Stratigraphic Nomenclature of the Central Santa Monica Mountains, Los Angeles County, California

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Stratigraphic Nomenclature of the Central Santa Monica Mountains, Los Angeles County, California

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With a section on AGE OF THE CONEJO VOLCANICS
By D. L. TURNER *and* R. H. CAMPBELL

CONTRIBUTIONS TO STRATIGRAPHY

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STRATIGRAPHIC NOMENCLATURE OF THE CENTRAL SANTA MONICA MOUNTAINS, LOS ANGELES COUNTY, CALIFORNIA

By R. F. YERKES and R. H. CAMPBELL

ABSTRACT

The stratigraphic nomenclature of the central Santa Monica Mountains is revised to conform with present knowledge of the age, distribution, and stratigraphic relations of about 35 bedrock units. The revision is based on 1:12,000-scale mapping of the entire stratigraphic sequence and its facies, the position and stage assignment of abundant fossils, and contact relations.

Of seven formational names in common use for the sequence north of the Malibu Coast fault, Chico (Upper Cretaceous) and Martinez (Paleocene) are inappropriate, and the new local names Tuna Canyon and Coal Canyon are proposed as replacements. The names Simi(?) Conglomerate and Llajas(?) Formation are introduced from the Simi Hills area for locally exposed lower Tertiary units. Although the names Sespe, Vaqueros, and Topanga are retained, the Sespe and Vaqueros Formations are locally subdivided into mappable members, and Topanga is proposed as the group name for a thick widespread heterogeneous sequence of middle Miocene marine and nonmarine sedimentary and volcanic rocks. The new name Topanga Canyon Formation is proposed for the lower (prevolcanic) part of the type Topanga as specified by Kew (1924), which contains the well-known Topanga Canyon molluscan assemblage; Conejo Volcanics is introduced for the generally thick and widespread sequence of extrusive rocks in Kew's Topanga; and Calabasas Formation is proposed for the thick widespread marine clastic sequence above the volcanic rocks in that section. These three formations of the Topanga Group are locally subdivided into named members.

The east-trending Malibu Coast fault is the northernmost through-going element of a zone of north-dipping reverse faults that forms the south boundary of the Transverse Ranges. Although the coastal sequence south of the fault is equivalent in age to parts of the mountain sequence north of the fault, it is dissimilar in provenance and history. The new name Trancas Formation is proposed for the mudstone-sandstone-breccia part of the coastal sequence; the new name Zuma Volcanics is proposed for the associated volcanic rocks; and the name Monterey Shale is applied to the shale sequence that directly overlies both the Trancas Formation and the Zuma Volcanics.

INTRODUCTION

The nomenclature of the stratigraphic succession in the central Santa Monica Mountains (fig. 1) requires revision to conform with present knowledge of the age, distribution, and structural relations of the many recognized units and their facies.

The Santa Monica Mountains form the southwesternmost of the east-trending Transverse Ranges of southern California. From the

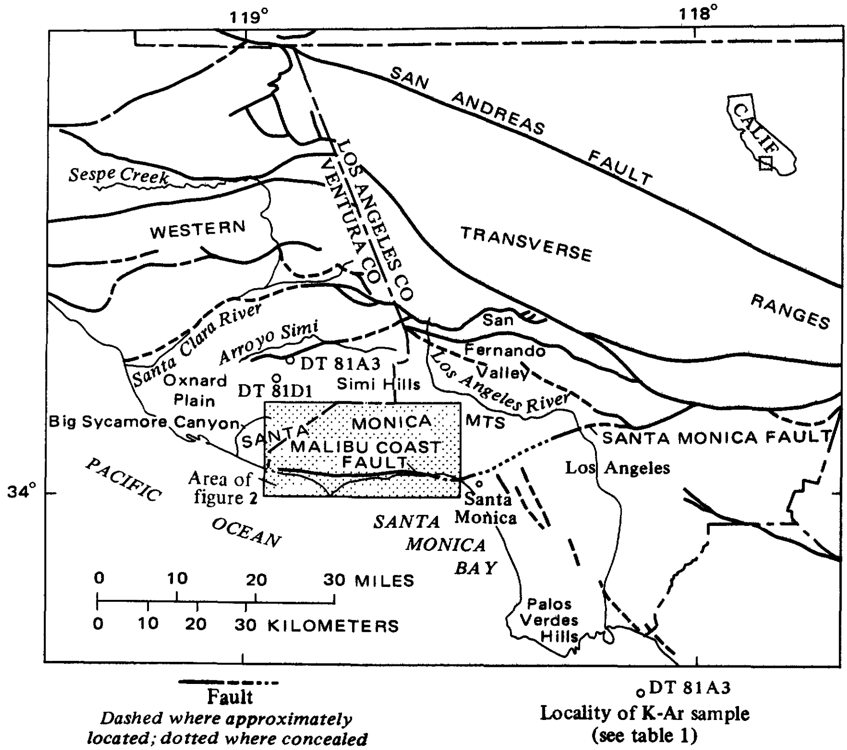

FIGURE 1.—Index map of part of southern California showing area mapped (stippled).

Oxnard Plain, they extend eastward about 80 km to the Los Angeles River and are 5 to 16 km wide from the Pacific Ocean on the south to the Oxnard Plain, Simi Hills, and San Fernando Valley on the north. The range is bounded on the south by the east-trending Malibu Coast and Santa Monica faults, elements of a 150-kilometer-long zone of north-dipping reverse faults that form the south boundary of the Transverse Ranges west of the San Andreas fault.

The Malibu Coast fault is the east-trending boundary between two very different geologic terranes: to the south, a basement of Catalina Schist is overlain by Miocene and younger deposits; to the north, a basement of Santa Monica Slate and plutonic granodiorite is overlain by Upper Cretaceous through upper Miocene deposits. The northern sequence, about 6,000 m thick, represents most of the megainvertebrate and foraminiferal stages from Campanian to Mohnian and exhibits evidence of early and middle Miocene shorelines.

PREVIOUS WORK

Geologic names now in common use (pl. 1) date chiefly from Eldridge and Arnold (1907), who introduced the following names, given in descending order, for formations in the Ventura basin area:

Modelo Formation, for upper Miocene strata exposed at head of Modelo Canyon north of the Santa Clara River, Ventura County.

Vaqueros Sandstone, for lower Miocene strata bearing the *Turritella inezana* fauna. Named by Hamlin (1904) for exposures in Los Vaqueros Creek, Monterey County.

Sespe Formation, for a redbed sequence in the Sespe Creek area north of the Santa Clara River, Ventura County. Named by Watts (1897).

Kew (1923,1924) introduced the following names in the eastern Ventura County-northern Santa Monica Mountains area:

Modelo Formation, extended use to the north flank of the Santa Monica Mountains.

Topanga Formation, named and defined by Kew (1923) for strata exposed below the upper Miocene Modelo Formation, above the lower Miocene Vaqueros Formation, and containing the *Turritella ocoyana* fauna in the Topanga Canyon area, north slope of the Santa Monica Mountains, Los Angeles County.

Martinez Formation, extended to so-called lower Eocene (Paleocene) strata in the Simi Hills area; type named earlier for exposures in the Martinez area, Contra Costa County

Chico Formation, extended to Upper Cretaceous strata in the Simi Hills. Named earlier for exposures on Big Chico Creek, Butte County.

Hoots (1931) extended use of the names Chico, Martinez, Sespe, and Vaqueros to the Santa Monica Mountains east of Topanga Canyon. He locally subdivided the Chico, Topanga, and Modelo and named the subdivisions in terms of their lithology or stratigraphic position within the formation.

Woodring, Bramlette, and Kleinpell (1936) extended the name Monterey Shale to the Miocene shale sequence in the Palos Verdes Hills southwest of Los Angeles. The name was taken from a lithologically similar sequence of the same age range in Monterey County, central California.

Soper (1938) subdivided the Sespe and Topanga Formations in the area between Malibu-Las Virgenes and Topanga Canyons but did not map or name the subdivision. He (1938, p. 164) also recognized the presence of nonmarine strata equivalent to the Vaqueros and from this inferred an early Miocene shoreline.

Durrell (1954, 1956) published a preliminary planimetric geologic map of the entire mountain range at a scale of 1:126,720. His students mapped and informally named subdivisions of the Topanga in the area west of Topanga Canyon and Durrell (1956) briefly described some of the stratigraphic complexities of the Miocene sequence north of the Malibu Coast fault, recognizing the need for revision of the stratigraphic nomenclature.

PRESENT REPORT

The present report is based on systematic geologic mapping at 1:12,000 of the unincorporated Los Angeles County part of the Santa Monica Mountains, that part between Santa Ynez Canyon on the east and Arroyo Sequit on the west (fig. 2). Preliminary maps and sections showing the distribution of the stratigraphic units, their sedimentary facies, locations and stage assignments of their fossil content, and their structural relations have been open filed (Campbell and others, 1970; Yerkes and others, 1971, 1973). These data are diagrammatically summarized in a composite section (pl. 2).

The field mapping was initiated in 1961 and continued intermittently into 1973 as part of a cooperative investigation with the County of Los Angeles. Report preparation, though delayed at many stages by other assignments, has been supported in part by Los Angeles County. Identification of fossil mollusks and assignment to megainvertebrate stages was by W. O. Addicott, D. L. Jones, E. J. Moore, and J. G. Vedder; identification of fossil Foraminifera and their assignment to microfaunal stages was by R. L. Pierce, P. J. Smith, and Kristin McDougall; all are of the U.S. Geological Survey.

STRATIGRAPHIC NOMENCLATURE

Of many stratigraphic names that have been in common use in the Santa Monica Mountains for 50 years or more, several are inappropriate in the modern context of regional stratigraphy. It is proposed that their use be discontinued and new names adopted. In addition, several major mappable units deserving of formal designation have been recognized within sequences formerly grouped under a single formation name; for these we propose using either new local names or names extended from nearby areas. Moreover, because the sequence of strata on the south side of the east-west trending Malibu Coast fault is different in provenance and history from that on the north side, a fact not recognized by previous stratigraphic nomenclature, new names reflecting this difference are proposed.

SEQUENCE NORTH OF THE MALIBU COAST FAULT

TUNA CANYON FORMATION

DEFINITION

The Tuna Canyon Formation is here named for an Upper Cretaceous marine sequence of sandstone, siltstone, and conglomerate ex-

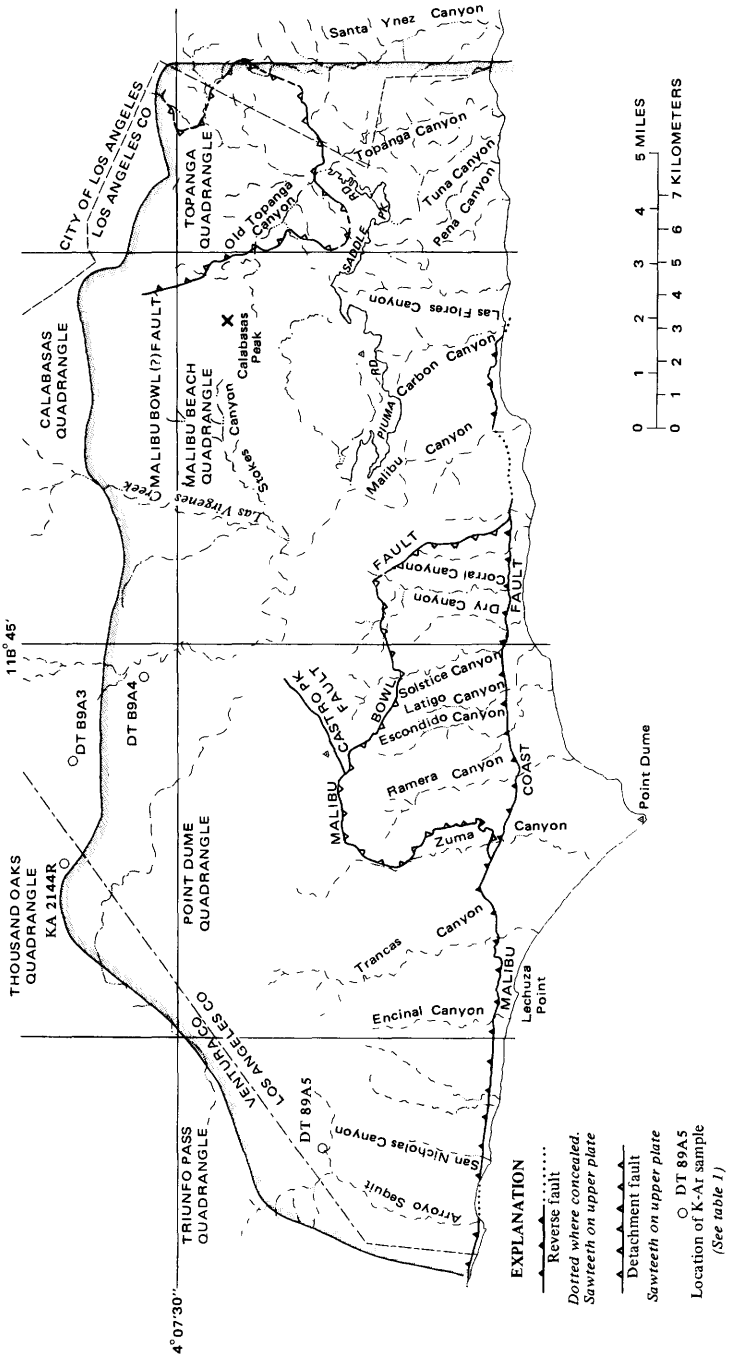

FIGURE 2.—Map of central Santa Monica Mountains showing area mapped in detail (shaded boundary) and 7½-minute quadrangles.

posed in Tuna Canyon in the southwest part of the Topanga quadrangle, Los Angeles County (pl. 3A).

Smaller, isolated exposures are present in Solstice, Trancas, and Zuma Canyons. The base is not exposed in the mapped area, but east of Santa Ynez Canyon it rests on the Santa Monica Slate or on a thin nonmarine conglomerate; the sequence is unconformably(?) overlain by the Coal Canyon Formation or the intervening Simi(?) Conglomerate (figs. 2, 3).

LITHOLOGY, THICKNESS, AND STRATIGRAPHIC RELATIONS

In Tuna Canyon, the type locality, the formation is dominantly thick-bedded graded laminated beds of coarse-grained arkosic sandstone (turbidite) containing abundant fragments of black slate(?). Some beds show convolute lamination, load casts, low-angle cross lamination, or concentrations of carbonized plant fragments or mica. Fossiliferous sandstone and siltstone are present locally as interbeds or thick lenses; sandy cobble conglomerate near the mouth of Tuna Canyon contains abundant fragments of slate(?) and as much as 50 percent well-rounded cobbles and boulders of gray or greenish-gray porphyries and quartzites.

In Las Flores Canyon, the Tuna Canyon Formation consists chiefly of massive coarse-grained poorly sorted tightly packed unfossiliferous lithic sandstone that is a distinctive grayish orange pink and closely jointed and fractured. The uppermost part contains several beds of olive-gray siltstone that locally contains Foraminifera; olive-gray to grayish-red mudstone is present locally near the upper contact.

In Solstice, Zuma, and Trancas Canyons, the formation consists of very thick- to thick-bedded fine- to coarse-grained sandstone (probably turbidites) and interbedded siltstone and small-pebble conglomerate. In Zuma Canyon, it locally contains mollusks and Foraminifera.

The Tuna Canyon Formation is nowhere completely exposed in the mapped area. The maximum exposed thickness, in the Peña Canyon-Tuna Canyon area, is nearly 800 m. East of Santa Ynez Canyon, equivalent strata rest on Upper Cretaceous(?) nonmarine red conglomerate (Trabuco Formation of Durrell, 1954) and the Upper Jurassic Santa Monica Slate. The formation is overlain disconformably(?) by the Simi(?) Conglomerate in Solstice Canyon and by a basal conglomerate of the Coal Canyon Formation (Paleocene) in upper Tuna Canyon and in Las Flores Canyon.

AGE

Numerous fossil mollusk collections from the Tuna Canyon Formation are assigned to the Campanian Stage of the Upper Cretaceous;

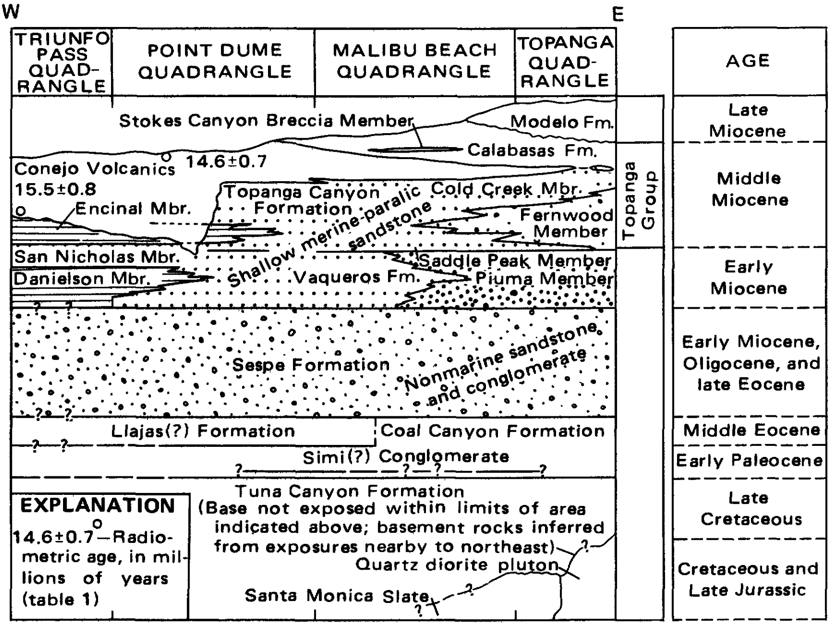

FIGURE 3—Correlation diagram of units north of the Malibu Coast fault (except for those restricted to the upper plate of the Malibu Bowl fault).

the diagnostic Campanian species *Metaplacenticeras pacificum* (Smith) is common. Microfossil localities are less abundant, but two collections of Foraminifera, one from siltstone on the east wall of Las Flores Canyon and one from the east fork of Trancas Canyon, are assigned to the early Maestrichtian or Campanian Stage.

SIMI(?) CONGLOMERATE

The name Simi Conglomerate is questionably applied to a distinctive thin nonmarine conglomeratic unit mapped locally at the base of the Tertiary sequence. The conglomerate is questionably correlated with the type Simi Conglomerate of the Simi Hills (Nelson, 1925). The best exposures in the mapped area are on the east wall of upper Solstice Canyon north of the Malibu Bowl fault in the Point Dume quadrangle (pl. 3B), where the sequence is about 46 m thick; the conglomerate is traceable westward for about a mile from that locality.

In Solstice Canyon the Simi(?) is characterized by an abundance of polished, very well rounded cobbles and boulders of quartzite, granitic, rhyolitic, and gneissic rocks in conglomeratic coarse-grained sandstone that contains a 1-m-thick bed of brick-red pisolitic clayey sandstone.

On the basis of its stratigraphic relations and position, the Simi(?) is inferred to be Paleocene in age. In the mapped area, the Simi(?) is conformably overlain by fossiliferous marine strata of the Paleocene Coal Canyon Formation; in the Simi Hills area, the type Simi is unconformable on Upper Cretaceous beds, and just north of the hills, it yielded a boulder of fossiliferous sandstone containing the diagnostic Upper Cretaceous species *Turritella chicoensis* Gabb (Kew, 1924, p. 15–16).

COAL CANYON FORMATION

DEFINITION

The Coal Canyon Formation is here used for part of a fossiliferous marine sequence of sandstone, pebble conglomerate, and siltstone that unconformably(?) overlies the Tuna Canyon Formation and underlies marine strata questionably assigned to the Llajas Formation. The name is taken from exposures in Carbon (formerly Coal) Canyon, the type locality, in the southeast part of the Malibu Beach quadrangle (pl. 3C). Large exposures are present in the north-central and southwest parts of the Topanga quadrangle and in Solstice Canyon, on the Trancas Canyon-Zuma Canyon ridge, and west of Trancas Canyon in the Point Dume quadrangle.

LITHOLOGY, THICKNESS, AND STRATIGRAPHIC RELATIONS

The Coal Canyon Formation consists chiefly of sandstone and pebbly sandstone; in some areas, the Topanga Canyon area in particular, it contains cliff-forming pebble conglomerate and siltstone; east of Topanga Canyon, the upper part of the formation contains several small pods of algal limestone.

The sandstone is chiefly very fine to medium grained, poorly to well sorted, and consists of subrounded quartz and feldspar in a sparse clayey matrix, locally biotitic; it locally contains abundant mollusks; beds commonly are thick and locally have graded upper parts and sharp upper contacts. Siltstone and silty claystone are present locally in the upper part of the formation; they are closely jointed, have conchoidal fracture, and contain abundant biotite and local partings of fine-grained silty biotitic sandstone and calcareous beds or concretions as thick as 15 cm and as long as 1 m.

Limestone occurs as scattered lenses and pods in siltstone sequences east of Topanga Canyon. Beds are massive, as thick as 5 m, and contain calcareous algalike structures, granular calcite, sparse mollusks, Foraminifera, and scattered grains of quartz.

Pebble-cobble conglomerate forms resistant steep slopes in Carbon and Topanga Canyons. It typically occurs in beds as much as 7 m thick with scattered pebbles, boulders, slabs, and interbeds of mudstone and medium- to coarse-grained sandstone. The rock consists of subrounded to well-rounded pebbles of light-colored granitic and gneissic rocks, brown and gray quartzite, and distinctive brick-red or lavender quartz-bearing porphyry.

The basal conglomerate locally exposed in upper Tuna Canyon contains rounded large cobbles and boulders of light-colored granitic and gneissic rocks and well-rounded cobbles of quartzite but lacks the red and lavender porphyries of the pebble-cobble conglomerate. The matrix is poorly sorted angular arkosic sandstone that contains abundant lithic fragments.

The only complete section of the Coal Canyon Formation in the map area is in Solstice Canyon, east-central Point Dume quadrangle, where it is about 335 m thick. However, the minimum thickness summed from incomplete sections in the Carbon Canyon-Topanga Canyon area is as great as 450 m where the sequence mapped as Coal Canyon may locally include some strata equivalent to the basal part of the overlying Llajas(?) Formation.

The Coal Canyon Formation overlies the nonmarine Simi(?) Conglomerate or equivalent strata inferred to represent the base of the Tertiary sequence; in its only complete section in Solstice Canyon, the formation is disconformably(?) overlain by marine strata of Eocene age.

AGE

Widely distributed locally abundant megainvertebrate assemblages from the Coal Canyon, including such diagnostic species as *Turritella pachecoensis* Stanton and *Mesalia martinezensis* (Gabb), are assigned to the Martinez Stage (Paleocene) of the Pacific Coast megainvertebrate classification (Weaver and others, 1944).

A few collections of mollusks from siltstone in the Tuna-Topanga Canyon area are questionably assigned to the Eocene; the siltstone may be a lateral equivalent of the Llajas(?) Formation farther west.

LLAJAS(?) FORMATION

The name Llajas(?) Formation is introduced for an unnamed sequence of Eocene marine sandstone and siltstone beds in Solstice and Steep Hill Canyons (pl. 3B). The formation is about 425 m thick in Solstice Canyon, between the Coal Canyon Formation below and the nonmarine Sespe above. The name is taken from strata on the northwest side of the north branch of Las Llajas Canyon just north of Simi Valley, eastern Ventura County (Schenck, 1931, p. 455).

In Solstice Canyon, the sequence consists of very fine grained sandstone, siltstone, pebble conglomerate, and interbedded platy to shaly siltstone and mudstone; it is locally characterized by fossil molluscan species not found in other stratigraphic units. The sequence is accordant with the Coal Canyon Formation below and the nonmarine Sespe Formation above.

Molluscan faunas from the Llajas(?), which include such diagnostic species as *Ectinochilus supraplicatus* (Gabb), *Turritella buwaldana* Dickerson, and *T. Uvasana* Conrad, are assigned to the "Domengine" Stage of the Eocene.

SESPE FORMATION

The name Sespe Formation is retained for a widespread predominantly nonmarine redbed sequence of sandstone, pebbly sandstone, and mudstone. The name was extended from Sespe Creek north of the Santa Clara River. An essentially complete section of the Sespe is exposed only in the upper Solstice Canyon area, where about 1,000 m is present; both lower and upper boundaries are accordant. No fossils have been found in the formation in the Santa Monica Mountains; its late Eocene, Oligocene, and early Miocene age assignment is based on its stratigraphic position above marine middle Eocene strata and below marine lower Miocene strata.

PIUMA MEMBER

The Piuma Member of the Sespe Formation is here named for exposures in Piuma Road and at the head of Carbon Canyon in the east-central Malibu Beach quadrangle (pl. 3D). In this area the lower and upper parts of the Vaqueros Formation tongue eastward into nonmarine strata (pl. 2 and fig. 3). The sequence here consists of a basal nonmarine sandstone about 60 m thick, a marine(?) sandstone-mudstone sequence about 45 m thick, and an upper nonmarine sandstone-mudstone sequence about 282 m thick. Only the lower and upper units are considered tongues of the Piuma Member, the middle unit being considered a tongue of the Vaqueros Formation. The lower tongue of the Piuma Member lies conformably on the undivided Sespe below. In contrast to the thicker bedded more coarsely grained sandstone and conglomerate below, the Piuma is distinguished by thinner individual beds, sandstone of generally finer grain size, absence of pebble and cobble conglomerate, and more interbedded lacustrine or lagoonal siltstone.

The lower tongue of the Piuma Member is grayish-red medium-grained biotitic sandstone with sparse stringers of small pebbles and chips of red mudstone; some beds have a laminated appearance produced by concentrations of biotite and partings of brownish-gray to pale-olive-gray mudstone. The medial unit, assigned to the Vaqueros Formation, consists of medium- to coarse-grained poorly sorted feldspathic sandstone that contains rare casts of *Turritella inezana*, some interbeds of olive-gray mudstone or shale with casts of reeds, and lenses of siltstone chips. The upper tongue of the Piuma Member consists of gray, grayish-red, and olive-gray sandstone, pebbly sandstone, and mudstone, and a 0.5-m-thick bed of resistant nodular limestone. The sandstone occurs in beds as thick as 2.5 m and is medium- to coarse-grained, well sorted, and feldspathic, with subangular to subrounded grains, and contains abundant locally hematized biotite. Mudstone occurs as partings or layers up to 8 m thick.

VAQUEROS FORMATION

The name Vaqueros Formation is retained for the sequence that is above the Sespe Formation and below the Topanga Group and that characteristically contains the *Turritella inezana* fauna. Although the name is from central California, it is well established in coastal southern California and is used consistently throughout intervening areas to refer to a well-recognized and widespread predominantly marine sequence that contains a distinctive molluscan fauna.

The Vaqueros is present throughout much of the mapped area west of Tuna Canyon; however, the sandy nearshore marine facies tongues eastward into nonmarine strata (Piuma Member of the Sespe Formation) between Malibu and Las Flores Canyons such that the marine facies in that area is contained within nonmarine beds above and below (pl. 2 and fig. 3). West of the Malibu Beach quadrangle, the sandy nearshore marine facies interfingers with dark platy or shaly siltstone. In the western part of the Point Dume quadrangle (pl. 3E) and farther west, the dark siltstone facies that predominates in the lower part of the Vaqueros (Danielson Member) is overlain by a thick tongue of sandstone (San Nicholas Member). Here the Vaqueros is overlain by another dark siltstone, the Encinal Member of the Topanga Canyon Formation (see pl. 2 and fig. 3), and the topmost part of the San Nicholas may include some lateral equivalents of the lowermost sandstone of the Topanga Canyon Formation as known farther east.

The Vaqueros consists of medium- to coarse-grained well-sorted thin- to thick-bedded biotitic sandstone and interbedded greenish or reddish mudstone. Sandstone beds are flat laminated and locally graded. In Malibu Canyon and west to Castro Peak, some of the pebbly sandstone beds and the red and green variegated mudstones interbedded in the predominantly nearshore marine sequence may represent brief episodes of nonmarine deposition. Farther west, in the western part of the Point Dume quadrangle and the Triunfo Pass quadrangle, nonmarine beds seem to be absent, and the sequence grades into deposits probably representing neritic environments. An incomplete section of the Vaqueros in Malibu Canyon is about 400 m thick, whereas a complete section in the Solstice Canyon area is about 800 m thick.

DANIELSON MEMBER

The Danielson Member of the Vaqueros Formation consists of beds termed the Danielson Formation by Sonneman (1956), who named the unit for exposures on the Danielson Ranch in Big Sycamore Canyon (fig. 1) in the Newbury Park 7.5-minute quadrangle a few miles northwest of San Nicholas Canyon (fig. 2), where he identified correlative strata. Although Sonneman's thesis (1956) is unpublished, the name Danielson Member is appropriate for the mudstone and siltstone beds that characteristically contain the *Turritella inezana* molluscan fauna and that are well exposed in upper Trancas Canyon, the reference locality (pl. 3E).

As exposed in San Nicholas Canyon, the Danielson Member is predominantly grayish black very fine grained sandy siltstone or mudstone, in medium and thin beds generally with indistinct parallel lamination. Fractures are locally platy or shaly but more commonly conchoidal or irregularly subparallel to bedding. Several prominent interbeds, ⅓ to 1 m thick, of calcareous very fine grained sandstone and sandy mudstone contain fossil remains of *Turritella inezana* Conrad in such numbers as to locally form biostromes.

It is conformably overlain by the San Nicholas Member of the Vaqueros Formation. The base is not exposed in the area where the Danielson has been mapped, but equivalent strata in the undivided Vaqueros of the western part of the Point Dume quadrangle lie conformably on redbeds of the Sespe Formation.

In addition to the numerous fossils of *Turritella inezana,* which is diagnostic of the "Vaqueros" Stage, the siltstone locally contains highly weathered Foraminifera and fish scales. Sonneman (1956, p. 14, 15) reports that the black shale of the Danielson contains Foraminifera referable to the Zemorrian Stage.

SAN NICHOLAS MEMBER

The San Nicholas Member is here named for exposures in San Nicholas Canyon (fig. 2) in the eastern part of the Triunfo Pass quadrangle, where about 150 m of cliff-forming sandstone crops out. To the west, this member has been mapped as the "Nicholas Formation" by Sonneman (1956).

The San Nicholas Member is predominantly very thick bedded to massive cliff- and ledge-forming sandstone, generally very light gray to pale bluish gray. Interbeds and partings of siltstone and shale are rare. The sandstone is very fine- to very coarse-grained and locally is pebbly arenite. Some beds appear massive, but internal cross lamination, parallel lamination, and disturbed (burrowed?) laminations are present. Some beds locally contain abundant fragmental fossil material, chiefly detritus of barnacles.

The San Nicholas Member is conformably underlain by the Danielson Member of the Vaqueros Formation in most of the area; in the western part of the Point Dume quadrangle, however, the contact has not been mapped continuously because siltstone interbeds are common near the base, and the underlying Danielson contains numerous sandstone interbeds. The San Nicholas is conformably overlain by the Encinal Member of the Topanga Canyon Formation. The topmost sandstone in the San Nicholas may be a lateral equivalent of the basal sandstone of the Topanga Canyon Formation in the eastern part of the Point Dume quadrangle (fig. 3).

The San Nicholas Member is assigned to the "Vaqueros" Stage because equivalent beds in the Point Dume quadrangle contain the gastropod *Turritella inezana* ss. Conrad, a species diagnostic of the stage; one collection includes both *T. inezana* and *T. ocoyana*. Foraminifera from interbedded silty shale in the Encinal Canyon area are assigned to the Saucesian Stage (lower and middle Miocene). No diagnostic "Vaqueros" mollusks were found in San Nicholas sandstone of the Triunfo Pass quadrangle; *Vertipecten nevadanus* Conrad (*V. bowersi*) [Arnold] is abundant locally in the topmost beds, and *Lyropecten miguelensis* is common at several horizons.

TOPANGA GROUP

The thick heterogeneous sequence of sedimentary and volcanic rocks that contains a marine facies with a middle Miocene molluscan fauna diagnostic of the "Temblor" Stage (Weaver and others, 1944) formerly was included within the Topanga Formation. In the central and western Santa Monica Mountains west of Topanga Canyon, this sequence totals about 6,100 m in thickness, underlies the entire northern flank of the range, and is readily divisible into three units of formation rank as indicated by Durrell (1954): a lower sequence of marine sedimentary rocks (with a nonmarine facies east of Malibu Canyon), a middle sequence of chiefly volcanic rocks, and an upper sequence of marine sediments that intertongue with and overlie the volcanic rocks. Accordingly, we herein (1) apply formation names to each of these units and (2) apply the name Topanga Group to the entire sequence between the Vaqueros Formation, below, and the Modelo Formation, above, defined by Kew (1923) as the "Topanga Formation."

Kew (1924, p. 48) measured a 1,830-m section on the nose of the Topanga anticline just west of Old Topanga Canyon. Our mapping of that section shows a thickness of about 2,680 m, still much thinner than equivalent sections to the west, largely owing to thinning of the volcanic sequence from many hundreds of meters in the Malibu Canyon area to less than 200 m on the nose of the anticline. Even so, the threefold subdivision persists throughout the mountains west of Santa Ynez Canyon, and the following formations are here named:

Topanga Group:

- Calabasas Formation (new name), marine sedimentary rocks that overlie and intertongue with—
- Conejo Volcanics (name extended eastward from area in western Santa Monica Mountains designated by Taliaferro (1924)), extrusive volcanic rocks.
- Topanga Canyon Formation (new name), prevolcanic, marine, and nonmarine sedimentary rocks.

TOPANGA CANYON FORMATION

The Topanga Canyon Formation is here named for the widespread sequence of marine sedimentary rocks that overlie the Vaqueros Formation and underlie the Conejo Volcanics. Its type locality includes the site of the "Topanga Canyon fauna" described by Arnold (1907, p. 525–526) and named by Kew (1924, p. 48) as exposed in the roadcuts of Old Topanga Road (pl. 3F). Here the overlying Conejo Volcanics is locally absent, and the Calabasas Formation rests directly on the Topanga Canyon.

The Topanga Canyon Formation in some areas is divided into members on the basis of well-developed nonmarine, nearshore marine, and neritic facies: two in the area west of the central Point Dume quadrangle, two east of the central Malibu Beach quadrangle (pl. 2 and fig. 3); the formation is not subdivided in the western Malibu Beach quadrangle and the eastern Point Dume quadrangle.

West of Malibu Canyon, the Topanga Canyon Formation rests conformably on the Vaqueros; the two formations locally contain many similar lithofacies. Where they are similar lithologically, they can still be separated on the basis of characteristic fossils. In the western Point Dume and Triunfo Pass quadrangles, the Topanga Canyon is dominated by a deep-marine siltstone, the Encinal Member. West of Zuma Canyon, the base of a thick shaly siltstone (Encinal Member) marks the base of the Topanga Canyon Formation.

East of Malibu Canyon, the topmost beds of the Vaqueros grade eastward to nonmarine redbed sandstone and siltstone of the Sespe Formation, and farther east, in the northwest part of the Topanga quadrangle, the Topanga Canyon Formation rests accordantly on redbeds of the Sespe Formation. Farther east, in and east of Topanga Canyon, basal beds of the Topanga Canyon Formation grade to a brackish-water fluvial sequence that directly overlies nonmarine redbeds of the Sespe. In the area east of Malibu Canyon, the Topanga Canyon Formation is thus divided into two marine sequences—the Saddle Peak Member below, and the Cold Creek Member above,—separated by a dominantly nonmarine sequence, the Fernwood Member.

TOPANGA CANYON FORMATION (UNDIVIDED)

The Topanga Canyon Formation is undivided in the central part of the area, generally between Trancas and Malibu Canyons. A composite section measured in the Malibu Canyon area consists of alternating thick and thin sequences of medium- to coarse-grained silty biotitic sandstone, hackly sandy siltstone, and pebbly sandstone. The sequences range in thickness from less than 10 cm to about 150 m; beds range from laminae to about 6 m. A conglomerate at the base of this section consists of about 65 percent subrounded pebbles in a matrix of poorly sorted lithic sandstone. The basal contact is obscured by a thick sill of intrusive rock; total exposed thickness of the sequences is about 675 m. The upper contact is mostly accordant with the base of the overlying Conejo Volcanics, but locally, as in the north central Point Dume quadrangle, this contact is sharply unconformable. The formation contains a locally abundant molluscan fauna referred to the "Temblor" Stage, middle Miocene.

TOPANGA CANYON FORMATION (DIVIDED)

West of Trancas Canyon, in the western Point Dume quadrangle, the Topanga Canyon Formation consists chiefly of dark shaly marine siltstone (Encinal Member); east of Malibu Canyon in the central Malibu Beach quadrangle, it is divided into lower marine (Saddle Peak), medial nonmarine (Fernwood), and upper marine (Cold Creek) members (fig. 3).

ENCINAL MEMBER

The Encinal Member is here named from its type locality, exposures on Encinal Canyon Road (pl. 3G), where it may be as much as 430 m thick. The Encinal Member is chiefly dark-gray siltstone or silty mudstone. It is commonly platy to shaly, but at many localities bedding fissility is obscured by a dominant conchoidal fracture. Large lenticular dolomitic concretions are abundant in places, generally along locally restricted stratigraphic zones as thick as 60 cm; none of the zones is so persistent as to provide a stratigraphic marker. The siltstone and mudstone beds are relatively weak, and natural outcrops are rare; the concretions, being relatively resistant to weathering, are commonly present on slopes underlain by Encinal siltstone.

Sandstone interbeds, chiefly medium- and fine-grained wackes (probably turbidites), are rare in the Point Dume quadrangle; they become increasingly abundant westward in the Triunfo Pass quadrangle.

For the most part, the Encinal rests conformably on sandstone of the underlying San Nicholas Member of the Vaqueros Formation, but there is apparent discordance in some places where exposures do not permit discrimination between local unconformity and possible fault contact. The Encinal Member is unconformably overlain by the Conejo Volcanics, generally with slight discordance. There may have been no subaerial erosion separating Encinal deposition (marine sedimentation) from Conejo deposition (volcanic flows and breccias that probably are chiefly submarine).

Poorly preserved Foraminifera in two collections from the type locality on Encinal Canyon Road are assigned to the Relizian (?) Stage and Saucesian or Relizian Stages of Kleinpell (1938). This assignment accords with that of Sonneman (1956), who reports that equivalent strata farther west contained Foraminifera assignable to the Relizian Stage.

SADDLE PEAK MEMBER

The Saddle Peak Member is here named for good exposures on the west shoulder of Saddle Peak in the eastern Malibu Beach quadrangle. Its type locality is designated the roadcuts along Piuma Road (NE¼ sec. 21, T.1 S., R.17 W.) southwest of the peak (pl. 3D), where about 220 m of thick-bedded to massive medium- to coarse-grained sandstone, pebbly sandstone, and hackly sandy siltstone is present above a 0.5-m-thick basal pebble conglomerate. The member is present chiefly in the east part of the quadrangle, where it conformably overlies the Piuma Member of the Sespe Formation and conformably underlies the Fernwood Member of the Topanga Canyon Formation.

A resistant sandstone sequence near the base contains an abundant "Temblor" megainvertebrate fauna that includes the gastropod *Antillophos dumbleanus* (Anderson), apparently restricted to the middle Miocene. Immediately above the basal conglomerate at this locality—and commonly near the base of the Topanga Canyon Formation elsewhere—is a 10-cm-thick bed of well-cemented sandstone that contains numerous well-preserved, in part articulated, valves of the giant pectinid *Vertipecten nevadanus* (Conrad) (also called V. bowersi [Arnold]. The fauna is assigned to the "Temblor" Stage, middle Miocene.

FERNWOOD MEMBER

The Fernwood Member is here named for exposures in the Fernwood area of the west-central Topanga quadrangle where an incomplete section is about 375 m thick (pl 3H). The member rests conformably on, and tongues into, the Saddle Peak Member or, as in the northern part of the Topanga quadrangle, lies directly on red beds mapped as Sespe. The Fernwood is overlain conformably by and tongues into the Cold Creek Member (pl. 2 and fig. 3).

The Fernwood consists chiefly of fluvial to brackish-water pebbly sandstone that forms thick lenticular ledge-forming beds and is complexly channeled and cross bedded; abundant grayish-red or olive-gray mudstone and minor altered (vitric?) tuff and algal(?) limestone are interbedded. The sandstone contains locally abundant closely spaced borings normal to bedding and rare fragments of bone; on the ridge west of Fernwood, one bed locally contains the shallow-water gastropod *Melongena,* known only from the provincial middle Miocene.

COLD CREEK MEMBER

The Cold Creek Member is named for exposures in the Cold Creek-Old Topanga Canyon area in the northeast corner of the Malibu Beach quadrangle, the type locality of the Topanga Formation specified by Kew (1924). In that area the member consists of about 707 m of marine sandstone, silty sandstone, and minor amounts of pebbly sandstone. The sandstone commonly is medium grained, moderately to well sorted, in laminated or graded beds to 2 m thick, and locally biotitic. The member conformably overlies the Fernwood Member. Its upper contact is an unconformity; in most places, it is overlain by the Conejo Volcanics or, where the volcanic rocks are missing, by the Calabasas Formation.

A locally abundant molluscan fauna collected from the area of well-known localities on Old Topanga Canyon Road in the northeast corner of the Malibu Beach quadrangle, the area of the "Topanga Canyon fauna" (Arnold, 1907; Kew, 1924), includes about 50 species of mollusks. The fauna is assigned to the "Temblor" Stage, middle Miocene.

CONEJO VOLCANICS

The name Conejo Volcanics, applied by Taliaferro (1924) to the Miocene volcanic rocks in the western Santa Monica Mountains ("Conejo Mountains"), is adopted for the thick sequence of middle Miocene igneous rocks that are widespread on the north flank of the central Santa Monica Mountains.

Although the volcanic rocks rest accordantly on Topanga, and locally Vaqueros, strata throughout much of the area, the relations locally are sharply discordant (pl. 2 and fig. 3), indicating that significant deformation preceded the outbreak of volcanism. Relations with overlying marine sedimentary rocks generally are accordant, but marked unconformities or onlaps are indicated locally. The volcanic rocks range in thickness from near zero in the Old Topanga Canyon area to about 200 m on the nose of the Topanga anticline, from which they thicken westward to about 3,000 m in the central part of the area.

The main sequence of the Conejo Volcanics consists of alternating interbedded andesitic and basaltic breccias, mudflow breccias, flows, pillow breccias, and aquagene tuffs with minor interbedded locally fossiliferous volcanic sandstone and siltstone, limestone, and tuff. A black shaly marine siltstone locally as much as 90 m thick and containing abundant fish scales is present at the base of the volcanic rocks in some parts of the area. Three stratigraphically distinct tongues of volcanic rocks are complexly interbedded with members of the Calabasas Formation in the upper plate of the Malibu Bowl fault (fig. 4). The volcanic tongues consist of flows, flow breccias, mudflow breccias, and tuff-breccias; their presumed stratigraphic equivalents in the lower plate of the fault are recognized only along the northernmost margin of the central mountains. On the basis of its stratigraphic position and relations, radiometric age, and sparse fauna, the Conejo Volcanics is assigned a middle Miocene age.

AGE OF THE CONEJO VOLCANICS

By DONALD L. TURNER and RUSSELL H. CAMPBELL

Plagioclase separates from four basalts and one andesite were dated by the potassium-argon method to determine the age and time span represented by Conejo volcanism. Data for the potassium-argon age determinations, made by analytical techniques reported earlier (Turner, 1970), are given in table 1. Locations of dated samples are shown in figure 2, their stratigraphic positions in plates 1 and 2 and figure 3.

As shown in plate 1, the radiometric ages, which range from 15.5±0.8 m.y. near the base to 13.9±0.4 (1σ) m.y. near the top of the volcanic pile, fit the stratigraphic sequence. Turner (1970) previously reported a potassium-argon age of 13.1±0.9 m.y. (KA 2144R) on plagioclase separated from a tuffaceous agglomerate near the top of the Conejo volcanic sequence, an age concordant with the date of 13.9±0.4 reported here. The location of the dated sample, KA 2144R, is shown on figure 2, the stratigraphic position on plate 1.

Turner (1968, p. 35) reported a potassium-argon plagioclase age of 9.7±1.9 (1σ) m.y. from andesite from a locality in Arroyo Santa Rosa, southeast of Moorpark. Subsequent dating of this unit from a sample collected approximately 0.2 km east along strike from this locality gave the age of 13.9±0.4 m.y. reported here (fig. 1 sample DT 81A3).

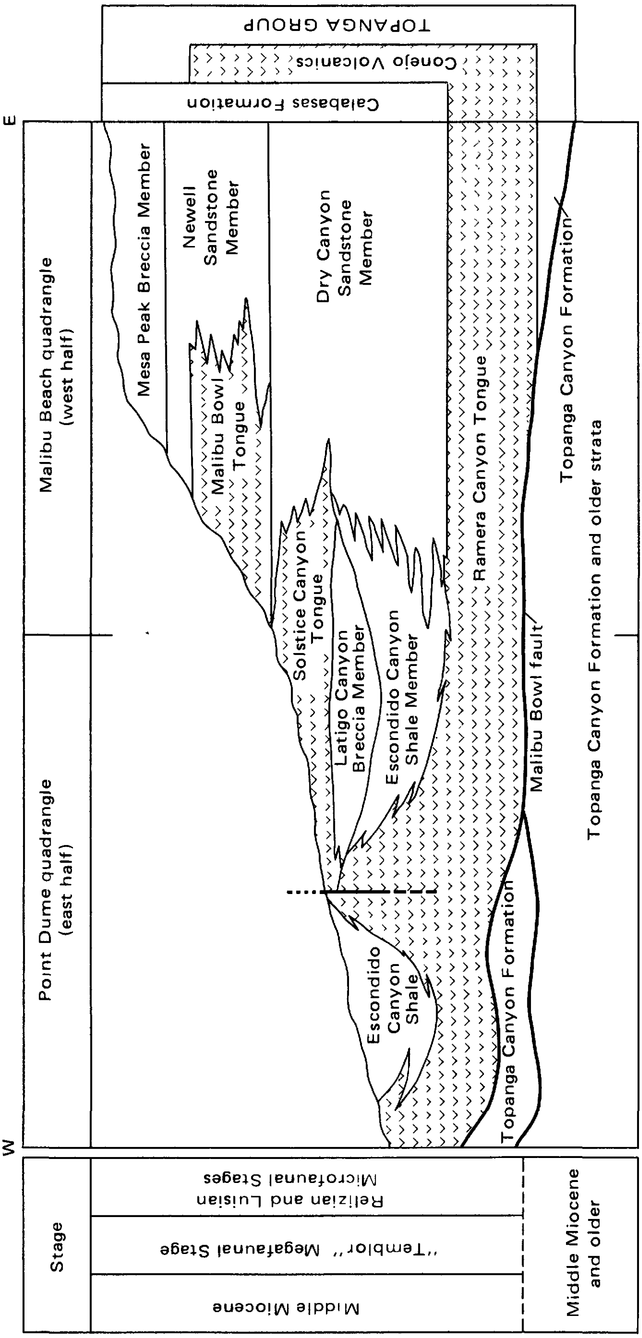

FIGURE 4.—Correlation diagram of units in upper plate of Malibu Bowl fault.

TABLE 1.—*Analytical data for potassium-argon age determinations*

Sample No. (see location data below)	Rock type	Mineral dated	K_2O (weight percent)	Sample weight (grams)	$^{40}Ar_{rad}$ (moles/gm x 10^{-12})	$\frac{^{40}Ar_{rad}}{^{40}K} \times 10^{-4}$	$\frac{^{40}Ar_{rad}}{^{40}Ar_{total}}$	Age $\pm\sigma$ (m.y.)
DT 81A3(69A172)	Andesite	Plagioclase	0.124, 0.125 $\bar{x} = 0.124$	7.0296	2.561	8.143	0.195	13.9±0.4
DT 81D1(70A94)	Basalt	do	0.082, 0.081 $\bar{x} = 0.081$	4.5888	1.889	9.144	.064	15.6±0.6
DT 89A3(70A91)	do	do	0.128, 0.128 $\bar{x} = 0.128$	7.0866	2.813	8.700	.403	14.8±0.4
DT 89A4(70A92)	do	do	0.124, 0.117 $\bar{x} = 0.120$	5.7669	2.620	8.608	.305	14.6±0.7
DT 89A5(70A93)	do	do	0.113, 0.107 $\bar{x} = 0.110$	5.0052	2.536	9.127	.0823	15.5±0.8

Constants used: $\lambda\epsilon = 0.585\times10^{-10}$ yr, $\lambda\beta = 4.72\times10^{-10}$ yr, $^{40}K/K_{total} = 1.19\times10^{-4}$ mol/mol.

Sample No.	*Stratigraphic position*	*Location (7½-minute quadrangle; local coordinate reference; distance in feet from reference)*
DT 81A3	Upper 50 ft of Conejo Volcanics	Simi, 1951 edition; N. lat 34°15′, W. long 118°52′30″; Roadcut 780 N., 2,460 W.
DT 81D1	Middle part Conejo Volcanics	Newbury Park, 1967 photorevision; N. lat 34°12′30″, W. long 118°55′; Roadcut about 1,550 N., 5,080 W.
DT 89A3	Flow interbedded in lowermost Calabasas Formation.	Thousand Oaks, 1967 photorevision; N. lat 34°10′, W. long 118°47′30″; Artificial cut 4,510 S., 2,080 E.
DT 89A4	Upper third, Conejo Volcanics	Thousand Oaks, 1967 photorevision; N. lat 34°07′30″, W. long 118°45′; Roadcut 4,550 N, 2,550 W.
DT 89A5	150 ft above base, Conejo Volcanics.	Triunfo Pass, 1967 photorevision; N. lat 34°05′, W. long 118°55′; cut NE side Mulholland Hwy., 800 N., 1,935 E.

Although these two ages are concordant at the 2σ level, the higher analytical precision of the 13.9-m.y. age and its agreement with the other age relations observed in the Conejo Volcanics indicate that it should be accepted as the more representative age for the andesite at Arroyo Santa Rosa.

The Conejo Volcanics overlies marine strata (Topanga Canyon Formation) assigned to the "Temblor" Stage, middle Miocene, on the basis of a molluscan fauna locally abundant in sandstone facies. Collections of sparse, poorly preserved Foraminifera from mudstone interbeds and siltstone members generally have not been diagnostic of a single stage. Overlapping stage ranges of the Foraminifera suggest that most of the Topanga Canyon Formation is best assigned to the Relizian, but it could be partly, even mostly, Saucesian (foraminiferal stages of Kleinpell, 1938).

The basal strata of the Conejo as represented by dated sample DT 89A5 (15.5±0.8 m.y.) are probably no older than the Relizian foraminiferal stage, as the underlying Encinal Member of the Topanga Canyon Formation includes a foraminiferal fauna no older than upper Relizian (K. McDougall, written commun., 1975), even though the age of 15.5±0.8 m.y. is very close to, and in fact analytically indistinguishable from, Turner's (1970) age of 15.3 m.y. for the Saucesian-Relizian boundary.

Along the north flank of the Santa Monica Mountains, the Conejo Volcanics is overlain by, and locally intertongues with, basal strata of the Calabasas Formation that carry Foraminifera assigned to the Luisian Stage of Kleinpell (1938). The upper part of the Conejo Volcanics probably is Luisian in age, and the radiometric ages of samples DT 81A3 (13.9±0.4 m.y.), DT 89A4 (14.6±0.7 m.y.), DT 89A3 (14.8±0.4 m.y.), and KA 2144R (13.1±0.9 m.y., from Turner, 1970) are no younger than Luisian. The probable Luisian age of the upper part of the volcanic pile agrees with Turner's dating (1970) of the Relizian-Luisian boundary within the interval 13.7–14.5 m.y. and suggests that the actual age of the boundary may be close to the older end of this interval.

The marine sedimentary strata interbedded with the volcanic rocks locally carry mollusks, foraminifers, and fish scales that generally can be identified as middle Miocene, but none are clearly diagnostic of a single faunal stage. For example, foraminifers from the Escondido Canyon Shale Member of the Calabasas Formation in the upper plate of the Malibu Bowl fault (see fig. 4) are reported as "middle Miocene" and "probably middle Miocene, possible Luisian" by R.L. Pierce (written commun., 1964, 1967).

Taken together, the available radiometric ages indicate that Conejo volcanism spanned about 2 m.y. This interval may have been chiefly during the Relizian but probably straddles the Relizian-Luisian boundary. Moreover, the considerable thickness of middle Miocene marine sedimentary rocks both above and below the volcanic rocks indicates that volcanism may have been restricted to a relatively short segment of middle Miocene time, as would be compatible with the age span suggested by the potassium-argon ages.

CALABASAS FORMATION

DEFINITION

The Calabasas Formation is here named for a thick widespread heterogeneous sequence of sandstone, siltstone, and sedimentary breccia that intertongues with, and locally unconformably overlies, the Conejo Volcanics and is unconformably overlain by the Modelo Formation. The name is taken from exposures in the Calabasas Peak area (sec. 3, T. 1 S., R. 17 W.), and the unit is well exposed in Stokes Canyon, its type locality about 3 km west of the peak (fig. 2; pl. 3K). The Calabasas is widely exposed in two areas: (1) along the north flank of the central mountains (north part of the Malibu Beach quadrangle) and (2) in the Solstice Canyon area of east-central Point Dume quadrangle and Corral Canyon area of west-central Malibu Beach quadrangle (fig. 4; pl. 3I, J). Complexly faulted outliers of the Malibu Bowl upper plate (not shown on pl. 2) just north of the Malibu Coast fault between Malibu and Peña Canyons also include some Calabasas strata.

LITHOLOGY, THICKNESS, AND STRATIGRAPHIC RELATIONS

The Calabasas Formation in the north area consists chiefly of sandstone (medium- to thick-bedded medium- to coarse-grained wackes, commonly showing graded bedding) and interbedded silty shale (locally diatomaceous or phosphatic, with zones of large dolomitic concretions and locally abundant rust-colored plant casts, fish scales, and sparse Foraminifera). In the Stokes Canyon area, north-central Malibu Beach quadrangle, the Calabasas contains a prominent interbed of sedimentary breccia, here named the Stokes Canyon Breccia Member (pl. 3K), that consists of angular fragments of redeposited sandstone that carry a molluscan fauna diagnostic of the "Martinez" (Paleocene) and "Domengine" (middle Eocene) Stages; the breccia is as thick as 60 m. Thinner less continuous breccia beds are present at two other horizons nearby. Another prominent sedimentary breccia, the Latigo Canyon Breccia Member (fig. 4), occurs in the upper plate of the Malibu Bowl fault, east-central Point Dume quadrangle; the clasts consist of red-bed (Sespe) sandstone and fossiliferous (Vaqueros) sandstone. About 1,200 m of Calabasas strata is exposed in the mapped area; an additional several hundred meters is exposed on the flanks of Las Virgenes Canyon north of the map.

The contact relations between the Calabasas and the underlying Conejo Volcanics are complex and locally variable. They probably reflect nearly continuous marine sedimentation, intermittently overwhelmed by episodes of the waning submarine volcanic activity (at different times in different local centers), punctuated by episodes of structural disturbance that may have been of only local extent. Consequently, in places such as Medea Creek (northeast Point Dume quadrangle), the Calabasas lies unconformably across one sequence of volcanic strata, yet the base nearby is accordant over another set of volcanic strata. In other places, best exposed in the upper plate of the Malibu Bowl fault, there is complex intertonguing of marine sedimentary and extrusive volcanic deposits (fig. 4). There is neither a persistent basal conglomerate nor other evidence that subaerial erosion of the volcanics preceded Calabasas deposition, but in several places there are significant variations in thickness of basal parts of the Calabasas that appear to represent onlap of the sedimentary layers onto a surface of considerable relief. That relief is tentatively interpreted to represent irregular surfaces on various extrusive volcanic deposits.

The contact between the Calabasas and the overlying Modelo Formation is unconformable in the eastern part of the mapped area; north and west of the mapped area, however, strata equivalent to the Calabasas and Modelo Formations may be conformable and gradational.

The Calabasas Formation and Conejo Volcanics in the upper plate of the Malibu Bowl fault have been divided into eight named members (pl. 2; fig. 4), listed generally from top to bottom:

Name	*Type area*	*Lithology*	*Approximate Maximum thickness (meters)*
Mesa Peak Breccia Member of the Calabasas Formation.	Mesa Peak, Malibu Beach quadrangle.	Angular fragments of volcanic rock in very coarse grained sandstone.	288
Newell Sandstone Member of the Calabasas Formation.	Newell Road, Malibu Beach quadrangle.	Sandstone (poorly sorted turbidites) and shaly siltstone with large dolomitic concretions; tongues westward into Malibu Bowl Tongue of the Conejo Volcanics.	244
Malibu Bowl Tongue of the Conejo Volcanics.	Malibu Bowl, Malibu Beach quadrangle.	Andesitic and basaltic flows and flow breccias; tongues eastward into the Newell Sandstone Member.	143
Solstice Canyon Tongue of the Conejo Volcanics.	Solstice Canyon, Point Dume quadrangle.	Basaltic and andesitic flows, breccias, and tuffs; local water-laid volcanic sandstone.	244
Latigo Canyon Breccia Member of the Calabasas Formation.	Latigo Canyon, Point Dume quadrangle.	Sedimentary breccia, large clasts of Sespe sandstone, and fossiliferous Vaqueros sandstone in sandy, tuffaceous, or volcanic breccia; intertongues with epiclastic volcanic breccia.	91

Name	*Type area*	*Lithology*	Approximate maximum thickness (meters)
Escondido Canyon Shale Member of the Calabasas Formation.	Escondido Canyon, Point Dume quadrangle.	Siltstone, mudstone, shale, and minor interbedded thin sandstone turbidites; locally prominent dolomitic concretions; tongues eastward into Dry Canyon Sandstone Member of the Calabasas Formation.	276
Dry Canyon Sandstone Member of the Calabasas Formation.	Dry Canyon, Malibu Beach quadrangle.	Sandstone and siltstone, many thin turbidites; locally prominent dolomitic concretions in siltstone; tongues westward into Escondido Canyon Shale Member.	686
Ramera Canyon Tongue of the Conejo Volcanics.	Ramera Canyon, Point Dume quadrangle.	Basaltic and andesitic breccias, tuff-breccias, and flows(?); minor volcanic sandstone; upper part tongues eastward into lower part of Escondido Canyon Shale Member.	518

AGE

Several collections of Foraminifera and fish scales, representing each of the major exposures of the formation, have been identified. With the exception of the exposures between Topanga and Old Topanga Canyons, the collections are provisionally assigned to the Luisian Stage of Kleinpell (1938), late middle Miocene. Two collections of Foraminifera from the siltstone-sandstone sequence between Topanga and Old Topanga Canyons are assigned to the lower Mohnian Stage, earliest late Miocene. The stratigraphic position of these collections relative to the Calabasas-Modelo boundary is indeterminate on the basis of map relations. Molluscan fossils have been collected from the undivided Calabasas strata in the McCoy Canyon area, southeastern Calabasas quadrangle, and from a locality in the Dry Canyon Sandstone Member in the upper plate of the Malibu Bowl fault in the southwest part of the Malibu Beach quadrangle; these fossils are assigned to the "Temblor" stage, middle Miocene. The fossiliferous material collected from the Dry Canyon Sandstone Member occurs in a broken coarse-grained arkosic arenite unlike adjacent wackes and lies stratigraphically at the level of the Latigo Canyon Breccia Member; the material may have been reworked from a pre-Conejo sandstone of the Topanga Canyon Formation and may not represent an indigenous fauna.

MODELO FORMATION

The Modelo Formation was defined by Eldridge and Arnold (1907) as a sequence of shale and sandstone above the fossiliferous Vaqueros Formation and below the Pico Formation in the area north of the Santa Clara River. Kew (1924) redefined the Modelo to include as much as 914 m of strata mapped as Vaqueros by Eldridge; as so redefined, the formation in the type area totals about 2,745 m in thickness. In most areas south of the Santa Clara River, the Modelo rests unconformably on the Topanga Group (middle Miocene) of this report or older rocks. Kew (1923) and Hoots (1931) subdivided the Modelo on the north flank of the Santa Monica Mountains, east of the present mapped area, but did not name the subdivisions. Kleinpell (1938) used the map by Hoots (1931) in erecting the type for his Mohnian (earliest late Miocene) foraminiferal stage in the lower part of the Modelo Formation along Topanga Canyon Road at and north of the north boundary of the Topanga quadrangle.

Although the basal Modelo includes the type Mohnian, the Calabasas Formation below the unconformity is not entirely pre-Mohnian, as foraminiferal faunas of several collections from the Calabasas on the ridge west of northern Topanga Canyon, as much as 245 m below the base of the Modelo, are assigned to the Mohnian Stage. Sparse megainvertebrate faunas from the basal Modelo are provisionally correlated with the "Briones" stage, early late Miocene, on the basis of the presence of the pelecypod *Aequipecten* cf. *A. andersoni gonicostus* (Trask).

Only the basal part of the Modelo is exposed in the mapped area. The base commonly consists of 1 to 3 m of pebbly sandstone and conglomerate, well sorted and bedded, containing well-rounded pebbles as much as 10 cm in diameter; the conglomerate commonly forms an angular unconformity with underlying Topanga strata. The basal conglomerate is succeeded by diatomaceous platy shale, silty claystone, or very thin bedded fine- to medium-grained sandstone.

SEQUENCE SOUTH OF THE MALIBU COAST FAULT

TRANCAS FORMATION

DEFINITION

The Trancas Formation is here named for a heterogeneous sequence of marine sedimentary rocks that unconformably underlies and locally intertongues with the Monterey Shale in an east-west-trending belt south of the Malibu coast (fig: 5). The type locality includes scattered exposures of an incomplete stratigraphic section near the mouth of Trancas Canyon, southwestern Point Dume quadrangle (pl. 3L).

LITHOLOGY, THICKNESS, AND STRATIGRAPHIC RELATIONS

The Trancas Formation consists chiefly of sandstone, mudstone, silty shale, claystone, and locally prominent sedimentary breccia on Lechuza Point and Point Dume; the breccias are distinctive for their

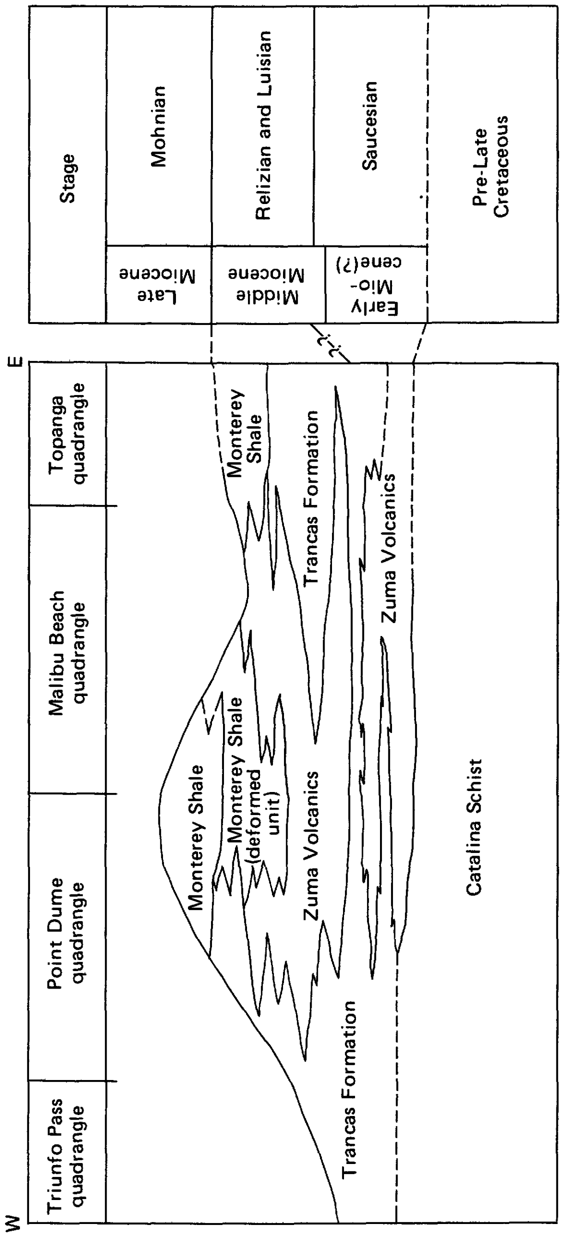

FIGURE 5.—Correlation diagram of units south of the Malibu Coast fault.

abundant detritus of the Mesozoic Catalina Schist, including glaucophane schist (San Onofre Breccia of Woodford and Bailey, 1928). Although the Trancas is in part equivalent in age to the Vaqueros Formation and Topanga Group north of the Malibu Coast fault, the Topanga does not contain glaucophane or other detritus of the Catalina Schist in the mapped area. Trancas sandstones exposed in the west part of the area are distinctive for their intense pervasive brecciation and sandstone intrusion that locally causes original bedding to be completely masked.

The Trancas has been so intensely folded and faulted that no complete section is exposed. An exploratory well, Sovereign Oil Co. Malibu 1, spudded in Monterey Shale near Point Dume and drilled through—

Trancas Formation:

Marine sandstone, mudstone, claystone, and sedimentary breccia (San Onofre Breccia) ---------------------- 290 meters

Zuma Volcanics:

Basaltic and andesitic flows, flow breccias, tuff-breccia, and mudflow breccia with interbedded siltstone, sandstone, and schist-breccia (San Onofre Breccia) -------- 850 meters

The well then penetrated 127 m of schist and other material that could represent either a basement of the Catalina Schist or yet another interval of San Onofre Breccia.

The base of the Trancas is not exposed; on the basis of correlations with equivalent sequences in the west part of the Los Angeles basin the Trancas is inferred to rest unconformably on the Catalina Schist; it intertongues with middle Miocene parts of the Monterey Shale and locally is unconformably overlain by middle and upper Miocene parts of the Monterey.

AGE

Siltstones of the Trancas contain locally abundant foraminiferal assemblages assigned to the Saucesian (lower Miocene) and Relizian or Luisian (middle Miocene) Stages of Kleinpell (1938). Two collections from sandstone along the shore in the southwesternmost Point Dume quadrangle contain *Turritella ocoyana* Conrad, commonly characteristic of the "Temblor" Stage, middle Miocene, but also found in faunas assigned to the lower Miocene "Vaqueros" Stage.

ZUMA VOLCANICS

DEFINITION

The new name Zuma Volcanics is here used for volcanic rocks that underlie the Monterey Shale south of the Malibu Coast fault. The volcanic rocks locally are interbedded with sedimentary rocks of the

Trancas Formation and Monterey Shale. The name is taken from Zuma Canyon, and the type locality is designated the exposures on the west side of Zuma Canyon (pl. 3M).

LITHOLOGY, THICKNESS, AND STRATIGRAPHIC RELATIONS

The Zuma Volcanics is exposed in several elongate fault slices south of the Malibu Coast fault; no single exposure contains a complete section of the volcanic rocks. Rock types include basaltic and andesitic flows, breccias, pillow lavas, mudflow breccias, aquagene tuffs, minor amounts of volcanic sediment, and locally, interbeds of mudstone and siltstone. The thickest section exposed, a synclinal sequence about 2½ km north of Point Dume, has an apparent thickness of 800–1,000 m; the Sovereign Oil Co. Malibu 1, drilled near Point Dume, penetrated an interval about 850 m thick, chiefly of Zuma Volcanics between schist below and the Trancas Formation above.

The volcanic rocks commonly are bounded by faults, and their base is nowhere exposed. The synclinal body north of Point Dume is overlain by the Monterey Shale; the contact is locally accordant, but small fragments of volcanic rocks locally present in the basal Monterey Shale indicate unconformable relations nearby. Complex interbedding of the volcanic rocks with marine sedimentary rocks (including the San Onofre Breccia) of the Trancas Formation and the presence of local interbeds of shale resembling the lower part of the Monterey suggest a depositional environment of normal marine sedimentation locally and episodically interrupted by tectonic activity (giving rise to slump structures, sandstone dikes, and sedimentary breccia) and submarine volcanic activity.

AGE

The Zuma Volcanics is interbedded with the lower and middle Miocene Trancas Formation and is interbedded with and overlain by the middle and upper Miocene Monterey Shale; it locally contains siltstone or shale beds that carry foraminiferal faunas referred to the Relizian or Luisian (middle Miocene) Stage of Kleinpell (1938). Plagioclase in a sample (69C24, pl. 3N) from the upper part of the volcanic pile near the tip of Point Dume has been dated radiometrically at 14.6±1 m.y. (Berry and others, 1976). The Zuma Volcanics is therefore considered to be early and middle Miocene.

MONTEREY SHALE

The name Monterey Shale, taken from exposures in Monterey County, central California, was extended to southern California by Woodring, Bramlette, and Kleinpell (1936) in their study of the Palos Verdes Hills, southwestern Los Angeles basin (see also Woodring and others, 1946). They applied the name to all similar Miocene shale throughout the California Coast Ranges. The name is here extended from the Palos Verdes Hills area (see fig. 1) to the sequence of marine shale, siltstone, and sandstone that intertongues with and overlies the Trancas Formation and Zuma Volcanics along the Malibu Coast south of the Malibu Coast fault.

In the Palos Verdes Hills, the exposed Monterey consists of about 655 m of silty to sandy shale, cherty and porcellaneous shale, phosphatic and bituminous shale, diatomite and diatomaceous and radiolarian mudstone; locally interbedded volcanic materials in the lower part include bentonitic tuff, pumiceous tuff, and vitric ash, in beds as thick as 18 m. An additional approximately 600 m of Miocene sedimentary and volcanic rocks is present in the subsurface. The basal contact is exposed locally on the northeast slope of the Palos Verdes Hills; the lower 3 to 25 m there consists of Catalina Schist-bearing breccia, sandstone, and conglomerate that rests unconformably on Catalina Schist. The Monterey is overlain disconformably by lower Pliocene siltstone on the northeast flank of the Palos Verdes Hills. On the basis of its foraminiferal faunas, the Monterey in the Palos Verdes Hills is assigned to the Relizian, Luisian, and Mohnian Stages (Woodring and others, 1946), middle and late Miocene.

In the Point Dume-Malibu Beach area, the Monterey consists of marine clay shale and laminated to platy siltstone that are variably diatomaceous, bituminous, phosphatic, siliceous, or cherty, and interbedded altered vitric tuffs and fine- to medium-grained sandstone that locally is schist bearing, including glaucophane schist. A uniquely deformed unit is mapped separately along the south boundary of the Malibu Coast fault. This unit consists of elongate pods and slices of dolomitic marine shale and siltstone with abundant chert and local very fine grained sandstone, all tightly folded about gently plunging east-trending axes.

On Point Dume, the Monterey is about 1,000 m thick. Numerous collections of Foraminifera are assigned to the Luisian and Mohnian Stages of Kleinpell (1938), late middle and early late Miocene. The base generally appears unconformable, as the basal beds commonly contain clasts resembling constituents of the locally underlying strata. However, Monterey beds of both middle Miocene and late Miocene ages locally lie directly on both the Zuma and Trancas Formation. This relation suggests a complexly intertonguing onlap of relatively quiet-water marine Monterey deposition across both underlying units (see Fig. 5).

No Pliocene units have been found in the mapped area; the Monterey and older units are unconformably overlain by upper Pleistocene marine terrace deposits.

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