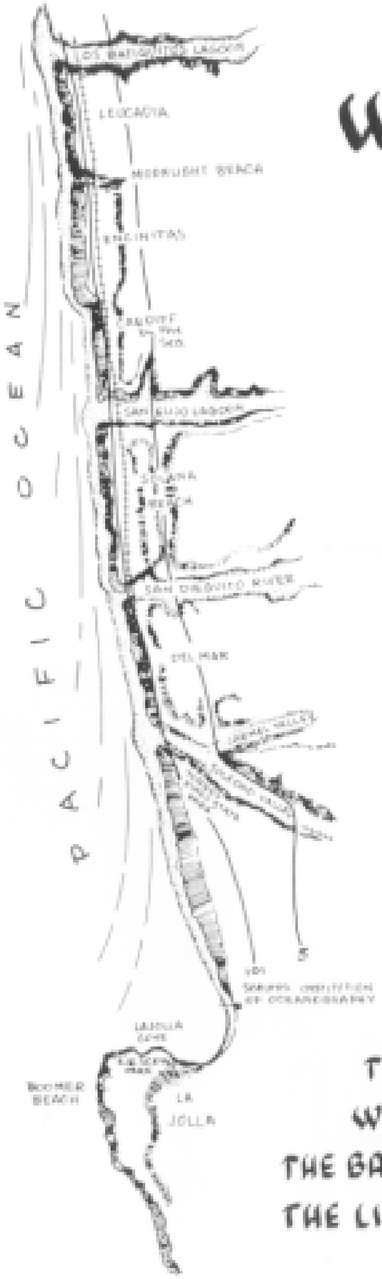

WALK ALONG THE OCEAN

A GUIDE FOR BEACH WALKERS
EXPLORING GEOLOGIC HISTORY
WAVE ACTION, BEACH PROCESSES
CLIFF EROSION, AND THE
MOST CONSPICUOUS SHORE LIFE.

by
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WITH CONTRIBUTIONS
by G.KUHN

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Introduction

The beach along most of our shore is a narrow strip of sand at the foot of a wall of cliffs which like a bulwark faces the ever-attacking surf of the Pacific Ocean. The beach widens where large valleys interrupt this wall of defense.

The cliffs with their rocky ramparts and narrow beaches, where land and sea are fighting a furious battle, are in charming contrast with the wide, gentle lagoons where land and sea work together in harmony to provide rich pastures for shore birds and other creatures.

The sea shore is a unique resource. Pressures on this resource are increasing as more and more people are coming to enjoy our beautiful coast. Decision regarding use of this resource are not always in the best interest of the public. A well-informed public can help its government make better judgments.

There is so much to enjoy along our shores. Let's keep it that way!

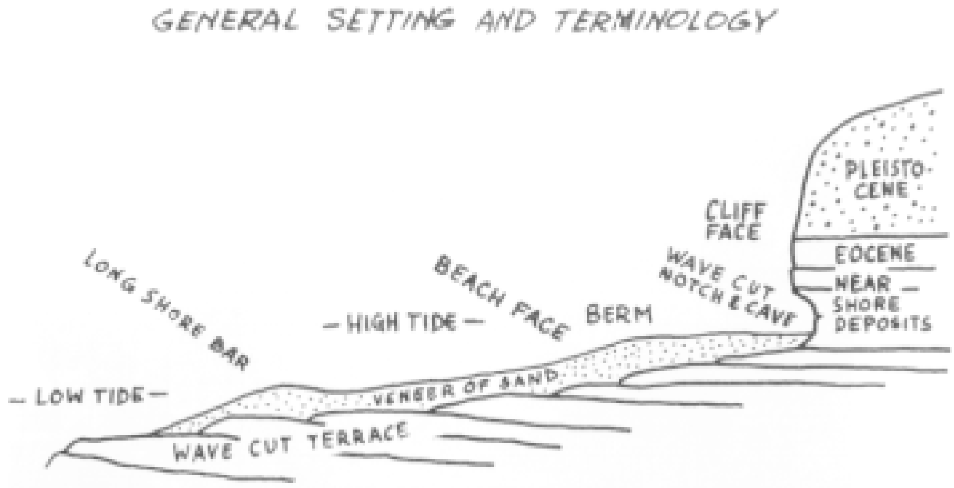


Figure 1.1. Sand covered terrace, Solana Beach.

A beach walker on our shore will usually walk on sand between the surf on one side and the cliffs on the other. If the walker is a child or has retained curiosity into adulthood, many questions will cross his mind.

What are the cliffs made of? Where does the beach sand come from? Where do the waves come from and why do they break? We shall consider these questions by and by. First, let us take a look at the architecture of the shore, its building plan as it were (Figure 1.1).

The beach consists of a thin blanket of sand, sitting on a bench or ''terrace'' in front of the cliff. The waves are cutting this bench into the land which opposes them. They do this by notching the cliff at its base. Sooner or later the overhanging part of the cliff will then fall down on the terrace. Wave action then wears down the fallen rocks.

Let us take a closer look at the stuff the cliffs are made of. Along much of the shore, the cliff face looks like the one shown in the photo of Figure 1.2. Horizontal layers of sandstone and siltstone are stacked on top of each other like pancakes on a platter. Each layer is made of tiny grains of quartz, feldspar, and mica. These were originally eroded from mountains to the east and brought into the area of deposition by ancient rivers. The rivers dumped the sand and silt into lagoons and shallow embayments along an ancient coast, which was much less rugged than today. The landscape may have looked much like some areas to the south of here, in central Mexico, with wide beaches, wandering dunes, sand barriers, and

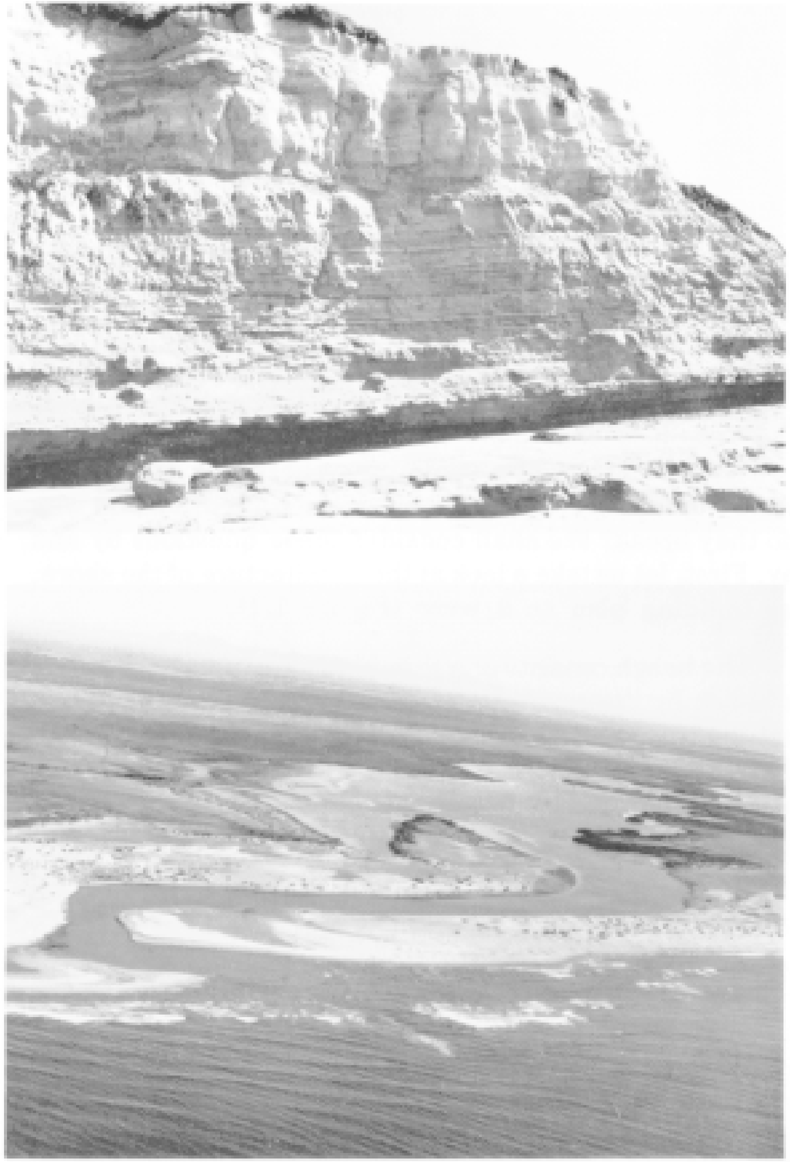


Figure 1.2. Eocene strata N of Del Mar, nearshore and lagoonal deposits. Air photo of lagoon and barrier beach environment in Mexico, similar to that recorded in Eocene rocks. (Airphoto courtesy F. B Phleger).

brackish lagoons. What we see in the cliffs are cross sections of these ancient sediments, now solidified.

We can see the evidence for this reconstruction in the beds of sandstone and siltstone. The cross-bedding structures and the burrows and tracks that worms, clams, and shrimp-like creatures left behind are typical for this kind of nearshore environment (Figure 1.3). Shell beds and oysters obviously indicate shallow marine conditions at the time of their deposition. Other clues to the ancient surroundings are more subtle. Especially helpful are the many kinds of snails, clams, and other fossils that are found in some of the siltstones (Figure 1.4). Some snails, for example, only lived in the brackish waters of the lagoons; others were restricted to the open beaches, just as on our present shores.

When carefully studying the fossils from the cliffs, it soon becomes clear that the kinds of organisms that made these shells no longer exist. Thus, the cliff rocks must be very old, many millions of years. Just how old are they? Comparison of the cliff fossils with those from other places where rocks have been dated shows that most of our cliffs are of ''Eocene'' Age, that is, about 40 to 50 million years old. The time which passed since is twenty times longer than the entire existence of people on Earth. It is, however, only one tenth of the time since fishes first became abundant, and only one hundredth of the age of Earth.

People there were none during that period (the ''Eocene'') but whales were around already, perhaps migrating along the coast like our own California Grey Whale. Only, Eocene whales looked more like sea snakes than like respectable Grey Whales! They were long and relatively thin, and had a face more like a horse's than a dolphin's, but with long rows of sharp teeth. The blow-holes sat way up front on the snout rather than on top of the head.

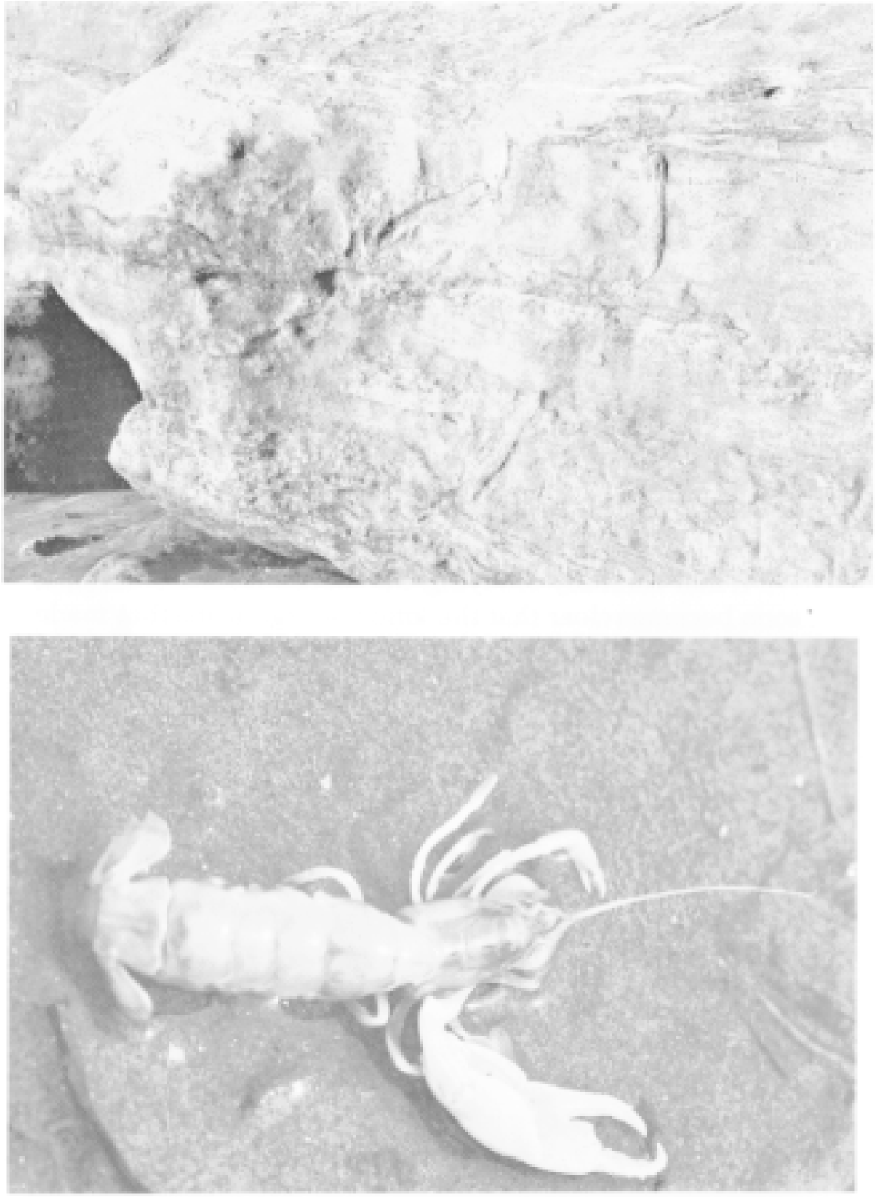


Figure 1.3. Burrows in Eocene strata, Solana Beach. Modern example of burrowing shrimp: ghost shrimp from San Diego slough. Certain shrimps make burrows several feet deep.

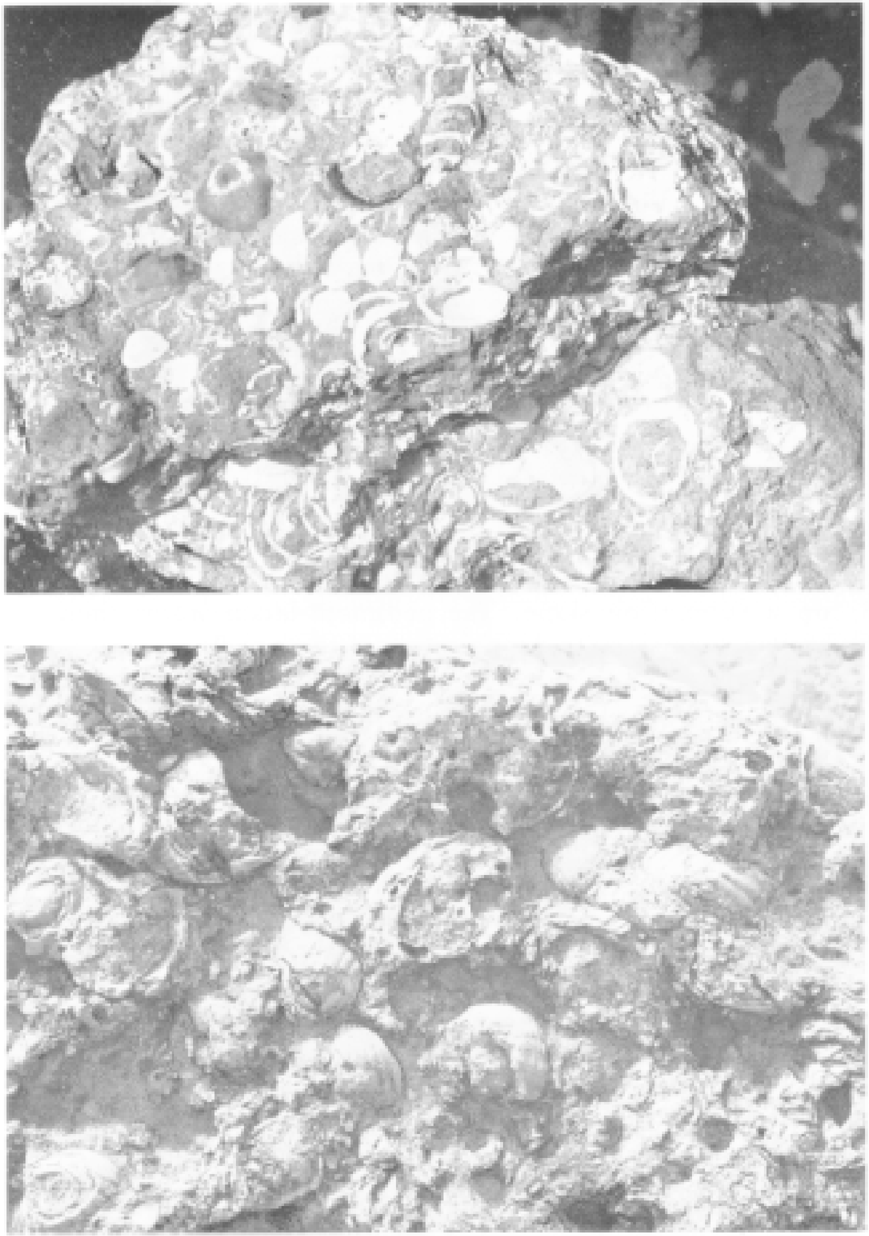


Figure 1.4. Fossils of Eocene strata, Del Mar. The various snails and clams indicate a nearshore environment. Bottom photo is close-up to chapter title photo.

The cliffs of La Jolla and Point Loma are quite different from the Eocene ones we just looked at. In addition to interbedded layers of sandstone and siltstone there are occasionally layers of black shale. Spacing of the layers is nearly perfect and there is much less disturbance from crossbedding and burrowing within layers than in the Eocene ones (Figure 1.5). Also, there are no shallow water shells. These beds were laid down in a quiet deep water environment, at a considerable distance from the shore. The astute observer will note that the sandy beds are ''graded,'' that is, grains are coarse at the base of each bed and become finer upward. Geologists think that the sediment for each bed was brought in by a single mud slurry.

Such slurries may form when nearshore deposits mix with water during storms or earthquakes, due to sliding on a submarine slope. The sediment-laden water then moves downslope to deeper parts of the sea floor. Grains settle out from such a slurry once it reaches the quiet offshore basins. Fine mud accumulates there during most of the time, the sandy beds marking the occasional interruptions.

Microscopic remains of planktonic organisms in the black shales tell us how long ago this happened: in the Late Cretaceous, some 70 million years ago. No whales were blowing along the coast then. Indeed, there were no large mammals around at all; perhaps some rat-like creatures foraged along the shore. If so, they probably scurried for shelter when the ''pterosaurs,'' the flying reptiles, swooped over them and out to sea to go fishing. Like very large pelicans they must have looked. ''Ammonites,'' huge squid-like creatures with coiled shells for houses, may have been part of their diet. If anything was blowing like a whale it was one of those large diving lizards called ''mosasaurs.''

When looking at today's hustle and bustle along the coast—the cities and pulsating freeways, the ships offshore, and the planes overhead—it is easy to forget

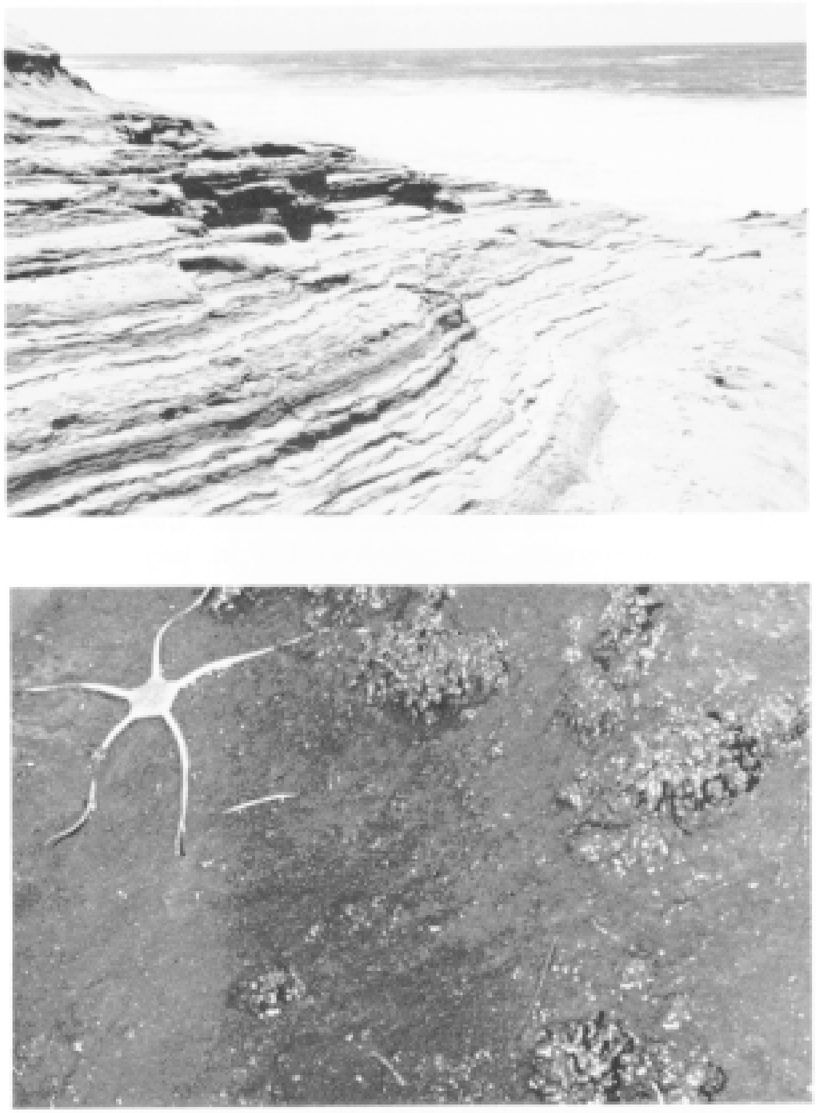


Figure 1.5. Late Cretaceous strata at La Jolla, thinly bedded. The environment of deposition was probably similar to that in the San Diego Trough offshore. The presence of these deep ocean deposits at the shore indicates considerable uplift. (Sea bottom photo by Dave Ripley).

how late Man came onto the scene. Until recently, many anthropologists believed that Modern Man (that is, *Homo sapiens*) only entered North America after the last glaciation, some 10,000 years ago. The immigrants are thought to have come across the Bering Land Bridge, now submerged. Recently a skull from the Del Mar Site has been dated at Scripps Institution of Oceanography using a new method based on the rate of alteration of amino acids within the bone (Figure 1.6). This skull was found to be much older than earlier estimates for the time of first immigration. Perhaps, people have been living here for more than 40,000 years!

Even so, this is but a small fraction of the time since Man's existence, some 2 million years. Poorly bedded, rubbly sands on top of the Eocene cliffs were deposited during this human time span, called the "Quaternary."

The Quaternary, the period we live in, has been and still is a time of uplift all along the coast of Southern California. This is why high up on the cliffs we find deposits that have only recently been laid down close to sea level. Also, well above sea level we find terraces that were cut not so long ago. La Jolla is built on such a terrace. The forces causing this uplift are deep within the Earth. From time to time we can feel their workings when the ground shakes under us. Most earthquakes are small, but some are strong enough to make freeway bridges collapse and to start catastrophic landslides.

We can now summarize the basic architecture of our coast: the land rises, exposing ancient marine deposits along the shore and making sea floor into dry land. The ocean resents this encroachment on its territory and cuts deep into the raised land. This makes a wave-cut terrace in front of the receding cliffs. Sand accumulates on this terrace to make a beach.

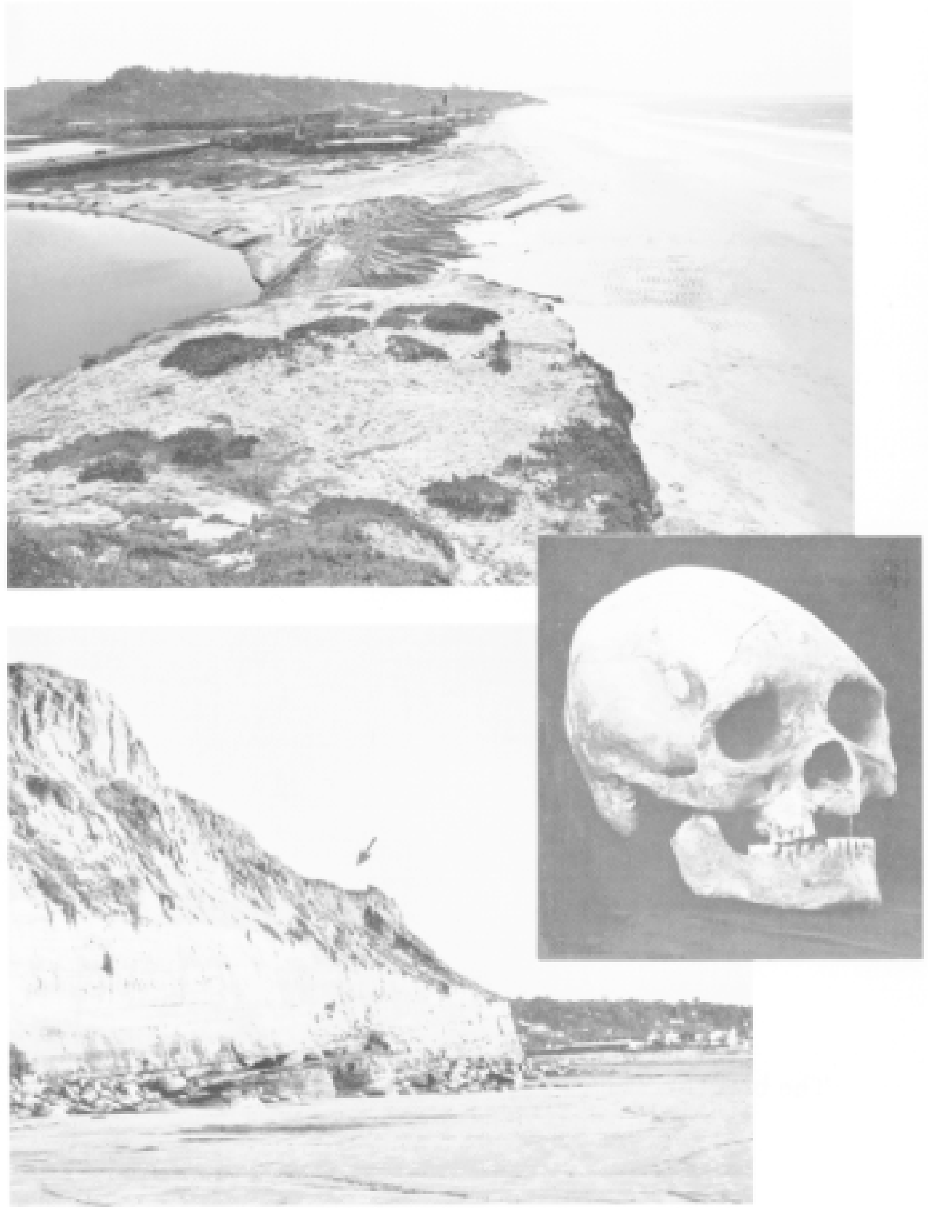


Figure 1.6. Site of Del Mar Man, a Paleo-Indian of great antiquity. (Skull at Museum of Man, San Diego. Photo SIO).

The breaking waves move the beach sand southward.

WAVES
AND THE
RIVER OF SAND

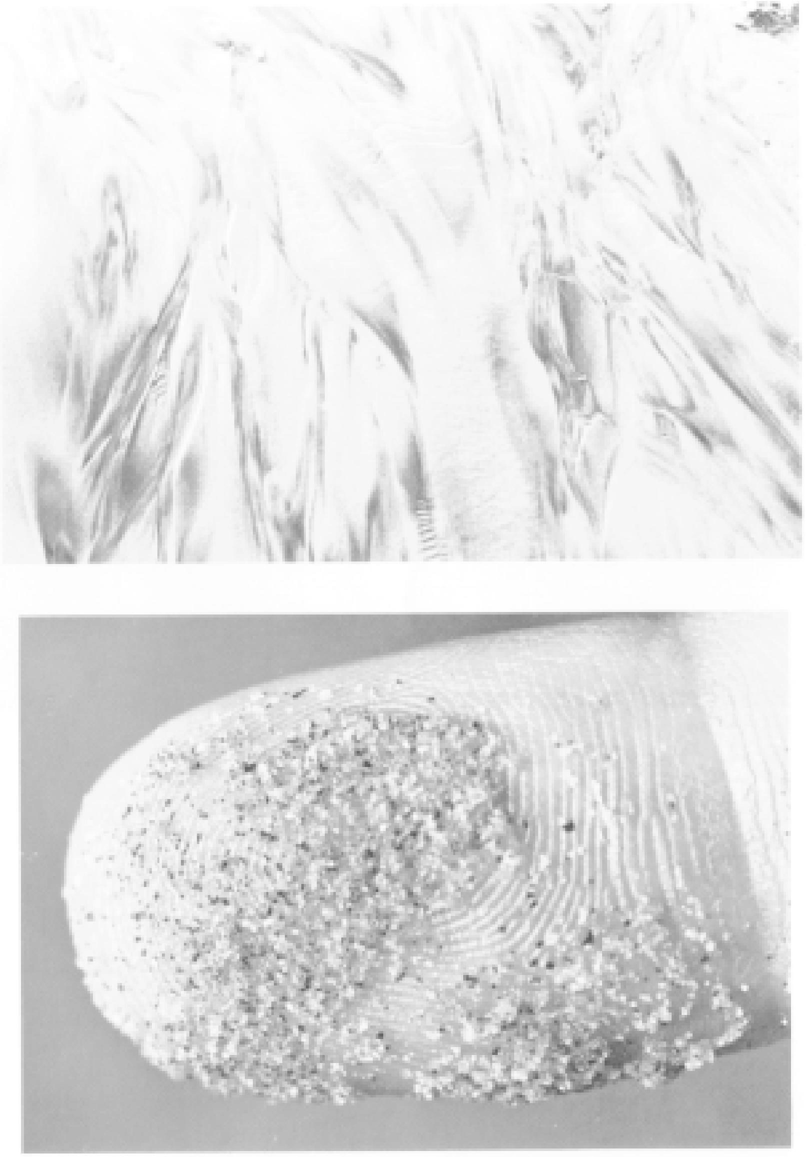


Figure 2.1. Water washing across the beach face segregates light and dark-colored sand grains into surrealistic patterns. The light grains are quartz and feldspar, the dark ones are iron-rich heavy minerals, such as hornblende.

First, the sand. It consists mainly of small grains of the minerals quartz and feldspar (Figure 2.1). Ultimately, this material is derived from the mountains to the east. The question is, how did it get here?

We have already seen one possible source of the sand in front of the cliffs: the receding cliffs themselves, made of sediments that came from mountains to the east. Let us check this idea.

We know, from work done by scientists at Scripps Institution of Oceanography, that the sand is moving southward. Strong wave action tends to stir up the sand and redeposit it slightly down-wave from where it was picked up. Most of the powerful waves of the kind transporting sand come from a northerly direction. Hence the overall southward movement.

Checking the amount of sand entrapped each year at certain harbor entrances, these scientists estimate that about 300,000 cubic yards of sand move past Solana Beach every year. At La Jolla Submarine Canyon, the sand is funnelled off to the deep basin off San Diego (Figure 2.2).

We can calculate how fast the cliffs would have to retreat if they were to deliver all this sand. The coastline collecting the sand reaches north to San Clemente, and is about 100,000 yards long. To get 300,000 cubic yards, a cliff 30 yards high would have to retreat one yard every ten years. Clearly, the cliffs do not, on the whole, retreat this quickly (although in a few vulnerable places they apparently do). Thus, we must look for a different source of the sand.

The only other source of sand is in the rivers emptying

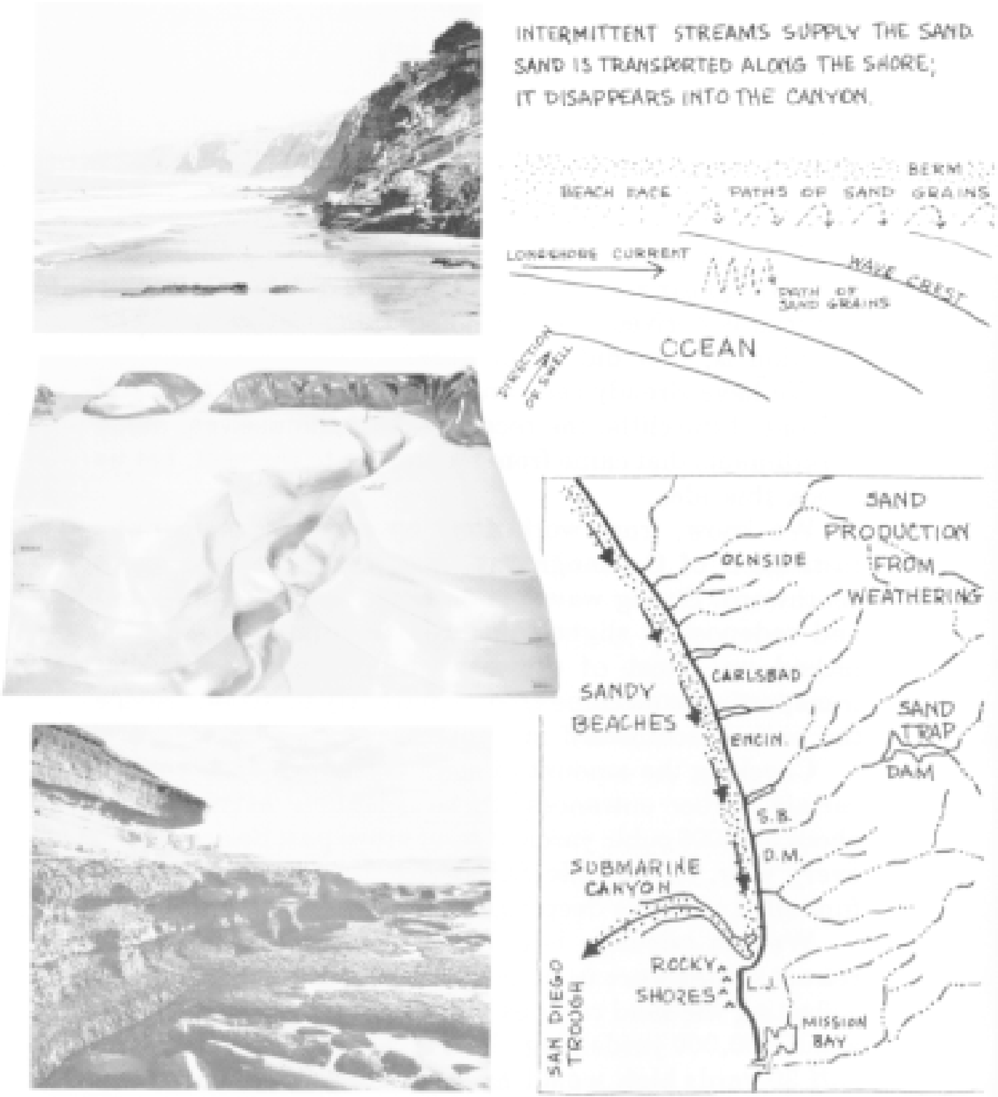


Figure 2.2. Sandy beaches prevail "upstream" from La Jolla Canyon, while the shore is rocky "downstream." The sand disappears into San Diego Trough.

into the ocean. There are a number of such rivers along our beach system: the San Juan Creek in Orange County, the Santa Margarita, San Luis Rey, and San Dieguito Rivers, and the San Onofre, Las Pulgas, Buena Vista, Agua Hedionda, San Marcos, Escondido, and Los Penasquitos Creeks.

Many of these rivers end in coastal lagoons before reaching the ocean. Here they drop much of their sediment unless they run high during strong floods. In fact, much of the sand brought by the rivers is transported during their flood stages: trickles don't carry much sand.

Immediately, then a problem arises: no floods means no sand to the beaches. The incidence of floods depends on climatic variations. We live in a period of relative scarcity of flooding: there has been only one significant flood-flow of the San Diego River (in 1952) during the past 38 years. Old-timers who have been around for a number of decades remember well when apparently harmless little creeks were swollen to fast-flowing muddy rivers after several days of strong rainfall. Between 1900 and 1940, strong floods developed about every 5 years, on the average. People protect themselves and their property against such floods by erecting dams. Dams also block the transport of sand.

Scripps scientists believe they may be seeing the effects of this sand blockage in a progressive decrease in sand level since 1960, as measured at Torrey Pines State Preserve (Figure 2.3). The waves, of course, keep on moving the beach sand along to the La Jolla Submarine Canyon where it disappears. Thus, we may in time have a pebble beach rather than a sand beach. Absence of the protective beach sands allows the destructive waves to reach the base of the cliffs in full force, speeding up their retreat.

It is rather difficult to establish exactly how sand levels change in response to changing sources. The reason is that the sand moves in and out in addition to moving longshore. During periods of storm waves, usually in the

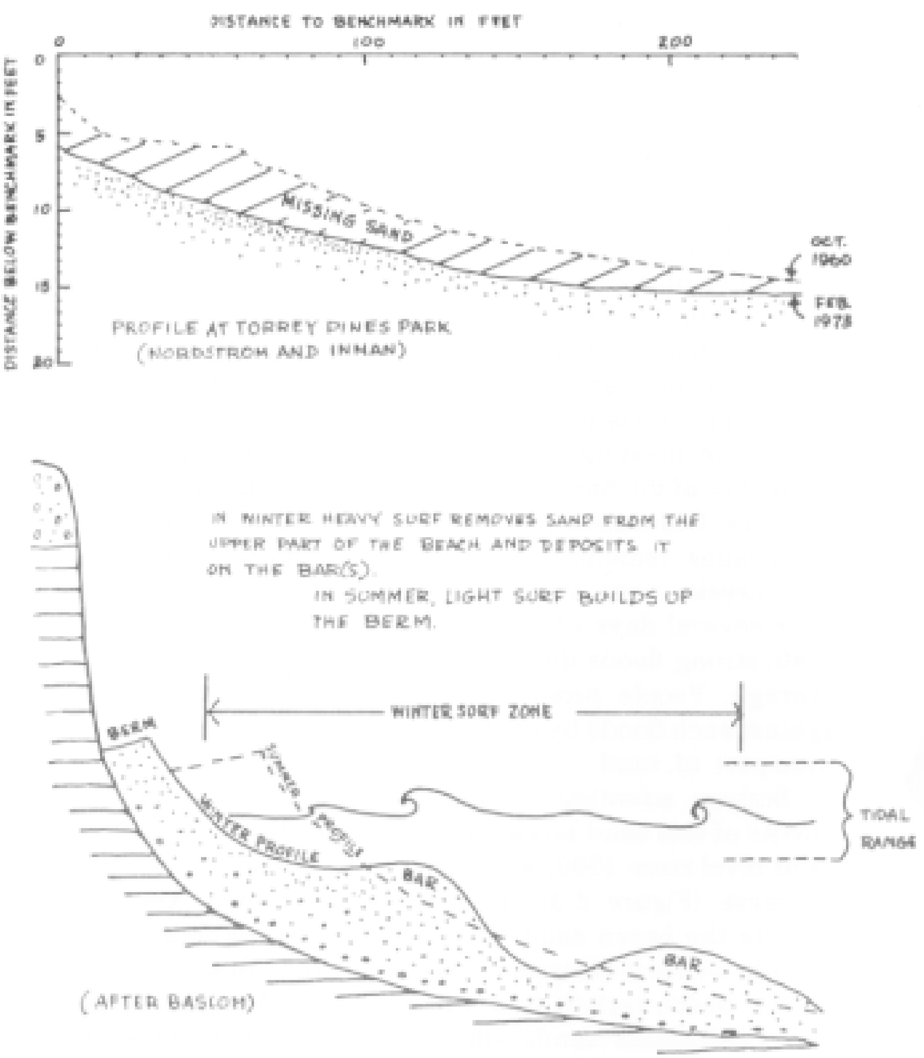


Figure 2.3. Changes in sand level on the beach have two possible reasons: (1) an increase or decrease in the availability of beach sand, and (2) a change in the location of the sand between beach face and offshore bars. S.I.O. scientists are studying the effects of reduced sand supply, due to flood control.

winter, waves erode the beach sand and deposit it offshore. During periods of gentle waves, the sand is transported shore-ward again (Figure 2.4).

This shifting back and forth of the sand, from offshore bars to the beach and back, makes some beaches appear bare and inhospitable during stormy seasons, while during the quiet seasons they are full of sand. The most spectacular example is Boomer Beach in La Jolla which annually changes its character from a boulder-strewn rock shore in winter to a pleasant sand-filled cove in summertime.

We have seen that the sand on the beach is very mobile: it goes in and out and moves southward along the shore. Let us now take a closer look at the waves themselves, whose power is responsible for this mobility.

The waves breaking on our beaches originated in storm centers somewhere in the Pacific. In the crashing of the winter surf we hear the fury of the wild wintry seas to the north. In the pounding of the summer surf we feel the great waves of the Southern Ocean, running forever around Antarctica before the howling fifties and sending us their long-distance messengers (Figure 2.5).

The closer the storm which made the waves, the more choppy and powerful the waves. If waves have to travel a long way to reach the shore, they get sorted out, the long ones out-running the short ones.

What exactly *is* a wave? Ideally, it can be described as a motion of the sea surface, in which all water particles involved move in circular paths (Figure 2.6). Thus, there is little or no actual transportation of water from one place to the other. In this the ocean waves are analogous to the waves that can be seen moving across a wheat field on a windy summer day. Obviously, the wheat stalks stay put while the waves move along.

When the ocean wave reaches the shore it changes its character. It starts to "feel bottom" and slows down. The same amount of power is still available to displace water

Figure 2.4. In- and out- movement of beach sand at Boomer Beach, La Jolla. The upper photo represents the summer condition (gentle waves), the lower one the winter condition (forceful surf).

Figure 2.5. Long swells coming from distant storms, choppy powerful surf from near-by storm centers.

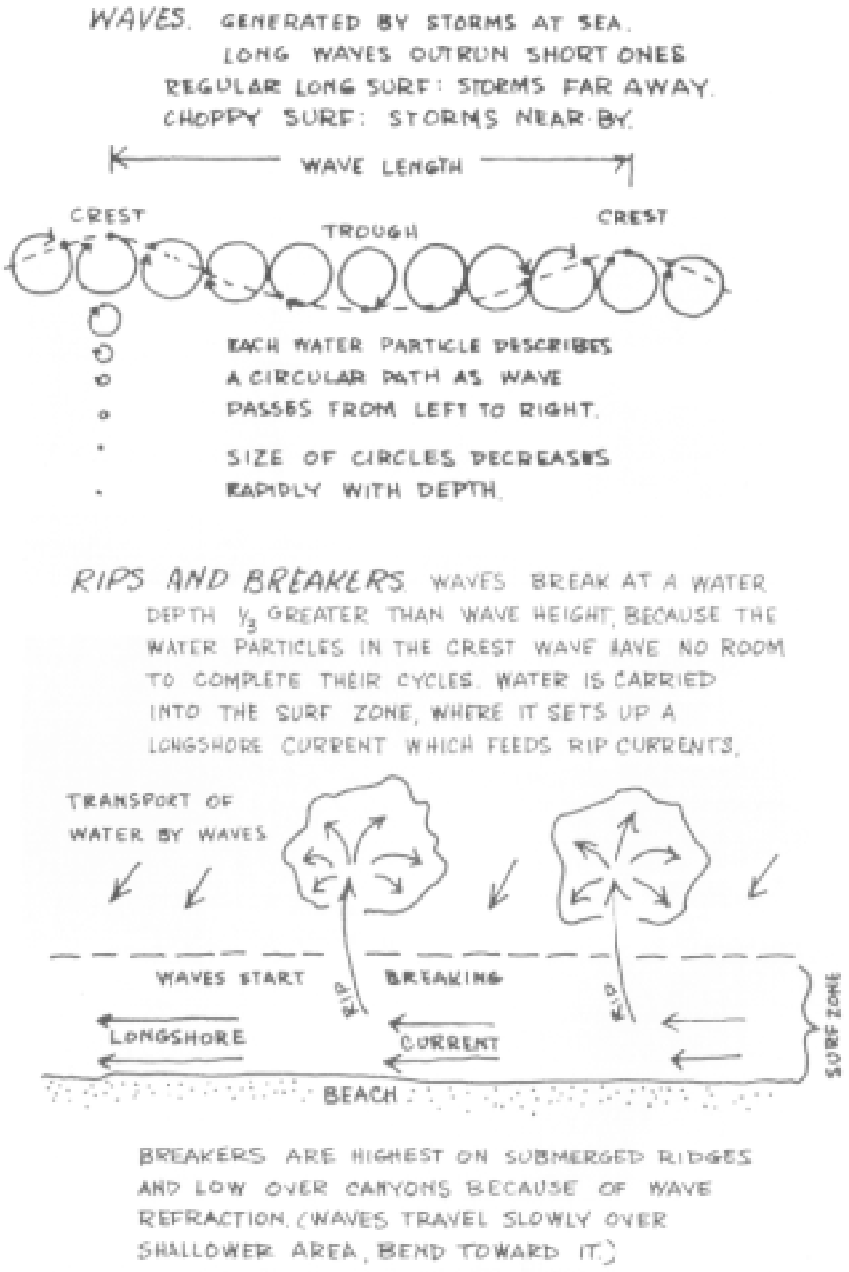


Figure 2.6. Waves, rips, and breakers.

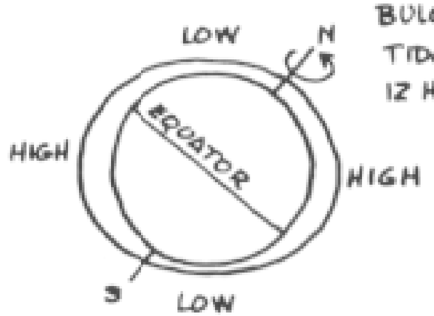
in the wave which is now much shortened. Thus the wave gets higher. Soon it steepens enough so that the forward motion of its crest outruns the trough in front of it. The wave breaks, and water is now actually carried forward as every surfer knows. Surfers also know that high waves come in sets, and are separated by a series of low waves. Wave trains coming from different storm centers interfere with each other: when crests and troughs coincide, the resulting waves are unusually high. When crests of one train coincide with troughs of another, waves are low.

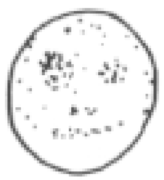
The water transported forward by the breaking waves piles up in the surf zone between the breakers and the beach. It has to return to the open sea. Along the line of onrushing breakers there are places where waves are less steep: here the piled-up water breaks through and returns in so-called ''rip currents.''

Swimmers who get caught in a rip current must not fight it, but swim parallel to the shore until they leave the rip, then they can return with the help of the surf.

Most people don't think of the tides as waves, yet that is what they are. They are waves generated by the rotation of the Earth interacting with the gravitational attractions of moon and sun (Figure 2.7). The tide in our area is a ''mixed'' tide with lows and highs of unequal extent following each other. A number of animals keep track of the tides and adapt their activities to it. The most spectacular one of these is the grunion, which comes ashore to spawn precisely in tune with the tides. In spring and summer great numbers of the silvery fish wriggle up onto the sandy beaches, during maximum high tides, at full moon or new moon. They bury their eggs high up on the beach. Here they are reasonably safe till they are washed by the next maximum high tide two weeks later, whereupon they hatch.

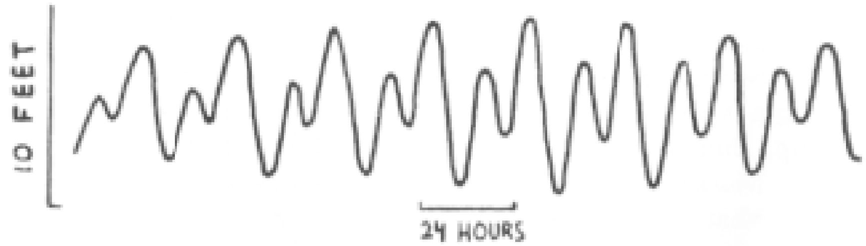
TIDES. EARTH TURNS UNDER THE TIDAL BULGES. IN LOW LATITUDES TIDAL PERIOD IS 12 HOURS 26 MINUTES





SPRING TIDE: SUN, MOON AND EARTH IN A LINE. (EFFECTS REINFORCE EACH OTHER)

NEAP TIDE: SUN, EARTH AND MOON MAKE 90° ANGLE. (EFFECTS TEND TO CANCEL)



TIDAL VARIATION OF SEA LEVEL AT LA JOLLA

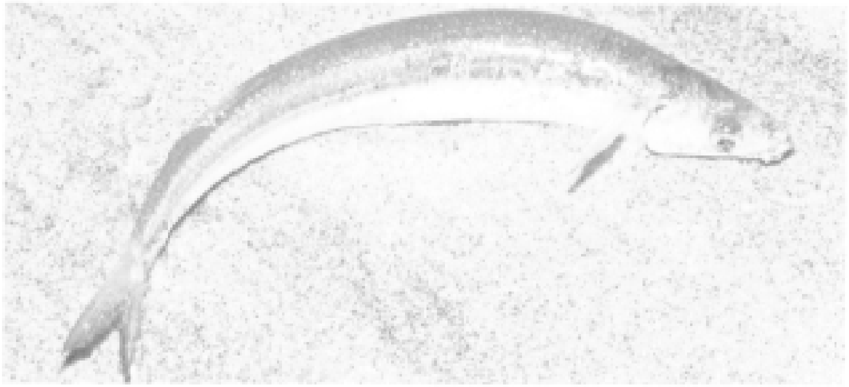


Figure 2.7.The grunion know their tide tables. Females bury their eggs in the beach sand, males fertilize them during deposition. Exhausted the silvery fish make their way back into the surf.

Cliff yields to wave attack and ground water action.
Note wave-cut notch above sand. Encinitas.
(Photo G. Kuhn).

THE BATTLE BETWEEN LAND AND SEA

Figure 3.1. Top: Wave-cut platform near head of La Jolla Submarine Canyon (S of Marine Room). Bottom: S of Casa Mañana in La Jolla; here the scenic road runs on a raised platform.

We have seen that the beach forms a battle line between the attacking waves and the defending cliffs. The battle is being lost by the cliffs, as they recede and only leave a platform near sea level where they once towered. This platform is the "wave-cut terrace" (Figure 3.1).

Once in a while mountain-building forces deep in the Earth raise the coast, lifting the terrace out of the ocean. After several uplifts, the wave-cut terrace finds itself high above sea level. The park on La Jolla Point (Ellen B. Scripps Park) is on top of such a terrace.

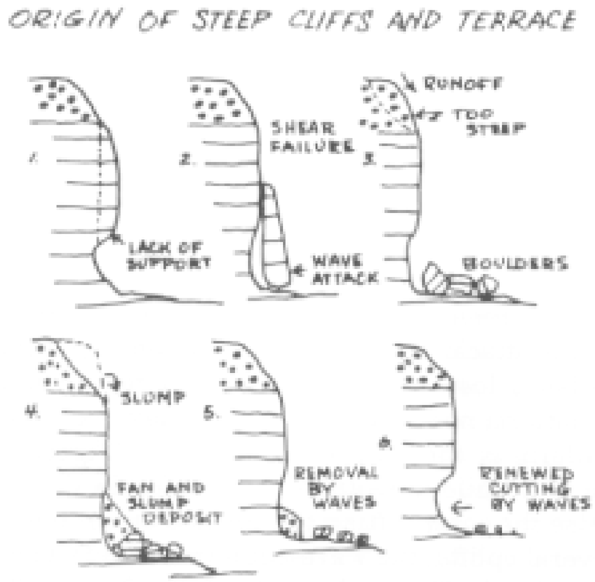
This raising up of the coast is the way the land fights back, and keeps the ocean from overrunning it. A new cliff forms sea-ward of the terrace, where undercutting starts anew. In time, a new terrace forms, the ocean wins back part of its territory, until this terrace also is uplifted. The result is a coast that resembles a giant stairway, where the terraces have not been obliterated by later erosion or fill.

In summary, then, most of the time the ocean is working its way landward. Only during times of uplift, every few thousands of years, the land gains the upper hand and the balance is redressed.

Exactly how does the ocean eat its way into the coast, and how fast?

Several processes are important. The basic cause of coastal retreat is the undercutting of the wall of defense, the cliffs (Figure 3.2).

The more powerful the waves and the softer the rock, the faster will this undercutting proceed. The waves are



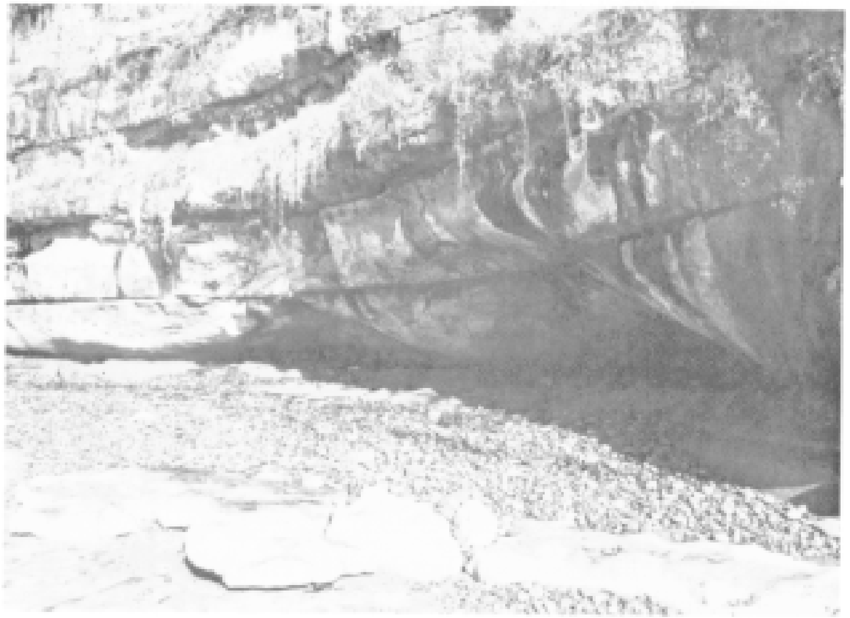


Figure 3.2. Undercutting and failure of the overhanging cliff as basic mechanics of ocean advance. Note the pebbles at the base of the cliff, which become powerful cutting tools in storm waves.

most powerful where the beach is narrow. Also they become concentrated where an underwater ridge runs from the shore out to sea. This is usually the case off places where the coastline sticks out toward the sea. Thus, here the wave-attack is most fierce, and unless the ''point'' jutting out has particularly resistant rocks, it will be chopped back more quickly than the rest of the coast. In contrast, where the coast retreats into lagoons or embayments, waves tend to be weak and surf is low. The waves do not transport sand as efficiently here as elsewhere and a wide beach can form. Thus, embayments tend to fill up with sand. The overall result is a straightening of the shore (Figure 3.3, Map).

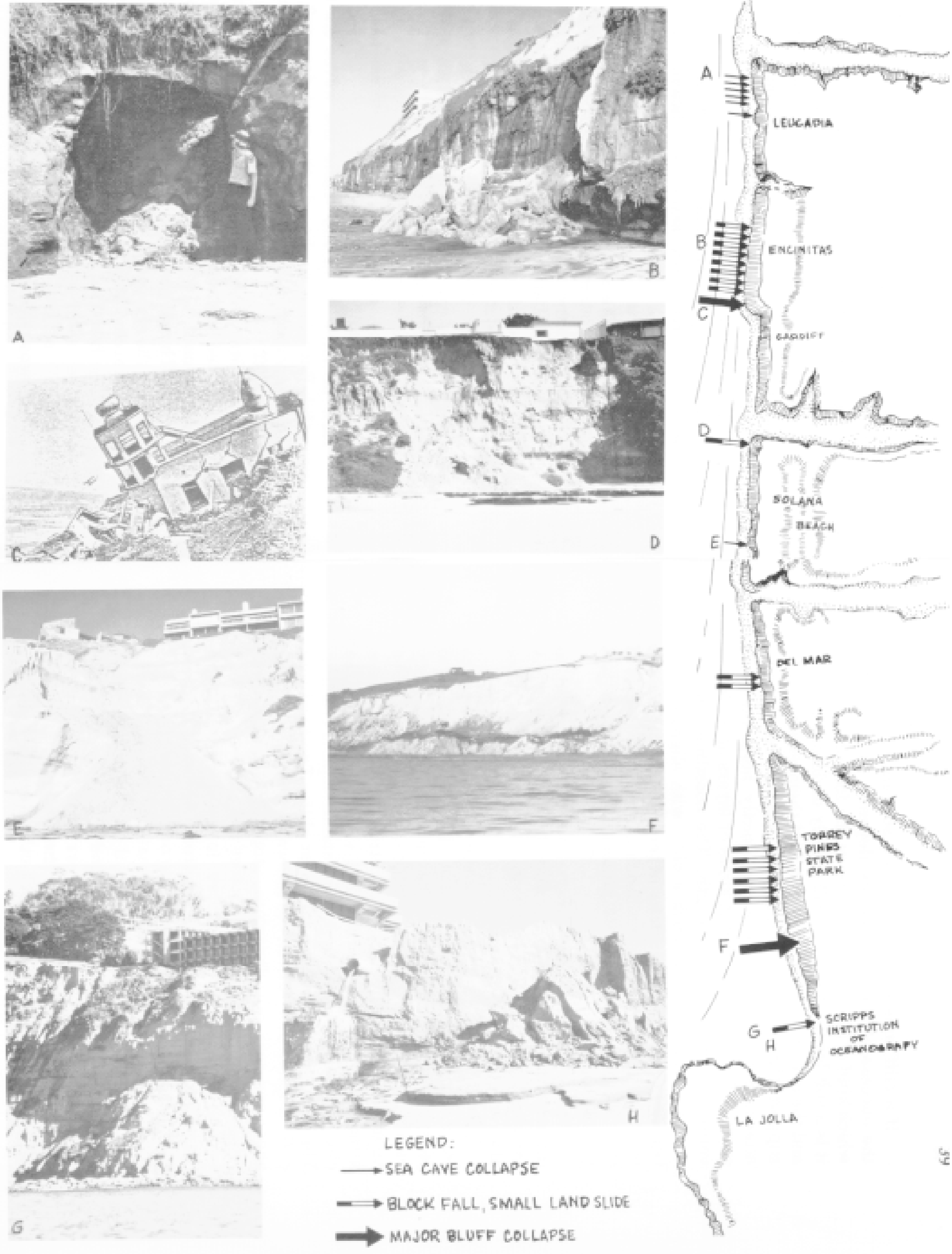
The cliff line determines where this shore will be, that is, how far the sand will build out in the embayments.

We have seen that wave attack is most powerful on the ''points'' of the cliffs, because of the ''convergence'' effect and because the narrow beach here offers little protection. Also, during periods when the beach sand is removed to offshore, storm waves can be especially effective. Instead of sand-blasting using the beachsand, they can now use pebbles and cobbles on the exposed foot of the cliff. Like thousands of stone masons the waves hammer away with their hard tools of volcanic rock.

Now we know when and where the waves are most powerful. But where do they do the most damage? This depends very much on whether a soft or hard rock is at the foot of a cliff.

If the entire cliff consists of soft rocks, such as young unconsolidated sediment, the cliff retreats rapidly before the attack until the beach is wide enough to offer protection. If beach protection is removed in such an area, by blocking the source of sand, the response of the coast becomes soon obvious: it retreats quickly before the wave attack. The blocking can be done, for example, by building a sand trap (harbor protection, jetty) ''upstream'' of the river of sand. Increased coastal erosion downstream is the result.

Figure 3.3. Evidence for cliff failure between La Jolla and Leucadia. The falls shown took place between 1973 and 1976, with two exceptions: C, landslide destroying the Self-Realization Temple in Encinitas, December, 1941, and F, major slide S of Torrey Pines Park, undated. (Photos A, D, G. Kuhn; F, G, F.P. Shepard; Map by G. Kuhn).



If a cliff consists of alternating soft and hard layers, the success of the wave attack depends crucially upon which kind of layer happens to be at the foot of the cliff. If it is a soft layer, the waves will readily undercut the cliff, and the overlying layers will soon find themselves without support. If a hard layer is at the foot, the cliff resists wave attack. Because layers are not exactly horizontal, the same cliff can have different kinds of layers at its foot at various places along its length. The coastline tends to swing in and out along such a cliff, with slightly wider beaches protecting those parts of the cliff which have soft layers at its base. When the beach is starved, the part of the cliff that needs the sand protection most will retreat the fastest.

There are two major ways the cliffs respond to under-cutting: rock fall, and land slides. Many intermediate situations between falls and slides arise also, as illustrated on the map (Figure 3.3).

In either case, the failure of the cliff is a response to removal of support by the waves. If the waves were to stop, the debris coming off the cliffs would eventually establish a relatively gentle, stable slope. There would be no more cliffs. Can we stop cliff retreat by stopping wave attack, therefore? Yes, but it is a slow process: still the cliffs will fall and retreat, until the stable slope is reached. This is true especially for soft-layer cliffs. The hard-rock cliffs respond more directly to the wave attack, by vertical shear and rock fall. Therefore, stopping the waves and plugging the notches does protect the cliff.

Landslides, which involve large areas and are therefore major events of cliff retreat, are most likely to occur if the layers slope toward the ocean. Also, if there is one or more layers with clayey material, this makes an excellent gliding plane, especially if the layers are soaked with water from rainfall, groundwater, or artifically increased drainage such as irrigation or sewage percolation. Soaking decreases the weight with which individual particles press on each other (sand is lighter in water) while increasing the total weight of the rock masses (water in the pores is heavier than air). If shaken by an earthquake, a soaked mass of unconsolidated material can actually loose all strength and start flowing. The last decades have been unusually dry. When it gets wetter again, chances are we will see many more landslides than now.

Soaking makes for land slides in loose material. It also softens up otherwise fairly hard rock (Figure 3.4).

Another important factor controlling cliff strength is faulting and shearing of the rocks through mountain building forces. In Solana Beach there are many sea caves which wave action carved out of such shear zones. The observant beach walker will note that virtually all the caves are elongate in the same direction. This indicates the direction in which the rock has been sheared.

Besides wave attack and gravity there is another force working quite efficiently on the cliffs. This is the rain which carves out ravines on top of the cliff (Figure 3.5).

The material from cliff failure and erosion ends up on the beach, at the foot of the cliffs where it offers some protection from wave attack for a while. Soon the waves disperse the loosened material which is an easy target of their washing and pounding. Some of the harder rocks may remain for some time as a cobble field.

Let us now make a rough estimate of the speed at which cliffs retreat. Is it inches per decade? Or feet per year?

From the foregoing it is already clear that such estimates are of a very general nature: they apply only in a statistical sense. It is no consolation to know that the overall cliff retreat is only inches per decade in some area if your house happened to go down in a landslide. In Encinitas, for example, a subdivision map filed in 1883 shows streets that nobody ever heard of. Nobody, that is, except some old-timers (Figure 3.6). One long-time resident told us how they closed 5th Street in 1946, south of Moonlight Beach (no 5th Street there today). So maybe

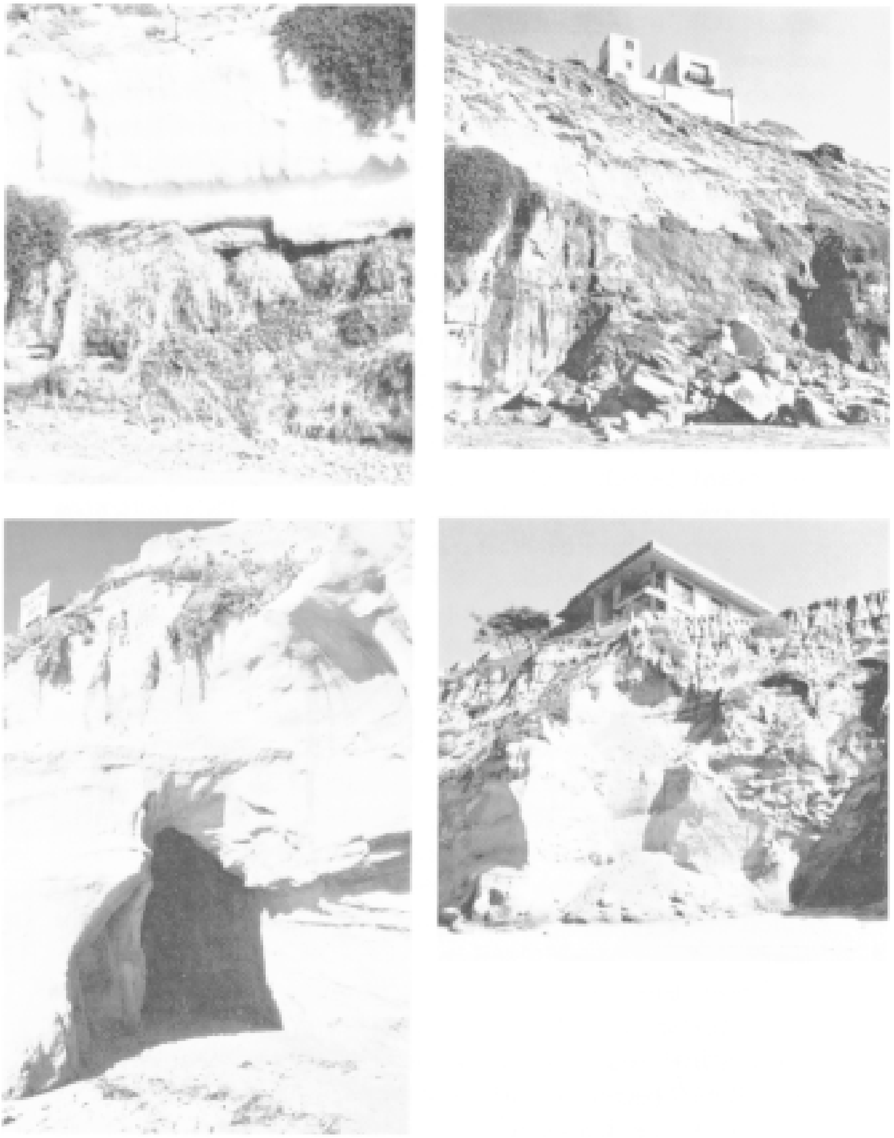


Figure 3.4. Soaking by groundwater (upper left, photo G. Kuhn) facilitates cliff failure (upper right, Encinitas). Where the cliff is weakened by shear zones and faults, sea caves develop due to wave action (lower left). Collapse of sea caves leads to cliff failure. (Solana Beach). Note rilling by runoff on top of cliff.

Figure 3.5. Two ways water erodes the cliffs: rainwash digging ravines at the top (upper photo; Del Mar), wave action eating away at the foot (lower photo; La Jolla Cove).

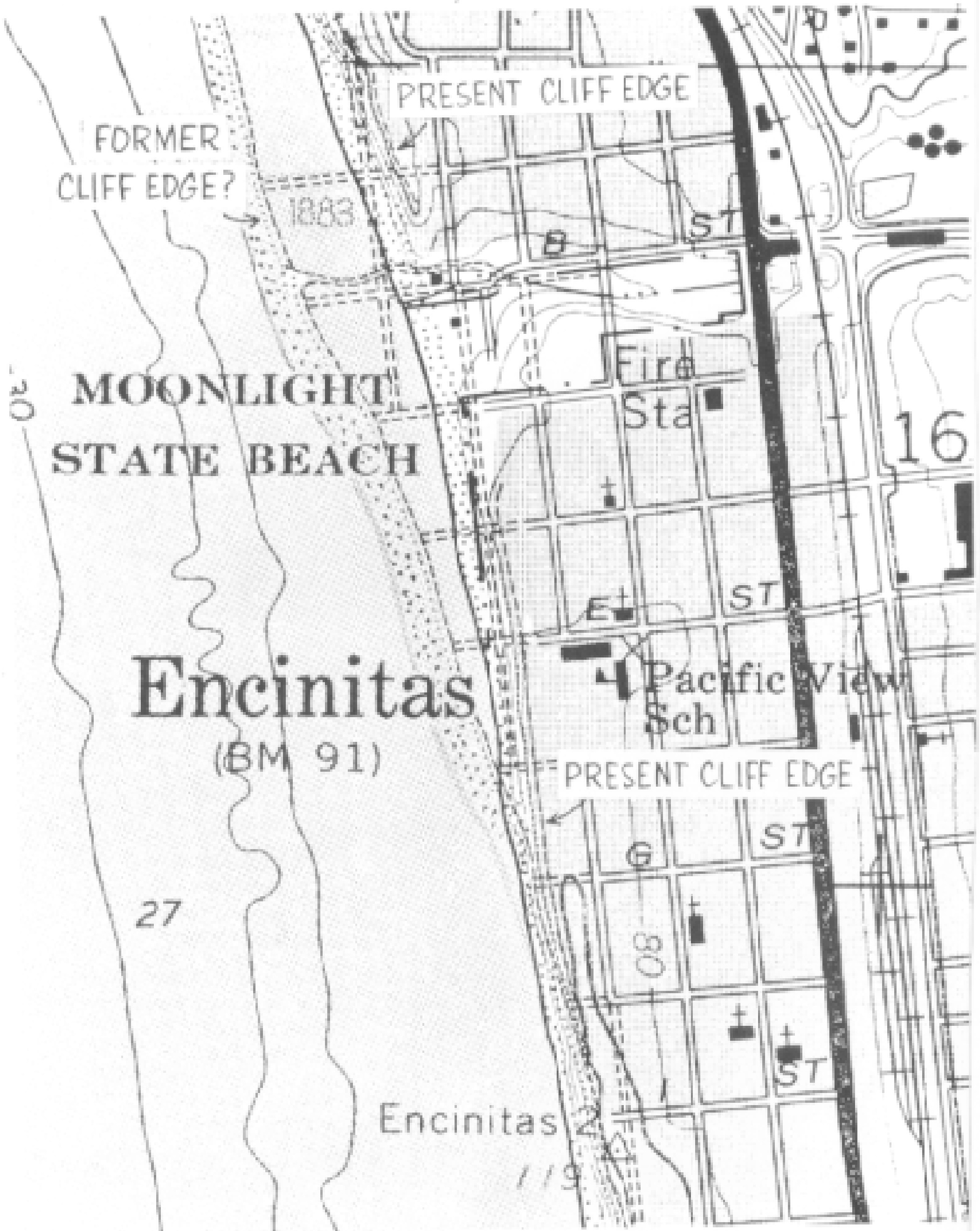


Figure 3.6. Subdivision map filed in 1883 superimposed on recent topography map. Sixth Street and Fifth Street are no more. A developers' pipe dream? Old-timers recall otherwise.

the old map isn't just a "developer's pipe dream," as one cliff dweller suggested. If the map is correct, the present Moonlight Beach is a fairly recent creation and the rate of retreat has been truly remarkable: up to several feet per year in some places.

Of course, retreat is very uneven in time and in space. From observing the cliffs north of Del Mar for a number of years, it appears that only a small portion of the coastline retreats at any one time. Typically, several feet of retreat are involved in any single rock fall or small slide.

A fresh scar marks the place on the cliff where material has recently come off. For a few weeks, even months, a debris pile remains on the beach, being quickly removed by the waves. About a dozen such falls can be seen each year along a mile long stretch in North County. The width of each fall is about 10 feet or so. Not all of these falls are near the foot of the cliff, whose retreat ultimately controls the overall cliff retreat. Thus, about one percent or so of the cliff retreats by a foot or more each year. In a hundred years, therefore, we expect an overall retreat of one, perhaps several feet. However, as we have seen, in any one place the pace of retreat can be a hundred times greater for a few years.

By their actions, people can help or hinder the forces of erosion. Soaking the cliff, or running storm sewers on it will speed its retreat. Building a sea wall will stop the waves from eating into the land all too rapidly (Figure 3.7). Sea walls can indeed help in cases. However, they do not solve all or even most problems of erosion, and may create problems of their own.

The best strategy is to avoid building on Sixth Street in the first place.

Figure 3.7. Helping erosion: running storm sewers on the cliff (Del Mar). Slowing erosion: building a sea wall (Solana Beach).