LATE PLEISTOCENE AND RECENT CHANGES OF SEA LEVEL ALONG THE COAST OF SANTA BARBARA COUNTY, CALIFORNIA

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ABSTRACT. At the mouths of three coastal valleys of Santa Barbara County, California—the Santa Ynez and Santa Maria Valleys and the Goleta Basin—evidence from well borings indicates that Pleistocene streams carved valleys graded to sea level which at that time was at least 200 feet and probably a maximum of about 300 feet below present level. These valleys, now filled with alluvium whose surface is graded about to present sea level, were cut below a marine terrace having a peak shore line about 100 feet above present sea level. Fossils in deposits on the wave-cut bench of the terrace suggest that the terrace is upper Pleistocene in age. The prealluvial valleys are believed to have been cut as a result of lowered sea level accompanying the maximum glaciation of the Wisconsin stage; and the terrace may have been formed during the immediately preceding interglacial stage. The suballuvial valley bottoms are about the same distance below present sea level; and the subsequent relative rise of the sea (about 300 feet) is considered to be a eustatic rise. The previous relative decline (maximum of about 400 feet) is considered to be almost wholly eustatic, although a small part of it may have been due to rise of the land.

Comparison of the longitudinal profile of the suballuvial valley of the Santa Ynez River on the one hand and that of the nearly contiguous Arguello submarine canyon on the other indicates that the two profiles were formed in distinctly different episodes. The formation of the submarine canyon (by whatever process) is thought to be older, and is considered pre-Wisconsin.

Introduction

PURPOSE OF THE PAPER

DROWNED valleys now more or less wholly filled with alluvium have been described at several places along the California coast. The most outstanding example is San Francisco Bay, but many similar though less conspicuous features have been noted elsewhere. Ellis and Lee (1919) early described alluvium-filled valleys along the streams in San Diego County; and Grant and Gale (1931, p. 65) mention the overdeepened valleys of the main coastal streams. Most writers have ascribed these features specifically or tacitly to an oscillation of the land up and then down with respect to sea level. However, along this and other continental coasts numerous examples of overdeepened stream valleys have been ascribed to eustatic lowering of sea level.

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This paper discusses certain overdeepened valleys along the coast of Santa Barbara County, California, and describes their relation to the youngest and lowest of several marine terraces. It outlines a sequence of geomorphic events during the late Quaternary which is believed to have resulted in large part from eustatic fluctuations of sea level that accompanied the waxing and waning of maximum glaciation during the Wisconsin stage. The sequence is correlated with similar sequences along other parts of the California coast; and a possible bearing on the time of origin of one so-called submarine canyon is suggested.

ACKNOWLEDGMENTS

The data and observations here discussed were accumulated during an investigation of the ground-water resources of Santa Barbara County by the U. S. Geological Survey in financial coöperation with the County. The writer wishes to acknowledge the aid and criticism of his colleagues both in the course of the work and in the preparation of this paper. Particular acknowledgment for review, criticism, and timely comment is due Prof. U. S. Grant, of the University of California at Los Angeles, Dr. W. P. Woodring of the U. S. Geological Survey, and Prof. A. O. Woodford of Pomona College. The writer is also indebted for criticism and comment to Prof. R. P. Sharp of the California Institute of Technology.

LOCATION OF AREAS

The areas of principal concern in this paper are the main coastal valleys of Santa Barbara County, California, which is on the Pacific coast about 300 miles south of San Francisco Bay and about 80 miles northwest of Los Angeles (see fig. 1). The county is in the right-angled part of the coast formed by two prominent points close together: Point Arguello, from which the coast trends generally northerly, and Point Concepcion, from which the coast trends easterly. In broad outline the coast is regular and simple, but in detail it has a variety of shore-line features. These range from bold headlands, where the shore line transects mountain ridges, to low plains and swamps at the mouths of the rivers and streams and in certain primarily structural basins along the south coast. Along most of the shore, extensive terrace remnants slope seaward to end at the water or at a narrow beach in abrupt cliffs from 40 feet to several hundred feet high.

The largest coastal valleys are along the lower courses of the two principal streams of the county, the Santa Ynez River

FIGURE I

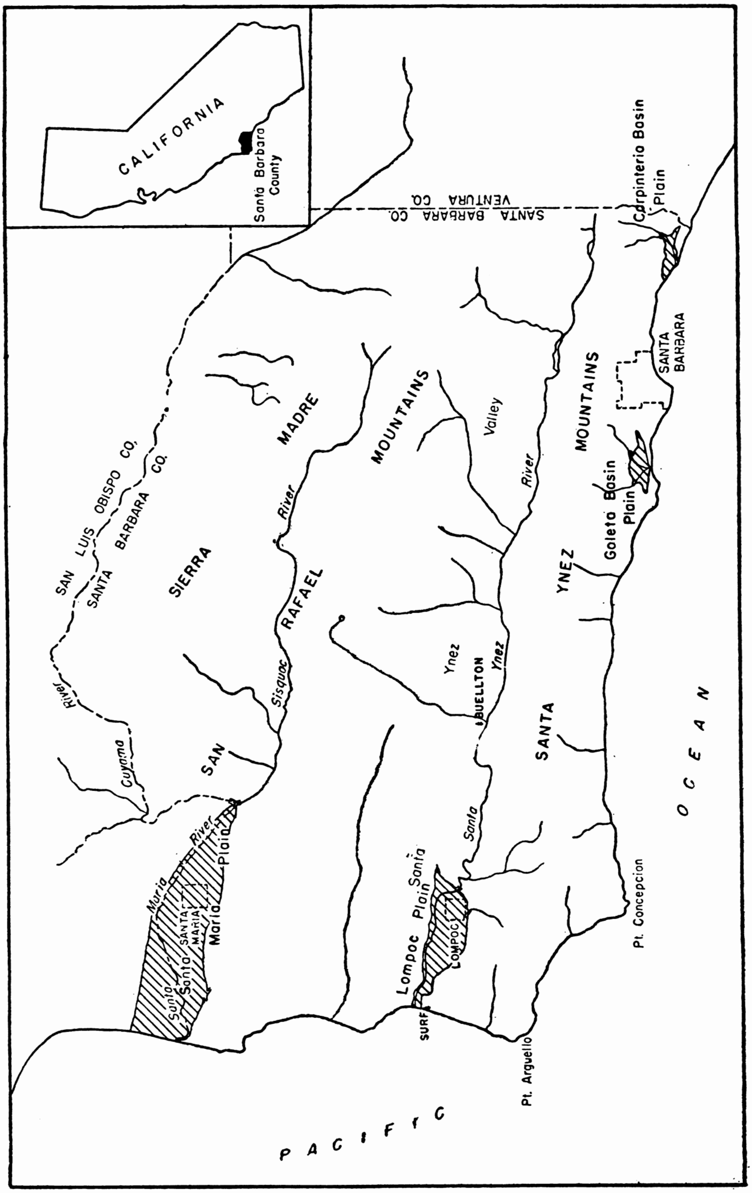


Fig. 1. Index map of Santa Barbara County, California, showing location of main coastal valleys.

and the Santa Maria River, which cross rather broad alluvial plains immediately before entering the sea. The plain of the Santa Ynez River, called the Lompoc Plain, extends about 12 miles inland, and that of the Santa Maria River, called the Santa Maria Plain, extends about 20 miles inland. In addition to these larger coastal valleys, two smaller ones, called the Carpinteria and Goleta Basins, lie along the south coast of the County. These are structural basins originated by faulting, and now contain alluvial plains formed by deposits of several short streams.

In the Lompoc Plain, the Santa Maria Plain, and the Goleta Basin, geomorphic and geologic features indicate a like sequence of events explainable in large part by a eustatic decline and rise of sea level. In the Carpinteria Basin not all elements of the sequence are demonstrable, but the history was probably the same. The pertinent features of the first three areas are described in ensuing paragraphs.

Relative Changes of Sea Level in Santa Barbara County

LOMPOC PLAIN

Geomorphic and geologic features

The Lompoc Plain lies in the lowermost part of the Santa Ynez River Valley, between the Purisima Hills on the north, the Santa Rita Hills on the east, and the foothills of the Santa Ynez Mountains on the south. It is a small alluvial plain which extends landward from the ocean for about 12 miles and ranges in width from half a mile to two miles. It is traversed by the Santa Ynez River, which enters the plain at the southeast corner from a narrow valley, called The Narrows, cut in the consolidated rocks (pl. 1, A), then flows westward along the north side of the plain and enters the ocean at the west end.

The geology of this area has been discussed in some detail in a report on the geology and water resources of the Santa Ynez River Valley (Upson and Thomasson, 1947). Considerable information, especially on the pre-Pleistocene deposits, is contained in the paper by Woodring and others (1943) on the Santa Maria district, which includes part of the Purisima Hills. Only certain salient features are summarized here.

The Lompoc Plain is underlain by alluvium, whose thickness and relationships are significant to the discussion in this paper.

The plain is a series of gently sloping alluvial-fan surfaces, each of which heads in the canyon of its originating river or creek. The surface of the plain thus formed abuts sharply against the sides of the bordering hills and terraces in the fashion characteristic of depositional surfaces. Both the surface of the plain and the Santa Ynez River channel appear to be graded to present sea level, but the river channel is entrenched below the plain surface by a progressively greater amount inland from the shore. Where the river enters the plain, this entrenchment is about 45 feet. Other tributaries on the south also have incised their channels at the margins of the plain in somewhat lesser amounts.

The alluvium occupies a valley which was excavated by the Santa Ynez River in the floor of an older valley now represented by a set of terraces 35 to 90 feet above present sea level and present stream grade. The terraces are capped by alluvial clay, sand, and gravel which rest unconformably on deformed older sediments of Miocene to upper Pleistocene age. Along the southeast and west margins of the plain the alluvium rests on the Monterey shale of Miocene age, but in the middle part of the plain it rests on the relatively unconsolidated marine Careaga sand of upper Pliocene age, the Paso Robles formation of Pliocene and questionable Pleistocene age, and the Orcutt formation of upper Pleistocene age.

These formations have been folded in more or less intermittent deformation with several periods of considerable intensity—the first at the close of Monterey time and the second in the lower Pleistocene after deposition of the Paso Robles formation. Since then some minor warping has taken place, but the Orcutt formation is only slightly tilted, and the deformation appears to be dying out. Within the area of the Lompoc Plain, the deformation developed a syncline whose axis trends southwestward, crossing the Lompoc Plain diagonally. Thus, the Monterey shale at the west end of the Lompoc Plain, which forms the northwest limb of the syncline, moved upward relative to nearby areas during deformation.

Characteristics and origin of the alluvium

In regard to Pleistocene and Recent changes of sea level, the thickness and shape of the alluvium and its relations to underlying formations are critical. About 110 water wells have been drilled below the surface of the Lompoc Plain; nearly all completely penetrate the alluvium and pass a short distance into the underlying formations. In most well logs these underlying formations are readily recognizable; and thus the base of the alluvium is accurately determined at about 100 points. Figure 2 is a contour map of the base of the alluvium based on the altitudes of these points. This map shows that the alluvium fills an old valley which is somewhat narrower than, but roughly corresponds to, the present valley. The old valley extends outward from The Narrows as a narrow, elongate trench, broadens somewhat beneath the central part of the alluvial plain, where it was excavated in the unconsolidated Careaga sand and Paso Robles and Orcutt formations, and then narrows seaward to a fairly narrow, steep-walled canyon in the consolidated Monterey shale bordering the seaward part of the present plain. Smaller tributary canyons can be crudely traced to the mouths of present-day tributaries entering the south side of the valley. The walls of the old valley are relatively steep, and they more or less continue the slopes of the present valley walls against which the alluvial fill was laid. The alluvium ranges in maximum thickness from about 190 feet at the head of the valley to over 200 feet at the seaward end. The base of the alluvium at the present shore line is not precisely known from well records but the gradient of the base up-valley, averaging 10 to 12 feet per mile, is sufficiently well fixed so that it can be projected from the nearest known points the remaining two miles to the shore with fair accuracy. The base of the alluvium and hence the valley floor at the deepest point is determined to be nearly 220 feet below sea level at the present shore line.

The well logs also show many of the characteristics of the alluvial fill itself. The deposits comprise two sharply defined members. The lower member is of coarse gravel which contains rounded cobbles and boulders as well as some sand, and constitutes a continuous, linear body filling the lower part of the old filled valley. It is 60 to 80 feet in maximum thickness and doubtless represents the channel deposit of the old river. The upper member is composed predominantly of fine-grained material—sand, silt, and clay. As indicated by the well logs, these deposits are lenticular and the various classes of deposits interfinger. Sand and silt seem to predominate in the headward and marginal parts of the valley, and clay and silt in the central and seaward parts. No clay beds seem to be continuous across the entire valley, and no marine shells are reported in the well logs. Therefore, it seems that beds of marine or lagoonal clay are rare or absent entirely and essentially all the deposits are stream-laid.

The Lompoc Plain is actually the lowest and youngest of a descending series of valleys. The inter-meander spurs and bordering hills in and immediately upstream from The Narrows have flat summits capped by terrace gravel at three levels (see pl. 1, B) the lowest of which is about 90 feet above present stream grade in The Narrows. The remnants are capped by as much as 30 feet of stream-laid gravel; hence the cut surface is about 60 feet above stream grade. Farther upstream it is locally somewhat less than 60 feet. In the gravels of this terrace several miles upstream, near Buellton, the writer found a fossil thigh bone which has been identified by the late C. W. Gilmore as belonging to the genus *Camelops*, thus dating the deposit as Pleistocene.

Downstream, principally along the north border of the Lompoc Plain, this low stream-cut terrace can be traced almost continuously to the ocean, where it merges with a low wave-cut terrace. This terrace is a sloping bench, in part now blanketed by windblown sand and a thin layer of shore deposits. At most places the deposits are not exposed, but they do crop out at the south side of the mouth of the Lompoc Plain where the road climbs to the town of Surf. Here the deposits are composed of lenses of thin-bedded silt, sand, and gravel, with a layer of coarse gravel at the base which truncates dipping shale beds of Miocene age. The base is about 35 feet above sea level at this place, but away from the river mouth the inland edge of the terrace base is somewhat higher.

From the evidence presented in the foregoing, the following sequence of events in late Quaternary time is outlined. The Santa Ynez River developed a cut terrace graded to a marine terrace roughly about 60 feet above present level. Then base level declined and the river excavated a valley graded to a point at least 220 feet below present sea level. Finally base level rose, causing the Santa Ynez River and tributary streams to aggrade their channels, and alluvium was deposited in that valley, filling it to a level graded about to present sea level.

Except for entrenchment in the upper end of the alluvial plain to a maximum depth of about 45 feet in The Narrows, the deposition of the alluvium is the last event in the area. The alluvial filling occurred after the development and strong dissection of the lowest terrace, which is of Pleistocene age, and thus is late Pleistocene or Recent in age.

SANTA MARIA PLAIN

Geomorphic and geologic features

The Santa Maria Plain is about 15 miles north of the Lompoc Plain. It is similar to, but larger than, the Lompoc Plain, and is much wider at the coast. It is the alluvial plain of the Santa Maria River, which is formed by the junction of the Cuyama and Sisquoc Rivers at the head of the plain. The plain extends inland about 20 miles, and is about 10 miles in maximum width. Its topographic and geologic features have been described in a report on the geology and ground-water resources of the Santa Maria Valley area, by G. F. Worts, Jr. (1947), and also by Woodring and others (1943).

The stratigraphy and geologic history are essentially the same as for the Santa Ynez Valley. The plain is underlain by alluvium which was deposited in a valley cut below a series of river terraces, the lowest of which is about 40 feet above the plain. The alluvium and deposits capping the terraces rest unconformably on the Orcutt formation of upper Pleistocene age, the Paso Robles formation of Pleistocene (?) and Pliocene age, and the Careaga sand of Pliocene age; also on the Foxen mudstone and Sisquoc formation of Pliocene and upper Miocene age, the Monterey shale of Miocene age, and locally on the Franciscan formation of Jurassic (?) age and the Knoxville (?) formation of Upper Jurassic age. Some deformation took place in the early Pliocene, as in the Lompoc area, but the principal Cenozoic deformation took place in the lower or middle Pleistocene after deposition of the Paso Robles formation. Later in the Pleistocene slight warping tilted beds of the Orcutt formation, but since then no appreciable deformation has occurred. Thus, since early Pleistocene time diastrophism has been on the wane.

The Santa Maria Plain, like the Lompoc Plain, is on the site of a major syncline. However, here the axis trends northwesterly and passes seaward beneath the broad west end of the plain. Thus, movement of the valley area near the shore has been, and any tendency for late movement probably would be, consistently downward.

Characteristics and origin of the alluvium

In the Santa Maria Plain the alluvium is less readily distinguished from the underlying deposits than in the Lompoc Plain, but reliable data are at hand from nearly 500 water and oil wells that penetrate the alluvium. These show that the alluvium was deposited in a valley whose lowest point near the ocean is about 230 feet below sea level. The alluvium comprises two members: an upper member of fine sand, silt, and clay that extends inland from the ocean 10 to 12 miles where it grades into the other member of coarse sand and gravel. The sand and gravel member comprises the lower part of the formation near the coast, but the entire thickness inland. The enclosing valley was carved below an older erosional level whose existing terrace remnants are some 40 to 100 feet above the alluvial plain and which is correlated with a low marine terrace along the ocean. The marine terrace is probably the equivalent of the low terrace at the mouth of the Santa Ynez River.

Thus, the sequence of events in the Santa Maria Valley is the same as in the Lompoc area. Streams developed an erosional plain, the youngest in a series of such plains; then with a decline of base level they trenched a valley graded to a sea level at least 230 feet below present sea level; and finally, with a rise of base level, they deposited alluvium in the valley and filled it to a surface graded to present sea level.

GOLETA BASIN PLAIN

Geomorphic and geologic features

The Goleta Basin contains a small alluvial plain about eight miles long from east to west and about three miles in maximum width, which, together with bordering foothills and terraced areas, lies along the south flank of the Santa Ynez Mountains (see pl. 2, A). This alluvial plain is open to the ocean only in a very narrow gap. Along its south (seaward) side, the plain is bordered by a nearly continuous block of deformed Miocene and Pliocene deposits which are truncated by a low marine terrace. Seven sizable streams flow from the mountains and cross the alluvial plain. Near the south side of the plain these streams join into two main channels across the coastal terrace. The channels pass on either side of Mescal "Island"—a small, round, flat-topped remnant of the coastal terrace once isolated by sea water, but now connected to the surrounding terrane by alluvial fill. South of the "Island" the two channels join to form one just before entering the ocean (see pl. 2, B).

The geology of the Goleta Basin has been described in some detail elsewhere (Upson, 1947). The alluvial plain is underlain by alluvium which occupies a valley system excavated by streams below a broad wave-cut plain of which the coastal terrace is the principal existing remnant. This terrace, and higher, older terraces, are cut across deformed rocks which range in age from Eocene to lower Pleistocene. The terrace deposits are considered to be upper Pleistocene in age, and are very little deformed if at all. The terrace deposits, and the alluvium of the plain, rest on unconsolidated marine clay, silt, and sand comprising the Santa Barbara formation of lower Pleistocene age. This formation has been rather strongly deformed—and has been displaced 1,000 or more feet by movement along faults. The Santa Barbara formation, and locally underlying marine clay and silt of upper Pliocene age, in turn rest unconformably on older marine and continental deposits that range in age from Eocene to Miocene. Locally, the Pliocene and Pleistocene sediments are absent and the alluvium rests unconformably on these older formations.

Thus, there have been two periods of deformation in late Tertiary and Pleistocene time—one in the upper Miocene or lower Pliocene following the deposition of the Monterey shale and the other after the deposition of the lower Pleistocene Santa Barbara formation. Earthquakes in the region attest to the continued presence of crustal stresses, but since the post-Santa Barbara deformation, earth movements have apparently been on the decline.

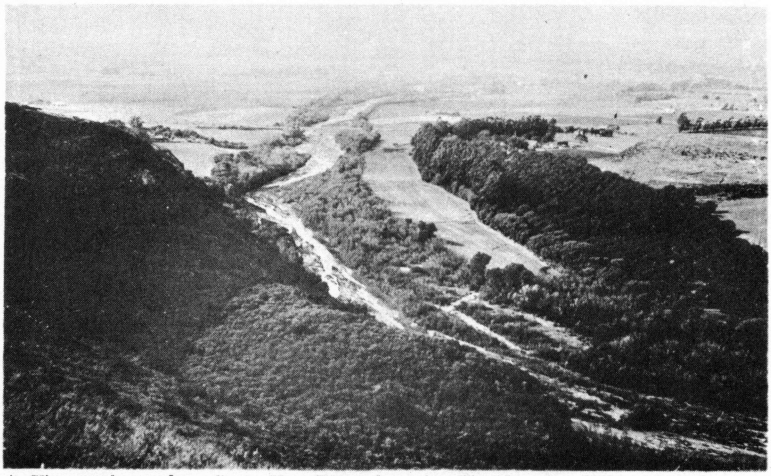
With respect to the current study, the principal result of the post-Santa Barbara deformation was the uplift of the Monterey shale along a reverse fault or fault zone, with upthrow to the south, which about parallels the present shore on a west-trending, curving trace concave to the north. The zone has been called the More Ranch fault by Hill (1932). It lies half a mile to a mile north of the shore and passes along the north side of the coastal terrace, which is cut across the

Monterey shale. This uplifted shale constitutes the south limit of the alluvial plain with the exception of the gap south of Mescal "Island." Thus, the alluvium of the main part of the plain rests on the unconsolidated Santa Barbara formation north of the fault, but in a narrow strip at the south edge of the plain south of the fault, it rests on the consolidated Monterey shale. Furthermore, any late diastrophic movements along the old structural lines would presumably comprise relatively upward and not downward movement of the coastal terrace block along the shore. The significance of these two features is brought out in subsequent paragraphs.

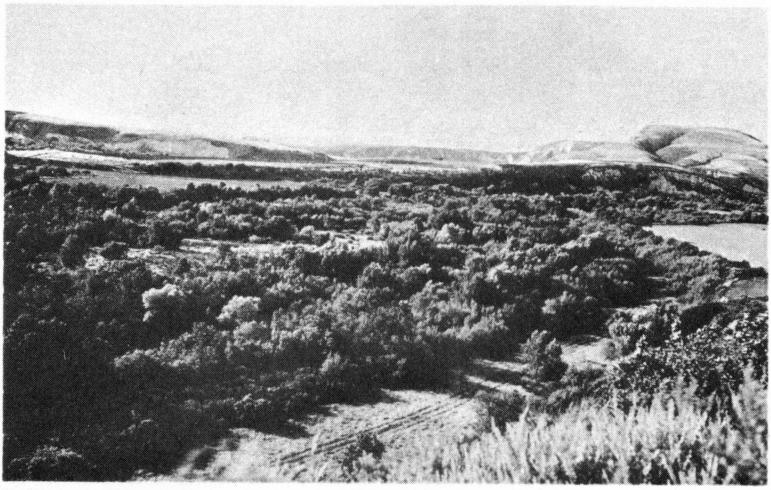
Characteristics and origin of the alluvium

Here, as in the other areas discussed, the thickness and characteristics of the alluvial fill underlying the plain are known primarily from logs of water wells. In the logs the base of the alluvium is fairly readily distinguished from the underlying Santa Barbara formation, which is characterized by distinctive shells of marine mollusks. Sufficient data are not at hand accurately to contour the base of the alluvium, but together with other general information they are adequate to show that the alluvium occupies a valley system which was graded to sea level at a lower position than the present, as in the other areas discussed in this paper. Several logs of oil-prospect holes drilled on a sand spit across the buried outlet disclose a body of sand and gravel overlying the consolidated shale and extending to an approximate maximum depth of 225 feet below sea level. It is inferred that this sand and gravel are the deposits of an older stream system which traversed the Goleta Basin and carved valleys whose currently recognizable low point is about 225 feet below present sea level. Most of the alluvial fill is composed of clay and silt; and any extensive lower member of gravel such as those underlying the Lompoc and Santa Maria plains seems not to exist.

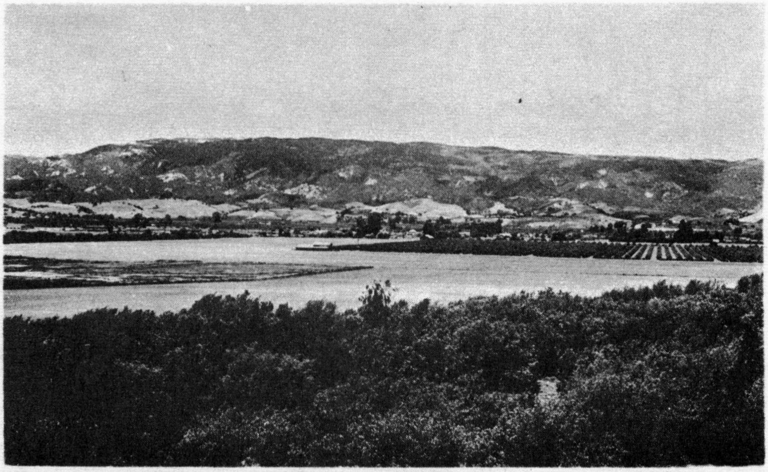
A corresponding sequence of events doubtless also occurred in the Carpinteria Basin, about 20 miles east, but the history there evidently was complicated by continuing movement along coastal faults. Also, the coastal barrier of Tertiary shale is missing along the coast south of the western half of the basin. Deposits which predate the alluvium are not readily distinguishable in well logs from the alluvium; and a prealluvial valley system, though recognizable near the mountains, cannot be traced seaward across the plain.



A. View northwest down Santa Ynez River channel at The Narrows. Hill at left and terrace remnant at extreme right are composed of Miocene shale. To right of brushy river channel is a plowed field on 15-foot alluvial terrace and farther right the walnut grove is on a 45-foot alluvial terrace continuous with the alluvial plain in the distance.

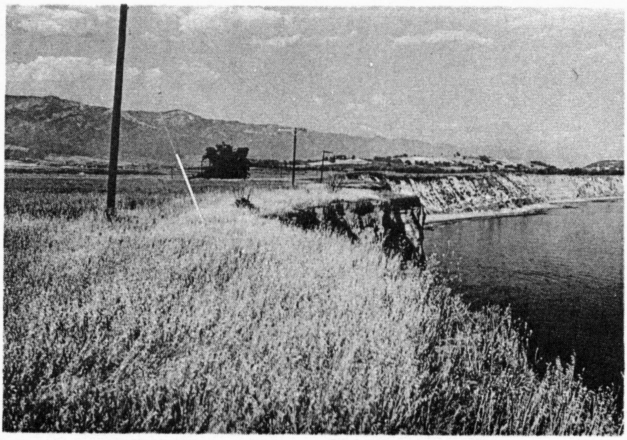


B. View northwest along meandering channel of the Santa Ynez River immediately above The Narrows. Meanders incised in Miocene shale cut by three terraces on right skyline. The lowest terrace is equivalent to the low marine terrace at the coast. Channel is underlain by alluvium to a maximum depth of about 145 feet.

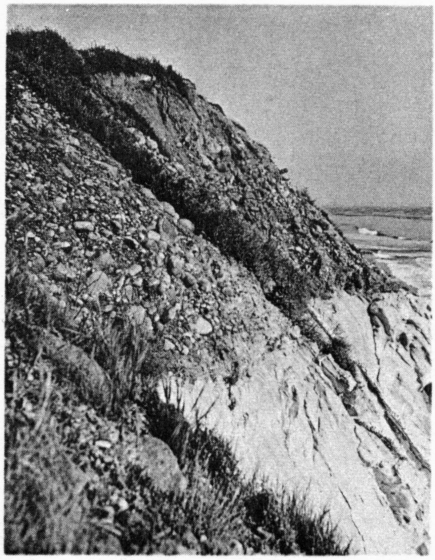


A. Alluvial plain of the Goleta Basin. View north from the coastal terrace; Santa Ynez Mountains in background.

B. View east in outlet of Goleta Basin plain; from a point south of Mescal "Island", and about at the confluence of the two channels flanking the "Island". The cliff nose just left of center is the east side of the gap. It is composed of steeply dipping Miocene shale truncated by marine terrace deposits. Shore deposits and alluvium below the camera site have a maximum thickness of about 200 feet.



A. View east along surface of marine terrace and sea cliff from point about 1 mile east of site of plate 2, B. Veneer of flat-lying deposits truncates north-dipping Pliocene marine beds. Santa Ynez Range and east end of Goleta Basin at left.



B. Terrace deposits on low wave-cut platform truncating steeply dipping Monterey shale near Naples, about 8 miles west of Goleta Basin.

In the Goleta Basin the old, now buried, valleys were cut below an erosional surface, which was probably almost entirely a marine wave-cut platform. This surface is revealed by extensive level surfaces (pl. 3, A) that are seen to level the contorted shale of the coastal block. That these are remnants of a marine platform is indicated by the capping deposits, which consist of a basal layer of coarse gravel and sand locally containing marine shells, and an upper body of silt, sand, and poorly sorted gravel in distinct but irregular lenses (See pl. 3, B). The basal layer of coarse gravel and sand rests with sharp contact on the beveled edges of the underlying deformed beds, and locally these and the boulders have the characteristic rounded pits and depressions bored by pholads. The deposits of the upper unit are composed of poorly sorted, irregularly stratified clayey and silty sand with lenses and zones of sandy gravel. Hence they were probably laid down by streams, although locally there are lenses of fairly well sorted sand that may be marine in origin. At a few localities fossil bones have been found in the upper deposits. In a cut along the Southern Pacific railroad near Capitan, about 12 miles west of the Goleta Basin, track workmen discovered the lower jaw of a mammoth which fortunately was observed in place and removed by Phil C. Orr, Curator of Vertebrate Paleontology and Anthropology of the Santa Barbara Museum of Natural History, who identified the jaw as belonging to *Archidiskodon imperator*. This fossil was found about 15 feet below the top of the deposits in the bottom of a lense of gravel. It is not badly worn and therefore probably was neither transported far before burial, nor eroded from other beds and redeposited. Accordingly, it is thought to represent the age of the deposits in which it was found, which are therefore considered Pleistocene, and together with their lithologic character shows that the deposits are continental.

This terrace extends east and west for several miles from the Goleta Basin, and it is represented by broad, gently sloping or nearly flat remnants. It has been called the Santa Barbara terrace by Grant and Gale (1931, p. 39), who studied fossil shells from the basal deposits; and has been correlated by Davis (1933, p. 1109) with his Dume platform along the coast of the Santa Monica Mountains.

The terrace remnants, where undisturbed, have a seaward slope formed mainly by the surface cover of continental deposits. The wave-cut platform also slopes seaward, but at a lesser angle; and its landward edge, which theoretically should abut against a wave-cut cliff (Davis, 1933) is ordinarily covered by the alluvium. Also, the seaward edge has been eroded back various distances by the Recent sea. Accordingly, the altitude of the surface varies from place to place; and at most places it is impossible to determine the altitude of the peak shore line represented by the platform. At the mouth of the Goleta Slough (pl. 2, B) the wave-cut platforms of the terrace is about 60 feet above sea level. At Goleta Point, about one mile to the southwest, it is about 35 feet. Remnants of this terrace also occur along the inland margins of the Goleta Basin, but there the alluvial cover conceals the actual eroded platform, and its elevation is not known. Farther west, where U. S. Highway 101 crosses the east side of the valley of Tecolote Creek, the eroded platform can be seen in a cut on the old highway some 40 feet above the present highway. The elevation of the platform here, which is about a quarter of a mile from the shore, and a somewhat lesser distance from the inland edge of the terrace, is about 80 feet. The platform is probably somewhat higher inland, but must be appreciably below the surface of the alluvial cover, whose elevation as estimated from the contours of the Goleta quadrangle is about 150 feet. Thus, the maximum height of the wave-cut platform is probably close to 100 feet above sea level.

Thus, the late geomorphic sequence in the Goleta Basin is as follows: waves cut a marine platform 35 to about 100 feet above present level, then streams cut a valley system, with an outlet through the coastal barrier of shale, graded to a position of sea level at least 225 feet below present sea level. Then with a relative rise of the sea this valley was filled with alluvium about to the present sea level. This seems to be unquestionably the last event of the three, and evidently it continued until very recent time because old residents report that 60 years ago tidal water was sufficiently deep near the present middle of the alluvial plain that ocean-going vessels docked at the town situated there.

Summary of the Geomorphic Sequence on the Santa Barbara County Coast

At three places along the Santa Barbara coast: the lower part of the Santa Ynez River Valley, the lower part of the

Santa Maria River Valley, and the Goleta Basin, waves developed a marine terrace at a maximum present elevation of about 100 feet. With retreat of the sea, streams first deposited alluvial debris in sloping cones and fans on the marine platform, but later entrenched their courses and cut valleys graded to a relatively lowered sea level. At its lowest position that sea level was at least 220 and probably 300 feet below present level. The major streams cut the deepest and largest valleys, but smaller streams also cut steeper, shallower valleys. Subsequently, with a relative rise of sea level, these valleys were filled with alluvium whose upper surface seems to slope evenly about to present sea level.

The cutting of the low marine terrace is the first event in the sequence; and is the least clearly defined. The terrace remnants have been traced along the Santa Barbara coast by reconnaissance only and there may be some errors in correlation. However, it is believed that the low terrace remnants here discussed represent the same event of marine abrasion.

The magnitude of the relative decline of sea level as measured from the approximate elevations of the marine terrace at the shore is 270 feet for the Santa Maria Plain, 255 feet for the Lompoc Plain, and 285 feet for the Goleta Basin. From a peak shore-line level of 100 feet, the maximum declines measured at the shore would be 330, 320, and 325 feet, respectively. As is discussed in the next paragraph, the actual maximum declines are probably somewhat greater.

At the time of maximum decline the shore must have been some distance seaward from the present shore, and streams flowing to it must have had some gradient. Hence the outermost part of the stream courses must have been somewhat lower than the 220- to 230-foot depths at the present shore. As is shown beyond, the Santa Ynez River was probably graded to a point about 300 feet below present sea level. This point corresponds closely with the outer edge of a submerged shelf bordering a large part of the Santa Barbara County coast and also much of the coasts of the Santa Barbara Channel Islands as shown on U. S. Coast and Geodetic Survey Chart 5202. The edge of this shelf is in the neighborhood of the 50-fathom line, or about 300 feet below sea level. This bench has been recognized by other writers on the California coast; and Shepard and Emery (1941, Charts I-IV) show the bench, somewhat discontinuous and of greatly varying width, along the entire California coast. It can hardly represent anything other than a stand of the sea at a maximum of 300 feet below present level; or, for the Santa Barbara coast, about 400 feet below the highest point of the lowest marine terrace now above sea level.

The magnitude of the relative rise to present sea level as measured at the shore is 230 feet for the Santa Maria Plain, 220 feet for the Lompoc Plain, and 225 feet for the Goleta Basin Plain. The agreement strongly suggests that the relative rise was an actual rise of sea level against an essentially stable coast and not a depression of the land. This conclusion is strengthened by the facts brought out in foregoing paragraphs, namely: (1) that differential deformational movements have been slight in late Pleistocene and Recent time in this area, and (2) the directions of any late local differential movements at the mouths of the valleys, if in accord with preexisting structures, would be downward beneath the Santa Maria Plain, but upward beneath the seaward parts of the Lompoc Plain and the Goleta Basin, and hence of no consistent direction for the whole coast. Thus it is concluded that local distrophic movements along existing structures could not have caused the relative rise of sea level.

Correlation with Other Areas Along the Pacific Coast

In the vicinity of Long Beach, California, a similar sequence of events has been described by Poland and others (1945). There streams carved valleys to a depth of about 150 feet at the present shore. The profiles of these valleys project seaward to correspond approximately to a submerged shelf interpreted to be a marine platform, whose inner and outer margins are at depths of about 120 and 240 feet below sea level, respectively. The valleys were evidently cut by streams graded to the sea at the lower level.

Along the coast of San Diego County, Ellis and Lee (1919, pp. 71 and 111-118) describe coastal valleys filled with alluvium whose base extends considerably below sea level. For example, records of wells in the lower parts of the Tia Juana, Mission, and San Diego Valleys (names derived from the respective streams) along the coast between San Diego and the international boundary show that the alluvial fill extends downward to maximum depths of about 100 feet below sea level at the shore. Grant and Hertlein (1944, p. 28) report similar depths of alluvium from a geophysical survey of the Tia Juana Valley. As in the Santa Ynez and Santa Maria Valleys, the alluvium comprises a lower member of coarse gravel and an upper member of finer-grained deposits. Farther north, near the mouth of the San Luis Rey Valley, the base of the alluvium is nearly 200 feet below sea level. The more southern valleys now empty into the ocean in San Diego Bay or Mission Bay, actually some distance back from the open ocean, whereas the San Luis Rey Valley enters the sea at the open coast. Accordingly, it is likely that the depth of fill in that valley is more nearly representative of the true relation between land and sea at the time of valley cutting.

The account of Ellis and Lee (1919, pp. 71, 75, and 110-112) is somewhat obscure as to the precise sequence of events along the coast of San Diego County. However, the latest events postulated by these authors seem to have been relative uplift of the land some 200 feet above present elevation and excavation of stream valleys. This was followed by submergence and filling of the valleys to the present levels of the valley floors. Marine terraces were apparently developed during the earlier uplift. Grant and Hertlein (1944, p. 31) suggest that the valley cutting may have been followed by a rise of sea level to about 100 feet above present level. However, inspection of topographic maps and observations made during a brief trip along the San Diego coast suggest to the writer that the 100-foot stand of the sea preceded the valley cutting, and that the sequence corresponds to that along the Santa Barbara coast.

North of Santa Barbara County similar features are known. Data on the Salinas Valley contained in a report on that area by the Division of Water Resources of the California Department of Public Works (1947) suggest that a similar alluvial valley, graded to a position 200 feet below sea level, may exist in the lower course of the Salinas River. Also, the stream system entering San Francisco Bay once flowed through the Golden Gate, whose maximum depth is about 350 feet below present sea level. Finally, a geomorphic sequence on the Oregon Coast having similar elements has been described by Baldwin (1945). In Oregon the valley of the Coquille River contains a deep fill of alluvium which apparently occupies a narrow valley excavated below a low marine terrace. This terrace has a maximum height of 225 feet above sea level and is capped by late Pleistocene deposits called the "Elk River beds." The sequence here is more complicated than in Santa Barbara County, California, because the low terrace is reported to be tilted, and it also truncates an older estuarine fill called the Coquille formation. The Oregon sequence cannot be surely correlated with the California sequence on the basis of existing data, but the similarity is striking and may be significant.

Thus, along most of the California portion of the Pacific Coast, at least, and possibly also the Oregon portion, streams have apparently carved older valleys below a low marine terrace. These valleys are apparently graded to a relative position of sea level that ranges from 120 to 300 feet below present level. It appears that the larger figure represents the maximum decline of sea level below the present level. These figures, especially the maximum 300 feet, are of the same order as figures assembled by Antevs (1928, p. 82) and more recently by Flint (1947, pp. 446-447) for various parts of the world. Stearns (1935, p. 1934) has presented similar evidence for a 300- to 360-foot stand of the sea below present level on Oahu and other islands of the Hawaiian group.

Origin and Age of the Geomorphic Sequence

The earliest event of the sequence here described, cutting of the low marine terrace, is considered late Pleistocene in age. The mammoth jaw at El Capitan and the camel femur in the alluvial terrace deposits along the Santa Ynez River suggest this age. Grant and Gale (1931, p. 39) concluded that the marine invertebrates in the lowermost deposits in the terrace near Goleta represent a late Pleistocene age. Grant and Strong (1934) considered that mollusks in tar-impregnated terrace deposits near Carpinteria, probably the same low terrace discussed in this paper, indicate a late Pleistocene age. Finally, Woodring and others (1946) consider all the terraces on the Palos Verdes Hills to be upper Pleistocene. Marine terraces cannot be precisely dated on the basis of contained fossils. Nevertheless, in the Goleta Basin, the low terrace here considered truncates deformed beds of the Santa Barbara formation of which the lower part is considered upper Pliocene by some geologists (Bailey, 1943, p. 1562); but whose upper part is considered lower Pleistocene by most geologists (see Woodring and others, 1940).

The low terrace must have been developed after the deformation of the Santa Barbara beds, which took place in lower or middle Pleistocene time (Bailey, 1943). Furthermore, it is the lowest and youngest of several terraces along the Santa Barbara coast; description of the higher and older ones of which is beyond the scope of this paper. In order to allow time for a major deformation and the cutting of several older marine terraces in post-lower Pleistocene time, the formation of the low terrace and the initiation of the geomorphic sequence here discussed are considered upper Pleistocene. The geomorphic sequence evidently ends in Recent time with the deposition of alluvium as essentially the latest geologic event of the region. Thus, together with the additional evidence summarized beyond, the intervening valley cutting is considered to have resulted largely from the lowering of sea level that accompanied the maximum glaciation during the Wisconsin stage. The low marine terrace may have been formed in the immediately preceding, or Sangamon, interglacial stage.

In regard to origin, the rise of sea level from the lowest position in the sequence to about the present level is considered eustatic because of its nearly equal magnitude throughout Santa Barbara County, its indifference to the probable direction of local crustal movements, its correspondence in magnitude with similar relative rises of sea level along the rest of the California coast, and its agreement with corresponding relative rises in other parts of the world. Now, if the rise of sea level is a eustatic rise in accord with the waning of a glacial stage, then the immediately preceding lowering of sea level must be in large part eustatic, resulting from a waxing of the same glacial stage and perhaps one or more preceding stages. The writer uses the words "in large part eustatic" because the low marine terrace has not been mapped carefully, its elevation along the coast has not been determined precisely, and it may be slightly deformed at places. A "200-foot" terrace (Putnam, 1942, p. 741) near the west end of Rincon Mountain slopes westward beneath the Carpinteria Basin—apparently tilted. Tilted low marine terraces have been reported at other localities along the California coast. (See Woodring and others, 1946, p. 115 and pl. 26.) However, for many miles along the coast west of the Carpinteria Basin in Santa Barbara County the low terrace certainly is not deformed very much; and it is believed that at least 300 feet, and probably more, of the relative decline of sea level from this terrace was a eustatic lowering of sea level and only a small part of the total difference in elevation can be accounted for by a rise of the land.

The writer does not wish to imply that all terraces older than the 100-foot terrace of this paper are also wholly or even in large part the result of eustatic fluctuations of sea level correlative with glacial stages. At some other localities along the California coast, older terraces are too numerous to be accounted for in this way, for example, on the Palos Verdes Hills, where Woodring, Bramlette, and Kew (1946, pp. 113-116) have described 13 terraces, and on Rincon Mountain, where Putnam (1942) has described 9 elevated terraces. At these localities some of the terraces are tilted, as has been mentioned, and the tilting may be the local expression of more widespread upward crustal movements. Davis (1933) ascribed the preservation of elevated marine terraces of the Santa Monica Mountains largely to uplift, but their origin to eustatic shifts of sea level which he correlated with a hypothetical set of glacial stages. Discussion of the origin and uplift of older terraces of the Santa Barbara coast is beyond the scope of this paper. If, following the lower or middle Pleistocene period of diastrophism, the land continued to rise but at a decreasing rate, the formation of marine terraces developed during the uplift may have been due primarily or entirely to temporary halts during the uplift and may have no genetic relation to glacial stages. On the other hand, to ascribe the origin of the late Pleistocene and Recent cut and fill of the coastal streams, here discussed, to uplift of continental proportions followed by a reversal on the same scale, seems unreasonable.

Relation to the Origin of Submarine Canyons

The writer believes that the age and origin of the geomorphic sequence here described has a bearing on the problem of origin of so-called submarine canyons. Off Point Arguello is a minor submarine canyon that heads in four distinct tributaries, one of which seems to be a seaward extension of the Santa Ynez River Valley. This canyon has been called Arguello Canyon by Shepard and Emery (1941), who have described it and others off the California coast.

Figure 3 shows a longitudinal profile of Arguello Canyon above a depth of about 6,000 feet, and a profile of the base of the alluvial fill of the Santa Ynez River. The profile of Arguello Canyon is taken from U. S. Coast and Geodetic Survey chart 5202, dated December 1940. The profile of the base of the alluvium is from well logs and dam-site corings (Upson and Thomasson, 1947, pl. 509). The profiles include distances of about 45 miles seaward and landward, respectively, from the shore. The lines are solid where based on specific data but broken where inferential. The profile of the Santa Ynez River Canyon is well controlled downstream at least to a point about 2 miles from shore. Thence it is projected seaward at about the same slope, as it is considered highly improbable that the gradient would steepen appreciably in that distance. Shepard and Emery (1941, pl. 12), and perhaps others, have drawn comparative longitudinal profiles for Arguello Canyon and the Santa Ynez River and for other seemingly contiguous submarine canyons and land valleys. The profile of Shepard and Emery for Arguello Canyon and the Santa Ynez River was evidently drawn on the surface gradient of the river. It happens that the surface gradient is very little different from the suballuvial profile, but it is believed that the difference is significant geomorphically.

The outstanding features of the profiles here given are (1) the coincidence of the projected suballuvial profile with the outer edge of the submarine bench (now blanketed by shore deposits) at about 300 feet below sea level; and (2) the abrupt steepening of gradient at the head of the profile of Arguello Canyon.

The abrupt change in gradient from the suballuvial Santa Ynez Canyon to Arguello Canyon is a marked physiographic discontinuity. It signifies that the headward part of Arguello Canyon originated in an entirely different geomorphic episode from that in which the prealluvial Santa Ynez River Valley was cut. The discontinuity alone does not indicate which geomorphic episode is the older. If the two profiles were now above sea level, the suggestion would be strong that the lower profile (that of Arguello Canyon) was the younger, and that the abrupt change in gradient was due to the headward cutting of a stream working in an older valley, but graded to a lower position of base level. However, in the existing case, the sub-alluvial profile of the Santa Ynez River seems clearly to have been graded to the 300-foot submerged bench which apparently truncates the steep head of Arguello Canyon thus suggesting that the steeper profile is the older. Further, if the suballuvial canyon of the Santa Ynez River was cut in Wisconsin time, as argued above, then Arguello Canyon would have had to be cut in pre-Wisconsin time. There seems to have been neither time nor opportunity for subaerial cutting in post-Wisconsin time; and a submarine process, perhaps now operating, would probably be much slower than any subaerial process. Thus, essentially all of the formation of Arguello Canyon, by whatever process, is believed to have taken place in pre-Wisconsin time.

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