APPENDIX B BATHYMETRIC AND SEISMIC PROFILING SURVEY

APPENDIX B BATHYMETRIC AND SEISMIC PROFILING SURVEYS

B.1 Introduction

Appendix B covers the bathymetric, seismic and topographic surveys work carried out by the JICA Study Team as part of the work for the proposed Port Reactivation Project in La Unión Province of the Republic of El Salvador.

The main components of the work consisted of a survey of the proposed Reclamation and Turning Basin of the Cutuco Port area, a survey of the channel which will be dredged to provide access to the new port, and a survey of the Anchorage Area in the approaches to the port. The scope of work included the following:

- Establishment of onshore DGPS control stations at the site;
- Establishment of tide recording stations;
- Marine survey at Cutuco in the Reclamation and Turning Basin over an area 1.2 kilometers by 1.0 kilometers;
- Marine survey of the approach channel over an area 18.0 kilometers by 0.4 kilometers;
- Marine survey of the anchorage area, 3.4 kilometers by 1.8 kilometers;
- Topographic survey of the shoreline in the Reclamation area;
- The marine survey operations included:
  - Positioning using DGPS
  - Tidal observations
  - Echo sounding
  - Sub bottom profiling

B.2 Survey Equipment

The following equipment was utilised during the course of the survey:

Navigation software

Survey computers and printers

3 No Aanderaa WLR7 tide gauges

Trimble 4000 RL DGPS base station + Satel telemetry links

Sercel NR103 DGPS receiver

Odom dual frequency echo sounder

Sub bottom profiling system comprising :

234 power pack

Boomer seismic source

Multi-element hydrophone

Octopus 360 sub-bottom processor

Dowty 3710 thermal line scan recorder

Leica Kinematic GPS topographic survey system

Backup spare units for most of the survey systems were shipped to El Salvador and transported by the survey team to the site.

B.3 Survey Vessel

An aluminum hulled motor patrol boat belonging to the El Salvador Navy was chartered for the survey works. The vessel dimensions were as follows:

Length	8.0m
Beam	3.0m
Draught	1.6m

The vessel was called "PC1" and was one of a range of identical vessels operated by the Navy from their base at La Unión.

B.4 Survey Procedure

B.4.1 Horizontal Control

Several different grid systems are currently in use in El Salvador. These are:

1) Local Coordinates : El Salvador Grid (metric)

The El Salvador Grid is a Lambert Conformal Conic projection based on the NAD 27 Geodetic Datum. This system is used for all National mapping.

2) NAD 27 Geographic System

North American Datum 1927, based on the Clarke spheroid of 1880 (NAD27). It is used to depict Latitude and Longitude on the National Charts.

3) NAD 27 UTM System

The metric UTM (Universal Transverse Mercator) grid based on NAD27 is shown on some of the newer Charts.

4) WGS 84 Geographic System

World Geodetic System 1984 (WGS84) geographic is used to depict Latitude and Longitude on United States versions of the Charts.

5) WGS 84 UTM System

The metric UTM grid based on WGS84 is commonly used where GPS is used for positioning.

It has the following parameters:

False Northing	295809.184m
False Easting	500000.000m
Longitude of the Centre of Projection	89° 00' W
Latitude of the Origin of Projection	13° 47' N
Latitude of the Southern Standard Parallel	13° 19' N
Latitude of the Northern Standard Parallel	14° 15' N

Survey planning, horizontal control of the survey and presentation of the results have all been carried out using the following geodetic parameters:

Ellipsoid	WGS84
Datum	WGS84
Projection	UTM Zone 17 (central meridian 87°W)

Coastal details for the site (High Water Line and Outline of Breakwaters, etc.) were digitized from the El Salvador topographic map for Conchagua (Ref HOJA 2655 IV) at a scale of 1:50,000. Survey boundaries were scaled from the drawings in the Tender Document. This process involved a conversion from the El Salvador Datum to UTM coordinates on the WGS84 spheroid.

A primary grid of control points was established in the area by the national Survey Department in the 1930s. These points were marked by small concrete monuments with metal pins. For previous topographic survey work at Cutuco, a control point at Punta Gorda was used as the main reference. From this point, secondary points were established around the site area. Of these, point 27A was selected as being useful for control, since it is visible from Cutuco Jetty. Both the Punta Gorda Trig point and point 27A are surrounded by trees which cause some obstruction to signals from the GPS satellites, but no unobstructed control points were available.

The positions for the control points together with coordinate values were provided by CEPA on site. Datum shift parameters were available for the El Salvador Grid, for the WGS84 spheroid and for the NAD 27 (North American Datum) system. It was therefore possible to convert positions recorded in

WGS84/UTM to the alternative Grids.

A DGPS base station was established on the end of the shed on Cutuco Jetty prior to carrying out marine survey operations on the site. The Sercel NR103 receiver was set up over the control (trig) point at Punta Gorda, and positions were recorded over the period of 30 minutes. This logged data of WGS84 UTM position was then averaged and compared with the calculated UTM coordinates for the point. The observed values gave a position 12.48 m North and 4.74 m East of the calculated UTM coordinates. This position offset was entered into the Trimble 4000 RL DGPS base station, to ensure that surveyed positions matched with map features. The following results were obtained for this calibration:

Calculated Position, from given Punta Gorda Trig Coordinates:

WGS84 UTM	411,560.84E, 1,473,151.89N

Observed Position (Average) after applying base station shift:

WGS84 UTM	411,560.95E, 1,473,151.85N

For work in the offshore approach channel, a second base station was established on the lighthouse at Punta El Chiquirín. The coordinates of this point were established by setting up the Sercel NR103 receiver at this location and recording positions over a period of 30 minutes.

On completion of the survey work, the Sercel NR103 receiver was set up over a point on Cutuco jetty, and positions were recorded over the period of 30 minutes. The coordinates of this point were determined by kinematic GPS measurements relative to control point 27A near Punta Gorda Jetty.

The coordinates of the Base Stations were as follows:

CUTUCO PIER

WGS84 Geographicals	13° 20.0315' N,	87° 49.2066' W
WGS84 UTM	411,183.8 E	1,474,202.9 N
AD27 Geographicals	13° 19.9763' N,	87° 49.2055' W
AD27 UTM	411,184.2 E	1,474,010.0 N
El Salvador Grid	627830.1 E	246297.2 N

CHIQUIRIN POINT

WGS84 Geographicals	13° 17.4964' N,	87° 46.7747' W
WGS84 UTM	415,558.9 E	1,469,515.8 N

NAD27 Geographicals	13° 17.4411' N,	87° 46.7737' W
NAD27 UTM	415,559.3 E	1,469,322.9 N
El Salvador Grid	632244.8 E	241644.8 N

The Sercel NR103 DGPS receiver was installed on the survey vessel and RTCM Differential GPS signal corrections were received by VHF telemetry link from the Trimble 4000 RL GPS receiver set up onshore at the Base Station.

Each day, the survey vessel was positioned alongside the jetty at Cutuco to board personnel to measure the tide height. A position was recorded during each landing, to monitor the stability and repeatability of the DGPS position.

An onboard computer running a navigation software was interfaced to the DGPS receiver. This enabled real-time display on the computer screen of the survey vessel position together with the survey lines. The use of a second monitor suitably positioned allowed the helmsman to steer the vessel along the required survey line. Survey vessel position was logged at a one second update rate. Every 50 m along track the navigation system generated a fix mark on the echo sounder and seismic profiler records.

The site was surveyed using a line spacing of 25 m perpendicular to the center line of the main channels as defined in the tender documents. In the turning circle area off Cutuco, three cross lines separated by about 400 m were run roughly parallel with the shore. The old center lines of the channels and newly specified center lines were also surveyed.

In the reclamation area, seismic survey lines were carried inshore as far as considered safe by the survey vessel captain, bearing in mind that the seismic equipment was being towed astern and turning room needed to be allowed. Further inshore coverage was then obtained at High Water, with the echo-sounder only deployed. The area of the beach was surveyed at low water using a Leica kinematic GPS system.

B.4.2 Vertical Control

Tides were recorded using three Aanderaa WLR7 automatic tide gauges. Gauge No 1246 was installed on a chain suspended from the Jetty at Cutuco. This gauge acted as the 'master' for level transfers, and was leveled in to a local Bench Mark.

Calibration readings of water level were made at the start and end of each survey day by tape measurements from the TBM to the water surface.

For the survey of the approach channel and anchorage area, additional gauge deployments were carried out to provide data bracketing the survey areas.

The approximate positions of the deployments (WGS84UTM) were:

Cutuco Jetty	411,100E	1,474,200N
Zacatillo Island	416,800E	1,470,400N
Punta Chiquirín	415,560E	1469,500N
Punta Las Mueludas	402,400E	1,455,800N

Deployment depths are approximate and are in meters below NCD.

All gauges except the gauge at Cutuco Jetty suffered from episodes of interference as follows:

The gauge off Zacatillo Island had one buoy and attached float stolen. This did not affect the level of the gauge.

The gauge off Punta Chiquirín had the deployment rope stolen. It was subsequently moved into deeper water. The level of the gauge was affected by these episodes.

The gauge off Punta Las Mueludas had the deployment chain stolen. The level of the gauge was affected by this episode.

Tidal variation relative to New Chart Datum was determined as follows:

- The tide gauge data for all gauges processed using recent calibration parameters to give water depths;
- Barometric data corrections were applied based on data recorded on a chart barograph from 7th October to 25th October. This data was extrapolated back for the period between 28th September and 7th October;
- The water depths at Cutuco were compared with the observed water levels during the survey;
- Tidal observations for Cutuco were reduced to New Chart Datum;
- Tide records at the other gauge positions were compared with the Cutuco data, and were divided into segments with a common datum;
- For each segment, Mean Sea Level was calculated and compared with the mean Sea Level at Cutuco over the same period;
- The relevant datum shift was then applied to each segment to reduce the data to new Chart Datum;
- The sets of data were compared graphically and found to be in good agreement;
- The data for Cutuco were subjected to harmonic Analysis to determine the Tidal Constituents and Mean Sea Level;
- Observed tides were compared with predicted tides to determine the level of the datum used for predictions.

The data from the gauge at Cutuco were subjected to Harmonic Analysis. Harmonic

constituents and the Mean Sea Level over the period of deployment were calculated.

A Bench Mark next to the old Port Police office, near the landfall of Cutuco Jetty, was used as the vertical reference for the marine and topographic surveys. The level of this Bench Mark was given as 4.1828m on the La Unión Datum, referred to as CNR (Centro National de Registros), which is a Mean Sea Level (MSL) datum.

The CNR Mean Sea level (MSL of CNR) has been ste as average mean sea level of all Central America based on the survey carried out in 1960.

The Bench Mark is alongside a building and could not be used directly for Kinematic GPS measurements. A combination of traditional leveling (using a Topcon automatic level) and Kinematic GPS measurements was therefore used to determine the elevation of a Temporary Bench Mark (TBM) for tide measurements adjacent to the tide -gauge location on Cutuco Jetty.

During September and early October, it was commissioned a set of tide observations at Cutuco Jetty. On the basis of harmonic analysis of this data, a new Chart Datum (NCD) was defined by the JICA Study Team as being 1.652 m below Mean Sea Level at Cutuco (MSL Cutuco). It was determined that MSL Cutuco lies at 0.367 m above MSL of CNR.

B.4.3 Topographic Survey

A land topographic survey of the beach between Cutuco Jetty and the Punta Gorda fishing wharf was carried out using a Leica 530 Kinematic GPS system.

The Leica Reference Station was established on the end (south east corner) of Cutuco Jetty, and position readings were taken on point 27 A with a roving unit to tie measurements into the survey grid. Positions and levels of points along the shoreline were then obtained at low water with the roving unit, in order to provide an overlap with the marine survey data. Readings near the High Water line were sparse in places due to the presence of overhanging trees which reduced available satellite data.

B.4.4 Echo Sounding

Echo sounding was carried out using an Odom survey echo sounder with a dual frequency transducer of 210 kHz and 33 kHz. The transducer assembly was mounted over the side of the survey vessel on a bracket secured to a deck cleat. The transducer was established forward by a bracing rope. Data were recorded both electronically and on a paper chart.

Calibration of the echo sounder record and digitized data was checked at the beginning and end of the survey day by the use of a bar check. The draft and speed of sound settings were adjusted as required.

The echo sounder was operated in conjunction with the seismic profiling system, at a boat speed of approximately 4 knots.

B.4.5 Seismic Profiling

The seismic profiling system used for this work comprised a towed boomer sound source, driven by a high voltage (4,000v) power pack triggered by the line scan recorder, and a towed multi-element hydrophone.

The boomer is a broad band seismic source offering a good balance between resolution and penetration (generally a trade off - one decreases as the other increases), and is the most frequently used seismic tool for near shore surveys where it is common to encounter very variable sediment types. The boomer produces a broad range of frequencies. Unwanted frequencies (containing noise caused by waves, ship's movements, engines, propellers) are rejected by passing the seismic signal collected by the hydrophone through a band pass filter. The signal from the filter is processed by a time varied gain signal processor prior to being recorded as a graphic trace of seabed and sub-seabed reflections on the thermal line scan recorder.

The boomer and hydrophone were towed from the starboard and port stern quarters.

Equipment settings were generally as follows:

Trigger time	250 ms
Sweep time	80 ms
Delay time	0 ms
Power output	100 Joules
Band pass filter	330 Hz - 4200 Hz

These settings gave the recorder a depth scale of about 0 – 60 m.

Seismic data were recorded concurrently with echo sounding data.

B.5 Survey Results

B.5.1 Survey Coverage

The realignments of the proposed access channel during the course of the survey necessitated extensions and infills of the survey coverage, and lines are broken in several areas due to this requirement. Additional lines were also surveyed.

B.5.2 Bathymetry

The values presented in the bathymetric maps are based on measurements along the survey lines at nominal 10 m intervals, and the contour interval is generally 1 m.

It can be seen that a deep scour hollow between Zacatillo Island and the mainland, which reaches depths of up to 48m below datum, takes the seabed below the proposed dredging datum over a considerable distance. Extensive dredging will be required both at Cutuco and along the channel eastwards from here towards Zacatillo Island. Note that the sounding records indicate the presence of occasional boulders on the seabed, particularly at the eastern end of this channel.

Within the scour hollow the seabed is uneven, as soft sediments have generally been removed to expose an uneven rocky seabed.

The seabed in the approach channel south of the scour hollow and within the anchorage area is smooth, rising to a minimum depth of about 9.5 m.

B.5.3 Seismic Profiling

(1) General

The seismic data have been interpreted as a soft sequence of sediments with a varied depositional history overlying bedrock. Within the sedimentary sequence are widespread areas of seismic scattering (diffractions).

The site is in an area of volcanic activity, and the Conchagua Volcano south of La Unión is reported to have last erupted in 1942. Eruptions during the accumulation of sediments since the last ice age are expected to have introduced volcanic pyroclastic rocks and ash layers into the sedimentary sequence. Several of the echosounding and seismic records show features on the seabed interpreted as large boulders. In these circumstances, 'bedrock' is unlikely to be represented by a continuous horizon, and could be perched in the sedimentary column if sufficient pyroclastic material has accumulated. The approach adopted has therefore been to take the top of strong concentrations of diffractions as Reflector 2, on the basis that this highly irregular surface represents the minimum depth at which bedrock is likely to be encountered. An unconformity above this horizon in the Turning Basin and Inner Channel has been presented as Reflector 1.

Two phases of marine geotechnical investigation are relevant to the survey area.

During 1977, 10 boreholes were drilled into the seabed from the Cutuco Jetty. These indicated a widespread blanket of organic sediments at the seabed, overlying sandy and silty horizons. Rock was encountered in two of the boreholes, at depths of 9 to 10 m below the seabed. Within the organic sediments, SPTs generally produced N values of 5 to 20, while in the underlying strata N values were typically in the range 50 to 100.

As part of the current investigation, marine boreholes were drilled both in the reclamation area and in the approach channel west of Zacatillo Island. The boreholes in the reclamation area lie in a zone of organic surface sediments which masked the

seismic data. These boreholes could therefore not be used directly for correlation of the seismic data. Boreholes BS-21, BS-22 and BS-23 lay in deeper water along the channel, where seismic data were good.

Borehole	Latitude	Longitude	Findings
BS-21	13° 20' 06.3" N	87° 48' 52.5" W	8 to 10 m of very soft silt (SPT 1) over sandy clay with gravel
BS-22	13° 19' 17.6" N	87° 47' 51.3" W	10 m of very soft silt
BS-23	13° 18' 22.7" N	87° 46' 56.0" W	10 m of very soft silt

Comparison of the data from Boreholes BS-22 and BS-23 with the bathymetric and seismic data obtained shows discrepancies, in that:

- The seabed depths obtained by the survey were –7.4 m at Borehole BS-22 and –9.2 m at Borehole BS-23, differences of 4.1 and 3.1 m respectively.
- The seismic data show bedding planes at shallow depth and 'Reflector 2', the minimum depth to bedrock, at about 12.5m below Chart Datum. This is within the sequence indicated as soft sediments with SPT values of 1 on the borehole records.

A difference of water depth may have been measured by the drilling contractor due to:

Sinkage of a measuring weight into the seabed

Deflection of a measuring weight by strong currents

(2) Turning Basin and Reclamation Area

The seismic data obtained offshore were of good quality, but close inshore the seismic energy was absorbed at or close to the seabed and penetration was severely restricted. This area of data masking has been interpreted as a zone of organic sediments at the seabed. This may be due to recent sewerage contamination from La Unión.

In the offshore area there is a well defined shallow reflector within the sedimentary sequence. This reflector separates horizontal bedding planes from gently dipping bedding planes. This reflector is referred to as Reflector 1, and marks an unconformity within the recent sedimentary succession. Although the significance of the unconformity is not clear from the geotechnical investigation, the level of this horizon has been mapped. It is anticipated that the materials below the unconformity will generally be more consolidated and have a more varied composition than the sedimentary sequence above the unconformity.

A deeper, strong, well defined reflector has been identified on the offshore part of the

site and is shown on the Drawings as Reflector 2. For the reasons discussed above it is unlikely that this reflector represents a continuous geological horizon. But Reflector 2 lies below the dredging datum offshore of Cutuco Jetty. There is some scattering within the sedimentary succession above Reflector 2; this is likely to be due to a variety of causes. Several of the echo sounding and seismic records inshore show features on the seabed interpreted as large boulders. Thus although bedrock is below the dredging datum, there is a possibility of encountering occasional boulders above the dredging datum.

(3) Inner Channel

Along the inner channel, seismic data is masked along the southern edge of the survey area, probably due to contamination by sewerage. Reflector 1 is generally well defined but is of unknown geotechnical significance, while Reflector 2 is highly irregular and rises close to the seabed in places. Boreholes BS-22 and BS-23 lie at locations where they were expected to intersect Reflector 2, but they failed to record anything except extremely soft sediments. It does not seem likely that the diffraction patterns on the seismic records, which define the Reflector 2 surface, are entirely due to organic sediments. In particular, both the sounding and seismic records show features interpreted as boulders and/or gravel beds at the seabed. These features lie on a slight ridge, strengthening the view that the seabed is firm in this area. It may be that accumulations of granular material in the sediments are not continuous, and that the boreholes happened to pass through soft sediments lying between patches of gravel/boulders. It remains likely that gravel and/or boulder beds will be encountered at shallow depth during the dredging operation, and account should be taken of this in selecting dredging plan and procedures.

(4) Scour Channel

A scour channel between Punta Chiquirín and Zacatillo Island takes the sea bed to well below the target dredging depth. In the deepest part of the channel, the seabed is irregular and sediments are generally absent. Strong currents and scour are to be expected in this area.

(5) Outer Channel and Anchorage

In the northern part of the outer channel there is a horizontal reflector just below the seabed. This reflector is underlain by material producing strong seismic diffractions, which largely prevents penetration of the seismic energy. This reflector (Reflector 2) is overlain by soft sediments which are probably highly mobile during periods of wave activity, and hence may well tend to refill any dredged channel. Below this horizon there are occasional indications that the bedding is horizontal. It is interpreted that this deeper material is part of the sedimentary succession, and that the scattering observed

is due to either organic or volcanic sedimentary material. The clear sediment layer thickens to around 8 m and is horizontally bedded. Near the end of the approach channel, seismic penetration is variable and the Reflector 2 horizon is again highly irregular. It is not clear whether the reflector represents the top of bedrock or simply the upper limit of localised diffractions. It is however unlikely that rock will be encountered above the dredging datum anywhere in the outer channel.

Photo B.5.1 shows the equipment used for seismic profiling survey. Figure B.5.1 to B.5.4 are samples of seismic data.

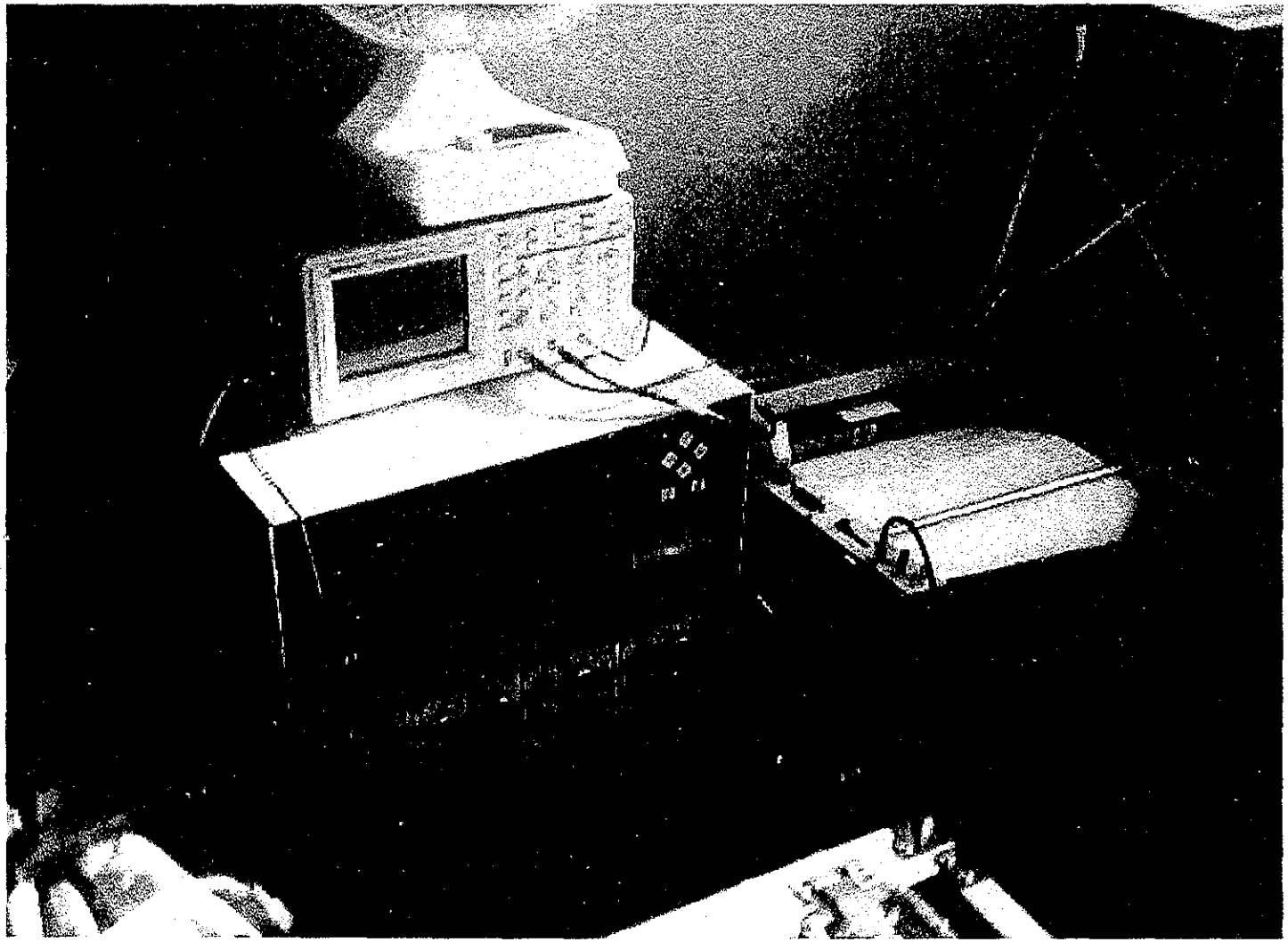
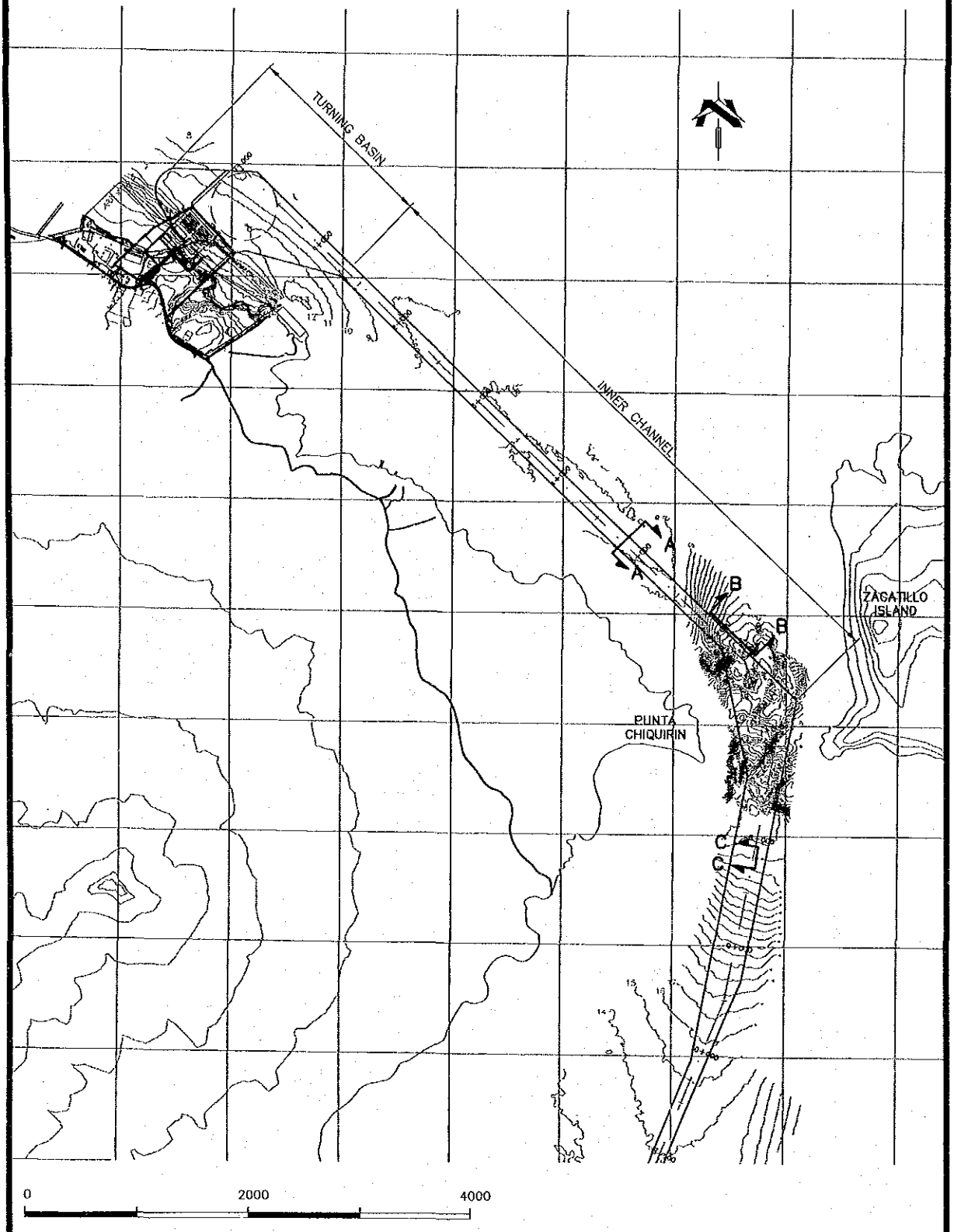
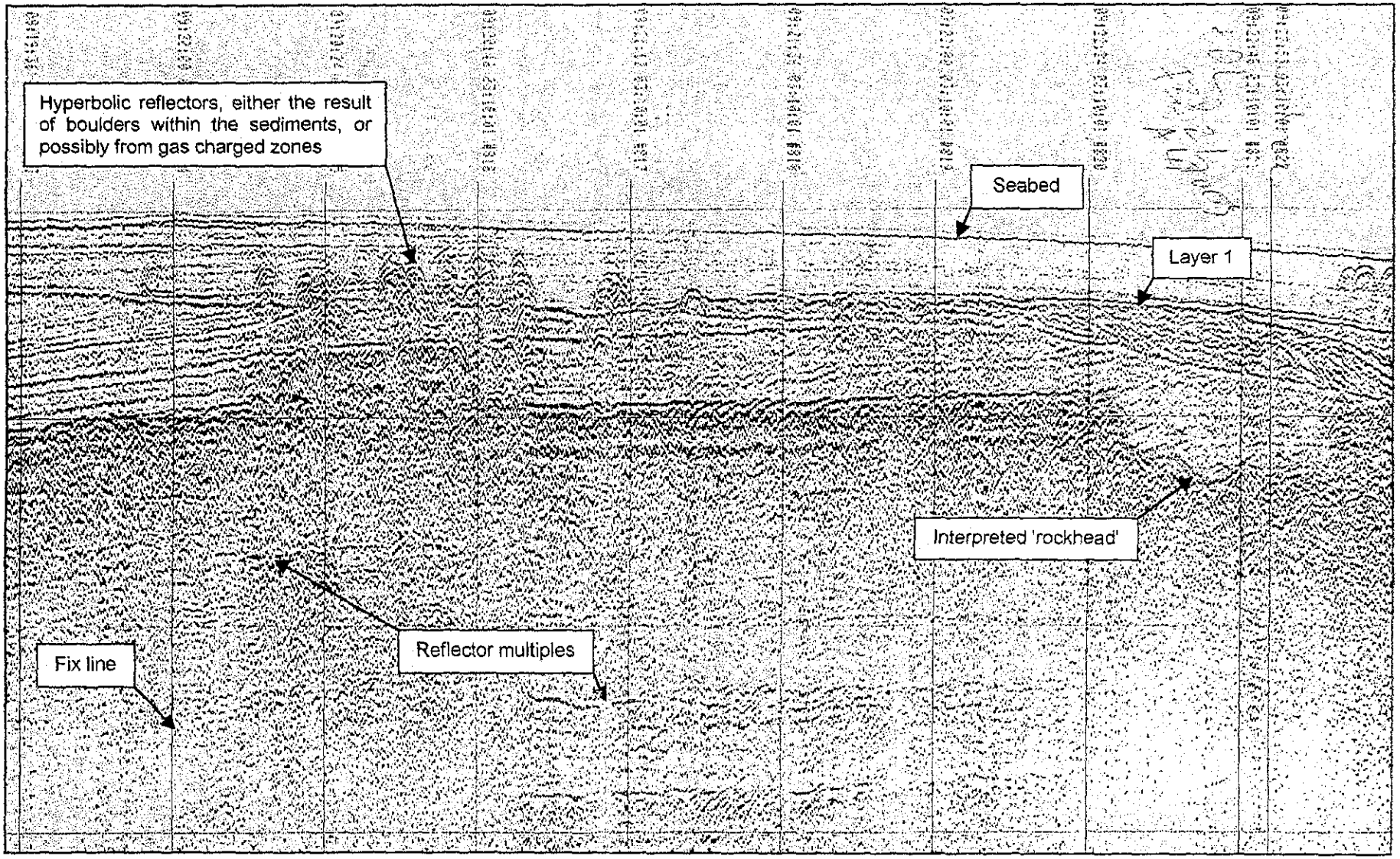


Photo B.5.1 Seismic Profiling Equipment

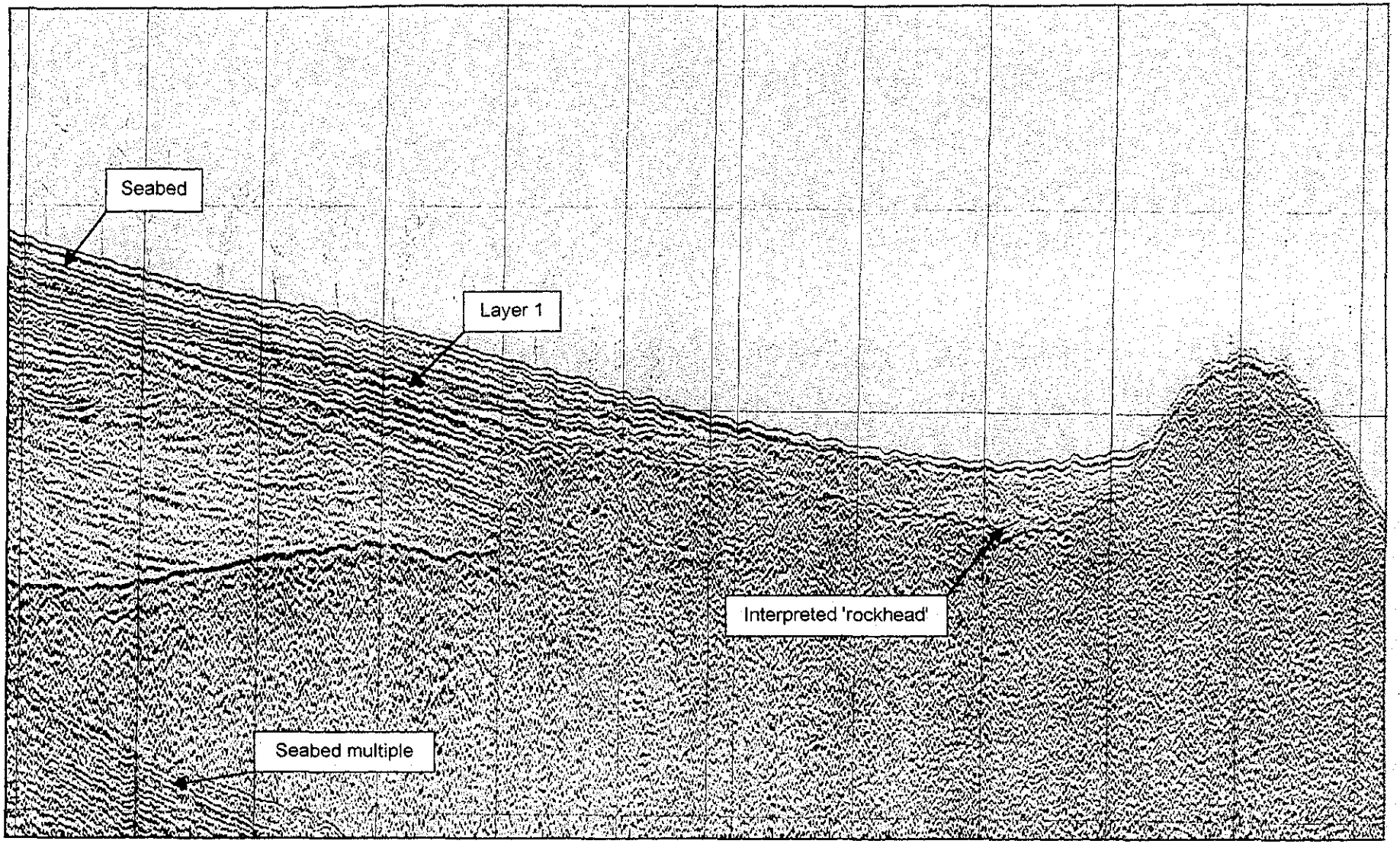


Japan International Cooperation Agency (JICA)	Figure	Title
Detailed Design on Port Reactivation Project in La Union Province of the Republic of El Salvador	B.5.1	LOCATION OF SAMPLE SEISMIC PROFILE OUTPUT



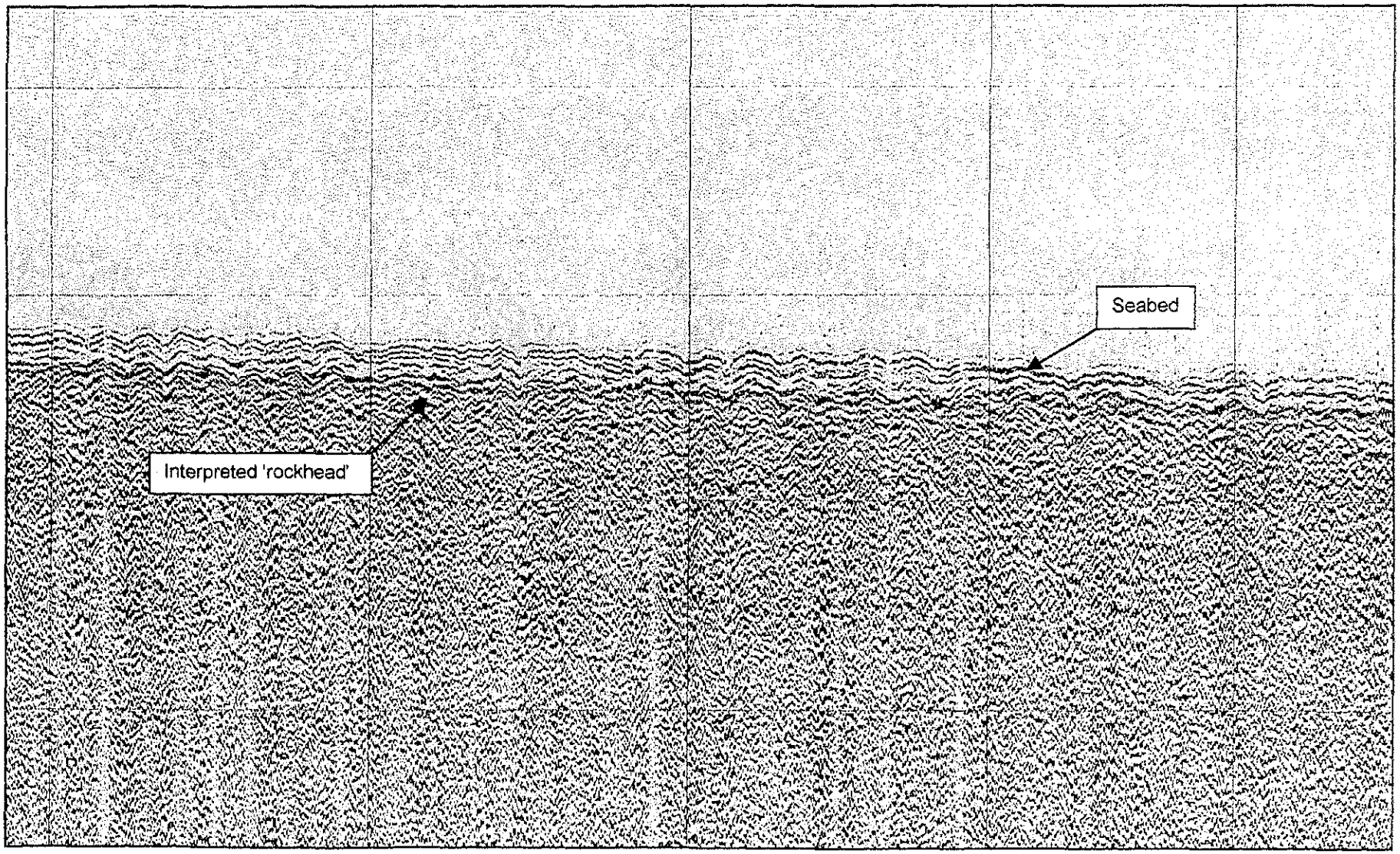
Note : Location indicated in Figure B.5.1

Figure B.5.2 Sample Seismic Profiling Output (A – A)



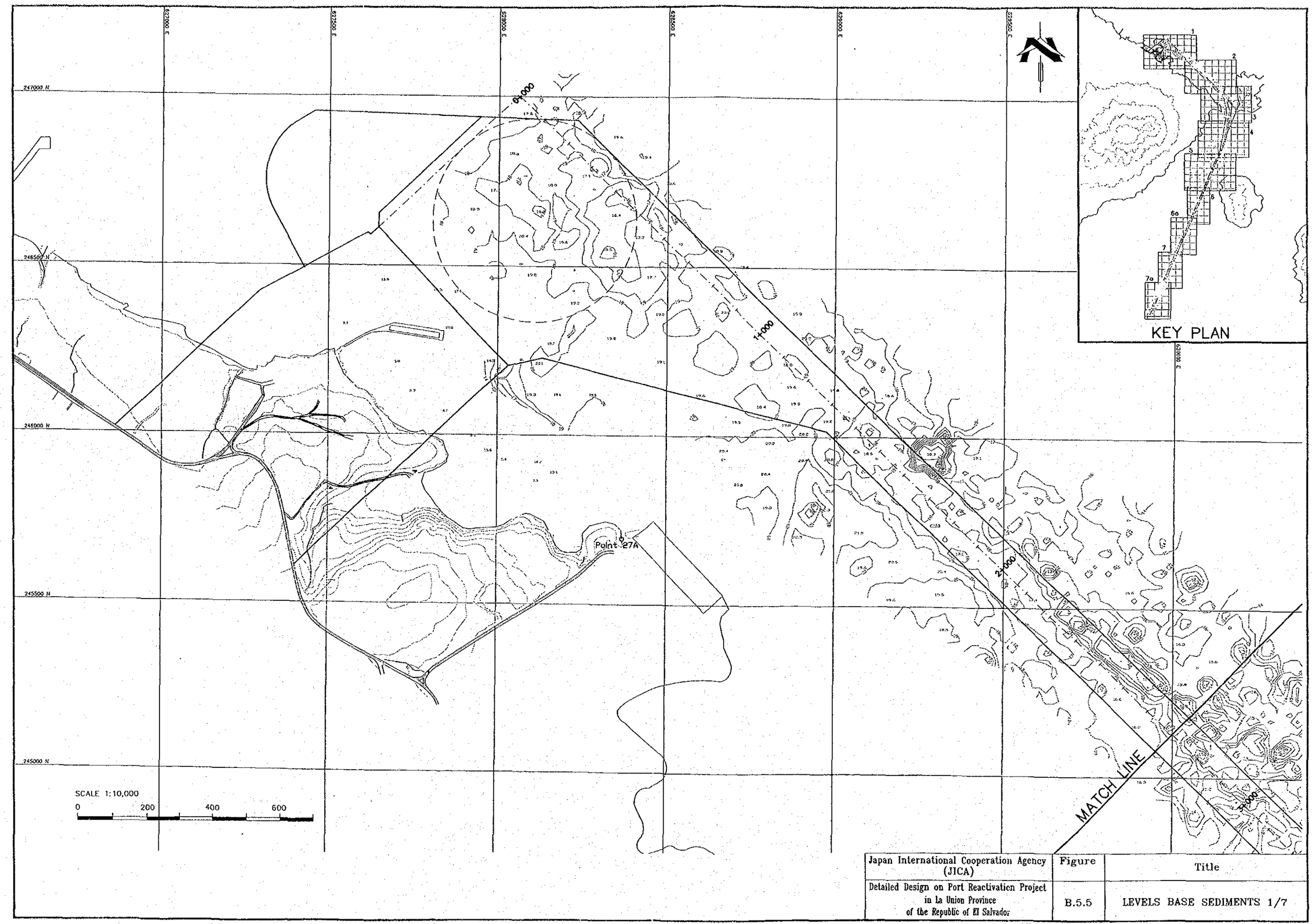
Note : Location indicated in Figure B.5.1

Figure B.5.3 Sample Seismic Profiling Output (B – B)

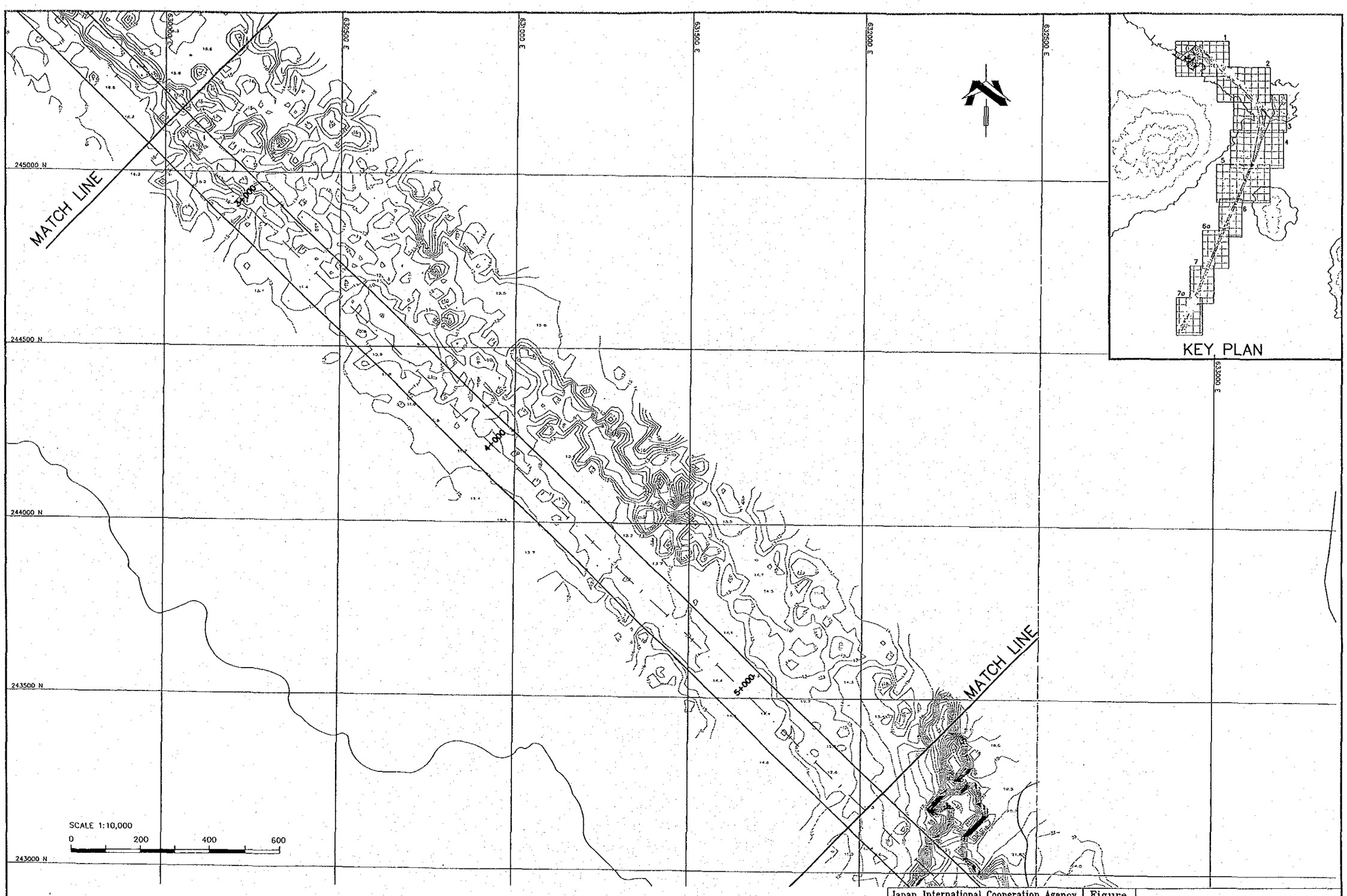


Note : Location indicated in Figure B.5.1

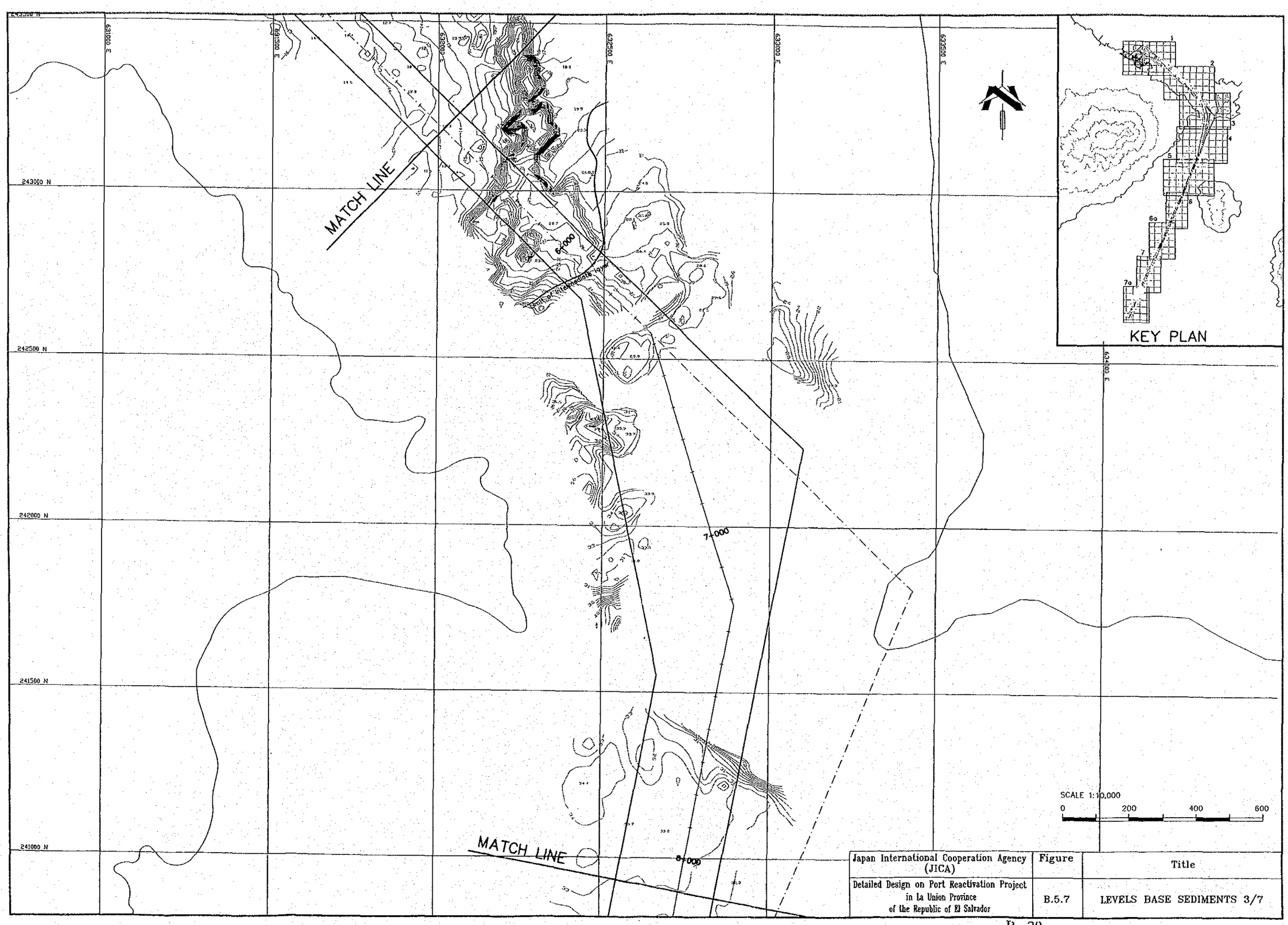
Figure B.5.4 Sample Seismic Profiling Output (C – C)



Japan International Cooperation Agency (JICA)	Figure	Title
Detailed Design on Port Reactivation Project in La Union Province of the Republic of El Salvador	B.5.5	LEVELS BASE SEDIMENTS 1/7



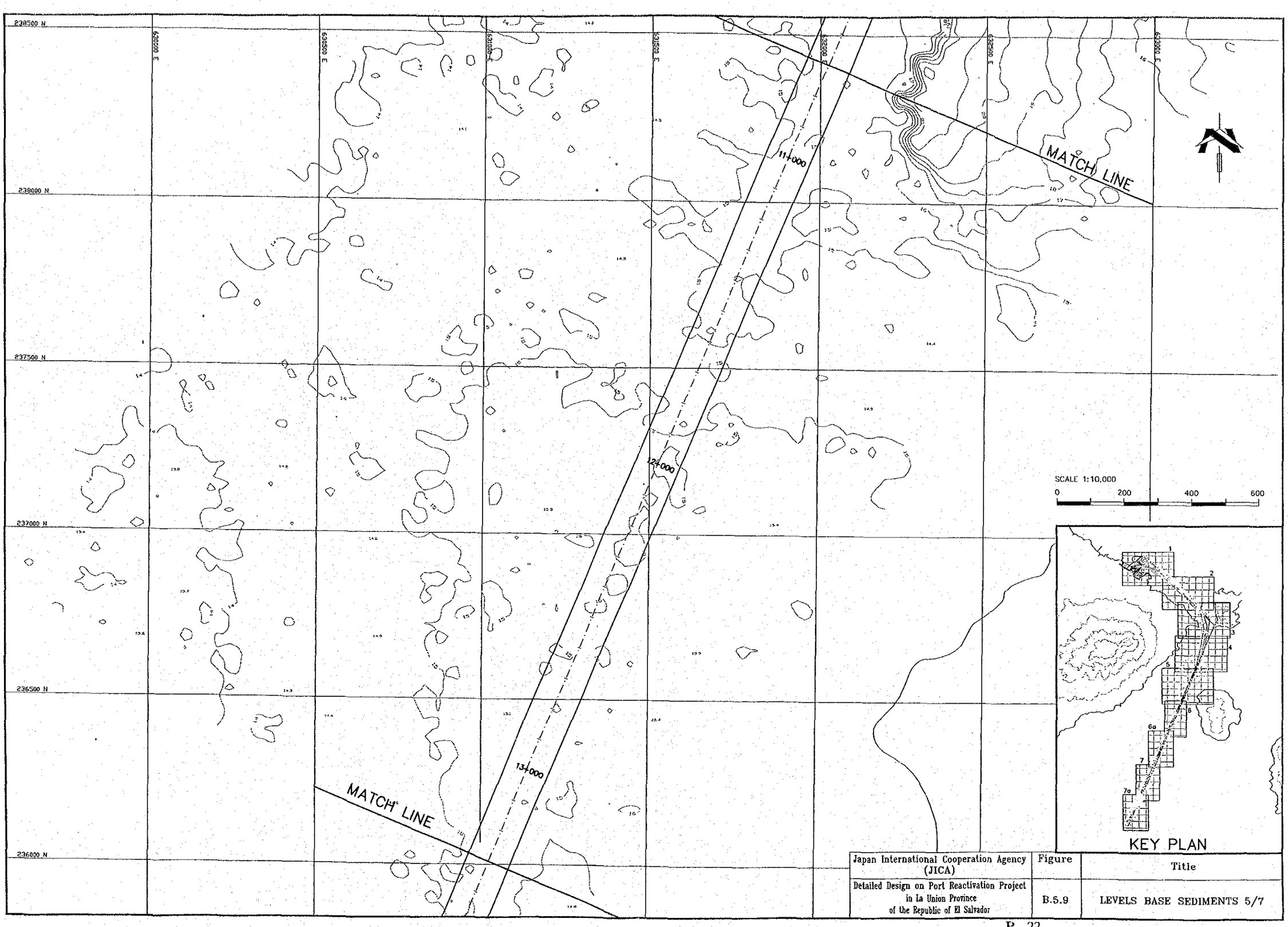
Japan International Cooperation Agency (JICA)	Figure	Title
Detailed Design on Port Reactivation Project in La Union Province of the Republic of El Salvador	B.5.6	LEVELS BASE SEDIMENTS 2/7



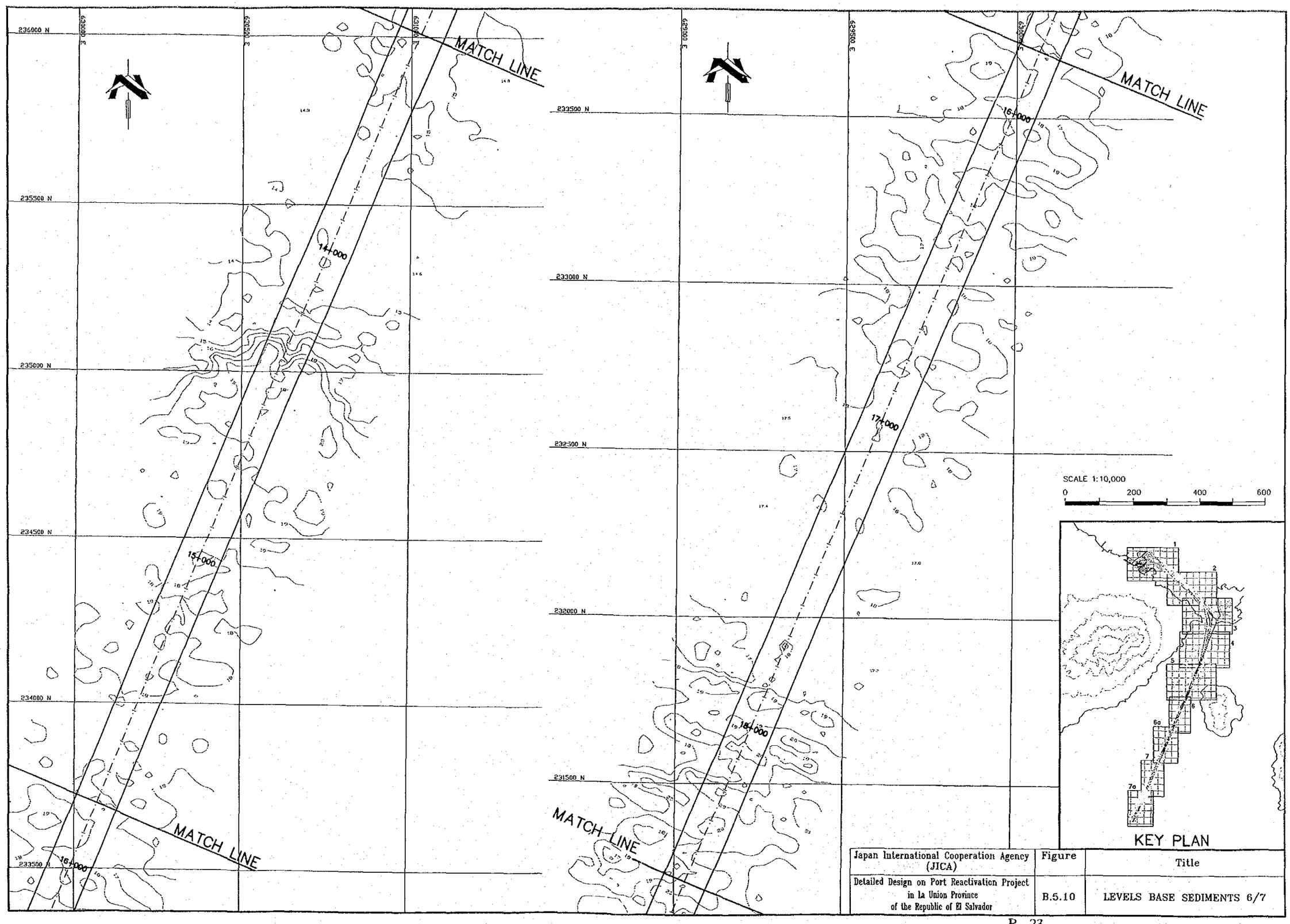
Japan International Cooperation Agency (JICA)	Figure	Title
Detailed Design on Port Reactivation Project in La Union Province of the Republic of El Salvador	B.5.7	LEVELS BASE SEDIMENTS 3/7

631000 E
631500 E
632000 E
632500 E
633000 E
633500 E
634000 E
240500 N
240000 N
239500 N
239000 N
238500 N
MATCH LINE
MATCH LINE
9+000
10+000
KEY PLAN
SCALE 1:10,000
0 200 400 600

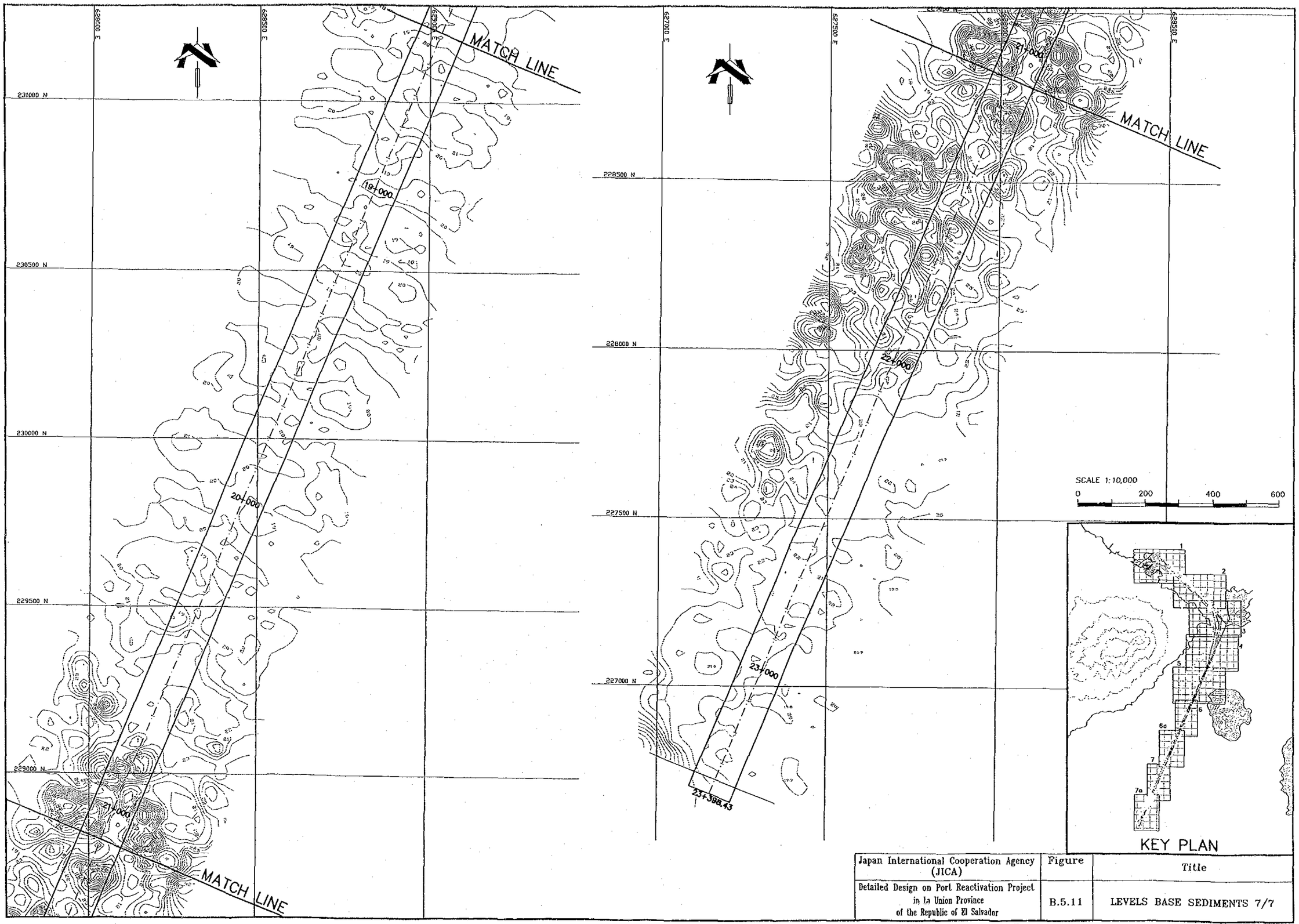
Japan International Cooperation Agency (JICA)	Figure	Title
Detailed Design on Port Reactivation Project in La Union Province of the Republic of El Salvador	B.5.8	LEVELS BASE SEDIMENTS 4/7



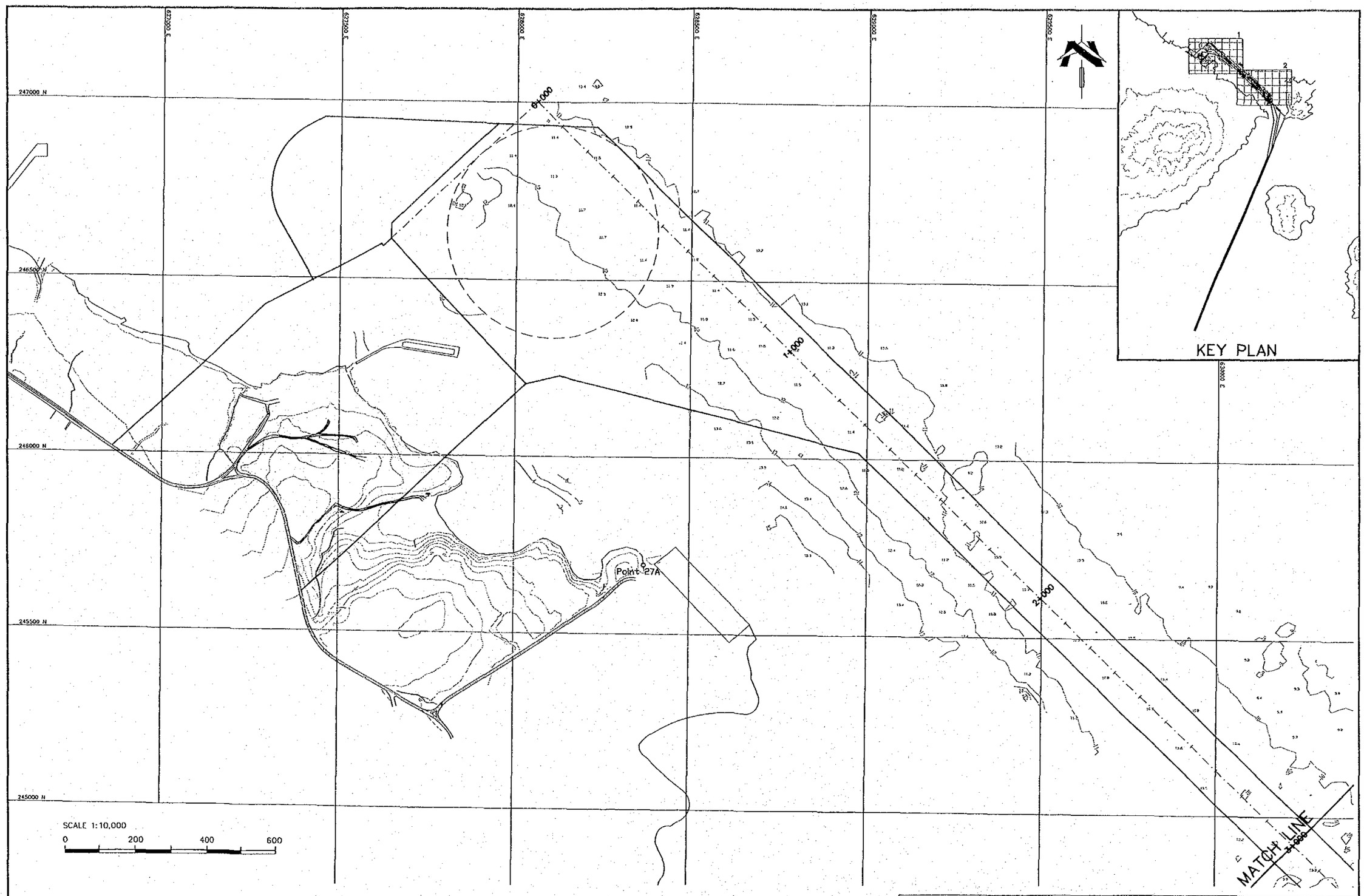
Japan International Cooperation Agency (JICA)	Figure	Title
Detailed Design on Port Reactivation Project in La Union Province of the Republic of El Salvador	B.5.9	LEVELS BASE SEDIMENTS 5/7



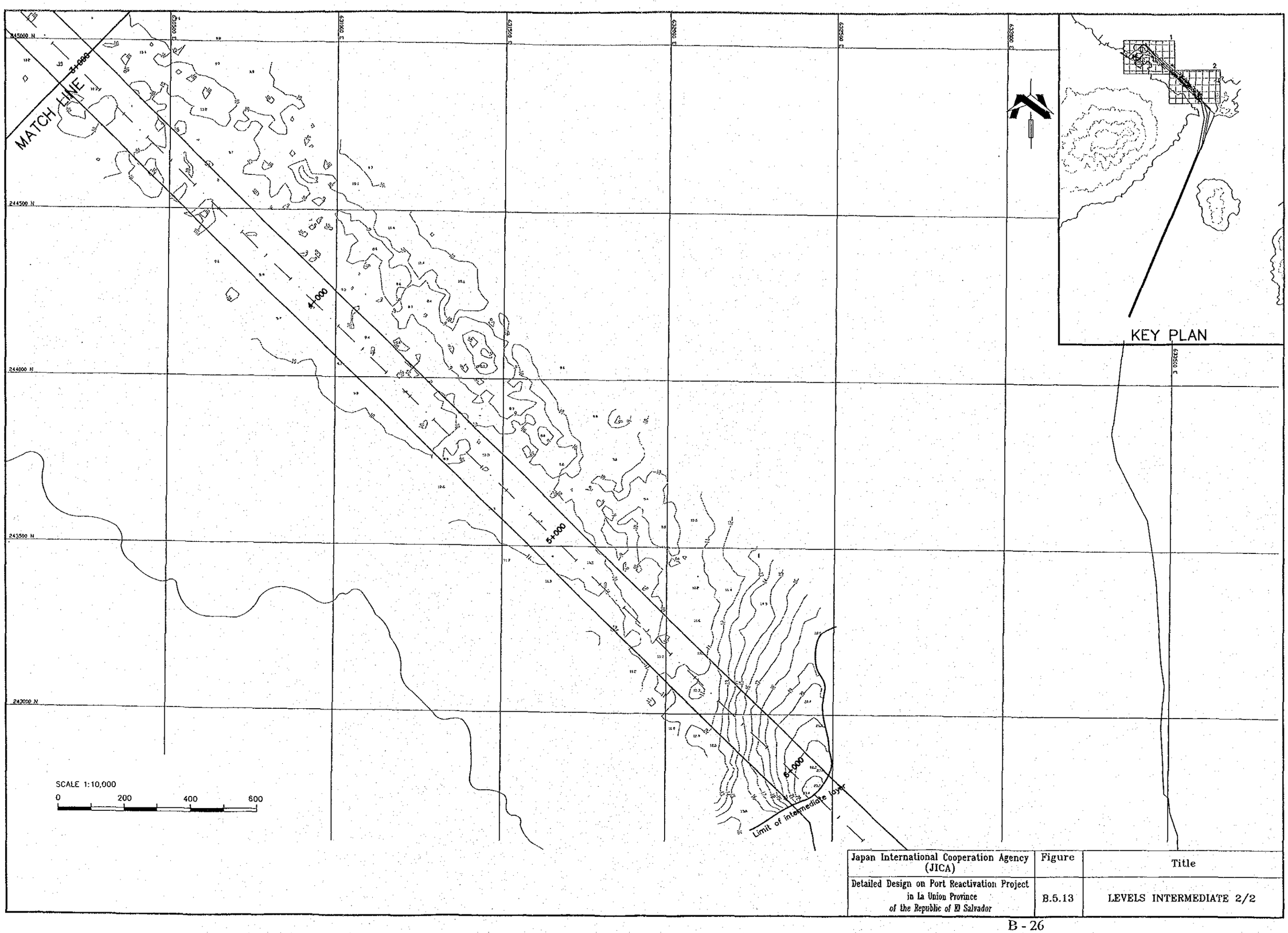
Japan International Cooperation Agency (JICA)	Figure	Title
Detailed Design on Port Reactivation Project in La Union Province of the Republic of El Salvador	B.5.10	LEVELS BASE SEDIMENTS 6/7



Japan International Cooperation Agency (JICA)	Figure	Title
Detailed Design on Port Reactivation Project in La Union Province of the Republic of El Salvador	B.5.11	LEVELS BASE SEDIMENTS 7/7



Japan International Cooperation Agency (JICA)	Figure	Title
Detailed Design on Port Reactivation Project in La Union Province of the Republic of El Salvador	B.5.12	LEVELS INTERMEDIATE 1/2



Japan International Cooperation Agency (JICA)	Figure	Title
Detailed Design on Port Reactivation Project in La Union Province of the Republic of El Salvador	B.5.13	LEVELS INTERMEDIATE 2/2