Squires, R.L.
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I hope that you
enjoy this chapter.
Good Reading, Señor.
[redacted]
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CHAPTER NINE

GEOLOGIC PROFILE OF SIMI VALLEY

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Simi Valley is in the western part of a region called the Transverse Ranges province. This province extends for a distance of about 300 miles (483 km), from the most westerly part of the southern California coast at Point Arguello in Santa Barbara County (near the town of Lompoc), to just beyond the eastern end of the Little San Bernardino Mountains in central Riverside County. In the vicinity of Simi Valley, the province is about 40 miles (65 km) wide.

The Transverse Ranges province is geologically very complex and comprises chains of mountain ranges that extend east-west and are separated by valleys. Simi Valley is one of these valleys. The Transverse Ranges province is divisible into over a dozen smaller regions, and one of these is the Ventura basin. The western half of the basin is presently covered by the Pacific Ocean. The eastern boundary of the basin is the San Gabriel fault, which extends along the San Gabriel Mountains and across the Santa Clarita Valley. To the north, the Ventura basin is bounded by the Santa Ynez Mountains and Topatopa Mountains, and to the south by the Santa Monica Mountains. Simi Valley is situated within the Ventura basin.

Like most of the valleys in the Transverse Ranges, Simi Valley contains a thick section of clastic sedimentary rocks. These kinds of rocks are layered and resulted from the compaction and cementation of sediments. Simi Valley is unusual because this section of rocks, which measures about 24,400 feet (7,438 m) in thickness, is in a relatively small area that is only about 10 miles (16 km) long and 9 miles (14.5 km) wide. To the north, Simi Valley is flanked by the Big Mountain area and the southwestern part of the Santa Susana Mountains (Figure 1). To the south and east, the valley is rimmed by the Simi Hills. To the west are unnamed hills that separate the valley from the Tierra Rejada Valley and Little Simi Valley.

The sediments that originally comprise clastic sedimentary rocks consist of particles of pre-existing rock. The sizes of the particles, listed in order of increasing size, are mud, silt, sand, pebbles, cobbles, and boulders. Following compaction and cementation, mud becomes mudstone; silt becomes siltstone; sand becomes sandstone; and the pebbles, cobbles, and boulders become conglomerate. Clastic sedimentary rocks are layered with the oldest layer (bed) at the bottom of the stack and the youngest layer at the top.

There are ten clastic sedimentary rock units exposed in the Simi Valley area (Figure 1). There is also a volcanic rock unit that resulted from lava flows. Collectively, these various rock units range in geologic age from Late Cretaceous (about 75 million years) through early Pleistocene (about 1 million years). Overlying the youngest rock unit are unconsolidated sediments deposited in the last 100,000 years or so. The sedimentary rock units and overlying unconsolidated sediments are listed below in proper order, along with their respective geologic time intervals. Nonmarine refers to river deposits, and marine refers to ocean deposits.

Alluvium (nonmarine, Holocene, last 10,000 years)
Terrace deposits (nonmarine, upper Pleistocene, about 500,000 to 10,000 years)
Saugus Formation (marine to nonmarine, upper Pliocene to lower Pleistocene, 3 to 1 million years)
Modelo Formation (marine, middle to upper Miocene, 12 to 6 million years)
Calabasas Formation (marine, middle Miocene, 13 million years)
Conejo Volcanics (marine to nonmarine, middle Miocene, 14 million years)
Vaqueros Formation (marine, upper Oligocene to lower Miocene, 23 to 20 million years)
Sespe Formation (nonmarine, middle Eocene to upper Oligocene, 45 to 24 million years)
Llajas Formation (nonmarine to marine, lower to middle Eocene, 54 to 50 million years)
Santa Susana Formation (marine, upper Paleocene to lower Eocene, 64 to 56 million years)
Las Virgenes Sandstone (nonmarine to marine, lower Paleocene, 64 million years)
Simi Conglomerate (nonmarine to marine, lower Paleocene, 65 million years)
Chatsworth Formation (marine, Upper Cretaceous, 75 to 70 million years)

Notice that the sedimentary rock units have names that generally reflect their geographic occurrence and their major rock type. If the rock unit consists of several major rock types (e.g., siltstone, sandstone, and conglomerate), then the term "formation" is used. The names "Simi Conglomerate," "Santa Susana Formation," and "Llajas Formation" are derived from Simi Valley place names. The names of the other rock units are derived from other locales in southern California.

All of the Simi Valley rock units, except the Chatsworth Formation, were formed during an interval of geologic time called the Cenozoic Era (from 66 million years ago to Recent). Sub-intervals of Cenozoic time (listed from oldest to youngest) are the Paleocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene, and Holocene. The Chatsworth Formation formed during the last part of the Mesozoic Era during Cretaceous time, which immediately preceded Paleocene time.

To understand the complex geologic history of Simi Valley, it is necessary to discuss the theory of plate tectonics. According to the theory, the earth's crust (lithosphere) today is constructed of seven huge slabs called plates. These plates are in constant motion, driven by hot magma moving just under the crust. The boundaries of the plates are either sea-floor spreading centers, subduction zones, or transform faults.

A *sea-floor spreading center*, also called a ridge or rise, is a long fracture on the ocean floor where heat and molten matter (magma) escape. The magma soon hardens and forms oceanic crust that is made up of basalt rock. If a plate consists mostly of oceanic crust, it is called an oceanic plate. Oceanic plates grow outward from spreading centers as new rock is added there. Eventually, the basalt rock is pushed aside as new magma rises to fill the space, solidify, and become a new part of the growing plate. Oceanic crust is about 3 miles (4.8 km) thick and is young material, geologically speaking. The oldest oceanic basalt that can be found on the ocean floor today is about 160 million years old.

A *subduction zone* is a long fracture (called a trench) on the ocean floor where plates collide. One plate underrides the other plate, plunges into the earth's interior, and its leading edge is melted. The entire process is called subduction. Collisions can take place between two oceanic plates, one oceanic and one continental plate, or two continental plates. Continental plates are those that are capped with a significant amount of continental crust that is derived from remelted oceanic crust as it descends into the earth in the subduction zone. Continental crust, which consists largely of granite, is lighter than oceanic crust and is not subducted. The process of formation of continental crust has been going on since the early history of the earth. The oldest known continental crust is about 4 billion years old. Today, about one-third of the earth's surface is continental crust; the other two-thirds consists of oceanic crust. Continental crust ranges in thickness from about 18 to 30 miles (29 to 48 km).

A *transform fault* occurs where the portion of a plate or spreading center on one side of a fault moves horizontally relative to the portion on the other side of the fault, and crust is neither created nor destroyed. Transform faults usually trend perpendicularly across sea-floor spreading centers, but, interestingly, no volcanic action takes places along the transform fault itself. Most transform faults are located on the ocean floor, but a few, including the San Andreas fault in California, are situated on the continents.

From Chatsworth Formation time about 75 million years ago to upper Sespe Formation time about 30 million years ago, the western margin of North America was a subduction zone. An offshore spreading center (East Pacific Rise) was slowly moving the oceanic plate underneath the North American plate. From Chatsworth Formation time through Llajas Formation time, the interaction of the oceanic plate with the continental plate caused repeated downwarping or subsidence of the crust, thereby allowing deep-ocean waters to repeatedly cover the Simi Valley region.

CHATSWORTH FORMATION

Accumulation of the Chatsworth Formation began during the latter part of Cretaceous time. The formation is 6,000 feet thick (1828 m) and is the thick-

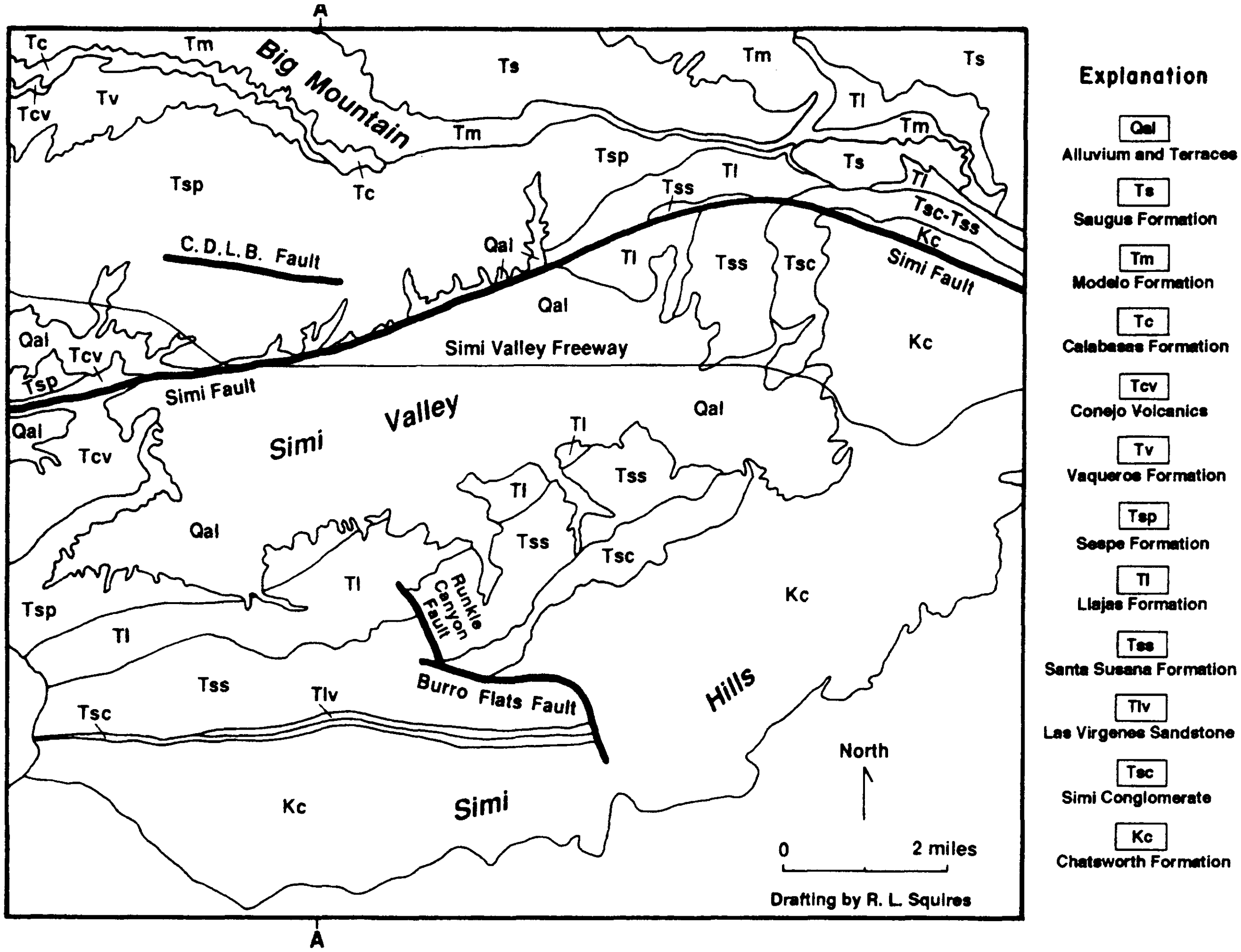

Figure 1. Generalized geologic outcrop map of Simi Valley showing exposures of the rock units, unconsolidated deposits, and major faults. Modified from Squires' (1983) geologic map in Squires and Filewicz (1983). A-A' refers to traverse of geologic cross section shown in Figure 5.

est formation in the Simi Valley area. Sandstone is the main component of the formation, and the sandy material was derived from mountain highlands to the south and transported to the edge of the continent by rivers. Very dense ocean currents, called turbidity currents, then eventually transported the sandy material from the shoreline down into a submarine canyon. At the mouth of the submarine canyon, in water depths of several thousand feet, the sands formed a delta-like accumulation called a submarine fan. After each turbidity current deposited its load of sand onto the submarine fan (thereby forming what is known as a turbidite deposit), fine mud settled out of suspension. This deep-sea submarine-fan complex comprised, not only the Chatsworth Formation, but also similar deposits of equivalent age in the Santa Monica Mountains and in the Santa Ana Mountains (Orange County).

Fresh exposures of the Chatsworth Formation can be readily observed in the extensive roadcuts along the Simi Valley Freeway in the Simi Hills, where the formation consists of thick-bedded gray sandstones interbedded with thinner mudstones. The rocks in these roadcuts are darker in color than those in the immediately surrounding hills because the roadcuts show unweathered rocks. Weathered exposures of the Chatsworth Formation are brown to reddish brown.

Additional roadcuts in the Chatsworth Formation occur along Santa Susana Pass Road, Corriganville, in Black Canyon Road, Box Canyon Road, and at the top of the Simi Hills near the Rocketdyne Santa Susana Field Laboratory. In addition, the Chatsworth Formation can be seen along the trail at Rocky Peak Park. The best area to see the Chatsworth Formation is at the east end of Simi Valley just east of Kuehner Drive. There, one can see large tilted slabs of sandstone. These sandstone beds were tilted about 40° from the horizontal by earth movements that took place when the Simi Valley syncline (discussed later) was formed.

During the time when the sediments comprising the Chatsworth Formation were accumulating, much of southwestern California (including the Simi Hills region) was several degrees of latitude farther south than it is today. Most of southwestern California may have been situated on a part of the crust that had been moving northward along the western edge of the North American continent for many millions of years before Chatsworth Formation time. Collision between this part of southern California and North America may have taken place just after Chatsworth Formation time. When the Chatsworth Formation was accumulating, however, the Simi Hills and the Santa Monica Mountains were together, possibly in an area that is now the Santa Ana Mountains in Orange County. During Miocene time about 60 million years later, they were separated from each other to their present locations by lateral movement along active faults.

The Chatsworth Formation accumulated when dinosaurs were present in the western United States. Dinosaurs, however, were not present in the Simi Valley area because of the existence of deep-sea conditions. The types of fossils found in the Chatsworth Formation are mainly deep-water microfossils of one-celled organisms called benthic foraminifera. Near the base of the formation, macrofossils (fossils large enough to be studied without the aid of a microscope) are found in beds that were deposited in somewhat shallower water than most of the rest of formation. These macrofossils, mostly snails (gastropods), clams (bivalves), ammonites (extinct creatures related to modern nautiloids), and shark teeth, were deposited in temperate (cool) waters. A total of approximately 54 species of snails, clams, and ammonites have been reported from the Chatsworth Formation. Some of the ammonite shells are quite large. They can be nearly two feet (60 cm) in diameter and weigh over a hundred pounds.

Some oil has been found in the Chatsworth Formation, but only in the Horse Meadows oil field north of Northridge. It is one of the few fields in southern California in which oil has been obtained from Cretaceous rocks.

Overlying the Chatsworth Formation is the Simi Conglomerate, which was deposited during the earliest part of the Cenozoic Era. The two formations are separated by an erosional surface called an unconformity. Following deposition of the Chatsworth Formation, the deposits were uplifted and subsequently eroded to produce the unconformity. The uplift may have been caused by the above-mentioned collision between southwestern California and North America. The gravels and sands that make up the conglomerate and sandstone deposits of the Simi Conglomerate were derived from nearby mountainous highlands to the east. Some of the rivers that cut through these mountains probably flowed from regions now in the Mojave Desert of southeastern California.

Along the south end of Burro Flats, in the Rocketdyne Santa Susana Field Laboratory area at the top of Simi Hills, the Burro Flats fault (Figure 1) bends to the north where it passes into another fault, called the Runkle Canyon fault, about 0.5 miles (0.8 km) west of Runkle Canyon. Just west of where these faults are, the Simi Conglomerate is 490 feet (150 m) thick and is overlain by the Las Virgenes Sandstone and the Santa Susana Formation. Toward the western edge of Simi Valley, the Simi Conglomerate thins to just a few feet thick.

THE SIMI CONGLOMERATE

The Simi Conglomerate, Las Virgenes Sandstone, and Santa Susana Formation west of the Burro Flats and Runkle Canyon faults represent a transitional sequence from river deposits to shallow-marine deposits to deep-marine deposits, respectively. Initially river, and then, shoreline to shallow-marine sands accumulated and make up the conglomerates of the Simi Conglomerate, the sandstones of the Las Virgenes Sandstone (300 to 640 feet thick = 100 to 195 m), and the lower part of the Santa Susana Formation, respectively. Eventually, as subsidence continued and waters deepened, silts and muds accumulated and make up the siltstones and mudstones of the remainder of the Santa Susana Formation. The total thickness of the Santa Susana Formation in this area is 3,370 feet thick (1,030 m). Macrofossils are locally abundant in the shoreline and shallow-marine deposits and consist mainly of many species of snails, clams, and nautiloids. The ocean waters were quite warm and subtropical species flourished. The gastropod Turritella was especially common at this time. Some fairly large specimens of nautiloids up to about 1 foot (30 cm) in diameter have been found, and a few specimens preserve their mother-of-pearl irridescence.

The sequence of Las Virgenes Sandstone and Santa Susana Formation formed mostly during Paleocene time, about 64 to 56 million years ago, and make up one of the best exposures of marine rocks of this age anywhere in western North America.

East of the Burro Flats and Runkle Canyon faults, the Simi Conglomerate and the Santa Susana Formation both consist of deep-marine deposits that accumulated in a similar fashion as the submarine-fan deposits of the Chatsworth Formation. The Simi Conglomerate in this area is quite variable in thickness and ranges from 100 to 1,440 feet (30 to 440 m), and the thickness of the Santa Susana Formation in this area is about 3,400 feet (1,050 m). Nonmarine deposits are not recognized on this side of the fault; nor is the Las Virgenes Sandstone. Shallow-marine macrofossils are locally abundant in the lower part of the Santa Susana Formation east of the Runkle Canyon area, but the shells were transported by ocean currents from nearby shallow-marine waters into the deeper marine waters. The shells consist mostly of warm-water, subtropical snails and clams. Also some nautiloids, scaphopods (tube-dwelling animals closely related to snails and clams), and shark teeth have been found. A total of about 145 species of macrofossils have been collected from the Santa Susana Formation east of the Runkle Canyon area.

The uppermost part of the Santa Susana Formation east of the Burro Flats and Runkle Canyon faults formed during earliest Eocene time, about 56 million years ago. The sandstones in this part of the formation reflect a shallowing event. Locally, warm-water snails, clams, and solitary corals can be found.

The Burro Flats and Runkle Canyon faults are very significant because they put, side-by-side, deposits of the same age but of vastly different types of environments. The deposits on either side of the fault complex, nevertheless, look quite similar.

Exposures of the deep-marine Simi Conglomerate can be observed on the south side of the Simi Valley Freeway in a roadcut between Kuehner Drive and the Yosemite Avenue overpass. The overlying Santa Susana Formation is exposed a short distance to the west along the north side of the Simi Valley Freeway in the vicinity of the Yosemite Avenue overpass, where steel-gray deep-marine mudstones form low hills.

The Llajas Formation

Overlying the Santa Susana Formation, on both sides of the Burro Flats and Runkle Canyon faults, is the Llajas Formation, which was deposited during most of Eocene time, about 54 to 50 million years ago. An unconformity separates the two formations. Following accumulation of the Santa Susana Formation, uplift resulted in erosion of some of this formation. The gravels that make up the conglomerate at the base of the Llajas Formation were deposited at the shoreline by rivers that flowed through a nearby mountainous highland to the east. Eventually, subsidence allowed the return of ocean waters, which, through time, deepened enough to allow formation of a thick section of shallow-marine storm-influenced sands, followed by a thin section of moderately deep-marine silts. These sediments make up the sandstones and siltstones of the formation. The thickness of the Llajas Formation is about 1,790 feet (545 m). Locally, macrofossils are very abundant in the shallow-marine deposits and consist mainly of warm-water, subtropical benthic foraminifera, snails, clams, and nautiloids. Also, some scaphopods, crabs, heart-urchins, and shark teeth have been found. A total of 107 species of macrofossils have been collected from the Llajas Formation, and some representative species are shown in Figure 2. These species are from a three-feet-thick (90 cm) sandstone layer known as the "Stewart bed."

Although most of the fossils in the Llajas Formation were concentrated in channels by means of the action of storms, the fossils in the "Stewart bed" lived together in a community that was positioned at the edge of a slope where the ocean floor began to deepen significantly. This slope edge was at least 6 miles (10 km) long, and it was where ocean currents upwelled and brought plentiful food to the animals.

Deposition of the Llajas Formation coincided with the warmest time of the Cenozoic Era about 54 million years ago. The early Eocene was the time of the last true greenhouse climate in the world. Warm climate was widespread because there was no land situated over the poles, and as a result, there was little mixing of the cooler polar waters with the warmer ocean waters elsewhere in the world. Even in the high Arctic, conifer-hardwood and deciduous-hardwood forests blanketed the land. Conditions were warm enough to support palms, cycads, tortoises, and alligators at a latitude of 77 degrees north in Ellesmere Island, Canada. Tropical to subtropical conditions extended as far north as southern England and probably as far north as the Gulf of Alaska. The Atlantic Ocean was narrower than today, and Central America was under water. There was a strong equatorial current that extended from the area now known as Pakistan, north Africa, and France into the Central American region. A branch of this current also extended along the west coast of North America. Many of the snail and clam species found in the Llajas Formation are closely related to species found in Pakistan, north Africa, and France. A few are the same.

As will be mentioned later, oil has been found in the Llajas Formation. Some of the wells that produce oil from the Llajas Formation were drilled just after the turn of the century, and a few of these wells still have the original oil-drilling equipment in daily operation (Figure 3). In lower Chivo Canyon on Marr Ranch, in the northeastern part of Simi Valley, there is also an active oil seep associated with oil-saturated sandstone of the Llajas Formation.

The Llajas Formation is not accessible to the public anywhere in Simi Valley, except in one very small exposure along Tapo Canyon Road at the mouth of Tapo Canyon, north side of Simi Valley. The conglomerate at the base of the Llajas Formation makes up a ridge just east of the golf course along the mouth of Las Llajas Canyon, near the northern end of Stearns Street. Grass-covered foothills on both sides of Runkle Canyon, on the south side of Simi Valley, consist of the Llajas Formation.

The Sespe Formation

Overlying the Llajas Formation is the Sespe Formation which was deposited during middle Eocene to late Oligocene time, about 45 to 24 million years ago. An unconformity separates the two formations and indicates uplift and erosion of the Llajas Formation prior to deposition of the Sespe Formation. The Sespe Formation, which is 5,430 feet thick (1,655 m), consists almost entirely of flood deposits laid down in river channels and on the adjacent floodplains. Initially, there were braided rivers (similar to those in southern California today) characterized by sand and gravel bars. Then, after much deposition, the land became fairly level, and muddy meandering rivers (similar to the Mississippi River) crossed the broad floodplains. During the time when the rivers changed from braided to meandering, and throughout the time of the meandering rivers, abundant land animals lived in the rivers and along the shores of the rivers. Among these animals were freshwater snails and clams, fish, frogs, turtles, snakes, crocodiles, birds, rodents, primitive land mammals (for example, rhinoceroses and camels), and primates. For a more elaborated treatment of these types of fossils and the environments in which they lived, see Lander (this volume). Toward the end of Sespe time, renewed uplift caused the return to braided rivers and the accumulation of sands and gravels.

Exposures of the Sespe Formation (lower to middle parts) are extensive along the north side of Simi Valley Freeway, especially near Madera Road. There are also excellent exposures along Tapo Canyon Road on the north side of Simi Valley. The Sespe Formation (lower part, braided-river deposits) is exposed in some of the foothills between Erringer Road and First Street on the south side of Simi Valley.

As will be mentioned later, oil and gas have been found in the Sespe Formation on the north side of Simi Valley.

During upper Sespe Formation time, there was a dramatic change in the interaction between the oceanic plate and the western edge of the North American continent. A transform fault offsetting the East Pacific Rise that had been pushing the oceanic plate to the west since Cretaceous Formation time now intersected the western margin of North America in the vicinity of central California. When this happened, about 30 million years ago, the subduction margin was slowly replaced by a margin in which the oceanic plate slipped past one another horizontally (in a sideways motion). This slippage occurred along the large transform fault associated with the sea-floor spreading center. Slippage has continued northwest and southeast of the intersection to present day at a rate of about 2 inches (5 cm) per year; hence, the transform fault has been increasing in length. Today, the transform fault is represented by the San Andreas fault. Slippage along this fault has caused the earth's crust west of the fault to move northwest away from the rest of southern California, which lies east of the San Andreas fault. In about 10 million years, Los Angeles will be adjacent to San Francisco.

Vaqueros Formation

The top of the Sespe Formation interfingers with shallow-marine deposits at the bottom of the overlying Vaqueros Formation, which was laid down during late Oligocene to early Miocene time, about 23 to 20 million years ago. The Vaqueros Formation consists of sandstone and siltstone that represent a transitional sequence from marsh and beach to shallow-marine deposits. The formation is about 1,600 feet thick (310 m) near the northwestern margin of Simi Valley but is not present east of the Big Mountain area because of erosion that took place prior to the deposition of the overlying Calabasas Formation. Volcanic glass debris in the Vaqueros Formation indicates active volcanism was occurring during deposition of this formation. Initially, the ocean waters spread northward and eastward across a relatively flat coastal floodplain with wave-dominated sandy beaches and coastal salt marshes. Continued deepening of the marine environment resulted in a fairly deep offshore shelf environment, but water depths did not exceed 180 feet (60 m). Gradual uplift or a sea-level rise then took place, with an associated decrease in water depth. Limestone beds composed almost entirely of snails, large oysters, other large clams, and barnacles are fairly common in

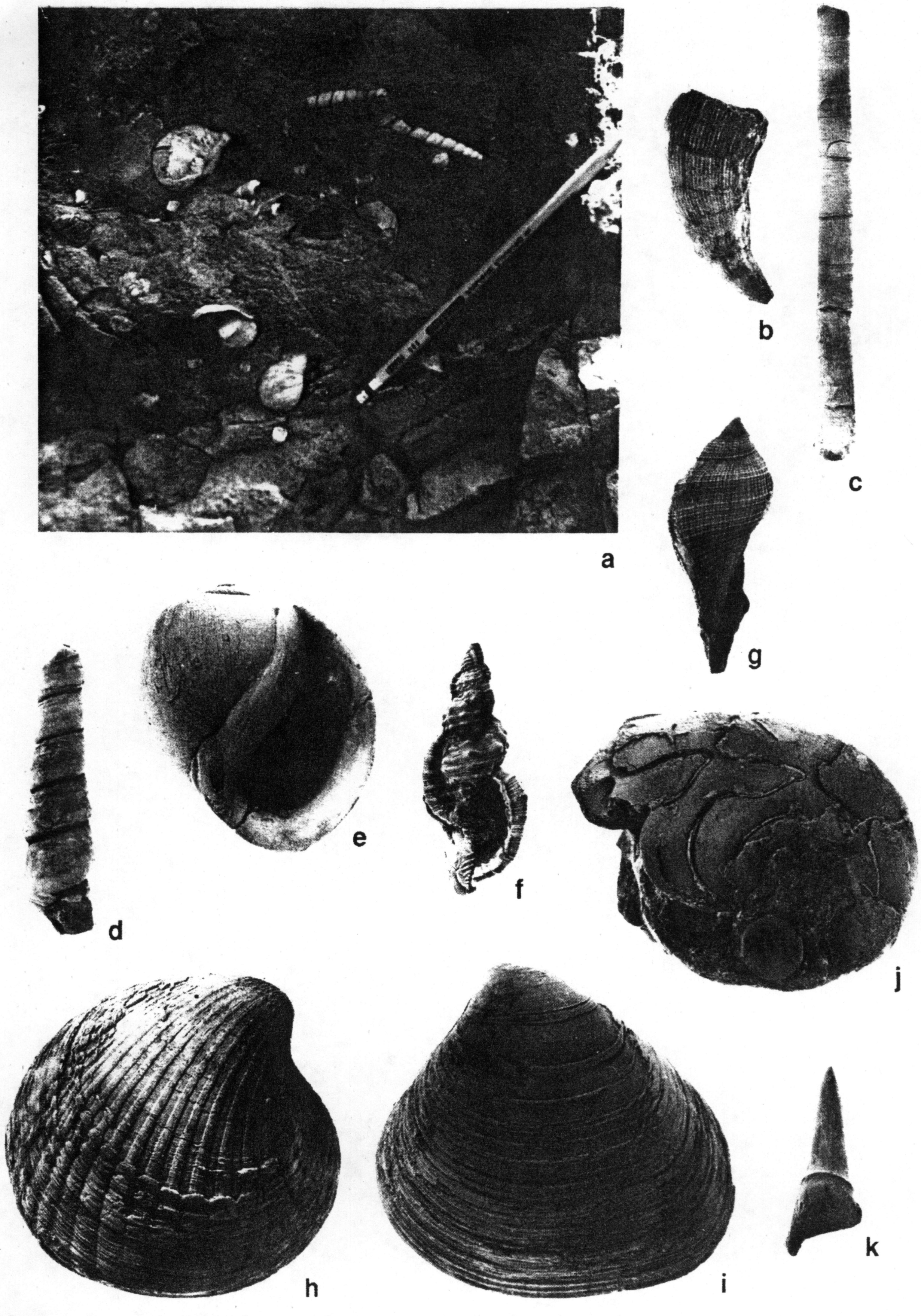

Figure 2. Representative macrofossils from the marine "Stewart bed" of the Llajas formation, north side of Simi Valley. All specimens are the same ones used in Squires (1984); a) typical exposure of the "Stewart bed"; b) solitary coral, Trochocyathus striatus, height 36 mm; c) scaphopod, Dentalium stentor, height 76 mm; d) snail, Turritella andersoni lawsoni, height 38 mm; e) snail, Eocernina hannibali, height 47 mm; f) snail, Cymatium (Septa) janetae, height 43 mm; g) snail, Ficopsis remondii crescentensis, height 43 mm; h) clam, Venericardia (Pacificor) hornii calafia, height 110 mm; i) clam, "Crassatella" uvasana, height 58 mm; j) nautiloid, Aturia myrlae, height 26 mm; k) shark tooth, Odontaspis sp., height 32 mm.