# CHAPTER V CURRENT PROBLEMS AND STUDY OBJECTIVES

The Port of Caldera was opened when the first stage construction work, including three berths, was completed in December 1981. The Port has recently experienced such serious problems as sand sedimentation in the harbour, insufficient berth length and inefficient cargo handling. Furthermore, port cargo demand in Costa Rica is increasing year by year.

The problems affecting the Port of Caldera must be solved so that the port can fulfill its role as the main gateway on the pacific coast of Costa Rica. The study should, of course, seek to minimize costs. The present capacity of the port may basically be able to cope with the future cargo demand if effective measures are taken to solve these problems. The current problems facing the port and possible countermeasures are discussed below.

## 1. Sand Sedimentation

There is littoral drift along almost the entire east coast of Nicoya Bay. In addition, sand movement always occurs when structures are constructed along natural sand beaches, and the Port of Caldera is no exception. Measures must be taken to protect the Port of Caldera from littoral sand drift. To put it concretely, the average annual sand sediment volume for the last three years is approximately 100,000 $m^3$ to 110,000 $m^3$. Since the first half of 1984, the rate of sedimentation at the harbour side of the breakwater has been accelerating.

Particularly, the edge of the sediment at the harbour side of the breakwater has reached the -11 m quaywall. The berth area for the said quaywalll has shoaled along a distance of about 100 m. Thus, large vessels of the design ship size are not able to load or unload cargoes at the wharf at present. Furthermore, the sedimentation has also caused some troubles for the maneuvering of large vessels in the turning basin. One large vessel touched bottom in July, 1985. The vessel stopped calling at the Port of Caldera at that time, and detoured to the Port of Limón because of the accident. Thus, the sand sedimentation has completely disturbed the expected port functions.

The sedimentation is causing a decrease in the number of ship calls and in the cargo volume, and this will significantly affect not only the finances of INCOP, but also the national economy and the people's livelihood in terms of stable commodity supply and low transportation cost. This will be all the more serious considering that international trade between Costa Rica and such Asian countries as Japan, Korea and Taiwan has been increasing. Thus, the sand sedimentation has become a serious and urgent matter to be solved at the Port of Caldera.

Generally speaking, there are two principal methods to protect harbour areas from sand sedimentation : dredging of deposited sand and construction of jetties. Both of these methods involve the investment of a large amount of capital. Therefore, related technical investigations should be carried out fully before making a decision concerning which countermeasures should be implemented at the port. Thus, the mechanism of sand drift and sedimentation should first be analysed based on such natural conditions as waves, water currents and topographical soundings over a wide water area and a long period of time. After the completion of said surveys, appropriate long-term countermeasures should be determined based on the careful analysis of the data collected. In this study, a computer simulation model is adopted to analyse the sand sedimentation mechanism and the proposed countermeasures.

Fortunately, some of the necessary data such as part of the required wave and sounding data have already been recorded by various JICA experts under the full cooperation of MOPT and INCOP in the past. Thus, the present JICA study team conducted only water current observation, sea bottom soundings and a topographic survey along the seashore. The countermeasures against sand sedimentation and the proposed construction works are discussed in CHAPTERS VI, IXand X, respectively.

## 2. Insufficient Berth Length

The existing quaywall is described in Chapter III. The total berth length is 490 m, but the berth length where large vessels (approximately 15,000 to 20,000 DWT) can berth is only 360 m. Especially, the present berth length of the -10 m quaywall is short. Thus, at present, only one large vessel can berth at the Port of Caldera at one time.

This problem of insufficient berth length will be serious for the port in the future considering the following facts :

(1) Grain cargoes will be handled at the Port of Caldera in the near future because Puntarenas pier has already become superannuated.
(2) Along with the recent advancement of containerization, more container ships will call at the port in the near future.

Thus, the port must have appropriate facilities to accommodate two vessels such as one container ship and one grain cargo carrier simultaneously.

This problem should be resolved as soon as possible because items (1) and (2) noted above are imminent. One possible alternative, of course, is to construct a new wharf to cope with the increased cargo demand. However, the most reasonable countermeasure is the extension of the existing No. 2 quaywall considering the urgency of the problem and the required amount of investment. Thus, this study will examine the best method of extending this quaywall. The sediment which has deposited in front of the wharf will, of course, have to be removed within the project period.

## 3. Necessity of Improving the Cargo Handling System

The Port of Caldera handles a great variety of commodities and has a relatively large throughput with a small number of berths. This situation will develop further along with the increase of port cargo in the future. Particularly, as mentioned in the previous section, the Port of Caldera will be obliged to handle imported grain which is currently handled at Puntarenas pier.

To cope with this imminent situation, the following two countermeasures can be considered :

(1) To aim at the rationalization of cargo handling through specialization of wharfs by constructing new quaywalls
(2) To create a multipurpose terminal which can handle any type of cargo at the most approprlate berth when necessary by improving existing facilities and increasing cargo handling efficiency without constructing any additional berths.

It is recommendable to construct a specialized container terminal and a grain terminal in the long term. However, it is preferable to establish a multipurpose terminal for the time being considering the ideal use of limited investment capital and the current financial situation of Costa Rica.

The essential aspects of the multipurpose terminal are the rationalization of cargo handling and the minimization of cargo handling costs. Thus, it is necessary to improve the existing cargo handling system at the port. The current cargo handling capacity is not fully utilized due to a shortage of spare parts and a lack of expertise on the part of the operators and workers.

Therefore, the study will seek means of improving the existing cargo handling system establishing a multipurpose use of the terminal to accommodate future port demand. This improvement will covers the entire cargo handling system including equipment, repair facilities, storage facilities and training of personnel. Through this program, it should become possible to efficiently handle the future cargo throughput in the short term without constructing any additional quaywalls.

## 4. Expected Port Functions and Study Objectives

Costa Rica is an isthmus lying between two oceans : the Atlantic and the Pacific. In the past, Costa Rican trade was conducted mainly through the Atlantic coast because of Costa Rica's strong historical ties with European and Caribbean countries. However, since World War II, Costa Rican trade through the Pacific coast has become prosperous, growing along with the economic development of Japan, Korea and Taiwan and the development of maritime transportation in the Pacific ocean. The Port of Caldera is the only international commercial port on the Pacific coast of Costa Rica. Thus, the port is expected to function as the international gateway on the Pacific coast as the Ports of Limón and Moín serve as Costa Rica's main international ports on the Atlantic coast.

However, the port has experienced such serious problems as (1) sand sedimentation, (2) insufficient berth length and (3) inefficient cargo handling systems as noted above. The countermeasures to solve problem (1) will restore the potential capacity of the port. The countermeasures to solve problems (2) and (3) are means to enhance the existing port capacity by improving existing facilities and equipment. The capacity restored and enhanced by the above countermeasures must, of course, be maintained well even after these countermeasures are implemented.

Therefore, the study seeks to restore the potential port capacity, to enhance the port capacity by improving existing facilities and adding needed equipment, and to maintain the enhanced port capacity by procuring machinery and devising an appropriate maintenance system so that the port can function to the utmost of its potential. Thus, the study covers not only how to execute the primary construction work itself, but also how to execute the regular maintenance work after the primary construction work is completed. The composition of the study is shown in Table V-1.

If proper countermeasures are implemented to solve these problems, the Port of Caldera will be able to properly fulfill its role as the main international gateway on the Pacific coast.

**Table V-1 Problems and Countermeasures**

| Problems | Countermeasures | | | Related CHAPTER in this report |
|---|---|---|---|---|
| | Restoration | Improvement | Maintenance | |
| (1) Sand sedimentation | ○ | | ○ | VI, IX |
| (2) Insufficient berth length | | ○ | | VII |
| (3) Inefficient cargo handling | | ○ | ○ | VIII |

# CHAPTER VI COUNTERMEASURES AGAINST SAND SEDIMENTATION

## 1. Sand Drift and Sand Sedimentation

### 1. 1 General

The coast around the Port of Caldera has much littoral drift as revealed by the huge sand spit of Puntarenas. Rivers and sea cliffs supply sand, and swells and tidal currents transport it. The coastline consists of some pocket beaches surrounded by rocky headlands on both ends. One of them is Caldera Bay. The area from Roca Carballo through the Barranca River and Boca de Barranca Beach towards Puntarenas is at the north end of a series of pocket beaches. Caldera Bay is next to the southern part of Roca Carballo. Tivives Beach, which is another pocket beach, is located south of Caldera Bay. The Tivives River flows into Tivives Beach.

These two pocket beaches, Caldera Bay and Tivives Beach, seem to be quite similar from the viewpoint of sand transportation. Northward littoral drift is predominant offshore and southward littoral drift is predominant near the shore. The topographical features of the shoreline of these beaches repeat seasonally. However, over time the northen parts of these beaches are eroding and the southern parts are accreting.

The littoral drift phenomena in Caldera Bay have become more complicated due to the construction of Caldera Port and the existence of Estero Mata de Limón.

The topography around Caldera Bay is shown in Fig.VI-1.

### 1. 2 Results of the Study on Natural Conditions

The following surveys were performed at the site as part of the examination of natural conditions related to sand drift.

(a) Hydrographic Sounding
(b) Topographic Survey along the Shoreline
(c) Water Current Observation
(d) Tide Observation
(e) Measurement of the Riverine Cross-Section Area
(f) Grain Size Distribution Analysis
(g) Sand Drift Survey using Fluorescent Sand

In addition to the above, the wave data observed by the wavemeter offshore the Port of Caldera are analyzed. The location map of these field surveys is shown in Fig.VI-2. The results of these surveys and the wave data analysis are shown in APPENDIX 3. They can be summarized as follows.

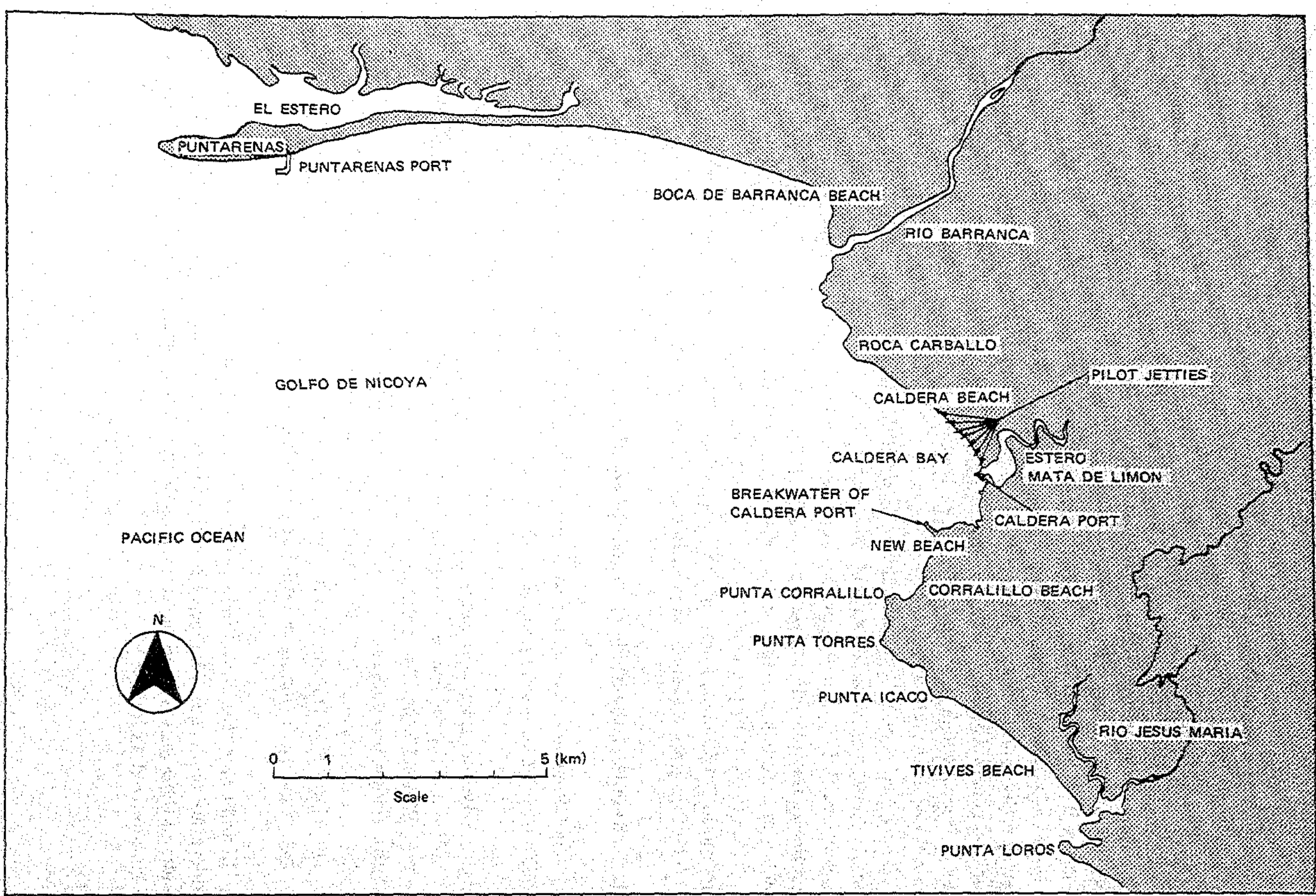



Fig. VI-1 Topography around Caldera Bay

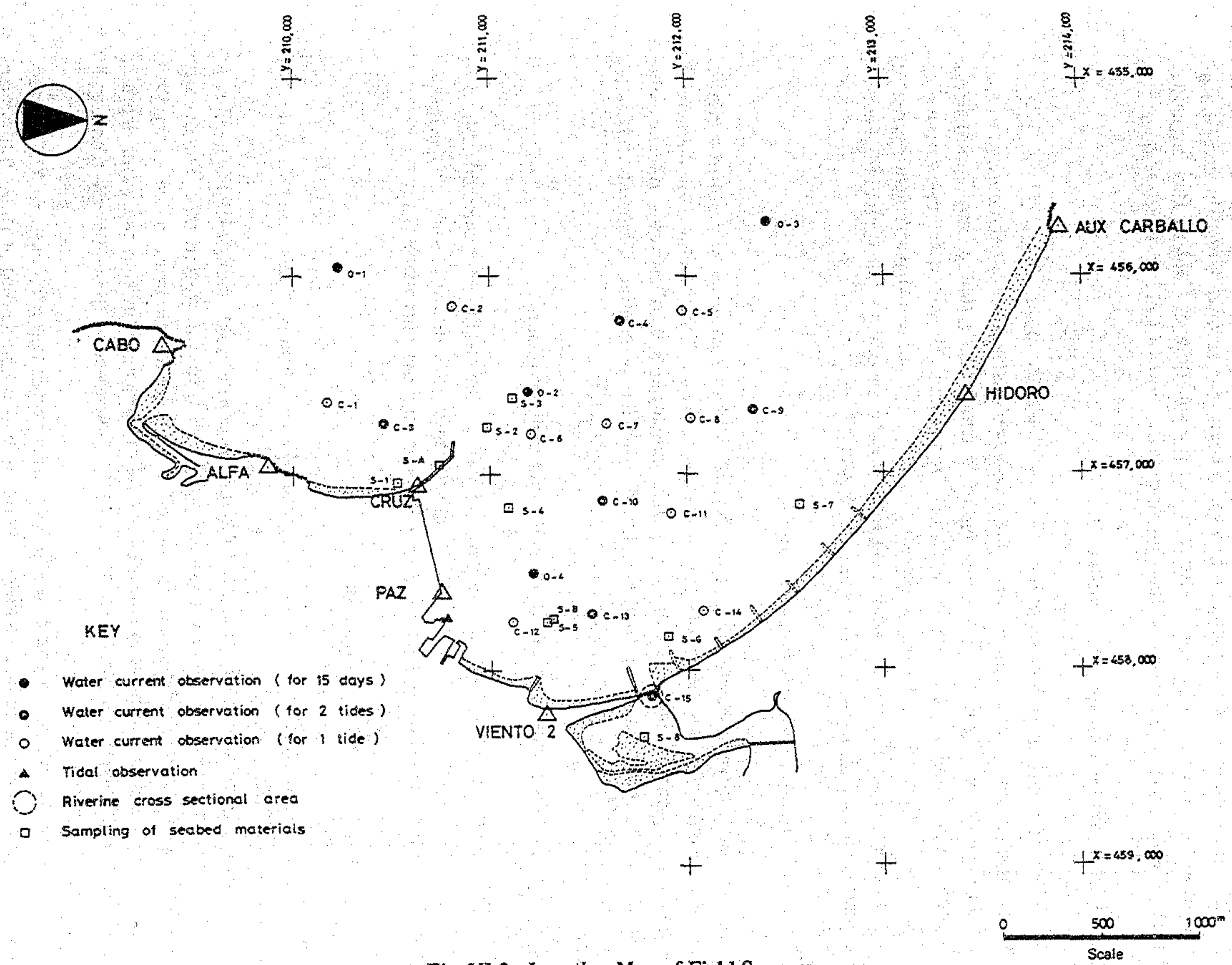



Fig. VI-2 Location Map of Field Surveys

### 1. 2. 1 Hydrographic Sounding and Topographical Survey

The location map of the sounding and the topographic surveys along the coastline are shown in Fig.VI-3. Fig.VI-4 shows the result of the sounding of Caldera Bay in October, 1985. Fig.VI-5 shows the result of the sounding of the Port of Caldera in September, 1985.

### 1. 2. 2 Water Current Observation

The water current at four fixed points was continuously observed around the clock for 15 days using Ono-type current meters. The frequency distribution of each current at the 4 points is shown in Fig.VI-6. From this figure, it can be seen that a semidiurnal period fluctuation predominates at each of the observation points. However, at observation point O-4, the northward component is extremely small. A southward permanent current of 0.04 m/s at this point is roughly equivalent to the tidal component. The typical tidal current around Caldera Port is assumed as shown in Fig.VI-7.

### 1. 2. 3 Grain Size Distribution Analysis

The sediment samples collected at the Port of Caldera were used to perform a grading analysis. Fig.VI-8 shows the results of this grading analysis. The median grain diameter at point S-4 in front of the quaywall is 0.14 mm, indicating a smaller value than at other locations. At locations other than S-4, the distribution of median diameter is between 0.24 mm and 0.34 mm, the mean of which is about 0.3 mm.

## 1. 3 Present Conditons of Sand Drift and Sand Sedimentation

The results of the current field survey as well as the results of many valuable field surveys which have been executed continuously since 1973 indicate some characteristic features of the sand drift and sand sedimentation around the Port of Caldera.

### 1. 3. 1 Sand Drift in Caldera Bay

The main sources of sand supply seem to be the sea cliffs of Punta Caldera and Roca Carballo and Tivives Beach.

Some topographic sounding results in Caldera Bay after 1981 show a slight shoaling in Caldera Bay, even in areas which are generally more than 10 m in waterdepth. The average trends of the water depth changes in this period at different locations are shown in Fig.VI-9. On the other hand, it can be seen from the results of the soundings that the water depth in Caldera Bay gradually increased from 1973 to 1981. The trend of the water depth change in this period is shown in Fig.VI-10.

Therefore, to grasp the trend of the long term water depth change, it will be very important to execute periodic soundings extending over a long period of time. The soundings should include some fixed points in Caldera Bay and offshore Puntarenas.

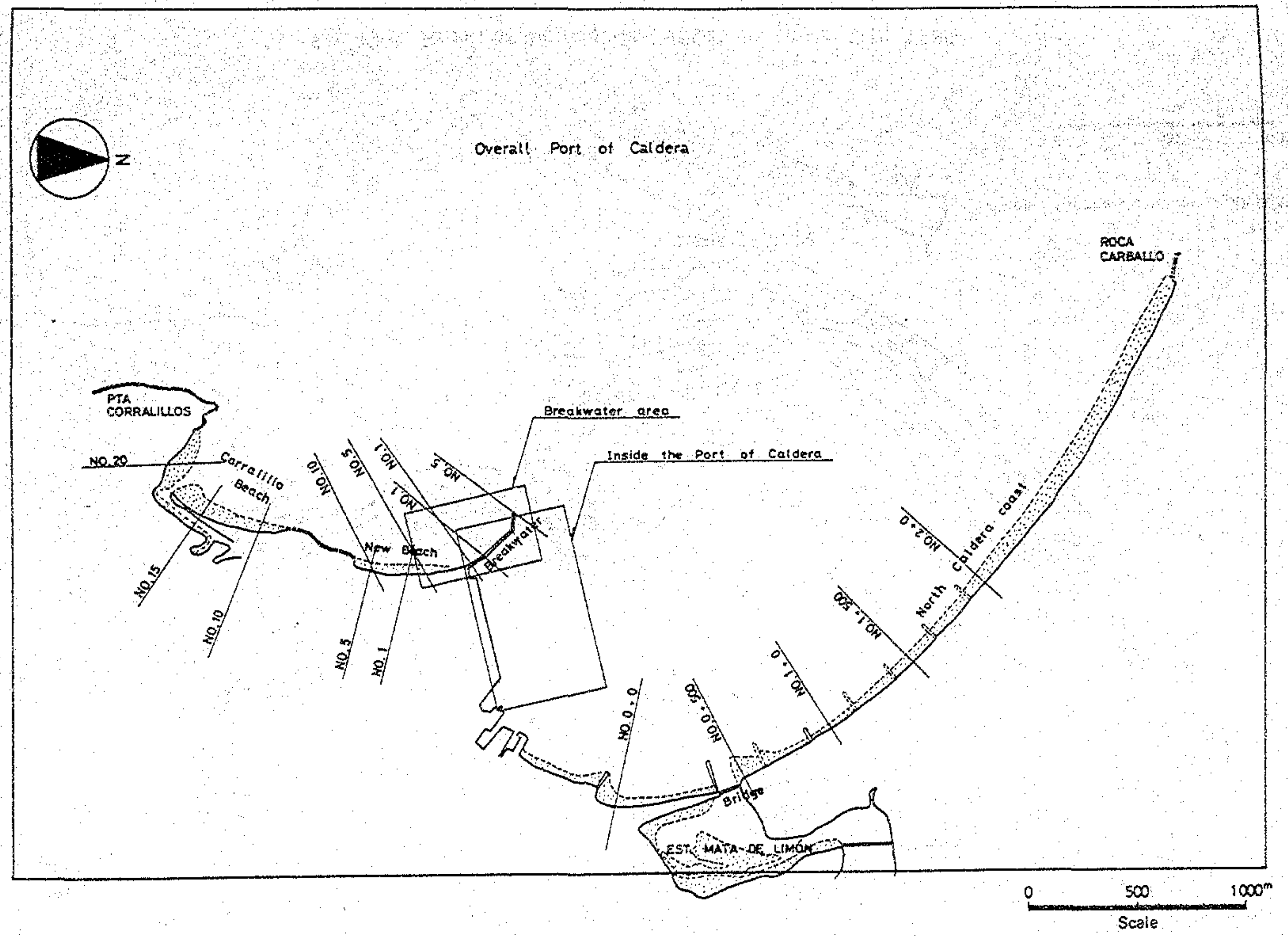



Fig. VI-3 Location Map of the Sounding and the Topographic Surveys

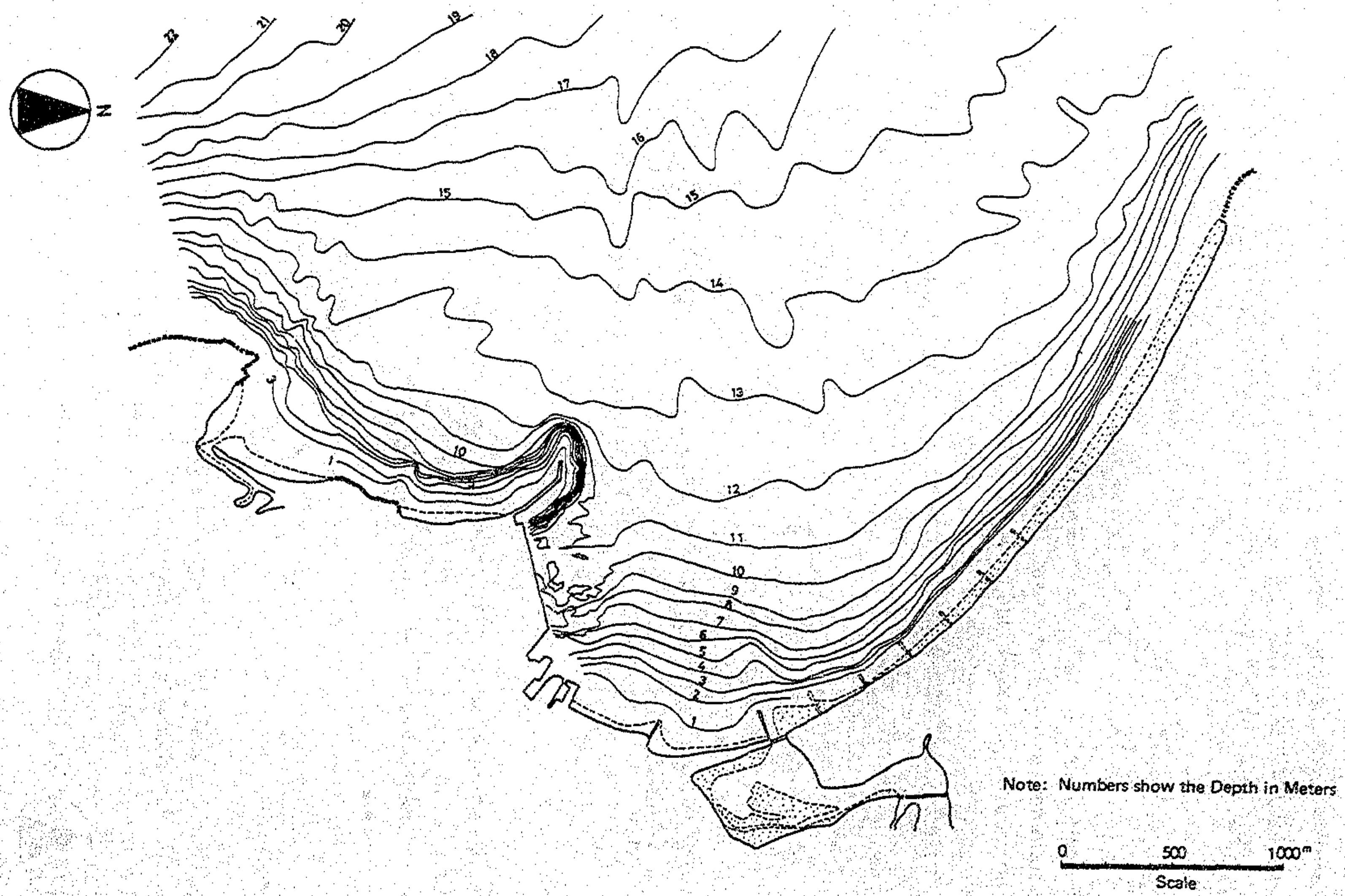



Fig. VI-4 Result of the Sounding of Caldera Bay in Oct. 1985

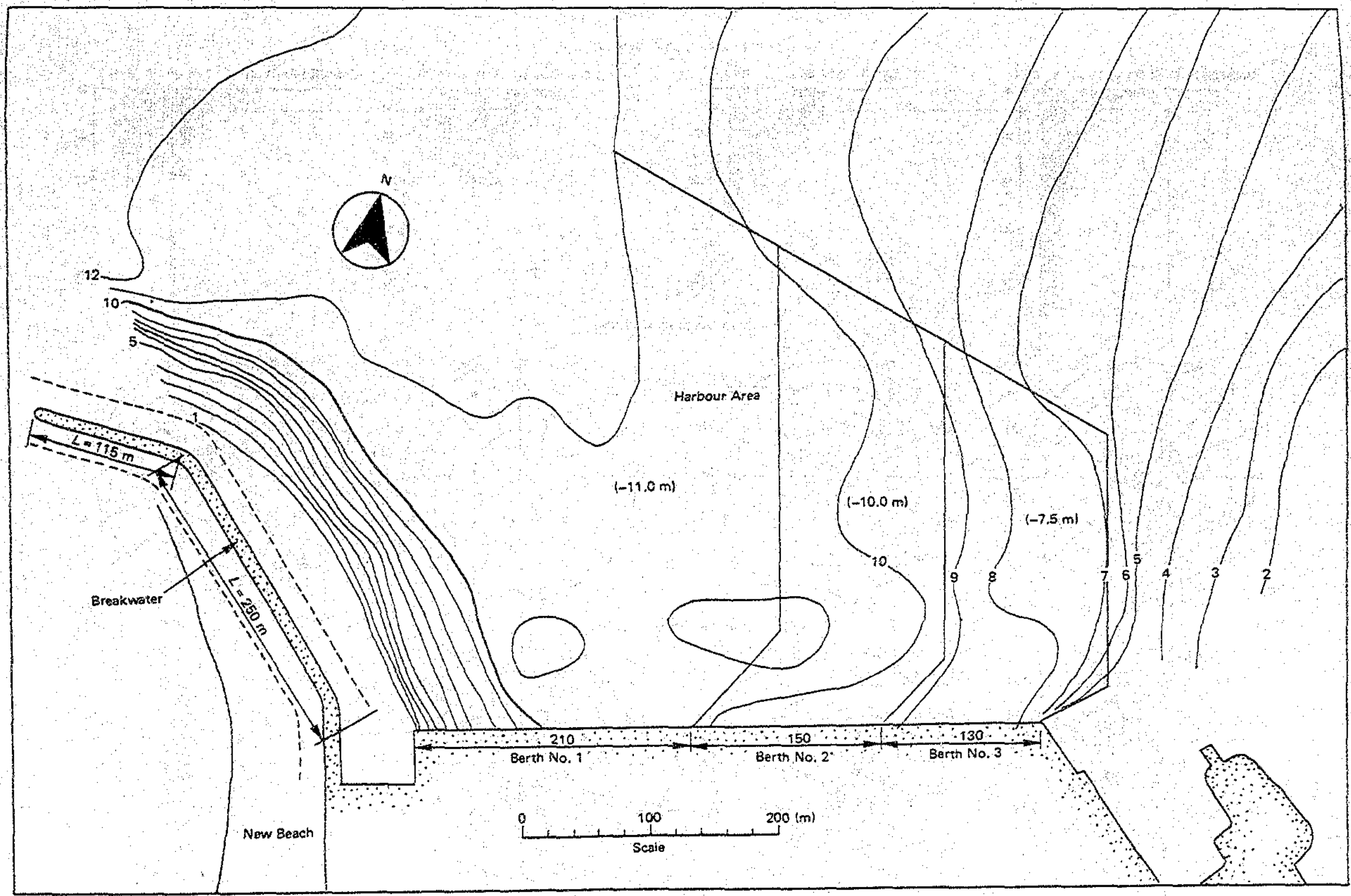



Fig. VI-5 Sounding Result (September 1985)

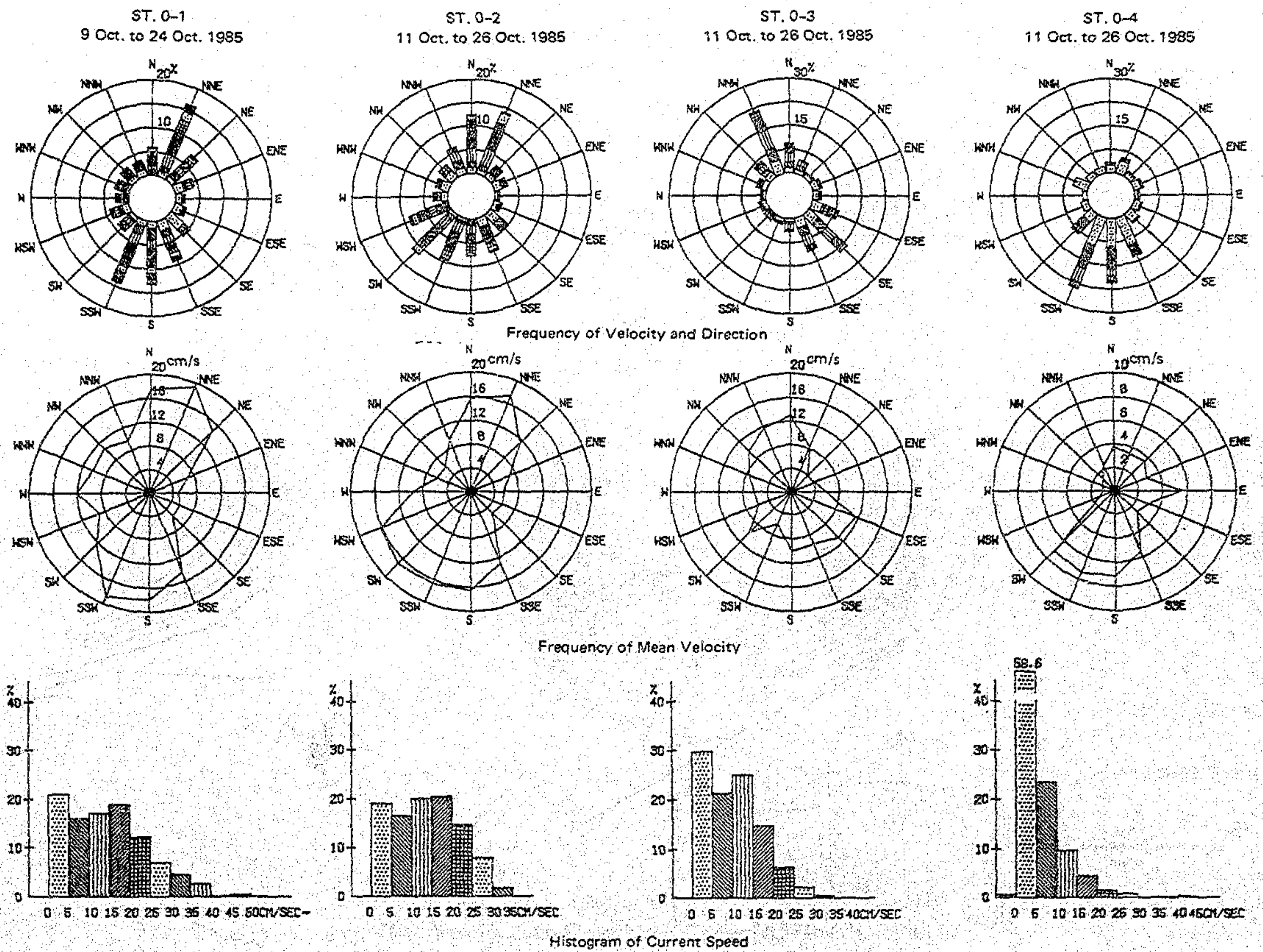



Fig. VI-6 Frequency Distribution of Current

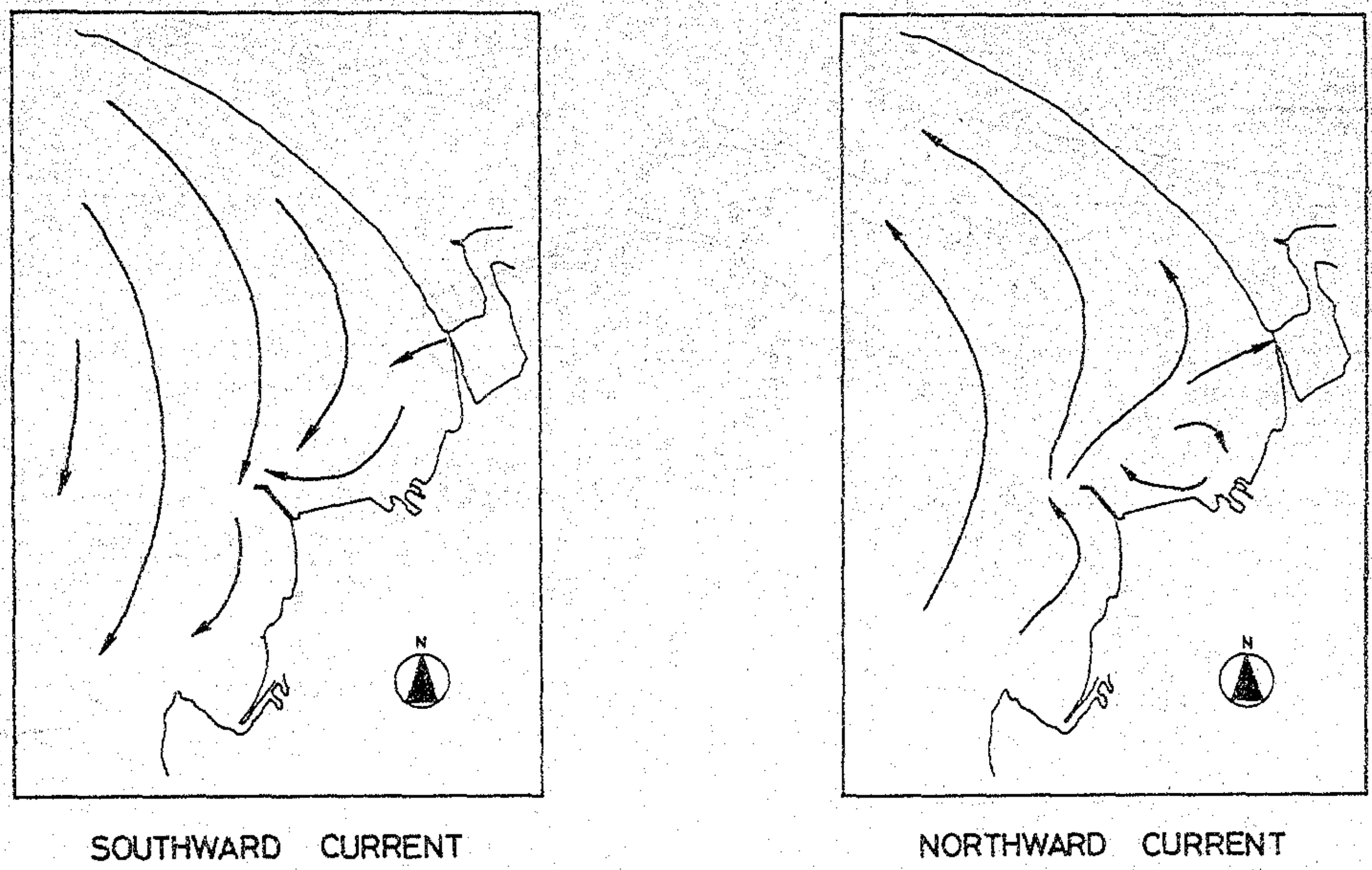



Fig. VI-7 Typical Tidal Current around Caldera Port

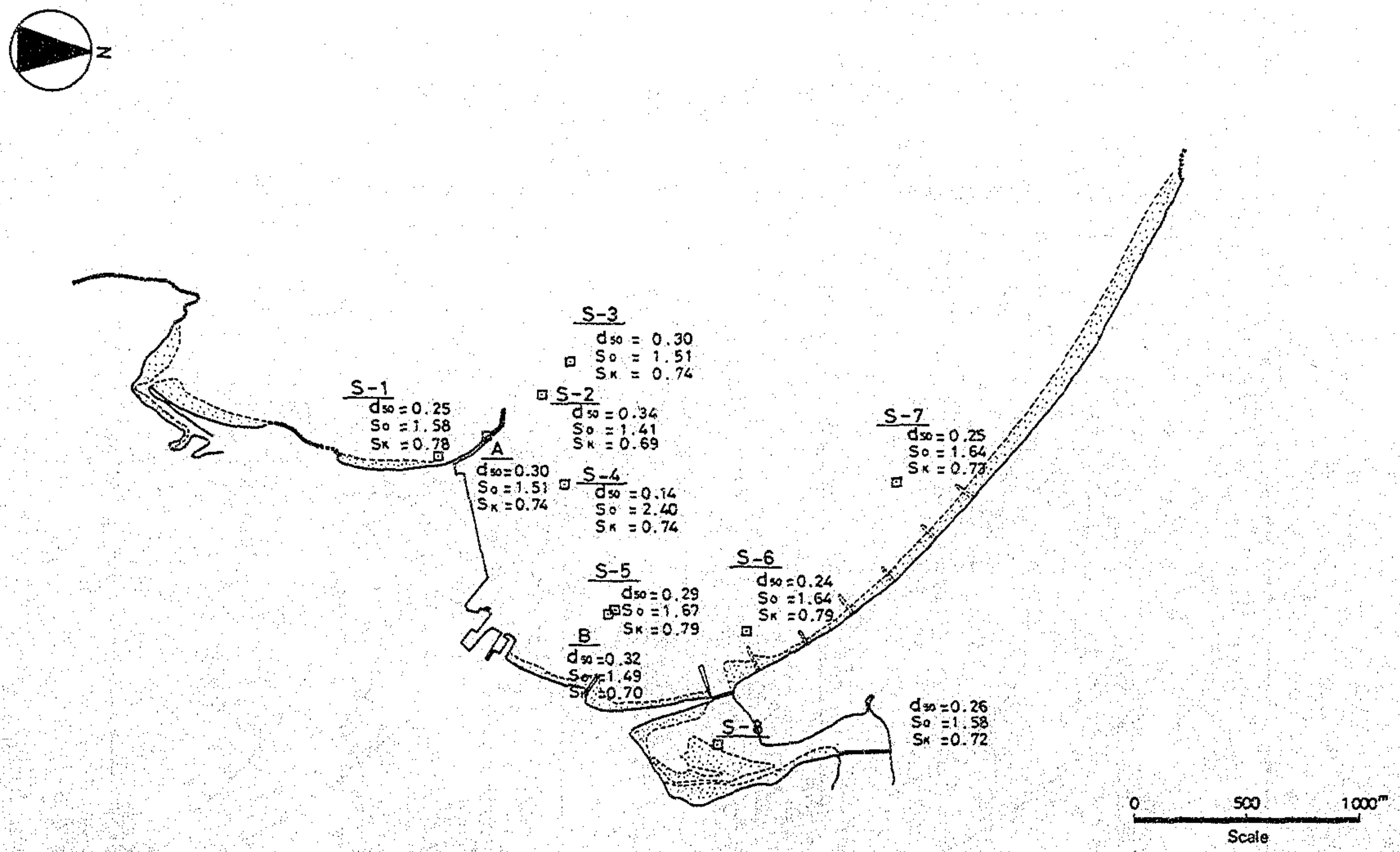
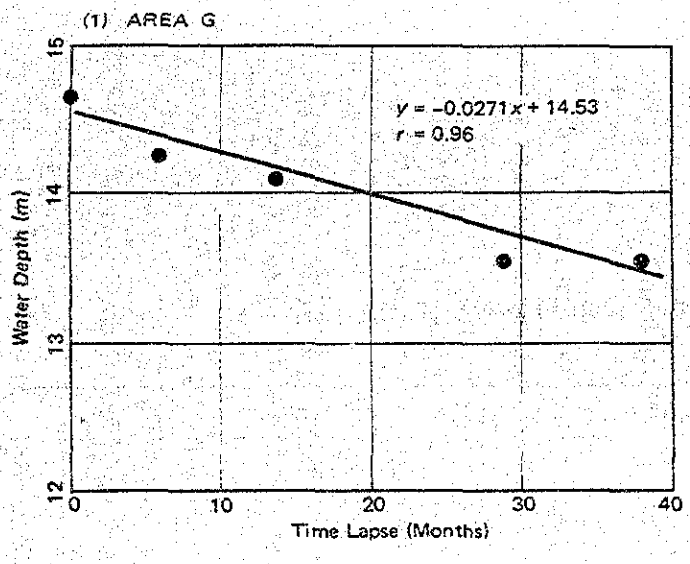
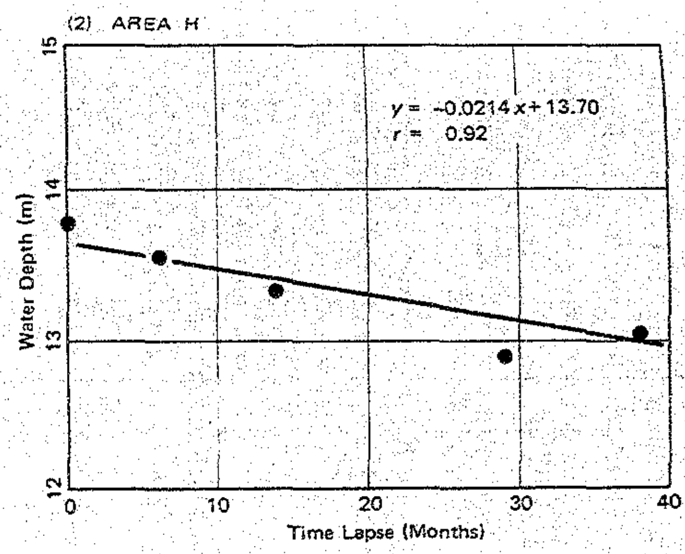
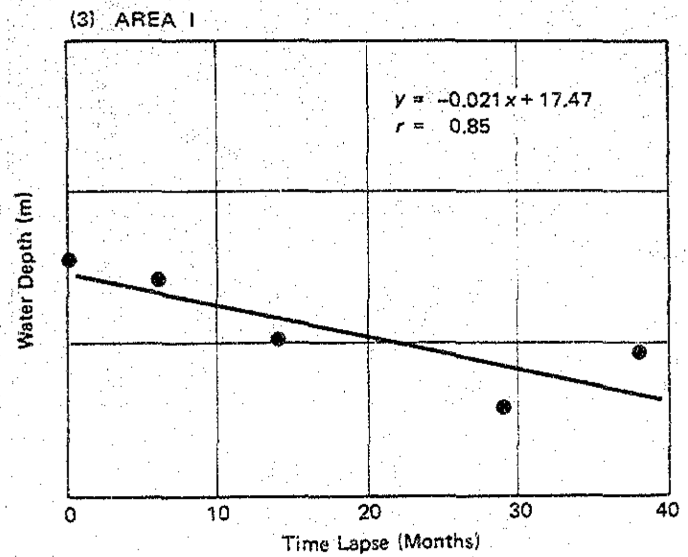
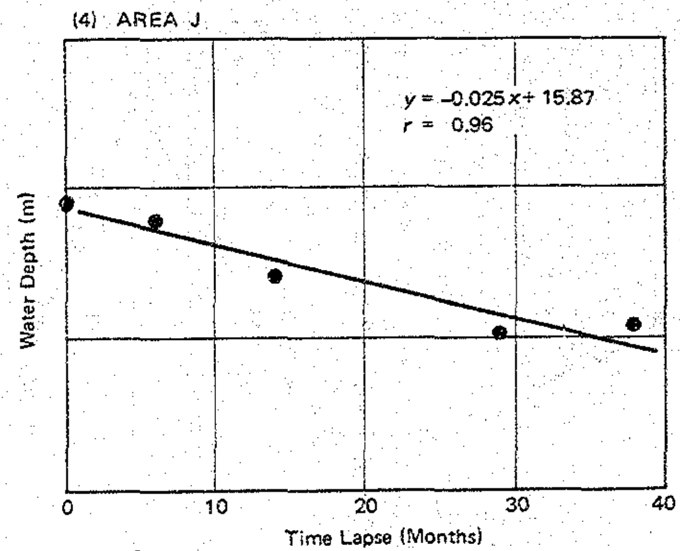



Fig. VI-8 Results of the Grading Analysis




Notes: 1) AREAS G, H, I, J are shown in APPENDIX 6.
2) The observation period is Apr. 1982 ~ Oct. 1985.
3) $r$ means the correlation coefficient.

**Fig. VI-9 Average Trend of the Water Depth Change**

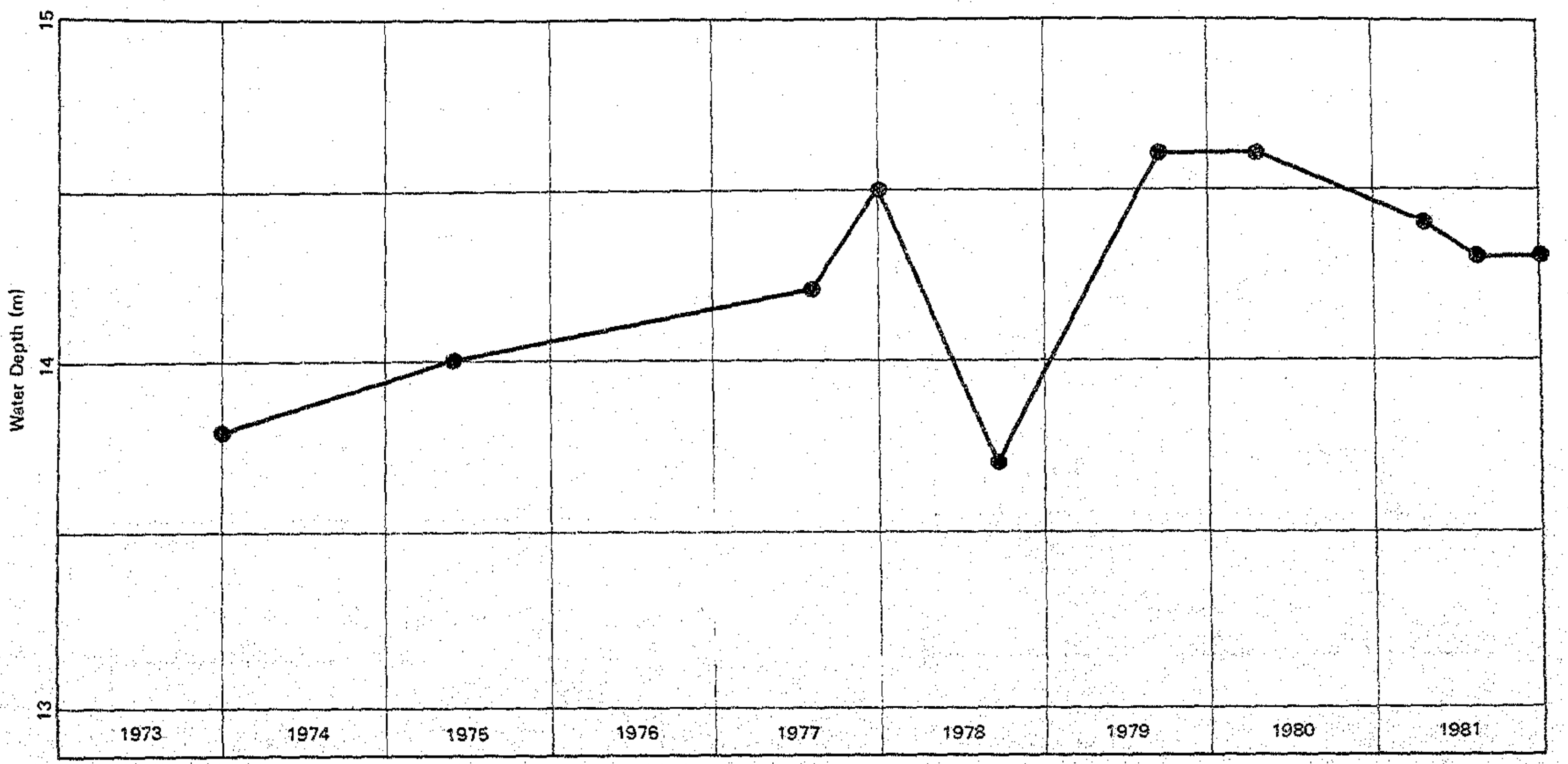



Fig. VI-10 Trend of the Water Depth Change at the Location (211, 456) in Fig. VI-2

### 1. 3. 2 Littoral Drift towards the Breakwater

The sources of sand supply seem to be the sea cliffs of Punta Caldera and Tivives Beach. Punta Caldera consists of three sea cliffs. They are Punta Corralillo, Punta Torres and Punta Icaco. Before the construction of the Port of Caldera, there was no beach at the northern part of Corralillo Beach. New Beach appeared after the construction of the Port of Caldera started. New Beach is gradually growing along with the extension of the breakwater. The process of the growth of New Beach is shown in Photo.VI-1.

In our site survey, new sand sedimentation between New Beach and Corralillo Beach was observed forming a pocket beach extending from Punta Corralillo to the breakwater. Within this new pocket beach the shoreline of New Beach is presently advancing continuously. However, the breakwater is too short to keep the littoral drift sand at New Beach and Corralillo Beach. The extension of the breakwater, therefore, would be a very effective way to keep sand in this area.

The rough littoral drift pattern in areas less than −10 m deep is shown in Fig.VI-11. This pattern is estimated based on the results of soundings which have been executed several times since 1981.

The annual northward drift sand volume offshore Punta Corralillo is estimated as 200,000 $m^3$/year. Within this sand volume, the sand sediment volume between the −5 m and −10 m contour line is estimated as 88,000 $m^3$/year. A sand volume of 14,000 $m^3$/year accumulates at Corralillo Beach, and 98,000 $m^3$/year is supplied to New Beach.

Part of the sand supplied to New Beach, which is estimated as about 26,000 $m^3$/year, accumulates there. The rest passes by the head of the breakwater, goes toward the north side of the foot of the breakwater and accumulates around there.

### 1. 3. 3. Littoral Drift at North Caldera Beach

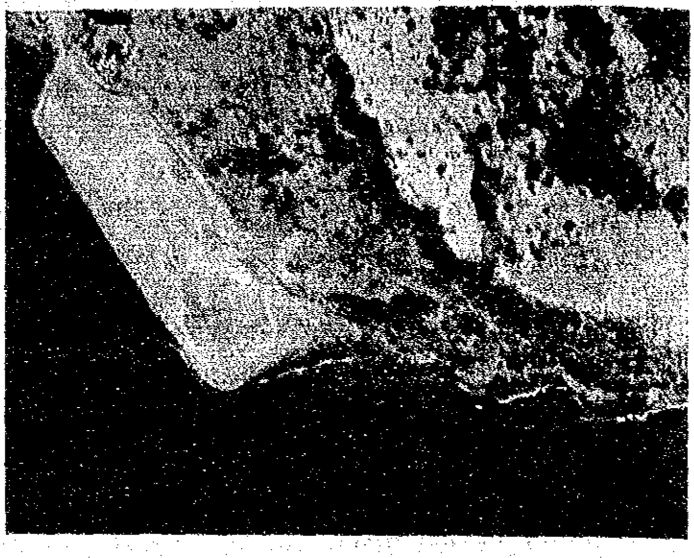
The littoral drift pattern at North Caldera Beach is roughly shown in Fig. VI-12, based on the results of soundings which have been executed since October 1981.

The shoreline at the northern part of North Caldera Beach is receding. On the contrary, the shoreline at the south side of Mata de Limón Inlet is advancing continuously. There are several pilot jetties at the south end of North Caldera Beach. The shoreline change is small in this area. Sand is accumulating on the north side of each jetty. These facts show that southward littoral drift is predominant near the shore at North Caldera Beach.

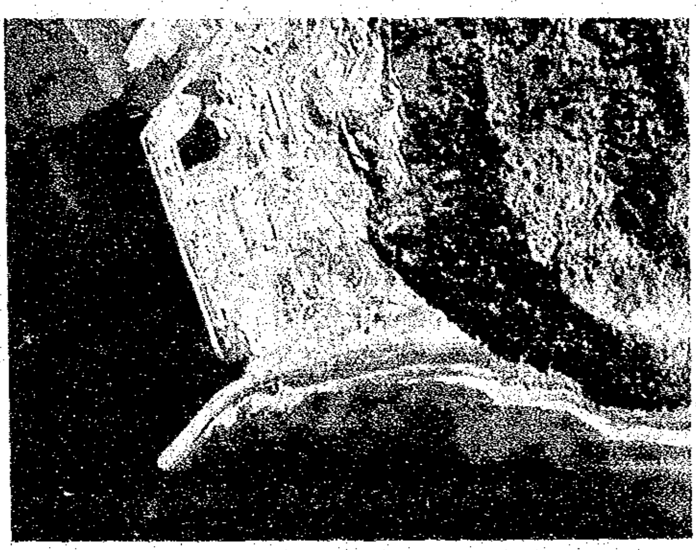
The sand volume change in the sea areas less than 5 m in water depth is as follows ;

(a) North Caldera Beach (Measuring point No.1 to No. 41)
−37,000 $m^3$/year
(b) North of Mata de Limón Inlet (Measuring point No.42~No.60)
+ 3,000 $m^3$/year
(c) South of Mata de Limón Inlet (Measuring point No.61 to No.70)
+45,000 $m^3$/year

Mar., 16, 1976



Jan., 21, 1980



Oct., 17, 1985

**Photo. VI-1 Shoreline Change at New Beach**

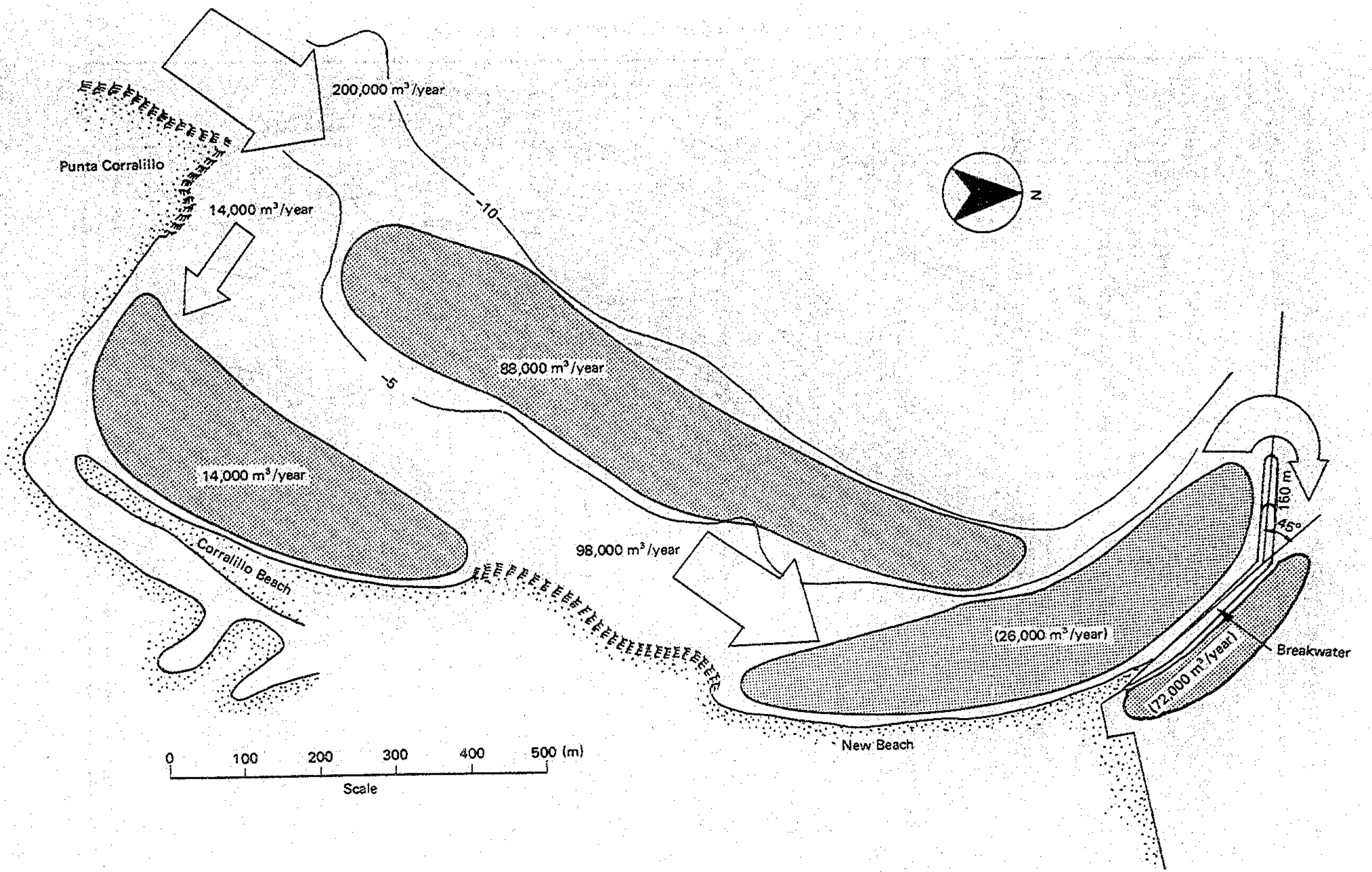



Fig. VI-11 Sand Drift Pattern at the Southern Beach of the Breakwater

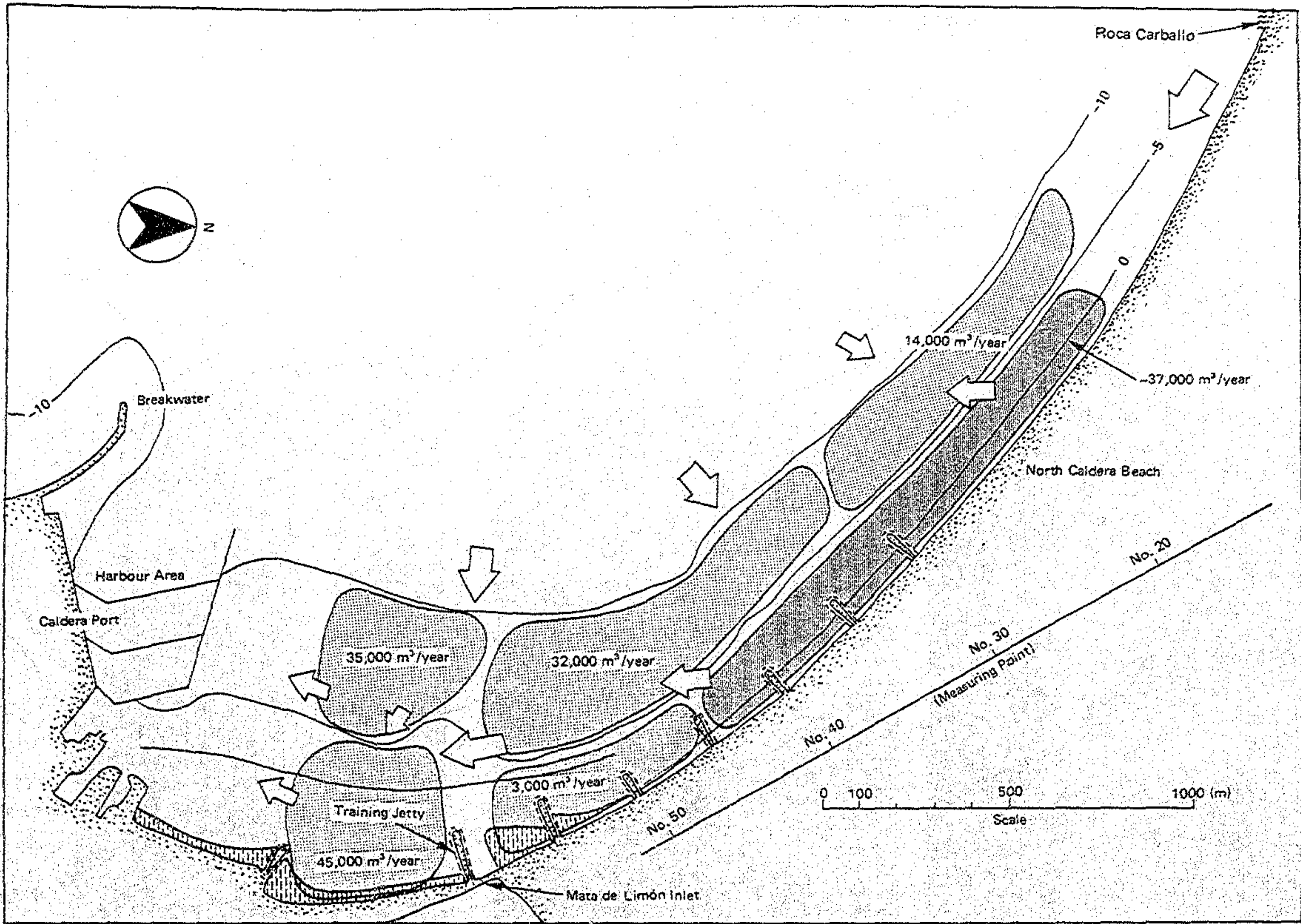



Fig. VI-12 Littoral Drift Pattern at North Caldera Beach

This means that the north side of North Caldera Beach is being eroded, and the south side of Mata de Limón Inlet is accreting (measuring point No.41 is the border between these areas).

The sand volume of 46,000 $m^3$/year includes the sand removed by INCOFE for use as construction material. The volume of sand removed by INCOFE is shown in Table VI-1.

In the sea area between the $-5$ m and $-10$ m contour lines the North Caldera Beach sand has accumulated from October 1981 through September 1985. Sand drift towards the shore seems to be included in this accumulation. The water depth change in this area may be repeated over a period of more than ten years as mentioned in section 1.3.1 of this chapter.

The behavior of sand drift in this area is very complicated because of the strong current to and from Mata de Limón Inlet caused by the tidal current. The characteristics of drift sand in this area are roughly summarized as follows :

(a) The sand from Roca Carballo and the northern part of North Caldera Beach is transported along the shore to the south, and also southwest away from the shoreline.
(b) There is also some sand supply to the nearshore by the on-off shore sand drift.
(c) A large volume of sand accumulates in the sea area to the south of Mata de Limón Inlet.
(d) Moreover, part of the sand in the sea area at the south of Mata de Limón Inlet is transported to the harbour basin and accumulates there. This may be another cause of the sedimentation of the harbour.

**Table VI-1 Volume of Sand Removed by INCOFE**

(Unit : $m^3$)

| | 1983 | 1984 | 1985 |
|---|---|---|---|
| January | 0 | 1916 | 1824 |
| February | 0 | 2532 | 2064 |
| March | 0 | 2424 | 1668 |
| April | 0 | 1848 | 960 |
| May | 0 | 2160 | 1692 |
| June | 0 | 2844 | 756 |
| July | 0 | 1812 | 888 |
| August | 0 | 1416 | — |
| September | 0 | 1968 | — |
| October | 0 | 984 | — |
| November | 0 | 2556 | — |
| December | 1500 | 468 | — |

Note : Total removed sand volume in this period is 34,100$m^3$

### 1. 3. 4 Present Situation of Sand Sedimentation in the Harbour

Sand sedimentation in the basin is caused by the two phenomena. As mentioned above, the drift sand from New Beach passes by the head of the breakwater, goes toward the foot of breakwater, and accumulates around there. This is one cause of the harbour sedimentation. This sediment volume is called 'sediment volume at the harbour side of the breakwater' hereafter. The other phenomenon is the sedimentation of the whole basin with almost a uniform thickness.

These two different sedimentation mechanisms are clearly distinguished in Fig.VI-5 by a thick contour line of −10 m. The breakwater side represents the former, the harbour side the latter. The result of the grain size analysis also reveals the different sedimentation mechanisms. The median grain diameter around the breakwater is around 0.3 mm. On the other hand, that of the whole basin is around 0.1 mm.

Table VI-2 shows the sand sediment volume since April, 1980. This volume is calculated based on the sounding results. About 30,000 m³ of sand has been dredged by MOPT since MOPT started the dredging on July 10 th, 1985. All of the dredged sand had accumulated at the harbour side of the breakwater. This volume, therefore, is included in the volume in Table VI-2.

**Table VI-2 Sand Sediment Volume**

| Period | Sand Sediment Volume ($m_3$) | | |
|---|---|---|---|
| | Harbour Side of the Breakwater | Turning Basin | Total |
| 1980' 4 ~1981'10 | 12,000 | − | − |
| 1981'10~1982' 7 | 21,000 | −26,000 | −5,000 |
| 1982' 7 ~1983' 8 | 40,250 | 70,813 | 111,063 |
| 1983' 8 ~1984' 8 | 24,125 | 77,938 | 102,063 |
| 1984' 8 ~1985' 9 | 94,500*) | 18,250 | 112,750 |

Note : ※) This volume includes the dredged sand volume

(1) Sand sediment at the harbour side of the breakwater

Littoral drift around the breakwater is considered to be mainly composed of sand drift in bed load. Therefore, as the seaside water depth of the breakwater becomes shallower, the littoral drift volume and also the sediment volume at the harbour side of the breakwater becomes greater. The New Beach shoreline advances year by year, and therefore, the sediment volume at the harbour side of the breakwater changes year by year. Shoreline changes and the length of the wing jetty in each year are shown in Fig.VI-13. In this figure, the −2 m contour line is shown instead of the shoreline. The wing jetty is generally referred to as the breakwater in this report.

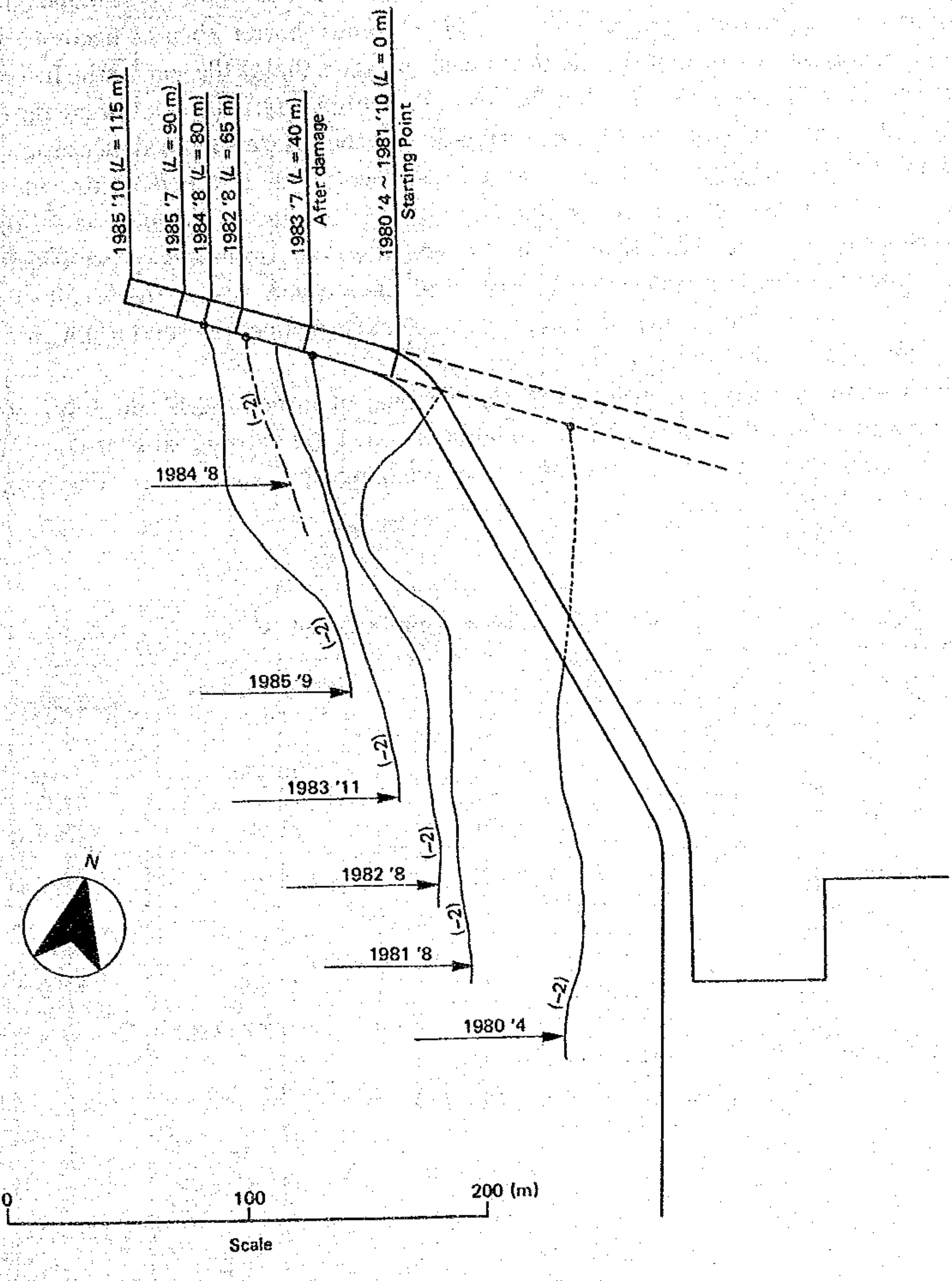



Fig. VI-13 Shoreline Changes and the Breakwater Length

The distance between the head of the breakwater and the −2 m contour line ($D$), and the sediment volume at the harbour side of the breakwater of each period since April 1984 are shown in Table VI-3. In this table, $Q_s$ is the sand sediment volume per year. Fig.VI-14 shows the relation between $D$ and $Q_s$. This figure shows that the $Q_s$ is determined only from $D$. When $D$ is more than 60 m, $Q_s$ is zero. If $D$ becomes shorter, then $Q_s$ becomes greater. Finally, $Q_s$ approaches asymptotically to 112,000 $m^3$/year, that is the sum of the littoral drift volume at Corralillo Beach and New Beach. This Fig.VI-14, which is based on the site surveys, plays an important role in the estimation of the future sand sedimentation.

Table VI-3 and Fig.VI-14 show that the sedimentation at the harbour side of the breakwater has accelerated since the middle of 1984 according to the advance of the New Beach shoreline. To leave this situation unchanged means the occurrence of sand sedimentation of more than 80,000~100,000 $m^3$ per year at the harbour side of the breakwater. At any rate, it is clear that countermeasures must be taken against the sand sedimentation at the harbour side of the breakwater.

Such sedimentation already impedes the berthing of large vessels. In July, 1985, one large vessel touched the sea bed. The vessel abandoned the berthing at that time. MOPT decided, under these circumstances, to execute dredging by a contractor. The details are described in CHAPTER IX.

**Table VI-3 Relation between D and $Q_s$**

| Period | Length of Wing Jetty (m) | $D$ (m)[1] | Sand Sediment Volume ($m^3$) | $Q_s$ ($m^3$/year)[4] |
|---|---|---|---|---|
| 1980. 4 ~1981.10 | 0 | 45[2] (Average) | 12,000 | 8,000 |
| 1981.10~1982. 7 | 65 | 25 | 21,000 | 28,000 |
| 1982. 7 ~1983. 8 | 65[3] (After Damage) | 15 | 40,250 | 37,000 |
| 1983. 8 ~1984. 8 | 80 | 20 | 24,125 | 24,000 |
| 1984. 8 ~1985. 9 | 90 | 10 | 94,500 | 87,000 |

Notes: 1) $D$ is the distance between the head of the breakwater and the −2.0 m contour line (See Fig. VI-13) at the start of each period.
2) $D$ in 1980'4~1981'10 is assumed as an average value.
3) The length of the wing jetty after damage in july 1983 is assumed as 65 m.
4) $Q_s$ is the sand sediment volume per year (See Fig. VI-14).

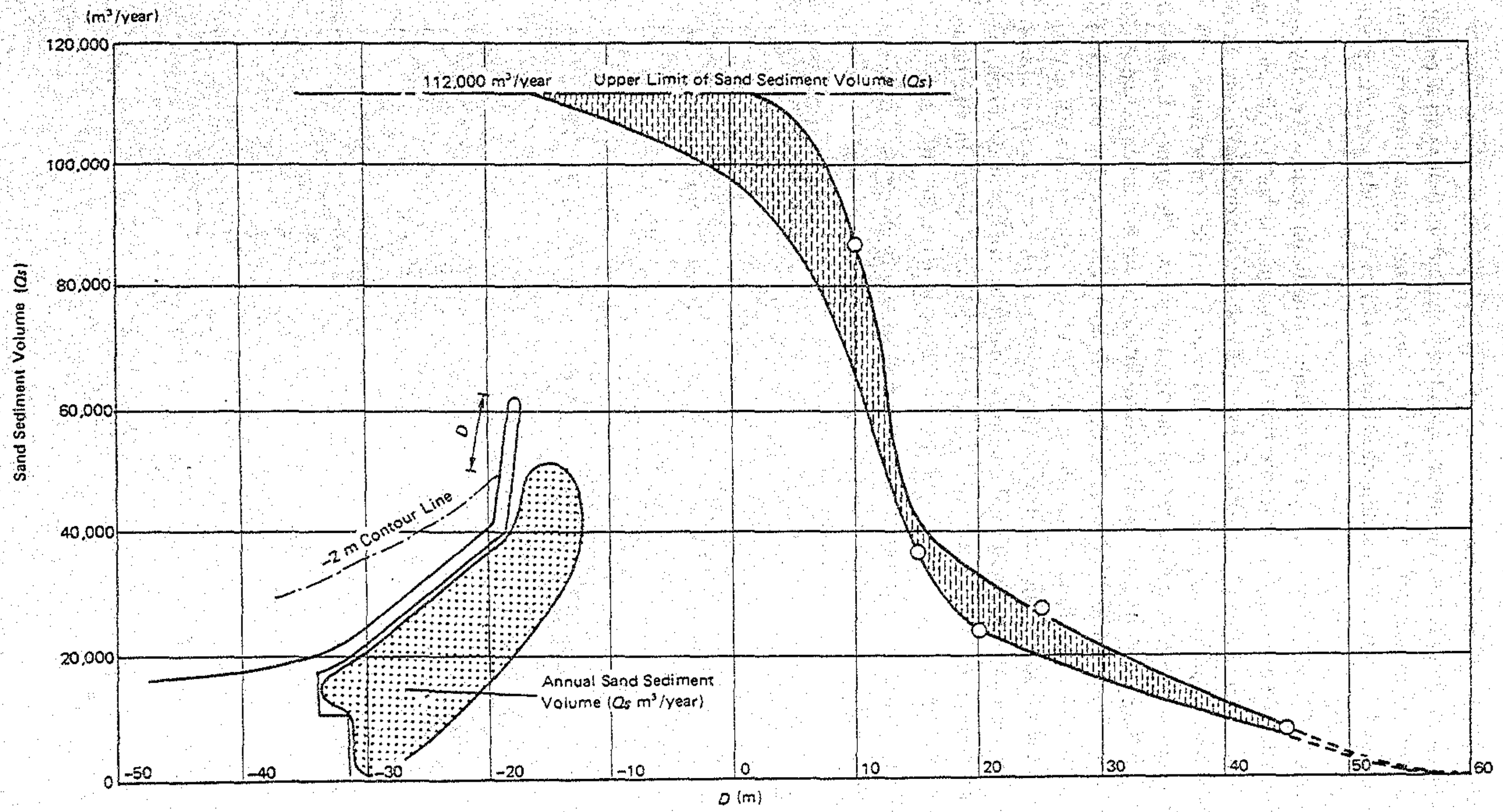



Fig. VI-14 Relation between $D$ and $Q_s$

(2) Sand sedimentation in the basin

In the harbour basin, there is also the other type of sedimentation, that is an accumulation of fine sand with an almost uniform thickness. The median grain diameter of this sediment sand is around 0.1 mm. This sediment is transported by the tidal current and the longshore current.

It can be seen in Table VI-2 that the sediment volume in the basin changes year by year. To grasp the long-term trends of sand sedimentation in the basin, the basin is divided into three zones, −7.5 m, −10 m and −11 m in depth. Fig.VI-15 shows the divided basin. In this figure, zones A, B and C correspond to −7.5 m, −10 m and −11 m, respectively. These zones are divided into 20 m×20 m blocks for calculation purposes. The zones D and E are also included in this figure for the purpose of the simulation using a mathematical model. This is described later. The relations between the lapse of time with a starting month of Feb. 1982 and the water depth of each zone are shown in Fig.VI-16. The sand sediment rates (cm/year) of each zone can be calculated from these figures. These ratios are shown in Fig.VI-17. The average annual sediment volume in the harbour area is also shown in this figure. It can be seen from this figure that the annual sediment depth in the basin is 12.5~16 cm/year, and the annual sediment volume in the basin is 16,900 $m^3$/year.

This sediment is caused by wave action and tidal and longshore currents. The relations among these factors will be considered later on.

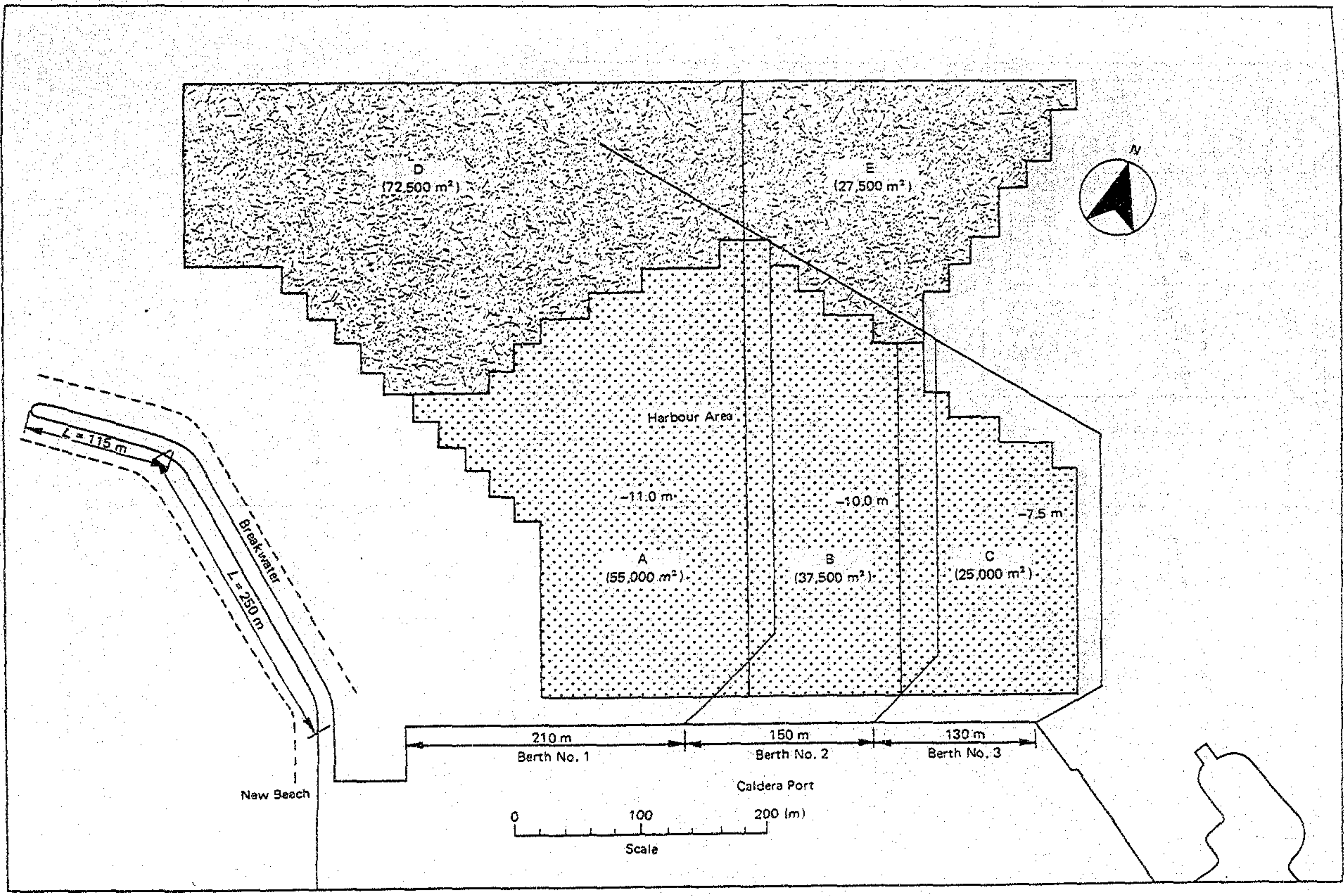
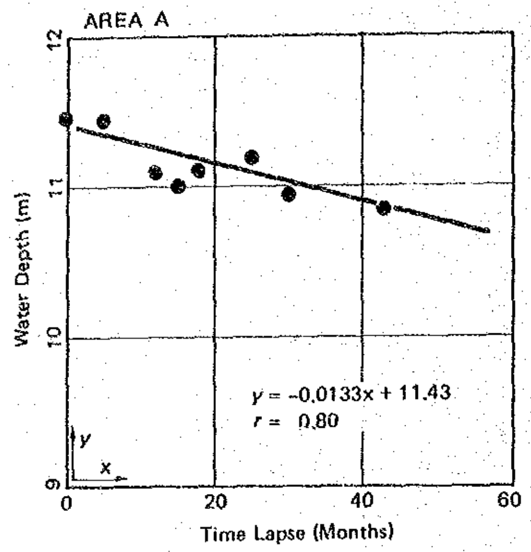
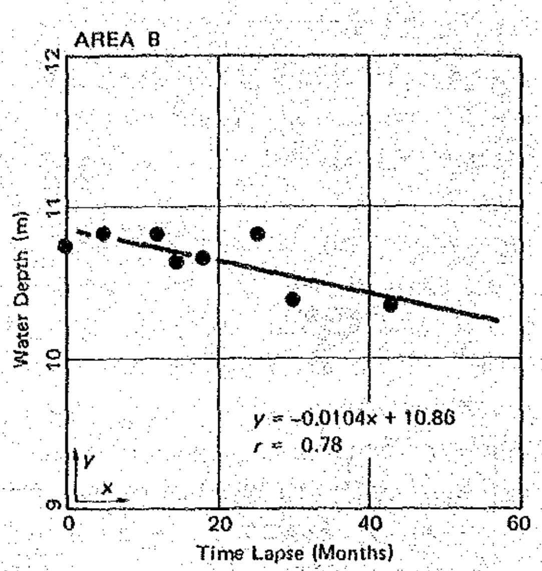
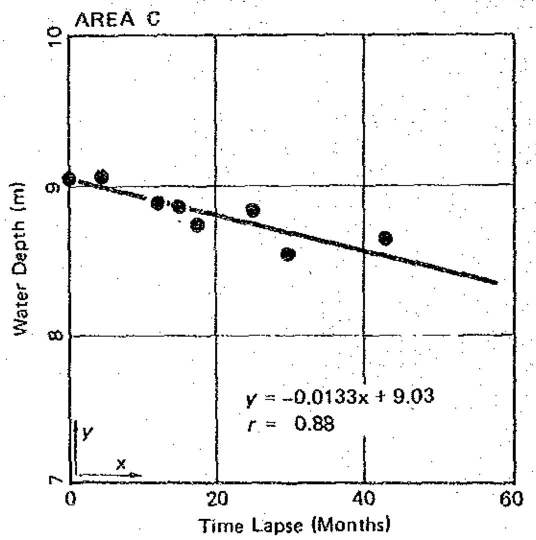
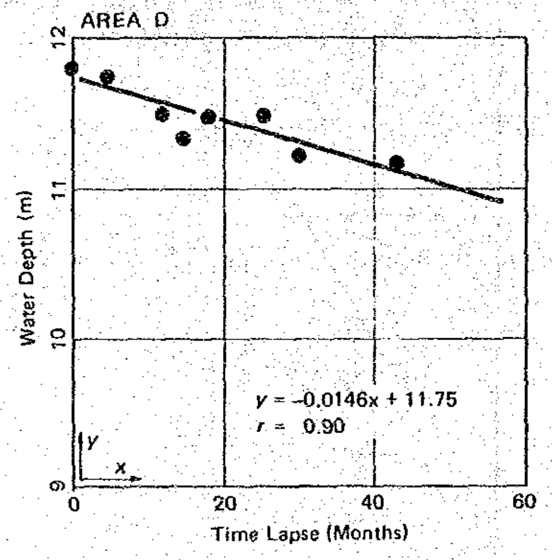


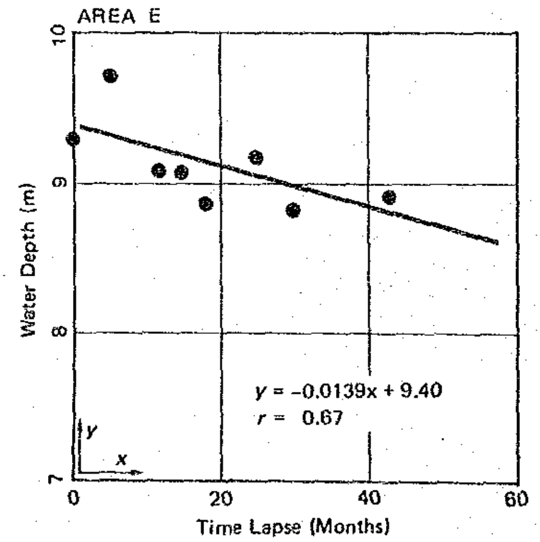

Fig. VI-15 Divided Harbour Area



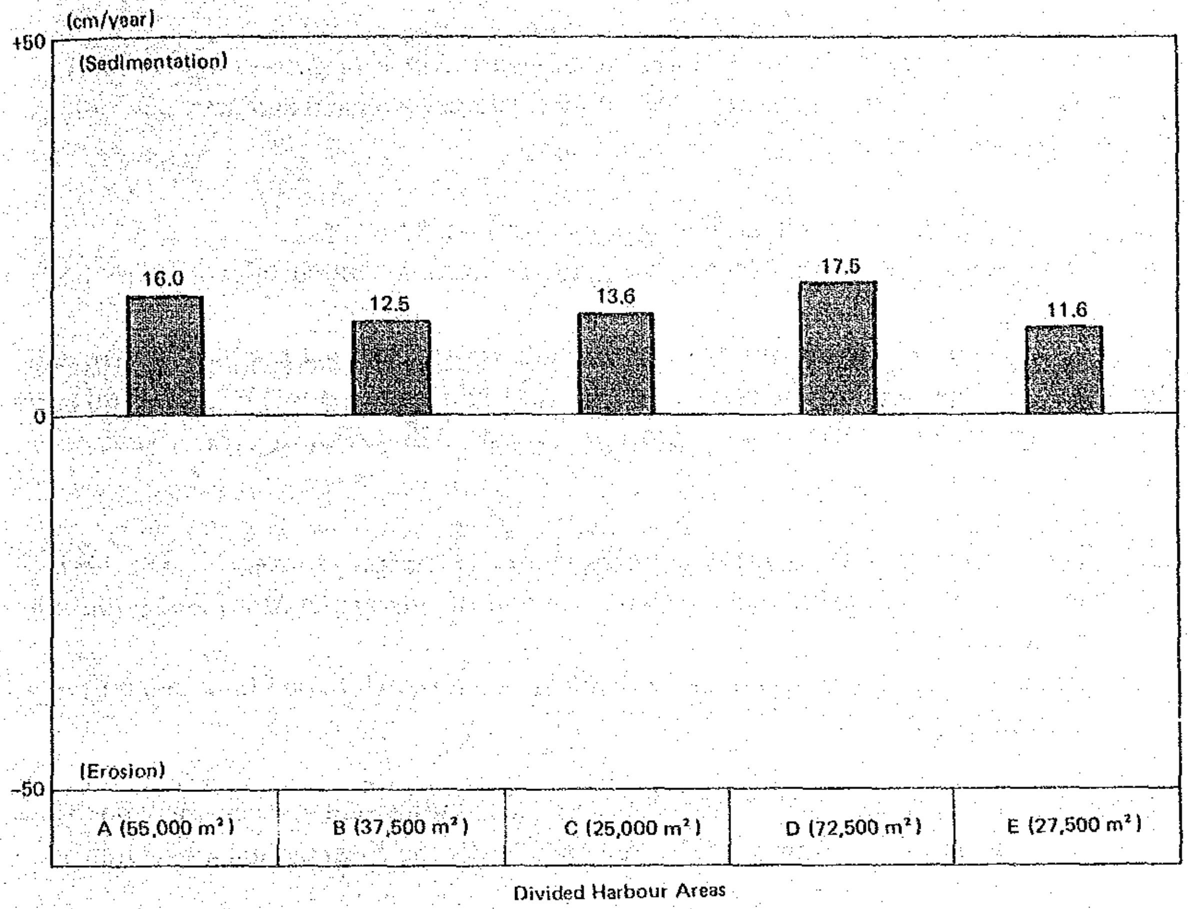




Notes: 1) Areas A ~ E are shown in Fig. VI-15.
2) The observation period is Feb., 1982 ~ Sept., 1985
3) $r$ is the correlation coefficient

**Fig. VI-16 Water Depth Change with the Lapse of Time**




| Zone | Area ($m^2$) | Annual Sediment Rate (m/year) | Annual Sediment Volume ($m^3$/year) |
|---|---|---|---|
| A | 55,000 | 0.160 | 8,800 |
| B | 37,500 | 0.125 | 4,700 |
| C | 25,000 | 0.136 | 3,400 |
| Total | 117,500 | – | 16,900 |

**Fig. VI-17 Annual Sediment Rate and Sediment Volume**

## 2. Review of Past Countermeasures against Sand Sedimentation

The construction of the Port of Caldera, which started in 1974, was completed in Dec., 1981 including a 250 m long breakwater. The major countermeasures against sand sedimentation of this period are as follows :

(a) The change of the Mata de Limón Inlet (1981～1982)
(b) The construction of the training jetty at the Mata de Limón Inlet (1981～1982)

New Beach, however, continued to grow. It can be estimated that the littoral drift sand started passing by the head of the breakwater into the harbour area in 1981. The full-scale countermeasures which include those against northward drift began in 1982. They are as follows :

(a) The construction of an 80 m long breakwater extension (started in Feb., 1982)
(b) The construction of the pilot jetties at the north side of the Mata de Limón Inlet (1982～1983)
(c) Removal of sand by INCOFE at the south beach of the Mata de Limón Inlet (Started in Dec., 1983)

The construction of the breakwater extension is continuing under severe sea conditions with limited construction machinery. The circumstances of the construction are as follows :

| | | |
|---|---|---|
| (a) | Feb. 1982 | : The construction of the breakwater extension started. |
| (b) | Aug. 1982 | : 65 m long breakwater extension was completed. |
| (c) | The end of 1982 | : 80 m long breakwater extension was completed. |
| (d) | July 17 and 18, 1983 | : The head of the breakwater extension was damaged, reducing the breakwater extension to 40 m. |
| (e) | From 1983 to 1984 | : The breakwater was extended after the repair of its head. |
| (f) | Apr. 8, 1985 | : The length of the breakwater extension reached 90 m. |
| (g) | Apr. 1985～ | : The breakwater is being extended despite severe damage. The length of the breakwater extension was 115 m in Oct. 1985. |
| (h) | From July 10, to Sept.,1985 | : MOPT dredged 30,000 $m^3$ of sediment sand at the harbour side of the breakwater. |
| (i) | January, 1986～ | : MOPT started to construct an additional breakwater extension. The breakwater extension will be completed at a length of 150 m (a part of the wing jetty) in May 1986. In this study, this imme- |

diate breakwater extension work is regarded as completed. Concerning this work, the Japanese Study Team has given some information to MOPT ; the details are shown in APPENDIX 4.

(j) In 1986 : According to the information from MOPT, 300,000 $m^3$ of sediment sand in the basin will be dredged by a contractor. In this study, this dredging is regarded as completed by May, 1986.

The circumstances show that the construction of the breakwater extension has met with serious difficulties since July, 1983.

Meanwhile, the sand sediment at the harbour side of the breakwater continues to grow. After the storm in July, 1983, the crown of the sand sediment, which was formerly under the sea, appeared at last above the sea surface. This new beach, which is located just behind the breakwater, is called 'New Beach Junior'. New Beach Junior has continued to grow.

# 3. Alternative Countermeasures against Sand Sedimentation

## 3. 1 Basic Alternative Countermeasures

The countermeasures against sand sedimentation can be roughly divided into two methods : to reduce the sand sediment in the harbour as much as possible, and to dredge the sediment in the harbour immediately. Specifically, alternative options to reduce sand sedimentation in the harbour include :

(a) Extension of the existing breakwater
(b) Construction of a new jetty at the upper side of the littoral drift
(c) Extension of the existing training jetty at Mata de Limón Inlet
(d) Removal of the sand at the southern beach of Mata de Limón Inlet
(e) Removal of the deposited sand at the seashore of New Beach

## 3. 2 Selection of the Countermeasures

### 3. 2. 1 Evaluation of each Countermeasure

The length of the existing breakwater is not sufficient to keep the northward drift sand in the pocket beach consisting of New Beach and Corralillo Beach as described above. A small extension of the breakwater would be greatly effective in keeping the drift sand within the pocket beach. Taking this fact into consideration it is clear from the observation data analysis that the extension of the existing breakwater is the most urgent and the most important countermeasure against sand sedimentation.

It would also be effective to construct a new jetty at the upper side of the littoral drift. The location of the new jetty would be between Tivives Beach and New Beach. It would not be effective to construct a new jetty at the rocky shore between New Beach and Corralillo Beach, because some of the drift sand is supplied from the offshore of Punta Corralillo to New Beach directly. Therefore, if it is necessary to construct the new jetty, the location should be at Punta Caldera. There is no approach road for the new jetty construction there at present. Temporary works such as the construction of an approach road would be very expensive. Construction of the new jetty from the sea using a construction ship would also be very expensive. Thus, the construction of a new jetty is uneconomical compared with the extension of the breakwater. Moreover, even if a new jetty were constructed, the drift sand at New Beach would continue to settle at the harbour side of the breakwater for a while after the new jetty was completed. This alternative is, therefore, not selected at present. However, it should be studied further if the New Beach shoreline advances and the sedimentation at the harbour side of the breakwater begins again in the future.

One possible countermeasure against the accumulation of fine sand with almost a uniform thickness in the harbour basin is to extend the training jetty at Mata de Limón Inlet. However, this should not be given top priority because of following reasons :

(a) The annual sediment is currently 12.5~16 cm. As discussed later on, this sediment rate will not increase so much even if the breakwater is extended. Therefore, countermeasures against this sedimentation are not so urgent. Dredging once in five years may be a reasonable countermeasure against this sedimentation.

(b) There is an accumulation of sediment at the north side of the basin. The annual sediment depth of this area is around 30 cm. Some of this sediment sand may be come into the north part of the harbour basin in the future. However, it is very difficult to estimate the future trends of this accumulation over a long period of time. The effectiveness of the training jetty extension is also difficult to estimate from the results of the observation data analysis because the tidal and the longshore currents around Mata de Limón Inlet are very complex. Therefore, long term observation of the water depth change is necessary. The extension of the training jetty should be studied after observation data are collected.

Removing the sand at the south of Mata de Limón Inlet is currently undertaken by INCOFE for the purpose of utilizing the sand as a material for civil works. This is an effective way to prevent the sand sedimentation of the harbour basin. It is preferable to remove the sand as frequently as possible.

Removing the sand at the seashore of New Beach is also an effective way to prevent sedimentation in the harbour if the sand can be utilized for other purposes. However, there seems to be no demand to use this sand at present. Therefore, this is not adopted as one of the countermeasures against sand sedimentation.

### 3. 2. 2 *Urgent Countermeasures*

As a result of the evaluation of the various alternative countermeasures against sand sedimentation, the extension of the breakwater and the dredging of unavoidable sediment in the harbour are recommended as urgent countermeasures. Of course, the removal of the sand by INCOFE shoud be continued.

(1) Extension of the existing breakwater

The extension of the breakwater is the main countermeasure against the sand sedimentation at the harbour side of the breakwater. Six alternative plans for the breakwater extension are studied. As shown in Fig.VI-18, and Table VI-4, two alternative centerlines for the extension of the breakwater are considered. One is in the same direction as the existing breakwater, and the other is 45° away from the existing breakwater. These alternatives are evaluated later on using the simulation method 'One-Line Theory'.

(2) Primary dredging and maintenance dredging

As mentioned above, the sand sedimentation at the harbour side of the breakwater has already caused some difficulties for berthing and other ship operations in the harbour. The immediate dredging will be completed by a foreign contractor by May 1986 as planned by MOPT. The rest of the sand sediment and additional sediment should be dredged as soon as possible after the breakwater construction is completed. This dredging is called the primary dredging. Further periodic maintenance dredging will be necessary even if the breakwater is extended. The extension of the existing breakwater will greatly affect the dredging. Therefore, not only the dredging volume but also the time schedule of the breakwater extension and of the dredging itself are studied and adjusted in CHAPTER IX. and CHAPTER X.

**Table VI-4 Alternative Designs of the Breakwater Extension**

| Direction of the Breakwater Extension | Breakwater Extension Length | Case |
|---|---|---|
| Without Extension | | 1 |
| Same Direction as the Existing Breakwater | 200m | 2 |
| | 300m | 3 |
| | 400m | 4 |
| 45° from the Existing Breakwater | 200m | 5 |
| | 400m | 6 |

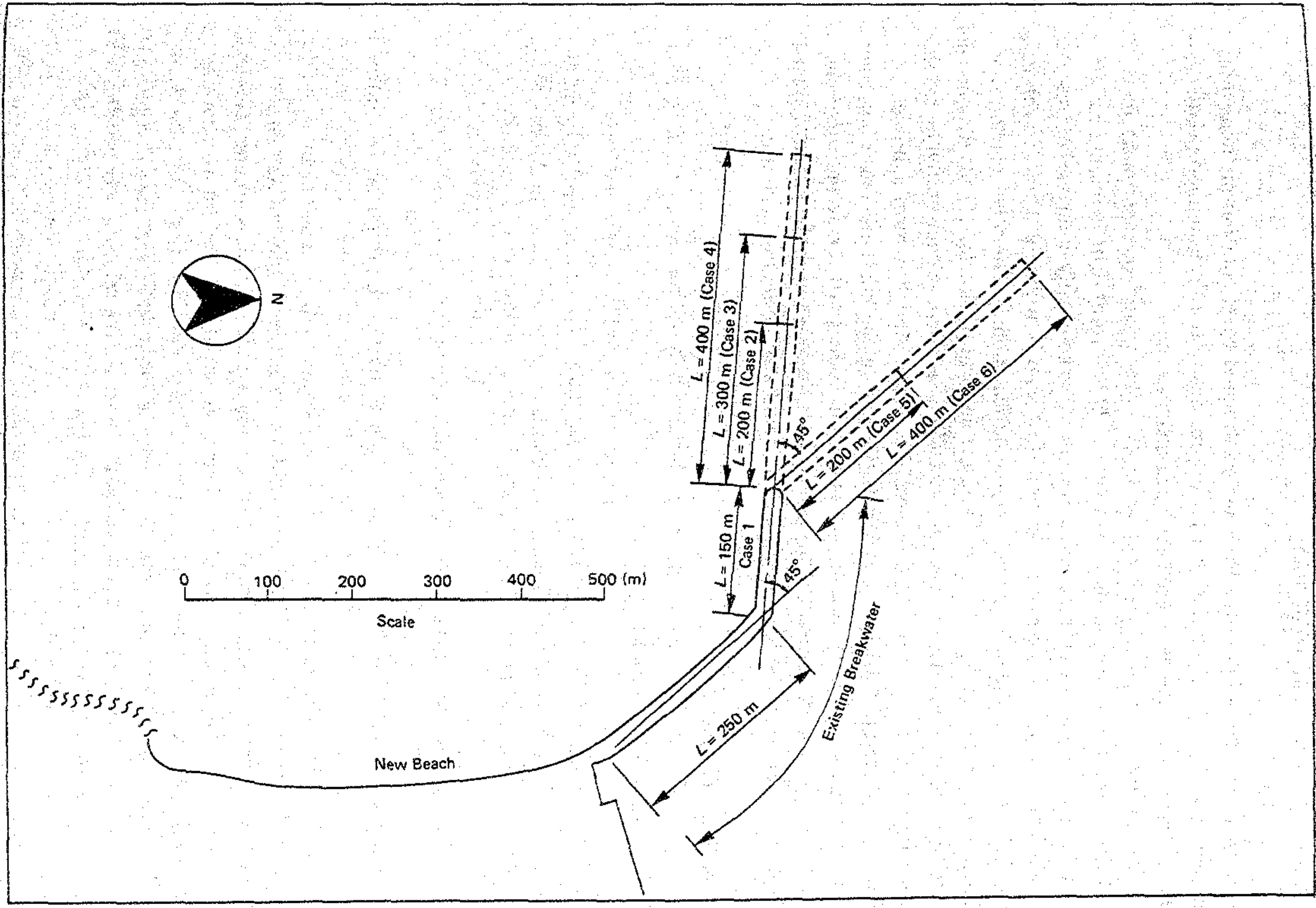



Fig. VI-18 Alternative Designs of the Breakwater Extension

## 4. Simulation using a Mathematical Model

### 4. 1 Selection of the Simulation Model

Future sand sedimentation in the harbour is estimated by simulation methods using a mathematical model. For the simulation it is most important to select an appropriate model which accurately reflects the sand sedimentation mechanisms.

Sand sedimentation in the basin is caused by two phenomena, as mentioned above. One is the littoral drift around the breakwater. This littoral drift is mainly caused by the wave action and longshore current, and is considered to be mainly composed of sand drift in bed load. The median diameter of the littoral drift sand is around 0.3 mm. In this case, the ' One-Line Theory ' is the most suitable mathematical model. The other phenomenon is the sedimentation of the whole basin with almost a uniform thickness. The sediment sand is fine, and the median diameter is around 0.1 mm. This sediment is transported by the tidal current and the longshore current. In this case, the 'Depth Model' is most suitable.

Fortunately, there are sufficient site observation data including data concerning waves, current and water depth. These data are very useful to reconstruct the actual conditions in the simulation model. If the actual conditions can be reconstructed in the simulation model with a high accuracy, then the future estimation should also be highly accurate.

### 4. 2 One-Line Theory

#### 4. 2. 1 Outline of the Model

This model consists of two parts. The first is for the calculation of wave deformation, and the second is for the calculation of shoreline changes. The details of the Model and the initial conditions are described in APPENDIX 5.

#### 4. 2. 2 Estimation Procedure of the Sediment Volume

The estimation procedure of the sediment volume by One-Line Theory is shown in Table VI-5.

In this table, the simulation model is used for step 1 and step 2. The annual rate of the shoreline advance changes according to the sediment volume at the harbour side of the breakwater ($Q_s$ m$^3$/year). As $Q_s$ becomes less, the annual rate becomes greater, and as $Q_s$ becomes larger, the rate becomes smaller. Therefore, at step 2, the future shoreline is calculated taking the annual sediment volume ($Q_s$) into consideration. In step 3, it is assumed from the observation data that the −2 m contour line is always located 68 m offshore from the shoreline (+1.4 m contour line). In step 4, the relation between $D$ and $Q_s$ in Fig.VI-14, is assumed to remain the same as present.

**Table VI-5 Estimation Procedure of the Sediment Volume**

| | |
|---|---|
| Step 1 | Reconstruction of the actual shoreline change using the simulation model |
| | ⇩ |
| Step 2 | Future estimation of the shoreline change |
| | ⇩ |
| Step 3 | Calculation of the distance between the head of the breakwater and the −2m contour line ($D$) |
| | ⇩ |
| Step 4 | Estimation of the annual sediment volume at the harbour side of the breakwater ($Q_s$) using Fig. VI-14 |

### 4. 2. 3 Reconstruction of the Actual Shoreline Change

(1) New Beach and Corralillo Beach

Fig.VI-19(a),(b) shows the simulation result of the shoreline change, with the following conditions.

a) Supplied sand volume to New Beach : 98,000 m³/year
b) Sediment sand volume at New Beach : 26,000 m³/year
c) Sediment sand volume at the harbour side of the breakwater : 72,000 m³/year

In this figure, the calculation period of the shoreline change is from Sept., 1981 to Sept., 1985. The actual shoreline change in this period is also shown in this figure. The figure shows that the actual shoreline change and the calculated shoreline change are quite similar. Therefore, this model can reasonably be applied for the future estimation of the shoreline change.

(2) North Caldera Beach

Fig.VI-20 shows the simulation result of the shoreline change with the following conditions :

(a) Supplied sand volume from both ends of the calculation area : 0 m³/year
(b) Supplied sand volume from the offshore area at the south of Mata de Limón Inlet : 25,000 m³/year

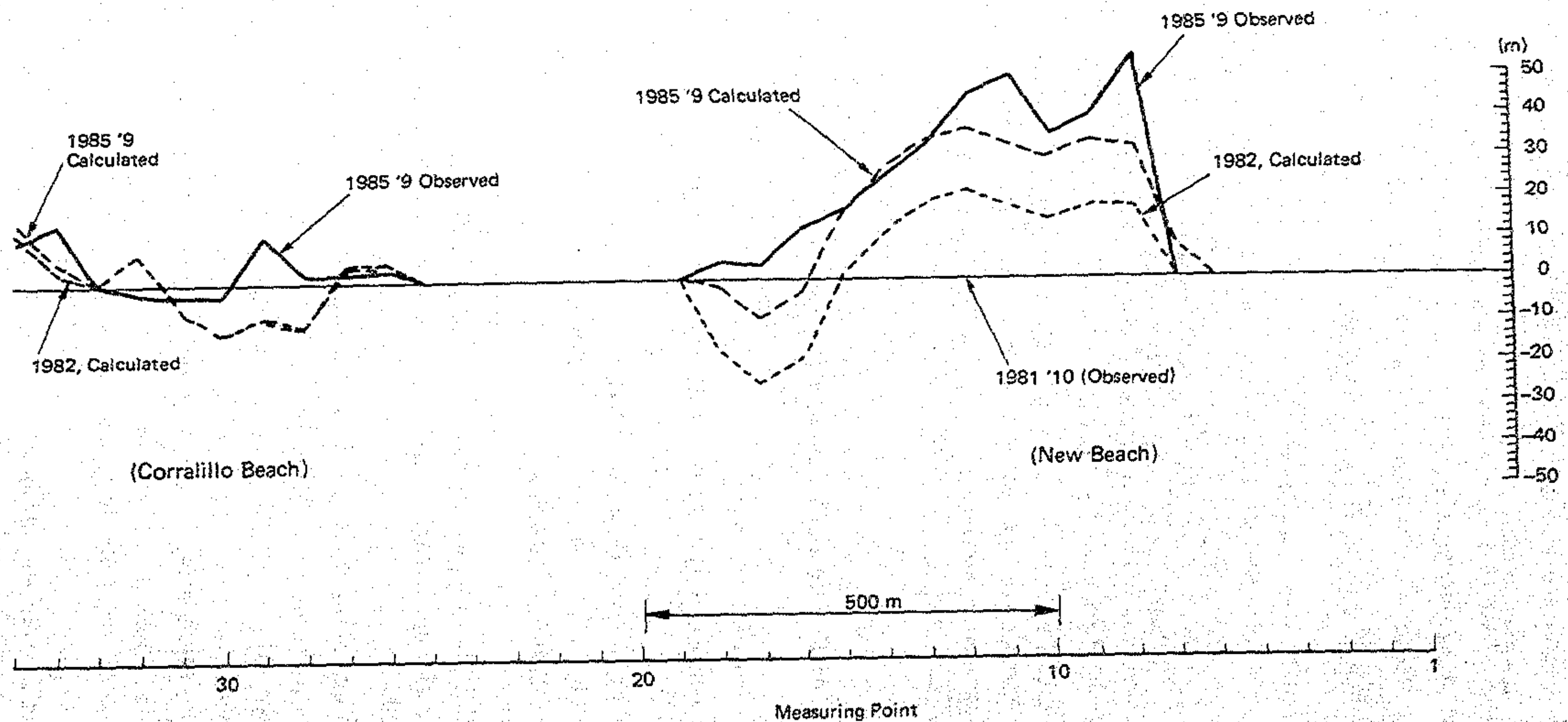



Fig. VI-19 (a) Simulation Result by One-Line Theory
(Reconstruction of the Actual Shoreline Change)

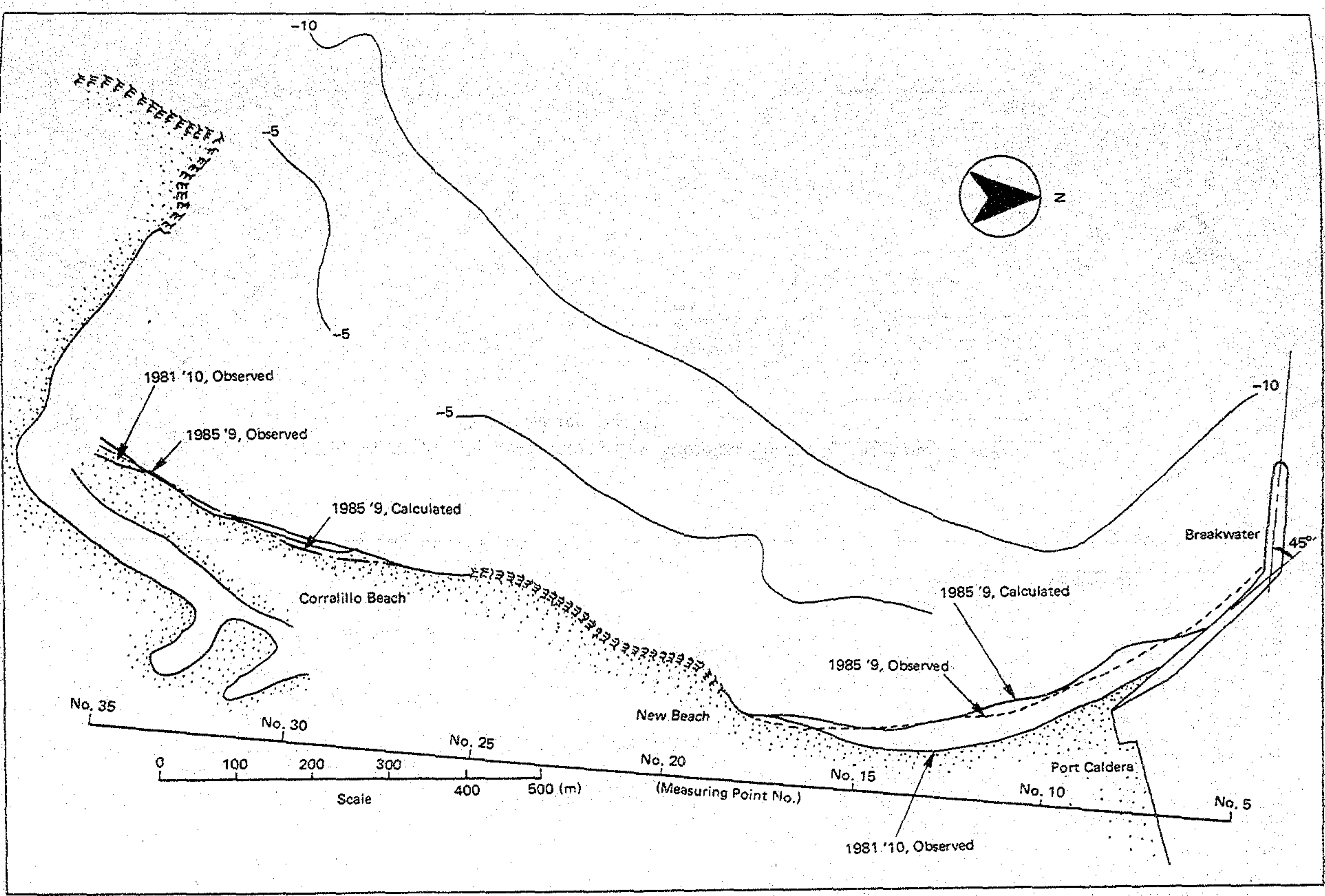



Fig. VI-19 (b) Simulation Result by One-Line Theory
(Reconstruction of the Actual Shoreline Change)

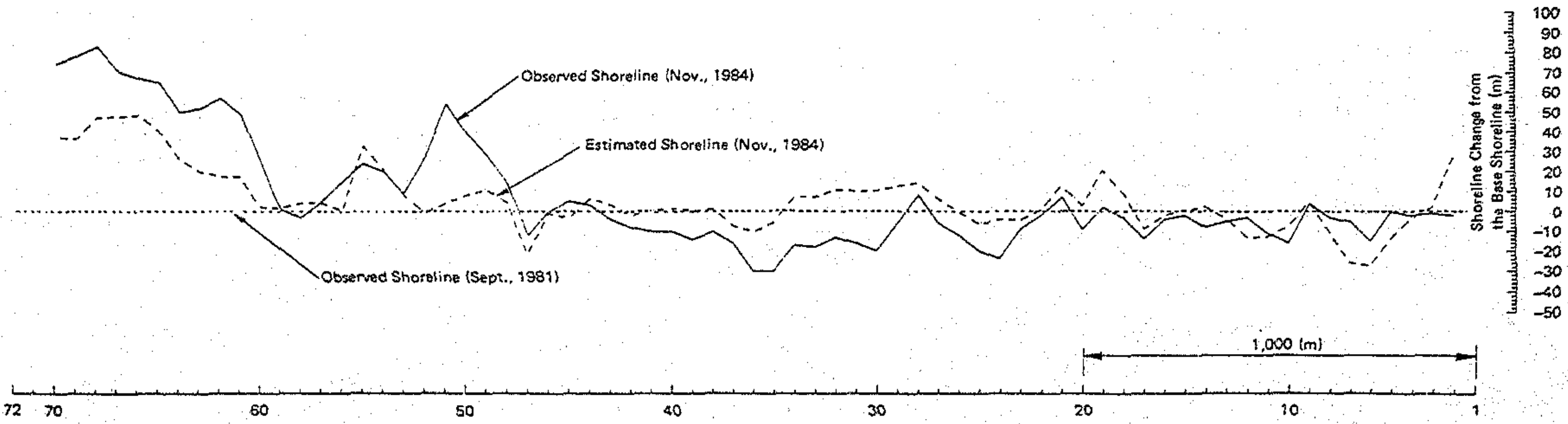



Fig. VI-20 (a) Reconstruction of the Shoreline Change by One-Line Theory (North Caldera Beach)

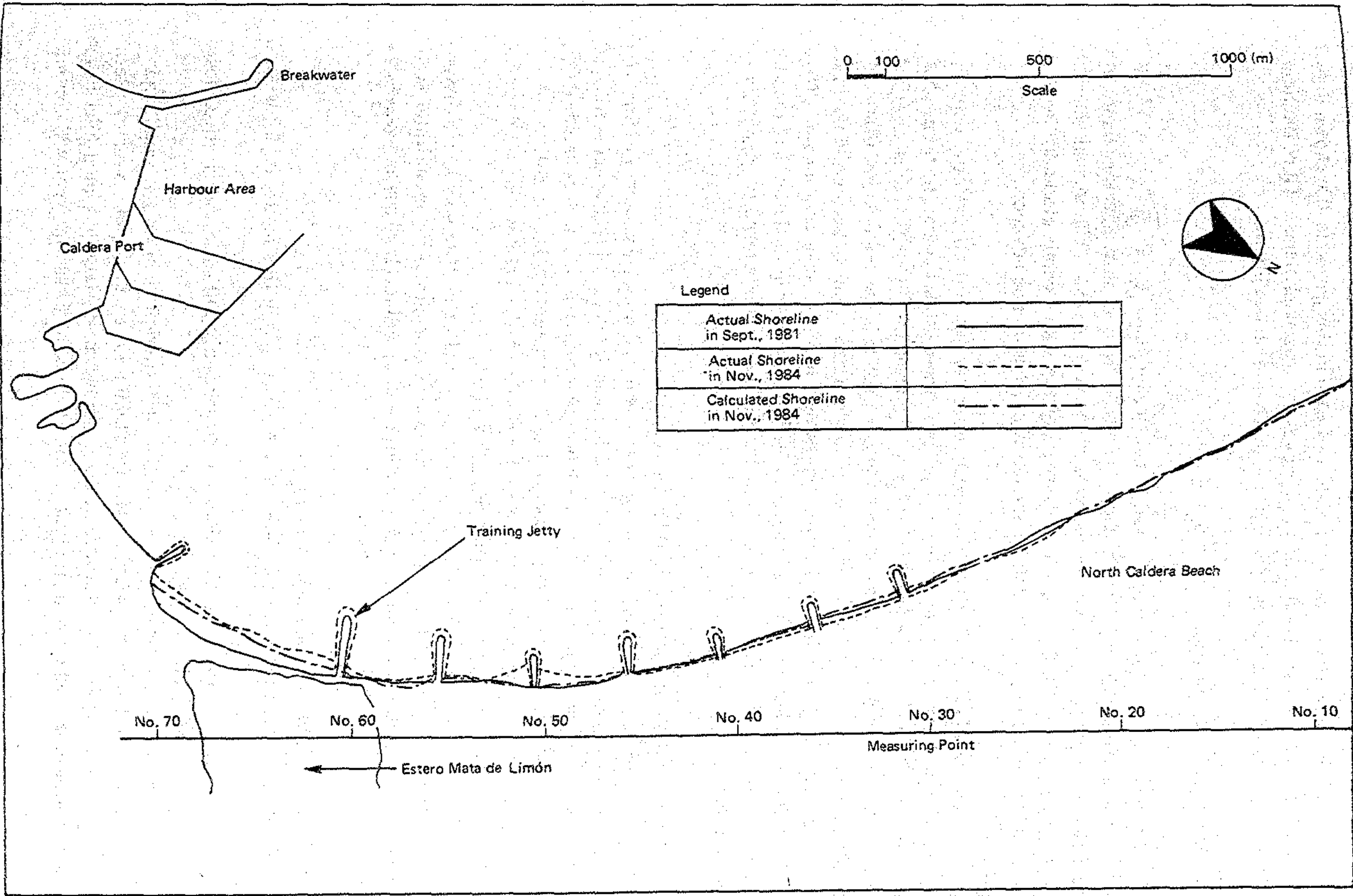



Fig. VI-20 (b) Reconstruction of the Shoreline Change by One-Line Theory
(North Caldera Beach)

The actual shoreline change at North Caldera Beach in this period is also shown in the figure. The actual and calculated shoreline changes are reasonably close. Thus, the future shoreline chage is estimated using this model under the same conditions.

#### 4. 2. 4 Future Estimation

(1) Advance of New Beach and Corralillo Beach shoreline

The calculated future shoreline is shown in Fig.VI-21. As shown in this figure, the annual shoreline advance rate before the year 2,000 is 7 m/year. The annual shoreline advance after the year 2,000 becomes less because the water depth gradually becomes deeper and therefore the same supply of sand brings less shoreline advance.

(2) Evaluation of the alternatives concerning the center line of the breakwater extension

The relation between the center line of the breakwater extension and the future shoreline in 2015 estimated by the One-Line Theory is shown in Fig.VI-22. It is clear that extending the breakwater along same center line as the existing breakwater (Cases 2, 3 and 4) is more effective than extending it at an angle (Cases 5 and 6) because in the latter case, the distance between the head of the breakwater and the −2 m contour line ($D$) is relatively shorter. Thus, the sand sedimentation will start earlier in the latter case than the former. Therefore, the former case is selected as the preferable alternative against sand sedimentation.

(3) Estimation of the future sand sediment volume

When the distance between the breakwater head and the −2 m contour line ($D$) becomes less than 60 m, the sedimentation at the harbour side of the breakwater starts, and therefore the shoreline advance rate becomes less as shown in Fig. VI-21. It is assumed that the −2 m contour line is always 68 m offshore from the shoreline (D.L.+1.40).

The annual sediment volume at the harbour side of the breakwater ($Q_s$) can be calculated based on the estimated results using Fig.VI-14.

Table VI-6 shows the $D$ and the $Q_s$ of each year and of each breakwater extension length. It can be seen from this table that if the extension length of the breakwater is 200 m, then the sedimentation will start in the year 2012 and $Q_s$ will reach 72,000 $m^3$/year in the year 2024.

(4) North Caldera Beach shoreline change

Calculated future shorelines are shown in Fig.VI-23. From this figure, it can be seen that :

- (a) the breakwater extension does not significantly influence the North Caldera Beach shoreline change,
- (b) the shoreline change at the north side of Mata de Limón Inlet is small, and
- (c) the shoreline at the south of Mata de Limón Inlet will advance year by year.

The result of the shoreline advance at the south beach of Mata de Limón Inlet in the future is obtained from the assumption that a sand volume of 25,000 $m^3$/year will continue

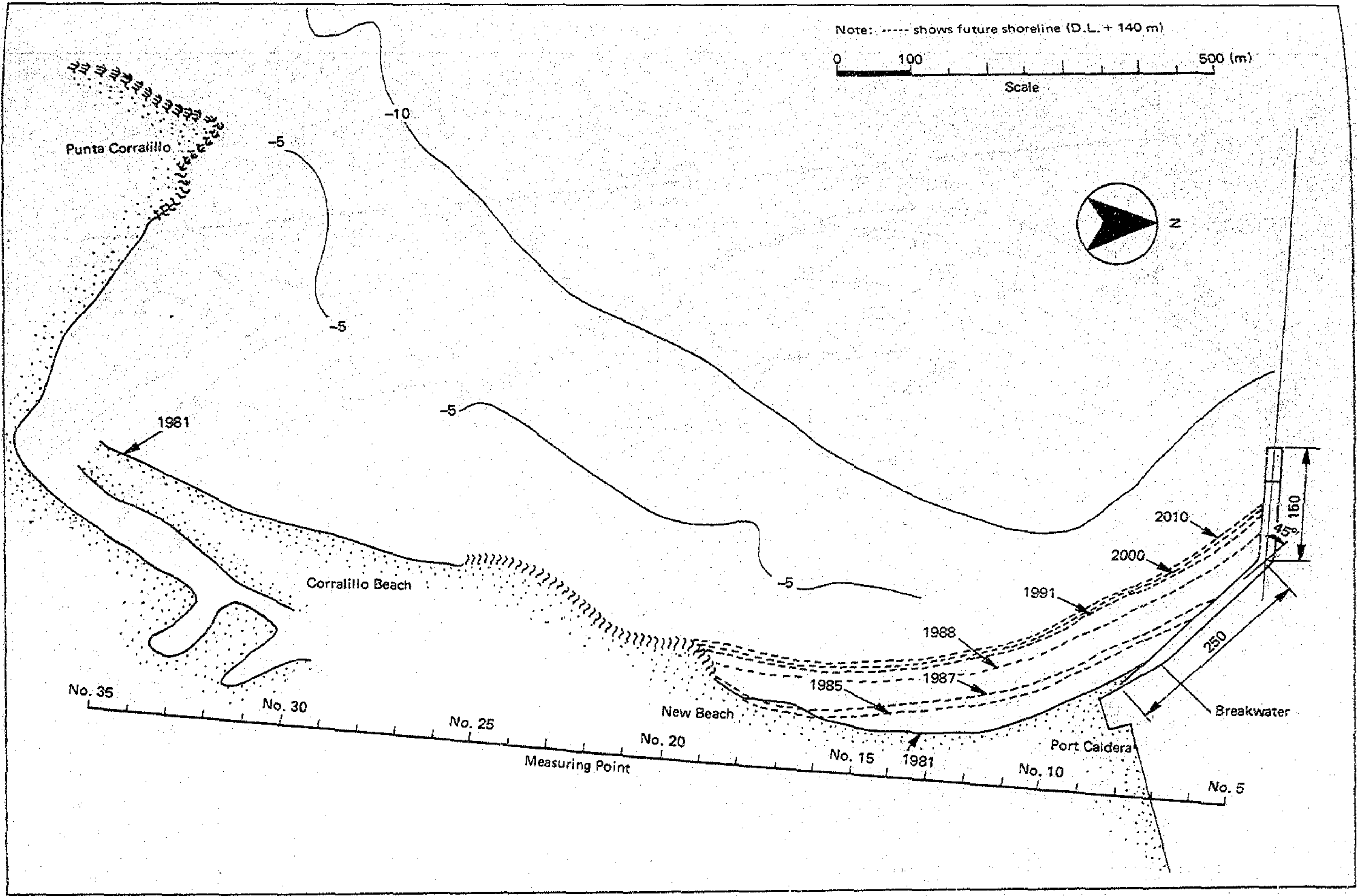



Fig. VI-21 (a) Calculated Future Shoreline (Case 1 $L = 0$ m)

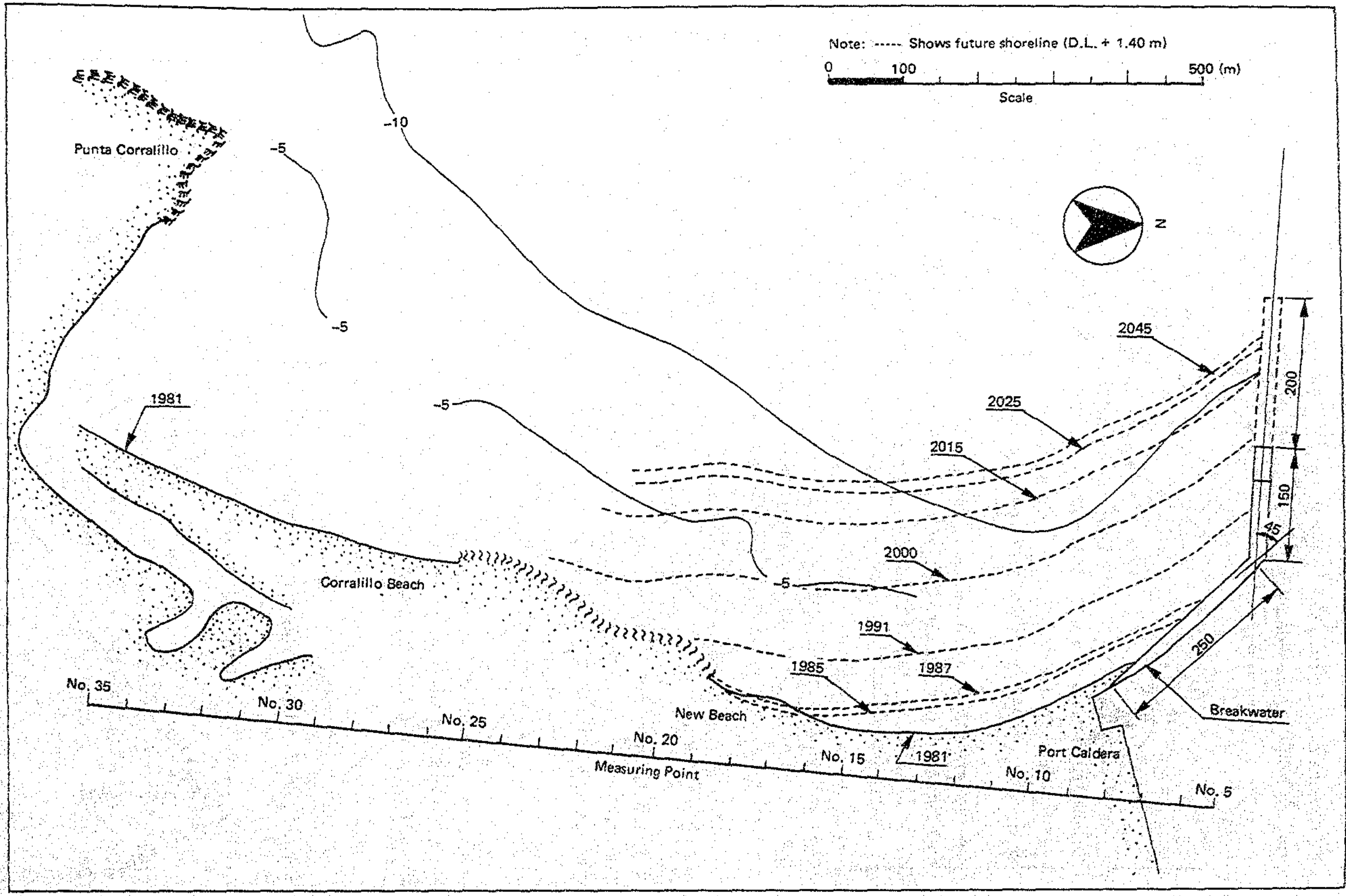



Fig. VI-21 (b) Calculated Future Shoreline (Case 2 $L = 200$ m)

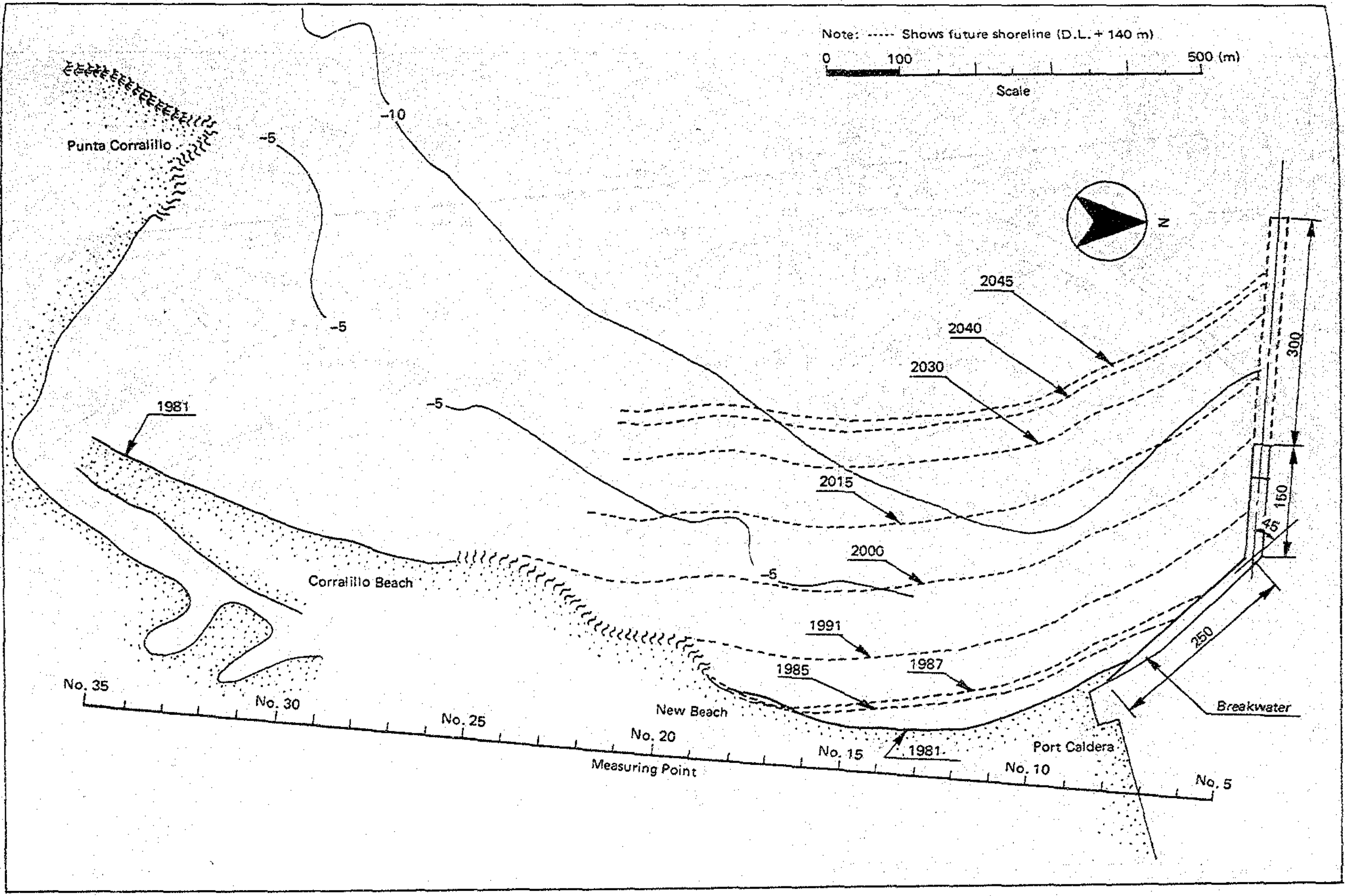



Fig. VI-21 (c) Calculated Future Shoreline (Case 3 $L = 300$ m)

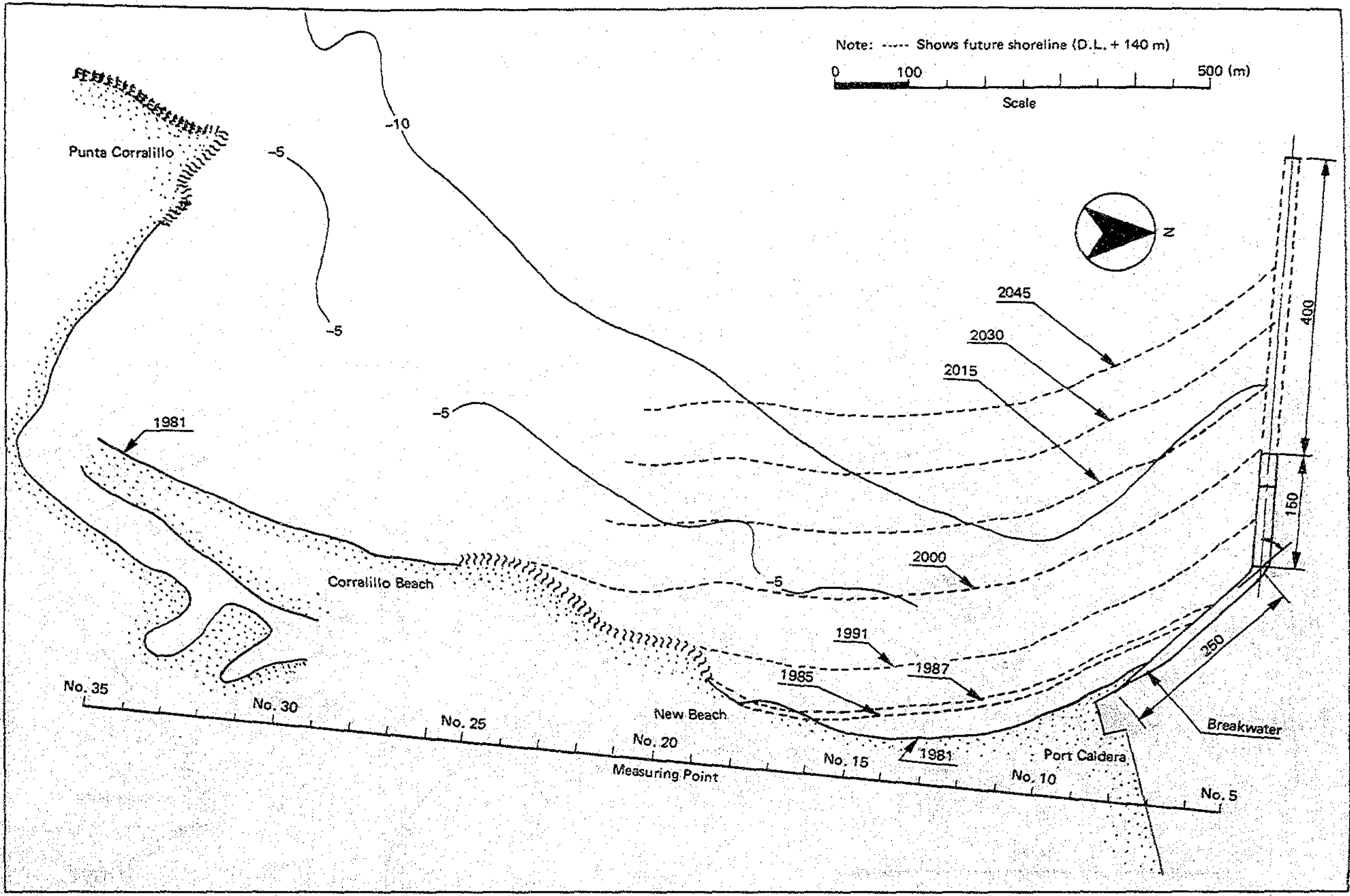



Fig. VI-21 (d) Calculated Future Shoreline (Case 4 $L = 400$ m)

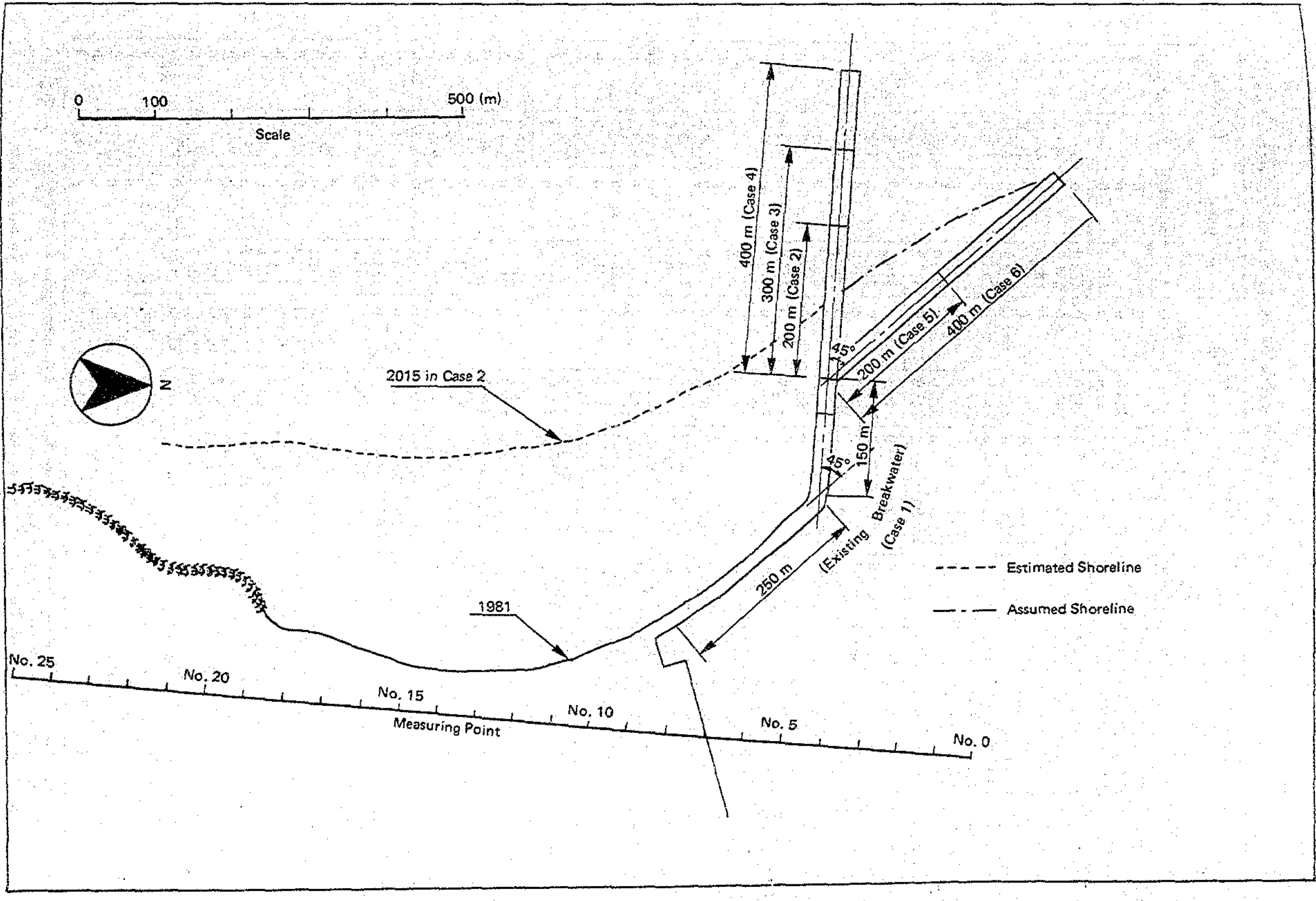



Fig. VI-22 Relation between the Breakwater Center Line and the Future Shoreline

## Table VI-6 $D$ and $Q_S$ of Each Year

| Year | Case 1 $L=0$m | | $L=100$m | | Case 2 $L=200$m | | Case 3 $L=300$m | | Case 4 $L=400$m | | $L=500$m | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $D$ (m) | $Q_S$ (m³/year) | $D$ (m) | $Q_S$ (m³/year) | $D$ (m) | $Q_S$ (m³/year) | $D$ (m) | $Q_S$ (m³/year) | $D$ (m) | $Q_S$ (m³/year) | $D$ (m) | $Q_S$ (m³/year) |
| Jan., 1988 | 35.4 | 15,000 | 135.0 | 0 | — | 0 | — | 0 | — | 0 | — | 0 |
| 9 | 31.0 | 19,000 | 129.0 | 0 | 228.0 | 0 | 328.0 | 0 | — | 0 | — | 0 |
| 1990 | 26.9 | 25,000 | 123.9 | 0 | 215.0 | 0 | 315.0 | 0 | 415.0 | 0 | 515.0 | 0 |
| 1 | 23.1 | 31,000 | 118.3 | 0 | 203.0 | 0 | 303.0 | 0 | 403.0 | 0 | 503.0 | 0 |
| 2 | 19.6 | 37,000 | 112.5 | 0 | 191.0 | 0 | 291.0 | 0 | 391.0 | 0 | 491.0 | 0 |
| 3 | 16.8 | 48,000 | 106.6 | 0 | 181.0 | 0 | 281.0 | 0 | 381.0 | 0 | 481.0 | 0 |
| 4 | 14.5 | 58,000 | 100.7 | 0 | 171.0 | 0 | 271.0 | 0 | 371.0 | 0 | 471.0 | 0 |
| 5 | 12.5 | 66,000 | 95.0 | 0 | 162.0 | 0 | 262.0 | 0 | 362.0 | 0 | 462.0 | 0 |
| 6 | 10.8 | 72,000 | 89.3 | 0 | 153.0 | 0 | 253.0 | 0 | 353.0 | 0 | 453.0 | 0 |
| 7 | 9.3 | 77,000 | 83.6 | 0 | 144.0 | 0 | 244.0 | 0 | 344.0 | 0 | 444.0 | 0 |
| 8 | 8.0 | 82,000 | 77.9 | 0 | 135.0 | 0 | 235.0 | 0 | 335.0 | 0 | 435.0 | 0 |
| 9 | 6.8 | 85,000 | 72.2 | 0 | 129.0 | 0 | 229.0 | 0 | 329.0 | 0 | 429.0 | 0 |
| 2000 | 5.8 | 88,000 | 66.5 | 0 | 123.9 | 0 | 223.9 | 0 | 323.9 | 0 | 423.9 | 0 |
| 1 | 4.8 | 91,000 | 60.8 | 0 | 118.3 | 0 | 218.3 | 0 | 318.3 | 0 | 418.3 | 0 |
| 2 | 4.0 | 93,000 | 55.3 | 3,000 | 112.5 | 0 | 212.5 | 0 | 312.5 | 0 | 421.5 | 0 |
| 3 | 3.3 | 96,000 | 50.0 | 5,000 | 106.6 | 0 | 206.6 | 0 | 306.6 | 0 | 406.6 | 0 |
| 4 | 2.6 | 98,000 | 45.0 | 8,000 | 100.7 | 0 | 200.7 | 0 | 300.7 | 0 | 400.7 | 0 |
| 5 | 2.1 | 99,000 | 40.0 | 10,000 | 95.0 | 0 | 195.0 | 0 | 295.0 | 0 | 395.0 | 0 |
| 6 | 1.5 | 101,000 | 35.4 | 15,000 | 89.3 | 0 | 189.3 | 0 | 289.0 | 0 | 389.0 | 0 |
| 7 | 1.1 | 103,000 | 31.0 | 19,000 | 83.6 | 0 | 183.6 | 0 | 283.0 | 0 | 383.0 | 0 |
| 8 | 0.8 | 105,000 | 26.9 | 25,000 | 77.9 | 0 | 177.9 | 0 | 277.9 | 0 | 377.9 | 0 |
| 9 | 0.4 | 107,000 | 23.1 | 31,000 | 72.2 | 0 | 172.2 | 0 | 272.2 | 0 | 372.2 | 0 |
| 2010 | 0.1 | 109,000 | 19.6 | 37,000 | 66.5 | 0 | 166.5 | 0 | 266.5 | 0 | 366.5 | 0 |
| 1 | −0.3 | 112,000 | 16.8 | 48,000 | 60.8 | 0 | 160.8 | 0 | 260.8 | 0 | 360.5 | 0 |
| 2 | | 〃 | 14.5 | 58,000 | 55.3 | 3,000 | 155.3 | 0 | 255.3 | 0 | 355.5 | 0 |
| 3 | | 〃 | 12.5 | 66,000 | 50.0 | 5,000 | 150.0 | 0 | 250.0 | 0 | 350.0 | 0 |
| 4 | | 〃 | 10.8 | 72,000 | 45.0 | 8,000 | 145.0 | 0 | 245.0 | 0 | 345.0 | 0 |
| 5 | | 〃 | 9.3 | 78,000 | 40.0 | 10,000 | 140.0 | 0 | 240.0 | 0 | 340.0 | 0 |
| 6 | | 〃 | 8.0 | 82,000 | 35.4 | 15,000 | 135.4 | 0 | 235.4 | 0 | 335.4 | 0 |
| 7 | | 〃 | 6.8 | 85,000 | 31.0 | 19,000 | 131.0 | 0 | 231.0 | 0 | 331.0 | 0 |
| 8 | | 〃 | 5.8 | 88,000 | 26.9 | 25,000 | 126.9 | 0 | 226.9 | 0 | 326.9 | 0 |
| 9 | | 〃 | 4.8 | 91,000 | 23.1 | 31,000 | 123.1 | 0 | 223.1 | 0 | 323.1 | 0 |
| 2020 | | 〃 | 4.0 | 93,000 | 19.6 | 37,000 | 119.6 | 0 | 219.6 | 0 | 319.6 | 0 |
| 1 | | | 3.3 | 96,000 | 16.8 | 48,000 | 116.8 | 0 | 216.8 | 0 | 316.8 | 0 |
| 2 | | | 2.6 | 98,000 | 14.5 | 58,000 | 111.5 | 0 | 211.5 | 0 | 311.5 | 0 |
| 3 | | | 2.1 | 99,000 | 12.5 | 66,000 | 106.1 | 0 | 206.1 | 0 | 306.1 | 0 |
| 4 | | | 1.5 | 101,000 | 10.8 | 72,000 | 100.8 | 0 | 200.8 | 0 | 300.8 | 0 |
| 5 | | | 0.8 | 105,000 | 9.3 | 78,000 | 95.4 | 0 | 195.4 | 0 | 295.4 | 0 |
| 6 | | | 0.4 | 107,000 | 8.0 | 82,000 | 90.1 | 0 | 190.1 | 0 | 290.1 | 0 |
| 7 | | | 0.1 | 109,000 | 6.8 | 85,000 | 84.7 | 0 | 184.7 | 0 | 284.7 | 0 |
| 8 | | | −0.3 | 112,000 | 5.8 | 88,000 | 79.4 | 0 | 179.4 | 0 | 279.4 | 0 |
| 9 | | | | 〃 | 4.8 | 91,000 | 74.0 | 0 | 174.0 | 0 | 274.0 | 0 |
| 2030 | | | | 〃 | 4.0 | 93,000 | 68.7 | 0 | 168.7 | 0 | 268.7 | 0 |
| 1 | | | | 〃 | 3.3 | 96,000 | 63.3 | 0 | 163.3 | 0 | 263.3 | 0 |
| 2 | | | | 〃 | 2.6 | 98,000 | 58.1 | 1,000 | 158.1 | 0 | 258.1 | 0 |
| 3 | | | | 〃 | 2.1 | 99,000 | 53.2 | 4,000 | 152.8 | 0 | 252.8 | 0 |
| 4 | | | | 〃 | 1.5 | 101,000 | 48.4 | 6,000 | 147.7 | 0 | 247.7 | 0 |
| 5 | | | | 〃 | 0.8 | 105,000 | 43.7 | 8,000 | 142.6 | 0 | 242.6 | 0 |
| 6 | | | | 〃 | 0.4 | 107,000 | 39.2 | 11,000 | 137.7 | 0 | 237.7 | 0 |
| 7 | | | | 〃 | 0.1 | 109,000 | 34.9 | 15,000 | 132.7 | 0 | 232.7 | 0 |
| 8 | | | | 〃 | −0.3 | 112,000 | 30.9 | 19,000 | 127.7 | 0 | 227.7 | 0 |
| 9 | | | | 〃 | | 〃 | 27.1 | 25,000 | 122.7 | 0 | 222.7 | 0 |
| 2040 | | | | 〃 | | 〃 | 23.5 | 30,000 | 117.7 | 0 | 217.7 | 0 |
| 1 | | | | | | 〃 | 20.2 | 35,000 | 112.2 | 0 | 212.2 | 0 |
| 2 | | | | | | 〃 | 17.5 | 45,000 | 107.7 | 0 | 207.7 | 0 |
| 3 | | | | | | 〃 | 15.2 | 54,000 | 102.7 | 0 | 202.7 | 0 |
| 4 | | | | | | 〃 | 13.3 | 62,000 | 97.7 | 0 | 197.7 | 0 |
| 5 | | | | | | 〃 | 11.6 | 69,000 | 92.7 | 0 | 192.7 | 0 |

Notes : 1) $D$ is the distance between the head of the breakwater and the −2.0m contour line at the start of each period (m).
2) $Q_S$ is the annual sand sediment volume (m³/year).
3) Dand $Q_S$ in the cases of $L=100$m and $L=500$m are assumed complementing the simulation results.

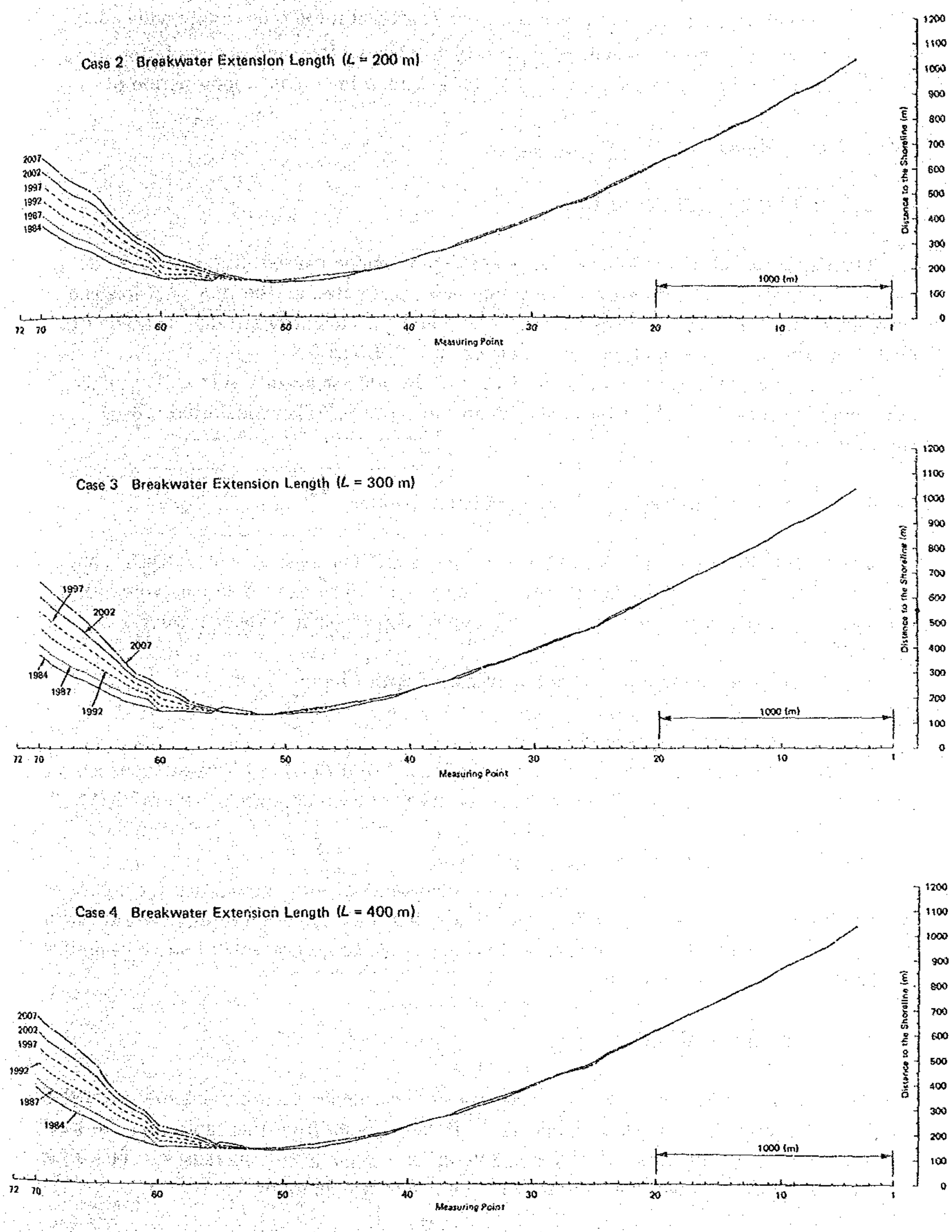



**Fig. VI-23 Calculated Future Shorelines at North Caldera Beach**