy substrata.

?*Pteroluter* n. sp. is inferred to have been an infaunal suspension feeder that lived in an intertidal or shallow subtidal environment. The burrowing depth of ?*Pteroluter* n. sp. cannot be determined, since burrowing depth varies from shallow to deep in mactrids, however, ?*Pteroluter* n. sp. has a pointed triangular shell which suggests a rapid, moderate to deep burrowing habit.

Solen sp.

Species of Solen from the coast of western North America live intertidally to depths of 75 m (Keen and Coan, 1974). Members of the genus live infaunally, in intertidal and shallow subtidal sands (Black, 1970; Stanley, 1970) in which they burrow rapidly and deeply (Moore, 1969a; Stanley, 1970). The smooth, compressed shell, fused siphon, and foot modified for rapid digging, indicate that Solen is adapted to rapid, deep burrowing (Black, 1970; Moore, 1969a). In the intertidal zone, members of the genus Solen suspension feed while at the top of their burrows and dig down when the tide goes out (Black, 1970).

Solen sp. from the study area is found associated with mollusks that lived in a subtidal environment. This species is interpreted to have lived as an infaunal, deeply buried suspension feeder in a subtidal environment.

Spisula sp.

Modern species of Spisula live intertidally to 100 m, in sand of exposed beaches, bays, tidal channels, and sublittoral shelves (Keen, 1958; Stanley, 1970). Fossil and living members of the genus Spisula are suspension feeders, living buried at moderate depths in sand substrata (Stanley, 1970; McKerrow, 1978).

Spisula sp. of the present study may include more than one species, but specific identifications could not be determined. Species present (one or more) in the study area are inferred to have been suspension feeders that lived buried at moderate depths in sandy substrates in a shallow sublittoral shelf environment.

Tellina n. sp.? aff. Givens T. townsendensis, Tellinia. sp.

Studies of modern species of Tellina indicate that they live in a variety of environmental settings. Modern representatives of the genus Tellina from the coast of western North America live intertidally to depths of 440 m, in silt and sand (Keen and Coan, 1974). Stanley (1970) has determined that living species live both within the intertidal zone and shallow subtidal zone. In the intertidal zone, Tellina burrows deeply to avoid unfavorable conditions at low tide. In the subtidal zone, Tellina lives shallowly buried in protected bays or lagoons, in muddy or muddy sand substrates. In areas affected by tidal currents, Tellina lives in coarse, clean sands (Stanley, 1970).

Although McKerrow (1978) and Stanley (1970) consider members of the genus Tellina to be siphon-feeding deposit feeders, Stanley (1970) believes that they may also derive part of their food supply by suspension feeding, but always as a secondary means of gathering food. Some species of Tellina employ suspension feeding as their primary means of obtaining food (Carole Hickman, oral commun., 1981).

Tellina n. sp.? aff. Givens T. townsendensis is a thin-shelled, elongate tellinid that occurs in the study area with Tellina sp., in clean, fine-grained sandstone. This species is morphologically similar to Tellina listeri, studied by Stanley (1970). T. listeri is a rapid burrower that inhabits coarse, clean subtidal sands swept by moderately strong currents. Stanley (1970) assumed T. listeri to be a deposit feeder.

Tellina sp. is an elongate form, similar to T. n. sp.? aff. Givens T. townsendensis and Tellina listeri. Its autoecology is, therefore, inferred to be the same as T. listeri.

Since members of the genus Tellina are capable of both deposit feeding and suspension feeding, it seems reasonable they would mainly employ that mechanism which is more efficient for the substrate they live in. Thus, T. n. sp.? aff. Givens T. townsendensis would find it more efficient to suspension feed in clean sands in which it lived, and is, therefore, inferred to have been primarily suspension feeding in a subtidal environment of moderate energy, where it probably lived moderately or deeply buried.

Gastropoda

Architectonica sp.

Architectonica is a mesogastropod with a rhipoglossan radula (Moore, 1960) which is suited for grazing (Carole Hickman, oral commun., 1981). It is an epifaunal (Taylor, 1970), herbivorous detritus feeder, which feeds on marine algae or leaves of plants (Carole Hickman, oral commun., 1981).

Architectonica in the study area occurs with mollusks that are interpreted to have lived in a shallow, sublittoral shelf environment. This fossil species is inferred to have been an epifaunal, herbivorous detritus feeder.

Buccinid

Modern buccinids live in sublittoral, bathyal, and abyssal environments. Buccinum, a genus belonging to the Buccinidae, lives today on the coast of western North America at depths ranging from 10 to 2,930 m (Keen and Coan, 1974). Buccinum is an epifaunal carnivore with a long proboscis and narrow rachiglossate radula adapted for boring through the shells of living prey such as barnacles or bivalves, or eating the bodies of carrion (Moore, 1960). Modern Buccinidae are carnivorous but "are more scavengers than active predators, content to feed on dead fish and other scraps" (Keen, 1958). The buccinid from the study area is inferred to have had the same life habits as its modern counterparts. It is found in an assemblage with mollusks that lived in a sublittoral environment, and is therefore interpreted to have lived sublittorally also.

Calyptraea sp.

Calyptraea from the west coast of western North America live today intertidally to depths of 140 m, on rocks (Keen and Coan, 1974). Some members of the family Calyptraeidae are ciliary feeders, drawing fine bottom deposits into the mantle cavity with the inhalant current and consolidating phytoplankton (Moore, 1960). Thus, Calyptraea is probably a ciliary, deposit-feeding herbivore. Calyptraea aperta is an Eocene, ciliary-feeding species which inhabited a nearshore, shallow water shelf environment in water 10 to

30 m deep. *C. aperta* probably lived in groups attached to empty shells (McKerrow, 1978). *Calyptraea* sp. in this study is inferred to have lived the same way as modern and ancient *Calyptraea*.

Cancellaria sp.

Species of *Cancellaria* from the west coast of North America live today at depths of 25 to 550 m (Keen and Coan, 1974). Living species of *Cancellaria* are epifaunal carnivores. Olsson (1970) concluded from the radular structure that cancellarids must feed on soft-bodied microorganisms. *Cancellaria* sp. in the study area is inferred to have had the same life habits as its modern counterparts.

Fusinus sp.

Fusinus lives today in subtropical water (Black, 1970). *Fusinus* from the coast of western North America live today intertidally to depths of 185 m (Keen and Coan, 1974). Recent species of *Fusinus* are epifaunal carnivores (Carole Hickman, oral commun., 1981). *Fusinus* sp. in the study area is inferred to have lived in the same way as living species of the genus.

Gemmula sp.

Gemmula is a member of the subfamily Turrinae (family Turridae). Turrinae habitate waters to depths of 4,020 m (Keen and Coan, 1974). The genus is of worldwide distribution (Hickman, 1976). Members of the family Turridae are considered to be epifaunal, predatory carnivores that eat mainly polychaetes and other soft-bodied invertebrates (McKerrow, 1978). *Gemmula* sp. from the study area is inferred to have also been an epifaunal carnivore that fed principally on polychaetes and other soft-bodied invertebrates.

Molopophorus californicus

Molopophorus californicus is a member of an extinct genus of the family Buccinidae. Living members of Buccinidae are epifaunal carnivores (Moore, 1960); they are more scavengers than active predators, content to feast on dead fish and other scraps (Keen, 1958). *M. californicus* is inferred to have lived in the same way as modern members of the family Buccinidae.

Naticid

Natica from the coast of western North America lives today intertidally to depths of 1,645 m, on mud (Keen and Coan, 1974). Members of the superfamily Naticacea are restricted to soft substrates (Moore, 1960). Naticids are highly active, specialized, carnivorous gastropods that generally feed upon infaunal prey, both sedentary and motile (Moore, 1960; Taylor, 1970). They are usually infaunal, moving through the sand just below the surface, feeding upon infaunal bivalves and occasionally upon gastropods when the need and opportunity arises (Paine, 1963; Moore, 1960; Black, 1970). Naticids generally bore when they and the prey are buried in the sand, secreting acid to soften the shells of their prey and extracting the soft parts for food (Taylor, 1970; Moore, 1960). Ancient members of the family Naticidae also fed upon infaunal bivalves, and occasionally upon epifaunal bivalves and gastropods (Taylor, 1970).

The naticids in the study area probably represent more than one species. It is inferred that these naticids also lived infaunally, preying mainly upon small bivalves.

Potamidid

Living members of the family Potamididae typically occur in swamps, estuaries and lagoons in tropical and subtropical areas where salinities are lower than that of normal sea water (Keen, 1958; Black, 1970). *Potamides vagus* was a common constituent of Paleogene brackish water communities where it deposit fed, extracting food material (probably diatoms and blue-green algae) from the surface layer of sediment (McKerrow, 1978). The potamidid from the study area is inferred to have been an epifaunal detritus-feeding herbivore which lived in a shallow water brackish estuary, lagoon or brackish part of a delta.

Scaphander sp.

Modern members of the family Scaphandridae are exclusively carnivorous snails that often have very specialized diets (Yonge, 1939). The genus is now restricted to high latitudes off western North America (Hickman, 1976). *Scaphander* sp. is found in the study area with mollusks that are indicative of normal marine, shallow water shelf environments.

Turrid sp.

Fossil species of the family Turridae are abundant in Eocene and Oligocene rocks, particulary in deep-water facies of the Pacific Northwest (Hickman, 1976). Some subfamilies have a toxoglossate radular structure, while others have a non-toxoglossate radular structure (Hickman, 1976). Modern and ancient members of the family Turridae are considered to be epifaunal, highly specialized predatory carnivores, eating mainly polychaetes and other soft-bodied invertebrates (McKerrow, 1978).

Turrid sp. from the study area is inferred to have been an epifaunal carnivore that fed principally on polychaetes and other soft-bodied invertebrates. Since its subfamily is unknown, its radular structure cannot be ascertained.

Turritella buwaldana, *Turritella buwaldana* subsp. *coosensis*?

Turritella buwaldana is found at several localities in the present study area, in siltstone and mudstone. A few fragments questionably identified as *Turritella buwaldana* subsp. *coosenesis*? were found at UCB loc. D-8151. Although the author did not find *Turritella merriami* at these localities, Huey (1948) reported both *T. merriami* and *T. buwaldana* from a fine-grained sandstone at locality VI, at approximately the same horizon as the author's UCB loc. D-8157. Except for the occurrence in Huey's locality, *T. buwaldana* appears to favor a finer-grained substrate than *T. merriami*.

Modern Turritella most frequently occurs in tropical waters at depths between 26 and 60 m (Keen, 1971; Keen and Coan, 1974). The autoecology of *T. buwaldana* and *T. buwaldana* subsp. *coosensis*? is inferred to have been the same as *T. merriami*. Like all turritellas, *T. buwaldana* and *T. buwaldana* subsp. coosensis? are inferred to be semi-infaunal suspension feeders that lived fixed or slowly crawled on the substrate surface.

Turritella merriami

Modern representatives of the genus Turritella live primarily in offshore waters of tropical and subtropical America (Moore, 1960). Turritellas live today in water depths of 20 to 185 m on the coast of western North America (Keen and Coan, 1974). Turritella prefers normal marine, upper sublittoral environments, and characteristically does not inhabit littoral regions (Merriam, 1941). The genus cannot tolerate brackish water (Moore, 1960). However, Stewart (1949) speculated that the heavily carinated Turritella merriami may have lived in an environment subject to frequent physical changes in or near water of low salinities. Merriam (1941) considers the living species Turritella communis to be a deposit feeder, living fixed and buried in the sea floor, feeding on fine bottom deposits. Keen (1971) stated that modern turritellas living in tropical west America are detritus feeding on fine bits of seaweed and other fragments. Black (1970), and Yonge (1939), however, considered T. communis to be an infaunal suspension feeder.

Fossil turritellas are interpreted to be suspension feeders, living semi-infaunally (partly buried), either fixed or slowly crawling through the substrate surface (McKerrow, 1978). The majority of fossil turritellas are found in moderately fine- to fine-grained sandstones.

Turritella merriami is found in the study area in fine-grained sandstone, where it is interpreted to have lived semi-infaunally, either fixed in the sediment or creeping through the sand. This species is interpreted to have been a suspension feeder.

Whitneyella sp.

Members of the genus Whitneyella were inferred to be epifaunal, carnivorous neogastropods (Carole Hickman, oral commun., 1981); therefore Whitneyella sp. from the Tesla area is inferred to have had the same life habits.

Scaphopoda

Dentalium sp.

Scaphopods live today in waters of normal salinity, in sublittoral and bathyal environments; only a few species inhabit the littoral zone (Moore, 1960). Modern species of Dentalium from the coast of western North America live at depths of 5 to 2320 m (Keen and Coan, 1974), where they live partly embedded in mud or sand on the sea bottom, with only the smaller, posterior end protruding into the water (Moore, 1960).

Dentalium is a common constituent of Eocene marine mud communities, where it lived shallowly infaunal, detritus-feeding on benthic foraminifers (McKerrow, 1978). Scaphopods are size-selective, removing foraminifers and similar organisms from the sediment (Carole Hickman, oral commun., 1981). Dentalium sp. in the study area is inferred to have lived in the same way as its modern and ancient relatives.

Paleoecology

Previous sections discussed the lithologic and stratigraphic characteristics that define the three facies of the Tesla Formation and the inferred depositional environments of each. The preceding section described the inferred autoecology of the fossils found in each facies. This section lists the fossils found, the details of fossil preservation, and the lithology of each fossiliferous assemblage found in each facies. This information is then used to develop a paleoecological interpretation of the fossil assemblages and depositional environments of these fossiliferous strata in each facies.

Paralic facies

UCB locs. D-8173 and D-8174

Anomia sp., *Corbicula* sp., *Corbula* n. sp. aff. *C. pozo*, *Mytilus* sp., and an indeterminate potamidid were identified from UCB loc. D-8173. ?*Corbicula* sp.,*Corbula* n. sp. aff. *C. pozo*, and *Mytilus* sp. were identified from UCB loc. D-8174.

UCB localities D-8173 and D-8174 were collected from an exposure limited to 1 m along strike and 1.5 m perpendicular to strike. The beds are vertical and the hillside has a heavy soil cover. UCB loc. D-8174 was collected 1 m stratigraphically higher than UCB loc. D-8173. A medium-grained, white, "salt and pepper" sandstone bed separates the localities. The lithology of UCB loc. D-8173 is a gray, fine-grained muddy sandstone that weathers dark gray. The bed is cemented by calcite and contains mostly small fragments of badly leached shell hash.

The fossils from UCB loc. D-8173 are randomly oriented in the sediment. *Corbicula* sp. valve molds and *Corbula* n. sp. aff. *C. pozo* are mostly whole, but disarticulated. All specimens of *Mytilus* sp. are articulated, but only the internal molds were found. Internal and external molds of a few potamidids are all that remain. *Anomia* sp. is represented only by small nacreous fragments of shell material.

UCB loc. D-8174 is a gray, silty mudstone bed 10 cm thick. Exposed surfaces are coated with a light yellow powdery material (jarocite?). The bed is a shell hash and contains only external and internal molds. Most valves molds are fragmented and disarticulated. Only internal molds of *Mytilus* sp. were found.

UCB loc. D-8150

Anomia sp., *Corbula* n. sp. aff. *C. pozo*, *Corbula* sp., ?*Corbula* sp., ?*Diodus tenuis*, ?*Pteroluter* n. sp., an indeterminate mactrid, pelecypod, buccinid, potamidid, and an indeterminate neogastropod that resembles *Tornatellacea pinguis*, were identified from UCB loc. D-8150.

The exposure is a large, isolated block on the side of a soil-covered hill. The block may be out of place, but if so, it did not move far from its stratigraphic position. The rock is a well-indurated, gray, fine-grained sandstone, cemented by calcite.

The fossils are randomly oriented in the sediment. Shell material is abundant and well preserved. Articulated and disarticulated valves, and valve fragments are present, but proportions of each could not be determined because the valves could not be extracted from the matrix. Shell fragments appear, however, to exceed the number of whole valves. *Anomia* sp. is commonly cemented to other *Anomia* sp. shells. Several potamidids are whole, or nearly whole; no apertures are exposed on the surfaces; apices, when exposed, are almost always intact.

UCB loc. D-8149

Anomia sp., *Corbula* n. sp. aff. *C. pozo*, *Corbula* sp., *Diodus tenuis*, *Mytilus* sp., an indeterminate potamidid, and an indeterminate pelecypod were identified from UCB loc. D-8149.

The outcrop consists of a buff, fine-grained sandstone exposed on a cliff in a roadcut. The bedding is nearly vertical and the outcrop can be traced laterally for about 2 m.

The rock is extremely friable and is weathered to a buff color. Abundant shell material is present, but most of the shell material consists of densely packed fine fragments. The material is easily broken to expose abundant whole valves of *Corbula* sp. and *Corbula* n. sp. aff. *C. pozo*. Most *Corbula* sp. and *Corbula* n. sp. aff. *C. pozo* valves are oriented concave down and parallel to the bedding, but randomly oriented within the bedding plane. Only external and internal molds of *Diodus tenuis* and the potamidid remain. *Anomia* sp. shell material is moderately well preserved; small and large valves are present and are often found in groups, side by side.

UCB loc. D-8147

Anomia sp., *Corbula* n. sp. aff *C. pozo*, *Corbula* sp., *Diodus tenuis*, *Mytilus* sp., ?*Pitar* sp., an indeterminate pelecypod, and an indeterminate potamidid were identified from UCB loc. D-8147.

The bed is exposed in a roadcut and can be traced for 3 m along strike. The bed is vertical, 1 m thick, and highly fossiliferous. Internal bivalve molds of *Diodus tenuis* are weathering out and can be easily spotted on the ground. The lithology is a light gray, fine-grained sandstone that weathers light brown. The bed is mostly cemented by calcite; noncemented friable pockets occur infrequently.

The fossils are randomly oriented in the sediment. Shell density is moderate. Shell material is present, but generally is badly leached and crumbles when the rock is broken. *Anomia* sp. shell material is moderately well preserved. Most of the valves are articulated. Valves of *Diodus tenuis* are almost always found articulated; a few were observed to be partly open with the valves filled with sandstone. *Corbula* sp. valves and *Corbula* n. sp. aff. *C. pozo* valves are found articulated and disarticulated with many valves whole. Three specimens of *Mytilus* sp. were found, but only one was articulated and whole. Valve nesting is common. *Anomia* sp. is frequently cemented to other *Anomia* sp. valves.

UCB loc. D-8148

Anomia sp., ?*Corbicula* sp., *Corbula* n. sp. aff. *C. pozo*, *Corbula* sp., *Diodus tenuis*, an indeterminate potamidid, and an indeterminate naticid were identified from UCB loc. D-8148.

UCB loc. D-8148 is from a roadcut exposure where the beds are nearly vertical. The bed is 0.5 m thick and can be traced for approximately 2 m along strike. The rock is a light gray, fine-grained sandstone. The bed is mostly cemented, but is friable in places.

Fossils are randomly oriented in the rock. Fossil density is moderate. Very little shell material is present; it is either crumbly or, where very thin, powdery. *Anomia* sp. shell material, however, is moderately well preserved. Pelecypod valves are mostly disarticulated; a few *Corbula* sp. and *C.* n. sp. aff. *C. pozo* valves are articulated. *Anomia* sp. is commonly found clumped together in groups, attached to other *Anomia* sp. shells.

UCB loc. D-8152

Anomia sp., *Callista* (*Costacallista*) *hornii vokesi*? Squires, ?*Corbicula* sp., *Corbula* sp., and an indeterminate potamidid were identified from UCB loc. D-8152.

UCB loc. D-8152 is located in a roadcut exposure in which the beds are nearly vertical. The fossils are found in 2 m thick siltstone bed traceable for 3 m along strike. The rock is a moderately indurated, brown, sandy siltstone. Surfaces are stained orange by limonite.

No shell material is preserved. Shell molds are randomly oriented in the sediment. Fossil density is moderate. All valves are disarticulated but most valves are whole. Nesting of shell molds is common.

Paleoecology of the Paralic Facies

Within the paralic facies in sandstone member, the presence of one or more of the taxa *Corbicula* sp., *Diodus tenuis*, and an indeterminate potamidid indicates brackish-water conditions (Keen, 1958; McKerrow, 1978). *Anomia* sp. and *Corbula* n. sp. aff. *C. pozo* occur in all but one locality; *Mytilus* sp. occurs in all but three. These taxa are able to tolerate both normal marine and brackish water conditions (Ladd, 1951; Moore, 1969a; Keen, 1971; Keen and Coan, 1974), but their occurrence with genera restricted to a brackish water environment suggests they lived in brackish water. A sublittoral shelf is indicated for these assemblages, as all genera found inhabit the inner sublittoral zone.

The fossil assemblage from UCB loc. D-8150 represents a mixed assemblage derived from two different habitats. The brackish water inhabitants ?*Diodus tenuis* and the potamidid occur with ?*Pteroluter* sp., and a buccinid, mollusks that indicate normal marine conditions. This composite fauna indicates deposition in a marginal marine environment, probably in or near a delta or bay. Normal marine mollusks may have washed shoreward or laterally into a brackish water part of a delta, or, more likely, the brackish water mollusks may have been transported outward or laterally into normal marine waters. In either case, deposition probably occurred in a shallow-marine or paralic environment in or near a delta or bay.

Substrate types vary among the assemblages in this facies, but none are inconsistent with the substrate requirements for genera found in the assemblages. All the assemblages are dominated by one or two genera of bivalves, usually *Corbula* or *Diodus*, and virtually all the bivalves are inferred to be suspension feeders. The potamidid is the only inferred detritus feeder. An indeterminate buccinid and an indeterminate neogastropod are the only inferred carnivores in the assemblages. The dominance of suspension feeders indicates a moderate or high energy regime with ample amounts of suspended organic matter.

Although no fossils were found in strata belonging to the paralic facies in the upper sandstone member (uppermost Tesla strata) during the present study, Stewart's (1949) identification of *Viviparus* in these strata suggests deposition in a fluvial or deltaic environment, as were some strata of the paralic facies in the lower sandstone member.

Shallow-marine Facies

UCB locs. D-8158 and D-8159

An indeterminate pelecypod fragment and *Turritella buwaldana* were identified from UCB loc. D-8158. *Nuculana* sp., two indeterminate pelecypods, and an indeterminate neogastropod were identified from UCB loc. D-8159. UCB loc. D-8159 is 5 m upsection of UCB loc. D-8158, in float material. UCB locs. D-8158 and D-8159 are from nearly the same horizon and are, therefore, discussed together.

UCB loc. D-8158 is a poorly exposed mudstone bed that can be traced laterally or vertically for only 0.5 m. The lithology of both localities is a gray, silty mudstone. The sediment is moderately indurated, but a cemented fossiliferous zone occurs in the material collected at UCB loc. D-8159.
Shell material is not preserved at either locality; external and internal molds are all that remain. The fossils occur in layers between non-fossiliferous or sparsely fossiliferous layers. Bivalve and gastropods molds are oriented parallel to bedding with the bivalve molds mostly oriented concave up. The bivalve molds are all whole but are disarticulated. The neogastropods molds are all whole. All *Turritella buwaldana* molds are fragmented, but most apices are present on the molds. All the fossils are slightly crushed. The ornamentation on *T. buwaldana* is beautifully preserved on the external molds.

UCB loc. D-8153

Nuculana sp., *Turritella buwaldana*, three indeterminate pelecypods, and an indeterminate neogastropod were identified from this assemblage.

The outcrop is in a roadcut exposure in a poorly exposed mudstone. UCB loc. D-8153 is about 7 m stratigraphically below UCB loc. D-8151. Fossil sparsity and extremely poor preservation dictated collecting only a small amount of material. Exposures were too poor to trace the bed laterally or to determine the thickness of the fossiliferous bed.

The rock is a moderately indurated light gray mudstone. Shell material is not preserved; only external and internal molds remain. Most *Turritella buwaldana* and *Nuculana* molds are fragmented and crushed. Individual molds are randomly oriented in the sediment, but concentrated in pockets. Most of the indeterminate pelecypod valve molds are whole, all are disarticulated.

UCB loc. D-8151

Acila (*Truncacila*) *decisa*, an indeterminate carditid, *Nuculana* (*Saccella*) *gabbii*, *Periploma* sp., *?Pitar* sp., and an indeterminate pelecypod were identified from UCB loc. D-8151. Gastropods found include *Fusinus* sp., *Gemmula* sp., *Scaphander* sp., *Turritella buwaldana*, *Turritella buwaldana* subsp. *coosensis?*, turrid sp., an indeterminate naticid, and an indeterminate gastropod. *Schizaster* sp. and a crab claw were also found at this locality.

The outcrop is a nearly vertical, sparsely fossiliferous bed 0.3 m thick. The bed can be traced laterally for 3 m. The lithology is a light gray, muddy siltstone. The rock is moderately indurated and weathers to a medium brown color. Because fossils are sparse, this assemblage was collected over the bed's entire thickness for a distance of 1 m along strike.

No shell material is present. Molds of whole valves, nearly whole valves, and valve fragments are all that remain. The molds commonly occur in isolated patches or pockets. Most of the turritellids are clustered in this manner. Valve molds are oriented with the axis of coiling predominantly parallel or nearly parallel to bedding, mostly concave down. The majority of gastropod molds are oriented roughly parallel to bedding. Most of the valve molds are disarticulated, but one articulated *?Pitar* sp. mold was observed, and one indeterminate pelecypod mold was found in butterfly position. All molds of *Turritella buwaldana*, *T. buwaldana* subsp. *coosensis*? are fragmented; other gastropod molds are whole. Abundant echinoid mold fragments occur in the sediment. One external mold of *Schizaster* sp. was nearly whole. Almost all the molds are crushed. The delicate ornamentation of *Acila decisa*, *T. buwaldana*, *T. buwaldana* subsp. *coosensis*? and *Nuculana* (*Saccella*) *gabbii* is excellently preserved in the matrix. Plant fragments are abundant.

Paleoecology of the Shallow-marine Facies

The presence of the genera as *Acila*, *Nuculana*, *Periploma*, *?Pitar*, and *Turritella* at several localities in this facies indicates that these strata were deposited in a nearshore, shallow marine environment. Living species of these genera commonly occur in inner sublittoral depths along the Pacific Coast of North America (Schenck, 1936; Merriam, 1941; Keen, 1958; Keen and Coan, 1974). The presence of *Fusinus* sp., an indeterminate naticid, and an indeterminate carditid suggests an intertidal to subtidal environment. Because all the genera found in this facies tolerate sublittoral depths, a sublittoral shelf environment is indicated for these assemblages.

Some of the infauna require a soft substrate (naticid, *Schizaster*), (Moore and others, 1952; Moore, 1960). *Acila* and *Nuculana* prefer a fine substrate. The presence of *Nuculana* (*Saccella*) *gabbii* and *Acila* (*Truncacila*) *decisa* in mudstones, silty mudstones and siltstones within this facies indicates deposition in a low-flow regime, below wave base, in a calm, or moderately calm protected environment, such as the edge of a delta where fine sediments accumulate. The genera *Nuculana* and *Turritella*, and the naticid are typically associated with a protected locale, characterized by a mud bottom with slight current action.

Middle Shoreface Facies

UCB loc. D-8154

Nuculana sp., *Solen* sp., *Spisula* sp., *Tellina* n. sp.? aff. Givens *T. townsendensis*, *Tellina* sp., an indeterminate pelecypod, *Whitneyella* sp., an indeterminate naticid, and a crab claw were identified from UCB loc. D-8154.

UCB loc. D-8154 was collected from a sandstone bed over a distance of 10 m. The rock is a light gray, fine-grained micaceous sandstone that weathers orangish-brown. Some surfaces have hard, orange-colored limonitic rinds.

Glauconite is present but not abundant. The rock has a platy fracture and breaks parallel or nearly parallel to bedding. Stratification is faint; there appears to be little, if any, bioturbation.

Fossiliferous and nonfossiliferous layers are present; the majority are non-fossiliferous. Within the fossiliferous layers, density commonly is sparse, but a few layers contain moderately dense, poorly preserved shell material. Tellinid ribbing is only rarely well-preserved. Shell fragments constitute less than 20 percent of the shell material. All pelecypod valves are disarticulated and most are whole. Gastropods are also whole. The majority of pelecypod valves and gastropod shells are aligned parallel to the bedding surface, but are randomly oriented on the surface. Valves are oriented mostly concave down in some layers, while in others they are oriented concave up and concave down in approximately equal numbers.

UCB locs. D-8155 and D-8170

Nucula sp., *Nuculana* (*Saccella*) *gabbii*, *Spisula* sp., *Molopophorus californicus*, an indeterminate naticid, an indeterminate neogastropod, and *Dentalium* sp. were identified from UCB loc. D-8155. *Nucula* sp., *Nuculana* (*Saccella*) *gabbii*, *Solen* sp., *Spisula* sp., an indeterminate neogastropod, and *Dentalium* sp. were identified from UCB loc. D-8170.

These two localities were collected from beds at nearly the same stratigraphic horizon, but over a distance of 0.2 km. The rock is a limonite-cemented, brown fine-grained sandstone, weathered to an orange color. The rock has a platy character and breaks along the bedding plane. Some of the rock has a mottled appearance, presumably a result of bioturbation.

Shell material is rarely present in either assemblage; most of the fossils are preserved only as external molds. Fossil density is low, except where valve molds are occasionally concentrated in pockets. All pelecypod valves and valve molds are disarticulated, but most are whole. Gastropod internal molds are whole, while *Dentalium* molds are all fragmented.

UCB loc. D-8156

Nucula sp., *Nuculana* sp., *Solen* sp., *Spisula* sp., *Tellina* sp., an indeterminate pelecypod, *Cancellaria* sp., *Molopophorous californicus*, *Scaphander* sp., *Whitneyella* sp., an indeterminate buccinid, an indeterminate naticid, four indeterminate neogastropods, and *Dentalium* sp. were identified from UCB loc. D-8156.

The outcrop is a poorly exposed resistant bed on the nose of a ridge, approximately 65 m west of, and above Tesla Road. The bed is exposed discontinuously along strike for 20 m. The rock is a well-indurated gray, fine-grained sandstone that is cemented by calcite. Fracture surfaces are weathered orangish-brown.

Shell material is abundant, but most shells are worn. Most pelecypod valves are disarticulated, but whole or nearly whole; most gastropods are whole. The fossils occur in thin layers between non-fossiliferous or sparsely fossiliferous layers. Most of the valves are aligned roughly parallel to the bedding, but their long axes are randomly oriented within the bedding plane.

The valves are oriented concave down and concave up in approximately equal numbers. The coiling axes of the gastropod shells are aligned parallel to the bedding, but are randomly oriented within the bedding plane.

UCB loc. D-8172

Acanthocardia (*Schedocardia*) cf. *A. brewerii*, *Acila* (*Truncacila*) *decisa*, *Nuculana* sp., *Spisula* sp., two indeterminate pelecypods, *Turritella buwaldana*, an indeterminate neogastropod, an indeterminate gastropod, and *Dentalium* sp. were identified from UCB loc. D-8172.

Fossils were collected from muddy siltstone concretions in float scattered over a 200 m^2 area. All contain the same fauna and are lithologically distinctive from other float material present. The limonite-rich concretions are dark red on the surface, and reddish-orange to orange in the center.

No shell material is preserved and fossil molds are sparse. The fossils are randomly oriented in the rock. Most pelecypod valve molds are disarticulated and whole. All *Turritella buwaldana* molds are fragmented.

UCB loc. D-8157

Acanthocardia (*Schedocardia*) cf. *A. brewerii*, *Anomia* sp., *Brachidontes* (*Brachidontes*) *cowlitzensis*, *Glycymeris* sp., *Nuculana* sp., *Nuculana* (*Scaeoleda*) sp., *Pitar* sp., *Solen* sp., *Spisula* sp., *Architectonica* sp., *Calyptraea* sp., *Fusinus* sp., *Scaphander* sp., *Turritella merriami*, an indeterminate naticid, archeogastropod, and neogastropod, *Dentalium* sp., *Stephanophyllia* sp., and ?*Myliobatis* sp. were identified from UCB loc. D-8157.

The outcrop is an isolated block of gray, fine-grained sandstone, located near the top of the Tesla Formation, where it is in fault contact with the Cierbo Sandstone. The rock is extremely hard; it is cemented by a limonite-carbonate aggregate, and is weathered to an orange color. This block may have moved downslope from lower in the section, but a heavy soil covers the entire hillside, preventing lateral tracing of the exposure. If the block is out of place, it is not far out of place, and is, nevertheless, from near the top of the Tesla Formation in the study area.

Except for valves of *Anomia* sp., no shell material is present. External and internal molds are abundant, however, thin layers (presumably bedding layers) and large areas of the rock are devoid of fossils. Orientation of fossils in the matrix is generally random, however, a few *Turritella merriami* molds show a preferred orientation with their long axes aligned parallel to each other and apices pointed in the same direction. Most pelecypod valve molds are nearly whole; all are disarticulated. Molds of *T. merriami* are mostly whole. Almost always, the larger pelecypod valve molds of *Spisula* and *Solen* , and large naticid and *T. merriami* molds shattered when the rock was broken into smaller pieces. *T. merriami* apices are usually preserved in the internal molds; apertures could not be freed from the matrix, but are probably present. Many small *Glycymeris* molds are nested inside larger *Glycymeris*, *Pitar*, and *Spisula* molds.

Paleoecology of the Middle Shoreface Facies

The presence of the molluscan genera *Acanthocardia*, *Acila*, *Glycymeris*, *Nuculana*, *Pitar*, *Solen*, *Spisula*, *Tellina*, *Turritella*, *Cancellaria*, *Calyptraea*, *Fusinus*, and *Architectonica* indicates deposition in inner sublittoral depths. Living species of these genera commonly inhabit sublittoral environments (Schenck, 1936; Merriam, 1941; Keen, 1958; Keen and Coan, 1974). The presence of *Stephanophyllia* sp. also confirms a shallow shelf environment (Vaughan and Wells, 1943; Fitch 1964).

Strata containing fossil assemblages in this facies represent two different subenvironments within the inner sublittoral realm. The assemblage from UCB loc. D-8172 contains genera that prefer a protected habitat and mud and silt substrates. The muddy siltstone of UCB loc. D-8172 contains an assemblage of genera dominated by the infaunal deposit feeders *Acila (Truncacila) decisa*, *Nuculana* , and *Dentalium* . *A.* (*T.*) *decisa* and *Turritella buwaldana* occur only in this muddy siltstone assemblage, and not in the fine- and medium-grained sandstones that host the other middleshore faunas. In the shallow marine facies, *A.* (*T.*) *decisa* and *T. buwaldana* occur only in mudstones and siltstones. The character of the substrate (grain size, density, or the amount of available nutrients) appears to have restricted *A.* (*T.*) *decisa* and *T. buwaldana* to the finer grained mudstones and siltstones in both the middle shoreface and shallow-marine facies. The genera *Solen* and *Tellina*, which commonly inhabit moderate to high energy environments, are conspicuously absent from the muddy siltstone assemblage at UCB loc. D-8172. The muddy siltstone at this locality was probably deposited in a relatively low energy environment.

All other fossil assemblages (UCB loc. D-8154, D-8155, D-8170, D-8156, and D-8157) in this facies are from sandstone. They all contain the genus *Spisula* and some contain the genera *Tellina* and *Solen*. These genera prefer moderate to high energy flow-regimes. The coarser grained substrates and different fauna found in these assemblages suggest a higher energy environment than at UCB loc. D-8172.

The genera present in the middle shoreface facies suggest that the fauna of both subenvironments lived on a marine continental shelf. The fauna found at UCB loc. D-8172 probably lived at slightly deeper depths, or a more protected part of the shelf than the fauna from the other assemblages in this facies.

OTHER FOSSILS FROM THE TESLA FORMATION IN THE TESLA AREA

An examination was undertaken of published and unpublished macrofossil collections deposited at the University of California, Berkeley. These collections contain fossil mollusks from the Tesla Formation in the Tesla area, and include Huey's (1948) (locs. I-VI) collections from the study area. In addition to Huey's collections, three unpublished collections were examined; localities A-1355 and A-1353 collected by D.C. Shay in 1934; and UCB loc. B-5546, collected by Joy McFate in 1973. UCB loc. A-1355 is located outside of the field area, 3 km to the west of the Tesla site, in the Altamont quadrangle. This locality is included in this report because it contains fauna similar to the assemblage from UCB loc. D-8157, in this study and is near the Tesla area. A few other collections from the Tesla Formation in the Tesla area are present, but the locality information is either missing or too poorly described to locate them accurately. The material from these other collections was examined, however, and no new species were noted. Huey's, Shay's, and McFate's localities are plotted for reference on plate 1.

The purpose in examining these fossil collections was: (1) to augment the list of fossils found in the Tesla Formation in the Tesla area; and (2) to compare Huey's fossils and lithologies with localities collected at or near the same locality or stratigraphic horizon by the author. In addition to determining if any unreported fossils had been collected, better preserved fossils, if present, would aid the author in identifying poorly preserved material from the author's localities. Additional taxa may also help refine the age and environmental interpretation of Tesla strata. Huey's collections were also compared to the author's because Huey's published lists contained fewer taxa than localities collected at, or near the same locality by the author. The author wanted to determine the reason for this discrepancy.

From the onset, many problems became apparent. Material was meager in all of the collections; preservation was poorer than the author's material; and with one exception (UCB loc. B-5546), individual specimens were not identified.

The results of the author's examination of Huey's, Shay's, and McFate's collections are discussed below. Huey's (1948) fossil lists from localities I-VI (and corresponding UCB locality numbers) are reproduced in this section for reference. Fossils identified by the author from Huey's localities, including additional taxa found, are listed immediately following Huey's fossil list. Shay's unpublished collections contained identifications only on museum locality cards, necessitating identification of the fossil material by the author. McFate's unpublished locality contained two identified specimens of *Viviparus* cf. *V. paludinaetormis* and an indeterminate pelecypod mold. Notes on lithologies and preservational characteristics are included in the discussion of each locality.

Huey loc. I (UCB loc. A-3083)

Huey (1948) reported *Anomia inornata* and *Diodus tenuis* from this locality. The author identified *Anomia* sp., *Corbula* sp., *Diodus tenuis* (Gabb) Stewart, 1930, *Mytilus* sp., an indeterminate pelecypod, and an indeterminate gastropod from the material.

The material examined is a buff fine-grained sandstone cemented by calcite. Only *Anomia* shell material is preserved. The remaining mollusks are represented by internal and external molds. Valve molds are mostly disarticulated, but a few whole, small *Corbula* molds are present. *Anomia* sp., *Corbula* sp., and *D. tenuis* are abundant; *Mytilus* sp., the indeterminate pelecypod and the indeterminate gastropod are rare.

UCB loc. A-3083 is located near and at approximately the same horizon as UCB loc. D-8149. The lithology and fauna are similar to localities D-8149, D-8147, and D-8157.

Huey loc. II (UCB loc. A-3082)

Huey reported *Anomia inornata* and *Diodus tenuis* from this locality. The author identified *Anomia* sp., ?*Diodus tenuis*, an indeterminate pelecypod, and a potamidid.

The fossils are in a buff-colored, fine-grained sandstone. Only *Anomia* shell material is preserved. *Anomia* sp. is abundant, but only one fragment of ?*D. tenuis* was noted. The potamidid and indeterminate pelecypod are rare.

UCB loc. A-3082 is located in Mitchell Ravine, at approximately the same horizon as UCB loc. D-8173 of the present study. The lithology and fauna are similar to UCB locs. D-8149 and D-8148, therefore, UCB loc. A-3082 is interpreted to be from the same macrofaunal zone.

Huey loc. III (UCB loc. A-3080)

Huey reported only *Corbicula* n. sp.? from this locality. The author identified *Anomia* sp., ?*Corbicula* sp., *Corbula* sp., *Mytilus* sp., and an indeterminate gastropod from the material.

The fossils are in a hard, gray, sandy mudstone. Shell material is present but highly fragmented. ?*Corbicula* sp. is abundant; the remaining mollusks are rare.

UCB loc. A-3080 is located in Mitchell Ravine, no more than 20 m from UCB locs. D-8173 and D-8174. The fauna and lithology are similar to UCB locs. D-8173 and D-8174.

Huey loc. IV (UCB loc. A-3084)

Huey reported *Nuculana* cf. *N. gabbii* from this locality. The author did not find the genus *Nuculana* in the material, but identified *Fusinus* sp., *Turritella buwaldana* Dickerson, 1916, *Dentalium* sp., and an indeterminate pelecypod (not *Nuculana*) in the material.

The lithology is a gray? fine-grained sandstone, weathered to an orangish-brown. No shell material remains, but external molds are abundant. Small juvenile pelecypod molds and small molds of indeterminate neogastropods are abundant. Huey may have identified these small pelecypod molds as *Nuculana* cf. *N. gabbii*, but this seems unlikely since they are so poorly preserved.

UCB loc. A-3084 is located at approximately the same horizon as the author's UCB locs. D-8155, D-8156, and D-8157 and is interpreted to be from the same macrofossil zone.

Huey loc. V (UCB loc. A-3081)

Huey reported *Brachidontes cowlitzensis*, *Glycimeris* cf. *G. meganosensis*, *Pitar* sp., *Plagiocardium* cf. *P. brewerii*, *Spisula* sp., and *Turritella merriami* from this locality. The author identified *Brachidontes cowlitzensis* (Weaver and Palmer) Turner, 1938, *Glycymeris* sp., *Nuculana (Saccella) gabbii* (Gabb) Vokes, 1939, ?*Gari* sp., *Pitar* sp., *Spisula* sp., *Tellina* sp., an indeterminate carditid, and an indeterminate peleycpod from the material. The author also identified *Conus caleocius* Vokes, 1939, *Fusinus* sp., *T. merriami* Dickerson, 1913, *Scaphander* sp., an indeterminate naticid, and numerous, small, indeterminate neogastropod molds from Huey's material.

Although Huey (1948) described the locality as consisting of soft, tan sandstone, only one fragment was soft. The remainder of the material is cemented and is an extremely hard, gray, glauconitic, medium-grained sandstone.

Some shell material is present. The fossils are densely packed, and layers of shell hash occur. *Nuculana (Saccella) gabbii* is abundant, and many are oriented parallel to the bedding plane. Beautifully preserved specimens of *Turritella merriami* are common. Only one mold of *Conus caleocius* was found; *Fusinus* sp., *Scaphander* sp., a naticid, and small neogastropod molds are common.

UCB loc. A-3085 is the lowest occurrence of *T. merriami* in the Tesla Formation in the study area and is from a horizon nearly the same as, or slightly lower than UCB loc. D-8154. The lithology and fauna resemble those of UCB locs. D-8157 and D-8156.

Huey loc. VI (UCB loc. A-3085)

Huey reported *Acila gabbiana*, *Plagiocardium* cf. *P. brewerii*, *Tellina* cf. *T. lajollaensis*, *Turritella buwaldana* (mold), and *Turritella merriami* from this locality. The author identified *Acanthocardia (Schedocardia)* cf. *A. brewerii* (Gabb) Givens, 1974, *Anomia* sp., ?*Spisula* sp., ?*Pitar* sp., *Turritella buwaldana*, and *Dentalium* sp. from the material.

The rock is a hard, concretionary, gray? fine-grained sandstone, weathered to a reddish-orange color. Shell material is not present. Molds are small in size and are concentrated in pockets.

UCB loc. A-3085 is located at approximately the same horizon as UCB loc. D-8157 of the present study. Both Huey and the author noted that their localities may be from float (but not far out of place).

Shay loc. UCB A-1353

Although specimens in the collection lack identification labels, the museum's locality card lists *Corbula* sp., and *Mytilus* sp. from this locality. The author identified *Corbula* sp., ?*Gari* sp., *Pitar* sp., *Spisula* sp., a carditid, *Ficopsis remondii crescentensis* (Weaver and Palmer) Vokes, 1939, *Fusinus* sp., a naticid, and *Dentalium* sp. from the material in the collection.

The lithology is a gray, cemented, fine-grained sandstone. No shell material is present. Only internal and external molds are preserved. The author traversed the hill where this locality was collected, and found the entire hill to be littered with float chips which may have traveled from as far as a nearby ridgecrest. The precise stratigraphic position of this sample, therefore, could not be ascertained. It is, however, lower than UCB loc. D-8157 and no lower than UCB loc. D-8172 of the present study. UCB loc. A-1353 is interpreted to be from the same macrofossil zone as UCB locs. D-8172, D-8155, D-8170, D-8154, and D-8156.

Shay loc. UCB A-1355

Acanthocardia (Schedocardia) brewerii, *Anomia* sp., *Corbula* sp., and *Glycyimeris* sp. were listed on the museum locality card. The author identified *Brachidontes* sp., *Spisula* sp., *Pitar* sp., *Megacardita* sp., *Nuculana* sp., an indeterminate pelecypod, *Turritella merriami*, an indeterminate gastropod, *Stephanophyllia* sp., and an indeterminate scleractinian coral from the material in the collection.

The rock is a gray?, fine-grained sandstone, cemented by calcite and weathered to an orange color. Little shell material is preserved but external molds are abundant. UCB loc. A-1355 is located outside of the study area, 3 km to the west of the Tesla site, but contains many genera in common with UCB loc. D-8157. UCB loc. A-1355 is interpreted to be from the upper part of the Tesla upper sandstone member.

McFate loc. UCB B-5546

McFate found two well-preserved whole gastropods and an internal pelecypod mold at this locality and brought them to the Museum of Paleontology, Berkeley for identification. The gastropods were identified as *Viviparus* cf. *V. paludinaetormis* by a museum scientist. The locality information she provided allows only an approximate location (pl. 1), within the lower sandstone member. The author identified *V.* cf. *V. paludinaetormis* from the material.

One specimen has a small amount of gray coarse-grained sandstone adhering to the shell. The sandstone is badly weathered, but the lithology resembles the white sandstones in the lower sandstone member. The fossils were most likely collected from float material, as the locality is located on a motorcyle park where the hillside is severly rutted by motorcyle activity.

Conclusions

Reexamination of Huey's, Shay's, and McFate's localities provided taxa previously not reported from the Tesla Formation. These include *Megacardita* sp., *Ficopsis remondii crescentensis*, *Conus caleocius*, and *Viviparus* cf. *V. paludinaetormis*.

The author identified *Conus caleocius* from an assemblage collected by Huey (1948) in the lowermost part of the upper sandstone member. *C. caleocius* establishes the age of the lowermost part of the upper sandstone member in the Tesla area.

The occurrence of the fresh-water dweller *Viviparus* cf. *V. paludinaetormis* in the paralic facies rocks allows further refinement of environmental conditions for deposition of the lower part of the Tesla, confirming the author's interpretation of a nearby fresh water source. The sandstone in which *V.* cf. *V. paludinaetormis* was found may have accumulated in a river or lake, or the shells may have been transported into a paralic or nearshore environment by floods.

The author's fossil list differs markedly from Huey's. Huey reported very few taxa from his localities, while the author found many more taxa at localities collected at or near Huey's. Particularly noticeable is the absence of any gastropods other than *Turritella merriami* and *Turritella buwaldana*. A plausible explanation for this discrepancy is the difference in scope between Huey's work and the author's. Huey's main concern was to use fossils to determine the age of the Tesla Formation. At the time Huey was working, turritellids were easily recognized and considered useful as stratigraphic indicators. Since *T. merriami* established Huey's age for the upper part of the Tesla Formation, he may have ignored other gastropods that no doubt would have been more difficult to identify in his poorly preserved assemblages.

Another discrepancy between Huey's fossil lists and the author's, is the absence in the author's lists, of genera reported by Huey (e.g. Huey reported abundant *Nuculana* cf. *N. gabbii* at UCB loc. A-3080). Some of the original material may have been missing when the author examined the collections.

SUMMARY OF TESLA FACIES

The paralic facies in the lower sandstone member of the Tesla Formation is lithologically variable and is divided into four associations of interbedded strata which suggest specific environments of origin. Deposition of this facies ccurred primarily in a marginal marine environment in and near a delta.

The burrowed sandstone-siltstone-mudstone association was deposited in a delta front or delta topset environment.

The organic-rich siltstone-mudstone-lignite association was probably deposited in a lagoonal or estuarine environment, located at the margins of the delta complex discussed for the first association.

The fossiliferous gray and brown sandstone-siltstone association, was deposited in a relatively high-energy nearshore environment probably near a delta. Fauna found in these strata are predominantly brackish water forms, including: *Corbicula* sp., *Diodus tenuis*, and an indeterminate potamidid. These genera suggest a shallow sublittoral shelf environment. The dominance of suspension feeders indicates moderate or high energy flow-regimes with ample amounts of suspended organic matter. Lithologic and fossil evidence indicates that this association was deposited in a nearshore environment: in a brackish water bay, the brackish water part of a delta, or in marine waters adjacent to these areas.

In the white sandstone-brown and gray sandstone-siltstone-lignitic mudstone association, the white sandstones could have orignated in a fluvial or deltaic environment. Brown or gray organic-rich sandstones and siltstones have several of the features common to some deltaic deposits: lack of a shelled fauna, variable lithology, abundant plant detritus, and common biotite. Glauconite in these strata suggest a marine (rather than non-marine) origin. Mudstone and lignitic mudstone are likely to have formed in a coastal swamp environment.

The paralic facies recogizable near the top of the upper sandstone member is poorly exposed but includes white sandstone similar to the white sandstones in the paralic facies in the lower sandstone member. Although no fossils were found in these uppermost Tesla strata during the present study, Stewart (1949) reported *Cuneocorbula* cf. *C. torreyensis*, ?*Elimia* sp., and ?*Viviparus* sp. from this facies. The presence of the Eocene genus *Cuneocorbula* indicates these beds belong to the Tesla Formation and not to the overlying upper Miocene Cierbo Sandstone. The presence of the freshwater gastropod ?*Viviparus* suggests deposition of these strata in a fluvial or deltaic environment.

Rocks belonging to the shallow-marine facies (fine-grained sandstones, siltstones, and mudstones) contain plant material and moderate amounts of biotite and glauconite, and differ little from some rocks of the paralic facies. The presence of mollusk genera *Acila*, *Nuculana*, *Periploma*, ?*Pitar*, and *Turritella* indicates deposition in a calm or moderately calm, nearshore shallow-marine environment, such as the edge of a delta or a nearshore environment adjacent to a delta.

The middle shoreface facies strata are predominantly buff-colored medium- and fine-grained sandstones, which contain rare to abundant plant material and moderate amounts of biotite and glauconite. Mollusks from this facies include the genera *Acanthocardia*, *Acila*, *Glycymeris*, *Nuculana*, *Pitar*, *Solen*, *Spisula*, *Tellina*, *Turritella*, *Cancellaria*, *Calyptraea*, *Fusinus*, and *Architectonica*. The presence of these genera indicates deposition on an inner sublittoral marine shelf. When the sandy substrate and uniform lithology of this facies are considered, deposition appears to have occurred on the middle shoreface of a marine shelf.

When the Tesla Formation is regarded as a whole, it is clear that deposition occurred in environments marginal to a land mass, resulting in both paralic and normal marine deposits. The change from paralic conditions in the lower sandstone member to marine conditions in the upper sandstone member is interpreted to be the result of a marine transgression. The paralic facies near the top of the upper sandstone member represents a marine regression and a return to depositional conditions similar to those of the lower paralic facies.

Molluscan faunas from the basal part of the Tesla are suggestive of a Late Cretaceous or Paleocene age. Mollusks from the shallow-marine facies restrict the age of this facies to "Capay" (early Eocene) through "Domengine" (late early Eocene through early middle Eocene), and possibly "Meganos" (late Paleocene to early Eocene). Mollusks from the middle shoreface facies indicate a ("Domengine") age. The paralic facies near the top of the upper sandstone member is "Domengine" to (possibly) late Eocene in age, based on its stratigraphic position above the middle shoreface facies and its Eocene fauna.

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REFERENCES CITED

Allen, J.R.L., 1964, Studies in fluviatile sedimentation: six cyclothems from the Lower Old Red Sandstone, Anglo-Welsh Basin: Sedimentology, v. 3, p. 163-198.

______1970, Sediments of the modern Niger delta: A summary and review; in Morgan, J.P., ed., Deltaic sedimentation, modern and ancient: Society of Economic Paleontologists and Mineralogists Special Publication 15, p. 138-151.

Allen, V.T., 1941, Eocene anauxite clays and sands in the Coast Range of California: Geological Society of America Bulletin, v. 52, no. 2, p. 271-294.

Anderson, F.M., 1943, Synopsis of the later Mesozoic of California, in Geologic formations and economic development of the oil and gas fields of California: California Division of Mines and Geology Bulletin 118, p. 183-186.

______1978, Upper Cretaceous of the Pacific Coast: Geological Society of America Memoir 71, 378 p.

Anderson, Robert, and Pack, R.W., 1915, Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, California: U.S. Geological Survey Bulletin 603, 220 p.

Atwater, Tanya, 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 81, p. 3513-3536.

Bailey, E.H., Blake, M.C., Jr., and Jones, D.L., 1970, On-land Mesozoic oceanic crust in California Coast Ranges: U.S. Geological Survey Professional Paper 700-C, p. C70-C81.

Bailey, E.H., Irwin, W.P., and Jones, D.L., 1964, Franciscan and related rocks, and their significance in the geology of western California: California Division of Mines and Geology Bulletin 183, 177 p.

Bartow, J.A., Lettis, W.R., Sonneman, H.S., and Switzer, J.R., Jr., 1985, Geologic map of the east flank of the Diablo Range from Hospital Creek to Poverty Flat, San Joaquin, Stanilaus, and Merced Counties, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1656, scale 1:62,500.

Bishop, C.C., 1970, Upper Cretaceous stratigraphy on the west side of the northern San Joaquin Valley, Stanislaus and San Joaquin Counties, California: California Division of Mines and Geology Special Report 104, 29 p.

Black, R.M., 1970, The elements of paleontology: Cambridge University Press, 339 p.

Blake, M.C., Jr., and Jones, D.L., 1974, Origin of Franciscan melanges in northern California: Society of Economic Paleontologists and Mineralogists Special Publication 19, p. 345-357.

______ 1978, Allochthonous terranes in northern California--A reinterpretation, *in* Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 397-400.

Booth, C.V., 1950, Geology of the west central portion of the Orestimba quadrangle: Berkeley, University of California, M.A. thesis, 58 p.

Briggs, L.I., Jr., 1953, Geology of the Ortigalita Peak quadrangle, California: California Division of Mines and Geology Bulletin 167, 61 p.

Clark, B.L., 1918, Meganos Group, a newly recognized division in the Eocene of California: Geological Society of America Bulletin, v. 29, p. 281-296.

______1921, The stratigraphic and faunal relationships of the Meganos Group, Middle Eocene of California: Journal of Geology, v. 29, no. 2, p. 125-165.

______1926, The Domengine horizon, middle Eocene of California: University of California Publications, Bulletin of the Department of Geological Sciences, v. 16, p. 99-118.

______1935, Tectonics of the Mt. Diablo and Coalinga areas, middle Coast Ranges, California: Geological Society of America Bulletin, v. 46, p. 1025-1078.

Clark, B.L., and Vokes, H.E., 1936, Summary of the marine Eocene sequence of western North America: Geological Society of America Bulletin, v. 47, p. 851-878.

Clark, B.L., and Woodford, A.O., 1927, The geology and paleontology of the type section of the Meganos Formation (lower middle Eocene) of California: University of California Publications, Bulletin of the Department of Geological Sciences, v. 17, no. 2, p. 63-142.

Clarke, S.H., Jr., Howell, D.G., and Nilsen, T.H., 1975, Paleocene geography of California, *in* Society of Economic Paleontologists and Mineralogists Conference on Future Energy Horizons of the Pacific Coast Paleogene Symposium, April, 1975, p. 121-154.

Collins, D.F., 1950, The geology of the southern third of the Orestimba quadrangle, Stanislaus and Merced Counties, California: Berkeley, University of California, M. A. thesis, 54 p.

Dibblee, T.W., Jr., 1980, Preliminary geologic map of the Midway quadrangle, Alameda and San Joaquin Counties, California: U.S. Geological Survey Open-File Report 80-535, scale 1:24,000.

______1981, Preliminary geologic map of the Solyo quadrangle, San Joaquin and Stanislaus Counties, California, U.S. Geological Survey Open-File Report 81-465, scale 1:24,000.

______1982, Preliminary geologic map of the Patterson quadrangle, Stanislaus County, California, U.S. Geological Survey Open-File Report 82-394, scale 1:24,000.

______1982, Preliminary geologic map of the Orestimba Peak quadrangle, Stanislaus County, California, U.S. Geological Survey Open-File Report 82-395, scale 1:24,000.

Dibblee, T.W., Jr., and Darrow, R.L., 1981, Guidebook to regional geology of the East Bay Hills and northern Diablo Range-Livermore Valley area, *in* Frizzell, V., ed., Geology of the central and northern Diablo Range, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 65-112.

Dickerson, R.E., 1913, Fauna of the Eocene at Marysville Buttes, California: University of California Publications, Bulletin of the Department of Geological Sciences, v. 7, p. 257-298.

______1914, The fauna of the *Siphonalia sutterensis* zone in the Roseburg quadrangle, Oregon: California Academy of Science Proceedings, Series IV, v. 4, p. 113-128.

______1916, Stratigraphy and fauna of the Tejon Eocene of California: University of California Publications, Bulletin of the Department of Geological Sciences, v. 9, p. 363-524.

Dickinson, W.R., and Ingersoll, R.V., 1978, Plate tectonic evolution of Sacramento Valley, California, *in* Hill, F.L. and others, Energy Exploration and Politics, Pre-prints, California Division of Oil and Gas, 12 p.

______1979a, Paleogene sediment dispersal and paleotectonics in northern California: Summary: Geological Society of America Bulletin part I, v. 90, p. 897-898.

Dickinson, W.R., Ingersoll, R.V., and Graham, S.A., 1979b, Paleogene sediment dispersal and paleotectonics in northern California: Geological Society of America Bulletin, part II, v. 90, p. 1458-1528.

Donaldson, A.C., Martin, R.H., and Kanes, W.H., 1970, Holocene Guadalupe delta of Texas Gulf Coast, *in* Morgan, J.P., (ed.), Deltaic sedimentation modern and ancient: Society of Economic Paleontologists and Mineralogists Special Publication No. 15, p. 107-137.

Dott, R.H., Jr., 1964, Ancient deltaic sedimentation in eugeosynclinal belts, *in* van Straaten, L.M.J.U., ed., Deltaic and Shallow Marine Deposits, p. 105-113.

Ernst, W.G., 1970, Tectonic contact between the Franciscan melange and the Great Valley sequence--Crustal expression of a late Mesozoic Benioff zone: Journal of Geophysical Research, v. 75, p. 886-901.

Evitt, W.R., and Pierce, S.J., 1975, Lower Tertiary ages from Coastal Belt Franciscan, northern California: Geology, v. 3, p. 433-436.

Fagerstrom, J.A., 1964, Fossil communities in paleoecology: their recognition and significance: Geological Society of America Bulletin, v. 75, p. 1197-1216.

Fischer, P.J., 1979, The Evolution of a late Paleocene submarine canyon and fan system: the Meganos Formation, southern Sacramento basin, California: Field Trip Guide Book for the Geological Society of America Cordilleran Section Meeting at San Jose, California, April 9-11, 1979, p. 1-10.

Fitch, J.E., 1964, The fish fauna of the Playa Del Rey locality, a southern California marine Pleistocene deposit: Los Angeles County Museum Contributions in Science, no. 82, 35 p.

Gardner, Julia, 1957, Little Stave Creek--a paleoecologic study, in Ladd, H. S., ed., Treatise on marine ecology and paleoecology, Geological Society of America Memoir 67, v. 2, p. 573-587.

Givens, C.R., 1974, Eocene molluscan biostratigraphy of the Pine Mountain area, Ventura county, California: University of California Publications in Geological Sciences, v. 109, 107 p.

Givens, C.R., and Kennedy, M.P., 1979, Eocene molluscan stages and their correlation, San Diego area, California, in Abbott, P.L., ed., Eocene depositional systems: Society of Economic Paleontologists and Mineralogists, Pacific Section p. 81-96.

Goudkoff, P.P., 1945, Stratigraphic relations of Upper Cretaceous in Great Valley, California: Bulletin of the American Association of Petroleum Geologists, v. 29, p. 956-1007.

Harms, J.C., 1975, Stratification and sequence in prograding shoreline deposits, in Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists Short Course No. 2, p. 81-102.

Hedberg, H.D., ed., 1961, Stratigraphic classification and terminology: International Subcommision on Stratigraphic Terminology, 21st International Geological Congress, Copenhagen, 1960, pt. 25, 38 p.

Herd, D.G., 1977, Geologic map of the Las Positas, Greenville, and Verona faults, eastern Alameda County, California: U.S. Geological Survey Open-File Report 77-689.

Herd, D.G., and Helly, E.J., 1977, Faults with Quaternary displacement, northwestern San Francisco Bay region, California: U.S. Geological Survey Field Studies Map MF-818, scale 1:125,000.

Hickman, C.S., 1976, Bathyal gastropods of the family Turridae in the early Oligocene Keasey Formation in Oregon, with a review of some deep-water genera in the Paleogene of the eastern Pacific: Bulletins of American Paleontology, v. 70, no. 292, 119 p.

Hoots, H.W., Bear, T.L., Kleinpell, W.D., 1954, Geological summary of the San Joaquin Valley, California, in Johns, R.H., ed., Geology of southern California, California Division of Mines and Geology Bulletin 170, p. 113-129.

Huey, A.S., 1937, Stratigraphy of the Tesla quadrangle, California [abs.]: Geological Society of America Proceedings 1936, p. 335-336.

______1940, The geology of the Tesla quadrangle of middle California: Berkeley, University of California, Ph. D. thesis, 115 p.

______1948, Geology of the Tesla quadrangle, California: California Division of Mines and Geology, Bulletin 140, 75 p.

Imlay, R.W., 1980, Jurassic paleobiogeography of the conterminous United States in its continental setting: U.S. Geological Survey Professional Paper 1062, 134 p.

Ingersoll, R.V., 1978, Paleogeography and paleotectonics of the late Mesozoic forearc basin of northern and central California, in Howell, D.G. and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Pacific Coast Paleogeography Symposium 2, p. 471-482.

______1979, Evolution of the Late Cretaceous forearc basin, northern and central California: Geological Society of America Bulletin, part I., v. 90, p. 813-826.

Kaufmann, E.G., and Scott, R.W., 1976, Basic concepts of community ecology and paleoecology, in Scott, R.W., and West, R.R., eds., Structure and classification of paleocommunities: Stroudsburg, Pennsylvania, Dowden, Hutchinson, and Ross, p. 1-28.

Keen, A.M., 1958, Sea Shells of Tropical West America: Stanford, California, Stanford University Press, 624 p.

______1971, Sea shells of tropical west America: Stanford, California, Stanford Univeristy Press, 1064 p.

Keen, A.M., and Bentson, Herdis, 1944, Check list of California Tertiary marine mollusca: Geological Society of America Special Paper No. 56, 280 p.

Keen, A.M., and Coan, Eugene, 1974, Marine molluscan genera of western North America: Stanford, California, Stanford University Press, 208 p.

Ladd, H.S., 1951, Brackish-water and marine assemblages of the Texas coast, with special reference to mollusks: Publications of the Institute of Marine Science, v. II, no. 1, p. 127-163.

Ladd, H.S., ed., 1957, Treastise on marine ecology and paleontology: Geological Society of America Memoir 67, v. 2, 1077 p.

Lawson, A.C., 1895, Sketch of the geology of the San Francisco Peninsula: U.S. Geological Survey, 15th Annual Report, p. 399-476.

Maddock, M.E., 1964, Geology of the Mt. Boardman Quadrangle, California: California Division of Mines and Geology Map Sheet 3, scale 1:62,500.

Matsumoto, Tatsuro, 1959, Upper Cretaceous ammonites of California, Part 1: Memoir Facility of Science: Kyushu University, Ser. D., Geology, v. 8.8, no. 4, p. 91-171.

McKerrow, W.S., ed., 1978, The ecology of fossils: Massachusetts Institute of Technology Press, 384 p.

Merriam, C.W., 1941, Fossil turritellas from the Pacific coast region of North America: University of California, Publications of the Department of Geological Sciences, v. 26, no. 1, p. 1-214.

Moore, R.C., ed., 1960, Treatise on invertebrate paleontology, Part I Mollusca 1: University of Kansas Printing Service, 351 p.

______ ed., 1969a, Treatise on invertebrate paleontology, Part N, v. 1, Mollusca 6, Bivalvia: University of Kansas Printing Service, 489 p.

______ ed., 1969b, Treatise on invertebrate paleontology, Part N, v. 2, Mollusca 6, Bivalvia: University of Kansas Printing Service, p. 491-952.

Moore, R.C., Lalicker, C.G., and Fischer, A.G., 1952, Invertebrate fossils: New York, McGraw-Hill, 766 p.

Morris, E.C., 1962, Mineral correlations of some Eocene sandstones of central California: Stanford, University of California, Ph. D. thesis 85 p.

Natland, M.L., 1957, Paleoecology of west coast Tertiary sediments, in Ladd, H.S., ed., Treatise on marine ecology and paleoecology, Geological Society of America Memoir 67, v. 2, p. 543-572.

Nilsen, T.H., 1972, Preliminary photointerpretation map of landslide and other surficial deposits of parts of the Altamont and Carbona 15-minute quadrangles, Alameda County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-321, scale 1:62,500.

______1977, Early Tertiary tectonics and sedimentation in California, *in* Nilsen, T. H., ed., Late Mesozoic sedimentation and tectonics in California: San Joaquin Geological Society, Short Course, p. 86-98.

Nilsen, T.H. and Clarke, S.H., Jr., 1975, Sedimentation and tectonics in the early Tertiary continental borderland of central California: U. S. Geological Survey Professional Paper 925, 64 p.

Olsson, A.A., 1970, The cancellarid radula and its interpretation: Palaeontographica Americana, v. 7, no. 43, p. 19-27.

Paine, R.T., 1963, Trophic relationships of eight sympatric predatory gastropods: Ecology, v. 44, p. 63-73.

Payne, M.B., 1951, Type Moreno Formation and overlying Eocene strata on the west side of the San Joaquin Valley, Fresno and Merced Counties, California: California Division of Mines and Geology Special Report 9, 29 p.

______1962, Type Panoche Group (Upper Cretaceous) and overlying Moreno and Tertiary strata on the west side of the San Joaquin Valley, *in* Bowen, O.E., ed., Geologic Guide to the Gas and Oil Fields of Northern California: California Division of Mines and Geology Bulletin 181, p. 165-175.

Popenoe, W.P., Imlay, R.W., and Murphy, M.A., 1960, Correlation of the Cretaceous formations of the Pacific Coast (United States and northwestern Mexico): Geological Society of America Bulletin, v. 71, p. 1491-1540.

Raymond, L.A., 1970, Cretaceous sedimentation and regional thrusting, northeastern Diablo Range, California: Geological Society of America Bulletin, v. 81, p. 2123-2128.

______1973, Tesla-Ortigalita fault, Coast Range thrust fault, and Franciscan metamorphism, northeastern Diablo Range, California: Geological Society of America Bulletin, v. 84, p. 3547-3562.

Reineck, H.E., and Singh, I.B., 1975, Depositional sedimentary environments: New York, Springer-Verlag, 439 p.

Repenning, C.A., 1961, Geologic summary of the central valley of California, with reference to disposal of liquid radioactive waste: U.S. Geological Survey Open-File Report (Trace Elements Investigations Report 769), 69 p.

Saul, L.R., 1983, Notes on Paleogene turritellas, venericardias, and molluscan stages of the Simi Valley area, California, in Squires, R.L., and Filewicz, M.L., eds., Cenozoic geology of the Simi Valley area, southern California: Society of Economic Paleontologists and Mineralogists, Pacific Sections, Volume and Guidebook, p. 71-80.

Schenck, H.G., 1936, Nuculid bivalves of the genus Acila: Geological Society of America Special Paper 4, 149 p.

______1976, Trophic classification of benthic communities, in Scott, R.W., and West, R.R., eds., Structure and classification of paleocommunities: Stroudsburg, Pennsylvania, Dowden, Hutchinson, and Ross, p. 24-66.

______1978, Approaches to trophic analysis of paleocommunities: Lethaia, v. 11, p. 1-14.

Shepard, F.P., 1964, Presidential Address, Criteria in modern sediments useful in recognizing ancient sedimentary environments, in van Straaten, L.M.J.U., ed., Developments in sedimentology, Volume 1, Deltaic and Shallow Marine Deposits, Elsevier Publishing Company, p. 1-25.

Squires, R.L., 1984, Megapaleontology of the Eocene Llajas Formation, Simi Valley, California: Los Angeles County Natural History Museum, Contributions in Science, no. 350, 76 p.

Squires, R.L., 1987, Eocene molluscan paleontology of the Whitaker Peak area, Los Angeles and Ventura Counties, California: Los Angeles County Natural History Museum, Contributions in Science, no. 388, 93 p.

Squires, R.L., (in press), Eocene macropaleontology of northern Lockwood Valley, Ventura County, California: Los Angeles County Natural History Museum, Contributions in Science.

Stanley, S.M., 1970, Shell form and life habits of the bivalvia (Mollusca): Geological Society of America Memoir 125, 296 p.

______1972, Functional morphology and evolution of byssally attached bivalve mollusks: Journal of Paleontology, v. 46, no. 2, p. 164-212.

Stasek, C.R., 1965, Feeding and particle-sorting in Yoldia ensifera (Bivalvia: Protobranchia), with notes on other nuculanids: Malacologia, v. 2, p. 349-366.

Stewart, Ralph, 1949, Lower Tertiary stratigraphy of Mt. Diablo, Marysville Buttes, and west border of lower central valley of California: U.S. Geological Survey Oil and Gas Investigations Preliminary Chart 34 (2 sheets).

Stewart, Ralph, Popenoe, W.P., and Snavely, P.D., Jr., 1944, Tertiary and late Upper Cretaceous stratigraphy of west border of San Joaquin Valley, north of Panoche Creek, Fresno, Merced, and Stanislaus Counties, California: U.S. Geological Survey Oil and Gas Investigations Preliminary Chart 6.

Taff, J.A., 1935, Geology of Mt. Diablo and vicinity: Geological Society of America Bulletin, v. 46, p. 1079-1100.

Taliaferro, N.L., 1943, Franciscan-Knoxville problem: American Association of Petroleum Geologists Bulletin, v. 27, p. 109-219.

Taylor, J.D., 1970, Feeding habits of predatory gastropods in a Tertiary (Eocene) molluscan assemblage from the Paris basin: Paleontology, v. 13, Part 2, p. 254-260.

Throckmorton, C.K., 1988, Depositional environments and molluscan biostratigraphy of the Tesla Formation, central California, *in* Filewicz, M.W., and Squires, R.L., eds., Paleogene Stratigraphy, West Coast of North America: Society of Economic Paleontologists and Mineralogists, Pacific Section, West Coast Paleogene Symposium, v. 58, p.209-223.

Turner, H.W., 1891, The geology of Mt. Diablo: Geological Society of America Bulletin, v. 2, p. 383-414.

______1898, Rocks of the Coast Ranges of California: Journal of Geology, v. 6, p. 493-499.

Vaughan, T.W., and Wells, J.W., 1943, Revision of the suborders, families, and genera of the Scleractinia: Geological Society of American Special Paper 44, 363 p.

Vickery, F.P., 1925a, The structural dynamics of the Livermore region: Stanford, University of California, Ph. D. thesis.

______1925b, The structural dynamics of the Livermore region: Journal of Geology, v. 33, p. 608-628.

Vokes, H.E., 1939, Molluscan faunas of the Domengine and Arroyo Hondo formations of the California Eocene: New York Academy of Science Annals, v. 38, 246 p.

______1945, *Protodonax*, a new Cretaceous molluscan genus: Journal of Paleontology, v. 19, no. 3, p. 295-308.

Walker, R.G., 1975, From sedimentary structures to facies models: example from fluvial environments, *in* Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists Short Course No. 2. p. 63-80.

Weaver, C.E., 1909, Stratigraphy and paleontology of the San Pablo Formation in middle California: University of California Bulletin of the Department of Geological Sciences, v. 5, p. 243-269.

______1953, Eocene and paleocene deposits at Martinez, California: University of Washington Publications in Geology, v. 7, p. 1-102.

Weaver, C.E., and others, 1944, Correlation of marine Cenozoic formations of western North America: Geological Society of America Bulletin, v. 55, p. 569-599.

White, C.A., 1885, On the Mesozoic and Cenozoic paleontology of California: U.S. Geological Survey Bulletin 15, 33 p.

Whitney, J.D., 1865, Geology, report of progress and synopsis of the field work from 1860-1864: Geological Survey of California, v. 1, 498 p.

Yonge, C.M., 1939, The food of invertebrates: Tabulae Biologicae, v. 21, p. 46-68.

APPENDIX I.—MACROFOSSILS FROM THE TESLA AREA

	UCB NO.	LOCALITY DESCRIPTION
		Neroly Formation, sandstone member
fresh-water gastropods (not identified) fish bones (not identified)	D-8166	NW¼ sec. 30, T.3S., R.4E. From west side of shallow gully, 165 m south of ridgecrest and 200 m west of powerlines. Lithology: tuffaceous sandy siltstone
fresh-water gastropods (not identified)	D-8165	NW¼ sec. 30, T.3S., R.4E. From east side of shallow gully, 150 m south of ridgecrest and 150 m west of powerlines. Lithology: light-tan waterlain tuff
antilocaprid, cf. *Merycodus* canid, wolf size but not *Canis* *Martinogale* sp. aff. *M. alveodens* Hall, 1930 *Serridentinus* sp. aff. *S. productus* (Cope) Osborn, 1936	V-4613	NE¼ sec. 35, T.3S., R.4E. From float material on south side of hill. Lithology: light-gray sandstone
leaves (not identified)	D-8164	Near center of sec. 29, T.3S., R.4E. Next to small adit in east bank of creek bottom, 20 m north of dirt road. Lithology: gray mudstone
leaves (not identified)	D-8167	NE¼ sec. 26, T.3S., R.3E. From roadcut on southeast side, at bend in Tesla road. Lithology: light-gray laminated mudstone
		Cierbo Sandstone
Ostrea bourgeoisii Remond, 1863	462	NW¼ sec. 20, T.3S., R.4E. On top of shallow knoll on north side of gully. Shell fragments occur in soil Lithology: tan sandstone. (not collected)
Ostrea bourgeoisii Remond, 1863	D-8162	NW¼ sec. 20, T.3S, R.4E. On top of shallow knoll, north side of gully. Shell fragments occur in soil. Lithology: tan sandstone.

	UCB NO.	LOCALITY DESCRIPTION
Ostrea bourgeoisii Remond, 1863 *Balanus* sp.	D-8169	NE¼ sec. 26, T.3S., R.3E. From roadcut on east side of Tesla Road, 45 m north of white sandstone in Tesla Formation. Lithology: tan, poorly sorted, coarse-grained sandstone
Ostrea bourgeoisii Remond, 1863 *Pecten raymondi* Clark 1915	D-8163	NE¼ sec. 26, T.3S., R.3E. On dirt road on ridge, approximately 70 m east of Tesla road. Lithology: brown, medium-grained sandstone
Tesla Formation, upper sandstone member		
Acanthocardia (Schedocardia) cf. *A. brewerii* (Gabb) Givens, 1974 *Anomia* sp. *Brachidontes (Brachidontes) cowlitzensis* (Weaver and Palmer) Turner, 1938 *Glycymeris* sp. *Nuculana* sp. *Nuculana (Scaeoleda)* sp. *Pitar* sp. *Solen* sp. Spisula *sp.* *archeogastropod (indeterminate)* Architectonica *sp.* archeogastropod (indeterminate) *Calyptraea* sp. *Fusinus* sp. naticid (indeterminate) neogastropod (indeterminate) *Scaphander* sp. *Turritella merriami* Dickerson, 1913 *Dentalium* sp. *Stephanophyllia* sp. *?Myliobatis* sp.	D-8157	NW¼ sec. 25, T.3S., R.3E. From isolated sandstone block (float?) 45 m northwest and 5 m below crest of saddle on northeast trending ridge. From approximately the same horizon as Huey's (1948) loc. VI. Lithology: gray fine-grained sandstone

APPENDIX I.--CONTINUED

	UCB NO.	LOCALITY DESCRIPTION
Acanthocardia (Schedocardia) cf. A. brewerii (Gabb) Givens, 1974 Acila (Truncacila) decisa (Conrad) Schenck, 1936 Nuculana sp. pelecypod (indeterminate) Spisula sp. gastropod (indeterminate) neogastropod (indeterminate) Turritella buwaldana Dickerson, 1916 Dentalium sp.	D-8172	NE¼ sec. 26, T.3S., R.3E. From float on small flat, beneath powerlines and southeast of powerline tower. Lithology: gray, muddy siltstone
Nucula sp. Nuculana sp. pelecypod (indeterminate) Solen sp. Spisula sp. Tellina sp. buccinid (indeterminate) Cancellaria sp. Molopophorous californicus Clark and Woodford, 1927 naticid (indeterminate) neogastropod sp. F (indeterminate) neogastropod sp. G (indeterminate) neogastropod sp. H (indeterminate) neogastropod sp. I (indeterminate) Scaphander sp. Whitneyella sp. Dentalium sp.	D-8156	NW¼ sec. 25, T.3S., R.3E. On nose of ridge, about 65 m west of and above Tesla Road. Huey's (1948) loc. IV. Lithology: gray fine-grained sandstone
Nucula sp. Nuculana (Saccella) gabbii (Gabb) Vokes, 1939 Spisula sp. Molopophorus californicus Clark and Woodford, 1927 naticid (indeterminate) neogastropod (indeterminate) Dentalium sp.	D-8155	NE¼ sec. 25, T.3S., R.3E. From a bed 10 m south of ridgecrest Lithology: brown fine-grained sandstone
Nucula sp. Nuculana (Saccella) gabbii (Gabb) Vokes, 1939 Solen sp. Spisula s. neogastropod (indeterminate Dentalium sp.	D-8170	NE¼ sec. 26, T.3S., R.3E. From float approximately 45 m south of ridgecrest. From the same or nearly same stratigraphic horizon as UCB loc. D-8154. Lithology: brown fine-grained sandstone

	UCB NO.	LOCALITY DESCRIPTION
Nuculana sp. pelecypod (indeterminate) Solen sp. Spisula sp. Tellina n. sp.? Givens, 1974, aff. T. townsendensis Clark, 1925 Tellina sp. A naticid (indeterminate) Whitneyella sp. crab claw	D-8154	NW¼ sec. 25, T.3S., R.3E. From a bed 45 m south of ridgecrest. Lithology: gray fine-grained sandstone

Tesla Formation, lower sandstone member

Acila (Truncacila) decisa (Conrad) Schenck, 1936 carditid (indeterminate fragment) Nuculana (Saccella) gabbii (Gabb) Vokes, 1939 pelecypod (indeterminate) Periploma sp. ?Pitar sp. Fusinus sp. gastropod (indeterminate) Gemmula sp. naticid (indeterminate) Scaphander sp. turrid sp. Turritella buwaldana Dickerson, 1916 Turritella buwaldana subsp. coosensis? (Merriam, unpublished) Turner, 1938 Schizaster sp. crab claw	D-8151	Near center of sec. 25, T.3S., R.3E. From roadcut on west side of Tesla Road, just north of powerlines and 3 m south of culvert 9.81. Lithology: gray siltstone
Nuculana sp. pelecypod (indeterminate) pelecypod (indeterminate) pelecypod (indeterminate) neogastropod (indeterminate) Turritella buwaldana Dickerson, 1916	D-8153	Near center of sec. 25, T.3S, R.3E. From roadcut on west side of Tesla Road, 9 m south of UCB loc. D-8151. Lithology: light-gray mudstone
Nuculana sp. pelecypod (indeterminate) pelecypod (indeterminate) neogastropod (indeterminate)	D-8159	Near center of sec. 25, T.3S., R.3E. From float on roadcut on west side of Tesla road, approximately 5 m north of UCB loc. D-8158. Lithology: gray silty mudstone

APPENDIX I.—CONTINUED

	UCB NO.	LOCALITY DESCRIPTION
pelecypod (indeterminate fragment) *Turritella buwaldana* Dickerson, 1916	D-8158	Near center of sec. 25, T.3S., R.3E. From roadcut on west side of Tesla Road, 80 m north of culvert 9.89. Lithology: gray silty mudstone
Anomia sp. *Callista* (*Costacallista*) *hornii vokesi*? Squires ?*Corbicula* sp. *Corbula* sp. potamidid (indeterminate)	D-8152	SE1/4 sec. 25, T.3S., R.3E. From roadcut on west side of Tesla Road, 32 m north of UCB loc. D-8148. Lithology: brown sandy siltstone.
Anomia sp. ?*Corbicula* sp. *Corbula* n. sp. aff. *C. pozo* Dailey and Popenoe, 1966 *Corbula* sp. *Diodus tenuis* (Gabb) Stewart, 1930 pelecypod (indeterminate) potamidid (indeterminate) naticid (indeterminate)	D-8148	SE1/4 sec. 25, T.3S., R.3E. From roadcut on west side of Tesla Road, 11 m north of UCB loc. D-8147. Lithology: light-gray fine-grained sandstone
Anomia sp. *Corbula* n. sp. aff. *C. pozo* Dailey and Popenoe, 1966 *Corbula* sp. *Diodus tenuis* (Gabb) Stewart, 1930 *Mytilus* sp. pelecypod (indeterminate) potamidid (indeterminate)	D-8147	SE1/4 sec. 25, T.3S, R.3E. From roadcut on west side of Tesla Road, 61 m north of sharp bend in Tesla Road. Lithology: light-gray fine-grained sandstone
Anomia sp. *Corbula* n. sp. aff. *C. pozo* Dailey and Popenoe, 1966 *Corbula* sp. *Diodus tenuis* (Gabb) Stewart, 1930 *Mytilus* sp. ?*Pitar* sp. pelecypod (indeterminate) potamidid (indeterminate)	D-8149	NE1/4 sec. 32, T.3S., R.4E. From roadcut on west side of dirt road on the west band of a north-sloping ravine. Nearby and approximately the same stratigraphic horizon as Huey's (1948) loc. I, which was collected in creek bottom. Lithology: buff (weathered color), fine-grained sandstone

	UCB NO.	LOCALITY DESCRIPTION
Anomia sp. *Corbula* n. sp. aff. *C. pozo* Dailey and Popenoe, 1966 *Corbula* sp. ?*Corbula* sp. ?*Diodus tenuis* mactrid (indeterminate) pelecypod (indeterminate) ?*Pteroluter* n. sp. buccinid (indeterminate) neogastropod (resembles *Tornatellacea pinguis* (Gabb) Stewart, 1927) potamidid (indeterminate)	D-8150	On section boundary between NW¼ sec. 31 and SW¼ sec. 30, T.3S., R.4E. From float 50 m above the top of the shale member of the Moreno, on the north side of the mouth of the creek. Lithology: gray, fine-grained sandstone
Anomia sp. *Corbicula* sp. *Corbula* n. sp. aff. *C. pozo* Dailey and Popenoe, 1966 *Mytilus* sp. potamidid (indeterminate)	D-8173	NW¼ sec. 31, T.3S., R.4E. On east bank of Mitchell Ravine, vicinity of Huey's (1948) loc. III, 45 m stratigraphically above the shale member of the Moreno, 6 m higher than road in Mitchell Ravine. Lithology: gray fine-grained muddy sandstone
?*Corbicula* sp. *Corbula* n. sp. aff. *C. pozo* Dailey and Popenoe, 1966 *Mytilus* sp.	D-8174	NW¼ sec. 31, T.3S., R.4E. On east bank of Mitchell Ravine, vicinity of Huey's (1948) loc. III, 46 m stratigraphically above UCB loc. D-8173 and 6 m higher than road in Mitchell Ravine. Lithology: gray silty mudstone
Moreno Formation, sandstone member		
Acila (*Truncacila*) *demessa* Finlay, 1927 *Gari* sp. *Lucina* sp. *Mytilus* sp. *Ostrea* sp. arcinid (indeterminate) pelecypods (indeterminate) *Psammobia* sp. archeogastropod (indeterminate) crab claw fish scale	D-8146	SW¼ sec. 25, T.3S., R.3E. On Tesla site; approximately 9 m north of, and 1 m higher in elevation than dirt road. Lithology: silty fine-grained sandstone

APPENDIX I.--CONTINUED

	UCB NO.	LOCALITY DESCRIPTION
Acila (*Truncacila*) *demessa* Finlay, 1927 pelecypod (indeterminate) gastropod (indeterminate)	D-8168	SW¼ sec. 25, T.3S, R.3E. On west side of ravine, west of Tesla site. From concretions 3 m above creek bottom, near large exposed tree roots. Opposite side of ravine from UCB loc. D-8146. Lithology: silty sandstone
Acila (*Truncacila*) *demessa* Finlay, 1927 *Pholadomya* sp. pelecypod sp. A pelecypod sp. B *Diplomoceras* cf. *D. notabile* Whiteaves, 1903	D-8171	NW¼ sec. 32, T.3S., R.3E. From roadcut on west side of dirt road on the west bank of north-sloping ravine, 60 m south of UCB loc. D-8149. Lithology: silty fine-grained sandstone

Knoxville Formation

Buchia elderensis Anderson, 1945 *Phylloceras* sp. pelecypods (indeterminate)	D-8160	NE¼ sec. 35, T.3S., R.3E. From roadcut exposure on east side of dirt road on east bank of Corral Hollow, approximately 6 m north of (?)andesite sill. Lithology: dark-gray limestone concretions

APPENDIX II.—MICROFOSSILS FROM THE TESLA AREA

Moreno Formation, sandstone member

	FIELD NO.	LOCALITY DESCRIPTION
Ammobaculites sp.	903	SE¼ sec. 26, T.3S., R.3E. From ravine bottom at about 1120 ft elevation, Lithology: gray siltstone
Bathysiphon eocenica Cushman and Hanna, 1927		
Bathysiphon sp.		
Cyclammina sp.		
Dentalina sp.		
Eponies sp.		
Gyroidina octocamerata (Subbotina), 1960		
Haplophragmoides excavata Cushman and Waters, 1927		
Haplophragmoides cretacea (Cushman and Goudkoff), 1944		
Trochammina cf. *T. whittingtoni* Tappan, 1960		
Vaginulinopsis/Saracenaria cf. *S. triangularis* (d'Orbigny), 1840		

Moreno Formation, shale member

	FIELD NO.	LOCALITY DESCRIPTION
Eggerella sp.	581	NW¼ sec. 26, T.3S., R.3E. Float (?) from bottom of ravine. May be from slide material, but probably in place. Lithology: hard, brown and yellow, slightly calcareous, laminated shale
Gyroidina orbicella Bandy, 1951		
Lenticulina sp.		
Praebulimina petroleana (Cushman and Hedberg) 1941		
Cenosphaera sp.		
Dictyomitra multicostata Zittel, 1876		
Spongodiscus sp.		
Inoceramus prisms		
Cretarhabdus conicus Bramlette and Martini, 1964		
Cribrosphaerella ehrenbergi Arkhangelsky, 1912		
Micula decussata Vekshina, 1959		
Parhabdolithus splendens (Deflandre, 1953)		
Tranolithus orionatus Stover, 1966		

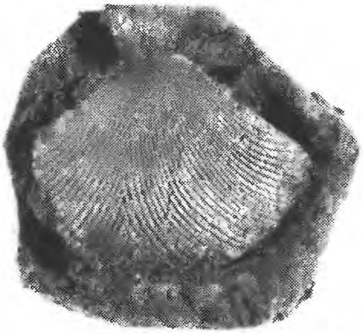
APPENDIX II.-CONTINUED

	FIELD	LOCALITY DESCRIPTION
Ammobaculites sp. *Osangularia cordieriana* (d'Orbigny), 1840 *Praebulimina aspera* Cushman and Parker, 1940 *Praebulimina* cf. *D. reussi* (Morrow), 1934 radiolaria (not identified)	501A	NW¼ sec. 33, T.3S., R.4E. From cliff exposure on west side of ravine approximately 10 m above creek bottom. Lithology: brown shaly mudstone.
?*Bulimina* sp. *Dentalina* sp. *Haplophragmoides* sp. *Praebulimina aspera* Cushman and Parker, 1940 *Saccammina lathrami* Tappan, 1960 *Siphogenerinoides whitei* Church, 1941 *Dictyomitra multicostata* Zittel, 1876	574	Near center of sec. 27, T.3S., R.3E., Altamont quadrangle. From gully on south bank of Arroyo Seco, 5 m higher than creek bottom, near fault contact with Moreno sandstone member. Lithology: chocolate brown mudstone
Bulimina sp. *Praebulimina* sp. radiolaria (not identified)	701	NW¼ sec. 32, T.3S., R.4E. From roadcut on west side of dirt road at 1100 ft elevation and 60 m northeast of loc. 535A (road not on map). Lithology: chocolate brown mudstone
Haplophragmoides sp. spicules diatom fragments (not identified)	535A	NW¼ sec. 32, T.3S., R.4E. From roadcut exposure on west side of dirt road at 1100 ft elevation (road not on map). Lithology: pinkish-brown mudstone

APPENDIX II.--CONTINUED

	FIELD NO.	LOCALITY DESCRIPTION
		Panoche Formation, shale member
Ammodiscus cretaceous (Reuss), 1845 *Bathysiphon varans* Sliter, 1968 *Cribrostomoides cretaceus* Cushman and Goudkoff, 1944 *Gaudryina bentonensis* (Carman), 1929 *Haplophragmoides excavata* Cushman and Waters, 1927 *Haplophragmoides impensus* Martin, 1964 *Nodellum valascoense* (Cushman), 1926 *Silicosigmoilina californica* Cushman and Church, 1949 *Cenosphaera* sp. *Dictyomitra* cf. *D. multicostata* Zittel, 1876 *Dictyomitra* sp. *Spongodiscus* sp.	518B	SW1/4 sec. 32, T.3S., R.4E. From south bank of northwest-trending ravine, where it merges into large southwest-trending ravine. Collected 1 m higher than ravine bottom. Lithology: hard, silty mudstone
		Franciscan assemblage
Gaudryina? sp. *Dictyomitra multicostata* Zittel, 1876 radiolaria (not identified)	513	SE1/4 sec. 32, R.3S., R.4E. From roadcut exposure on side of dirt road, at Cedar Mountain and Midway quadrangle boundary. Lithology: sandstone

PLATE 3



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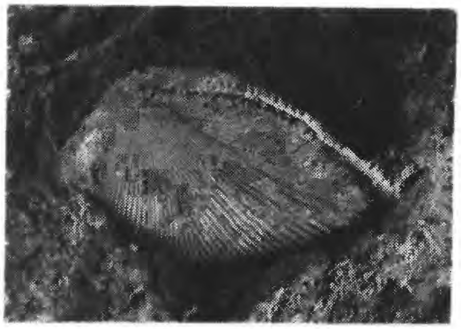

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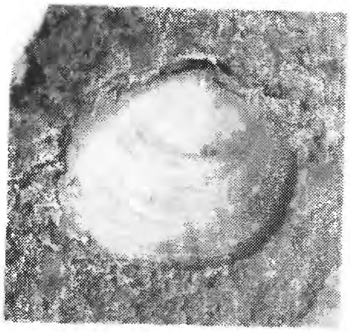

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PLATE 3

1. *Acila* (*Truncacila*) *demessa*,
   UCB loc. D-8146, x 2.0 (latex impression)

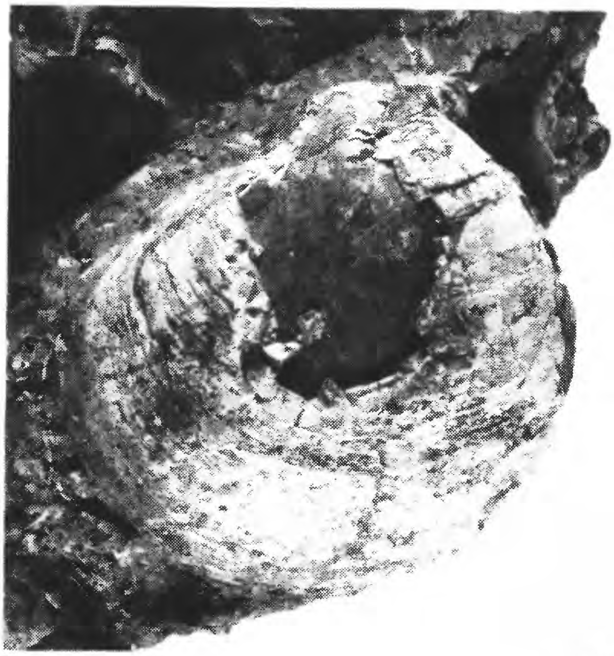
2. *Acila* (*Truncacila*) *demessa*,
   UCB loc. D-8146, x4.0 (latex impression)

3. *Lucina* sp., UCB loc. D-8146, x3.2 (latex impression)

4. indeterminate pelecypod,
   UCB loc. D-8146, x4.1 (latex impression)

5. *Diplomoceras* cf. *D.* *notabile*,
   UCB loc. D-8171, x1.0 (internal mold)

PLATE 4



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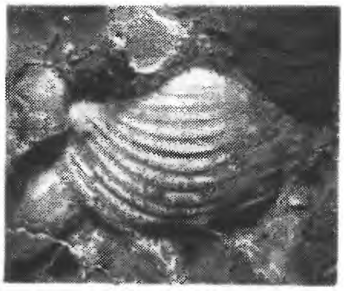

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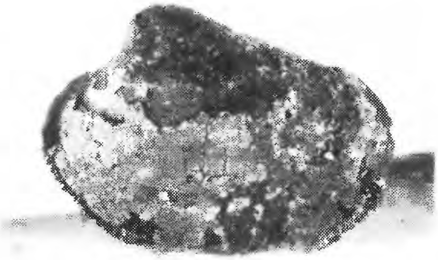
PLATE 4

1. ?*Diodus tenuis*, UCB loc. D-8150, x1.4
2. *Anomia* sp., UCB loc. D-8150, x2.3
3. *Corbula* n. sp. aff. *C. pozo*, UCB loc. D-8150, x2.1
4. Rock specimen showing orientation of fossils, UCB loc. D-8150, x0.7

PLATE 5


1


2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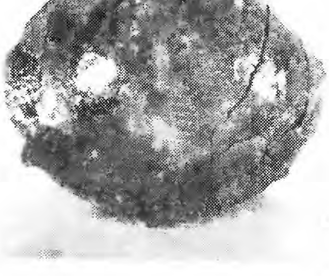
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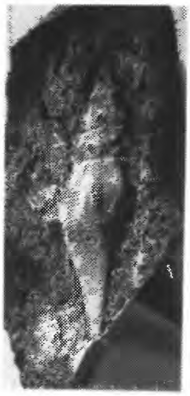
PLATE 5

1. *Callista* (*Costacallista*) *hornii vokesi*? Squires, UCB loc. D-8152, x4.2 (latex impression)
2. indeterminate potamidid, UCB loc. D-8152, x3.1 (latex impression)
3. ?*Pitar* sp., UCB loc. D-8147, x1.4
4. indeterminate potamidid, UCB loc. D-8152, x4.2 (latex impression)
5. *Diodus tenuis*, UCB loc. D-8147, x1.1
6. *Diodus tenuis*, UCB loc. D-8147, x1.4 (internal mold)
7. Rock specimen showing orientation of fossils, UCB loc. D-8149, x0.9.

PLATE 6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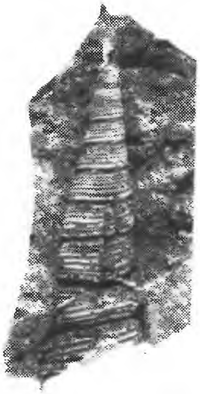
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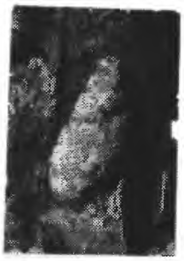
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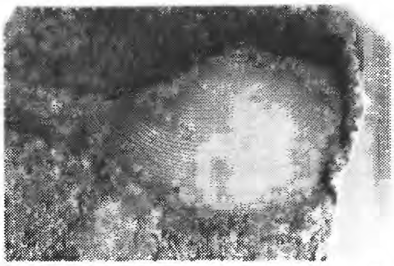
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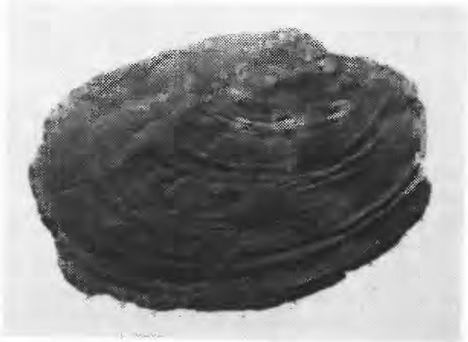
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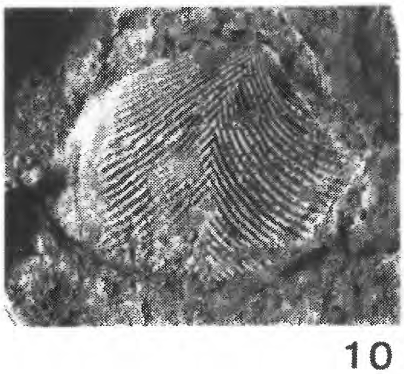
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PLATE 6

1. indeterminate turrid, UCB loc. D-8151, x4.0 (latex impression)
2. *Gemmula* sp., UCB loc. D-8151, x2.7 (latex impression)
3. *Turritella buwaldana*, UCB loc. D-8151, x2.0 (latex impression)
4. *Turritella buwaldana* subsp. *coosensis*?, UCB loc. D-8151, x2.0 (latex impression)
5. indeterminate gastropod, UCB loc. D-8151, x4.3 (latex impression)
6. *Nuculana (Saccella) gabbii*, UCB loc. D-8151, x3.1 (latex impression)
7. ?*Pitar* sp., UCB loc. D-8151, x4.5 (latex impression)
8. *Nuculana (Saccella) gabbii*, UCB loc. D-8151, x3.1 (latex impression)
9. *Periploma* sp., UCB loc. D-8151, x2.0 (internal mold)
10. *Acila (Truncacila) decisa*, UCB loc. D-8151, x4.0 (latex impression)
11. *Acila (Truncacila) decisa*, UCB loc. D-8151, x4.0 (latex impression)
12. *Acila (Truncacila) decisa*, UCB loc. D-8151, x4.0 (latex impression)

PLATE 7

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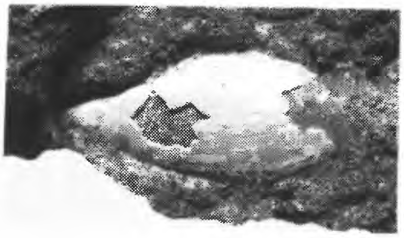

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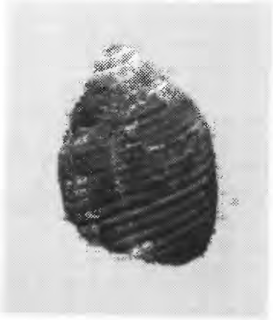

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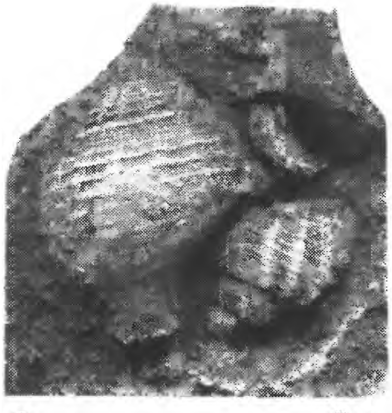

6 6a

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PLATE 7

1. Rock specimen showing fossil orientation,
UCB loc. D-8156, x1.0

2. *Molopophorous californicus*,
UCB loc. D-8156, x4.2 (latex impression)

3. *Tellina* n. sp.? Givens 1974 aff. *T. townsendensis*,
UCB loc. D-8154, x1.7

4. *Tellina* sp., UCB loc. D-8154,
x1.9

5. indeterminate buccinid, UCB loc. D-8156, x2.1
(internal mold)

6. *Whitneyella* sp., UCB loc. D-8156,
x4.1 (latex impression)

6a. *Cancellaria* sp., UCB loc. D-8156,
x4.1, (latex impression)

7. Rock specimen showing orientation of fossils,
UCB loc. D-8154, x1.8

PLATE 8

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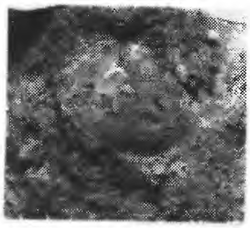

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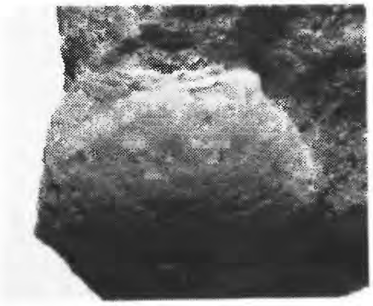

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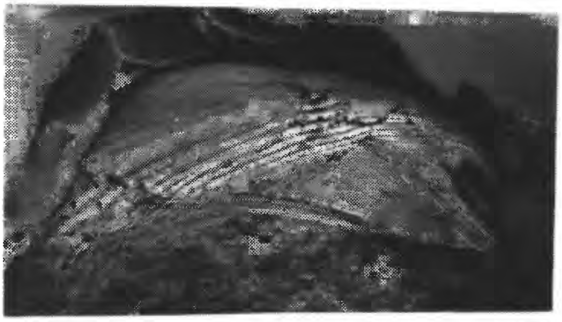

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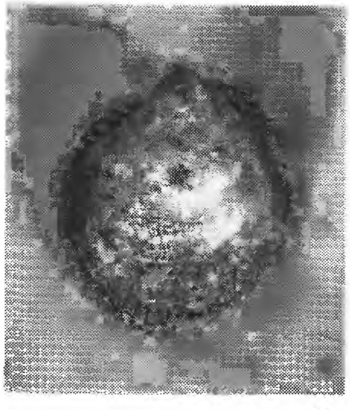

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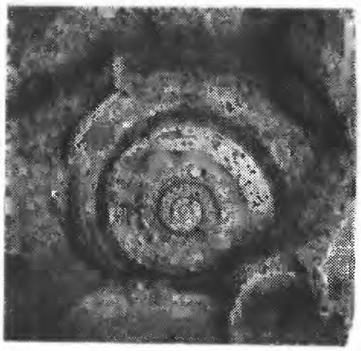

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PLATE 8

1. *Turritella merriami*,
   UCB loc. D-8157, x1.5 (internal mold)

2. *Turritella merriami*,
   UCB loc. D-8157, x2.0 (latex impression)

3, *Turritella merriami*,
   UCB loc. D-8157, x2.0 (latex impression)

4. *indeterminate naticid*, UCB loc. D-8157,
   x2.0 (internal mold)

5. *Nuculana* (*Scaeoleda*) sp.,
   UCB loc. D-8157, x2.0 (internal mold)

6. *Spisula* sp., UCB loc. D-8157, x1.8
   (internal mold)

7. *Brachidontes* (*Brachidontes*) *cowlitzensis*,
   UCB loc. D-8157, x3.0 (latex impression)

8. *Glycymeris* sp., UCB loc. D-8157, x2.1
   (internal mold)

9. *Acanthocardia* (*Schedocardia*) cf. *A.*
   brewerii, UCB loc. D-8157, x3.0
   (internal mold)

10. *Architectonica* sp.,
    UCB loc. D-8157, x3.5 (latex impression)