DEPARTMENT OF THE ARMY CORPS OF ENGINEERS

BEACH EROSION BOARD
OFFICE OF THE CHIEF OF ENGINEERS

BEACH CYCLES IN SOUTHERN CALIFORNIA

TECHNICAL MEMORANDUM NO. 20

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FOREWORD

This paper was prepared by Francis P. Shepard of the University of California. The report appeared in limited issue as Submarine Geology Report No. 11 of the Scripps Institute of Oceanography, Scripps Contribution No. 474, University of California. It is believed that the results of the investigations outlined herein are of sufficient value to merit publication at this time.

The authority for publication of this report was granted by an act for the improvement and protection of beaches along the shores of the United States, Public Law No. 166, 79th Congress, approved July 31, 1945.

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BEACH CYCLES IN SOUTHERN CALIFORNIA

ABSTRACT

The large waves accompanying winter storms cause a widespread denudation of southern California beaches. During the summer period of small waves the sand is brought back, completing an annual cycle. The beach berms vary in width with the seasonal changes so that in general they are widest at the end of summer and narrowest at the end of winter. Variation in berm width is related also to the spring and neap tides, the berms being widest during neap tides and narrowest during spring tides. The cutting back of the berms often results in scarp formation at the top of the foreshore, the scarps being most commonly developed in the fall during the first period of large waves following the small waves of summer. In addition to offshore-onshore movements of sand there are also important lateral shifts. The sand is shifted along the beach in the direction in which the waves are approaching. As a result of this lateral shift the northwest storms of winter cause the southern ends of some beaches to grow during the winter, and the southerly approach during the summer moves the sand north and therefore produces a cut.

Some partially protected beaches lack seasonal changes. Certain beaches have undergone long period changes which are non-cyclincal; some of these changes are associated with engineering structures. All beaches must have a permanent loss of sand during the period of maximum cut. This loss from pocket beaches enclosed between headlands is believed to be very small since many of them have very meager sources of new sand. The more extensive open beaches, however, have a large loss of sand because of a net seasonal migration along the shore in the direction of dominant wave approach or because of sand settling into submarine canyons. In general this loss is replenished by new sources of sand introduced by floods and cliff erosion.

Introduction

The California state law gives beach rights to owners of coastal property as far as the mean high tide line.[1] Actually, this line, as applied to beaches on the exposed California coast, is constantly shifting, being affected by virtually every high tide during both large and small wave conditions. During the course of a year the mean high tide lines on many beaches shift hundreds of feet seaward and landward.

Several years before World War II investigations of the changes in southern California beaches were begun by U. S. Grant IV, E. C. LaFond

1 Some old land grants extend rights farther seaward.

and the writer. A mass of records had been accumulated by the time that the war interfered with the studies. Late in the course of the war the need for information concerning beach landing operations led to the resumption of the studies under Navy grants to the University of California, both at the Berkeley campus and at Scripps Institution. This work has continued to date under Army and Navy **sponsorship.** As is so often the case, the extension of the beach studies has led to the finding that the simple solutions, which were suggested at first, are not satisfactory. Many of the problems are still unsolved but the data have accumulated to such an extent that some of the salient features which have been observed to date are discussed here and an attempt is made to interpret some of the results.

Acknowledgments

In addition to the help received from Army and Navy appropriations, the writer has been assisted in this work by a large number of individuals. Appreciation is expressed particularly to Messrs. D. L. Inman, E. C. LaFond, and D. B. Sayner and Miss Ruth Yound. Dr. Roger Revelle made helpful suggestions in the revision of the manuscript.

Definitions

The present discussion restricts the term "beach" to sediment-covered areas along the shore which are exposed by the lowest tides and covered by the highest tides and largest waves. Figure 1 illustrates various beach terms used in the present article. This diagram is taken with slight changes from Shepard (1948a, fig. 33) and is also very similar to that which appeared in the Interim Report of the Beach Erosion Board of the U. S. Engineers (1933). The diagram indicates the common features of beaches, coast and offshore, although most beaches lack some of these features at least part of the time. Thus many beaches have no berms and others lack low tide terraces. The berm crest of earlier diagrams is changed in the present treatment to berm edge because crest suggests a high point whereas the outer berm margin may be the lowest part of the berm, especially on fine sand beaches. Seaward of the berm edge the shore slope may be even or a beach scrap may exist (figure 2). The latter may be vertical if recently cut, but the scarp is soon reduced to an angle of repose as shown in the upper scarp of Figure 2 where an old scarp has been partially covered by the building of a new berm. Subsequent erosion has formed a new scarp, cutting away a portion of the double berm. The beach may be horizontal inside the berm edge, it may slope shoreward, or it may slope seaward.

Changes Associated with Breaker Height

Seasonal Changes in Beach Profiles. In southern California the large waves reaching shore come mostly from the stormy area lying 100 to several thousand miles off the coast. On some occasions these waves are augmented by local windstorms which rarely exceed 30 miles an hour. The storms which produce most of the high waves occur during the winter and spring, although occasional periods of large waves are observed during the summer. Most of the high summer waves come from gales in high latitudes in the southern hemisphere, but a few are derived from the hurricanes off and along the Mexican coast.

Since most of the large waves occur in winter and spring, it is not surprising that the beaches are most denuded of sand during those seasons. A comparison of profiles taken along the same range at a series of southern California and central California beaches,[2] (figures 4, 5, and 6) shows striking seasonal differences. Almost all of the beaches in southern California are cut back in winter and spring. The berm virtually disappears from many of the beaches. In some cases the sand cut from the outer berm is piled up and forms a high bern on the inside above the previous berm (see the Pt. Reyes section, figure 5). However, the great bulk of the sand cut from the berm is carried seaward. In some cases fill takes place on the lower portion of the foreshore (see figure 5) but more commonly the sand is carried well beyond the low tide line.

The sections along Scripps Beach (figure 6) show that winter cut takes place along this entire beach. However, the cut is small along sections F to H, and is large in sections C and D. The difference is the result of wave refraction due to the La Jolla Submarine Canyon (Munk and Traylor, 1947). Because of divergence the waves are much lower along sections F to H, which lie on the inside of the canyon (see figure 9), whereas the waves reach a maximum at C and D which represent the zone of convergence north of the canyon. Similarly the cut is very small on the south side of Pt. Sur (figure 5) where the beach is protected from the violent northwesterly storms and very large on the north side where these storms hit with great fury. The southern ends of several beaches build seaward in winter and cut back in summer. These special cases will be considered later.

<u>Berm Variations</u>. Most southern California beaches have berms at least during the season of greatest growth. The berm width is a good index of beach variation throughout the year and the necessary data are more easily obtained than are profile measurements. The variation with season at a series of beaches in southern California is indicated in Figure 7.[3] Many of these graphs do not run through the entire year but they all show the change from winter to summer so that the rest of the cycle can be inferred. It will be observed that the majority of these graphys show summer fill and winter cut, being in agreement with the profiles of Figures 4 to 6. The exception at San Onofre at the south end of the Cove (Fence Station, section G) is particuarly impressive since it has been observed for 5 years and is therefore almost as well established as are the normal changes at the La Jolla beaches. The reverse from normal winter cutting in the vicinity of the mouth of Mission Bay (sections T and U) is probably an unusual occurrence. Fragmentary records of this area taken in other years show summer fill and winter cut. Balboa Pier (section B) and North San Clemente (section E) may have winter fill and summer cut although the evidence is not very conclusive. The beach at Balboa Pier faces south-southwest and is largely protected from the winter storms, whereas it is exposed to the long southerly swell of summer. This may explain the apparent reversal.

2/ See Figure 3 for all beach locations, except those in the La Jolla area which are shown in Figure 9. Shepard (1948b) includes more detailed maps of most of the areas.

3/ Note that the base line for these graphs represents an arbitrary range.

A daily study of the berms along the beach south of Scripps Institution showed some of the factors causing this berm variation. Two major factors are illustrated by Figure 8. The berms are cut back as the result either of large waves or of the high water levels of spring tides. Both of these influences can be detected from the variations of the berm at Scripps Beach. The highest waves indicated on the diagram, June 12th, were quite free from berm cutting because this happened to be a time of very low tides so that the large waves were unable to attack the berm. The effect of the waves on the berm is not as well illustrated as is that of the tide during the period covered by Figure 8, although the slow berm growth in late September during a period of gradual increase in the height of the higher high tide but of small waves is unmistakable evidence. The cuts indicated on about the 19th of October during a period of decreasing tide heights is also a wave effect. In some instances, not shown on the diagram, the berms at Scripps Beach have been cut back 50 feet or more during the first period of large waves following the small waves of the summer. Such large cuts, however, have almost invariably occurred during spring tides.

The variations in the berm width will be seen to be larger at the two stations on Scripps Beach where the waves are higher as a result of convergence north of a submarine canyon than at the station taken at the head of the canyon where the waves are much smaller.

The cutting back of the berm during spring tides and times of high surf takes place as a result of the surge of the waves over the berm edge. Ordinarily the water returns along concentrated channels causing the straight berm edge to become crenulated. After a moderate retreat the ridges between bights are attacked by the convergence of the incoming surge so that the berm edge is again straightened.

It is possible that berms grow seaward by the direct addition of sand at the outer edge, but daily observations of berm growth at La Jolla indicate that the building out of the berms takes place by the development of double berms below the edge of the main berm. If low waves prevail, these double berms start developing during neap tides and are pushed landward during the succeeding spring tides. If the beach is undergoing a period of growth, the new berms are added to the old ones, often with little break in slope between the new and the old. Therefore, during these building periods each semi-lunar tidal cycle may show a new increment added to the old berm.

<u>Scarp Formation in Retreating Berms</u>. It has been observed that the beach berms may retreat with an even slope or the retreat may be accompanied by scarp formation below the berm edge, (figure 2). The scarps are much more common on steep coarse sand beaches where they not infrequently become 5 or 6 feet high. They occur less frequently on fine sand beaches, and, so far as has been observed, never with more than one or two foot elevations. The scarps develop during periods of large waves, particularly if the berms had been built out previously to their greatest extent, as for example at the time of the first large waves following the summer and fall period of berm growth.

There is some evidence that scarp development comes more at times of neap tides than at spring tides.

During local storms where short period waves cause heavy surging over the edge of the berm, scarps are less frequently developed. Thus profile measurements on Cape Cod just before and just after a relatively weak hurricane which it the coast in 1945 indicated a straightening of the slope (Shepard, 1949a, figure 19). Despite the violence of the storm and the great retreat of the berms, no scarps were discovered.

So far as can be told from available information, scarp formation is the result of concentrated surf action on the slope below the berm edge. Apparently the scarps develop on steep beaches better than on gentle, because the waves break nearer the berm edge and therefore violent cutting is more likely. The backwash down from the berm edge is necessarily more violent on a steep beach than on a gentle beach. The foreshores are always steepest after the berms have been extended seaward so that this state favors scarp formation. During neap tides the waves tend to develop the most concerted position of attack and thus to produce scarps.

Beach Changes Related to Wave Approach

Shifting of Pocket Beaches. Years of measurements of La Jolla beaches have shown numerous examples of cut at one place and contemporaneous fill at another. The shifts which take place in the small pocket beaches along the rocky coast which extends south from La Jolla are particularly impresive (figure 9). Boomer Beach, near La Jolla Cove, shows the most rapid transformations of this type (figure 10). On occasions during the course of 24 hours a 5 to 10 foot thickness of sand has virtually disappeared from one end of the beach, while at the same time the exposed rocks at the other end have become buried in sand to depths ranging up to about 8 feet. In general these changes take place more gradually as shown by measurements at 4 points evenly spaced along the beach (figure 11).

The shifting of sand along Boomer Beach is very definitely related to the direction of approach of the waves. This was clearly indicated by a period of southerly approaching swells in September 1949 which gradually modified the beach, cutting away the south end and building up the north. Later northwesterly approaching waves were accompanied by a beach change in the opposite direction. Since the beach faces northwest, the southerly swell, after refraction, approaches the beach from the south side and thus induces longshore currents to the north, accounting for the sand shift in that direction. Since the northwest waves approach essentially normal to the beach, the reason for the shift of sand to the south is not as obvious. However, these waves from the northwest carry water over the reef lying outside the north end of the beach and this water can escape only to the southwest along the shore, producing southerly currents. The longshore currents under the two directions of approach produce rip currents as follows: (1) near the north end of the beach but south of the reef with southerly waves, and (2) near the south end of the beach with northwesterly approach. The longshore currents transport sediment towards these outmoving rip and small counter currents carry a portion of the sediment landward inside the rips causing a local building of the beaches. This explanation is probably far from complete but must suffice while awaiting more information from concurrent studies of bottom water and sand movements using current meters and sediment traps.

Casual observations of shifts of this type might lead one to the belief that the waves simply carry sand along the beaches from one point to another, as suggested by Leypoldt (1941), rather than move it seaward and shoreward. Such an idea, however, loses its force when the effect of any unusually large waves is observed (figure 11). At such times the beaches are cut back by wave attack at all points where sand exists at the initiation of the waves.

In the pocket beach known as Windansea (see figure 9) there is the same shift from north to south in winter. The magnitude and clarity of these changes at Windansea is indicated by profiles made at two-week intervals (figure 12). The appearance of these pocket beaches is changed so completely that one unfamiliar with the local setting might think that they represented different localities.

The changes at Windansea Beach differ slightly from those at Boomer Beach because there is a submerged ridge off the center of the beach which causes wave convergence and piling up of water along the shore directly inside, similar to that described elsewhere for the convergence at Scripps Beach (Shepard and Inman 1950). When the waves approach from the northwest along the north-south trending beach at Windansea, the water from the convergence moves dominantly south and the principal rip current extends seaward near the south end of the beach. This in turn is accompanied by an eddy which builds up the sand at this end of the beach. The southerly approach reverses the direction and position of these currents, as would be expected.

<u>Shifting of Beach Near a Submarine Canyon</u>. The long, relatively straight beach which extends for a mile south of Scripps Institution (figure 9) is under the special influence of waves refracted by La Jolla Submarine Canyon. In general the maximum erosion occurs at the wave convergence north of the canyon. Water is moved shoreward in this zone of convergence and the resulting rise in sea level develops longshore currents flowing out from the convergence in both directions (Shepard and Inman, 1950, figure 3). As a result the material stirred up by the waves is moved in either direction. Munk and Traylor (1947, figures 8-12) have shown how the zone of wave convergence migrates according to the direction of approach and the period of the waves. The seasonal variation in the direction of wave approach changes the position of beach cutting.

A portion of the material cut away at the point of convergence tends to be deposited at a position which lies midway between the large rip which turns seaward from a feeder current derived from the convergence and a small rip which moves out from the divergence (see Shepard and Inman, 1950, figure 3). In this zone there are weak counter currents which carry material in to the beach. The zone is marked by a point of sand which is occasionally covered by great masses of kelp and eel grass. This zone of weak counter currents also shifts to some extent with the seasonal variation of wave approach.

In southern California a change in direction of wave approach usually occurs in the fall. During the summer most of the large waves have been coming from the southern hemisphere. Westerly and northwesterly approach set in during occasional storms in the fall and are repeated at infrequent intervals during the winter and spring. In spring the approach again becomes more southerly. The result is that in general the convergence is farther to the south during the fall and winter than in the spring and summer. Similarly the inter-rip zone of deposition is also shifted in the same direction. These effects have been shown during many years of measurement of sand height along the sea walls. Changes over a period of 7 years are indicated in Figure 12 where station D represents the convergence during the winter and station B the convergence zone during the spring.

Actually the effect of large breakers is to produce cut all along the Scripps Beach, as was shown to be the case at Boomer Beach. However, the cutting is greater at the convergences and smaller at the inter-rip zones and at the divergences.

Unusual Changes at San Onofre. The cove at San Onofre (Shepard, 1948b, figure 11), 50 miles north of San Diego, was one of the places chosen for beach profiles started in 1945. At the end of the period of measurements one station at the south end of this cove had proven to have a reversal of the usual winter cut and summer fill. As a result observations have been continued at infrequent intervals up to the present time. During the four and a half years of berm width observation, the same cycle has been repeated annually (figure 7, section G). Superimposed on the cycle is a net retreat of the coast in this area, the bank being cut back a little each summer.

The situation is somewhat similar to that at the south end of Boomer Beach where the same reversal takes place. The San Onofre locality, called "Fence" (because of a barbed wire fence remnant), lies at the south end of the cove. Outside this part of the beach there is a broad boulder-strewn terrace which is laid bare in part during the lowest tides. This terrace is more pronounced to the south where it produces conditions for good surf board riding at high or immediate stages of the tide. To the north, however, there is deeper water adjacent to the beach although similar boulders are exposed in a fringe below the sand at low tide.

It was supposed at first that the winter berm building at this unusual station must be balanced by a cut at the north end of the beach and the summer cut at "Fence" station by a fill to the north. However, this has not proven to be the case. A station called "Crescent" in the center of the cove and a station called "North San Onofre" at the north end have been observed for the past three years. These stations have shown very little change and northing which could be called seasonal. It was thought also that there might be a reversal in longshore currents with the coming of winter. Measurements of the longshore currents made at 10 day intervals for a year, however, failed to show any appreciable difference (Shepard, 1948b, p. 33). However, the change must be related in some way to the change in direction of wave approach during the seasons.

Beaches Lacking Cyclical Changes

The berm variation diagram (figure 7) shows a number of cases where beaches appear to have undergone little if any seasonal variation. La Jolla Cove (figure 9) a locality not included in the diagram because measurements are not available, has been observed on many occasions over the past 15 years. The narrow beach at this cove varies only slightly in width during the year and, unlike Boomer Beach which it adjoins, is not cut down to underlying rocks. When large waves are approaching from the right direction (west-northwest, long-period being the best), waves sweep high up onto the beach, sometimes reaching the cliffs at high tide. On such occasions the beach is steepened and occasionally small scarps are cut. When the waves have subsided, the beach grows back very rapidly to normal. The removal of the entire beach would constitute no greater cut than takes place during one storm at Boomer Beach. However, the situation differs radically from Boomer Beach in one respect. A reef on the outside, which is exposed at low tides, prevents the waves from breaking directly on the Cove beach.

Less certain evidence suggests that Shell Beach (figure 9), south of Boomer Beach, is not greatly affected by winter storms. This beach like the Cove beach, is protected by off-lying reefs. Similarly Casa Beach, which is protected by the small sea wall at the Casa de Manana Hotel and is therefore not attacked by large waves, shows little seasonal variation. Casa Beach did not exist until the sea wall was built. The wall was constructed to form a semi-protected pool for swimming, but, because it has stopped the summer sand movement to the north, the pool has gradually filled in. Sluices which allowed water access from the ocean to the south proved to be too small to prevent southward migrating sand from blocking this circulation so that a natural trap developed which held sand carried in from the northwest. The beach now nearly fills the pool. On rare occasions cutting on the south side of the wall exposes the sluices (figure 14) and allows a small portion of the sand to escape, but this has never cleared out the sand fill nor appreciably influenced its size.

Long-period Changes

In addition to seasonal changes or storm cutting, long-period variations occur on some of the beaches. One of the most puzzling of these is the apparent growth of the beach south of Scripps Institution. Part of the evidence for the growth comes from accounts of old residents who claim that in winter it was not unusual to find cobbles all along the beach. Confirmation of the denuded state of the beach comes from old photographs (see Shepard and Grant, 1947, pl. 3, figure 1) although the evidence is not as complete as one would like. The cobbles were exposed during the winters and springs of 1937[4] to 1946, but never to the extent described by the older residents. Since that time the exposures of cobbles have become very restricted in area and of very short duration. In the past two years (winter and spring 1948 to 1950) only scattered cobbles have been seen. Furthermore, the beach profiles show a great cutting even at the points of wave convergence

4/ When my observations began.

The cause of the failure of the beach to cut deeply during the storm season in recent years is not readily apparent. The waves in recent years appear to have been of comparable size to those existing when the beach was considerably denuded. Furthermore, there have been no heavy rains since 1938 which could be expected to provide large supplies of sand for beach building. Erosion of the alluvial cliffs, which is probably another large source of sand for the beach, has been decreasing in recent years and has entirely stopped along two-thirds of the cliffed area because of the building of sea walls. Accordingly, there is no clearly evident cause of the growing stability of this beach. In addition to this increasing stability, the sand along Scripps pier is slightly shoaler than in former years and also the troughs and bars formerly found along the pier have not been detected in recent years (Shepard, 1949b).

Changes Associated with Engineering Structures

The unusual summer cut near the entrance to Mission Bay referred to previously is possibly the result of dredging in Mission Bay which strengthened the currents in the approaches to the bay. Continuing changes can be expected because of the building of the breakwaters connected with the new harbor and the San Diego River drainage channel. The extensive cutting reported in recent years at Oceanside may be associated with the jetties at Camp Pendleton to the north. A serious cut at Redondo in the Los Angeles area is the result of a breakwater which prevents introduction of sand from the north so that the cutting of winter storms is not replaced by a summer fill. The cutting is accentuated because the locality is just north of a submarine canyon head.

Relation of Beach Changes to Grain Size

Observations of the southern California beaches indicate that changes are much more rapid where the sand is coarse than where it is fine. The steep, high scarps are also confined to coarse sands. For example, the beaches around La Jolla Point which have sand averaging about 0.5 mm. in median diameter undergo much faster changes than do the long, fine-sand beaches like Scripps Beach and the beach at Mission Bay. The complete disappearance of the coarse sand of the northern portion of Boomer Beach in one storm has been mentioned previously.

As a cause for the rapid erosion of coarse sands we can point to the steep foreshore which causes the waves to break much closer to the berm edge. Also the backwash gathers more momentum running down the steep slopes than down the gentle slopes of fine sand beaches.

Conservation of Sand Supply

The observation of beach cycles, particularly in the La Jolla area where 15 years of observations are available, has shown that the beach is cut every winter and built up every summer without any evident decrease in the total sand. This is partially substantiated by profiles of the maximum cut and maximum fill along the Scripps

Institution pier over a period of 6 years (figure 15). Many of the beaches of California have been mapped with sufficient care by the Coast and Geodetic Survey for the past 50 or even 75 years to tell whether or not there is any large net change. Comparisons indicate that very little has happened during this period except where shifts have resulted from the building of jetties and other engineering structures. This conservation of the sand supply must indicate either that new sand is being added as fast as old is lost or that the same sand washed out during the winter is carried back during the summer.

Beaches like Boomer in La Jolla appear to have little source of new sand because there are no appreciable streams entering even during floods, the cliffs are being eroded very slowly (probably not more than an inch in 10 years) and the jutting rocky points on both sides prevent access of new supplies. Therefore, it appears virtually certain that the sand removed during the winter must return during the summer. It might be supposed that in an area where the prevailing direction of wave approach alternates with the season, the sand supply would be conserved provided that the components of wave energy along the beach from the two directions were approximately equal. Actually there are few, if any, areas in southern California where this condition exists. Boomer Beach, which faces northwest, may be an exception but even here the principal cause of sand conservation is probably the jutting headlands which prevent longshore migration. Elsewhere, along more open beaches, the southerly swell in summer probably balances only a part of the south drift coming from the northwest storms of winter. This is particularly true along portions of the coast extending east and west, such as the Santa Barbara area where the waves approach predominantly from one direction throughout the year. Therefore a large, new supply appears to be necessary to take the place of the sand drifted along the coast during the period of beach cutting. This is demonstrated by the disastrous effects of the building of the Santa Barbara breakwater. Shortly after it was built the beaches to the east became deeply eroded because the source of sand from the west was removed.

Permanent loss of sand from the beaches must occur also where submarine canyon heads extend in close to the coast. The repeated measurements of profiles at canyon heads show that fill is invariably followed by deepening (Shepard 1949b). Evidence from Redondo pier and from the pier at Moss Landing shows that the changes at the canyon heads are relatively rapid (Shepard and Emery, 1941, pp. 94-103), probably occurring as slides or "mud" flows of the accumulated sediment. This process carries material out to sea where it must certainly get beyond the reach of the shoreward push exerted by the waves during summer conditions. The introduction of new sand from an up-current area explains the persistence of the beaches in the canyon areas. During northwest storms large quantities of sand are carried south along the coast. After the storm waves have decreased, the portions of this sand which have not fallen into the canyon creep shoreward, building up the beaches. An indication of the importance of this source comes from Redondo where the construction of a breakwater cut off the sediment from the north of Redondo submarine canyon. As a result the sand which was carried into the canyon could not be replaced. The beach has been entirely removed at this point and deep water extends up to the shore which is protected by large blocks of rock.

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FIGURE I

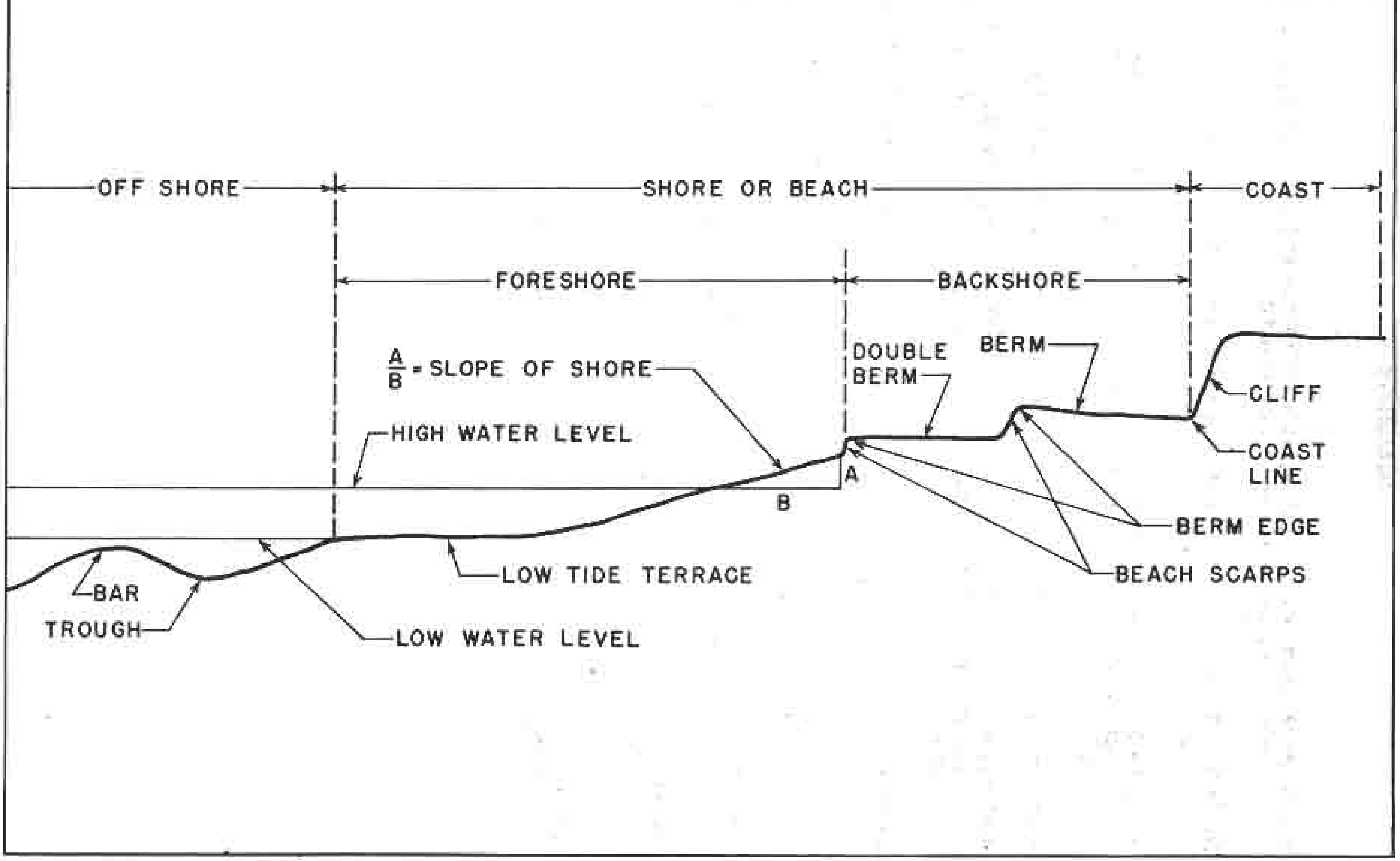
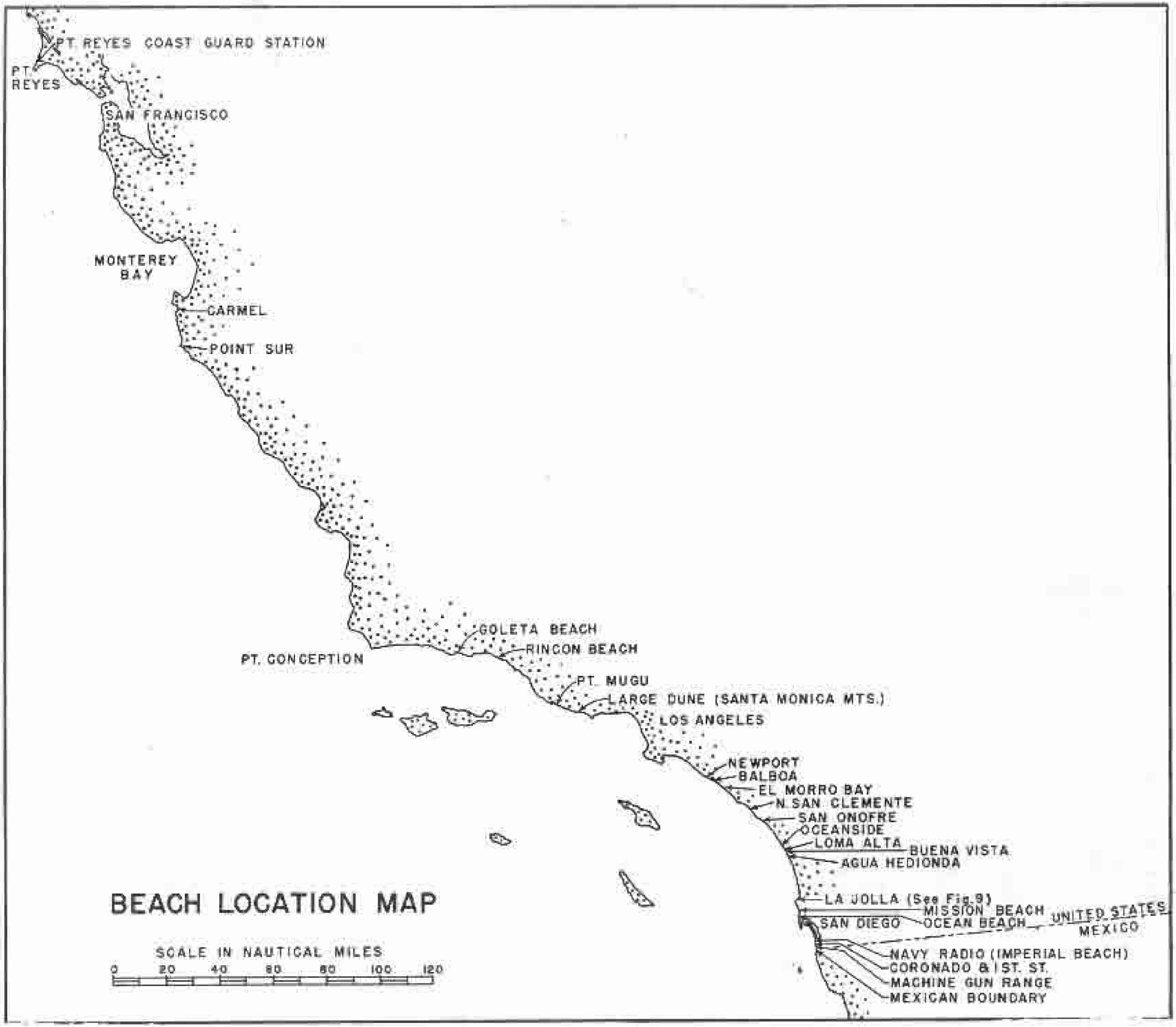
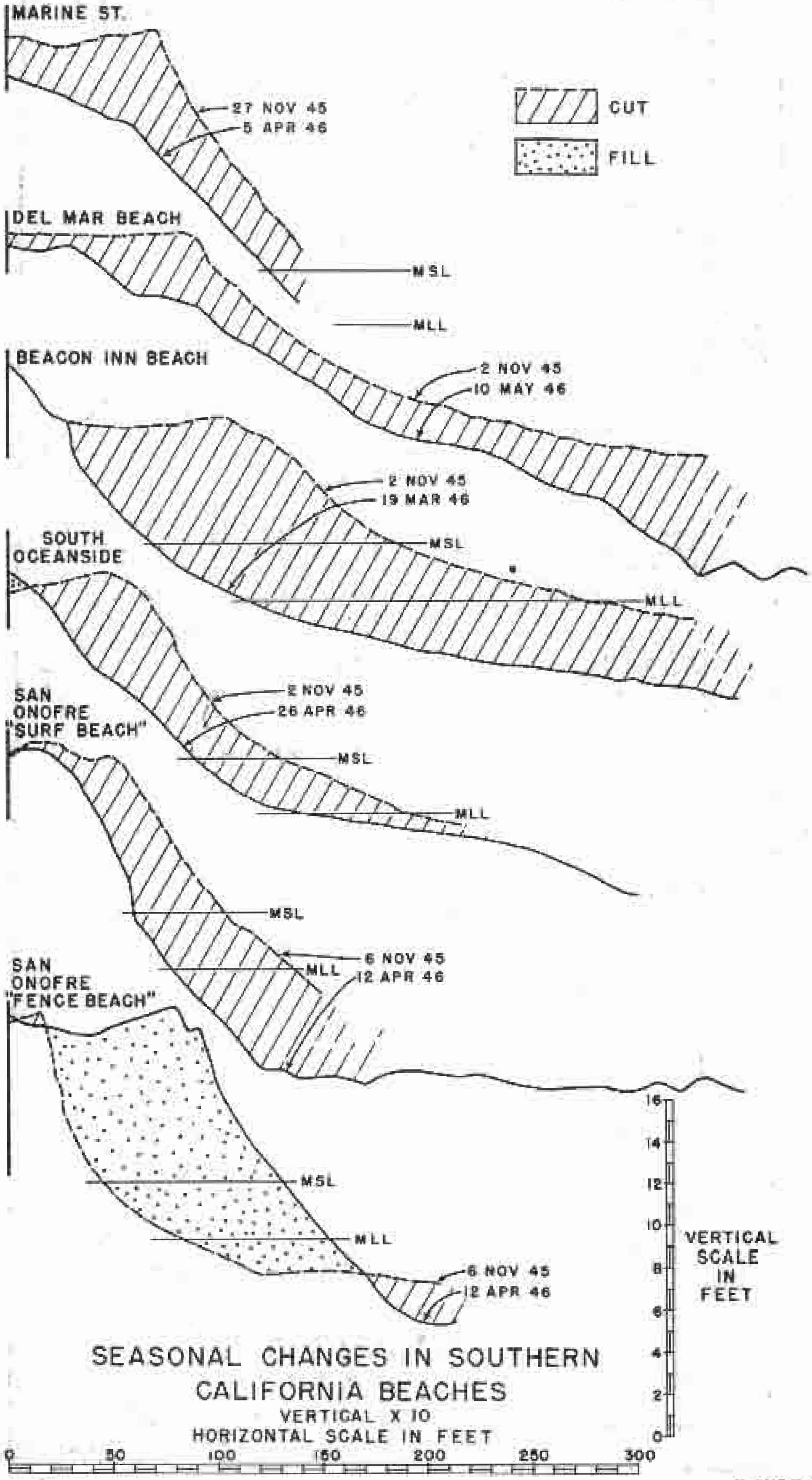

OFF SHORE
SHORE OR BEACH
COAST
FORESHORE
BACKSHORE
A/B = SLOPE OF SHORE
DOUBLE BERM
BERM
CLIFF
COAST LINE
HIGH WATER LEVEL
A
B
BERM EDGE
BEACH SCARPS
LOW TIDE TERRACE
BAR
TROUGH
LOW WATER LEVEL

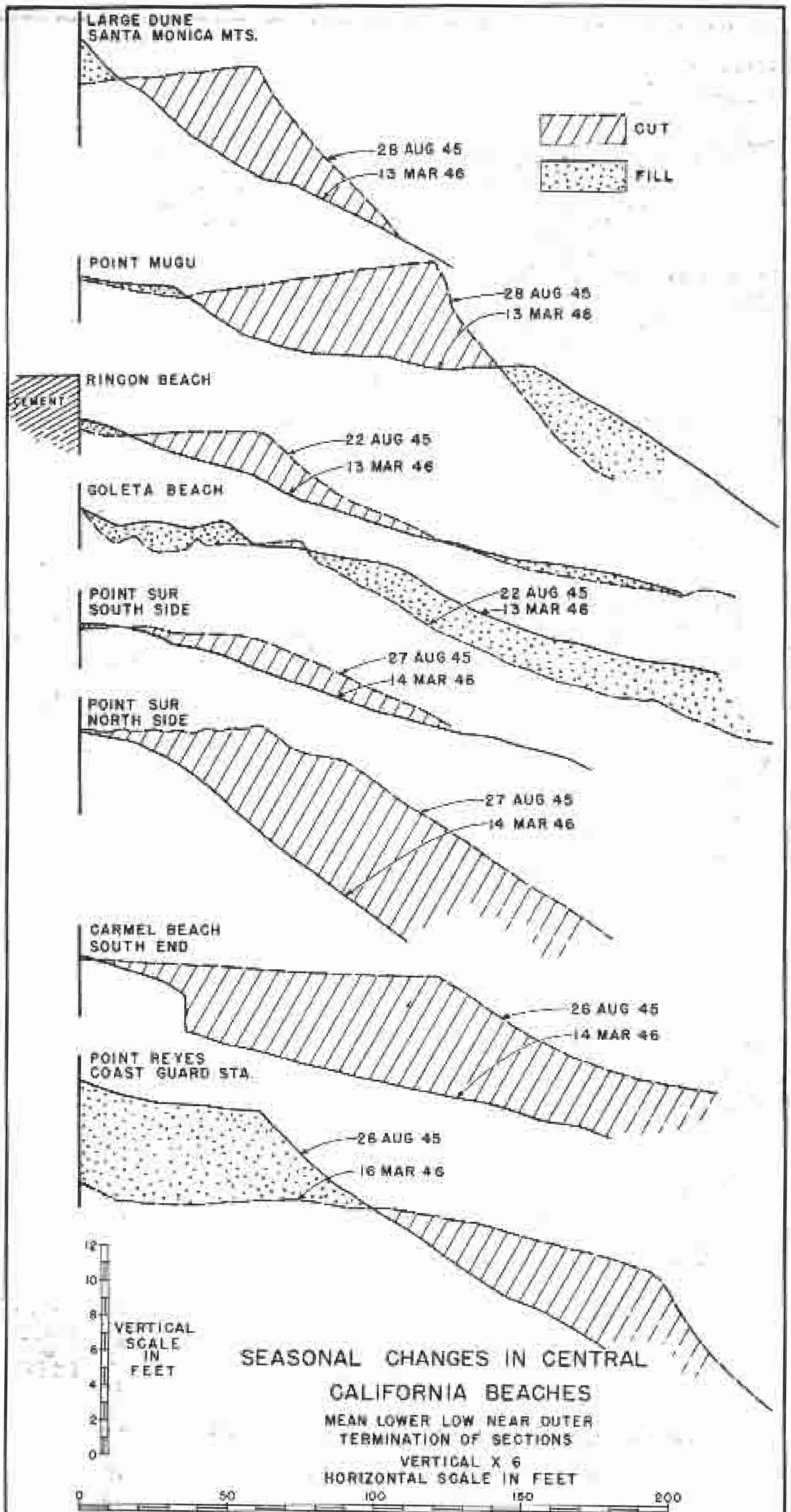
FIGURE 2. SCARPS AND BERMS AT WINDANSEA BEACH. OLD SCARP LARGELY BURIED BY THE DOUBLE BERM AND LOWER SCARP FORMED SUBSEQUENTLY.


PT. REYES COAST GUARD STATION
PT. REYES
SAN FRANCISCO
MONTEREY BAY
CARMEL
POINT SUR
PT. CONCEPTION
GOLETA BEACH
RINCON BEACH
PT. MUGU
LARGE DUNE (SANTA MONICA MTS.)
LOS ANGELES
NEWPORT
BALBOA
EL MORRO BAY
N. SAN CLEMENTE
SAN ONOFRE
OCEANSIDE
LOMA ALTA
BUENA VISTA
AGUA HEDIONDA
LA JOLLA (See Fig.9)
MISSION BEACH
SAN DIEGO
OCEAN BEACH
UNITED STATES
MEXICO
NAVY RADIO (IMPERIAL BEACH)
CORONADO & 1ST. ST.
MACHINE GUN RANGE
MEXICAN BOUNDARY
BEACH LOCATION MAP
SCALE IN NAUTICAL MILES
0 20 40 60 80 100 120



SEASONAL CHANGES IN SOUTHERN CALIFORNIA BEACHES
VERTICAL X 10

FIGURE 4



SEASONAL CHANGES IN CENTRAL CALIFORNIA BEACHES

MEAN LOWER LOW NEAR OUTER TERMINATION OF SECTIONS

VERTICAL X 6

FIGURE 5

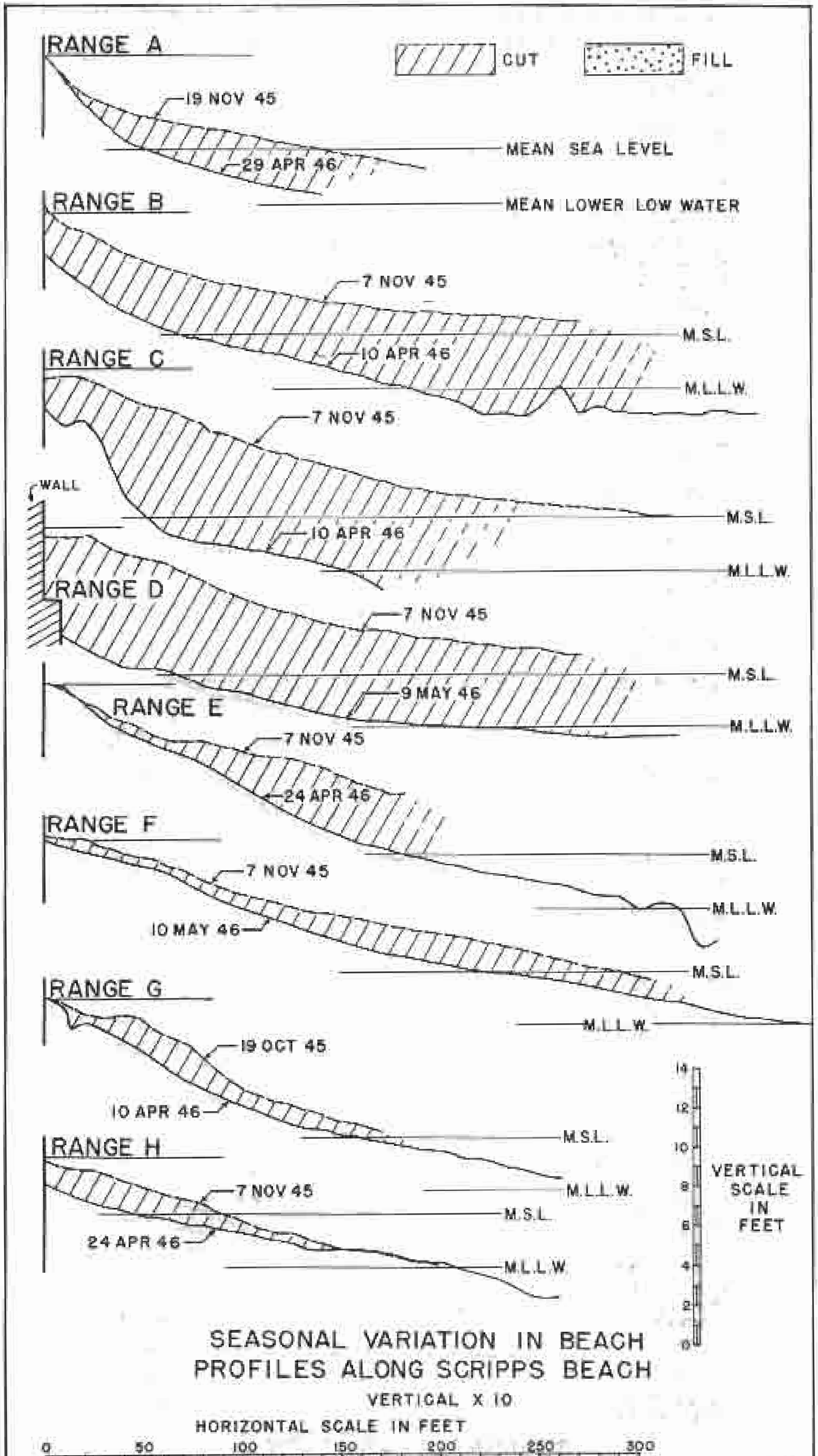
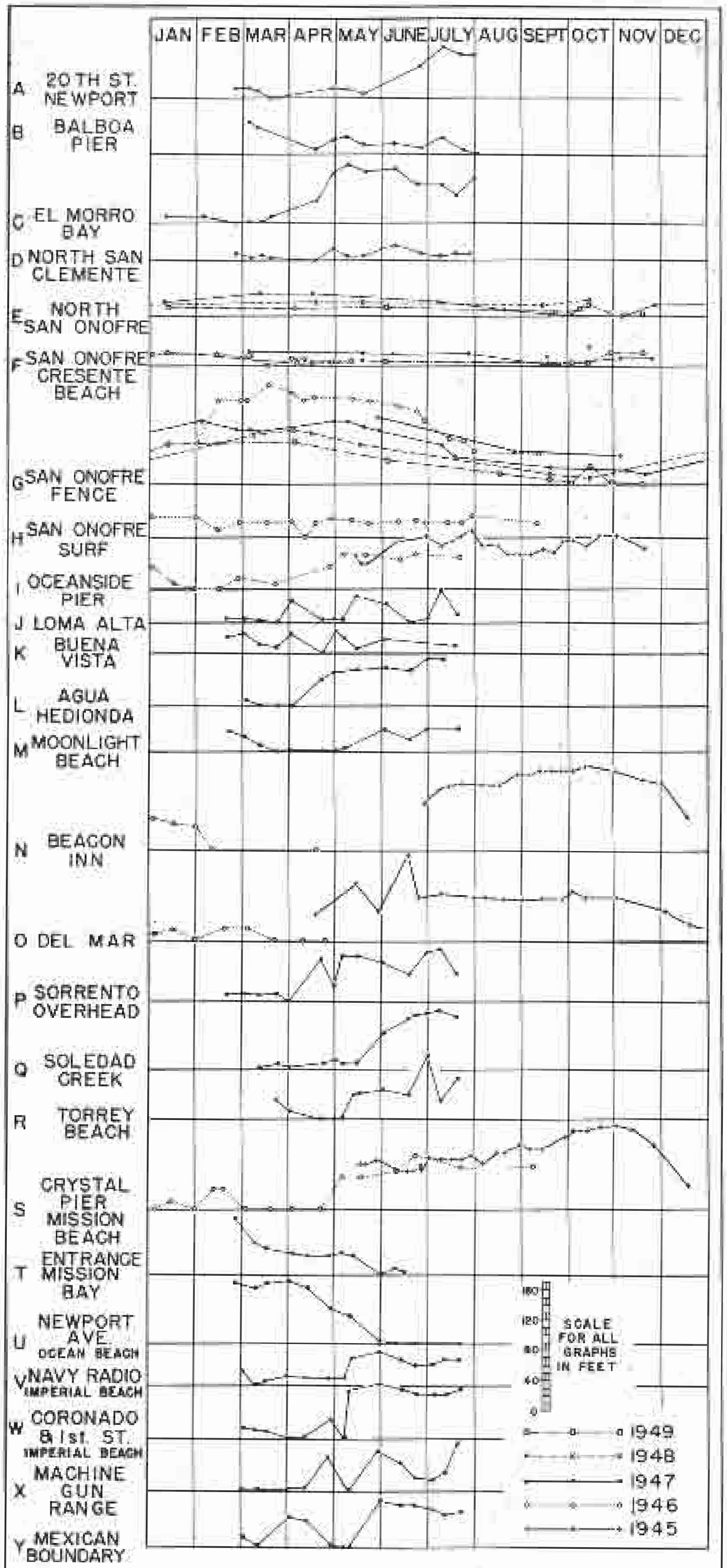
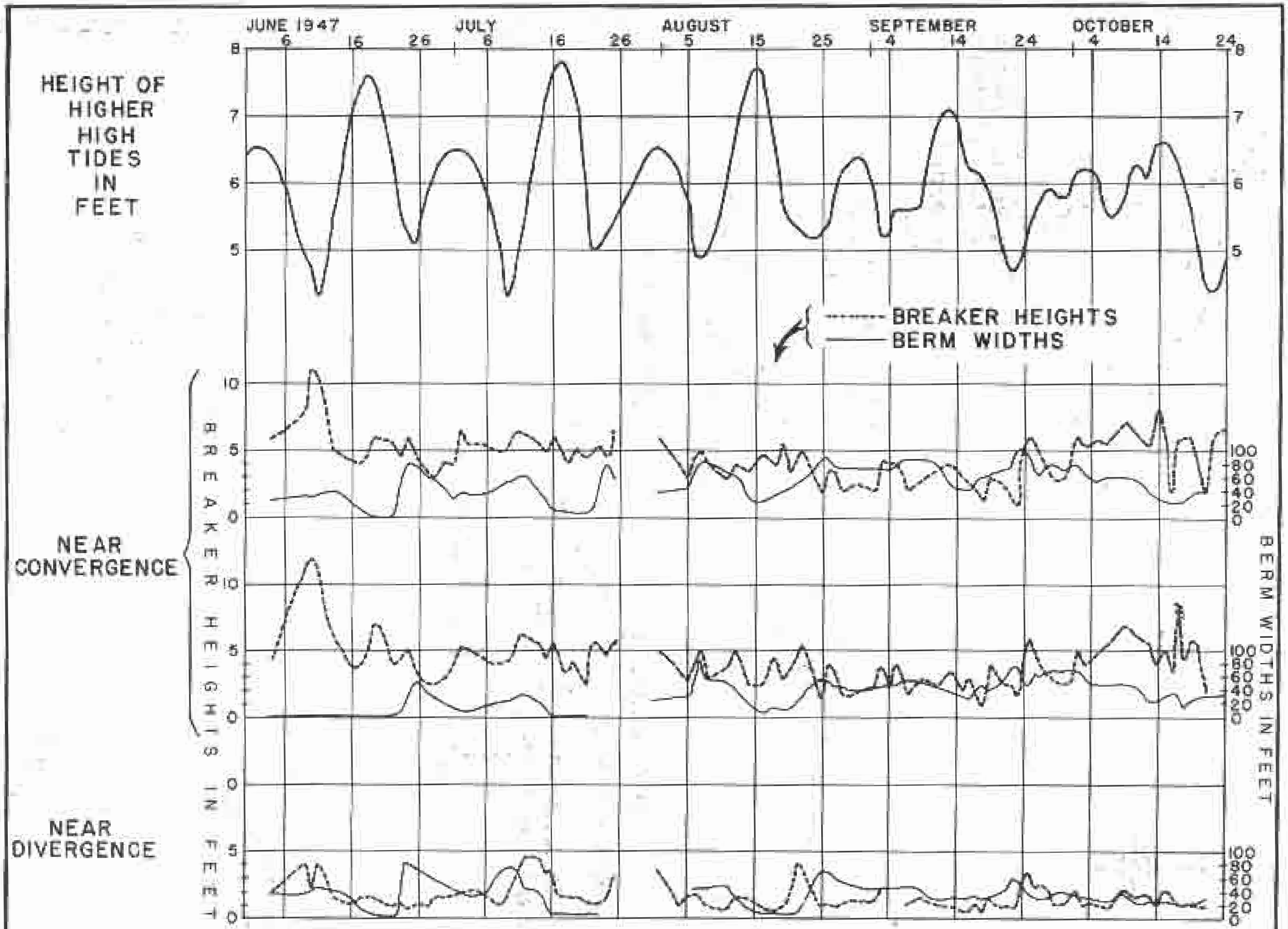

RANGE A
CUT
FILL
19 NOV 45
MEAN SEA LEVEL
29 APR 46
RANGE B
MEAN LOWER LOW WATER
7 NOV 45
M.S.L.
10 APR 46
M.L.L.W.
RANGE C
7 NOV 45
WALL
M.S.L.
10 APR 46
M.L.L.W.
RANGE D
7 NOV 45
M.S.L.
9 MAY 46
M.L.L.W.
RANGE E
7 NOV 45
24 APR 46
RANGE F
M.S.L.
7 NOV 45
M.L.L.W.
10 MAY 46
M.S.L.
RANGE G
M.L.L.W.
19 OCT 45
10 APR 46
M.S.L.
RANGE H
M.L.L.W.
7 NOV 45
M.S.L.
24 APR 46
M.L.L.W.
VERTICAL SCALE IN FEET
0 2 4 6 8 10 12 14
SEASONAL VARIATION IN BEACH PROFILES ALONG SCRIPPS BEACH
VERTICAL X 10
HORIZONTAL SCALE IN FEET
0 50 100 150 200 250 300

FIGURE 6



SEASONAL VARIATION IN BERM WIDTHS

FIGURE 7



RELATION OF TIDE RANGE, BREAKER HEIGHT AND BERM WIDTHS

FIGURE 8

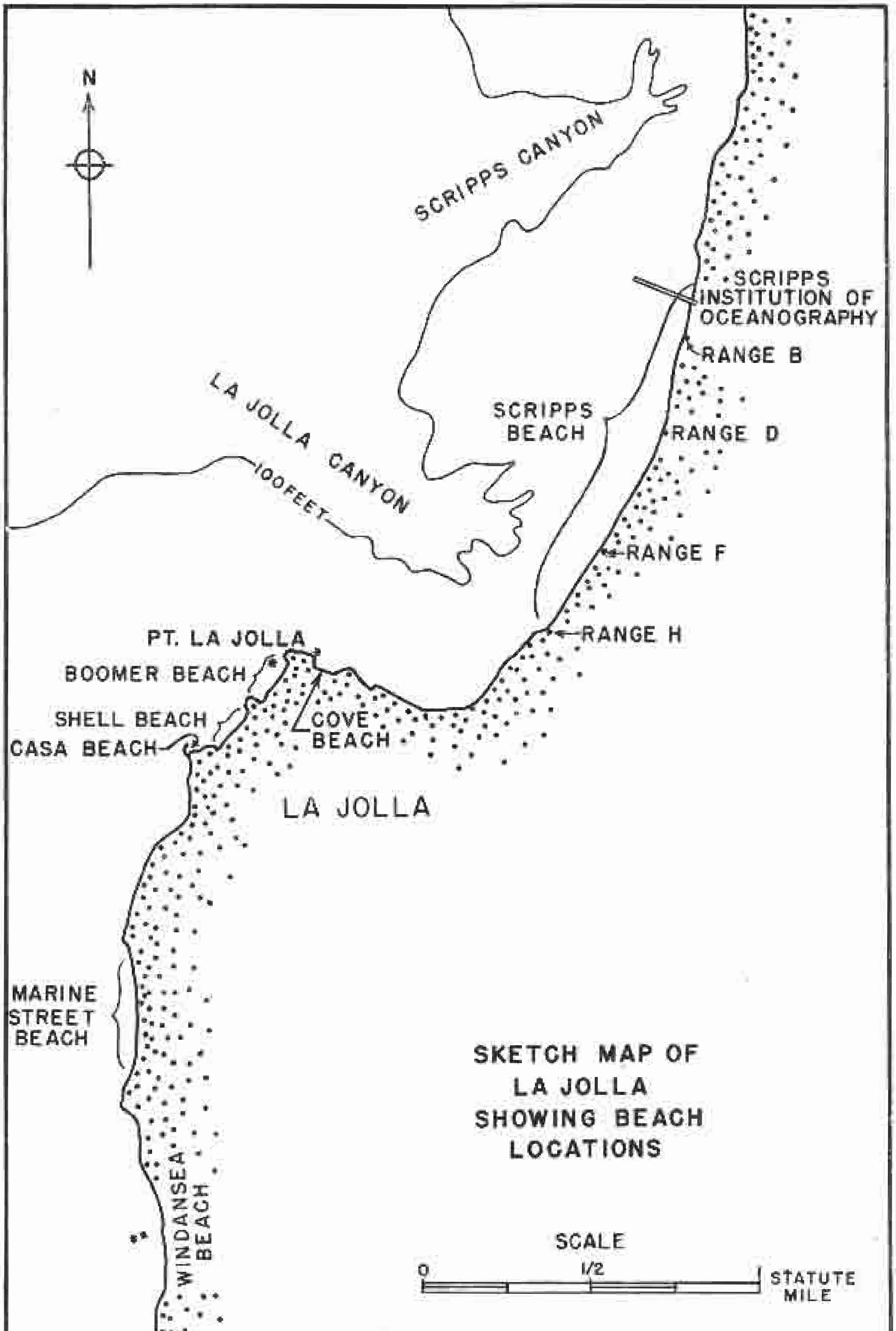

N
SCRIPPS CANYON
SCRIPPS INSTITUTION OF OCEANOGRAPHY
RANGE B
SCRIPPS BEACH
RANGE D
LA JOLLA CANYON
100 FEET
RANGE F
RANGE H
PT. LA JOLLA
BOOMER BEACH
SHELL BEACH
CASA BEACH
COVE BEACH
LA JOLLA
MARINE STREET BEACH
WINDANSEA BEACH
SKETCH MAP OF LA JOLLA SHOWING BEACH LOCATIONS
SCALE
0
1/2
1 STATUTE MILE

FIGURE 9

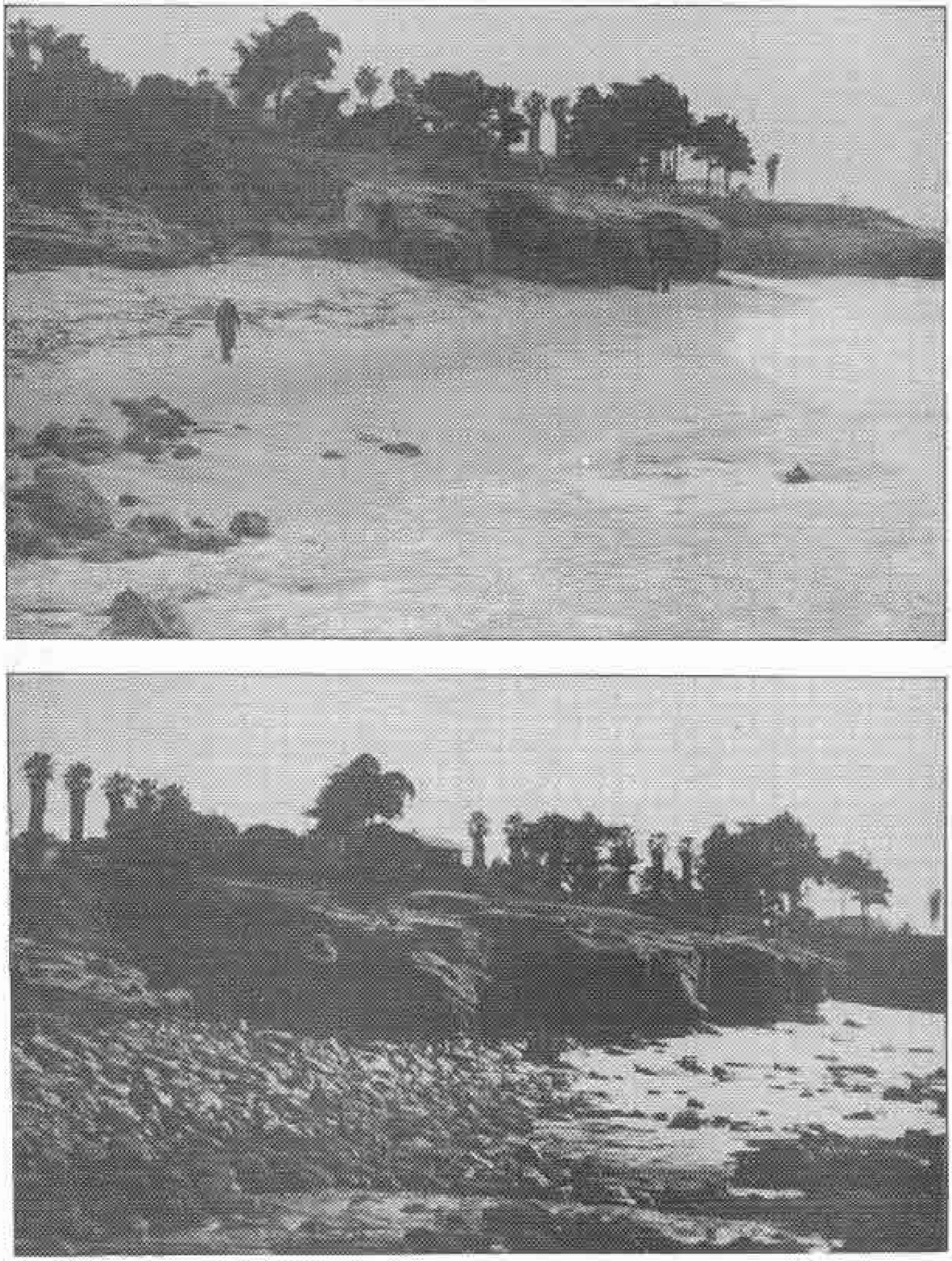
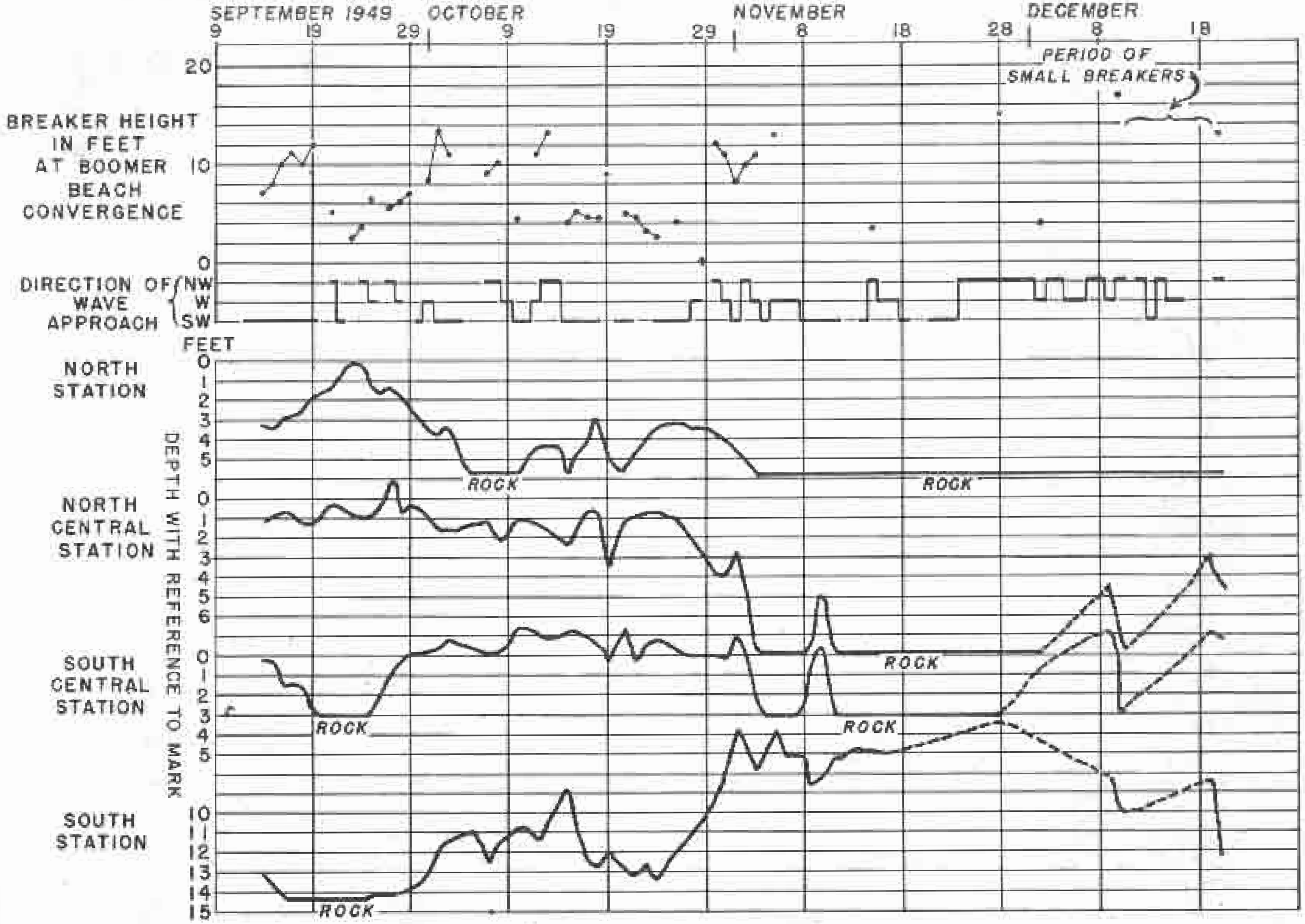


FIGURE 10. SOUTH END OF BOOMER BEACH UNDER CONDITION OF SOUTHWEST WAVE APPROACH (TOP PHOTO) AND NORTHWEST APPROACH (BOTTOM PHOTO.)



CUT AND FILL AT BOOMER BEACH IN RELATION TO WAVE APPROACH AND BREAKER HEIGHT

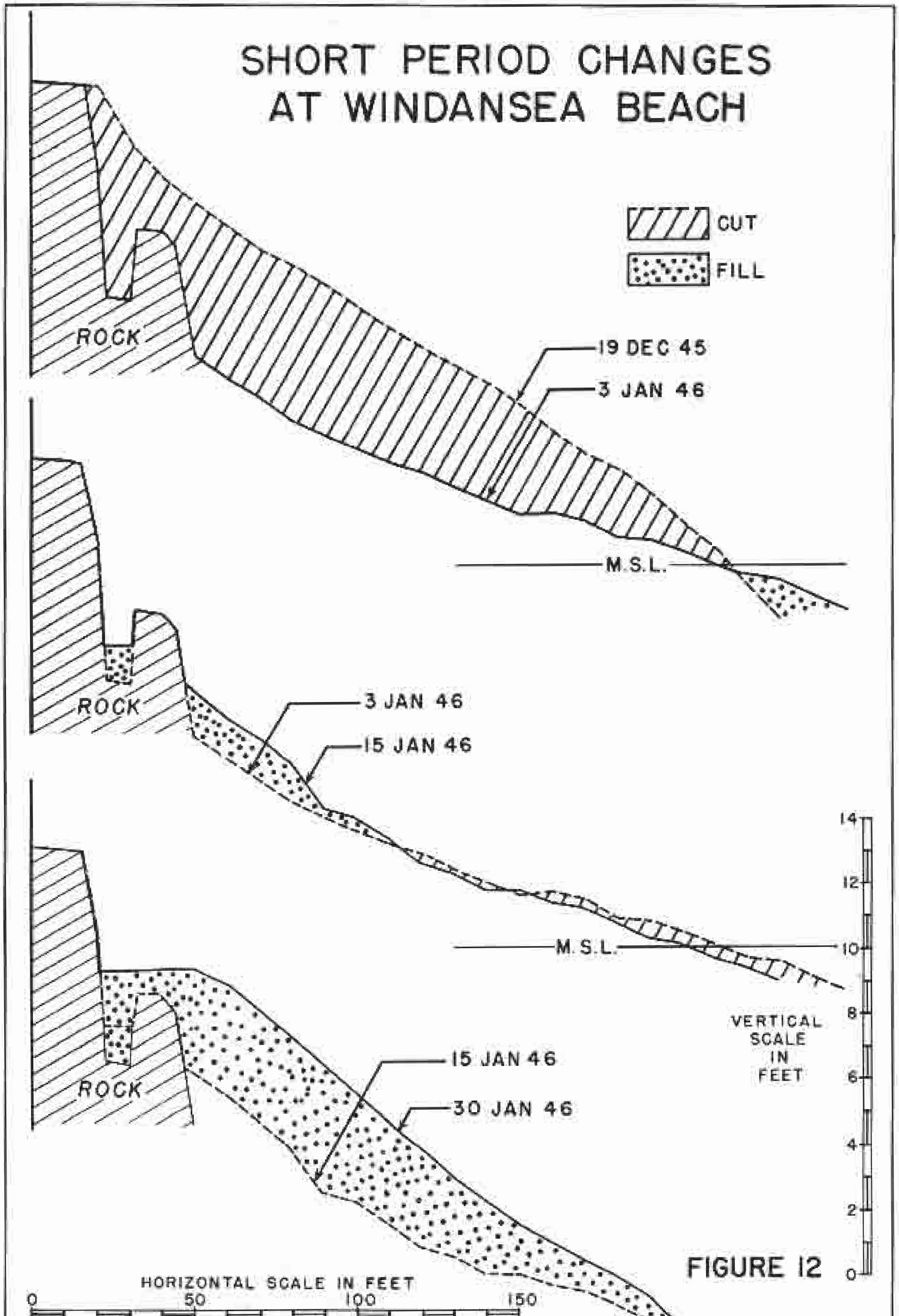
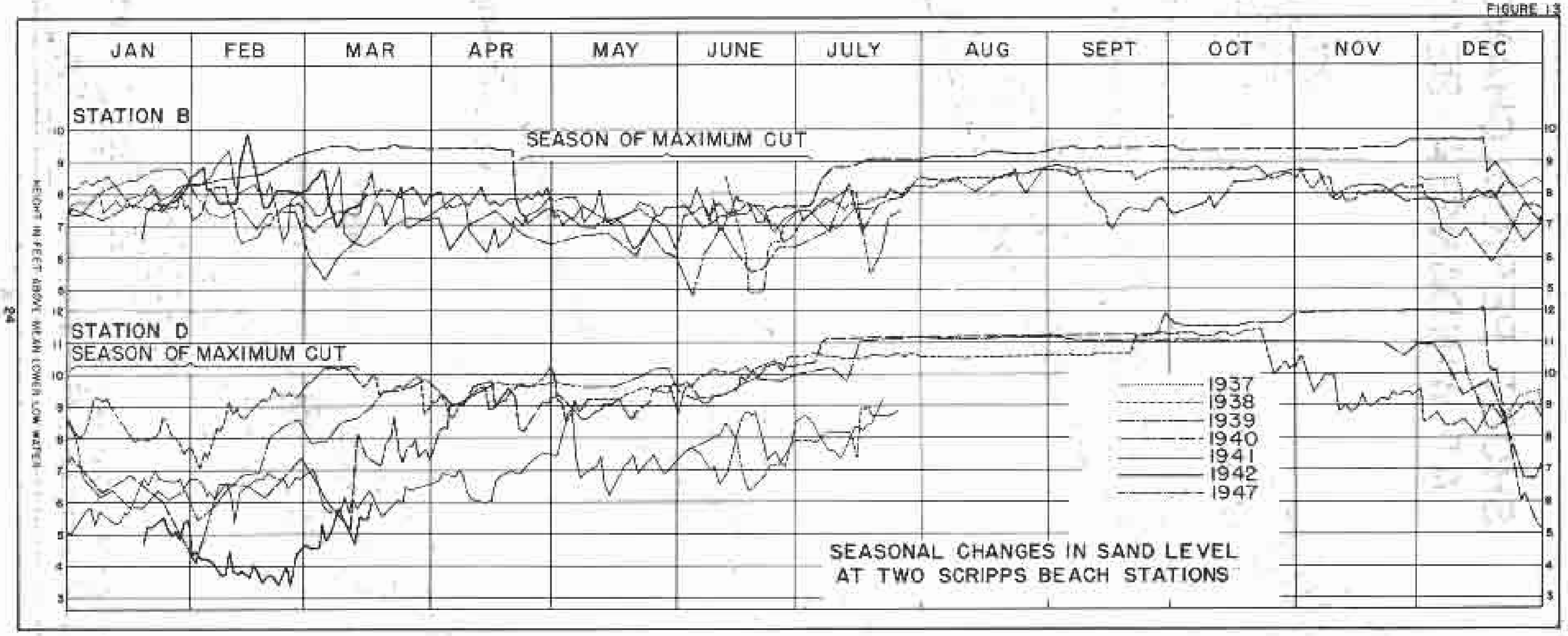

SHORT PERIOD CHANGES
AT WINDANSEA BEACH
CUT
FILL
ROCK
19 DEC 45
3 JAN 46
M.S.L.
ROCK
3 JAN 46
15 JAN 46
M. S. L.
ROCK
15 JAN 46
30 JAN 46
M. S. L.
VERTICAL
SCALE
IN
FEET
14
12
10
8
6
4
2
0
HORIZONTAL SCALE IN FEET
0
50
100
150

FIGURE 12

FIGURE 13



SEASONAL CHANGES IN SAND LEVEL AT TWO SCRIPPS BEACH STATIONS

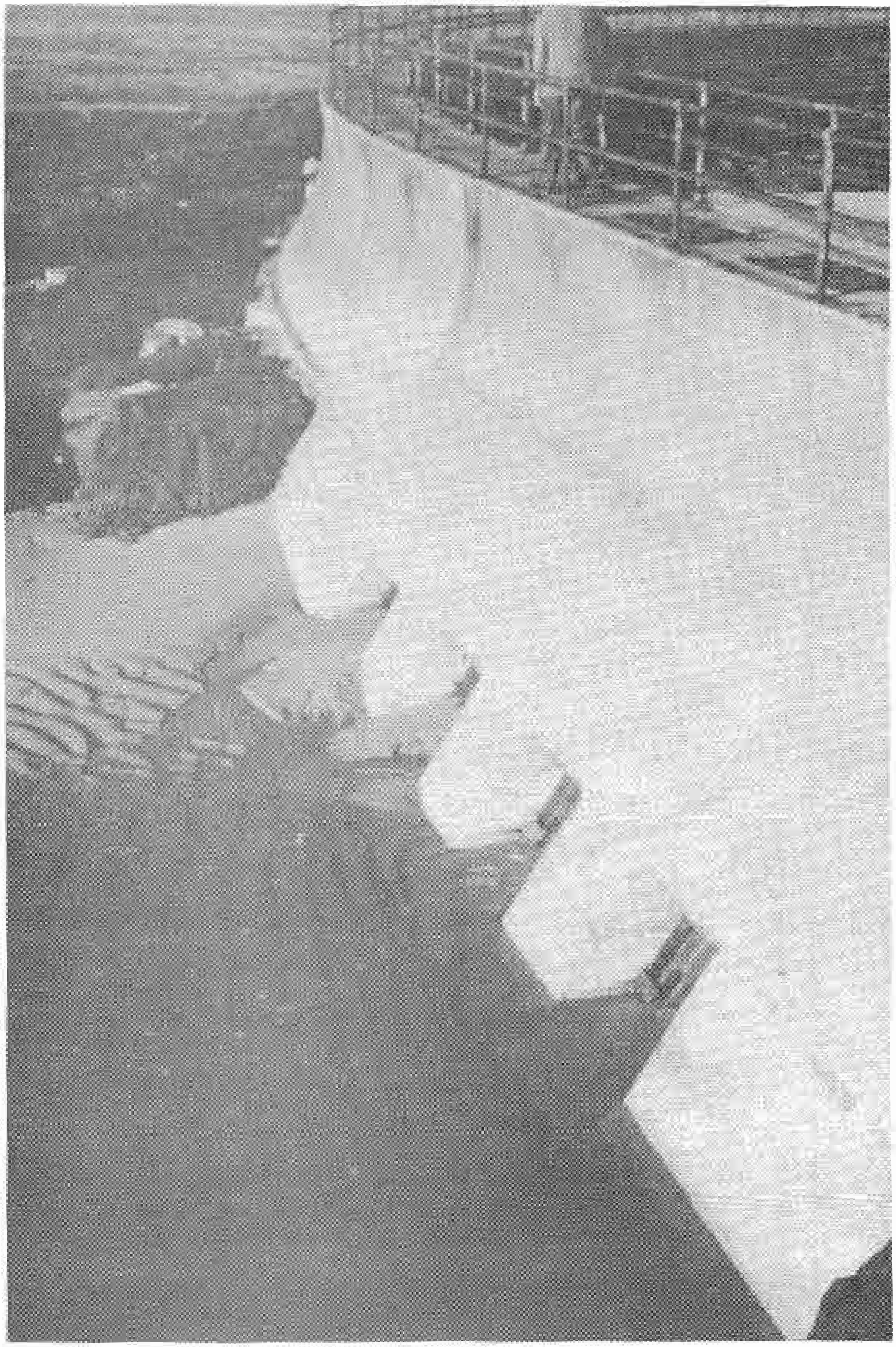
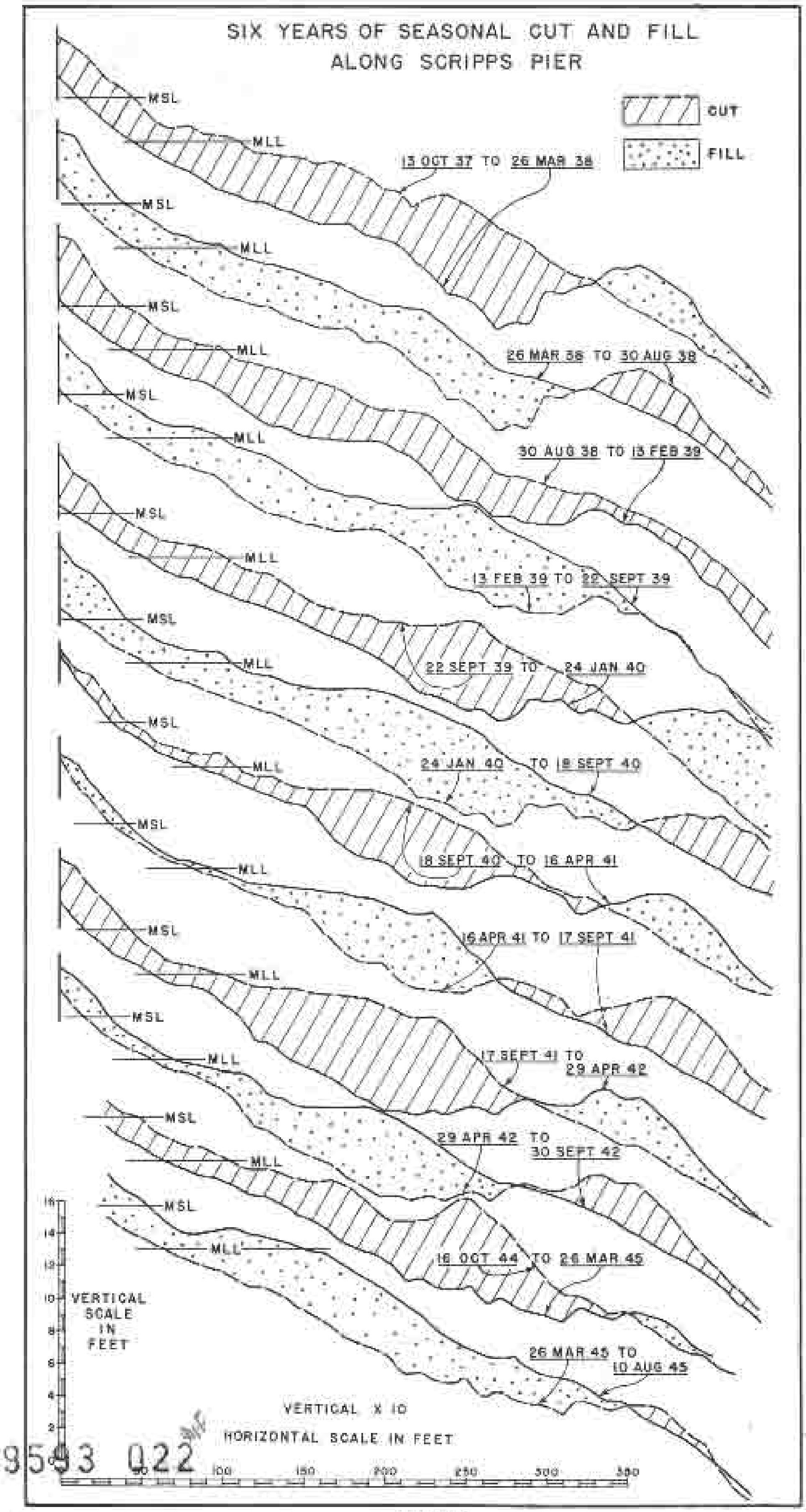


FIGURE 14. SOUTH SIDE OF SEA WALL AT CASA POOL WITH SAND CUT LOW ENOUGH TO EXPOSE SLUICES. NORMALLY, THE SAND IS BUILT UP NEARLY TO TOP OF WALL.



9593 022

FIGURE 15