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COASTAL EROSION ALONG OCEANSIDE LITTORAL CELL, SAN DIEGO COUNTY, CALIFORNIA

by

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Abstract

During the past two decades there has been a tremendous boom in land development along the cliffs at the seaward margins of the coastal terraces of San Diego, particularly to the north of La Jolla. Until the enactment of the California Coastal Zone Conservation initiative in 1972, local agencies permitted construction of single-family residences and multiple-unit residential structures within feet of the bluffs and on the beach. Developers justified the building by citing that studies had showed that none of the sea cliffs were retreating at an appreciable rate. What was overlooked was that these low retreat rates were based on the experience of the last 25 or 30 years which was an unusually benign period characterized by low rainfall and very few storms capable of producing heavy surf in the area. Earlier studies of coastal erosion in the area provided a far less optimistic picture of the stability of sea cliffs, but these were either overlooked or discounted.

In 1889, during a wet and stormy period which lasted from 1884 to approximately 1893, the United States Coast and Geodetic Survey (U.S.C.G.S.) conducted topographic and bathymetric surveys along the San Diego County coastline. Their topographic notes for the year 1889 indicate that the bluffs showed " ... new erosion during each winter storm as the characteristic feature of this coast." Years later Hanna (1926, p. 233) noted

(Shepard; R/NP-1-9G) (Shepard; R/CZ-43A)

that the cliffs north of La Jolla were actively retreating during the wet and stormy years of the 1920's. Vaughan (1932) reported that alluvial bluffs near Scripps Institution of Oceanography in La Jolla retreated 10 to 20 feet between 1923 and 1930. Shepard and Grant (1947) found erosion at the same site occurring at a rate of about 1 ft/yr during the stormy period that preceded 1947.

From various sources summarized in Shepard and Wanless (1971, p. 265) there are indications that cliffs of Eocene and Cretaceous slightly dipping strata have retreated episodically due to large rock falls, although the rock cliffs in many places showed no indication of retreat possibly because photographic records were begun only a half-century earlier..

The stormy period including high rainfall levels that began in early 1978 has changed the picture considerably, especially on the beaches and along the bluffs north of Del Mar (Figure 1) and extending to Oceanside where much building has been done on the low terrace close to the bluff edge in recent years. The alluvial cliffs near Scripps Institution in La Jolla, which had appeared to stabilize after 1947, became active areas of erosion once again during this period.

Beginning in 1973 Kuhn (1977) has made extensive and continuing studies of the coastal erosion in the area from La Jolla to San Onofre State Park, a section of coastline about 60 miles in length, including repeated measurements and phitographic coverage of critical points. Kuhn has also investigated the erosion history of the area through a search of old maps and land ownership records, as well as interviews with long-time residents whose families have inhabited the coastal areas for generations. Many of these personal accounts of historical erosion have been verified

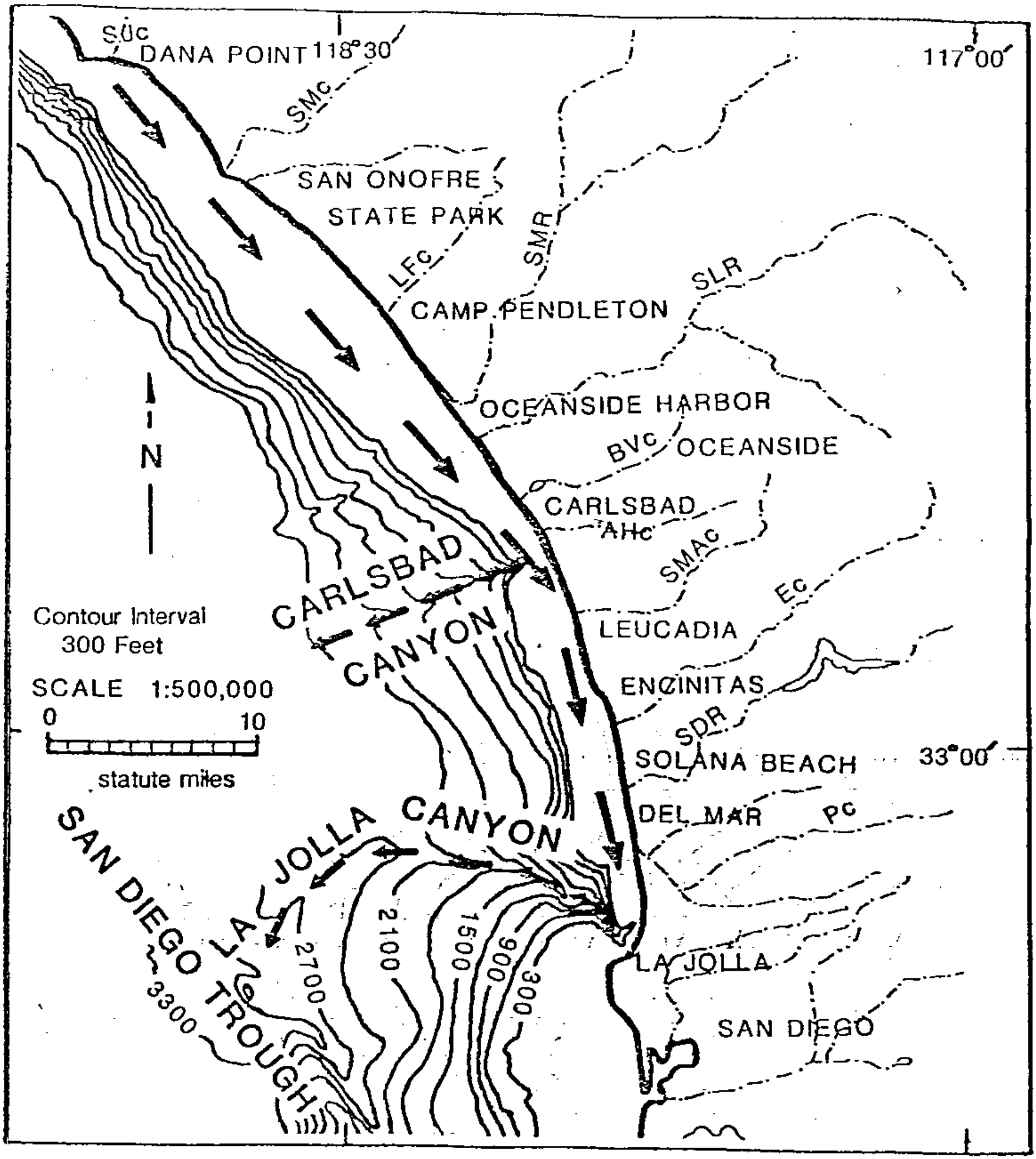


Figure 1. Location map. Arrows indicate predominant longshore sand transport current direction.

by examination of old newspaper files, historical maps and weather bureau reports of the same storms reported by the residents.

Thus it appears that erosion of the sea cliffs, bluffs and canyon heads is episodic, site specific, directly related to prevailing meteorological conditions and, in recent years, to man's altering of natural drainage patterns.

Introduction

Coastal hazards management is of utmost importance to regulatory agencies, lenders and developers, as well as the general public. Erosion within the coastal zone is both natural and man-induced. This report places emphasis upon the role of man-induced processes and their impact on accelerating erosion rates. The following case histories document man's impact on the Coastal Zone along San Diego County.

Artificial Coastal Protection

Construction intended to protect the coast, such as groins, jetties, concrete or sooden seawalls, riprap and rock debris, as well as concrete lifeguard towers and buildings, are located along the cliffed shoreline of San Diego County. The erosive effects of improperly located artificial protection and other structures have not been fully understood, especially during periods of large storms and high tides. It has been observed that where such protective measures project or extend seaward beyond adjacent unprotected lots, there is immediate erosion and notching of the unprotected lots (Kuhn and Shepard, 1979). As beach sand levels fall, storm waves converge on projecting structures and the waves refract toward unprotected lots.

A classic example of this occurred in 1905, affecting the low-lying cliffs at Coronado, San Diego County, California (Figure 2.A) (Shepard and Grant, 1947). This erosion was produced by large waves, but an underlying cause may have been the building of the 7500-ft-long Zuniga jetty the year before along North Island in San Diego Bay. In 1905 wave attack during winter storms produced the disastrous effects seen in Figure 2.B. More than 110 ft of the beach cliff was eroded in March of that year.

Recent examples have also occurred along the San Diego County shoreline, as described below.

Del Mar. Houses have, in recent years, been constructed directly on the beach sand (Figure 3.A). During the winters of 1978-80 storms at sea, coupled with river flooding, caused erosion of the beach and houses were endangered at Del Mar (Figure 3.B) (Kuhn and Shepard, 1980).

During storms of January through April 1978 and February 1980 beach sand levels dipped to a very low point, storm waves and high tides undercut the slope toe, and unprotected lots located adjacent to artificial projections were eroded landward in a short period of time (Figure 4).

La Jolla. Because of heavy rainfall in early 1978, cliffs that had been relatively stable were subject to considerable retreat. A notable example is the low Quaternary alluvial cliffs south of Scripps Institution of Oceanography which seemed to have stabilized during the dry period from 1947 to 1977 (Figure 5.A). The series of homes built along the edge of these low cliffs, mostly without seawalls or any protection, were subjected to erosion in January and February 1978. As the rains continued and the beaches were washed out by a combination of

Figure 2. A. (Before) View looking south toward the Hotel Del Coronado, San Diego, California. January 2, 1905; photo: U.S. Grant

B. (After) Photograph of same area taken March 17, 1905 after severe storms eroded more than 110 ft of beach cliff sediments. 30,000 sandbags were placed north and south of hotel. Photo: U.S. Grant IV.

Note: Ocean Boulevard vanished all the way back to curb in front of homes in photo.

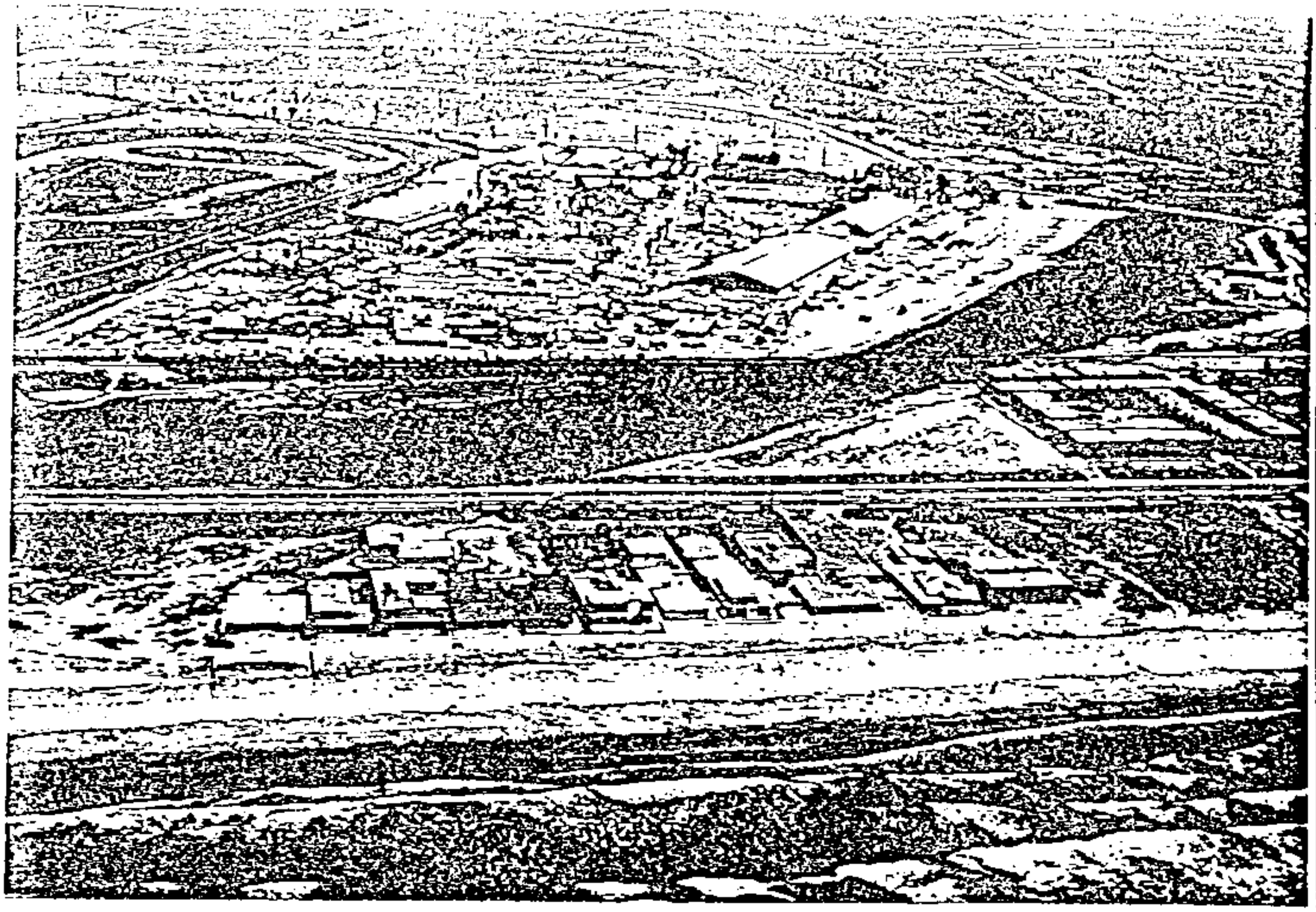


Figure 3. A. 1974. View of Summer Beach at Del Mar, California. Photo: B and A Engineering. Note: Del Mar fairgrounds located in San Dieguito River floodplain.

B. 1980. Winter (February) view of same area at Del Mar as in Fig. 3.A. Photo: SIO/OLR - L. Ford. Note: San Dieguito River is open to the sea during a stormy period and beach is being eroded.

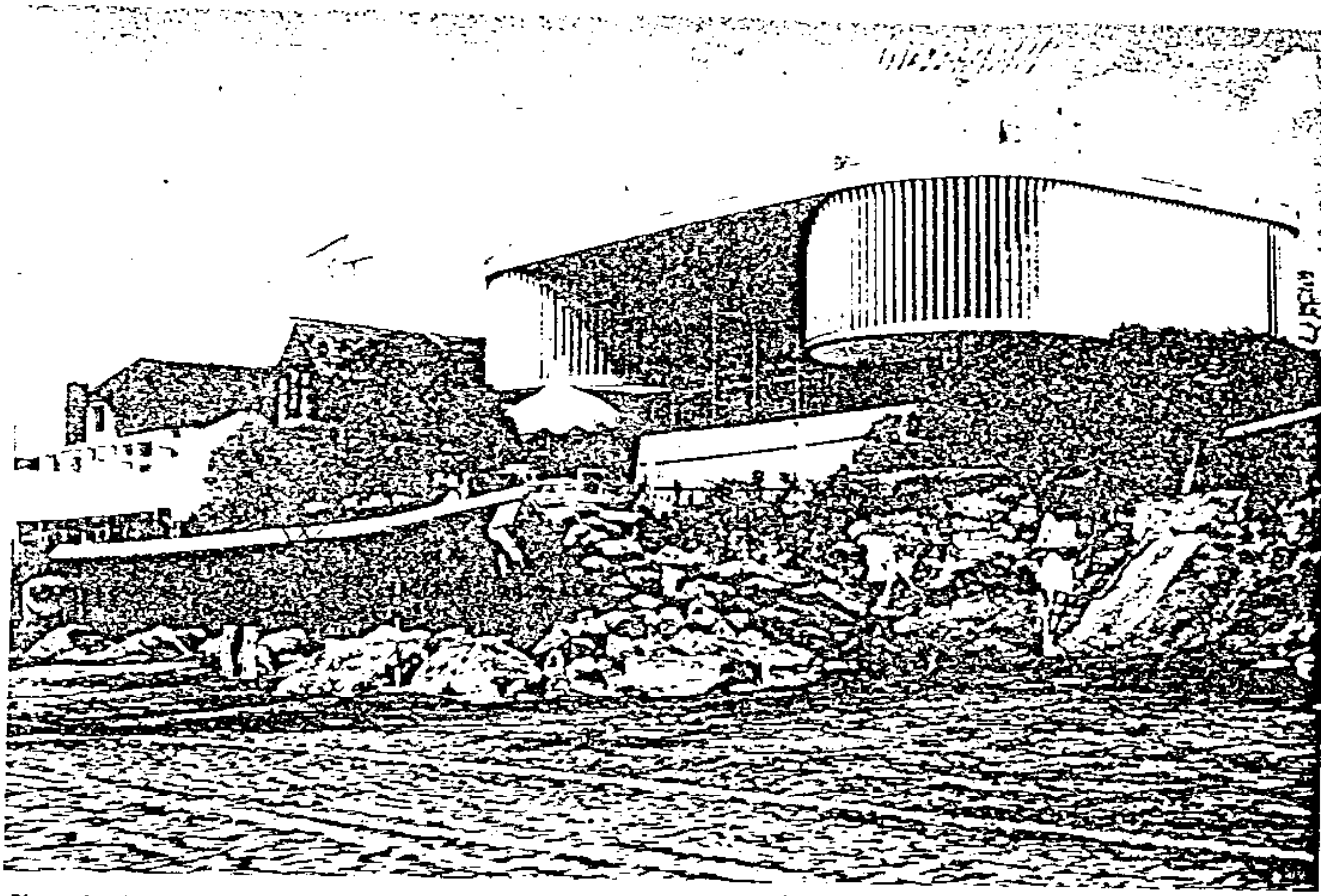
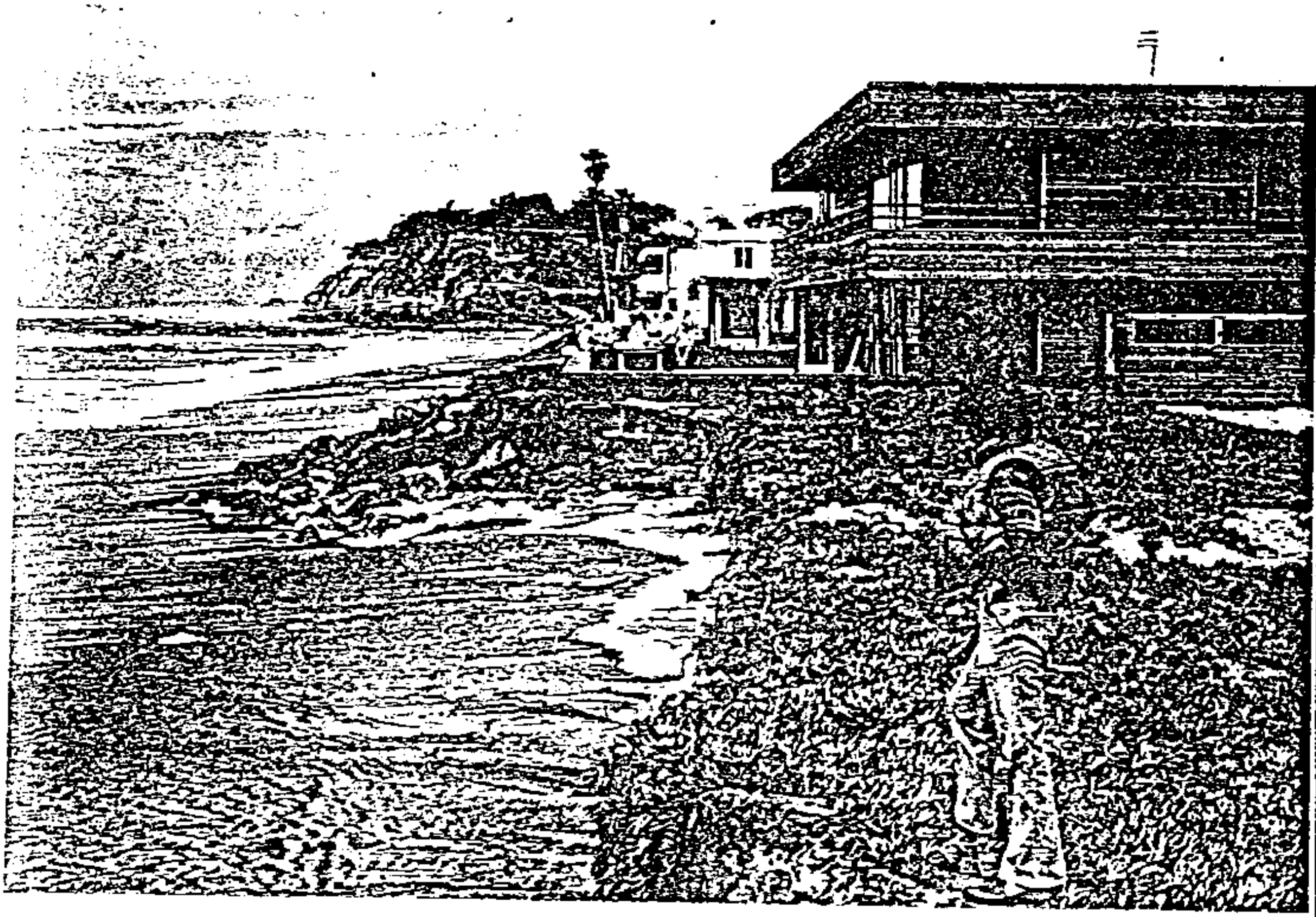
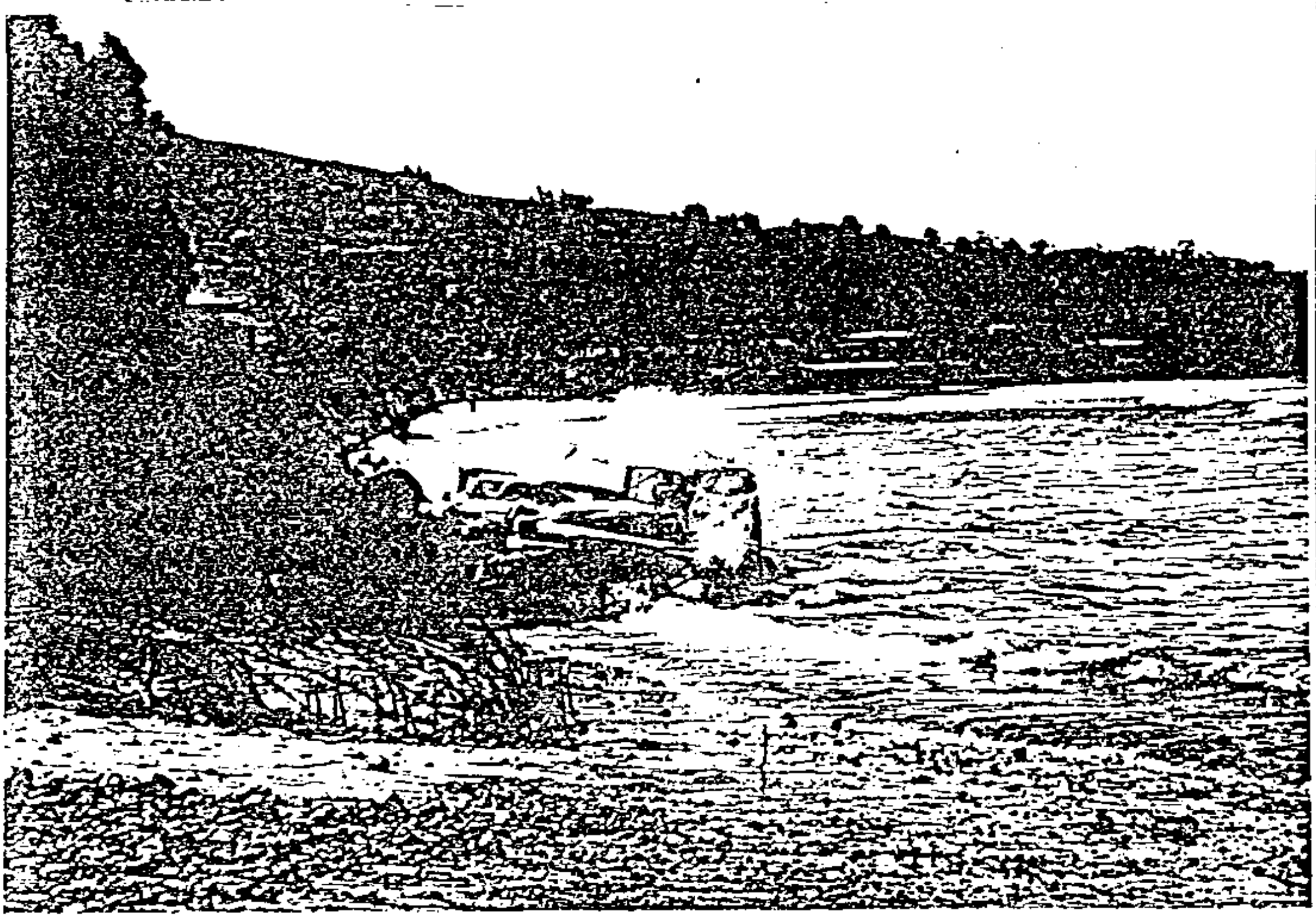


Figure 4. A. March 1978 view of eroded beach at Del Mar, California. Wooden seawall collapsed and adjacent unprotected lots were eroded. Photo courtesy of Sea Grant/G. Kuhn: March 5, 1978.



B. February 1980 view of beach erosion at Del Mar, California. Photo: G. Kuhn. Note: Concrete dumped on beach in front of house accelerated erosion of adjacent unprotected lots.

Figure 5. A. 1938 view along eroding cliffs south of Scripps Institution of Oceanography at La Jolla Shores, California. Photo: F. P. Shepard.



B. Same general location as 5.A. Automobiles were driven onto beach and left in front of one residence in effort to slow erosion along the slope toe. Autos were scattered and doors were ripped off during period of 2-m high waves January 24, 1978. Photo: Sea Grant.

storm surf and high perigean spring tides, as well as by rain gullying, erosion again occurred along these cliffs. The residents were threatened with loss of their property and went to desperate measures to stop the erosion. Old car bodies were placed at the slope toe in one case (Figure 5.B) and later riprap was placed at these sites and cemented in place, and temporary seawalls were installed. This was only partially successful as the houses had to be reinforced in various places to prevent their collapse. Adjacent unprotected lots were even more severely eroded during the storm period (Figure 5.C). In 1979 a concrete seawall was constructed along most of this area (Figure 5.D).

It is increasingly apparent that where buildings or structures of any kind are located on the beach, measures must eventually be taken to protect them from wave attack (Figure 6).

Historical Wide Beaches

Prior to 1900 the sandy beach served as the most heavily traveled "highway" along the California coast. During the 1880's the coastal sand beaches varied in width from 100 to 300 ft. The U. S. Coast and Geodetic Survey (1889) noted that "... from Mussle Rocks [Bathtub Rock at Torrey Pines] there is an unbroken sand beach for forty or fifty miles or as far north as the valley of San Juan Capistrano and in former times this stretch of beach was used whenever specially fast time [was] to be made on the route Los Angeles, via Capistrano, to San Diego." These wide, sandy beaches existed along the shore until the early 1940's.

Dams, Harbors and Floodplains

Today the formerly wide and sandy beaches south of Oceanside have, for the most part, been replaced by beach cobbles resting on exposed

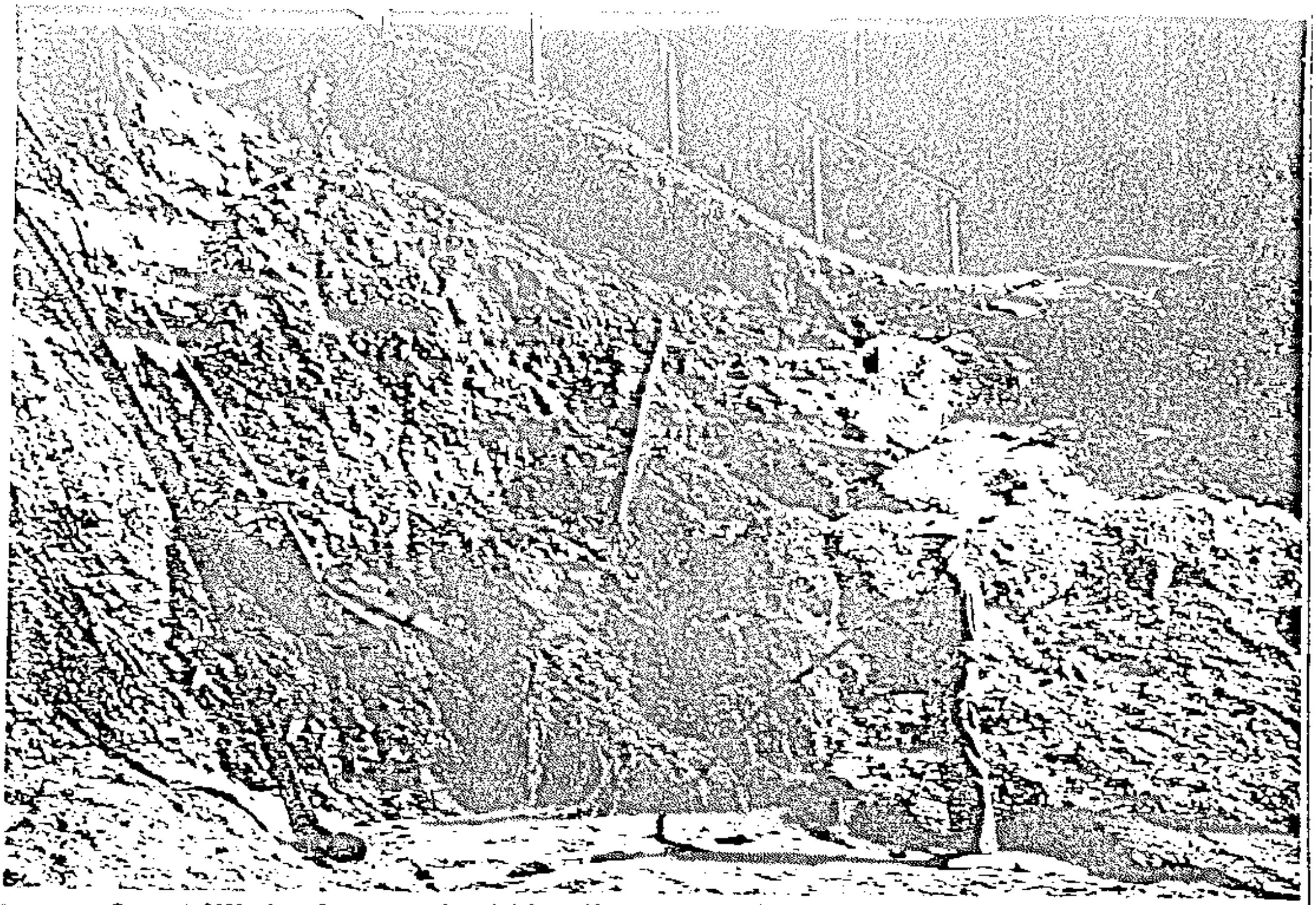
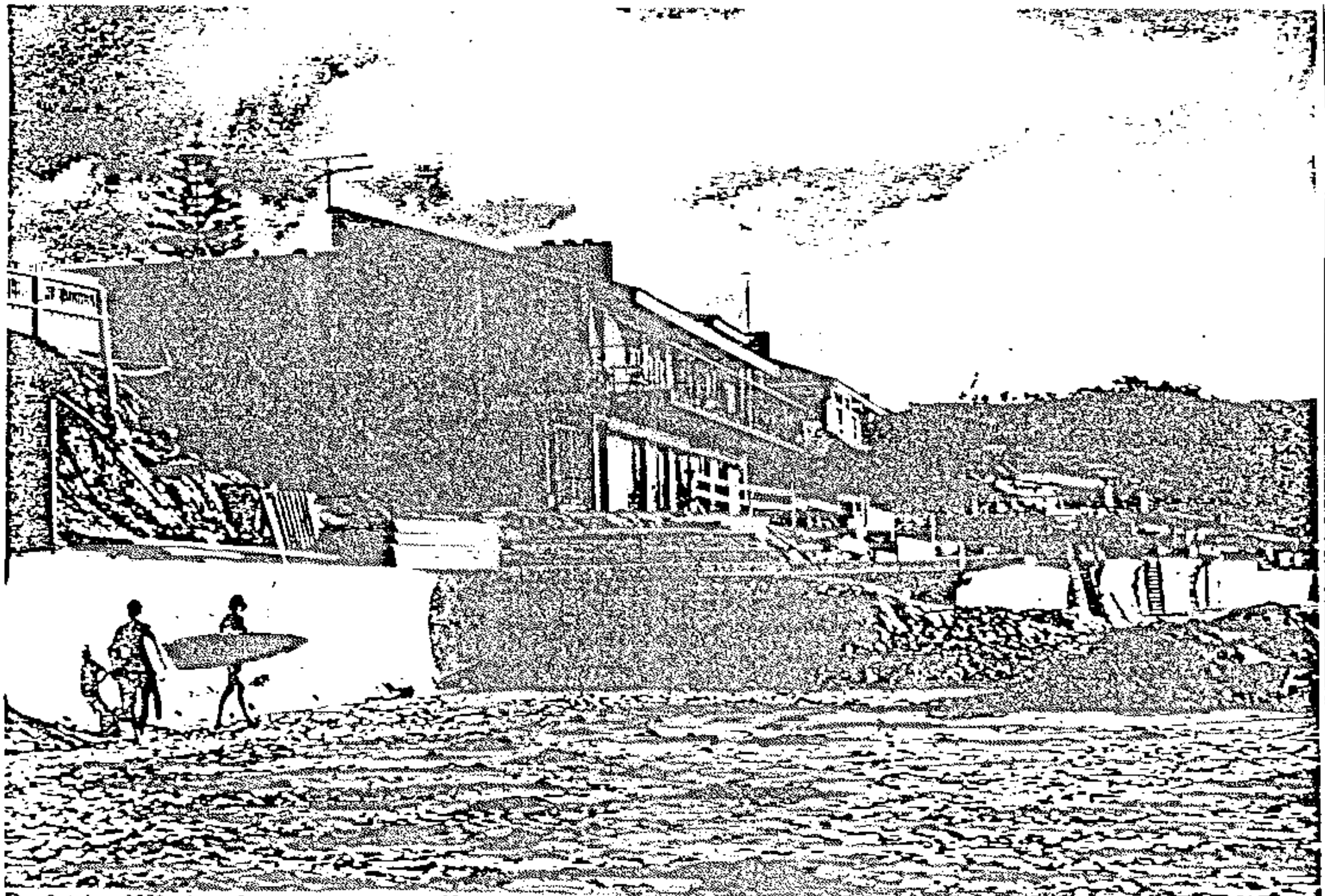
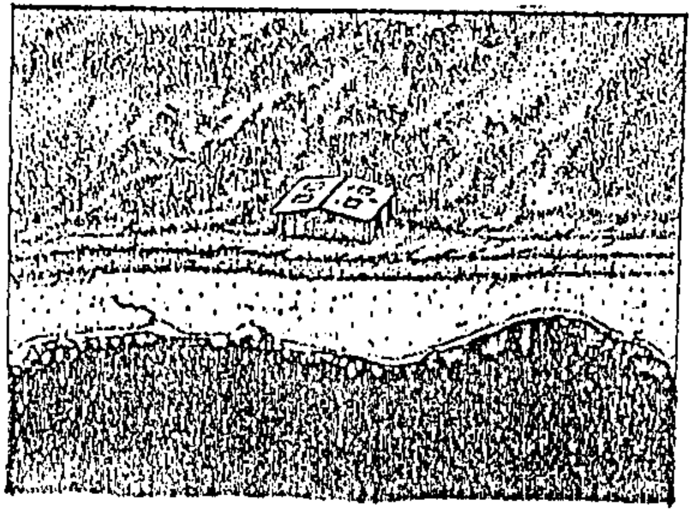


Figure 5. C. March 1978 view of unprotected eroded lot adjacent to lot seen in Figure 5.C. Note: The lot was eroded 12-15 ft landward when waves were focused on the site. Photo: Sea Grant/G. Kuhn, March 14, 1978.



D. October 1979 view of new concrete seawall at same location as Figures 5.B-D. Note: A single, uniformly designed seawall was constructed in front of all houses along this specific area. Photo: Sea Grant/G. Kuhn, October 13, 1979



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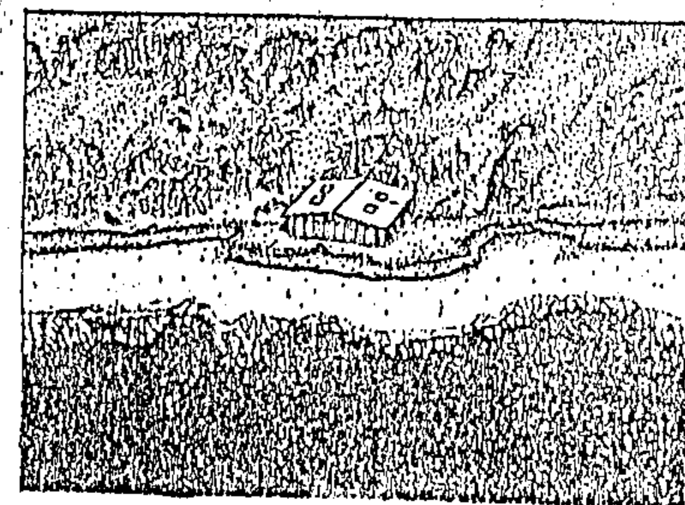
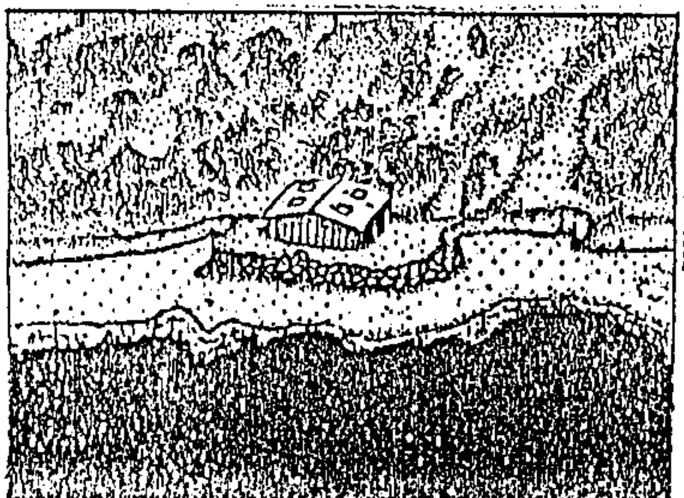


B

Figure 6. Sketches showing sequential stages of erosion and subsequent protection around a structure located on a beach.
DRAWING BY CHRIS CAROUTHERS /UCSC SEA GRANT INTERN PROGRAM.



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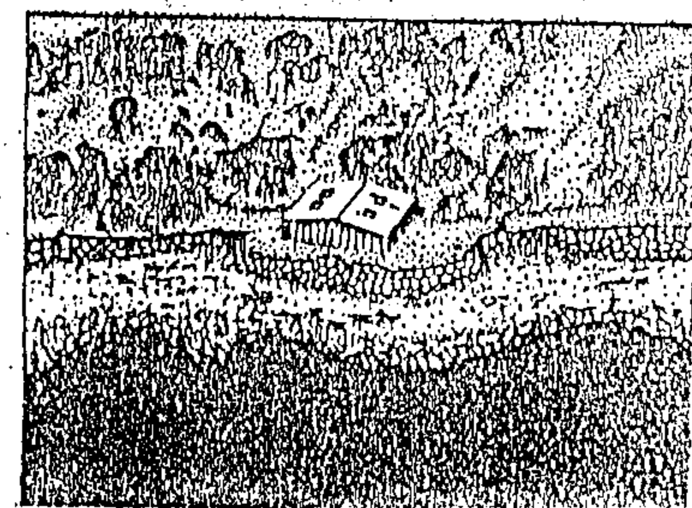


D

bedrock outcrops. This is the result of a number of factors, both natural and man-induced. (1) Agricultural storage dams have been constructed on the principal rivers in San Diego County with the effect that there is no migration of sand, as in former flood years, being carried down the rivers to build sandy beaches. (2) No flood of any significance occurred on the undammed segments of the river basins for forty years, or until 1978 (Figure 7.A). Note the extensive development and urbanization that has and is occurring directly in the river floodplain. This is the case in many areas along the coast of Southern California. The net result is that very little sediment has reached the coast. (3) In 1942 the Camp Pendleton Boat Basin was constructed directly north of Oceanside and began silting up immediately following construction (Figure 7.B). There are several such cases of man-made harbors capturing the sediment as it moves along the coast, thus starving the beaches. The sand is also intercepted at lagoon inlets. An example of this is seen at Agua Hedionda Lagoon, Carlsbad, Calibornia, where an electric plant is located.

An interesting observation is noted in that from 1889 until development of the surrounding area, the inlet mouth of Agua Hedionda Lagoon was located on the south (Figure 8.A). Following severe floods and storms from the south during the 1880's and 90's the mouth shifted to the north, where it is today (Figures 8.B & C). Dredging of the lagoon is necessary periodically as sediment is trapped there. In 1954 approximately 5 million cubic yards of sediment was dredged from the lagoon and placed on the beach (Figure 8.D).

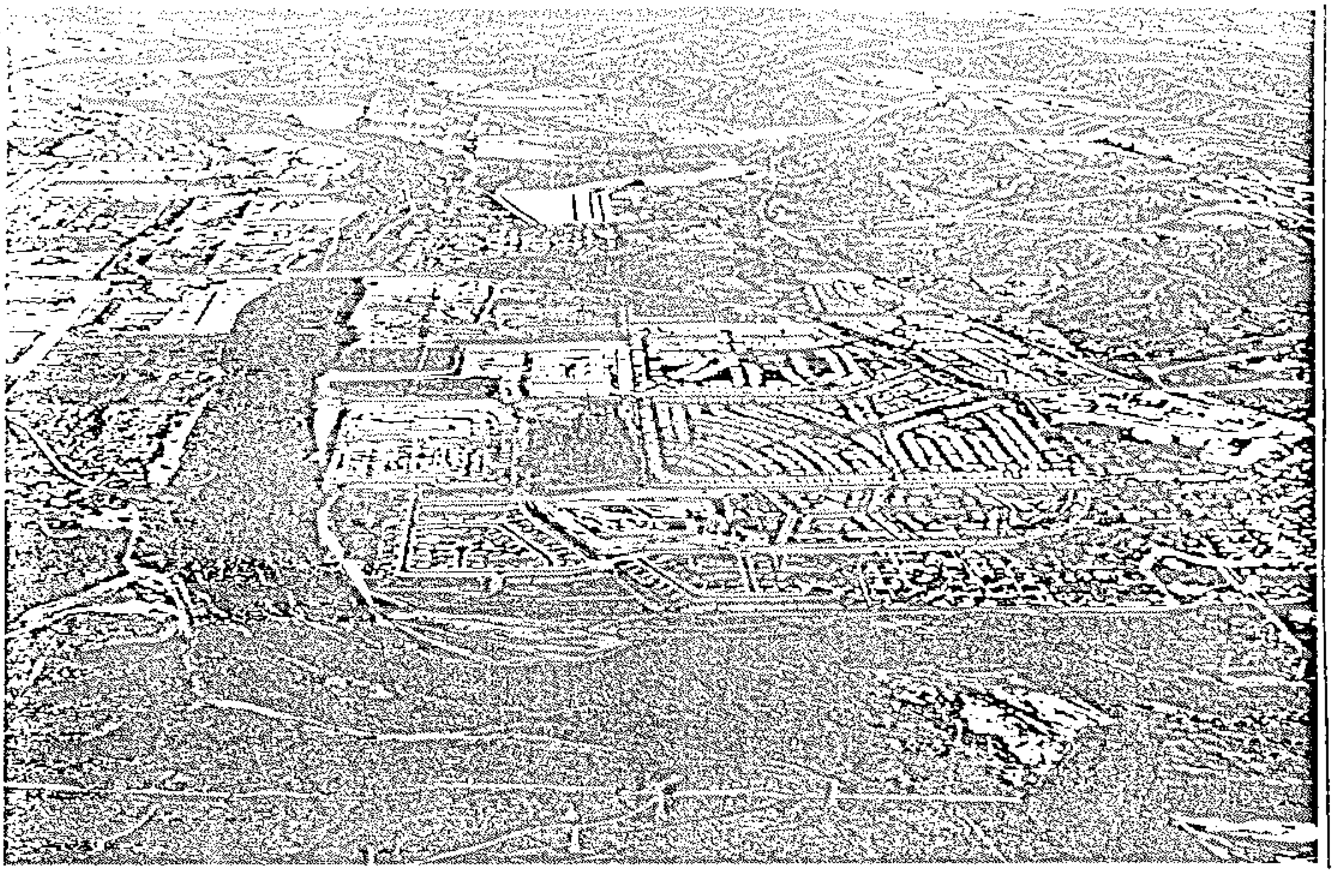


Figure 7. A. Flooding in the San Luis Rey River east of Oceanside, California; February 1980. Note extensive development located directly in the flood plain. Photo: G. Kuhn.

B. 1980 aerial view looking north across City of Oceanside toward the Camp Pendleton Boat Basin and Oceanside Harbor. Note that the width of beaches markedly decreases to the south of the harbor. Photo: Sea Grant/G. Kuhn, February 23, 1980.

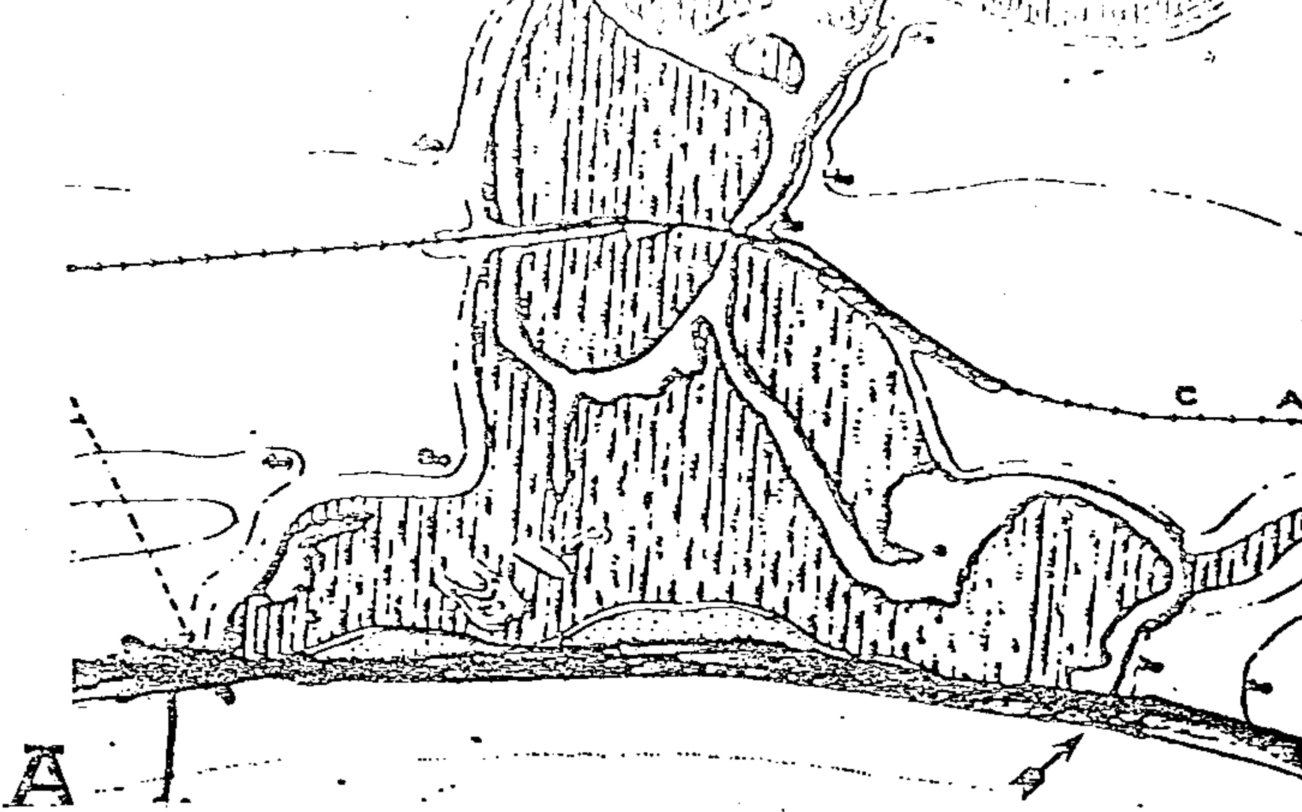
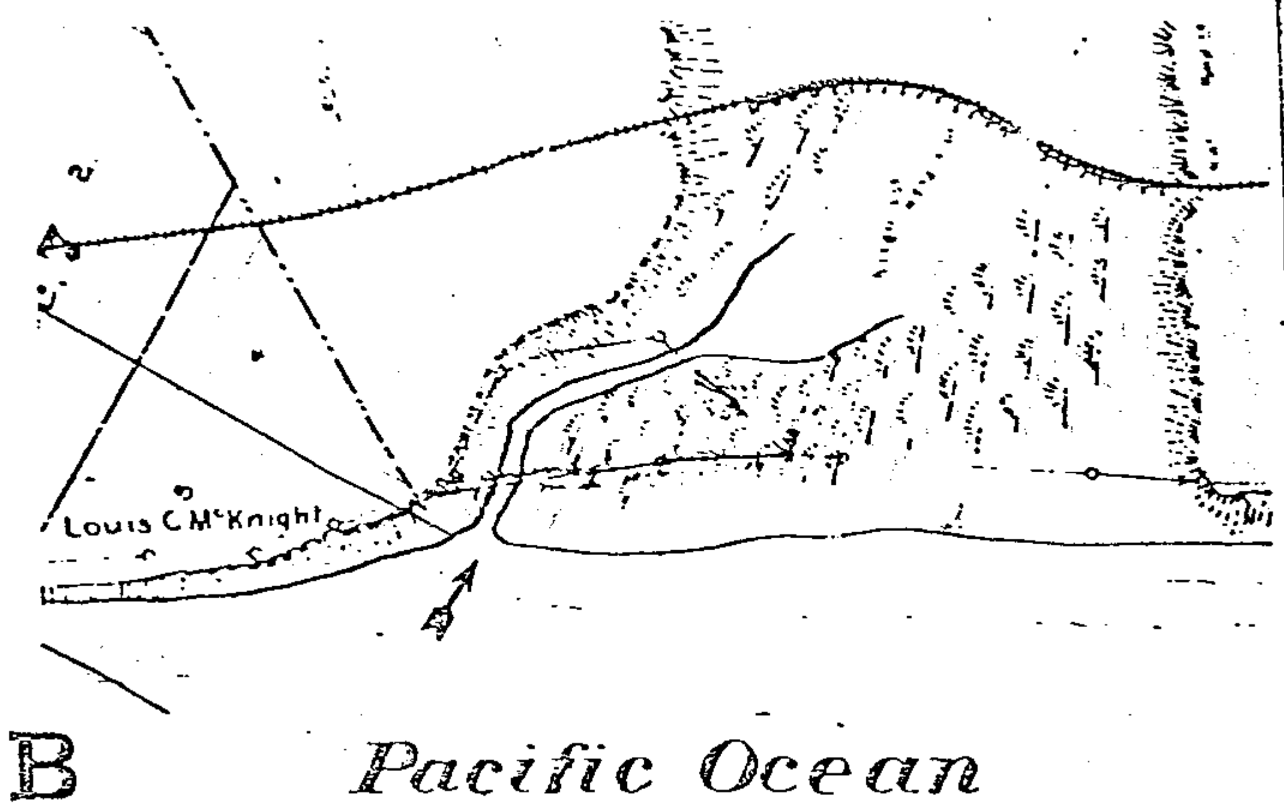
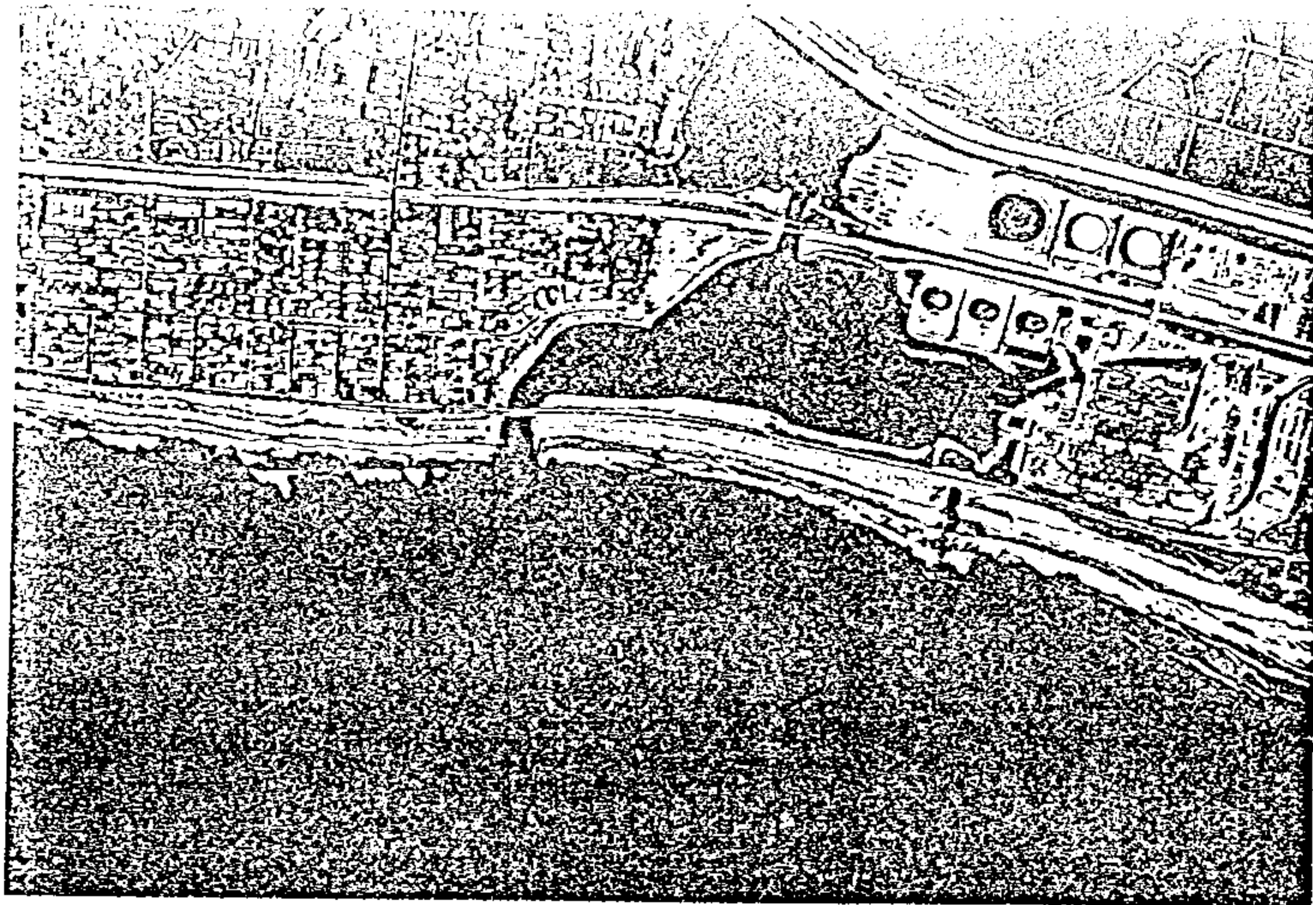


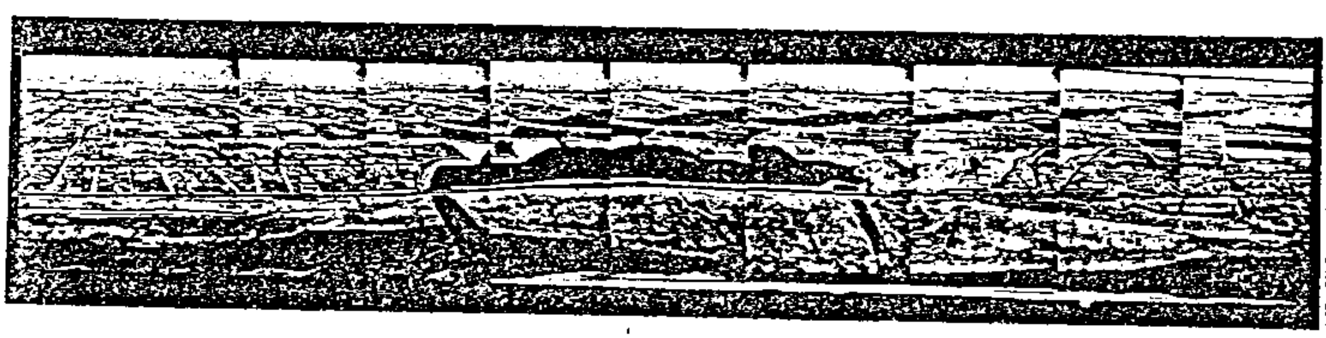
Figure 8. A. 1869 map of Agua Hedionda Lagoon, Carlsbad, California.
Note: Arrow points to the lagoon entrance inlet.
Courtesy of U.S. Coast & Geodetic Survey.



B. 1898 map of same site as Fig. 8.A. Note lagoon mouth opening has relocated from south to north since 1889. Courtesy San Diego County Road Survey, 1898.



C. October 1975 vertical aerial photo looking east across Agua Hedionda Lagoon, Carlsbad, California. Note: Lagoon must be periodically dredged. Sediment which is removed is then placed on the beach to the south. Photo: San Diego County Sanitation and Flood Control.



D. Photomosaic view of Agua Hedionda Lagoon showing approx. 5 million cubic yards of sedimentary material dredged from lagoon and placed on the beach. Note: Mean high water was extended 250 ft seaward following deposition of material on beach. Photo: U.S. Navy, October 1954.

Beach Cobble Abrasion

Beach cobbles, mentioned earlier, are derived from both rivers in flood and directly from the bluffs at some localities (Emery, 1955, 1960). During the 1880's lenses or these rocks were so extensive that at one location across the mouth of Penasquitas Lagoon south of Del Mar a "beach shingle railroad siding" was installed by the Santa Fe Railroad to mine the beach stones for street-paving material in the City of San Diego. During the early part of the 20th century two other sites in northern San Diego County were "mined" to obtain abrasives.

In 1963 approximately 300 x $10^3 m^3$ of sedimentary material (clay, sand and cobbles) was dredged from the Oceanside Harbor and placed on the beaches to the south. During the destructive winter storms of 1977-78 the buffering sand beach was removed at Oceanside by wave action and high tides. The beach cobbles became exposed, were withdrawn by the waves and thrown toward buildings located at the top of the former beach (Figure 9). Again in the winter of 1980 the cobbles were a destructive force, contributing to the undermining and subsequent collapse of the beach road and damage to apartments and homes along the shore (Figures 10-13).

In 1978 and again in 1980 it was observed that sea caves, weak shear zones, loosely-cemented bedding planes and even concrete placed on the cliff face were eroding as cobbles abraded these sites during periods of 1-meter surf and high tides (Figures 14-16).

Since 1978 the sandy beach continues to decrease in width and at many locations has been replaced by extensive cobble beaches. The cobbles in turn have accelerated erosion by moving over and abrading

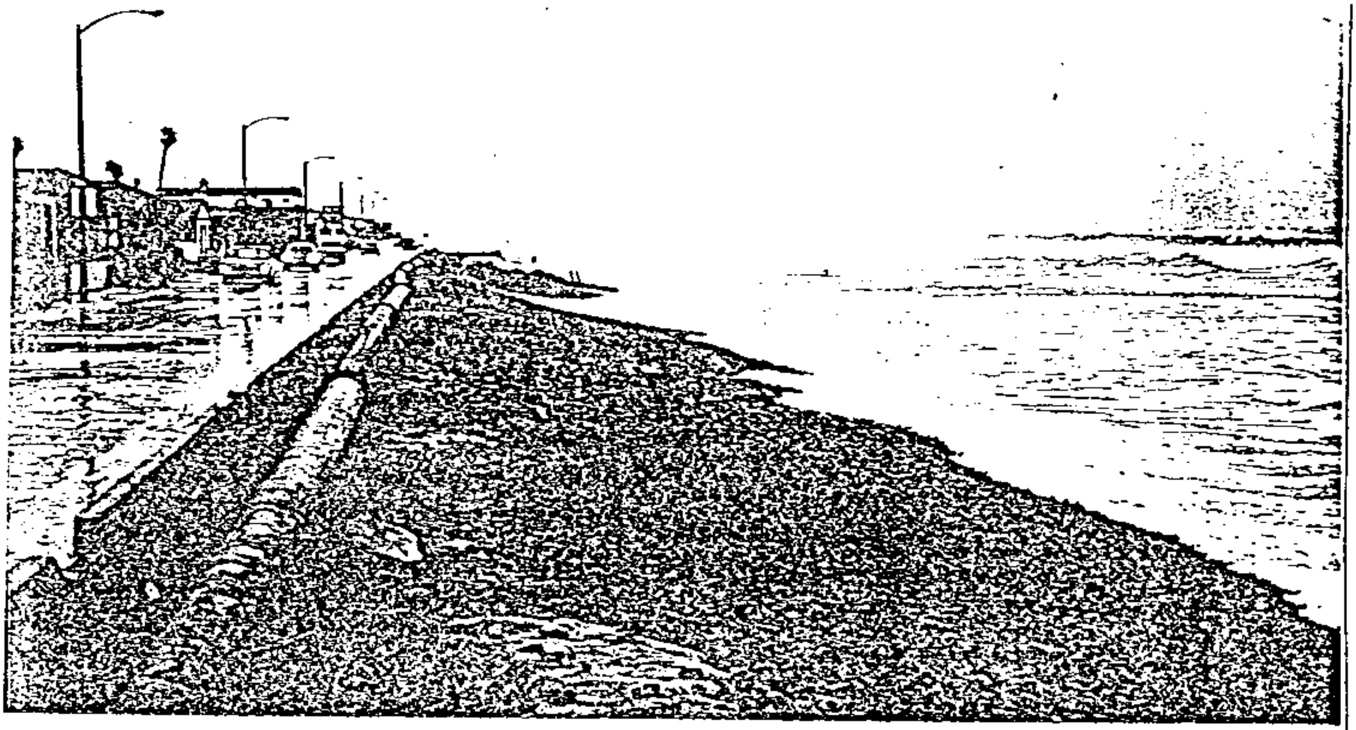
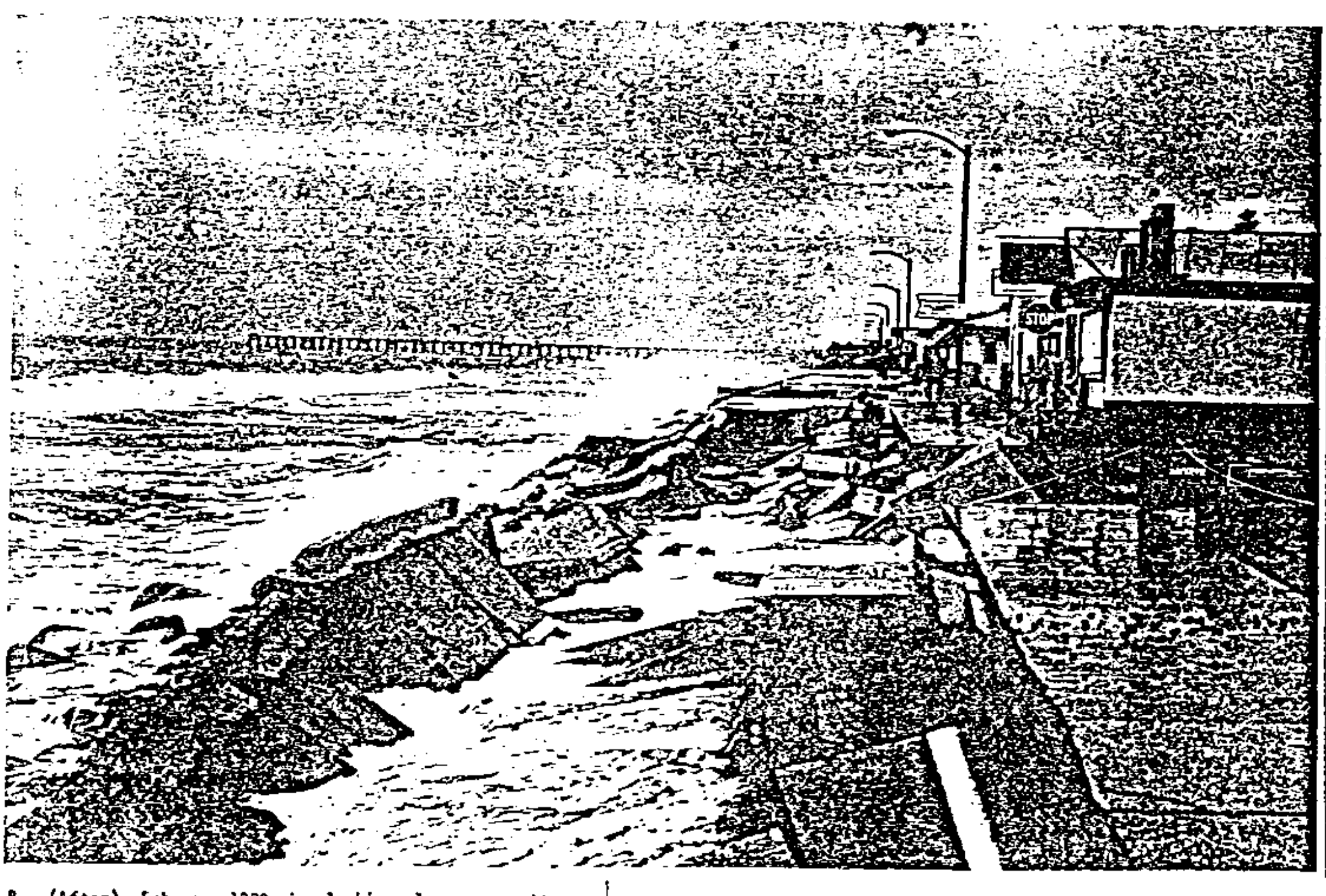


Figure 9. A. January 1978. Winter view looking south along "The Strand", Oceanside, California. Note: Arrow points to end of conduit pipe used to transport sand dredged from Oceanside Harbor to rebuild the beaches. Photo: Sea Grant/G. Kuhn, January 14, 1978.

B. March 1978. Same view as Fig. 9.A. Beach cobbles were withdrawn by waves and thrown through the air. Buildings along the shore at Oceanside, Calif. were damaged. Photo: Sea Grant/G. Kuhn, March 4, 1978.

Figure 10. A. (Before) September 1979. View looking north along "The Strand" at Oceanside, Calif. Building and road were constructed on former beach. Riprap fronts and protects concrete seawall and road. Photo: Sea Grant/G. Kuhn, Sept. 22, 1979.



B. (After) February 1980 view looking along same site as Fig. 10.A. The road and seawall were undermined and collapsed February 12-15, 1980. Photo: G. Kuhn,

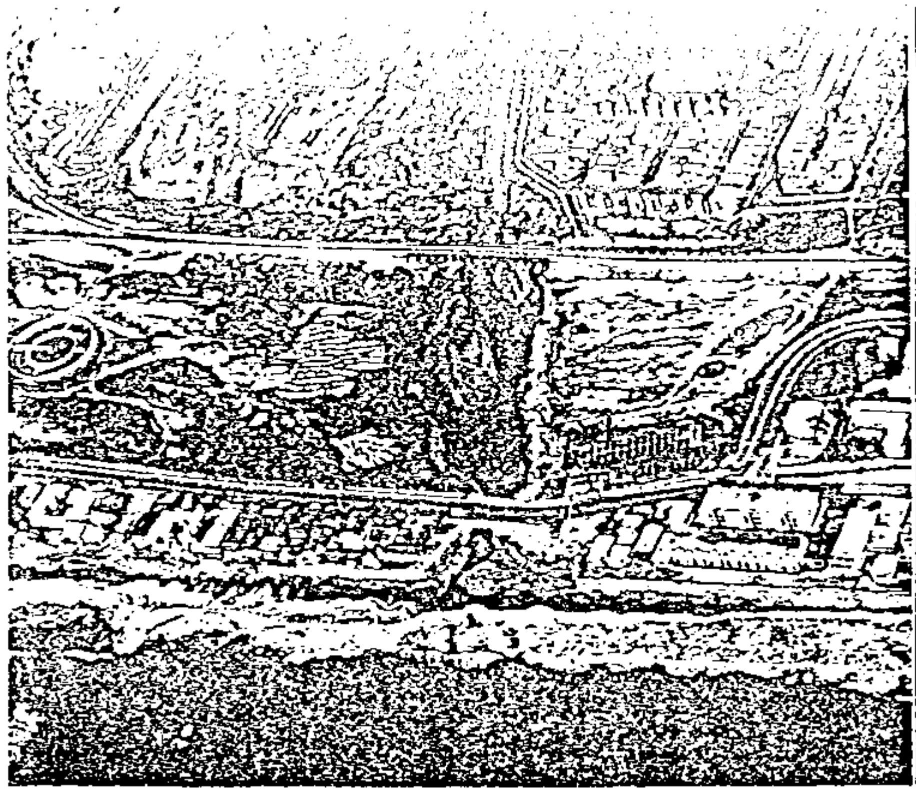
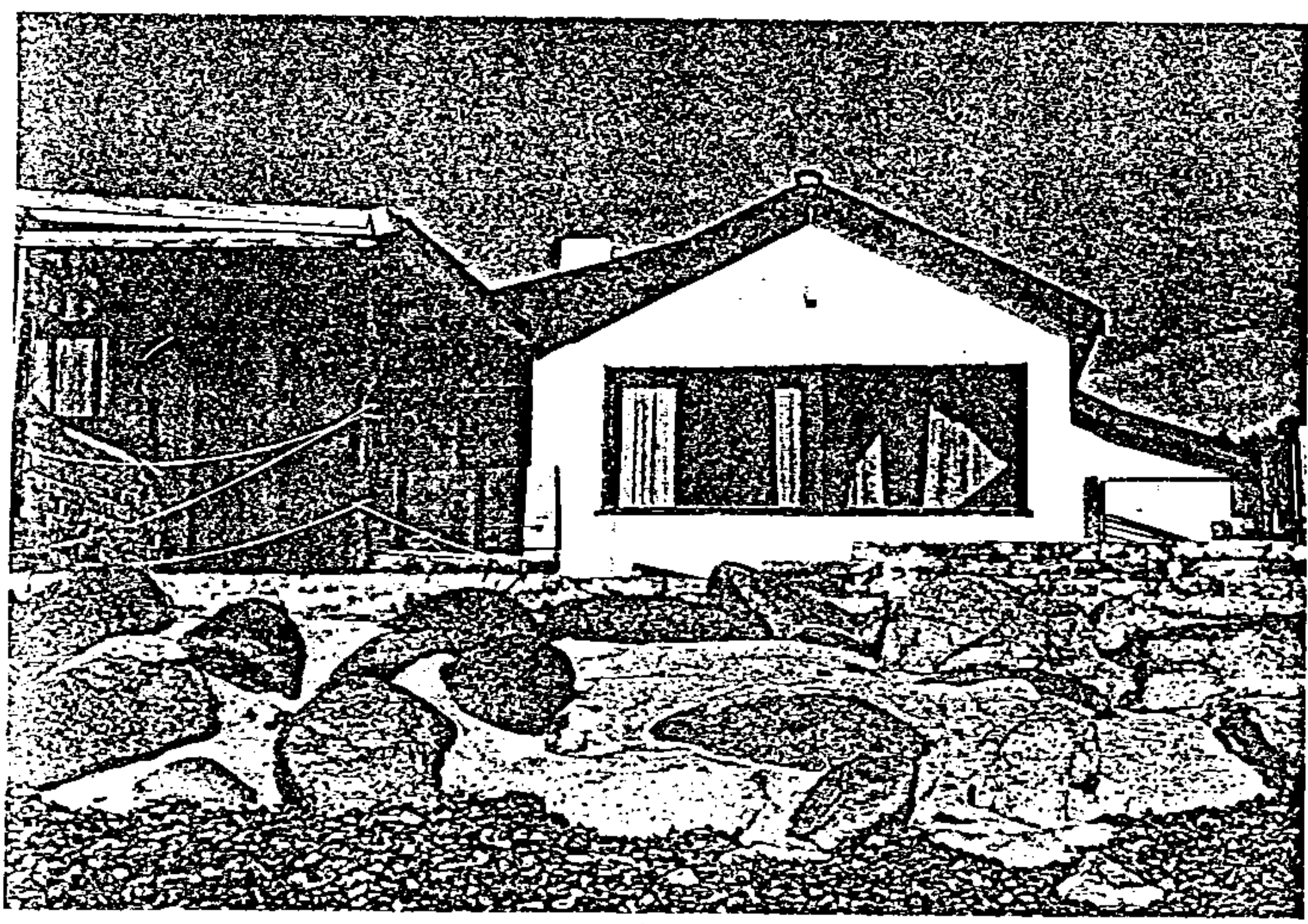


Figure 11. A. 1980. Oblique aerial photo looking east along Loma Alta Creek, Oceanside, Calif. Note houses located directly on beach north & south of creek mouth. Arrows point to houses damaged by cobbles as seen in Figure 11.B. Photo: SIO/OLR - L. Ford, February 23, 1980.



B. 1980. View of house damaged by beach cobbles. Note that windows were broken and roof collapsed as cobbles were withdrawn during storm period of only 1-2-meter waves. Photo: G. Kuhn, Feb. 17, 1980.

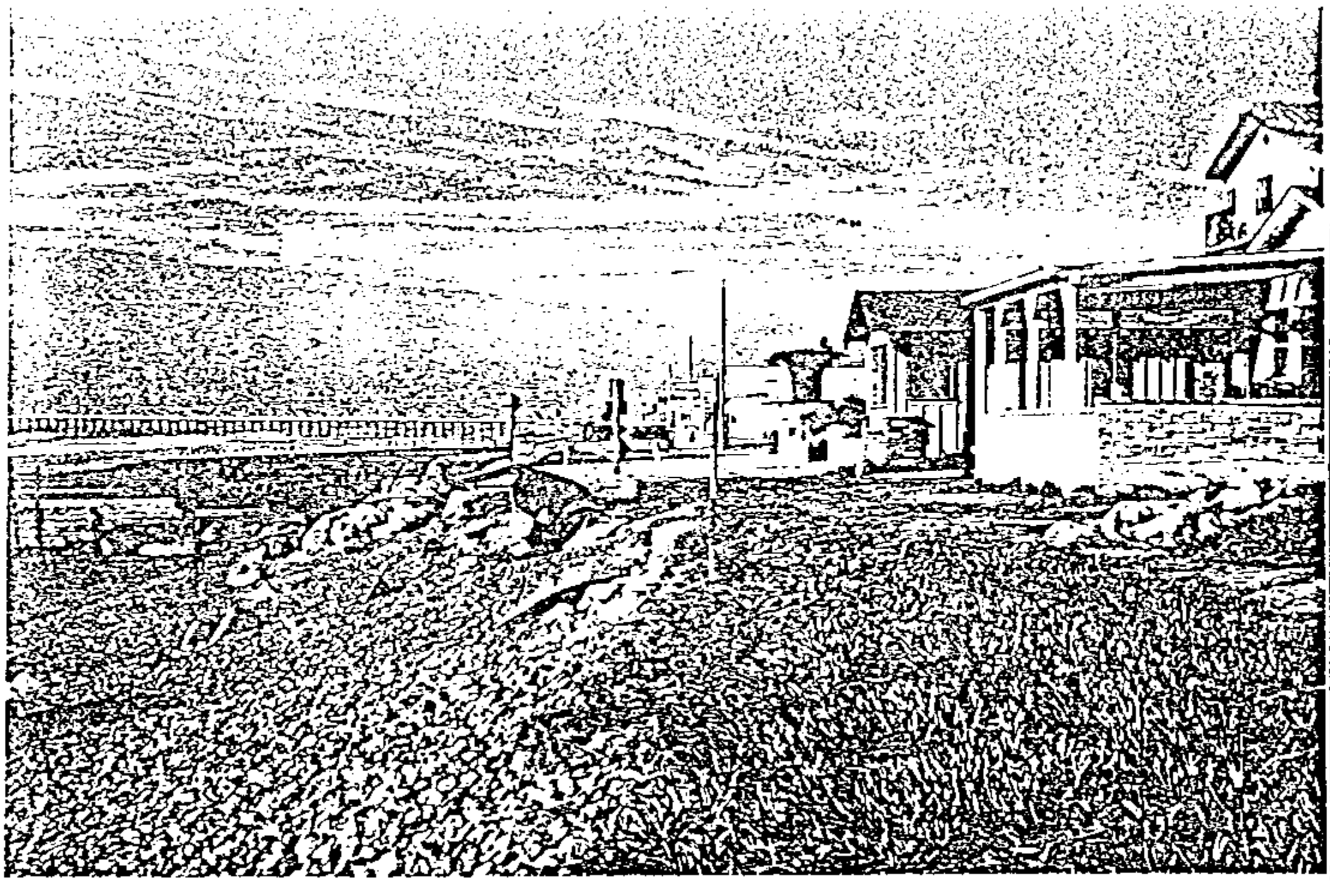


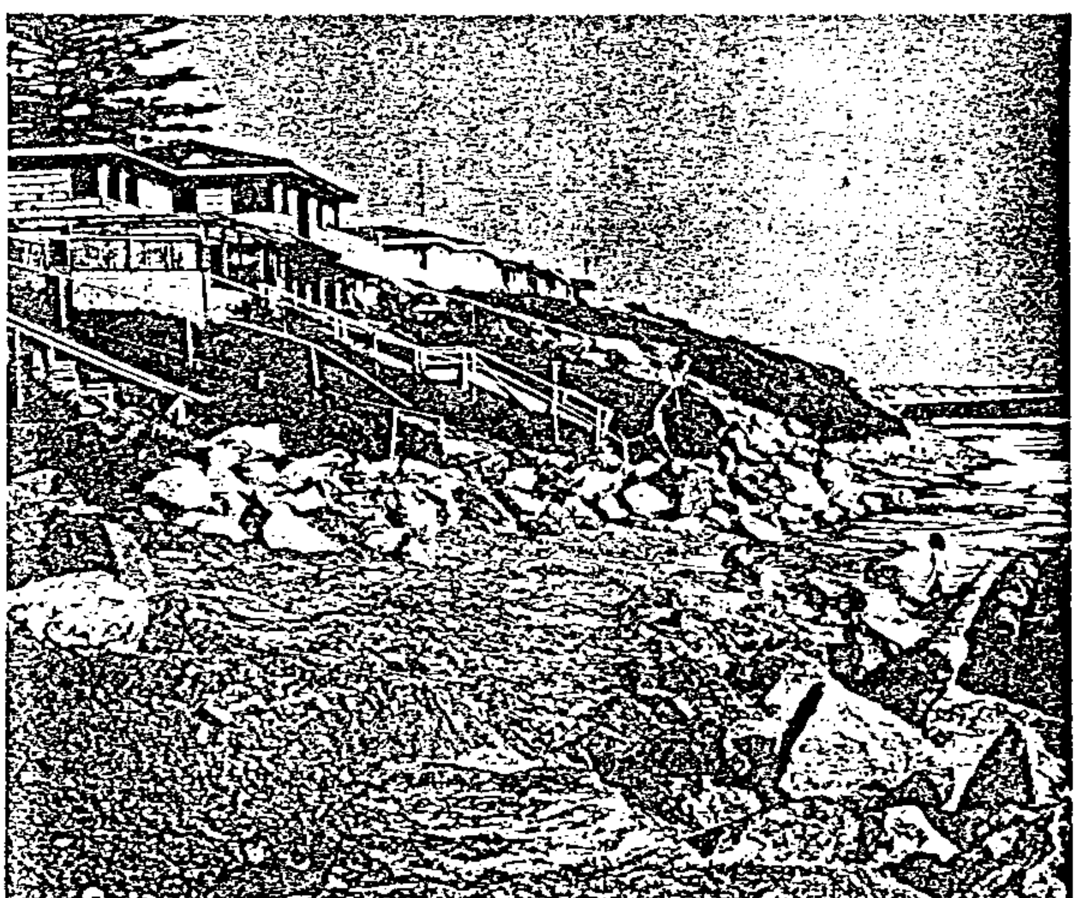
Figure 12. A. (Before) 1978 photo of beach cottages located south of Wisconsin Street in Oceanside, Calif. Photo: Sea Grant, Jan. 4, 1978.

B. (After) Same view in 1980 showing wave and beach cobble abrasion which damaged houses along the shore during storms in Feb. 1980. Property damaged occurred during relatively small (4-6 ft) swell. Photo: Sea Grant, Feb. 17, 1980.

Figure 13. A. December 1977. View along the shore at Carlsbad, Calif. Photo: Sea Grant/G. Kuhn, Dec. 17, 1977.

B. March 1978 view of same site as 13.A. Sand levels dipped to very low point and beach cobbles abraded under and around fences, stairways and walls. Photo: Sea Grant/G. Kuhn, March 16, 1978.

C. April view of same site as 13.A & B. Large riprap was placed adjacent to shore. Waves refracted around riprap and accelerated erosion on adjacent properties. Photo: Sea Grant/G. Kuhn, April 1, 1978.



D. June 1978 view of same site. Riprap was placed in front of all houses at this site. Photo: Sea Grant/G. Kuhn, June 3, 1978.

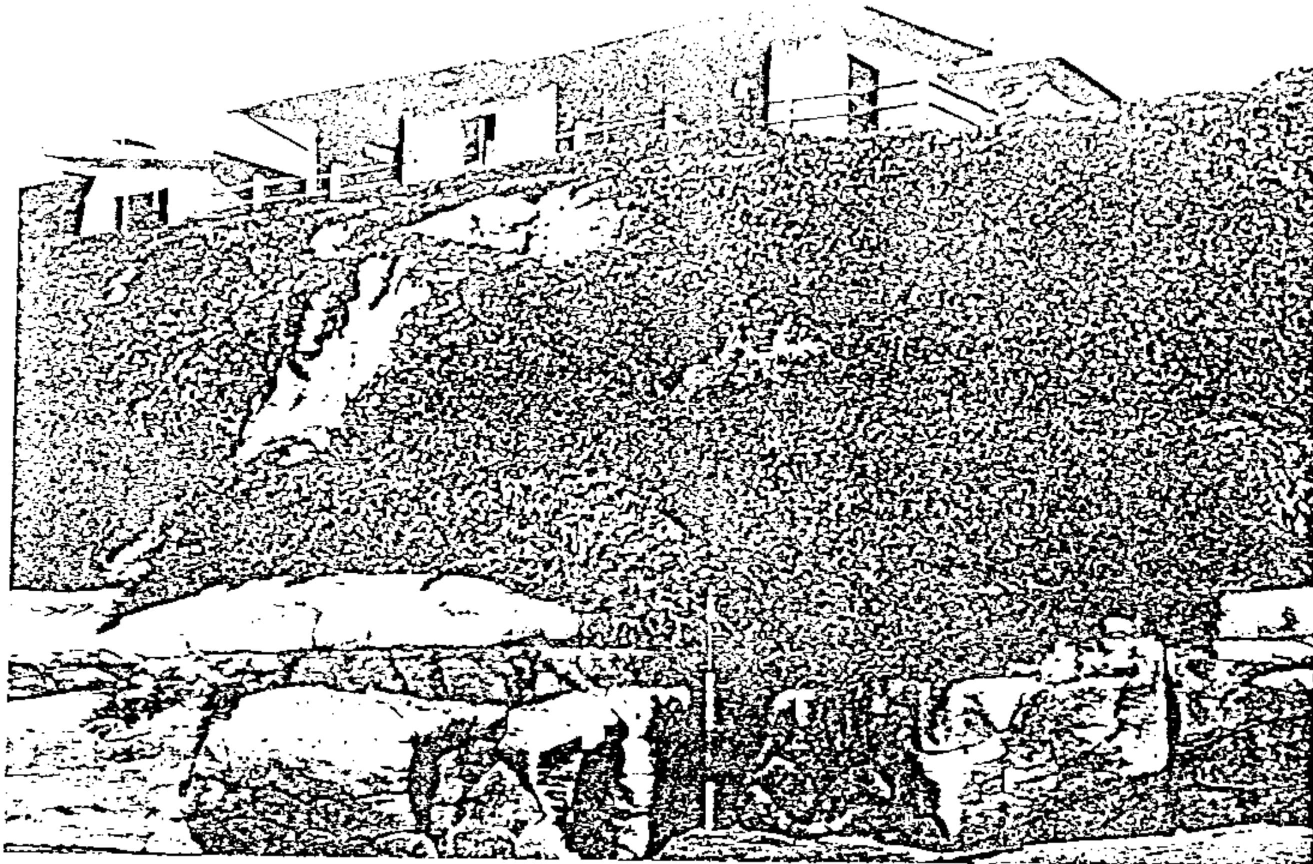


Figure 14. A. December 1977. View at coastal site along beach at Carlsbad, Calif. Photo: Sea Grant/G. Kuhn, Dec. 17, 1977.

B. June 1978. View of same site as 14.A. Note height to which beach cobbles have moved. Photo: Sea Grant/G. Kuhn, June 3, 1978.

Figure 15. 1979 view along the beach at Carlsbad, California. "Shotcrete" which was placed on these cliffs has collapsed from the landward side as a result ground-water spring sapping undermining its support and beach cobble abrasion on the seaward side.
Note that the beach cobbles have abraded through the shotcrete to the underlying wire mesh.

Fig. 15

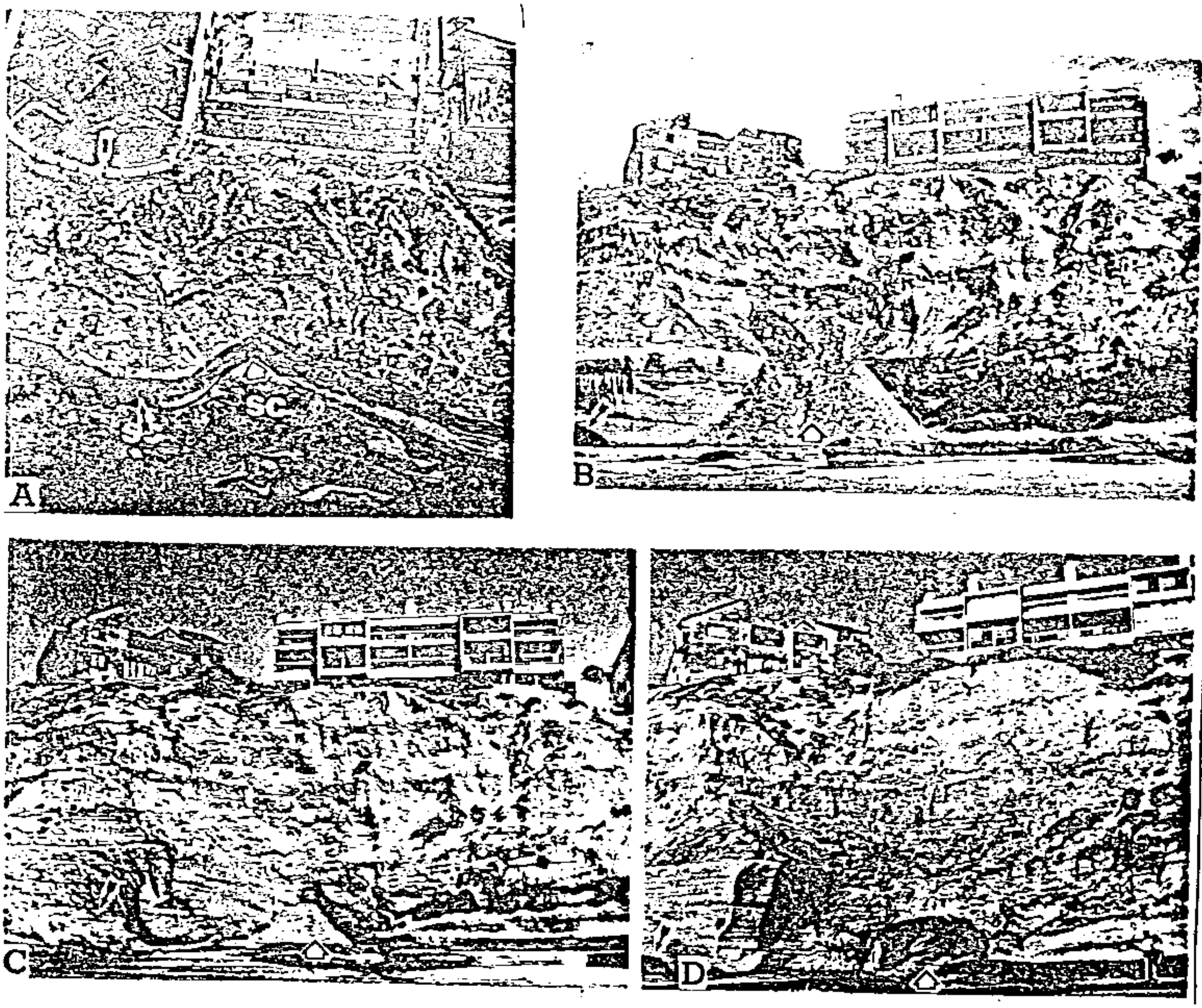


Figure 16. A. Oblique Aerial photo looking East along South Solana Beach, California. Note the two well-developed sea caves (Indicated by arrows) which were intact at the time this photo was Taken. Photo: B and A Engineering, June 1974.

B. 1975 view of large sea-cave roof collapse. Note that the upper sands have also collapsed to the beach. Photo: G.G.Kuhn,April 1975.

C. A second sea cave collapsed in 1977. Photo: G.G.Kuhn, March 10, 1977.

D. View along the base of this cliff at the same site as 16 A, B, C, seen above. Photo was taken following the storms of February through April, 1978. Note:the recently enlarged sea cave is a result of beach cobble abrasion during periods of high tides. Photo: Sea Grant/G.G.Kuhn, June 10, 1978.

behind existing seawalls, riprap and other structures located along the shore, even during the summer months (Figure 17).

Increased Ground Water

At many locations along the coast, cliff failures and landslides are partially related to the undercutting of the sea cliff. More importantly, a recent steady rise in ground water levels along the sea cliffs is found to be a major contributing factor in cliff erosion (Saint and Turner, 1980) (Figure 18). This rise is commensurate with urbanization along, and inland of, the sea cliff. It is a result of excessive watering of lawns, introduction of non-native vegetation, agricultural irrigation, septic tanks, leach lines and cess pools. Over-irrigation of landscaping in residential subdivisions alone is the equivalent of approximately 50-60 inches of rain per year (Sorben and Sherrod, 1977).

This extensive watering has lead to at least three important effects: It has caused a slow but steady increase in the water table, even during the dry period which preceded the rains of 1978. This has added weight to the cliff material which contributes to development of landslides. It has lubricated surfaces along which slides and block falls are initiated, and in some cases has greatly increased solution in the underlying rocks. specific sites that evidenced erosion during the drought years prior to 1978 are continuing to collapse. Large sections of cliff face have separated along parallel joint sets (Figures 19-21).

Canyon Head and Gully Erosion

Accelerated headward erosion is occurring along existing paleo-drainage avenues where culverts have been constructed under the railroad

Figure 17. A. (Before) Beach cobble abrasion along the shore at South Oceanside. Cobbles moved up beach 18-20 feet and covered riprap seawall in places; eroded lawns directly behind seawall. Photo; Sea Grant/G.G.Kuhn, January 1978.

B. (After) Same view at South Oceanside in June, 1978. Only remnant pockets of cobbles remain. Photo: Sea Grant/G.G.Kuhn, June 20, 1978.

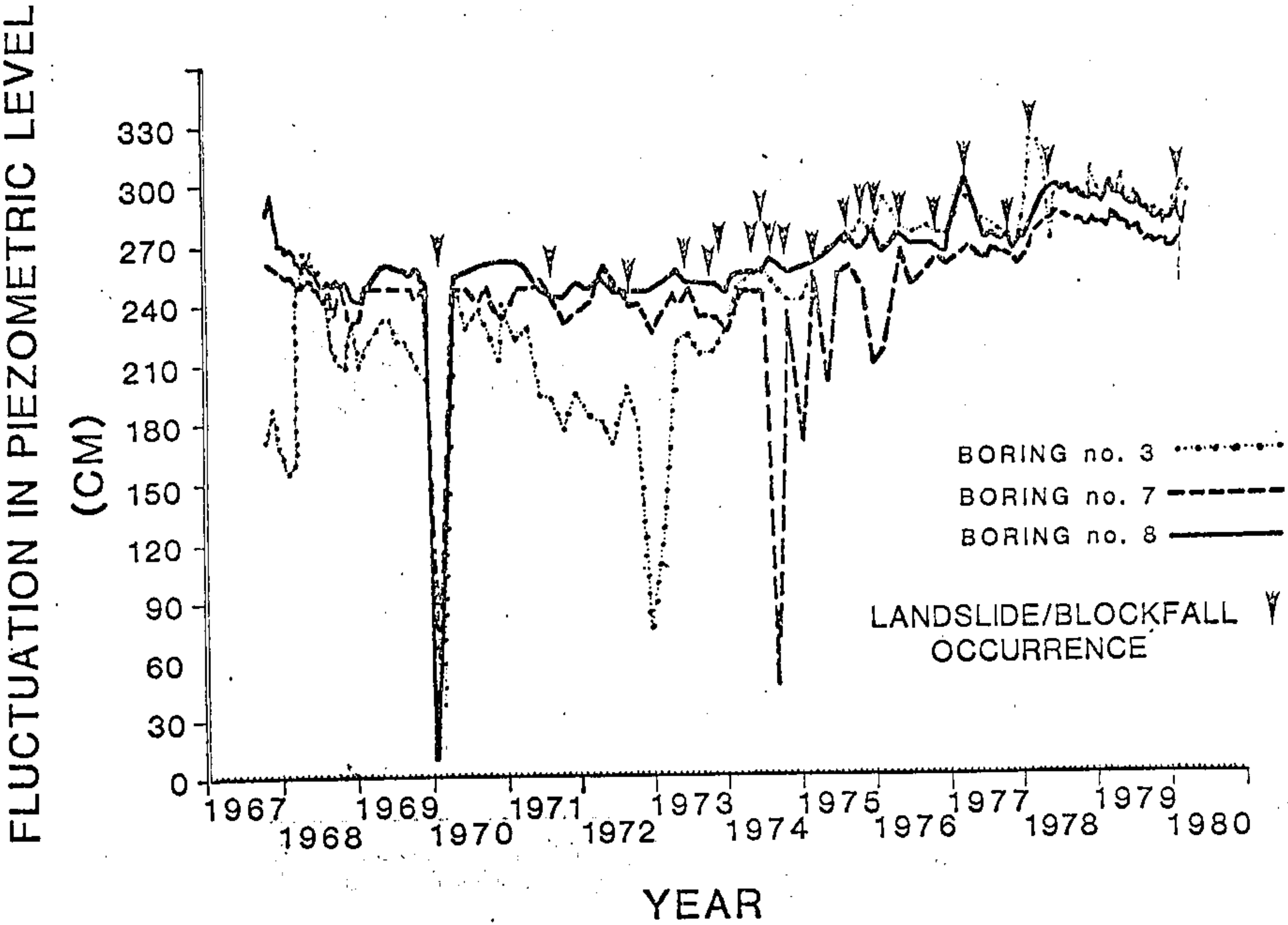


Figure 18. Graph showing piezometer well-level ground water table data at the Self Realization Fellowship property, Encinitas, California. Photo:G.G.Kuhn.

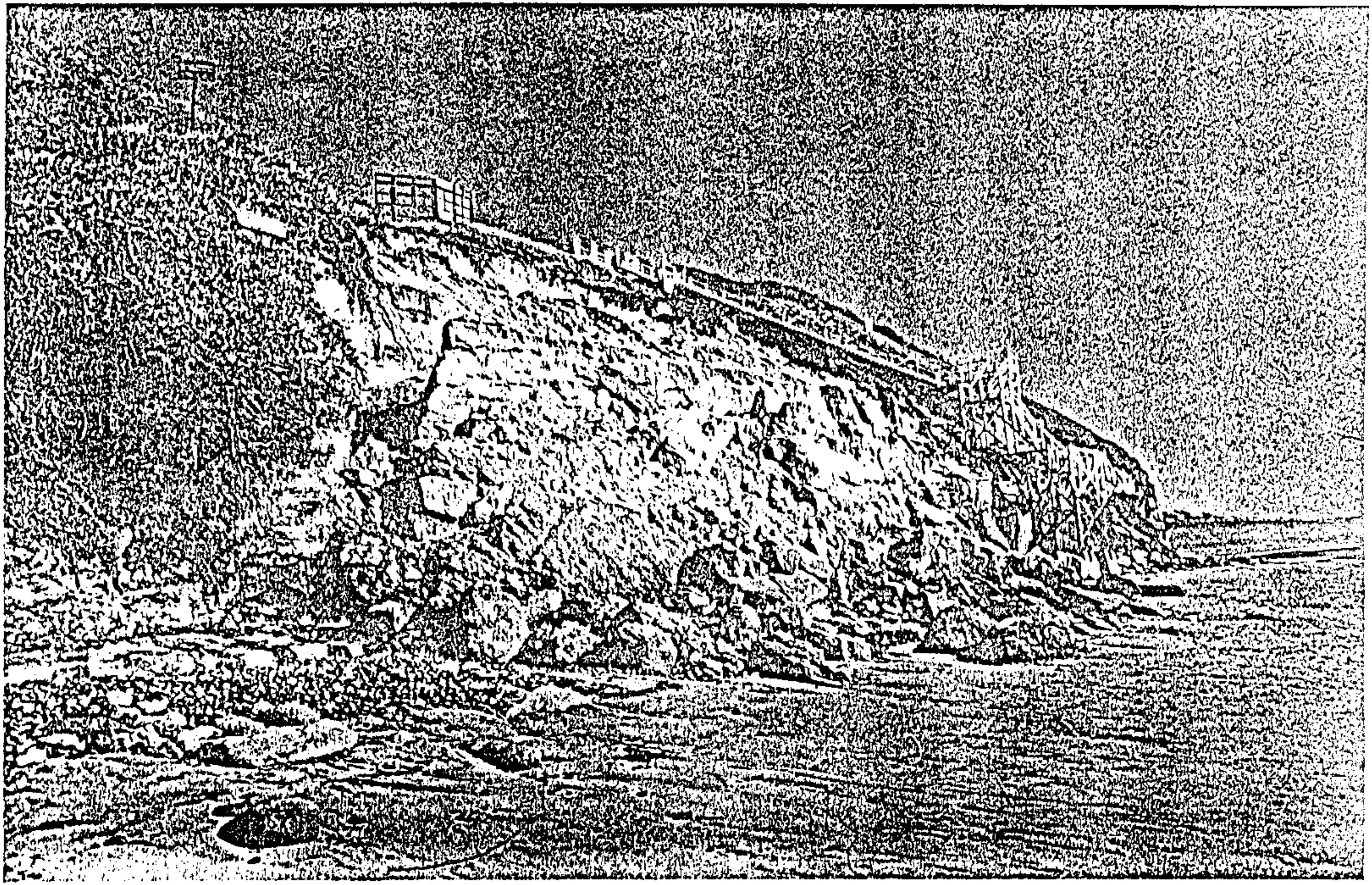


Figure 19. 1978 photo looking southeast along the base of the cliff that collapsed at the self realization fellowship property in Encinitas on April 26, 1978.

Photo: Sea Grant/G.G.Kuhn, December 1978.

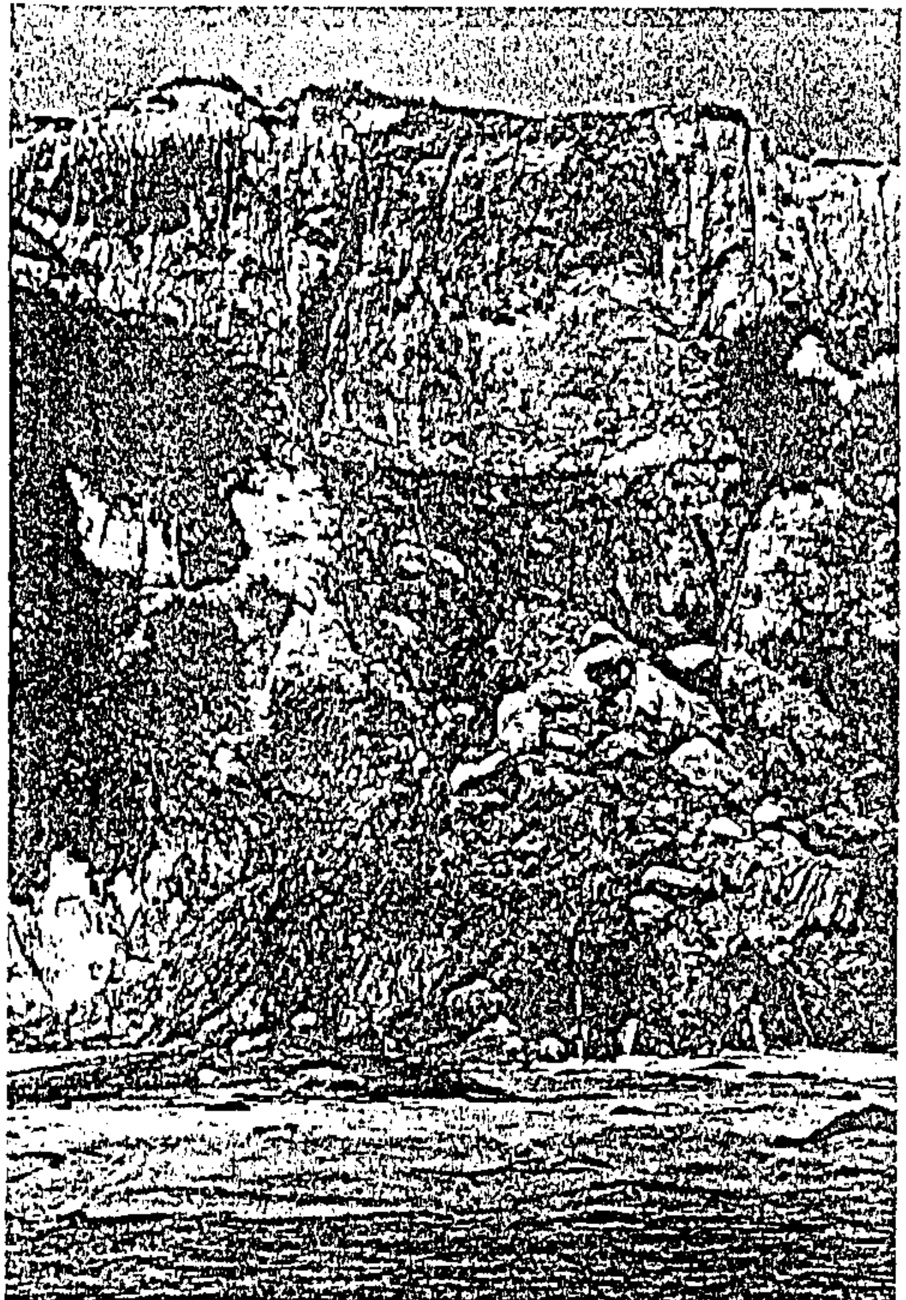
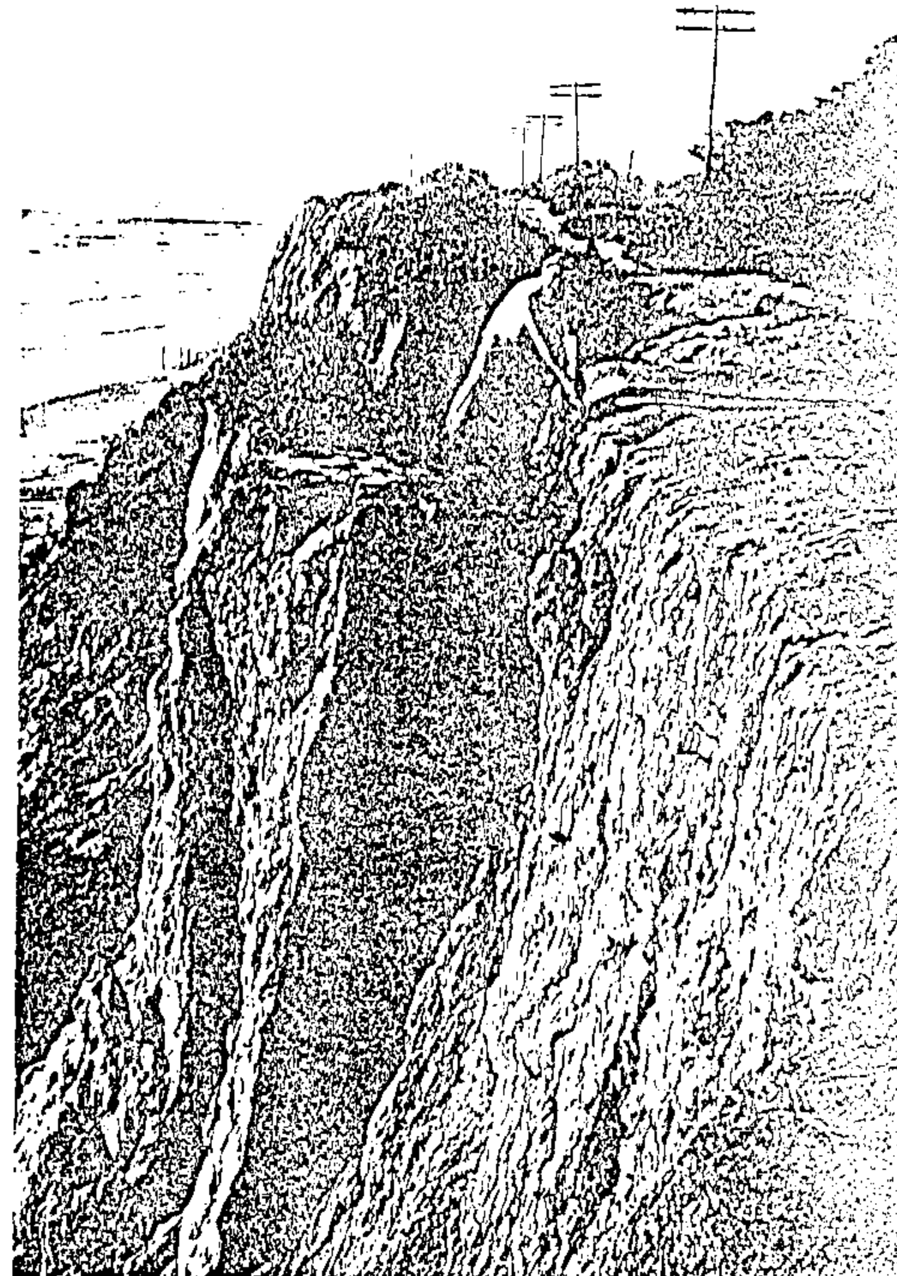


Figure 20. A. August 1979 view of recent cliff failure at Del Mar, California. Note: Cliff failure occurred as a result of a rise in the ground water table from watering of non-native vegetation inland of the sea cliff. Photo:Sea Grant/G.G.Kuhn, August 22,1979.



B. September 1979 view along the bluff top at Del Mar, California. Note:That the block in photo foreground has partially separated from the cliff face. Photo: Sea Grant/G.G.Kuhn, September 10, 1979.

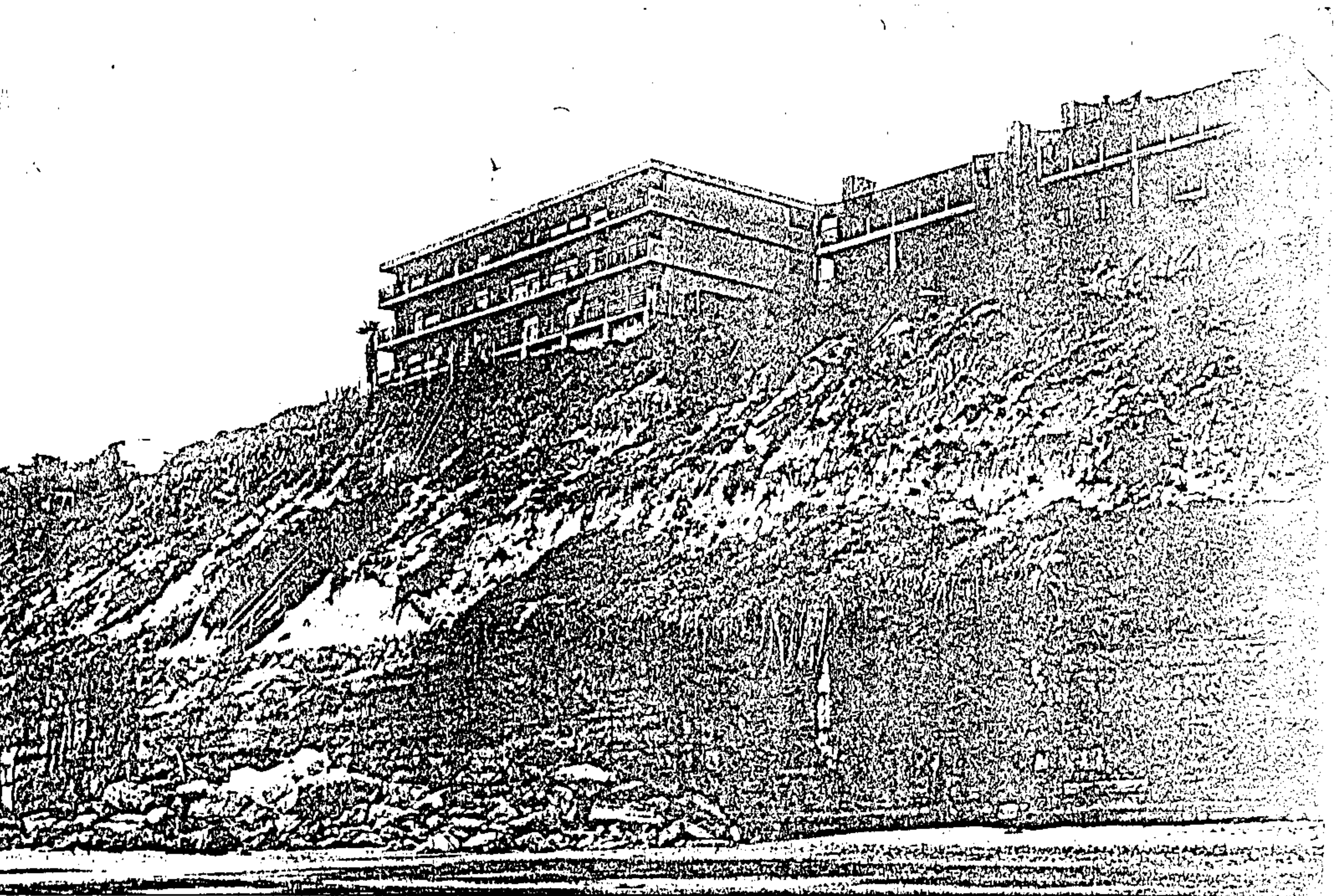


Figure 21. A. Blockfall on the beach at the foot of F street, Encinitas, California. The cliff collapsed and crushed the apartment beach access stairway on November 30, 1977. Note the wet condition of the cliff face. Photo:G.G.Kuhn, December 10, 1977.

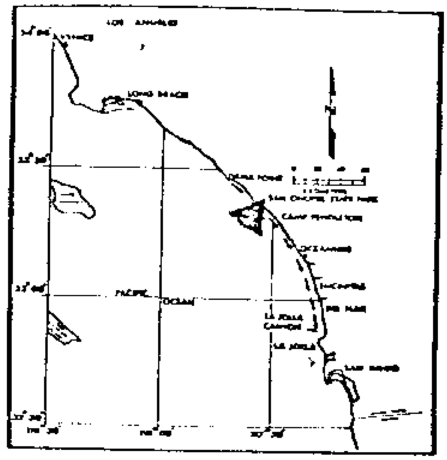
track and highways. Obvious examples of this are found at San Onofre State Park and Camp Pendleton (Figure 22.A).

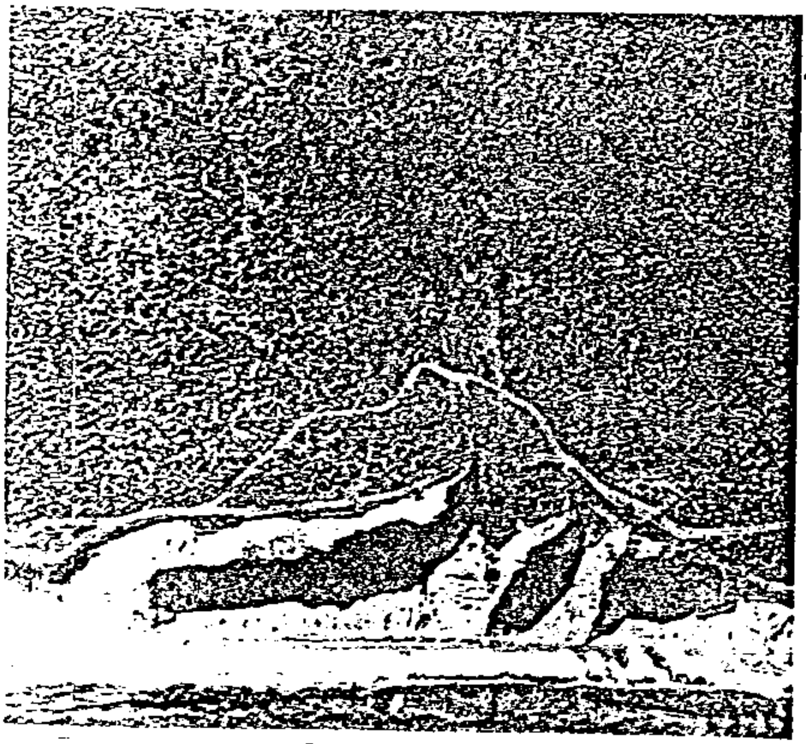
Between 1885 and 1980 normal erosional drainage avenues have been drastically altered by man (Kuhn, Baker and Campen, 1980). In 1885 the Atcheson-Topeka & Santa Fe Railroad Company constructed trestles across existing gullies and canyons. The structures were designed to span the channels and did not appreciably alter the existing drainage patterns. During construction of California State Highway 101 in 1912-1918, however, culverts were installed under the highway to control surface runoff under the road and down the canyons during the rainy periods. In the wet years that followed installation of these drains, erosion of gullies accelerated where these structures concentrated flow.

During construction of Interstate 5 in the late 1960's large culverts and storm drains were installed directly below the San Onofre watershed and east of old Highway 101. These drains concentrated the surface runoff from numerous adjacent drainage avenues and directed it parallel to the highway and then west into culverts under Highway 101. No wet years occurred after completion of Interstate 5 until 1978. During January-April 1978, however, rainfall was greater than normal and headward erosion along these altered drainage avenues accelerated rapidly. At one canyon the southbound lanes of Highway 101 collapsed leaving a 75-ft deep vertical scarp.

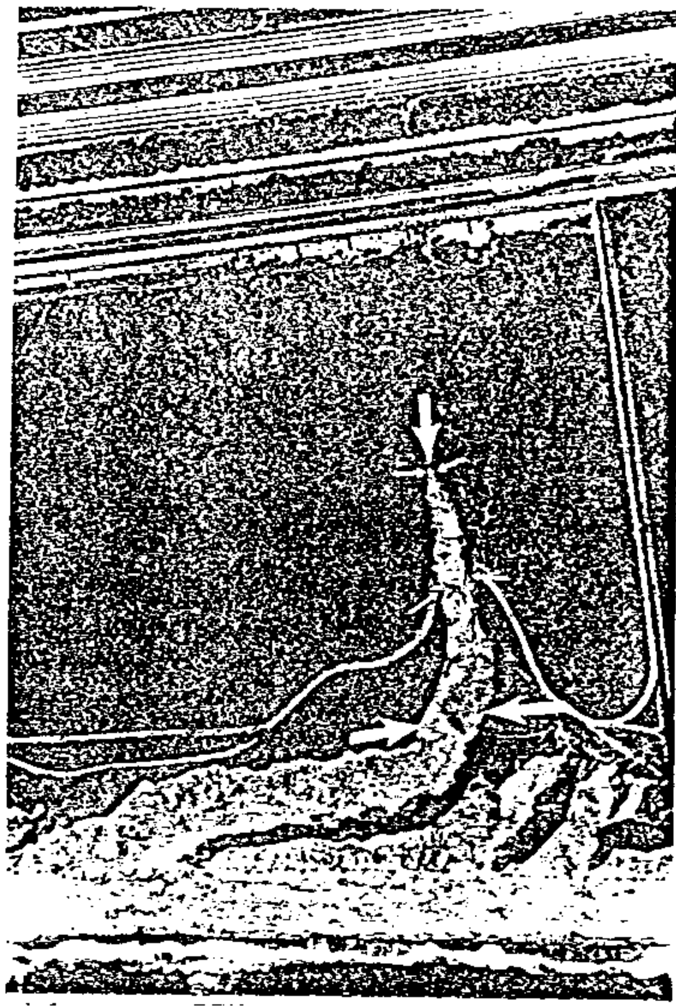
At another location no canyon existed perpendicular to the shoreline prior to the 1969 storms (Figure 22.B). Between 1968 and 1976 a new canyon began to cut headward, reaching about 60 ft inland. During January and February of 1978 approximately 160 ft of headward erosion occurred. On February 14, 1980 another 5 ft of headward erosion

Figure 22. A. 1980 View looking West along canyon cut in colluvial Terrace deposits at San Onofre State Park, San Diego County, Calif. Photo: Sea Grant/G.G.Kuhn, February 1980.





B. (Before). 1968 vertical aerial photograph of a canyon along the bluffs at San Onofre State Park in northern San Diego County. Prior to this time only a notch existed perpendicular to the shoreline at this site. Photo: U.S.Navy, 1968.



C. (After). March 1980 vertical aerial photograph showing development of 460 feet canyon perpendicular to the shoreline. It was actually cut 235 feet on February 20, 1980 alone. Photo: U.S.Navy, March 1,1980.

occurred, and on February 20, during one day, the canyon actually eroded approximately 235 ft landward, 50-100 ft deep and 60-90 ft in width (Figure 22.C). This amounted to approximately 50,000 cubic yards of sedimentary material which moved immediately out onto the beach.

Rapid degradation of the bluffs also occurs where fences, stairways, lifeguard towers and storm drain pipes are located along former drainage avenues. Surface water tends to adhere and flow along the underside of such structures, thus eroding the bluff face. At numerous locations beach stair accesses have been undermined and storm drains collapsed between 1978 and 1980 (Figures 23-25).

Numerous gullies have been cut into the bluffs and canyons below subdivisions within the coastal zone. This is a direct result of the location and design of storm drains (Figure 26). This has created added siltation problems by filling in low-lying wildlife habitats in coastal lagoons.

At one location, above San Elijo Lagoon in San Diego County, erosion began immediately after the bluff top was graded and storm drains installed at canyon heads (Figure 27). The storm drain which collected surface runoff from a large area of this subdivision is seen in Figure 28.A). As water flows downhill, the gully enlarged and erosion increased (Figure 28.B). Artificial fill material was placed in a section of the gully (Figure 28.C) but this material rapidly eroded following a small storm (Figure 28.D). Concrete debris and rubble was then dumped at the site (Figure 28.E) but it was also eroded and flushed down-canyon. The site was once again filled with rubble debris and covered with concrete (Figure 28-F), but continues to erode.

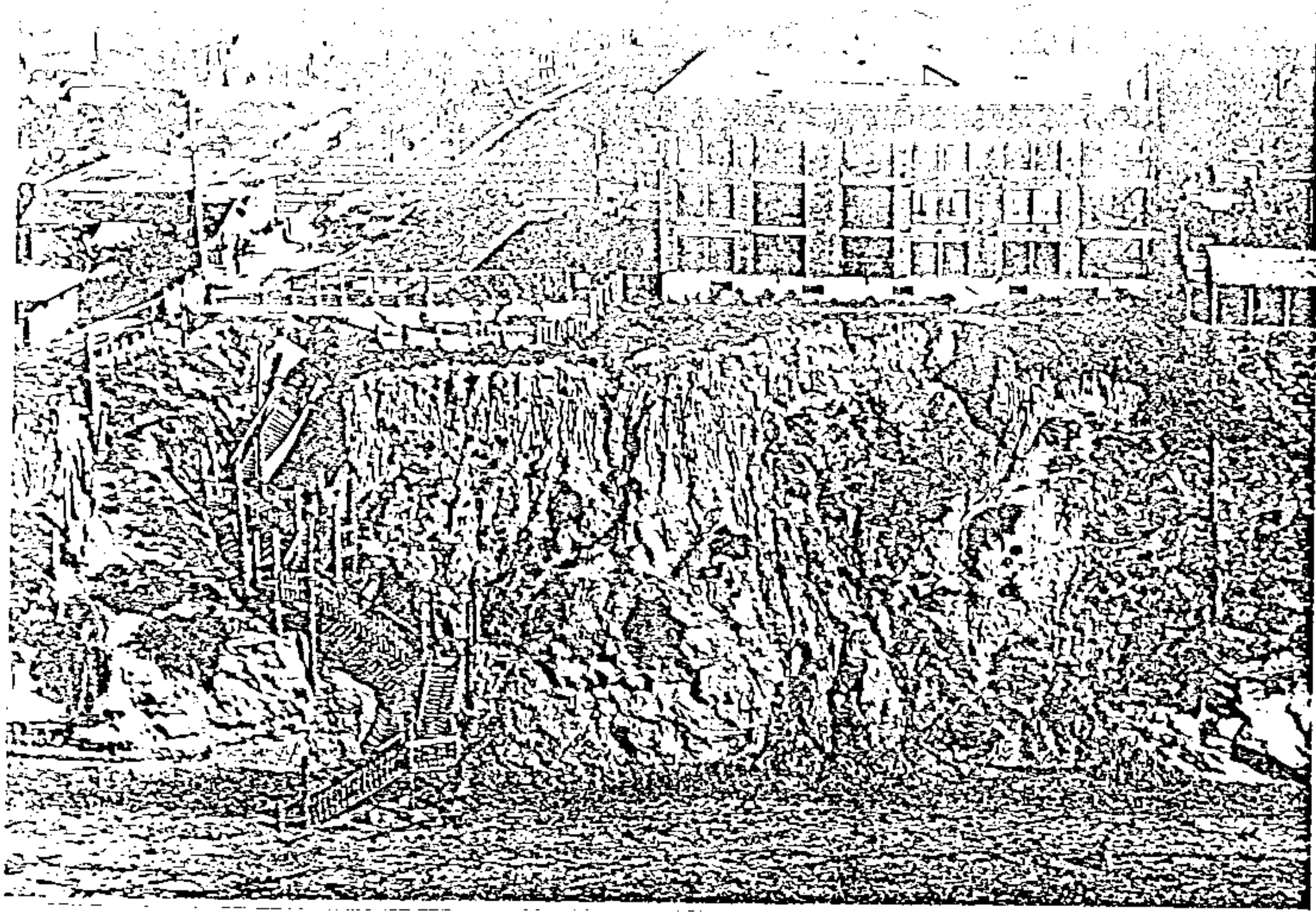


Figure 23. A. March 1980. Oblique view of eroding bluffs at D street, Encinitas, California. Note:(1) The stairway collapse at the bluff top at the street end; (2) the recent slope failure located directly in front of large building. Photo: Sea Grant/ O.L.R.- L.Ford, March, 1980.

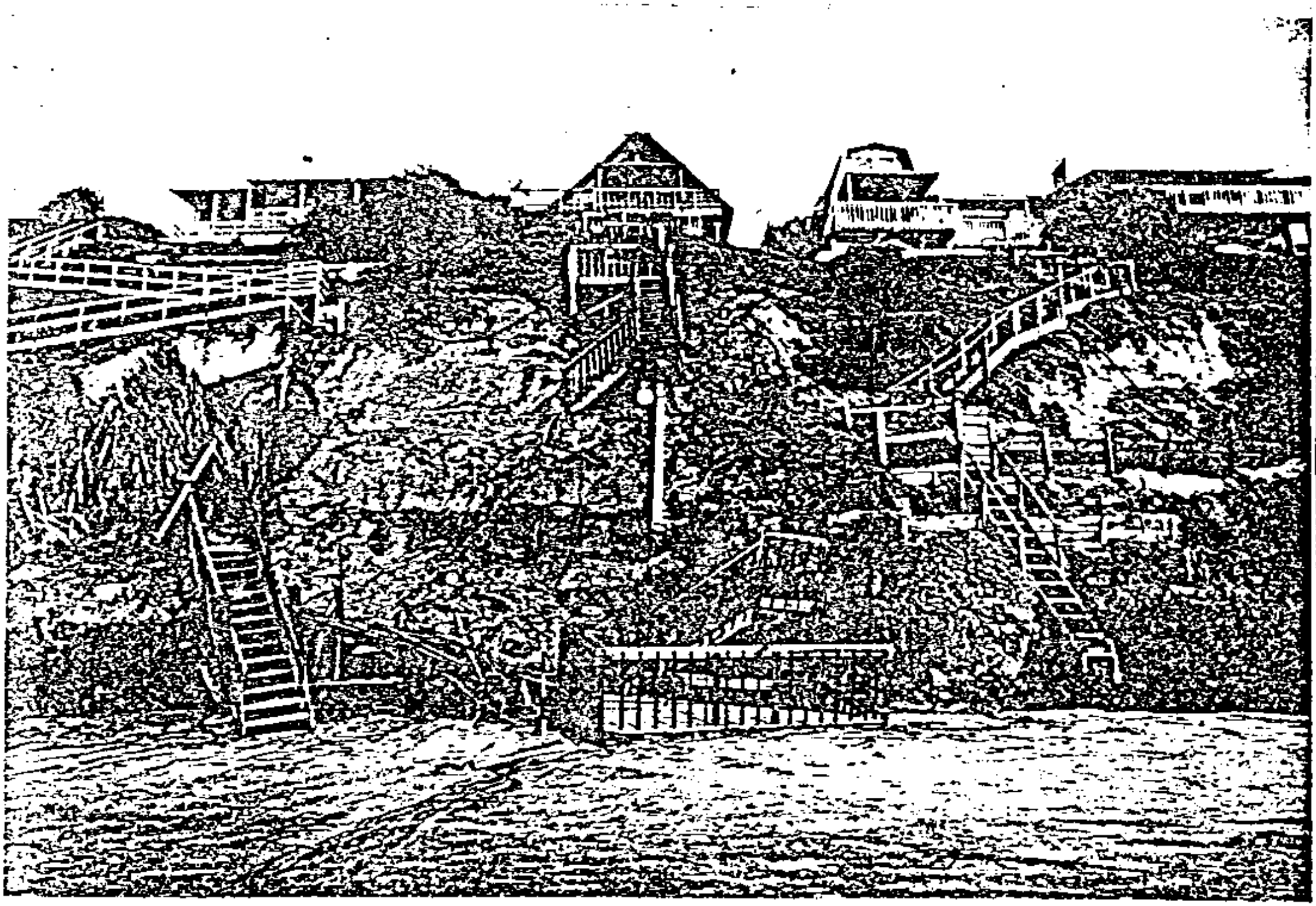
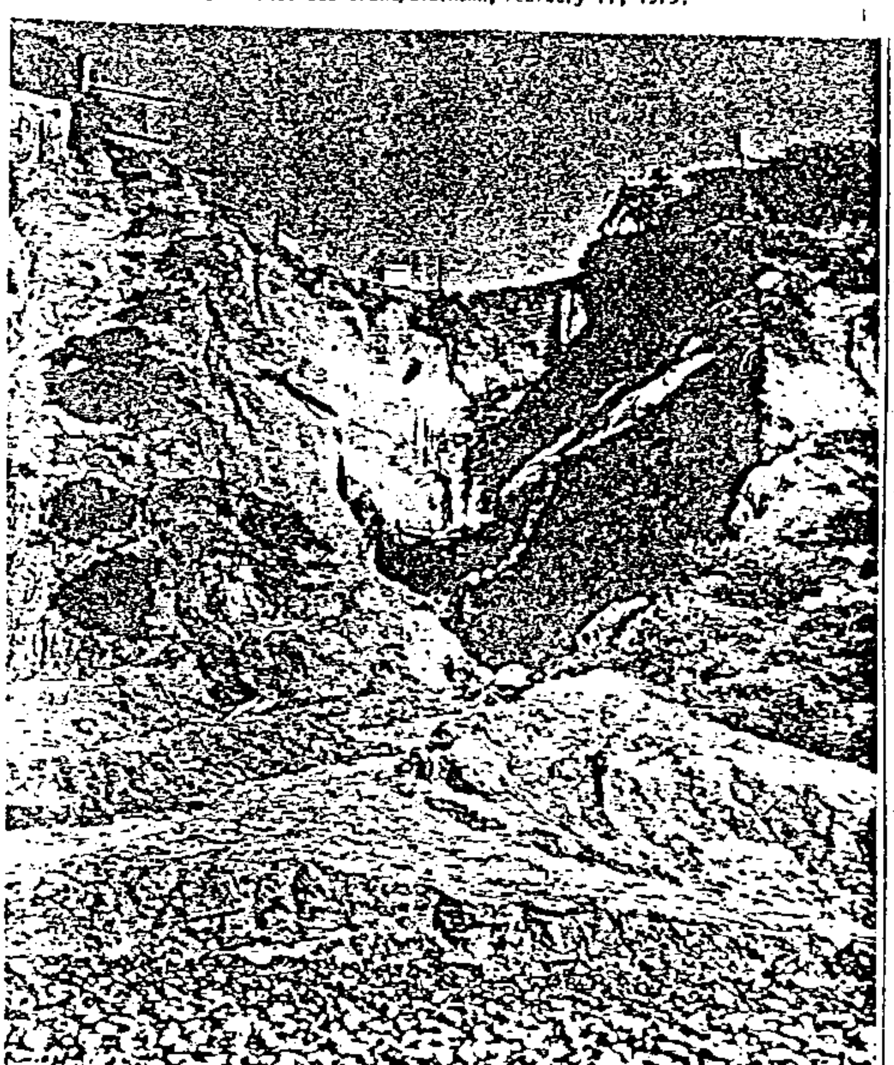


Figure 24. A. January 1978 view of private beach access stairways along the bluffs at Leucadia, California. Note: One large stairway collapsed during aperiod of intense sediment saturation between January 14-20, 1978. Photo: Sea Grant/G.G.Kuhn, January 29, 1978.

Figure 25. A. (Before). 1977 view of storm drain designed to carry surface water down and away from slope face at Carlsbad State Park, California. Photo: Sea Grant/G.G.Kuhn, December 17, 1977.

B. (After). 1979 view at the same location following the collapse of storm drain pipe, which caused severe gullying of the bluff face. Photo: Sea Grant/G.G.Kuhn, February 11, 1979.



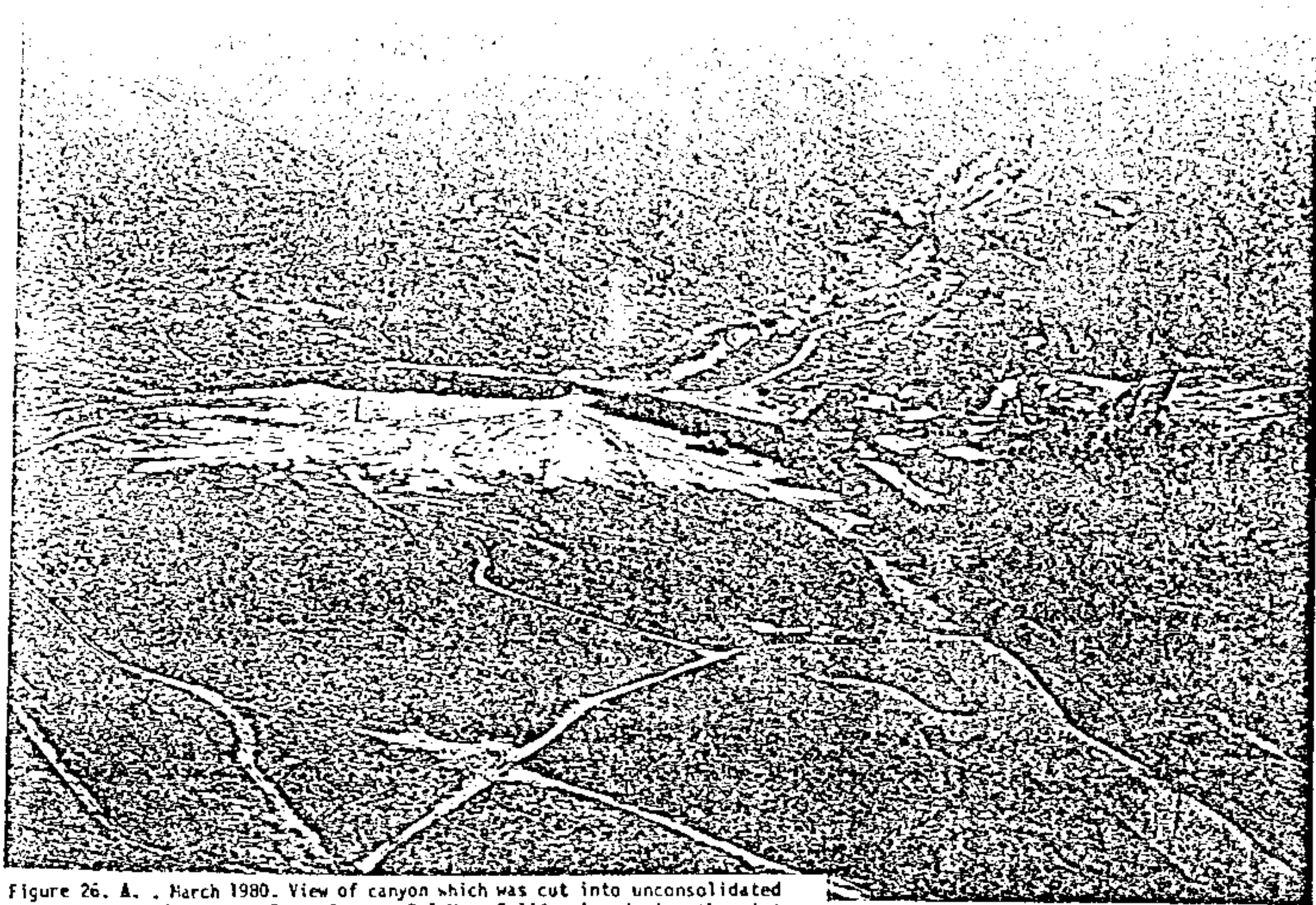
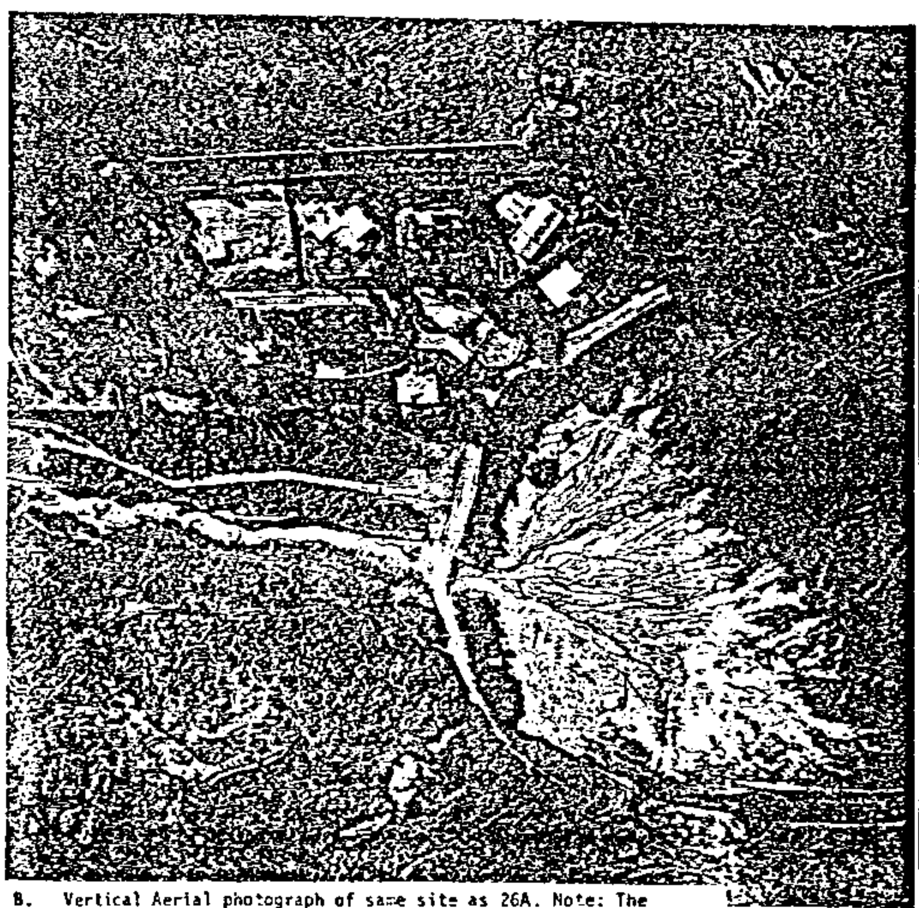


Figure 26. A. . March 1980. View of canyon which was cut into unconsolidated sediments at Crest Canyon, Del Mar, California, during the winter of 1977-1978. Note; an arrow points to a culvert/storm drain upcanyon and under housing subdivision. Photo: SIO/OLR-L.Ford, March 1980.



B. Vertical Aerial photograph of same site as 26A. Note: The large alluvial fan in the center of photo. Photo: SIO/OLR-L.Ford, March, 1980.

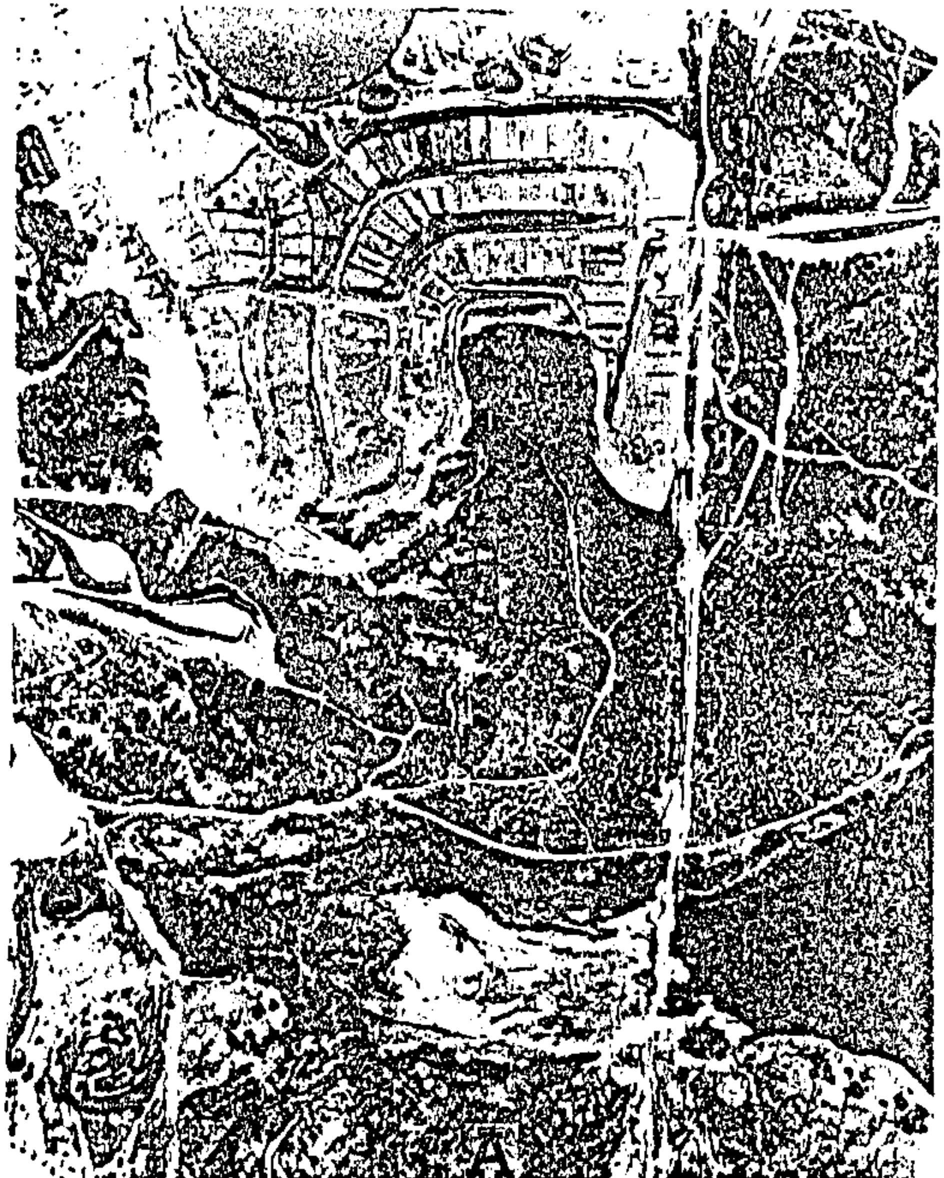
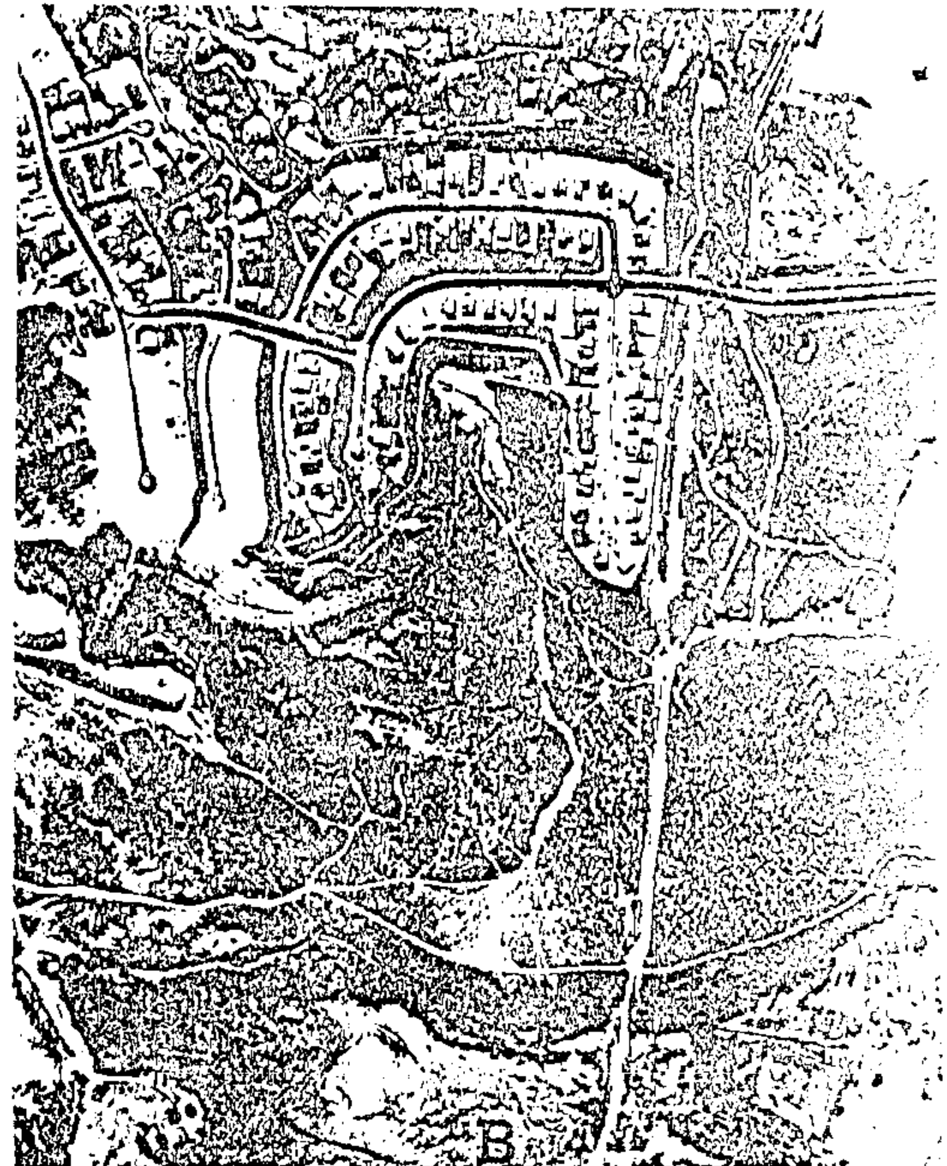


Figure 27. A. 1972 Vertical Aerial photo of subdivision seen in the construction phase adjacent to San Elijo Lagoon, San Diego County, Calif. Photo: Sanitation and Flood Control, County of San Diego., 1972.

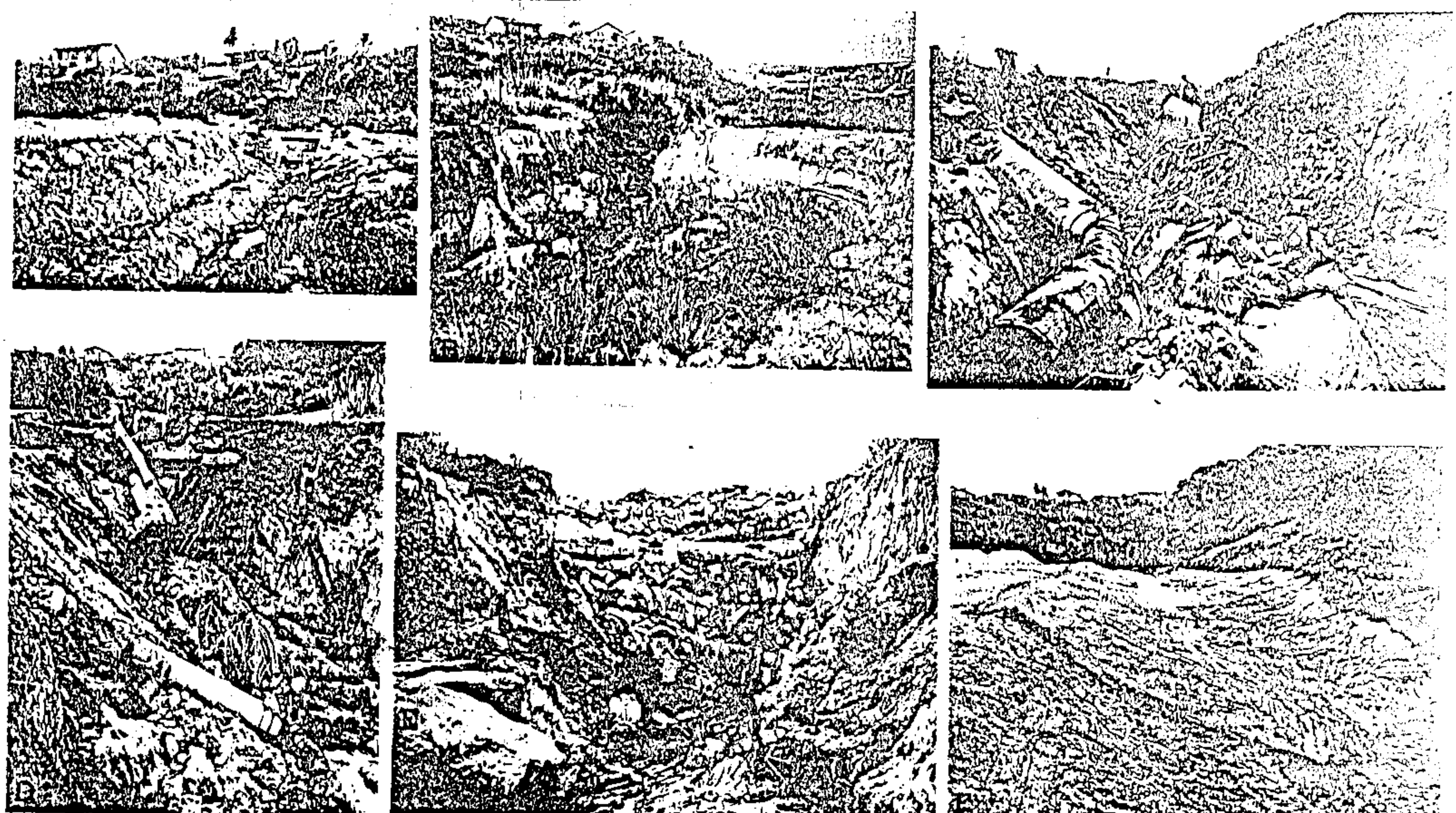


B. 1974 Vertical Aerial Photo of same location as 27A. Note: The large alluvial fan that was developing at this time (Denoted by arrow). Photo: Sanitation and Flood Control, County of San Diego., 1974.

Figure 28. A. View of storm drain located at head of canyon adjacent to recently constructed subdivision. Photo: SIO/OLR-L.Ford, December 23, 1976.

B. View of gully forming in unconsolidated sediments . Located downslope of storm drain seen in fig.28A. Photo: SIO/OLR-L.Ford, December 23, 1976.

C. View of artificial fill and debris used to fill in eroded section of canyon. Note: storm drain located in background and collapsed section of water main in foreground.Photo: SIO/OLR-L.Ford, December 1976.



D. Same view as 28c. Artifical fill has been eroded out, leaving a water main pipe left unsupported. Photo: OLR/SIO-L.Ford, January 1977.

E. Same view as 28C,D. Section of canyon filled in with concrete debris. Photo: SIO/OLR-L.Ford, March 1977.

F. Same location as 28C,D,E; Site again filled with debris and Covered with concrete. Photo: SIO/OLR-L.Ford, 1977.

A sediment settling basin was constructed at the base of an adjacent canyon and street end (Figure 29.A), but the basin did not last long as it was eroded out the following week (Figure 29.B) leaving rock and sandbags scattered; a new gully began to form below (Figure 29.C). Ultimately, the sediment reaches the lower portion of the slope and adds to increased siltation of the lagoon (Figure 29.D).

Bluff-Top Grading

The grading of the bluff tops, in many cases to the edge of the slope, initiates slope failures in the sea bluff and creates drainage avenues along which further surface runoff erodes the bluff face. It has been observed that where existing bluff terrace deposites and soil profiles are left intact, and surface drainage diverted, the bluff edge appears to erode very slowly (Figure 30.A), whereas following development the bluff face is seen to erode (Figure 30.B). In 1972 along South Solana Beach, the bluff top was lowered about 15-18 ft by excavation and surface water was allowed to run over and down the bluff face (Figure 31.A). The upper bluff face and slope continued to collapse during and following heavy rainfall in subsequent years (Figures 31.B, 31.C). The base of the cliff along this site eroded a maximum of 8-10 ft between 1972 and 1978.

A condominium homeowner's association involved with the property threatened at this location has spent in excess of $1.5 million since 1978 in an attempt to forestall and retard erosion. A concrete seawall was constructed along the slope toe and concrete 'cribbing' was installed along specific sites in the unconsolidated bluff face (Figure 31D). In early May 1979, the week that the 'crib wall' was expected to be finished,

Figure 29. A. View of settling basin constructed at the base of adjacent canyon and street end. Photo:SIO/OLR-L.Ford, December, 1976.

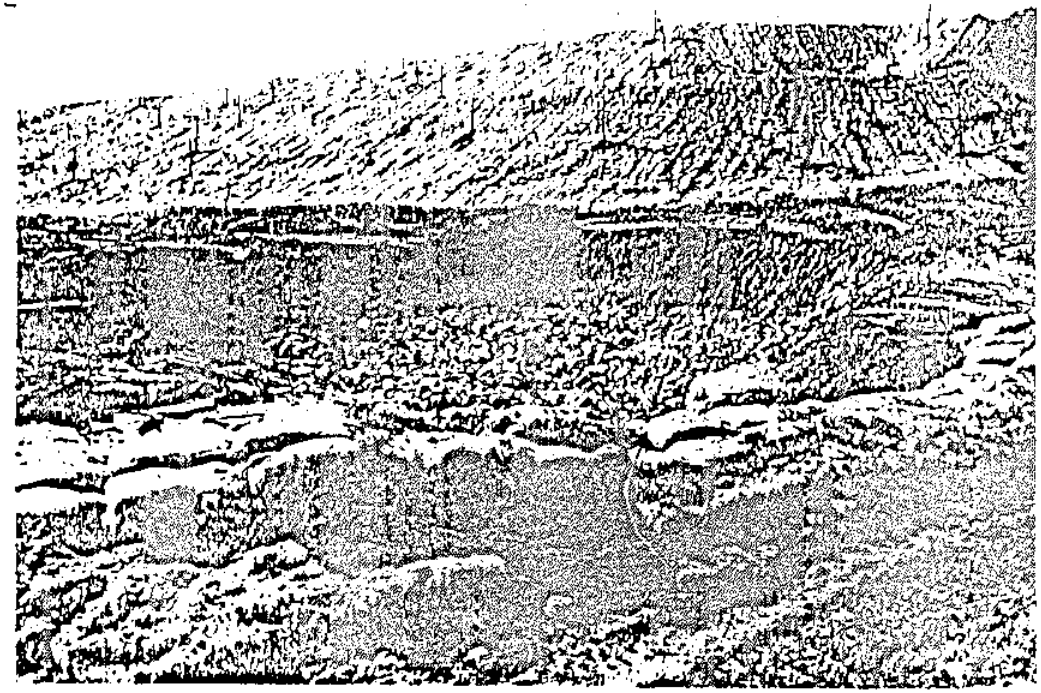
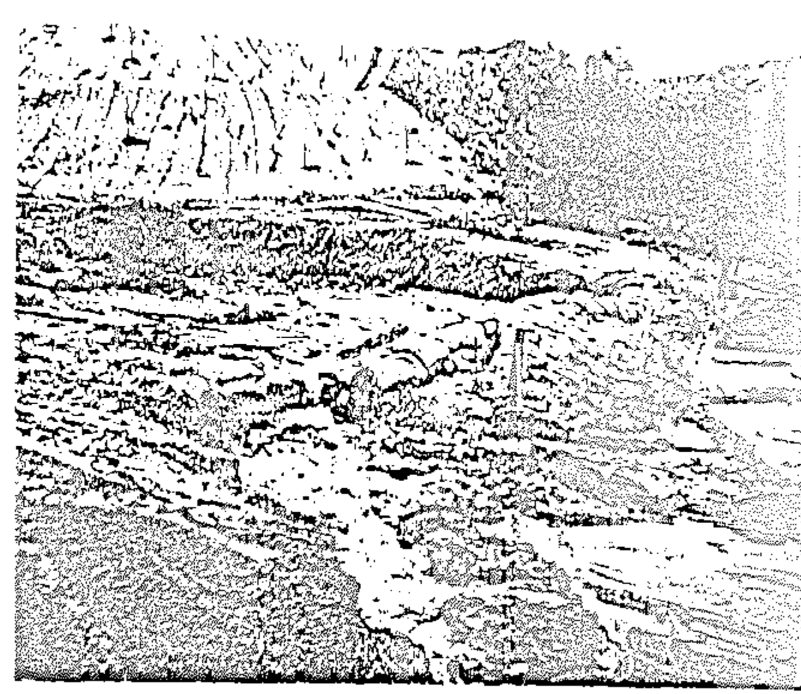


Figure 29. B. Same view as 29A. Siltation basin eroded. Photo: SIO/OLR-L.Ford, January, 1977.



C. Same location as 29B, view looking northeast. Note: sandbags and filter rock have been scattered and a new gully is being cut. Photo: SIO/OLR-L.Ford, January, 1977.

D. View looking across alluvial fan at base of canyon. Photo: SIO/OLR-L.Ford, December, 1976.

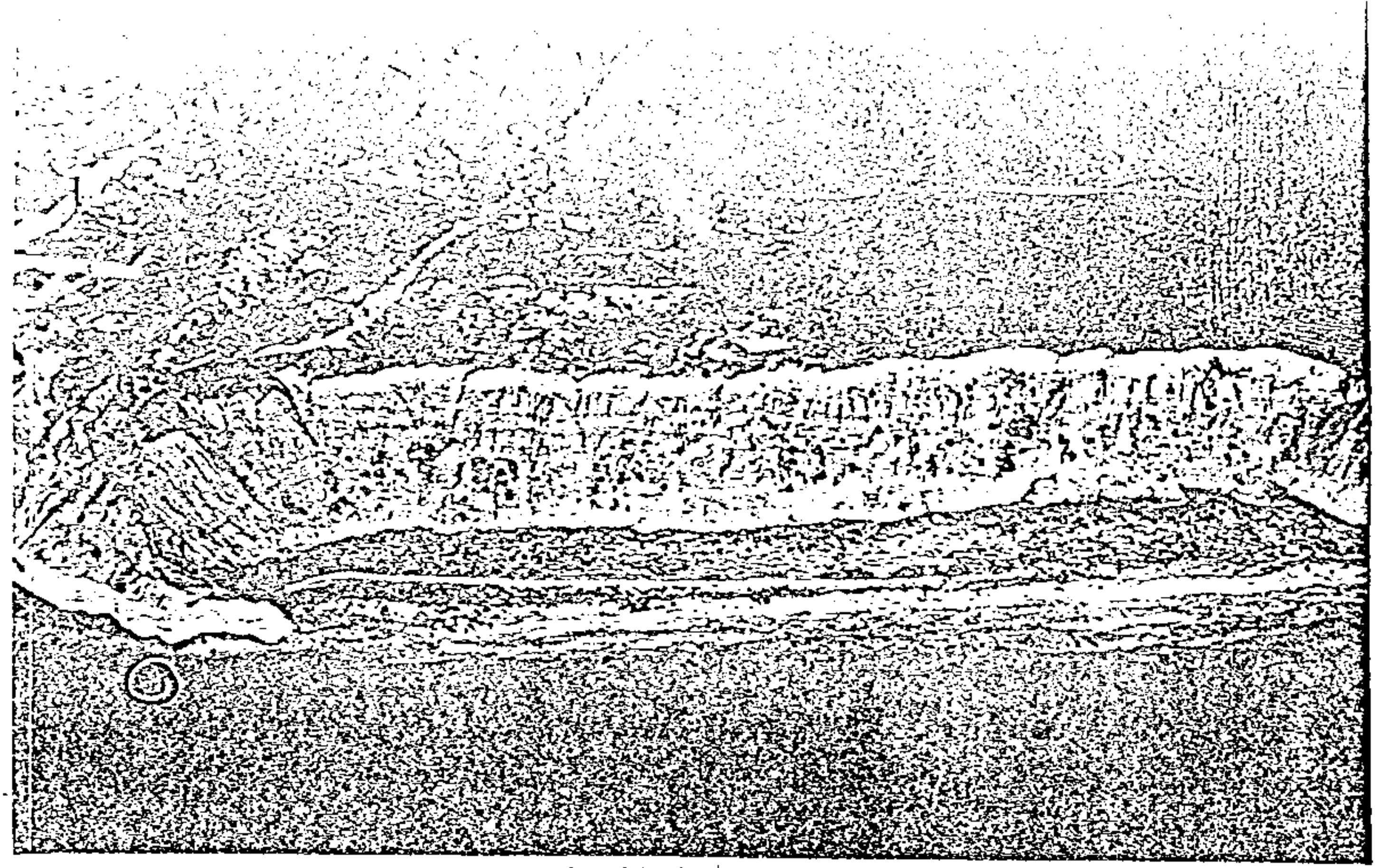
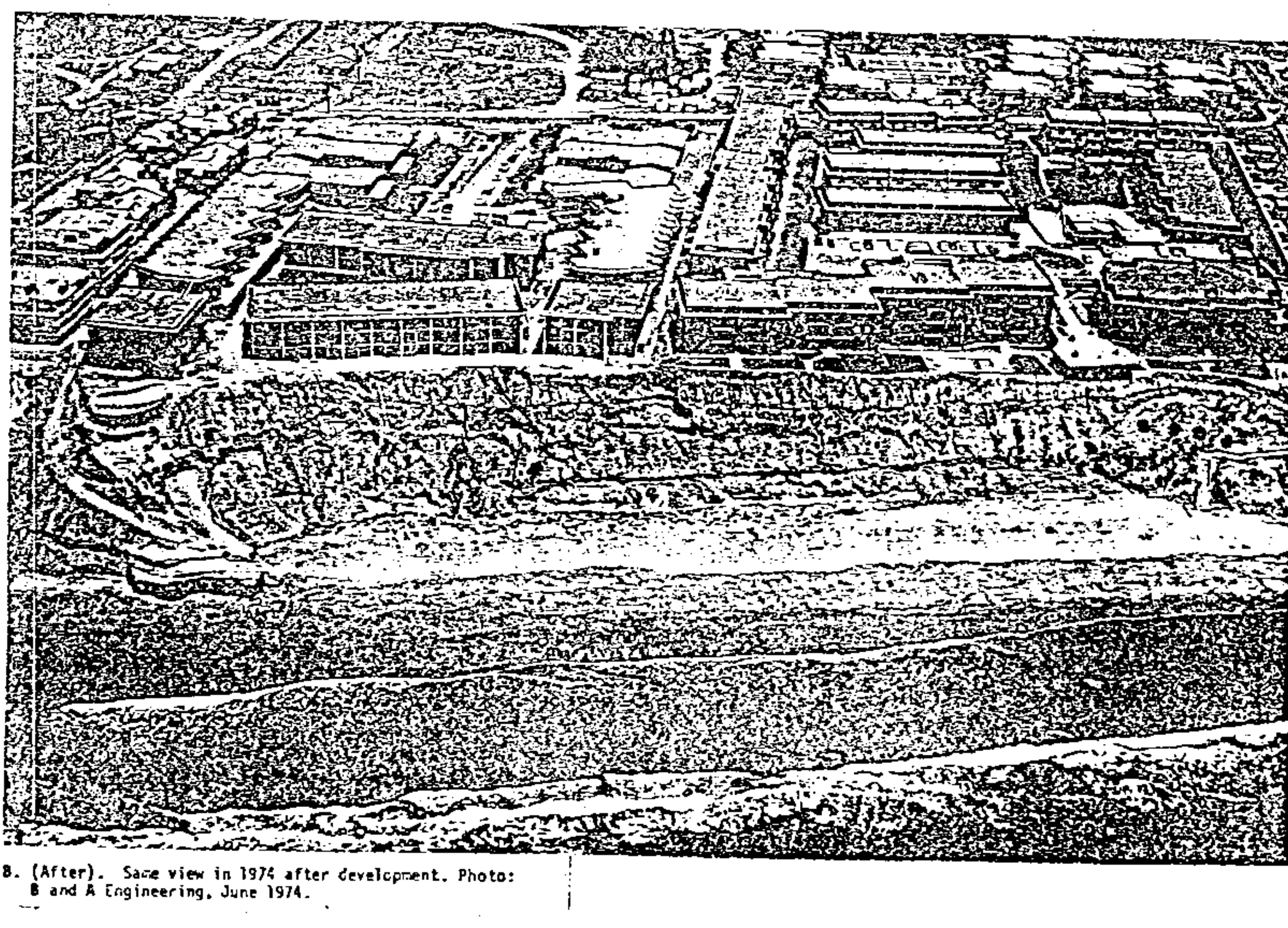


Figure 30. A. (Before). 1954 oblique aerial view of a portion of South Solana Beach, California prior to bluff top development. Photo: U.S.Navy, 1954.



B. (After). Same view in 1974 after development. Photo: B and A Engineering, June 1974.

Figure 31.

1972 oblique view looking East along the bluffs at South Solana Beach, California., taken during the grading of the bluff top. Note: Prior to grading, surface drainage was directed away from the bluff face. In 1972, 15-18 feet of the bluff top was excavated, surface drainage patterns were altered, and numerous slope failures occurred. Photo: California Coastal Commission, 1972.

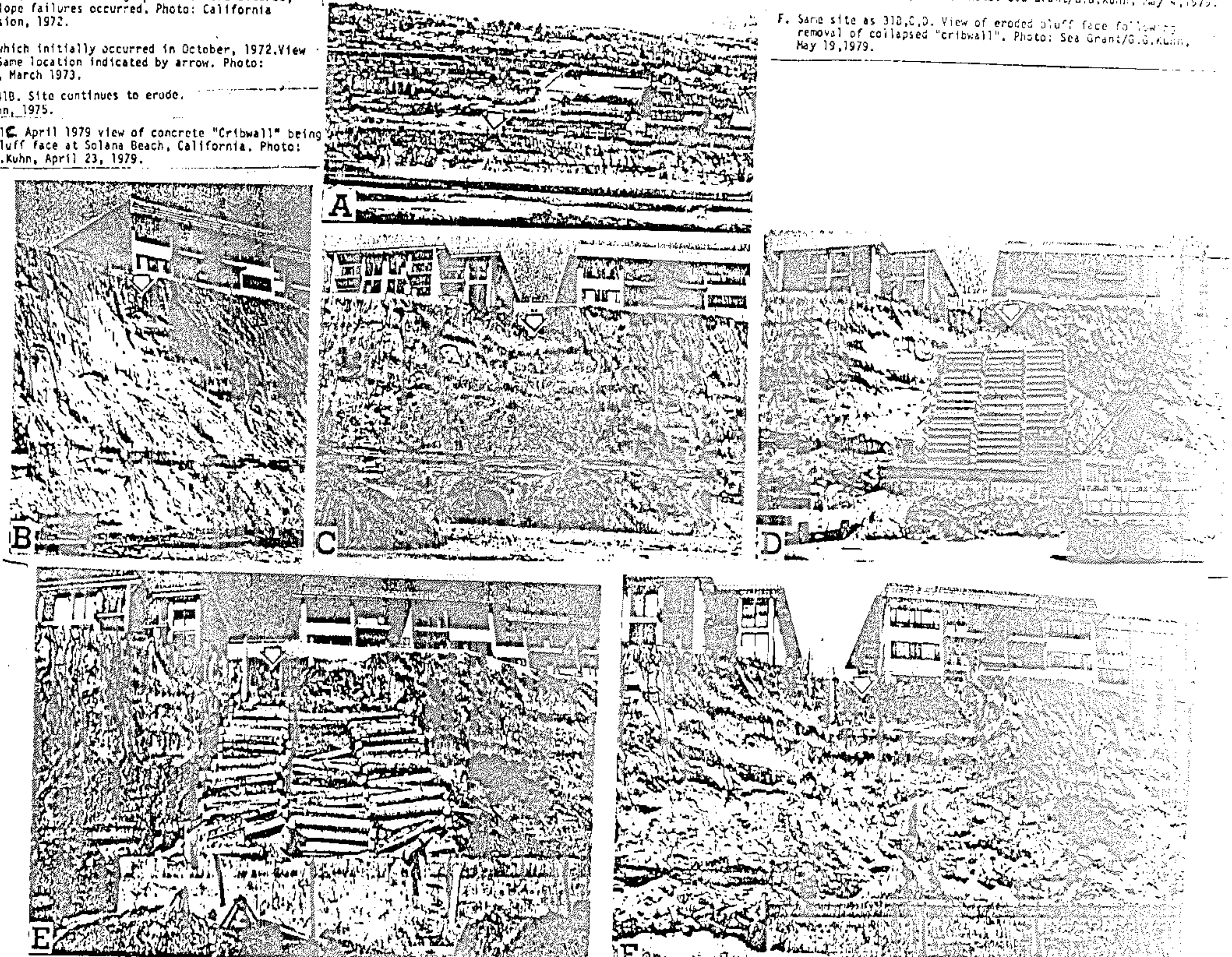
Slope failure which initially occurred in October, 1972. View looking East. Same location indicated by arrow. Photo: A.P.H.Cochrane, March 1973.

Same site as 31B. Site continues to erode. Photo: G.G.Kuhn, 1975.

Same site as 31C. April 1979 view of concrete "Cribwall" being installed on bluff face at Solana Beach, California. Photo: Sea Grant/ G.G.Kuhn, April 23, 1979.

E. May 1979 view of same site as 31C. Note: The cribwall collapsed before it was completed. Photo: Sea Grant/G.G.Kuhn, May 4, 1979.

F. Same site as 31B,C,D. View of eroded bluff face following removal of collapsed "cribwall". Photo: Sea Grant/G.G.Kuhn, May 19, 1979.



the entire structure rotated and collapsed, leaving debris and sediment resting on the seawall below (Figure 31.E). Within a week following the collapse the debris was removed and sections of the sidewalk along the bluff top collapsed. Surface water was seen to flow down the bluff face (Figure 31.F).

These are but a few of the more graphic examples that illustrate man's impact on the coastal zone along San Diego County.

Conclusions

The popular concept of an average coastal-retreat rate for the evaluation of developmental projects is open to serious questioning, at least in the San Diego area. Sea-cliff and bluff retreat is episodic, site-specific and strongly related to the meteorological conditions, induration and stability of rock formations within a given area, and to a combination of erosive agents, both natural and man-induced, that may act upon them.

Both canyon head erosion and landslides are presently contributing significant quantities of sand to the beaches at San Onofre State Park and Camp Pendleton, north of Oceanside. It had previously been believed that most beach sand along the shore in San Diego County was supplied by rivers in flood, with only minor contributions from other sources.

A combination of continuing detailed observations in selected areas, detailed mapping on a large scale, careful review of historical records, and consideration of rock structures and competence along with hydrological considerations gives us the opinion that much of the coastal bluff area of San Diego County is a hazardous area for building, particu-larly near bluff edges.

Acknowledgments

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