Beach Erosion

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CALIFORNIA GEOLOGY

April 1979

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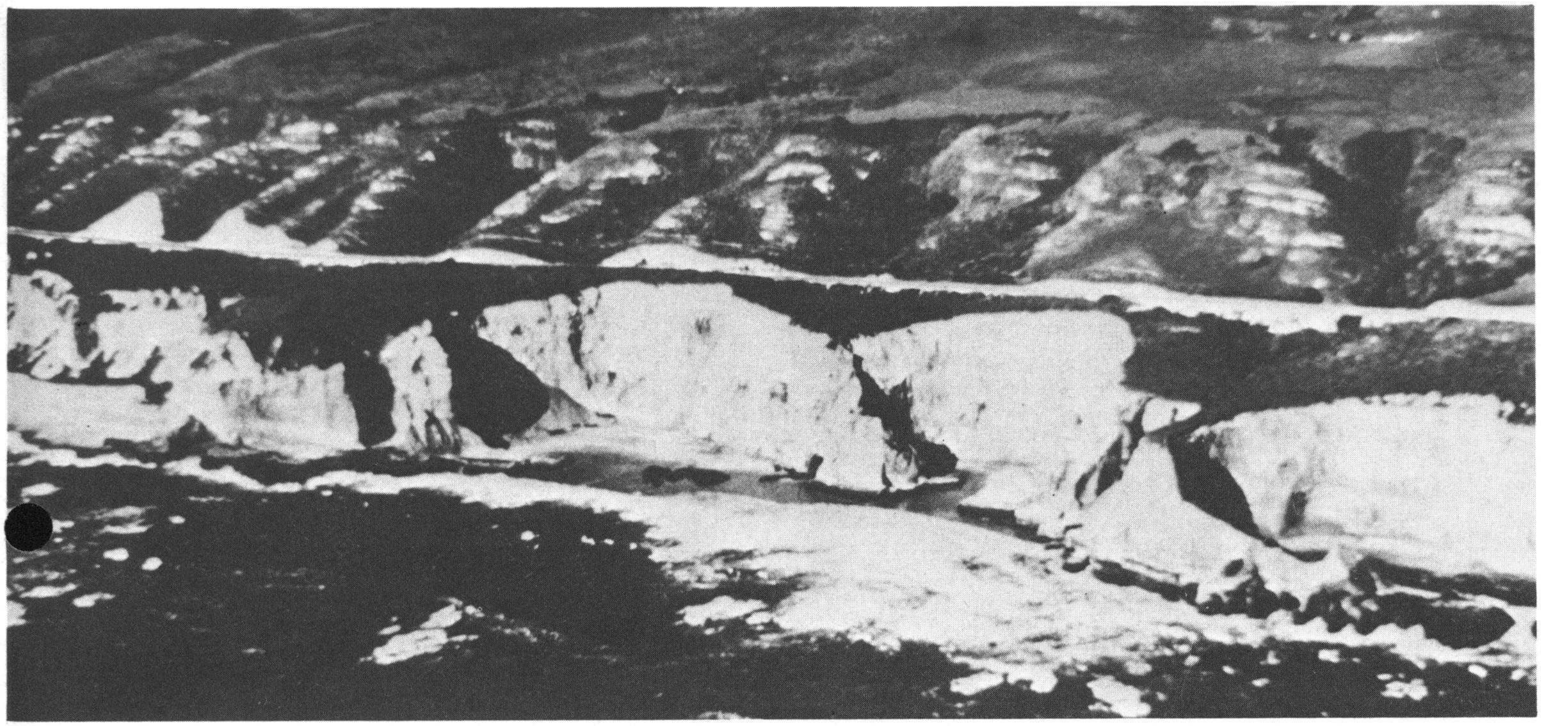
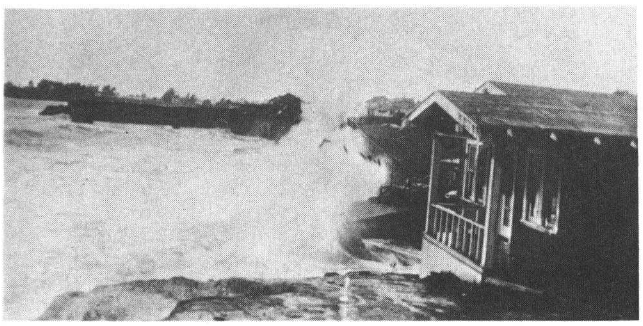
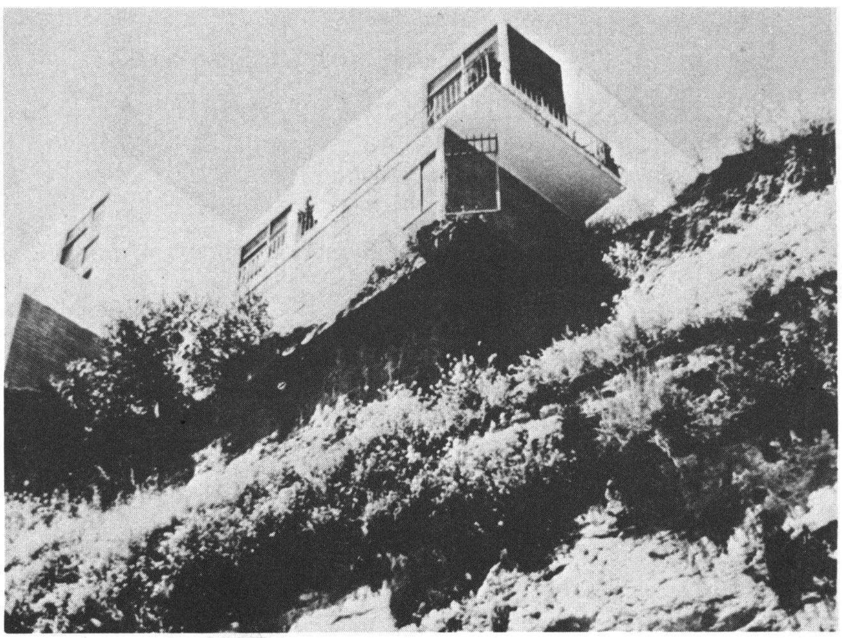




COASTLINE EROSION

Santa Cruz County



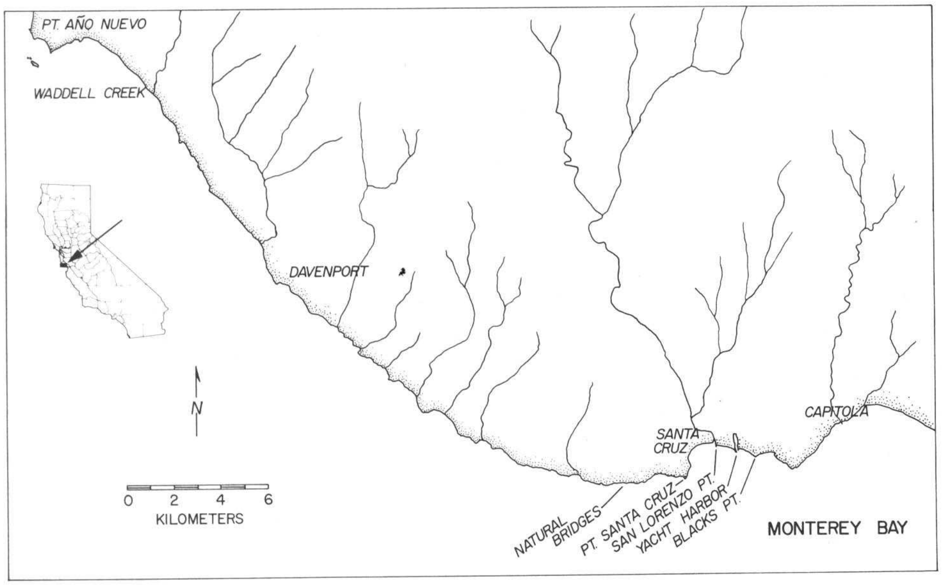


Figure 1. Coastline of northern Santa Cruz County.

COASTLINE EROSION

SANTA CRUZ COUNTY

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INTRODUCTION

The Tertiary sedimentary rocks exposed along the Santa Cruz coastline vary considerably in their resistance to erosion due to differences in exposure, degree of cementation, structure, and stratigraphy. The presence of joints, faults, and erodible stratigraphic units have led to average long–term erosion rates of about 30 centimeters (cm) per year or greater in some areas. Much of the erosion, however, is episodic, and occurs during major storms.

Considerable damage has occurred along the coast during past winter storms. Valuable beach–front property has disappeared, roads have been destroyed, homes have been undercut, damaged, or ruined. The 1977–78 winter storms produced damage, even though extensive shore protection devices had been installed.

GEOLOGY

The city of Santa Cruz lies on the northern edge of Monterey Bay along the central California coast (figures 1, 2). Uplifted marine terraces flank most of the northern bay and also the open coast to the north. The present seacliff varies in height from about 6 to 27 meters (m).

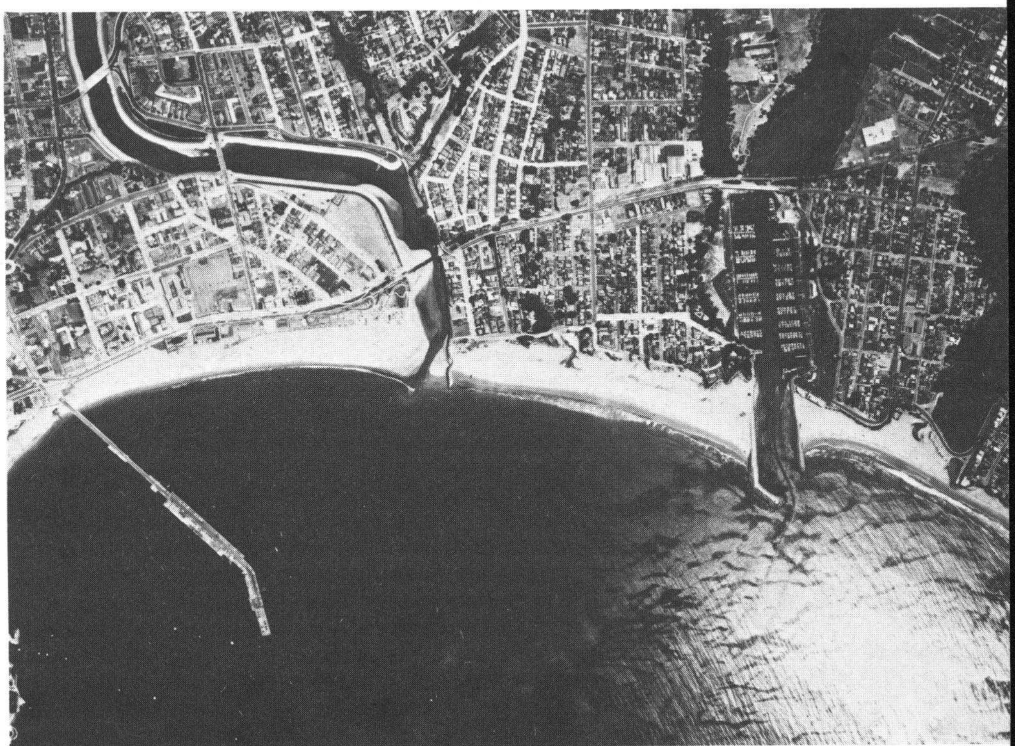


Figure 2. Aerial photo of the city of Santa Cruz on northern Monterey Bay, showing wide sandy beaches, San Lorenzo River, and small craft harbor. Note the wide beach to the west (left) of the harbor and the narrow beach to the east (right) of the harbor. *Photo by California Department of Fish and Game, July 1969.*

Figure 3. The seacliff along the northern portion of Monterey Bay. The Pliocene Purisima Formation (Pp), composed of siltstone, is capped by unconsolidated marine and nonmarine Quaternary terrace deposits (Qt). *Photo by G. B. Griggs*

The Mio–Pliocene Santa Cruz Mudstone and the Pliocene Purisima Formation (siltstone and sandstone) form the seacliffs throughout this area. These sedimentary rocks usually lie almost horizontal or dip gently seaward and are capped by 1.5 to 6 m of unconsolidated marine and non–marine Quaternary terrace deposits (figures 3, 4).

The Santa Cruz Mudstone is predominantly a diatomaceous siliceous mudstone. It is thin–to–thick–bedded and individual beds vary from several centimeters to a meter in thickness. Joints and fractures give most outcrops a blocky appearance. The large number of rockfalls and block landslides which occur in the mudstone indicate its susceptibility to failure on steep slopes such as canyon walls and seacliffs.

The Purisima Formation consists of thick bedded, poorly to moderately indurated siltstones and sandstones with occasional interbeds or lenses composed almost entirely of mollusk shells. This formation is jointed, faulted, and warped.

The influence of individual stratigraphic units within the Santa Cruz Mudstone and in the Purisima Formation on local geomorphology and erosion rates is significant.

EROSIONAL PROCESSES AND RATES

Coastal erosion or seacliff retreat is caused by both marine and terrestrial processes. Surf action is usually the dominant agent, producing both hydraulic (wave) impact and abrasion. The rate of seacliff retreat is dependent upon the following natural factors:

1) available wave energy and exposure (including the presence or absence of a protective beach at the base of the cliff)

2) lithology of seacliffs and their resistance to erosion

3) geologic structure including joints, faults, and folding

4) height of the seacliff.

Runoff and human activities are factors that can add significantly to the rate of cliff retreat.

Wave Energy

The oceanographic conditions which prevail along the central coast in the vicinity of Monterey Bay are well documented (National Marine Consultants, 1960; Yancey, 1968; Wolf, 1970; and Bradley and Griggs, 1976). Waves (both sea and swell) reaching this coastline come from all sectors of the northwest and west–northwest. The largest waves are caused by winter storms, and a significant number of these arrive in the arc between northwest and southwest. Deep–water waves with heights of 4.5 m can be expected five times a year, and those with heights of 6 m occur every 8 to 10 years (National Marine Consultants, 1960). The open coast north of Santa Cruz is directly exposed to these waves. Protective beaches are almost totally lacking except at the mouths of the small coastal streams.

Lithology

Seacliffs bear the brunt of the wave attack, although they are protected in some areas by shore platforms (figure 5). Shore platforms develop where bedding planes in the Santa Cruz Mudstone dip gently seaward, but are also found where dips are landward (Bradley and Griggs, 1976). At Natural Bridges State Beach, just north of Monterey Bay, the shore platform has formed by progressive erosion of the Santa Cruz Mudstone until a very resistant siliceous bed was encountered. This

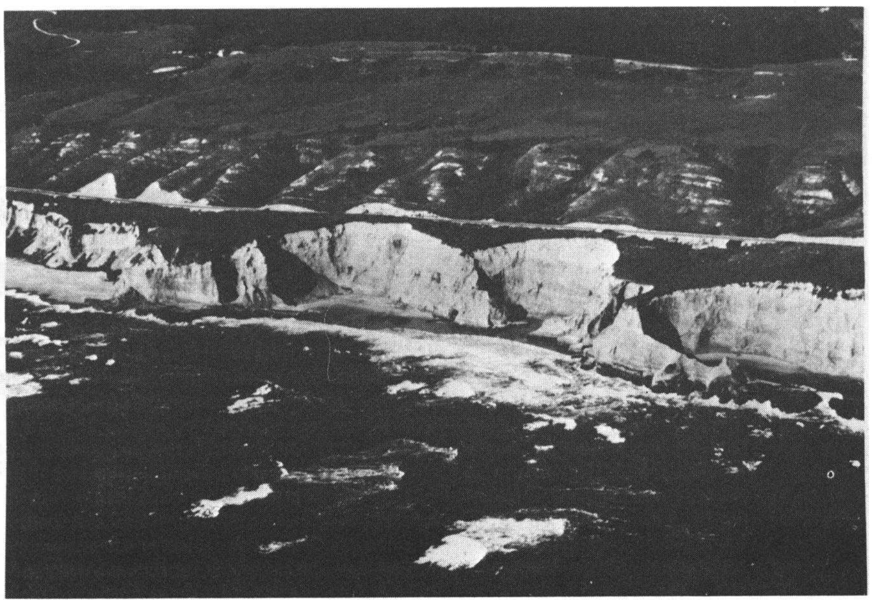


Figure 4. Coast of Santa Cruz County, north of Davenport. State Highway 1 follows the coastline. Tertiary sedimentary rocks form the steep eroded cliffs. *Photo by G.B.Griggs.*

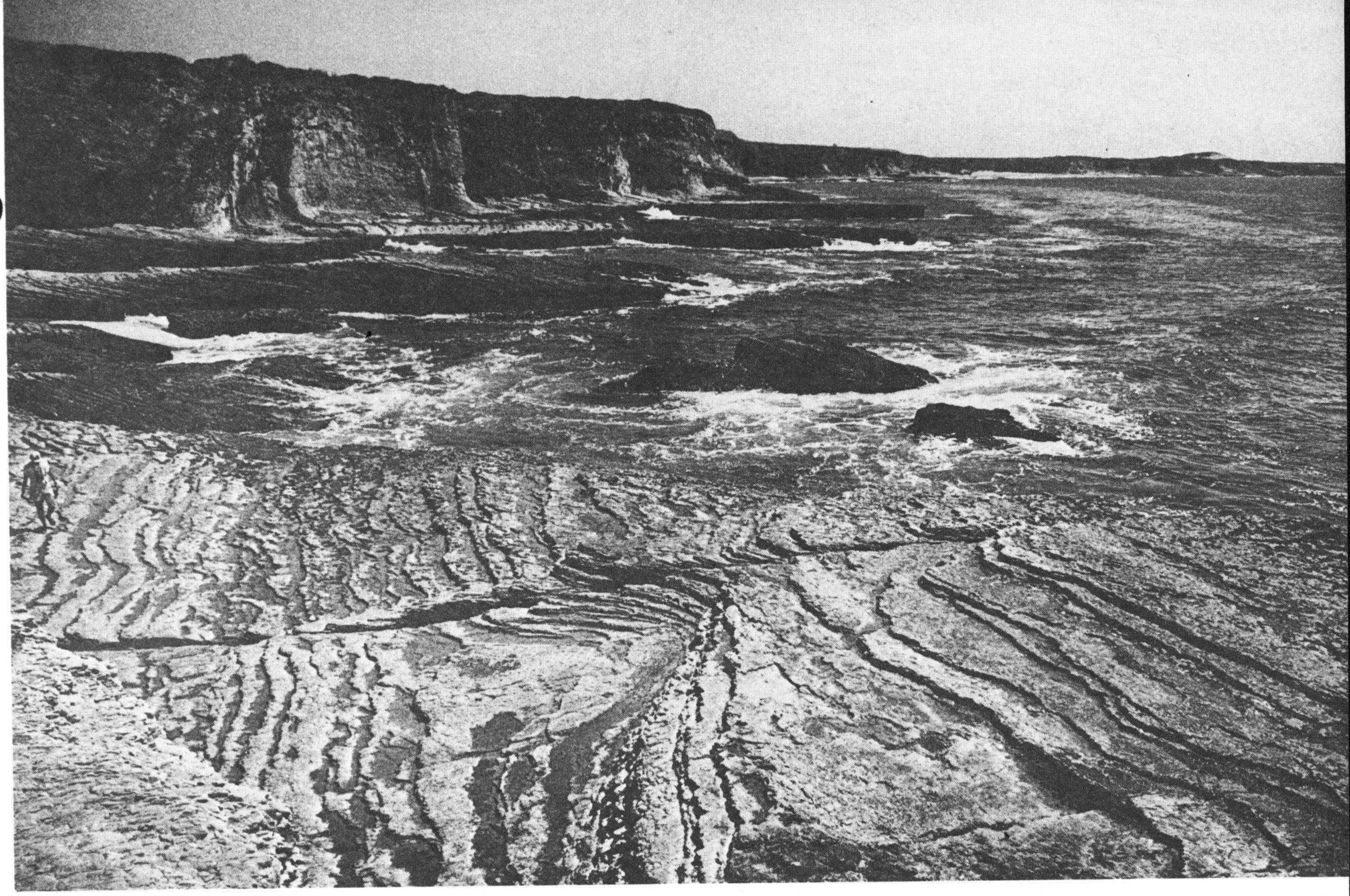


Figure 5. This coastal area is protected from wave action to some degree by a well-developed shore platform (foreground) formed by resistant beds in the Santa Cruz Mudstone. The formation dips seaward at this location just south of Davenport, Santa Cruz County. *Photo by G.B. Griggs.*

resistant bed in the nearly flat-lying mudstone forms the upper surface of the platform.

Despite the direct exposure to strong wave attack, the resistance of the Santa Cruz Mudstone to the hydraulic impact of the waves and abrasion generally has produced only moderate rates of coastal retreat (figure 6). Between the city of Santa Cruz and the town of Davenport, 16 km to the north, aerial photo measurements (by the authors) at 13 sites indicate average values of 0 to 21.5 cm/year of cliff retreat over a 20 year period. Periodically an arch or sea cave in the seacliffs will collapse, which locally produces rapid retreat of up to 24 meters in some instances (figure 7a, b).

Differences within the Santa Cruz Mudstone have locally altered both the rates and patterns of erosion. Sandstone

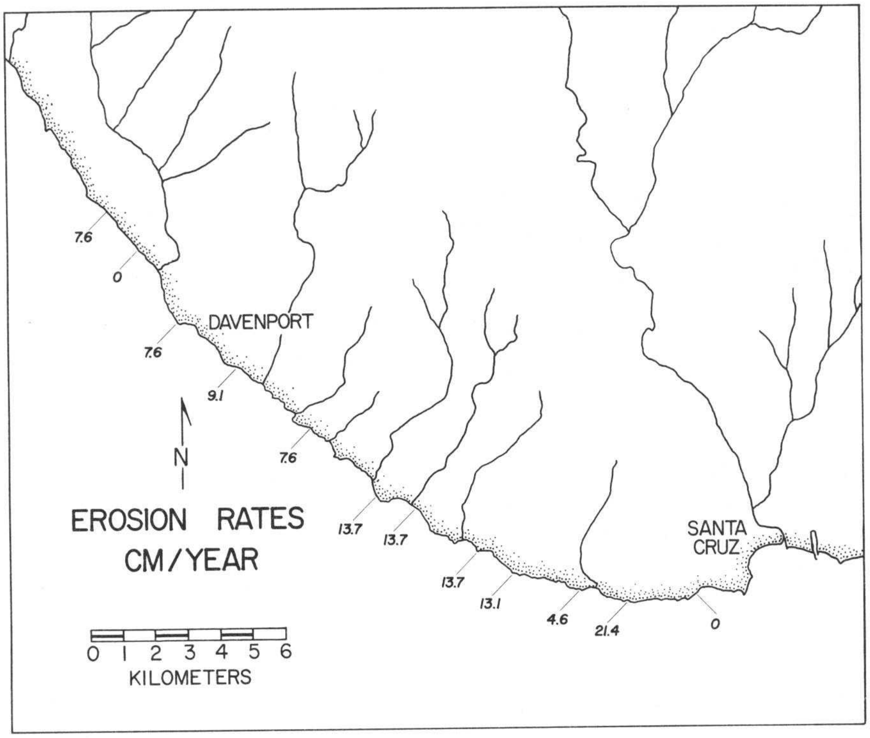


Figure 6. Average erosion rates along the northern coast of Santa Cruz County for the 20–year period 1943–1963. *Measurements by R.E. Johnson.*

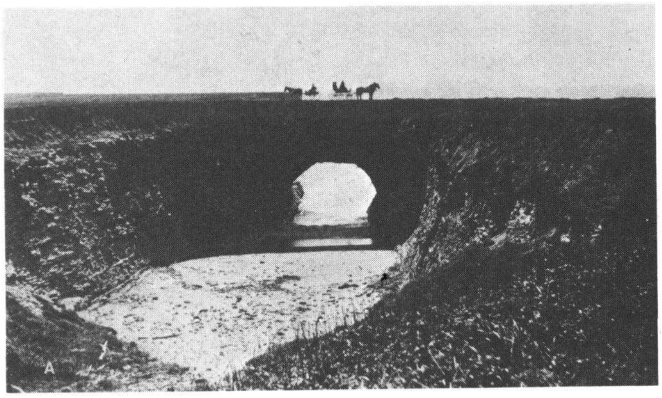


Figure 7. The collapse of an arch or sea cave in the cliffs along the coast contributes to the cliff retreat. A. This 1882 photo was taken at a site known as Wilder's natural bridge. B. The site of Wilder's natural bridge, 1973. *Photo by R.E. Johnson.*

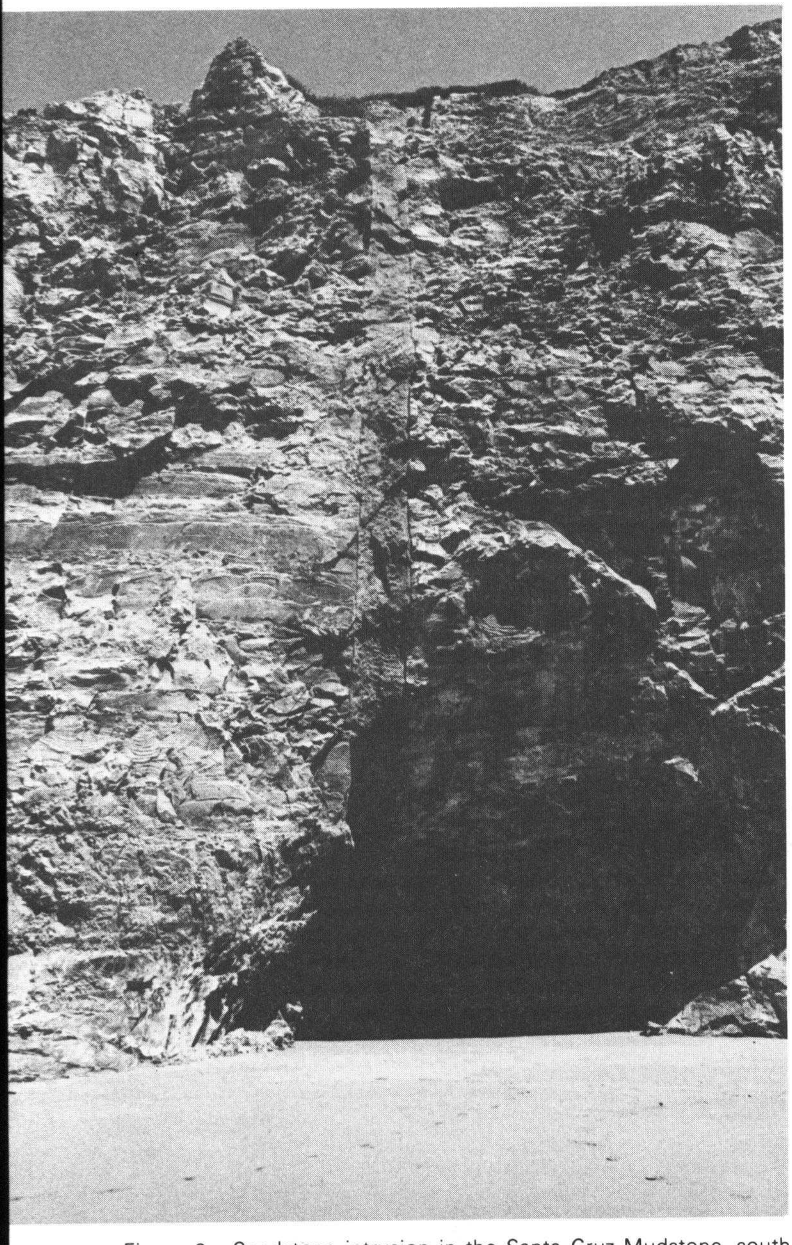


Figure 8. Sandstone intrusion in the Santa Cruz Mudstone, south of Davenport. The position of the intrusion has determined the location of the tunnel (dark area at lower right of photo). *Photo by G.B. Griggs.*

intrusions* commonly occur within the Santa Cruz Mudstone north of Monterey Bay. These intrusions probably were derived from the underlying Santa Margarita Sandstone, or possibly the sands in the older Monterey Formation. Many of the intrusions are saturated with hydrocarbons, and sandstone intrusions with both carbonate and ferruginous cement occur within the Santa Cruz Mudstone. Erosional resistance of the intrusions is dependent upon the size and location of the sandstone body, the nature of the contacts between the intrusion and mudstone, and the cementing agent. The location of erodible sandstone becomes a focal point for erosion and wave impact, creating arches, caves, and tunnels (figure 8). The differential resistance to erosion resulting from this lithologic heterogeneity has produced a variety of coastal landforms and consequently a scenic stretch of coastline.

Erosional resistance due to stratigraphic variation is very noticeable in the seacliffs, both within the Purisima Formation and along its contact with the overlying terrace deposits (figures 9, 10). Where unconsolidated or poorly indurated beds are exposed to surf action at the base of the seacliff, undercutting usually occurs in the form of notches, seacaves or arches, followed by collapse of the overlying material (figure 11).

Within Monterey Bay, the seacliffs are protected from direct wave attack. The predominant waves from the west–northwest are refracted almost 90° before striking the coast, and wide sandy protective beaches begin to appear. The coastal cliffs throughout most of the City of Santa Cruz are composed of erodible sediments

* Intrusion structures, such as sandstone dikes or sand volcanoes, are produced by the forcing, under abnormal pressure, of a sedimentary material into a preexisting deposit or rock, either along some plane of weakness or into a preexisting crack or fissure. Abnormal pressure can be caused by movement along a fault, hydrostatic pressure, or gas pressure.

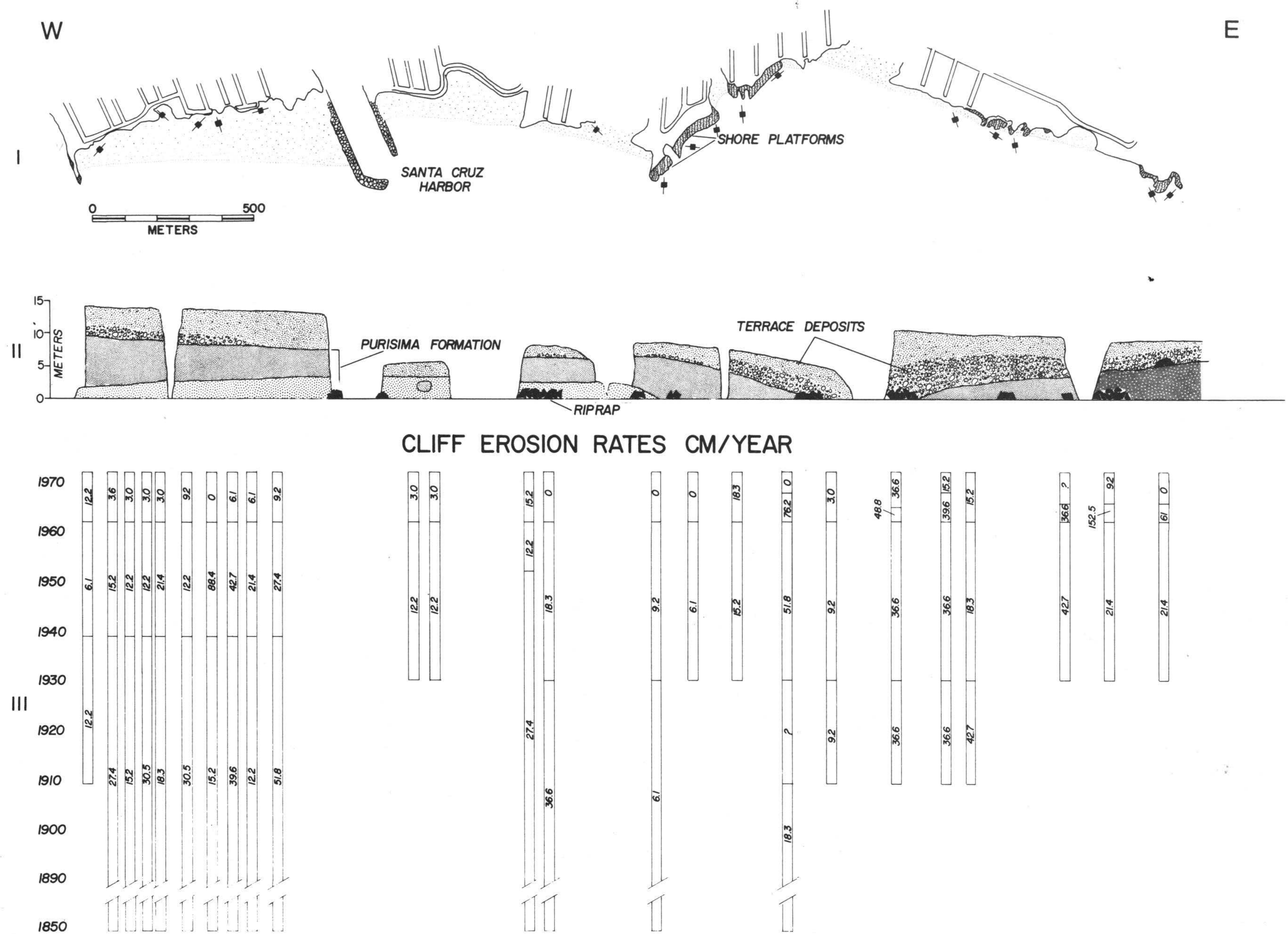


Figure 9. Plan view (I), cross section (II), and long term average erosion rates along northern Monterey Bay from San Lorenzo Point to Soquel Point (III). Note joint orientations on plan view and variations in elevation of terrace surface on cross section. Erosion rates are shown for specific intervals for which control exists.

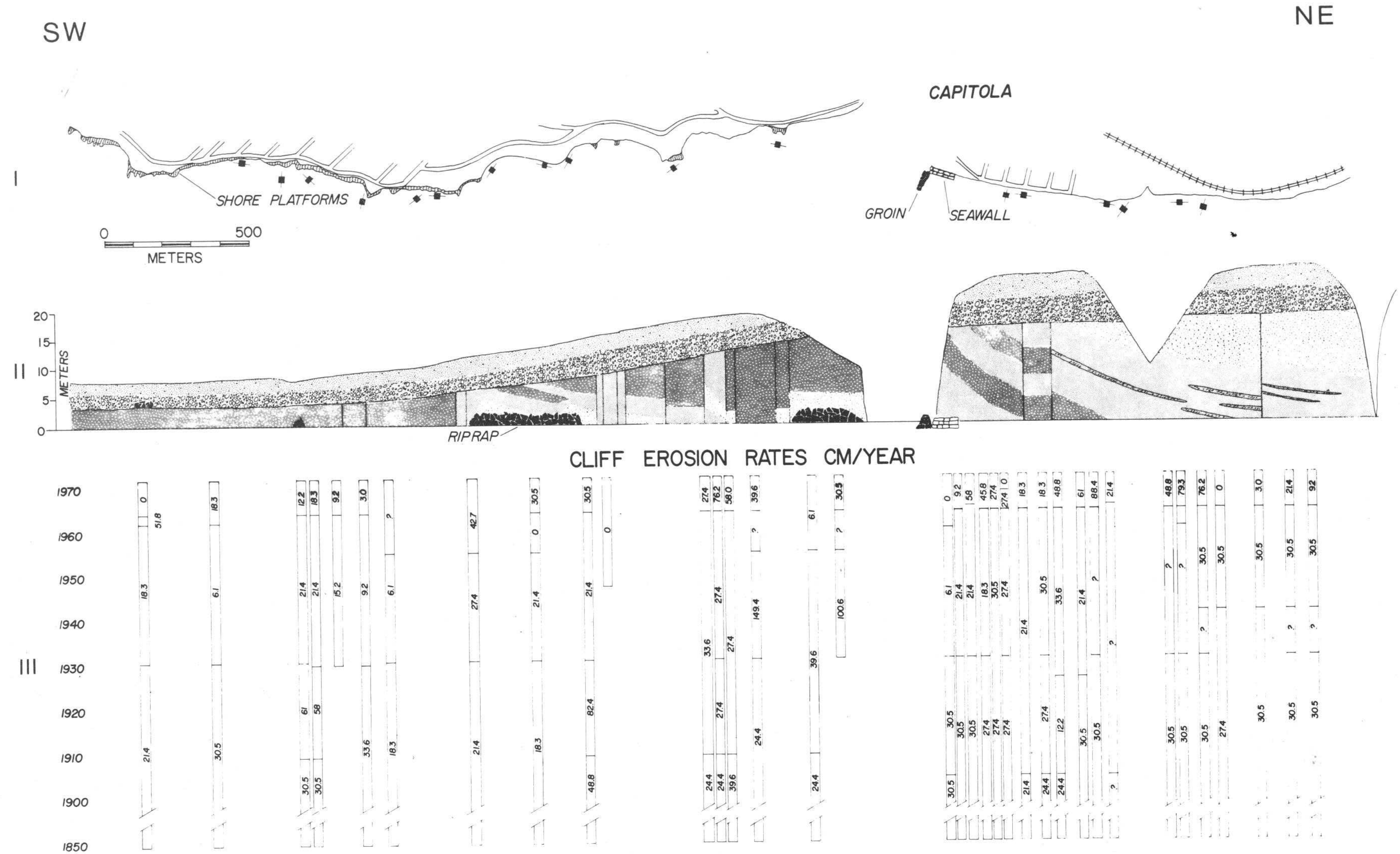


Figure 10. Plan view (I), geologic cross section (II), and long term average erosion rates along northern Monterey Bay from Soquel Point to Capitola(III). Note joint orientations on plan view, variations in elevation of terrace height, faulting in the bedrock, and shell horizons within the Purisima Formation. Erosion rates are shown for specific intervals for which control exists.

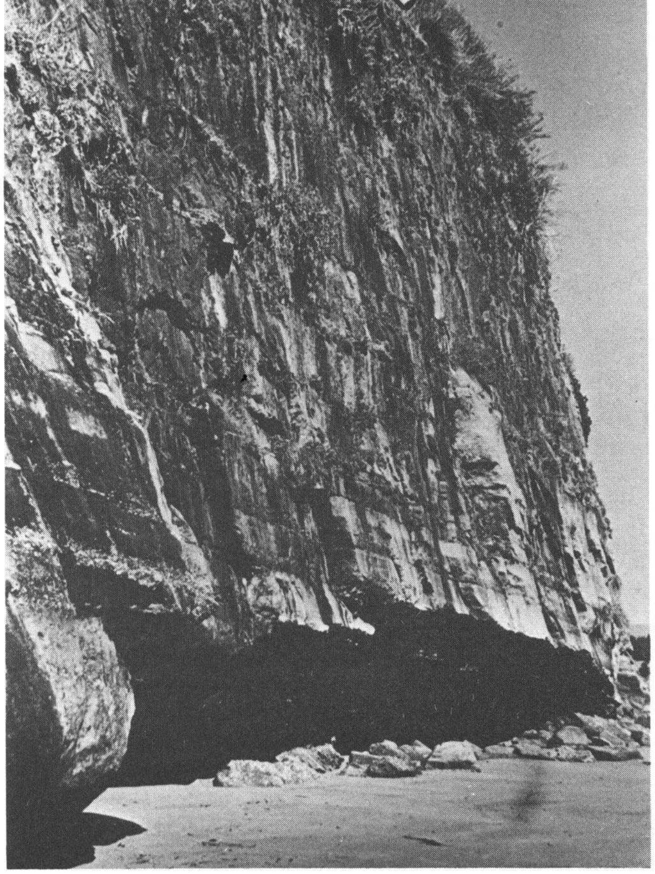


Figure 11. Erosion of a weak stratigraphic unit within the Purisima Formation near Capitola has undercut the seacliff. *Photo by R.E. Johnson.*

of the Purisima Formation. Rapid erosion has cut back the cliffs, changing the trend of the coastline and creating the embayment known as northern Monterey Bay. Although the bay configuration protects this area from direct wave attack, erosion rates in these sandstone and siltstone beds (Purisima Formation) are still greater than the rates in the Santa Cruz Mudstone along the open coast to the north. The erosion rate of the Purisima Formation is influenced by the varying hardness of different lithologic units within the formation, the orientation of well developed joint sets, and the presence of faults (figures 9, 10).

The unconsolidated deposits which lie unconformably on the marine terrace that forms the top of the present day seacliff are exposed to surf action where the terrace has been extensively downwarped (figures 9, 10). In these locations, the bedrock portion of the cliff may be 1.5 to 3 m high, or less, leaving little resistance to wave action. In these cases, the terrace deposits are usually stripped off the platform, and cliff retreat is rapid, up to 50 cm/year.

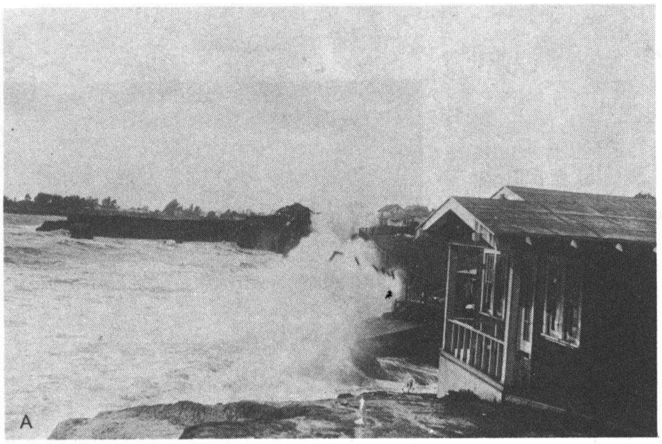
Structural Influences

Faults affect erosion rates in two ways. First, they act as zones of weakness along which erosion is accelerated. This is common in the Santa Cruz Mudstone north of Monterey Bay. A number of faults oriented perpendicular to the coastline have led to erosion of embayments trending in the direction of fault strike. Inside the bay, numerous faults have juxtaposed lithologic units within the Purisima Formation which have varying resistance to erosion. Much of the local coastal geomorphology can be ascribed to this process. Directly up and downcoast from Capitola average erosion rates in weak units in the surf zone were as high as 1.5 m/year. The promontories which form natural littoral drift barriers are a result of a resistant bed being present in the surf zone along sub–parallel faults between less resistant material. Measured erosion rates at these points are low relative to adjacent areas.

Seacliff Height

Cliff height sometimes exerts an indirect control on erosion rates. The quantity of material produced by a given amount of coastal retreat is a direct function of cliff height. For example, cliffs have been undercut and have subsequently failed, and large blocks have broken out along joint sets and fallen to the beach below (figure 12). To the extent that this material remains in place at the foot of the cliff, it serves as temporary riprap to buffer the cliffs from direct wave attack. However, the large sandstone and siltstone blocks produced by breakdown of the Purisima Formation last only a few years in the surf zone.

Figure 12. Large blocks of sandstone and siltstone have fallen to the beach due to failure along joint sets and undercutting by surf action. Note person on right side of photo for scale. *Photo by R.E. Johnson.*



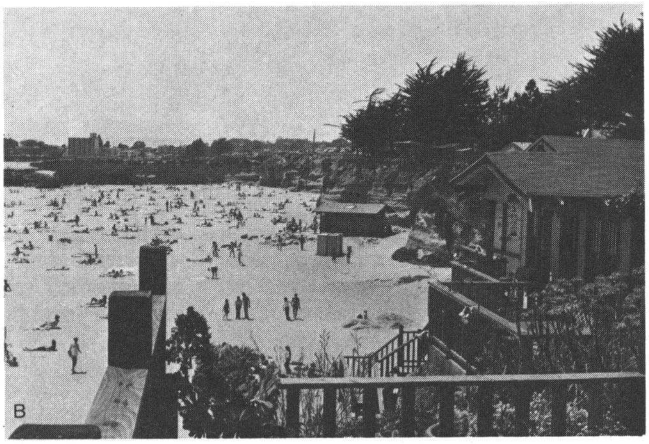


Figure 13. Jetties constructed as a part of the Santa Cruz small craft harbor have had an effect on coastal erosion processes in northern Monterey Bay. A. Seabright Beach (between San Lorenzo River and harbor) during a 1925–26 winter storm. *Photo by Dorothy Miller.* B. Same view, summer 1976. Waves from winter storms no longer attack the low cliffs (background) due to the protective beach built up against the west jetty of the harbor. *Photo by Ann Carlson.*

IMPACT OF COASTAL EROSION

Human Activities

Human activities can affect natural rates of coastal retreat. Those actions which have been the most widely observed and documented are those which lead to the formation of a beach or loss of protective beaches. The construction of groins,* jetties, and breakwaters are good examples of manmade structures that alter beach–shore conditions. In addition, intervention at the top of the seacliff can produce direct increases in cliff failure.

Two jetties constructed as part of the Santa Cruz small craft harbor have had an effect on coastal processes in northern Monterey Bay (Griggs, and Johnson, 1976). A broad protective upcoast beach formed where severe erosion (up to 90 cm per year) had been occurring (figures 2, 13a, b). The interruption of littoral drift and loss of sand downcoast led to increased erosion, and private property owners had a buffer of riprap placed to prevent erosion along the ocean front. At Capitola, several miles downcoast, a groin was constructed to trap sand moving downcoast in order to form a protective beach. The existing beach disappeared following the upcoast construction of the harbor at Santa Cruz. The downcoast side of the groin is devoid of a beach and is adjacent to a vertical concrete wall which encloses a sewer pumping station. The lack of sand, combined with the concentration of wave energy immediately downcoast from the retaining wall, produces above average erosion rates (figure 10).

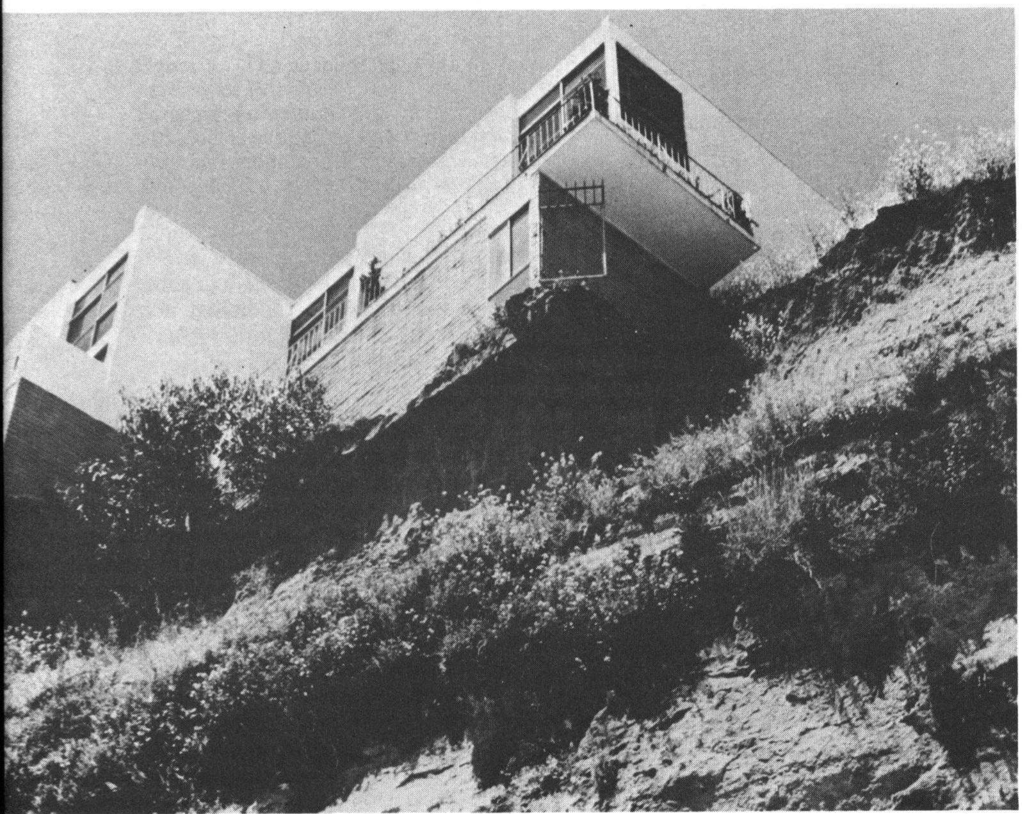


Figure 14. This seacliff in the Purisima Formation is jointed and erodible. Severe cliff retreat has undercut the foundations of buildings along the coast in the Capitola area. *Photo by G.B. Griggs.*

The stretch of coast from Capitola Beach southwestward to New Brighton Beach (figure 10) is composed of well-jointed erodible beds within the Purisima Formation. The combination of erodible material and lack of a significant protective beach has led to severe cliff retreat along 1.5 km of ocean front. The lack of a protective beach is due to the fact that the cliff line is oriented in a direction conducive to high rates of littoral drift, and also because there is no structure downcoast to trap littoral materials. The average erosion rate in this area over the past 100 years has been about 30 cm/year. In the last 5 or 10 years, rates of 45 to 90 cm/year have been occurring (figure 10). As a result, the foundations of apartment

* A low, narrow, rigid barrier or wall constructed of timber, stone, concrete, or steel, usually extending roughly perpendicular to the shoreline.

Figure 15. Riprap has been placed at the foot of the low cliff to retard coastal erosion. *Photo by R.E. Johnson.*

buildings on the seacliff have been gradually undercut, leaving portions of the concrete foundations unsupported (figure 14). A similar failure continues to occur in the area; the exceptionally severe storms of the 1977–78 winter caused numerous failures along this stretch of coast. No structures were immediately endangered during the 1977–78 winter but some may be endangered within 5 to 10 years.

Vehicle traffic along a road located at the top edge of the seacliff, the saturation of the cliffs by storm drain discharge, and the wedging action of tree roots along joint sets have all contributed to rapid cliff retreat in this area. Although vegetation may serve to stabilize steep slopes in some locations, deep rooted plants may actually increase erosion along near–vertical seacliffs.

In an area of naturally high erosion rates, the effects of human activity have accelerated cliff retreat even more. Human habitation of the bluff top and along the back beach itself is nearly continuous along much of northern Monterey Bay. Although many of the cliff–top residences may have been initially built with some setback from the cliff edge, continued erosion has threatened many of the homes and led to the expenditure of hundreds of thousands of dollars to place protective riprap (figure 15). However, even this precaution does not insure permanent protection from surf action. Undercutting and settling necessitates periodic replenishment of riprap at additional cost. Effects of reflected or altered wave action in transferring damaging erosion to adjacent unprotected properties can also be a serious problem.

1978 Storm Damage

Continued heavy wave action, combined with high tides, during January of 1978 caused severe damage to a number of beach–front residences along northern Monterey Bay south of New Brighton Beach. Most of these houses were built within the last 10 to 15 years at the base of a seacliff on a back beach area. Although a 30 to 60 m wide beach normally protected the homes, the severe wave action of the storm and high tides removed the entire beach, undermined foundations, broke glass windows, and led to the loss of decks, patios, stairways, and landscaped front yards. One residence with a shallow concrete wall foundation partially collapsed as the foundation was undercut. Although this beach is normally in equilibrium, it is only a matter of time

Figure 16. Railroad track embankment 1 km south of Davenport. Heavy rain and runoff during the winter of 1973, combined with surf action, undercut this track built across a cove. *Photo by G.B. Griggs.*

before the 50 or 100 year storm will totally remove the beach and destroy these homes.

Episodic Seacliff Retreat

Numerous observations indicate that major cliff retreat occurs episodically when large blocks fail or collapse due to undercutting or weakening. Much of this activity occurs during severe storms when wave action is intense and the cliffs are weakened by saturation from rainfall and runoff.

Although the overall long term erosion rates in the Santa Cruz Mudstone along the exposed coast northwest of Santa Cruz are relatively low, episodic seacliff retreat in certain places has led to problems. Near the town of Davenport heavy rains and runoff during 1973 combined with surf action to undercut the Southern Pacific Railroad track. A cove was extended landward, leaving about thirty feet of train track suspended in mid–air (figure 16). Farther north, in the vicinity of Waddell Creek, State Highway 1 has been constructed on fill at the base of high, steep cliffs in intensively fractured Santa Cruz Mudstone. A resistant bed in the surf zone has acted as a natural groin to trap littoral drift upcoast, forming a protective beach. The road–fill on the downcoast side was unprotected and rapidly eroded until protective riprap was emplaced.

SUMMARY

In the aftermath of the 1977–78 winter storms, individuals and groups of homeowners are applying to local government for permission to install riprap, bulkheads, and seawalls in a variety of sizes and shapes. The expenses are considerable and the secondary effects of such protective structures are not always known or understood. Local planning agencies are working to develop a uniform plan of coastal protection. The California Coastal Commission (CCC) has the authority to make decisions on such proposals in addition to planning ahead for future land usage.

The coastal zone is one of the earth's most dynamic environments and is also one of the most heavily populated. The present geomorphic processes and landforms, and the past record of coastline changes, need to be carefully considered before any new coastal construction occurs. Long term average erosion rates must be understood and used with caution; the nature of episodic cliff retreat, whereby rapid erosion occurs during the infrequent large storms, must be kept in mind.

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