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EOCENE LLAJAS FORMATION, SIMI VALLEY, SOUTHERN CALIFORNIA

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ABSTRACT

The late early through early middle Eocene Llajas Formation in the Simi Valley area, southern California, represents a transitional alluvial to marine system. Most of the formation is part of a transgressive sequence of strata that grades vertically upward from 1) massive clast-supported conglomerate deposited in stream channels on coastal alluvial fans, to 2) fossiliferous alluvial-fan like conglomerate interbedded with well-laminated, well sorted, Ophiomorpha-burrowed fossiliferous sandstone deposited along the shoreline, to 3) alternating laminated and bioturbated sandstone with scattered channel-fill shelly deposits deposited in nearshore warm temperate to tropical waters, to 4) bioturbated silty sandstone with in situ Eocernina-Turritella-Crassatella-?Trochocyathus megafaunal assemblages that formed where the shallow-marine and outer shelf to slope environments intergrade, and to 5) bioturbated siltstone with diverse benthic foraminiferal assemblages that formed in outer shelf to slope waters. Locally, amalgamated turbidite sandstone fills channels incised into outer shelf to slope siltstone.

The uppermost part of the formation is part of a regressive event in which the outer shelf to slope channel-fill deposits and enclosing siltstone were covered by bioturbated silty sandstone with shallow-marine molluscan and benthic foraminiferal assemblages. The regressive sequence is incomplete due to truncation by erosion prior to deposition of the overlying, nonmarine early late Eocene through Oligocene Sespe Formation.

INTRODUCTION

The name "Llajas Formation" was first used informally by Schenck (1931) and McMasters (1933). Cushman and McMasters (1936) later formalized it, based on brief descriptions of surface outcrops at the type section in Oil Canyon (now known as Chivo Canyon) and corehole data from the Tapo No. 42 oil well, 2 km west of the type section (Fig. 1). Above an unfossiliferous basal conglomerate, it consists

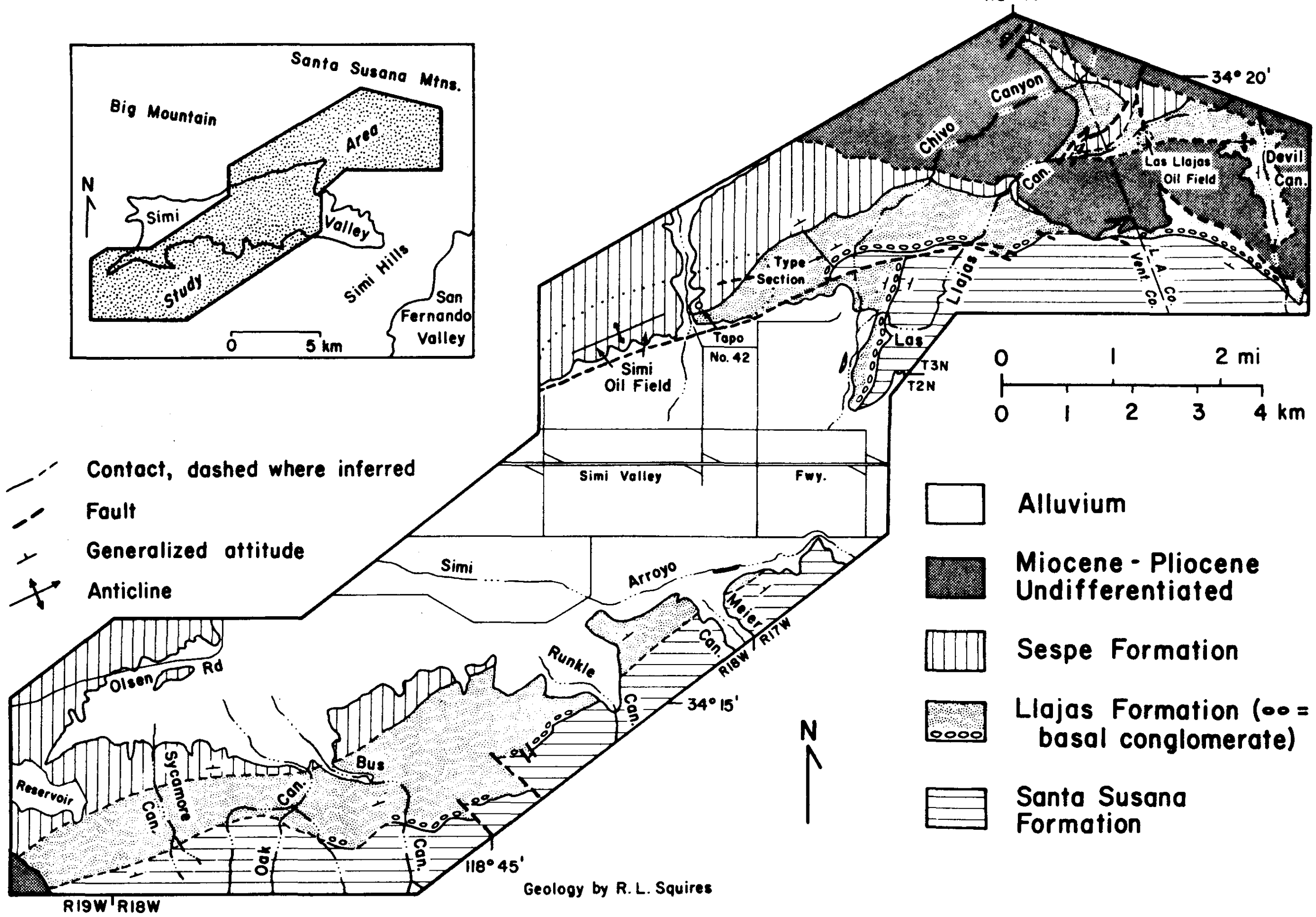

Figure 1. Geologic map showing outcrops of the Llajas Formation in the Simi Valley area, southern California.

in Squires, R.R. and Filewicz, M.V., eds., 1983, **Cenozoic Geology of the Simi Valley Area, Southern California**, Pacific Section, S.E.P.M., Fall Field Trip Volume and Guidebook, p. 81-96.

mostly of very fine-grained sandstone and siltstone with scattered fossiliferous beds.

The Llajas Formation crops out on both sides of Simi Valley. Best exposures are on the north side of the valley at the 545 m-thick type section (Fig. 1). Elsewhere surface outcrops are generally poor, especially along the south side of Simi Valley.

Early workers referred to these strata by various names. A summation of the most widely used early names and how they correspond to the Llajas Formation is shown in Figure 2. The Llajas Formation

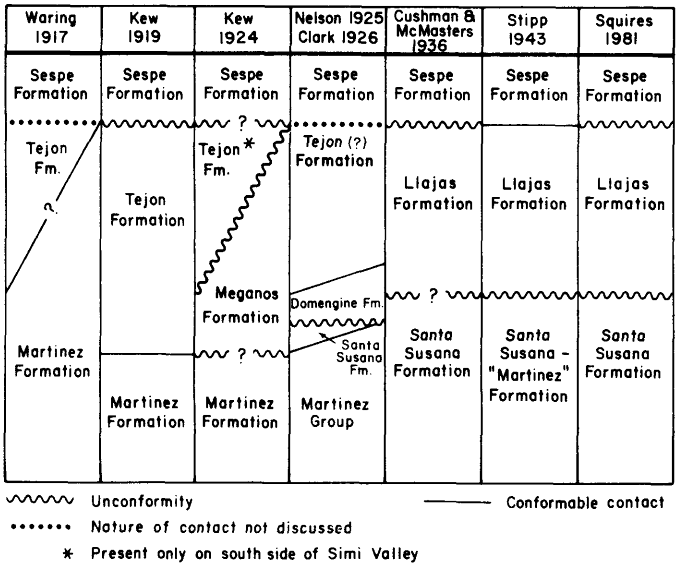

Figure 2. Abbreviated historical development of upper Paleogene stratigraphic nomenclature in the Simi Valley area.

disconformably overlies the late Paleocene through earliest Eocene marine Santa Susana Formation. Except where local faults are present, the Llajas is unconformably overlain by the nonmarine Sespe Formation, considered to be early late Eocene through Oligocene in age (Golz, 1976).

The Llajas is mostly a transgressive sequence of facies that grades vertically upward from a coastal alluvial fan, to shallow marine, to outer shelf to slope with incised channels. The outer shelf to slope facies was subsequently covered by regressive shallow-marine facies (Fig. 3). The regressive sequence is incomplete due to erosional truncation by the overlying Sespe Formation. The amount of erosion increases toward the east (Squires, 1981).

The Llajas is late early Eocene through early middle Eocene in age, based on mollusks, benthonic foraminifers, and calcareous nannofossils.

Workers using mollusks have reported the Llajas Formation as Eocene (Waring, 1917; Kew, 1919, 1924), middle Eocene (Clark, 1921, 1926; Cushman and McMasters, 1936), early through middle Eocene (Clark and Vokes, 1936; Merriam and Turner, 1937; Vokes, 1939; Merriam, 1941; Weaver et al., 1944; Squires, 1981; or late early through early middle Eocene (Squires, 1983, in press; Saul, this volume). A detailed discussion of these works is given in Squires (in press). The late early Eocene strata are in the zone of interfingering between the coastal

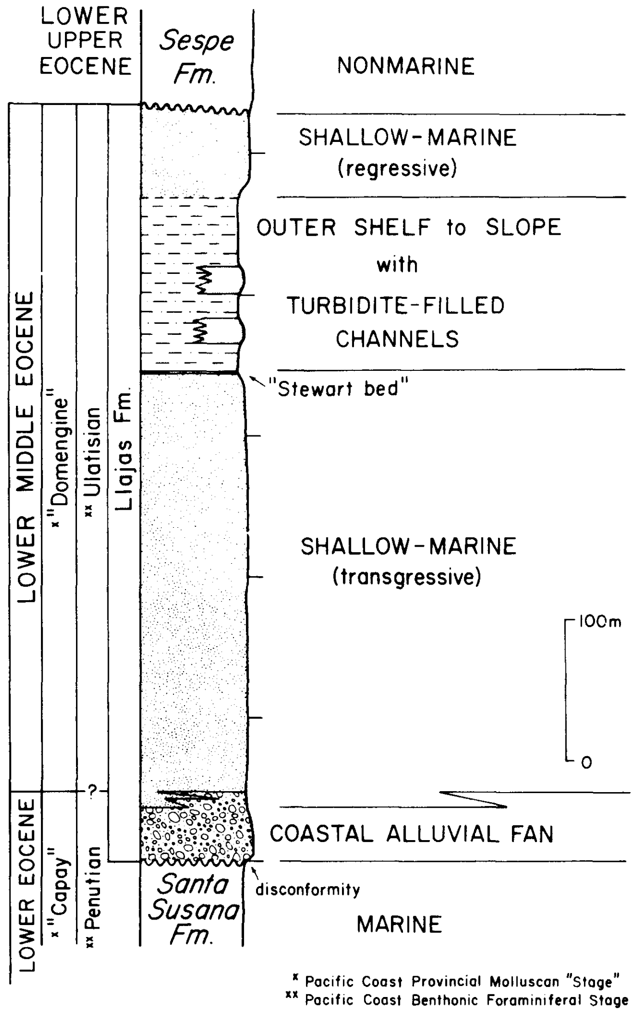

Figure 3. Stratigraphic column of the Llajas Formation, showing depositional environments.

alluvial-fan facies and the shallow-marine facies and would correspond to the lower of the two faunal zones of the Pacific Coast provincial molluscan "Capay Stage" of Clark and Vokes (1936). The remaining fossil-bearing part of the Llajas would correspond to the "Domengine Stage" of Clark and Vokes (1936).

Workers using benthonic foraminifers have reported the Llajas Formation as middle Eocene (Cushman and McMasters, 1936) or early through middle Eocene (Laiming, 1940a, 1940b, 1943; Mallory, 1959; Schymiczek, 1983a, this volume). Mallory (1959) reported that the lower Llajas corresponds to his Pacific Coast benthonic foraminiferal Penutian Stage and that the bulk of the formation corresponds to his Ulatisian Stage. An up-dated refinement of these stages, now known to be time-transgressive, is given in Poore (1980).

Filewicz and Hill (this volume), using calcareous nannofossils, report that most of the shallow-marine (transgressive) facies of the Llajas Formation is of latest early Eocene or earliest middle Eocene age. The uppermost 30 m or so of this facies and the rest of the overlying Llajas Formation is of middle Eocene age.

The upper part of the Santa Susana Formation is earlist Eocene in age (Filewicz and Hill, this volume), thus the unfossiliferous coastal alluvial-fan facies of the Llajas Formation may be early Eocene in age, as it is underlain by early Eocene strata and overlain by latest early Eocene through earliest middle Eocene strata.

In the last 69 years, starting with Waring (1914), there have been many investigations dealing with the megafossils of the Llajas Formation. These previous studies have dealt with undocumented partial faunal lists, descriptions of new taxa, and taxonomic refinements or miscellaneous comments on known species. A listing of these previous workers is given in the comprehensive analysis of the paleontology and biostratigraphy of these fossils by Squires (in press).

Sandstone beds in the Llajas serve as reservoirs in faulted anticline accumulations of oil in the eastern portion of the "Main Area" of the Simi Oil Field in the vicinity of the type section (Fig. 1). This entire field, which was discovered in 1900, had produced nearly 3 million barrels of oil through 1961 (Stipp, 1943; California Oil and Gas Fields, 1961).

Alternating sandstone and siltstone beds serve as reservoirs in a faulted-anticline accumulation of oil in the Union Oil, Las Llajas Oil Field about 5 km northeast of the type section (Fig. 1). This field, which was discovered in 1946, had produced 38,500 barrels of oil through 1963 (Tudor, 1963). According to Nagle and Parker (1971), the Llajas is an oil-producing horizon in other various oil fields in the onshore Ventura Basin. Schymiczek (1983b) discussed the occurrence of oil in the Llajas Formation.

FACIES

The various facies of the Llajas Formation as recognized and discussed by Squires (1981) are summarized below.

Coastal Alluvial-Fan Facies

The coastal alluvial-fan facies is present in the lowermost part of the formation and is shown as "basal conglomerate" in Figure 1. It interfingers with the overlying shallow-marine (transgressive) facies. The coastal alluvial-fan facies is present throughout the northern part of Simi Valley wherever the basal part of the formation is exposed. Thickness ranges from 20 to 40 m. According to Seedorf (this volume), the basal conglomerate can be recognized in the subsurface as far northwest as Oak Ridge, 8 km northwest of the type section. Although the coastal alluvial-fan facies is mostly covered along the south side of Simi Valley, it does crop out between Runkle and Oak Canyons (Fig. 1). Thickness varies from nearly zero to 10 m in that area.

The facies consists of conglomerate (80%) and sandstone (20%) (Fig. 4). The conglomerate consists of channel-fill deposits that average 3 m thick. A few well-exposed beds can be traced for about 100 m. Well rounded clasts consist predominantly of cobble-size light-gray, tan, or purple quartzite. Locally, granite, green andesite, and/or gneiss make up as much as 30 percent of the clasts. Most of the conglomerate is poorly sorted, clast-supported, unstratified, and ungraded (Figs. 5A, B). Sheared clasts and half-round clasts are fairly common. Quartzite boulders with percussion marks are present but are uncommon. The sandstone beds are lenticular and are interbedded with the conglomerate. They average 1 m thick. Most of the lower contacts of the sandstone beds are gradational, and the upper contacts are erosion surfaces. Most of the sandstone is silt to granule subarkose, very poorly sorted, subangular to subrounded, and usually massive. In some places, it is cross-bedded or laminated (Fig. 5C).

Active oil seeps from the basal conglomerate are present at the type section and nearby Chivo Canyon. The seeps are related to small faults that cut the conglomerate. At the type section, some of the sandstone is oil-stained and some of the laminated sandstone contains gilsonite veinlets. Where the gilsonite is present as small streaks parallel to the laminae, it resembles carbonized plant fragments.

Discussion

The massive, poorly sorted, interbedded channelized sequences of conglomerate and sandstone are similar to flood-dominated, stream-channel deposits on alluvial fans. Nilsen (1982, fig. 43C) also interpreted them to be streamflow deposits. The interfingering of the upper part of the facies with shallow-marine deposits indicates that this alluvial-fan system prograded into marine waters. Alluvial fans that prograde into a standing body of water from an adjacent highland have been defined as fan-deltas (Holmes, 1965; McGowen, 1970). The coastal alluvial-fan facies could be called a fan-delta facies, but for the sake of consistency with earlier designations (Squires, 1981, in press), the name "coastal alluvial fan" will be used. It is envisioned that the coastal alluvial-fan depositional setting of the Llajas resembles those of modern high-relief areas along the west coast of Baja California, Mexico. According to Howell and Link (1979), the hydrology and hydraulics of cobble transport for such areas are flood-dominated. The steep topography produces narrow and confined channels that rapidly give way to coastal plains. Where braided rivers carry coarse sediment into the ocean, they produce steep fan deltas. Similar conditions existed in Eocene depositional systems of the San Diego area (Howell and Link, 1979; Link, et al., 1979), as well as in Late Cretaceous depositional systems of the Santa Ana Mountains (Cooper, et al., 1982).

The clasts of the conglomerate beds of the Llajas coastal alluvial-fan facies are well rounded. To produce well-rounded quartzite requires a great deal of transport or abrasion, unless they were derived from nearby exposures of older conglomerate that consist of well-rounded clasts. The nearby Paleocene Simi Conglomerate and portions of the Santa Susana Formation consist of well-rounded clasts very similar in composition (Sage, 1973; Janes, 1976; Parker, this volume) to those of the Llajas basal conglomerate and could have been the source rocks. The poorly sorted nature of the clasts also supports the local-source interpretation.

Shallow-Marine Facies

The shallow-marine facies is divisible into two parts. The transgressive phase of the shallow-marine facies is present in the middle part of the formation whereas the regressive phase is in the uppermost part (Fig. 3).

Shallow-Marine (Transgressive)

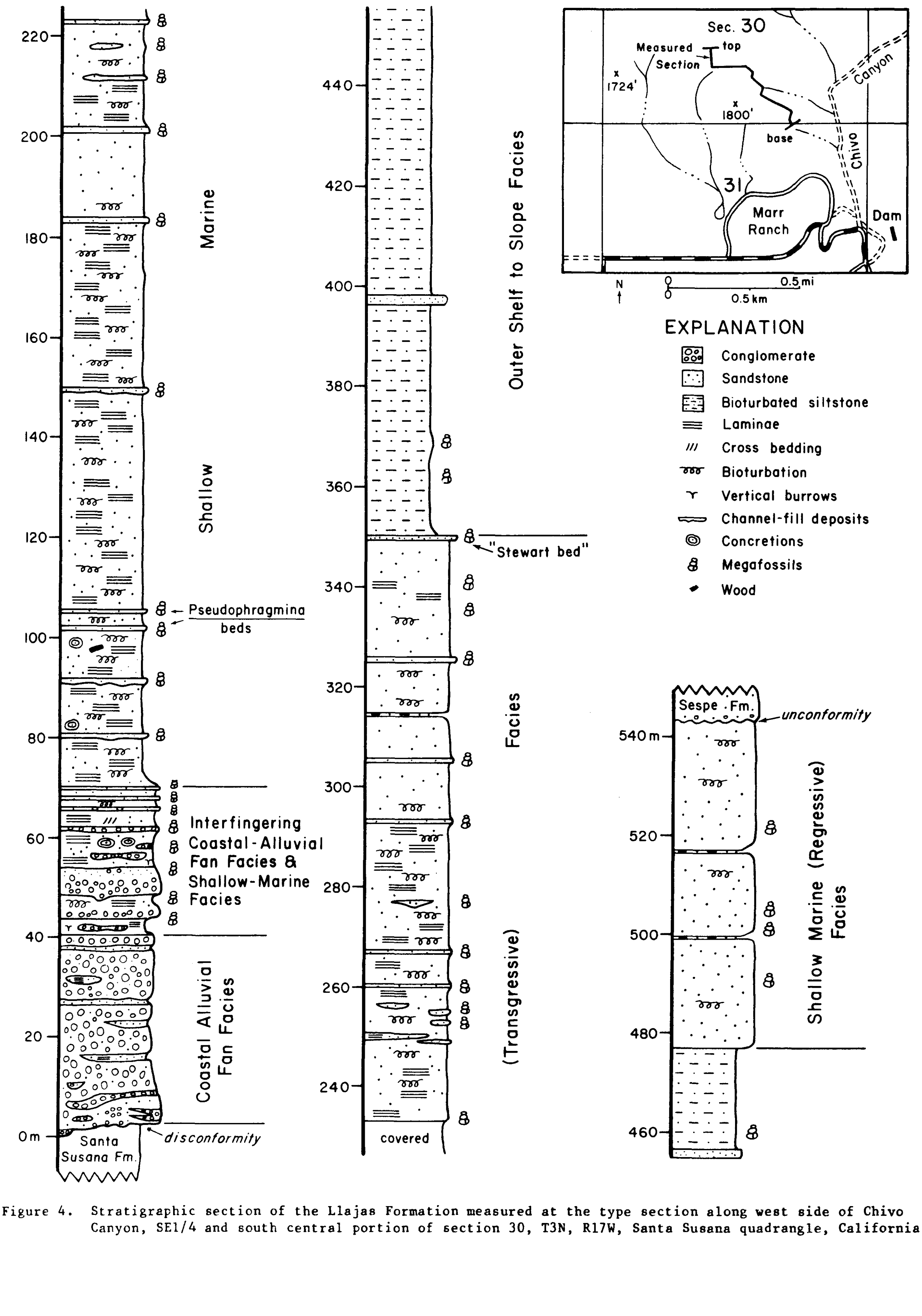

Figure 4. Stratigraphic section of the Llajas Formation measured at the type section along west side of Chivo Canyon, SE1/4 and south central portion of section 30, T3N, R17W, Santa Susana quadrangle, California.

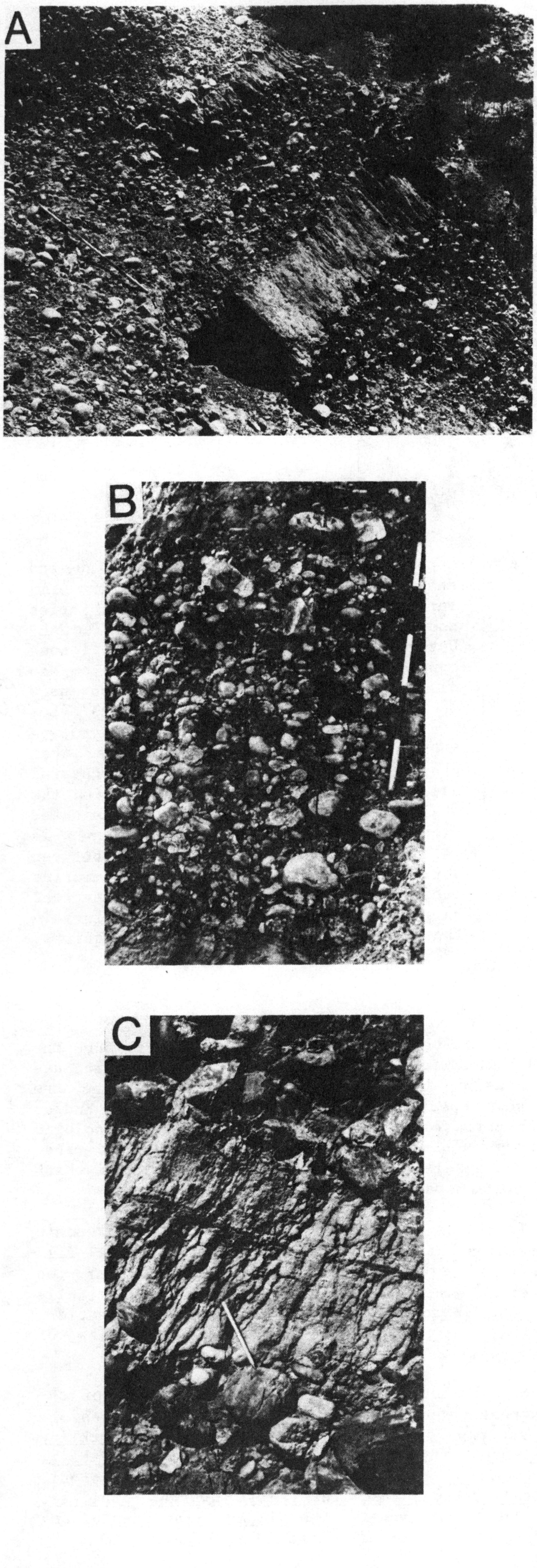

Figure 5. Coastal alluvial-fan facies, type section: A) Conglomerate with interbedded lenticular sandstone; scale is 1.5 m. B) Unstratified and ungraded conglomerate; scale is 1.5 m. C) Laminated sandstone interbed; pen is 14 cm long. (From Squires, 1981).

The shallow-marine (transgressive) facies consists of fossiliferous conglomerate and sandstone where there is interfingering with the conglomerate beds of the coastal alluvial-fan facies (Figs. 4, 6A). The fossiliferous conglomerate beds are similar in geometry, fabric, and lithology to the unfossiliferous conglomerate beds in the coastal alluvial-fan facies. The fossiliferous conglomerate beds grade upward into channelized laminated coquinas consisting mostly of ostreid and unidentifiable gastropod and pelecypod remains (Fig. 6B). In places, there are thick-shelled *Venericardia* (*Pacificor*) *aragonia joaquinensis* fragments. Growth series of thick-shelled *Turritella meganosensis protumescens* can be found locally. This taxon (Fig. 6C) is confined to these beds and characterizes where the coastal alluvial-fan facies interfingers with the shallow-marine facies.

Most of the sandstone in this interval of interfingering facies is very fine-grained, well sorted subarkose. The sandstone is usually laminated (Fig. 6D) although in places low-angle crossbedding, ripple bedding, and channels are present. Vertical burrows, some of which are *Ophiomorpha* (Fig. 6E), are more common in this part of the Llajas Formation than anywhere else. Locally, there are pieces of *Teredo?*-bored petrified wood and transported concretions which have boreholes made by pholadid bivalves.

Overlying the interval of interfingering coastal alluvial fan and shallow-marine facies, the shallow-marine (transgressive) facies consists of alternating laminated and bioturbated sandstone (Figs. 7A, B) with scattered fossiliferous units. The laminated beds can be up to 2 m thick. Many of the lower contacts are erosion surfaces. The sandstone is very fine-to fine-grained subarkose moderately well sorted, subangular, and usually containing some broken small calcareous foraminifers. Commonly, there are penecontemporaneous, very low-angle erosion surfaces within the laminated beds (Fig. 7C). Locally, some beds have undulatory bedding, seemingly related to scouring. Well-preserved *Ophiomorpha* burrows are common.

Bioturbated sandstone is in beds that can be up to 3 m thick. Usually, the lower contacts are gradational with the laminated sandstone. The bioturbated sandstone is very fine to fine subarkose, moderately well sorted and subangular. The sandstone is usually thoroughly mottled by bioturbation (Fig. 7D). *Ophiomorpha* is recognizable in places.

The scattered fossiliferous units in the shallow-marine (transgressive) facies are mostly channel-fill shelly deposits (Figs. 8A,B) that can be up to 50 cm in thickness and 30 m in width. The deposits are calcareous subarkose with variable amounts of mollusks and calcareous benthic foraminifers. Most gastropods and foraminifers are complete and show little or no signs of abrasion or rounding. In many beds, the apices of the *Turritella* shells show a strong bimodal orientation and point mostly toward the northwest or the southeast. Most