Detailed sedimentary structure off Sissano Lagoon, northern coast of Papua New Guinea
- Preliminary result of the SOS-4 Cruise by R/V NATSUSHIMA -

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abstract

The SOS-4 cruise was carried out in February 2001 to study the sub-surface structures corresponding to the 1998 hazardous earthquake and tsunami event off Sissano Lagoon, northern coast of Papua New Guinea by use of digital single-channel seismic profiler. Both the focussed survey on the amphitheatre area off Sissano Lagoon and regional survey off Vanimo - Sissano - Aitape identified some recent/fossil events, active deformational structures and regional tectonics. Contrast in the sedimentary layer features between the eastern and western half was observed clearly by the focussed quasi-3D survey on the amphitheatre area. Eastern half is characterised by layered stiff sediment where a rotational failure should take place after the 1998 earthquake. Relics of sliding of soft sediment were observed on the slope of the western half of the amphitheatre. A 70km^3 block of a transparent sedimentary layer, apparently derived from a slope failure, was located in the fore-arc area of the New Guinea Trench off Vanimo. The sediment block is completely filling the fore-arc basin. A number of seamounts colliding and subducting underneath the New Guinea Trench are also observed. Since the study area is characterised by an oblique subduction of the Caroline Plate towards WSW underneath the Australian Plate, tensile stress perpendicular to the strike of the trench is predominant in the whole area, considering a number of normal faults are located.

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1. Introduction

Background of the study

The area off the northern coast of Papua New Guinea (PNG) is known to comprise a subduction zone on the northern margin of the Australian Plate where the Pacific Plate (to the north) and comprising the North Bismarck Sea and Caroline plates are being subducted southward. From general plate motions the convergence is considered to be oblique along an azimuth of 070 °at 10mm/year. GPS measurements to the east of the area surveyed by the SOS cruises proves the convergence to be partitioned across a number of structural boundaries, mainly the New Guinea Thrust Zone, the Ramu-Markham Thrust and the microplates that lie to the east of mainland PNG (Tregonning et al., 2000). Convergence rate decreases towards the west. Published data indicates that in the far west off Irian Jaya, there is no convergence at all. Table 1 lists the significant tsunamis induced by earthquakes in the Aitape-Sissano Lagoon area, extracted from Everingham (1997). Port Moresby Geophysical Observatory (PMGO) keeps a catalogue of PNG region tsunamigenic earthquakes from 1900. It must be noted here that not a lot of record exist for tsunami events prior to 1990.

The location of the Sissano Lagoon at a structural boundary was considered a dominant influence in the formation of the amphitheatre area by sediment failure. The particular vulnerability to tsunami hazard of the Sissano Lagoon area is increased by the seaward projection of the submerged delta front outbuilding from Sissano and the Bliri River. A tsunami formed offshore in the amphitheatre area would thus be focused onto the Sissano Lagoon area. A compounding factor is the noted subsidence of the Lagoon over the past 100 years. Subsidence offshore has also been recorded from observations that include the identification of a subsided reef at 500 m water depth on the northeast margin of the submarine delta front. Additional data on subsidence has been provided from diving on the seaward margin of the Bliri outfall (Davies, 2000). Submerged peat of paludal origin has been dated at 1000 years.

The SOS (Sissano Offshore Survey) Programme started through the request from SOPAC to JAMSTEC after the 1998 Papua New Guinea Earthquake (M=7.1) and the subsequent large-scale tsunami which occurred on 17th July 1998 on the northern coast of Papua New Guinea mainland (Ripper et al., 1998, Ripper and Letz, 1999). In January 1999, regional bathymetric and geophysical survey was carried out by R/V KAIREI as SOS-1 cruise (cruise ID = KR98-13). Based on the

Table 1 Significant tsunamis induced by earthquakes off Sissano Lagoon, northern coast of Papua New Guinea in the 20th century. Extracted from Everingham (1997).

No.	date	time(UTC)	lat(S)	long(E)	magnitude	depth	remarks
(1)	15 Dec 1907	1735	3.1	142.5	7.0	shallow	At Sissano, new lakes and lagoon were formed from subsidence and tsunami effects. There is no information on a tsunami run-up.
(2)	29 July 1971	2152	3.5	141.0	7.7	shallow	A tsunami of wave height of 0.5 metres was generated.
(3)	03 July 1918	0652	3.5	142.5	7.4	shallow	Tsunami effects at Aitape and other northern coastline. There is no information on a tsunami run-up and type of tsunami effects.
(4)	07 Aug 1931	0211	4.0	142.0	7.2	shallow	Tsunami effects along coastine from Aitape to Ulau in the southeast. There is no information on tsunami run-up, and type of tsunami effects.
(5)	20 Sep 1935	0146	3.5	141.8	7.9	shallow	Significant tsunami effects at Aitape; sea wave inundated coast lines of Aitape and Sissano Lagoon. There is no information on tsunami run-up. It is not known how many lives were lost. Massive landslides and slumping occurred and affected River systems in the rugged Toricelli Mountains. Large volume of sediments were transported by the river systems and deposited off-shore on the New Guinea Trench.
(6)	20 Sep 1935	0523	3.3	142.5	7.0	shallow	Aftershock of Toricelli Mountains earthquake. It is not known if a tsunami was generated.
(7)	17 Jul 1998	0649	2.96	141.93	7.0	shallow	The Aitape tsunami earthquake was followed by an aftershock which was than followed by three huge waves which inundated Sissano Lagoon and villages; 15 metres wave run-up and villages at the Lagoon were wiped out; more than 2200 people killed and injured 500.
(8)	17 Jul 1998	0709	3.04	141.93	6.4	shallow	Aftershock of the Aitape earthquake.

results from the cruise, precise visual observation and sampling were carried out by R/V NATSUSHIMA and ROV DOLPHIN-3K in February (SOS-2 cruise, cruise ID = NT99-02) and by R/V NATSUSHIMA and Research Submersible SHINKAI2000 (SOS-3 cruise, cruise ID = NT99-15). Through cruises, the joint JAMSTEC-SOPAC-PNG scientific team succeeded in identifying the possible collapse, underwater landslide, and seismic faulting on the amphitheatre off Sissano Lagoon.

From the multibeam bathymetry acquired during SOS-1 the detailed morphology of the offshore area was identified, confirming the convergent nature of the boundary and that offshore of Sissano there was located the junction between the New Guinea Trench and the ancient West Melanesian Trench. The Sissano area was thus located at a transition zone, almost forming a triple junction. To the east the inner trench slope is narrow (25-30 km) with steep gradients, the trench is V-shaped and relatively shallow at 3000 m and immediately to the north of the trench there is located a shallow water area at the western end of the North Bismarck Sea Plate. By contrast, to the west of Sissano, the inner trench slope is wide (50 km), with a stepped-like morphology with back-tilted sedimentary basins descending the slope. The New Guinea Trench is wider and deeper (4,000 m) than in the east. Water depths over the Pacific Plate are greater at 4,000 m. Two major submarine canyons dissect the inner trench slope, the Yalingi to the east of Sissano and the Pual in the west.

The morphology of the offshore area was considered to be attributable to the oblique convergence between the Pacific and Australian plates (Tappin et al., 2001a). Along the New Guinea Trench in the east the subduction of the shallow North Bismarck Sea Plate causes subduction erosion along the foot of the slope and a narrow and steeply, downfaulted inner trench slope. There is a strong strike-slip component to the faulting. In the west, subduction of the older and denser Caroline Plate is considered to result in more 'extensional' type of morphology resulting in the formation of the backtilted lower slope basins. The evidence was interpreted as supportive of the model that convergence decreased westward. Dominant strike slip movement results in diachronous convergence of the North Bismarck Sea Plate that is now impacting in the region offshore of Sissano leading to increased subsidence here.

Overall, the prominence of submarine canyons in the offshore area suggests that it is subject mainly to erosion, and the margin was thus described as 'sediment-starved'. In the context of the onshore drainage systems, the offshore area was considered to receive little sediment input and that this input is channelled through the river systems of the Pual and Yalingi, both of which have cut major offshore canyons. The Bliri terminates in the Sissano Lagoon area, with sediments deposited in the subsiding basin located here an extending towards the Yalingi Canyon. Little sediment escapes offshore. The dominant fluvial system that drains northern PNG is the Sepik River. This eastward draining river is located to south of the Bewani-Torricelli mountains with an outfall to the sea farther east.

Collapse of the inner trench wall due to subduction erosion was considered a prime tsunami source mechanism by Tappin et al. (2001). In the area off Sissano the focused study using both multibeam bathymetry and seabed observation confirmed that this area is particularly tsunamigenic, with sediment slumps creating the arcuate feature termed the amphitheatre. Several episodes of slumping were identified with that most recent proposed as taking place in the eastern upper landward scarp and considered the likely source of the tsunami of July 1998.

A marked variation in sediment thickness on the inner trench wall was considered to be a major factor in determining the location of potential slumps. Thick sediment accumulations are considered more prone to failure either by earthquake shock or inherent instability. Multichannel seismic data across the eastern part of the amphitheatre, acquired aboard the Thomas Washington in late 1999 located a slump in this area traversing the upper landward scarp down onto a midslope bench or mound (Sweet and Silver). Simulation of a slumped sediment mass of 6 km^3 approximated the measured tsunami run-up along the Sissano coast (Tappin et al., 2001).

<u>SOS-4 objectives</u>

Although a strong database of bathymetry, high resolution seismic, multichannel seismic, coring and observation supported the evaluation of the tsunamigenic hazard of the Sissano (Aitape) area, there is little data on which to base evaluation of the tsunami hazard to the remaining area onshore of the multibeam survey of SOS-

1. Penetrative seismic data was required both to make a more complete assessment of the likelihood of seabed failure offshore of Sissano (Aitape) and, also, more regionally. Using this data in conjunction with that previously acquired it was intended to assess the tsunamigenic potential of northern PNG more extensively.

The previous three tsunami surveys organised by JAMSTEC and SOPAC for the investigation of the tsunami hazard off the north coast of PNG have up until now focused mainly on discovering the probable source of the July 1998 event and why it was so large. The source of the tsunami has remained to some extent controversial, with both fault and sediment slump alternatives being investigated. There have now been a number of serious discussions at major international scientific meetings, including three at AGU and one at IUGG in Birmingham in 1999. Notwithstanding, in the opinion of the senior author of this contribution the most probable tsunami source is from a sediment slump within the amphitheatre area located ~20 kilometres northeast of Sissano Lagoon. The evidence for this conclusion has now been presented in two major scientific papers (Tappin et al., 2001a and b).

The offshore evidence acquired previous to the survey NT01-01 (SOS-4) includes multibeam bathymetry, high-resolution 4.2khz seismic, sediment piston cores, and potential (gravity and magnetic) data (SOS-1), observational information by Remotely Operated Vehicle (ROV) (SOS-2) and Manned Submersible (MS) (SOS-3) and multichannel seismic (Sweet and Silver). This geological and geophysical database has been supported by a considerable body of mathematical simulations. It was in this context that the single channel seismic survey of SOS-4 took place. The objectives of the survey were to acquire a comprehensive regional grid of seismic data across the area surveyed with multibeam bathymetry and a more detailed, closer grid in the area of the amphitheatre.

Thus SOS-4 had a number of objectives: (1) To investigate the amphitheatre area in detail, to identify its tsunamigenic potential, especially as regards the 1998 tsunami event, (2) To investigate the northern PNG area as regional context for tsunami generation elsewhere along the coast, and (3) To continue to improve the tsunami simulations both for the Sissano (Aitape) area and for the offshore region more generally.

2. Instrumentation - single-channel seismic profiling

Brief Theory of Single-Channel Seismic Profiling

Single-channel seismic reflection profiling is seismic reflection surveying in its simplest form, and is a highly effective marine seismic surveying technique. A marine seismic/acoustic (energy) source is towed behind a survey vessel and triggered at a fixed firing rate. Signals reflected from the seabed and sub-bottom reflectors are detected by a hydrophone streamer towed in the vicinity of the source. Individual hydrophone outputs are summed and fed to a single-channel amplifier/processor unit and then to a chart recorder. This type of surveying is only possible at sea where the source and detectors can be moved forward continuously, and a sufficiently high firing rate achieved, making it possible for continuous surveying from a moving vessel.

The source and hydrophone streamer are usually towed at shallow depth but there are deep-tow systems where source and receiver are towed near the seabed for improved penetration of the seabed as a result of minimal transmission losses. Energy sources used are pingers, boomers, sparkers, and airguns, which are by far the most versatile sources for single-channel profiling.

Single-channel seismic data are simple to interpret but there may be multiple reflections paths if the seabed is rugged and reflector geometries are complex, and therefore, records obtained in deep water using shallow-tow systems contain hyperbolic diffraction patterns, bow-tie effects, and other features of non-migrated seismic sections. Seabed multiples may obliterate primary reflections from the later parts of records, especially in shallow water depths. Multiples from deeper reflectors occur later in the records.

Velocity information cannot be derived from single-channel seismic recordings and therefore depth-conversion utilizes independent velocity estimates. However, imaging of subsurface geology and estimates of reflector depth are sufficiently accurate for most purposes.

A single-channel seismic system can be operated in conjunction with a precision echo sounder, for high quality bathymetric information, and/or with a side-scan sonar for reliable information on the configuration and orientation of sedimentary bedforms or on the pattern of rock outcrops.

A simple single-channel seismic data processing stream involves (1) static corrections to reduce the effects of source depth variations, (2) spectral analysis to obtain frequency and phase information essential for the design of frequency filtering and deconvolution operators for noise elimination, and (3) migration to correctly reposition subsurface reflectors, collapse diffractions, and obtain accurate depth sections from time sections.

GI gun source

The acoustic energy source used in the SOS-4 cruise is the GI GUN (Seismic Systems, Inc. TX. USA), a pneumatic seismic source constituted of two independent air guns within the same casing. The GI GUN is also known as the air gun that controls its own bubble. The first air gun is called the GENERATOR, as it generates the seismic pulse. The second air gun is called the INJECTOR, and it injects air inside the bubble produced by the generator. It is used to control and to reduce the oscillation of the bubble produced by the generator.

A common hydrophone attached to the underside of the gun casing provides the "time break" and the shape of the near field signal. This gun phone is located inside the air bubble and therefore responds to the actual air blast of the GI GUN to which it is attached, without being affected by neighbouring air guns in a multi-gun array.

The GI GUN works in the following manner:

Phase 1 - the generator is fired and the blast of compressed air produces the primary pulse and the bubble starts to expand.

Phase 2 - when the bubble approaches its maximum size, it surrounds the injector ports, but its internal pressure is far below the outside hydrostatic pressure. At this time, the injector is fired, injecting air directly inside the bubble.

Phase 3 - the volume of air released by the injector increases the internal pressure of the bubble, and prevents its violent collapse. The oscillations of the bubble and the resulting secondary pressure pulses are reduced and reshaped.

The signature of the GI GUN can be adjusted by adjusting (1) the volume of the generator and/or the volume of the injector from 45 cu.in. to 105 cu.in. (2) the time when the injection starts, and (3) the duration of the injection. The GI GUN can be adjusted to operate in three different modes each with a different signature. The air gun is towed behind the survey vessel and discharged at regular time intervals, for example: every 16 seconds. In this survey, the generator had a volume of 45 cu.in. and the injector had a volume of 105 cu.in., giving a total gun volume of 150 cu.in. In this cruise the GI gun was towed at ca. 30m on the starboard side of R/V Natsushima at a towing depth of about 4-6m. Shooting rate was 16 sec with a ship speed of ca. 8 knots (that was changed to 6 knots later). The firing controller (Clover Tech Inc., Japan) controls the power supply to the GI gun and the generator-injector firing time delay.

Air compressor

The air gun is supplied with compressed air by a compressor setup situated on the ship. The setup consists of two compressors motors in a protective metal frame. The compressors supply air at pressures of 1000 to 3000 psi. via one input cable. In this survey, air compressed at 1740 psi (12 mPa) was supplied to the air gun. The air gun and compressors worked 24 hours, day and night.

Hydrophone streamer

An S.I.G. (Services et Instruments de Geophysique, France) streamer array was used during the SOS-4 cruise. The diameter of the streamer cable was about 31 mm and enclosed in sheaved PVC for protection. An air valve system enables the streamer's depth to be modified by acting on the cable's density during profiling. Inert oil is used for buoyancy. SIG hydrophones and streamer can operate at a maximum depth of 80 m, and were towed at an average depth of 5 to 10 m at speeds of 5-7 knots in this survey. The streamer is approximately 200 m long with a 65 m long active section, a 135 m lead-up section, and a 30 m tail rope. No tail buoy was required because the streamer was relatively short and therefore light. The streamer is linked directly to the shipboard recording equipment.

There were 48 hydrophones spaced at 1 m intervals on the streamer. All 48 channels are summed into 1 channel by a preamplifier located about 8 m from the first hydrophone. A depth transducer compartment is located further along the lead-up section of the streamer. The depth transducer is pressure sensitive and monitors the depth of the streamer, which can be read from a console in the recording room aboard the survey vessel.

The SIG 16 brand of hydrophones were used in SOS-

4. These hydrophones have a sensitivity of -90 db, or 1 volt per microbar of fluid pressure, and weigh approximately 14.8 grams. They have a frequency response over the range from 10 to 1000 Hz and can operate in temperatures ranging from -5 to 70 ℃.

The streamer depth depends on the ship speed because it does not have a depth controller "bird." But if the operator would like to set the streamer to reduce the noise level, the operator can sink the streamer deeper by opening the "air connector." In this cruise, we did not need to do this thanks to the good weather and the sea condition and the rubber rope called "shock absorber."

Acquisition and Processing Parameters

Received seismic data are monitored by an on-line processing system and recorded in SEG-Y format. Delph Seismic (TRITON ELICS International, Inc., USA) software was used to control both seismic source and seismic data processing. It can also plot out to the grey-scale printer GSP-1086 (EPC LABORATORIES, Inc., Danvers MA USA). The seismic data are transferred to the off-line processing system SPW (PARALLEL GEOSCIENCES, Inc., USA) for further processing and analysis.

The SOS-4 single-channel seismic survey acquisition and preliminary onboard processing parameters are summarised in Table 2 below.

Table 2 SOS-4 single-channel seismic survey acquisition and preliminary onboard processing parameters.

PARAMETER	DETAILS
Survey Area	Offshore Aitape/Sissano
Number of Lines	49
Line orientations	Amphitheatre survey: N-S Regional survey: NNE-SSW
Date Acquired	9th – 19th February 2001
Contractor	Nippon Marine Enterprises, Ltd.
Survey Vessel	R/V Natsushima
Sea Depth	300 - 4000 m
Vessel Speed	4 - 7 knots
SP Interval	16 seconds
Cable Depth	Average 8 m
Source	
Air Gun type	GI GUN (Seismic Systems, Inc.)
Volume	150 × 1 cu.in. Generator = 45 cu.in., Injector = 105 cu.in.
Air Pressure	1740 psi (12 mPa)
GI Delay Time	27 - 36 msec
Recording	
Sampling frequency	1000 Hz
Sample interval	
Record length	8 - 12 seconds
Water Delay	0 msec
Digital Low Pass Filter	200 Hz
Digital High Pass Filter	20 Hz
Automatic Gain Control	Decremental, upslope=10, downslope=15, AGC window=10 msec
Streamer	
Streamer Model	SIG 16.48.65
Active Streamer	65 m
Hydrophone Type	SIG 16
Sensitivity	-90 db, 1 V/μbar, ±90 db
Number of hydrophone groups	48
Front stretch section	135 m

3. Outline of the cruise

The current SOS-4 cruise (cruise ID = NT01-01) was planned to study the sub-surface structures corresponding to the hazardous 1998 Papua New Guinea earthquake and tsunami. Therefore, surveying sub-bottom structure by use of digital single-channel seismic profiling was exclusively carried out during the whole cruise. Primarily, the information obtained from the cruise was of great help for geological mapping of the amphitheatre area where active deformational structures caused by underwater landslides and/or earthquake faulting were revealed by the previous cruises. Secondarily, regional survey off Vanimo ~ Sissano ~ Aitape was also carried out in order to identify regional tectonics which is to be a background of the present events. Detecting fossil events was also planned to measure the rate and frequency of the geo-hazardous phenomena in the study area. Characterisation and volume estimation of the slump sediment along the amphitheatre offshore Sissano Lagoon was mostly prioritised for this cruise. Therefore, the first four days was focussed on the surveying of the Amphitheatre, Pop-up Block and nearby in order to get pseudo 3-D image of the sub-surface structure by closely spaced survey lines with the spacing of 0.5nm. Then after that regional survey was started to cover the pre-surveyed area by SOS-1 cruise. Fig. 1 shows all the survey tracks in SOS-4 cruise. Fig. 2 shows the survey tracks focussed on the amphitheatre off Sissano Lagoon. Fig. 3 (Line 1 - 49) shows the result of single-channel seismic reflection survey. Table 3 summarises the seismic survey lines.

4. Results

25 N-S trending seismic lines were acquired at a line spacing of mainly 900m, with seven ENE-WSW trending tie lines. The area covered is approximately between the southern margin of the submerged delta slope in the south and the 40-Kilometre Fault in the north and from the Yalingi Canyon in the east to the central region of the subsided delta in the west. The main features of the amphitheatre were mapped, including the 40-Kilometre and 14-Kilometre faults, the Upraised Block, the

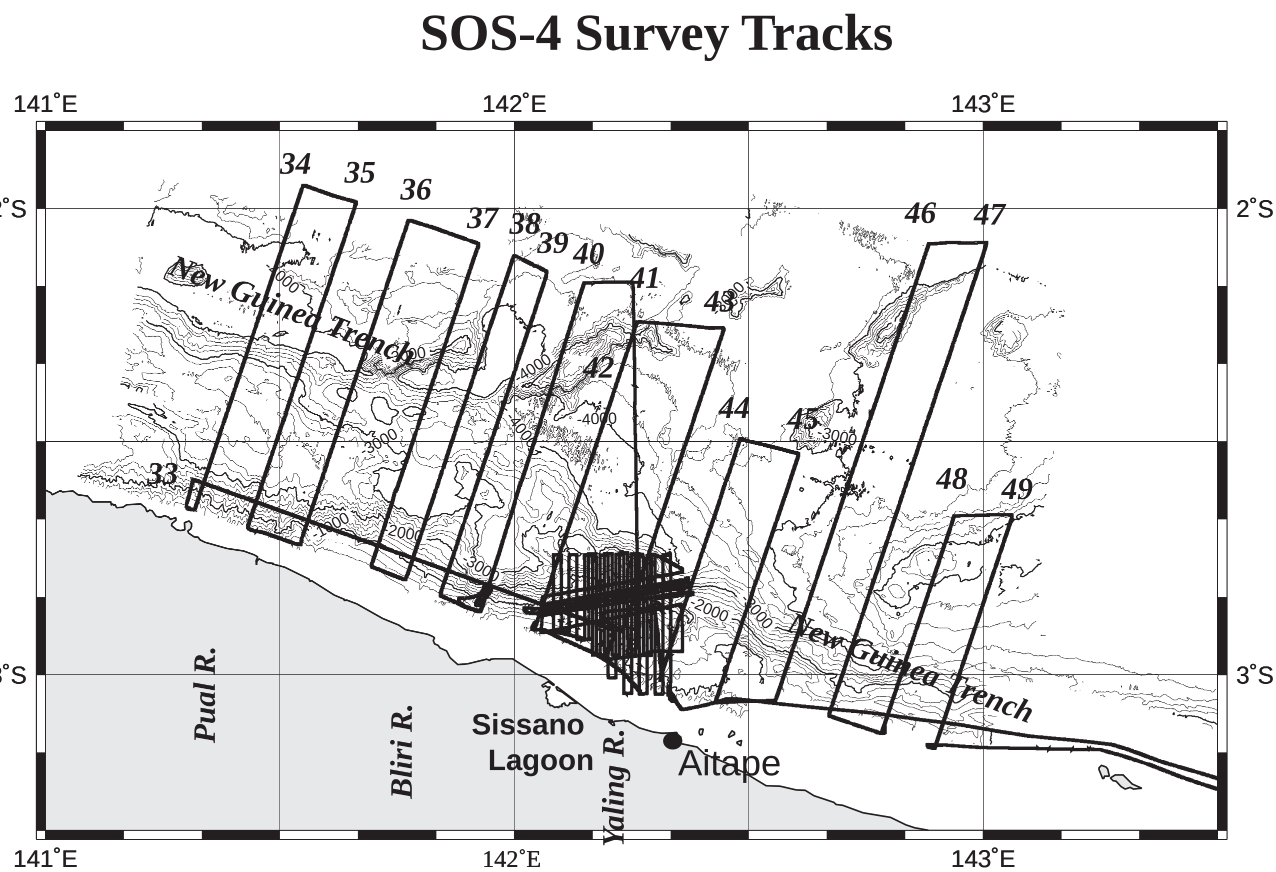


Fig. 1　All the survey track lines in the SOS-4 cruise.

SOS-4 Survey Tracks in the Amphitheatre Area

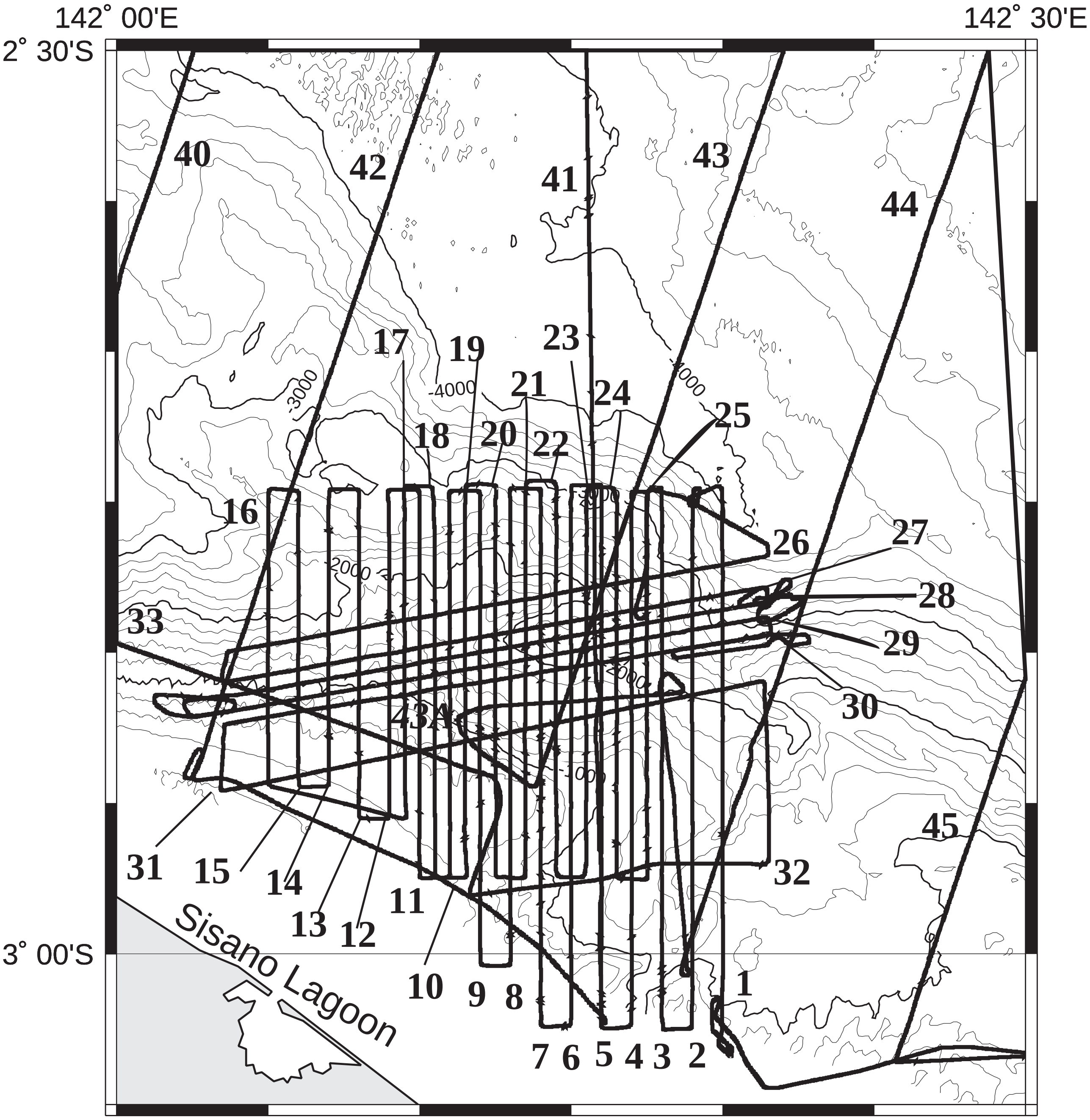


Fig. 2　Close-up view of the survey track lines in the amphitheatre area off Sissano Lagoon.

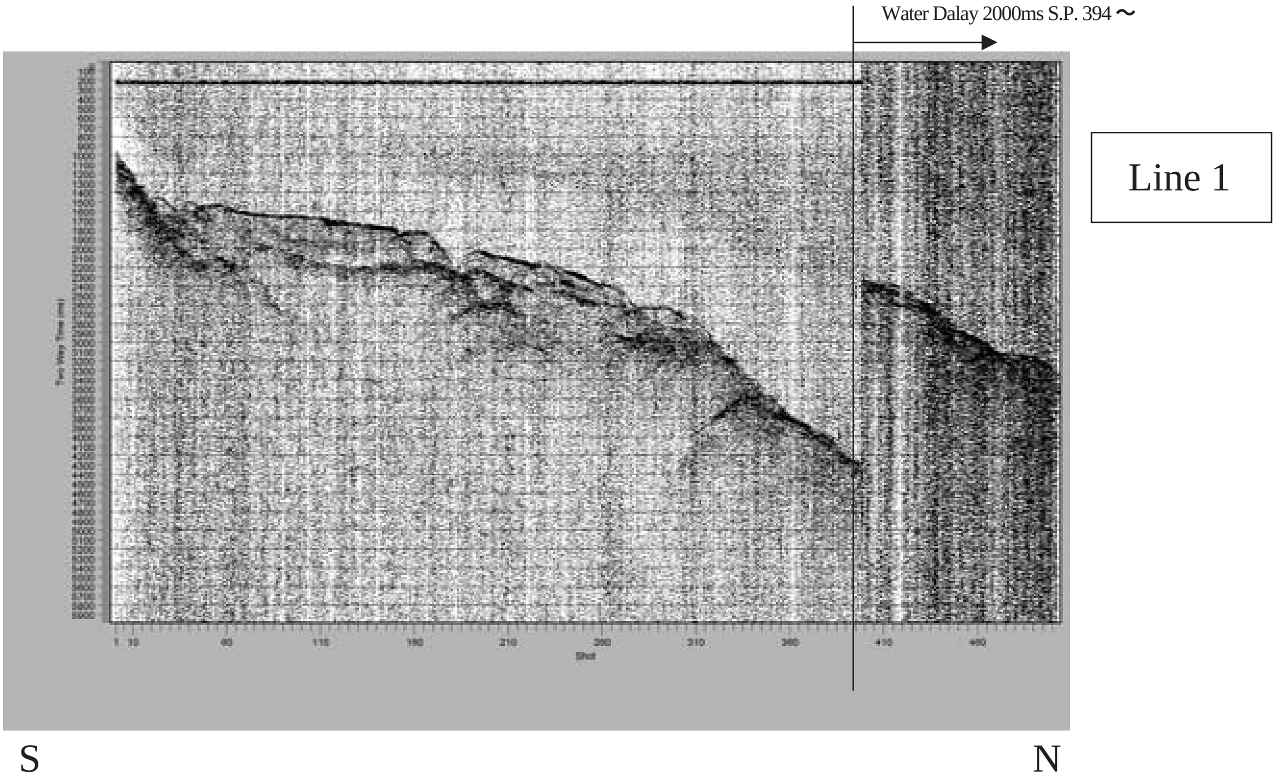


Fig. 3 (Line1)　Seismic profiles along the survey tracks.

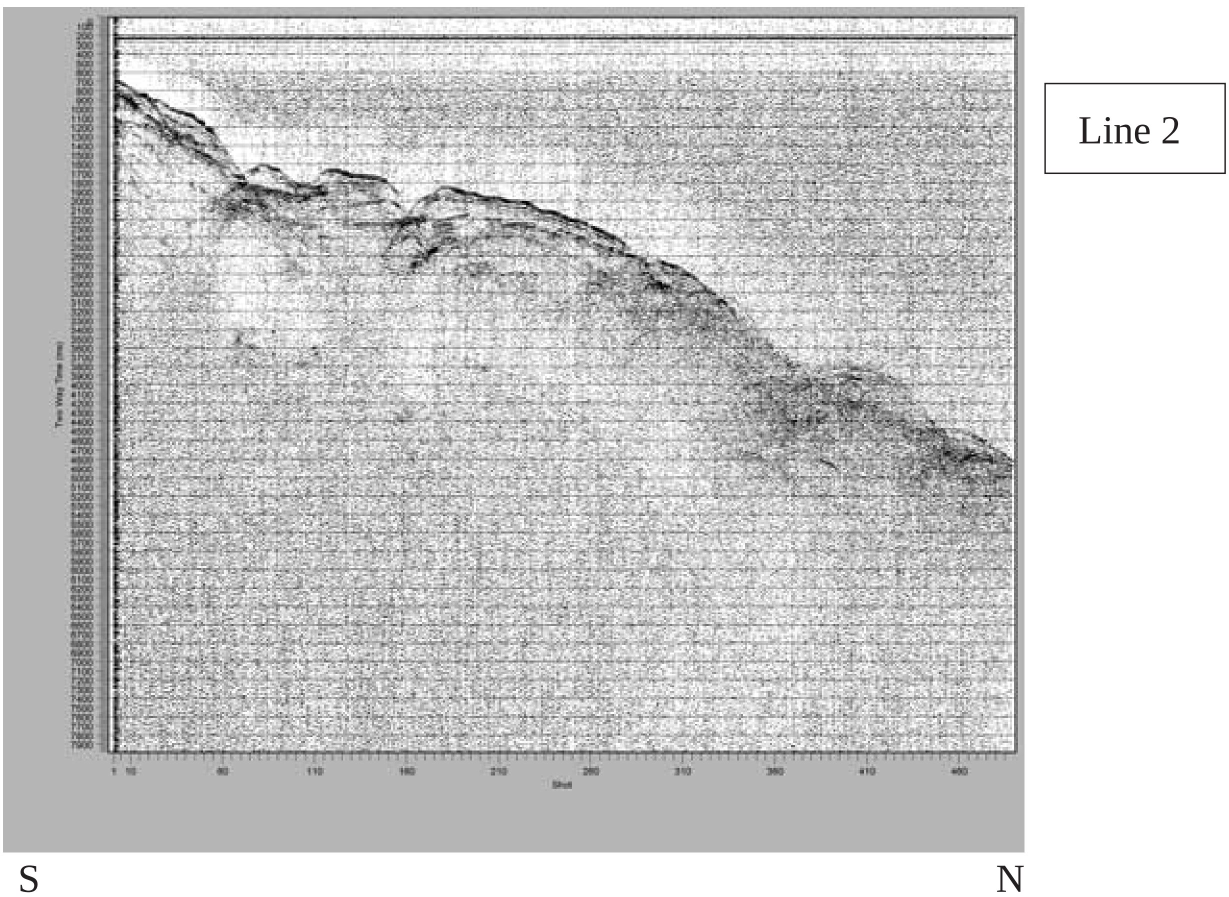


Fig. 3 (Line2)　Seismic profiles along the survey tracks.

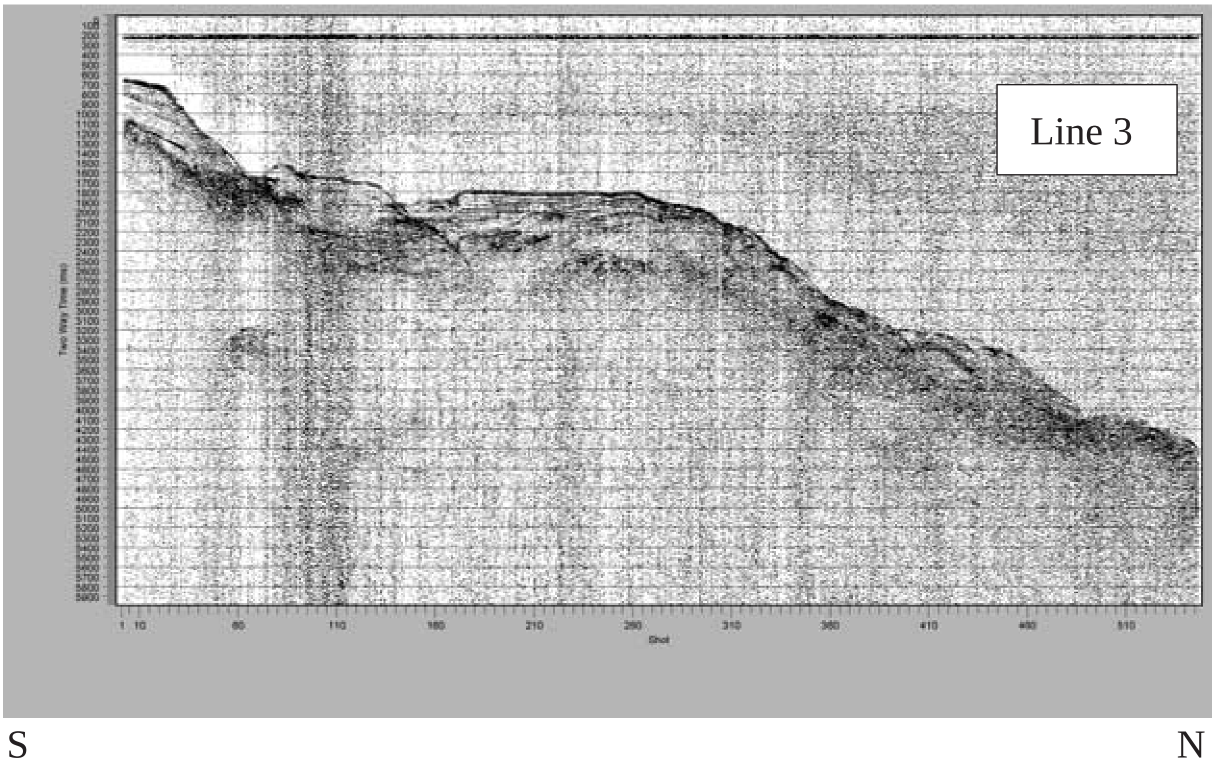


Fig. 3 (Line3)　Seismic profiles along the survey tracks.

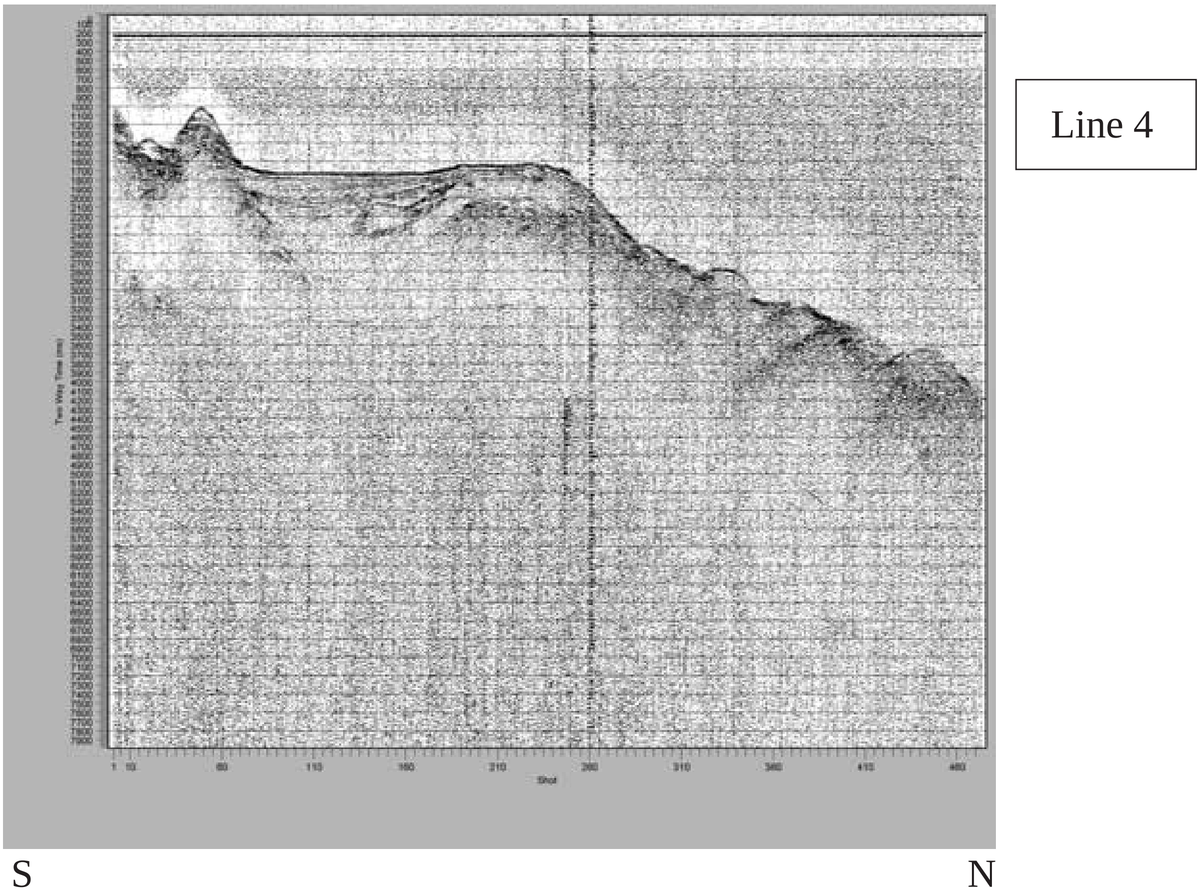


Fig. 3 (Line4)　Seismic profiles along the survey tracks.

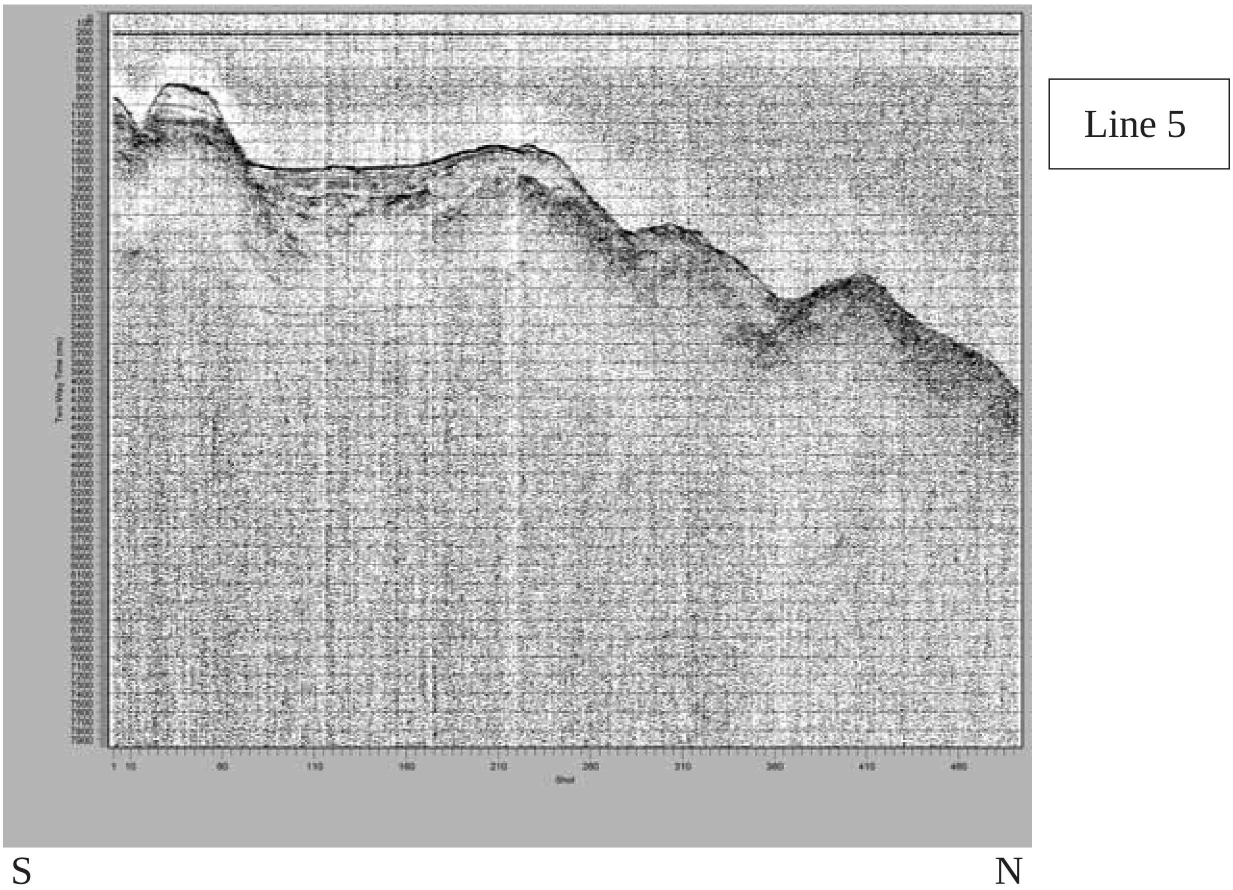


Fig. 3 (Line5) Seismic profiles along the survey tracks.

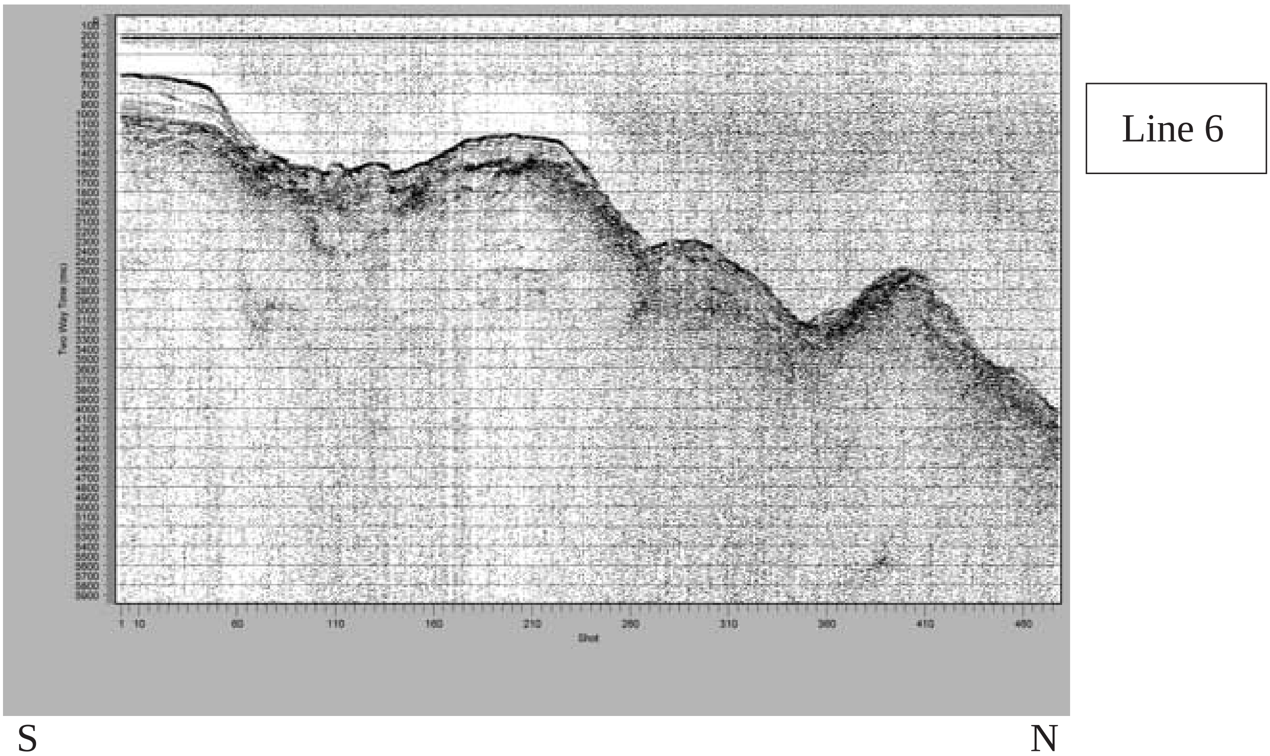


Fig. 3 (Line6) Seismic profiles along the survey tracks.

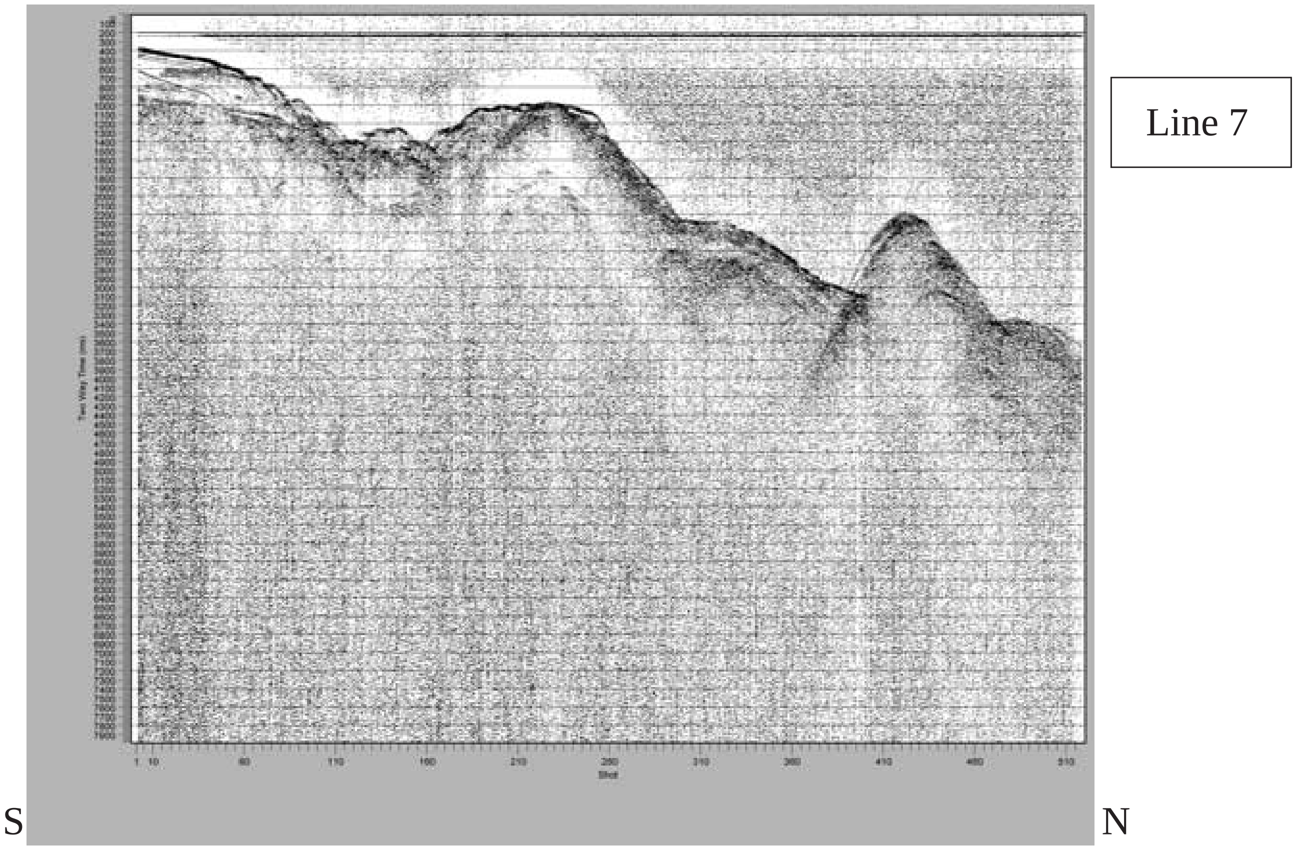


Fig. 3 (Line7)　Seismic profiles along the survey tracks.

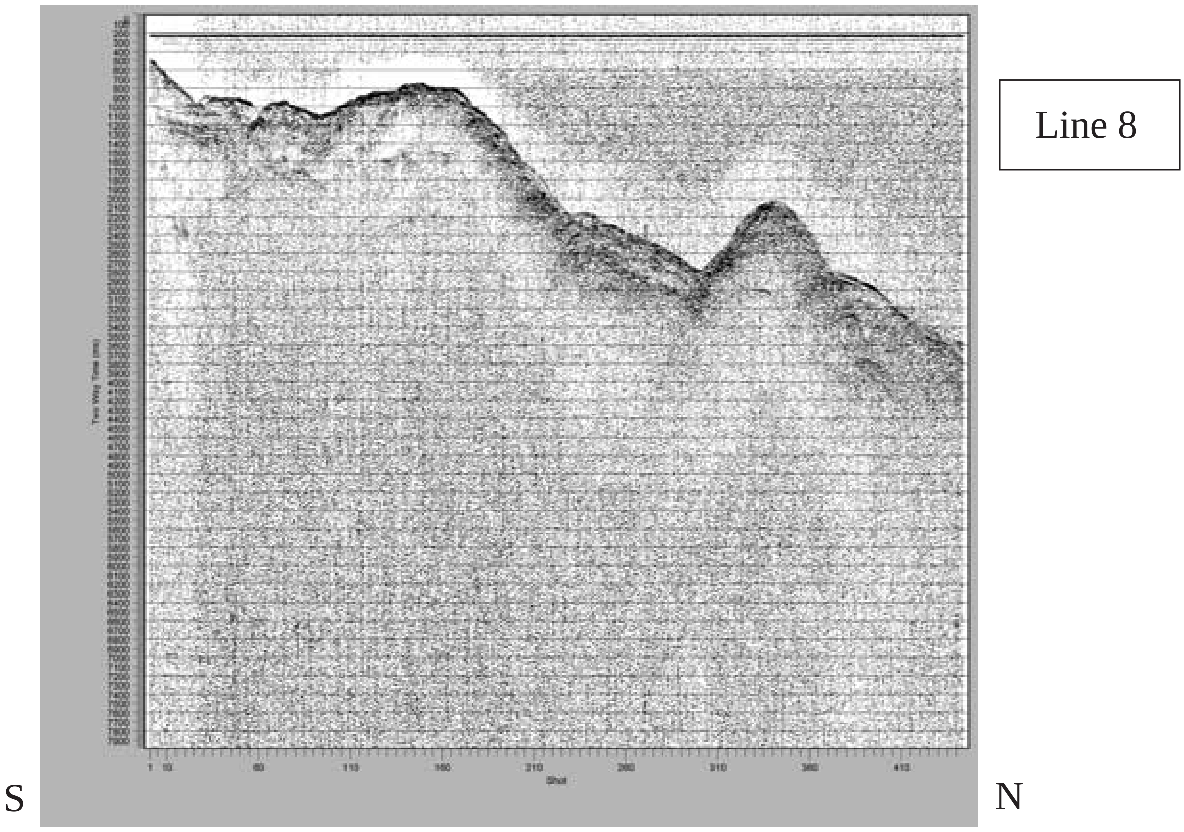


Fig. 3 (Line8)　Seismic profiles along the survey tracks.

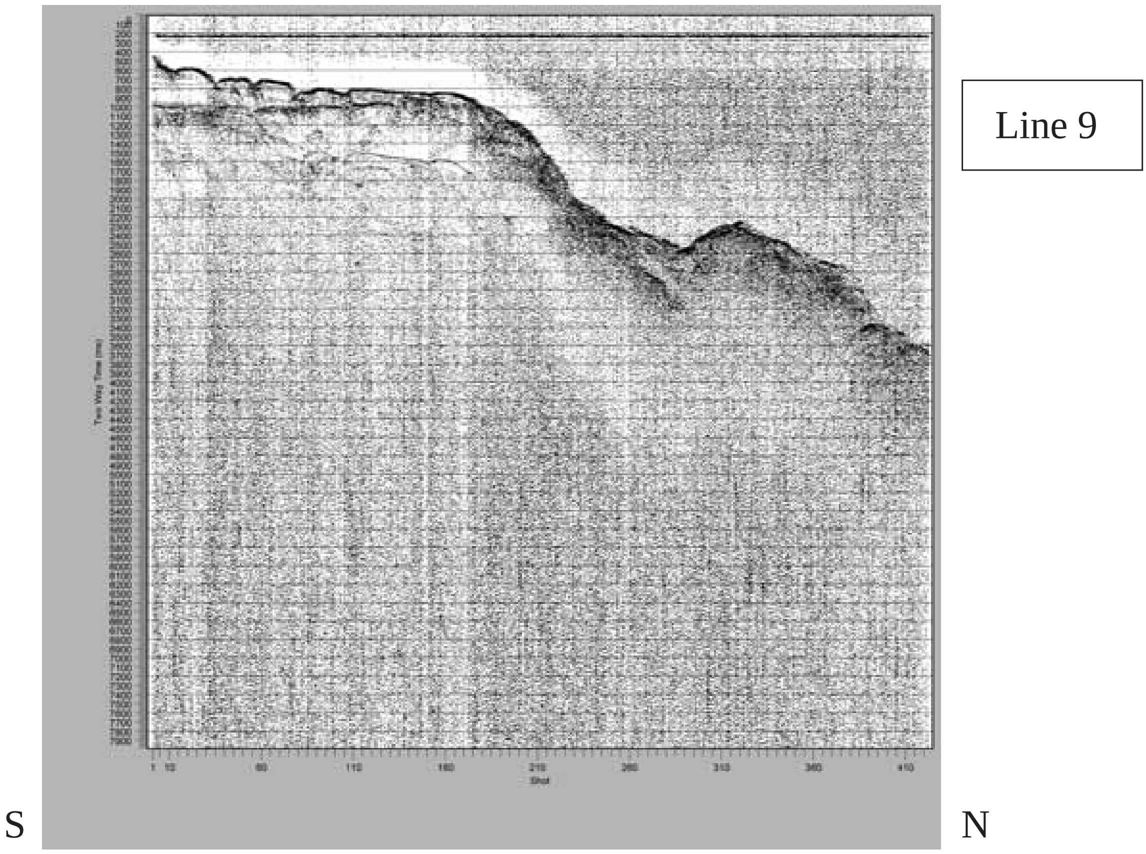


Fig. 3 (Line9)　Seismic profiles along the survey tracks.

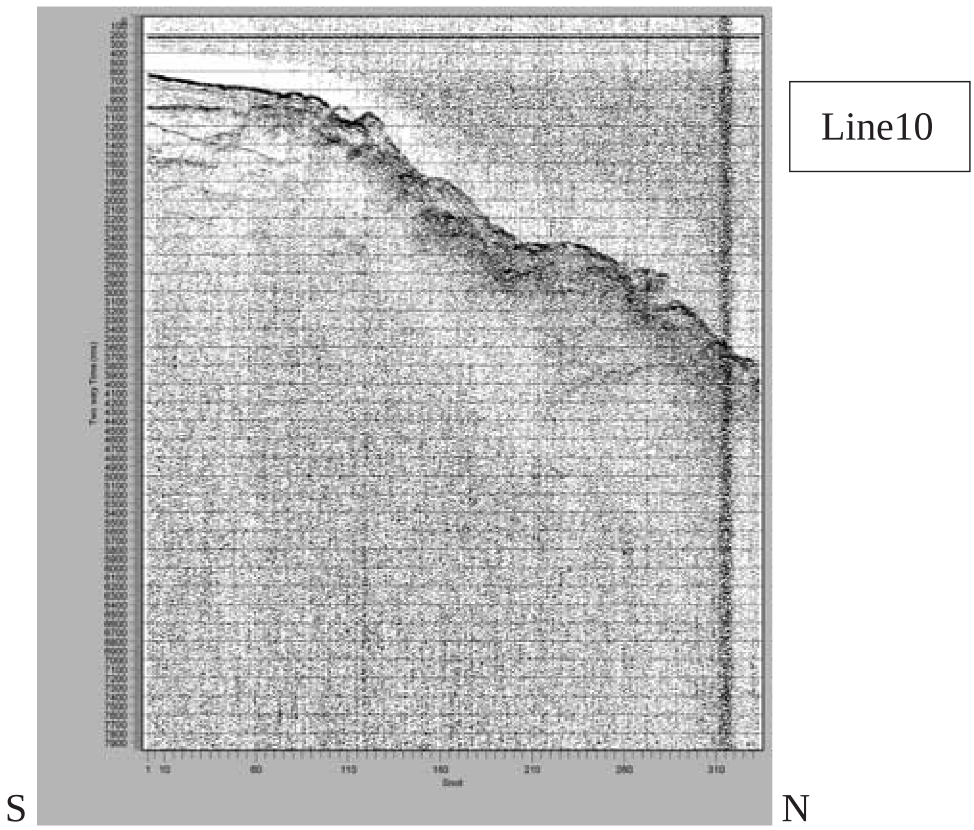


Fig. 3 (Line10)　Seismic profiles along the survey tracks.

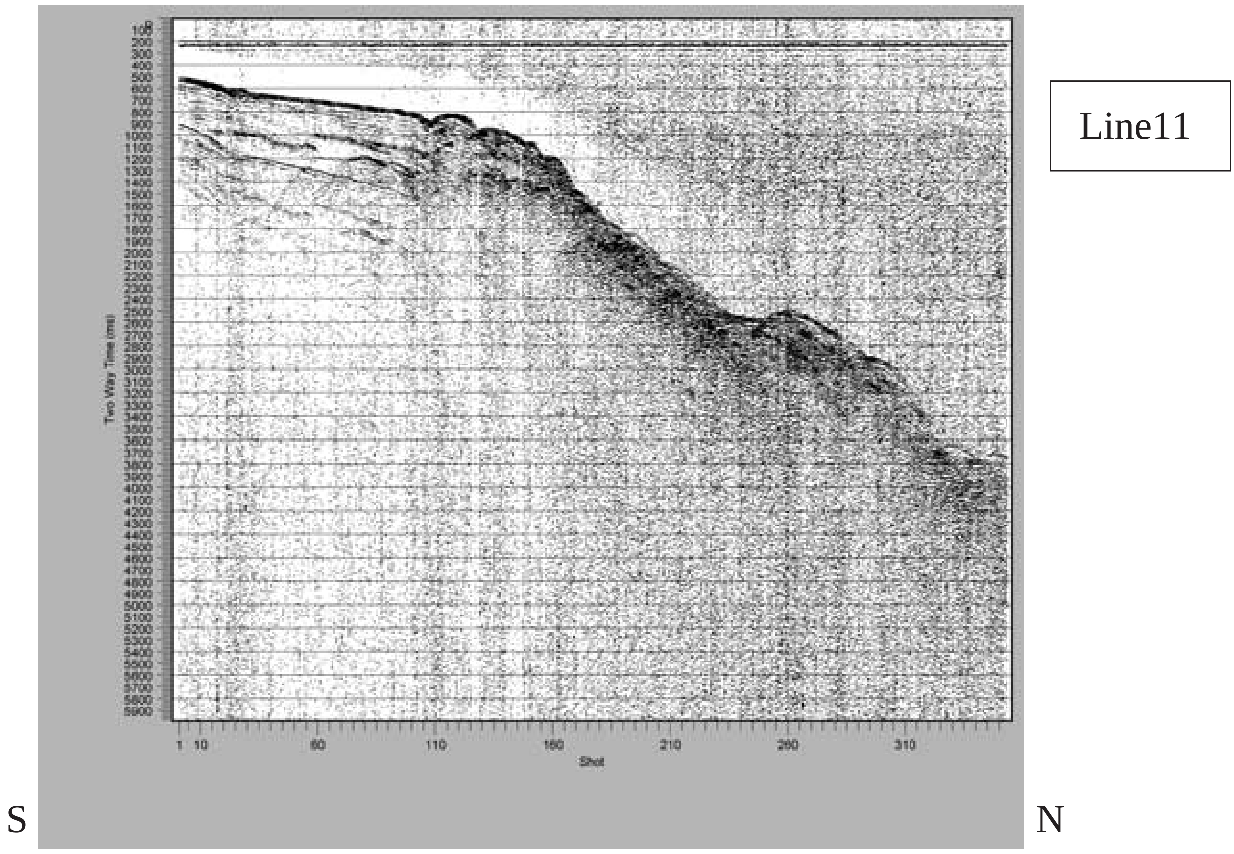


Fig. 3 (Line11)　Seismic profiles along the survey tracks.

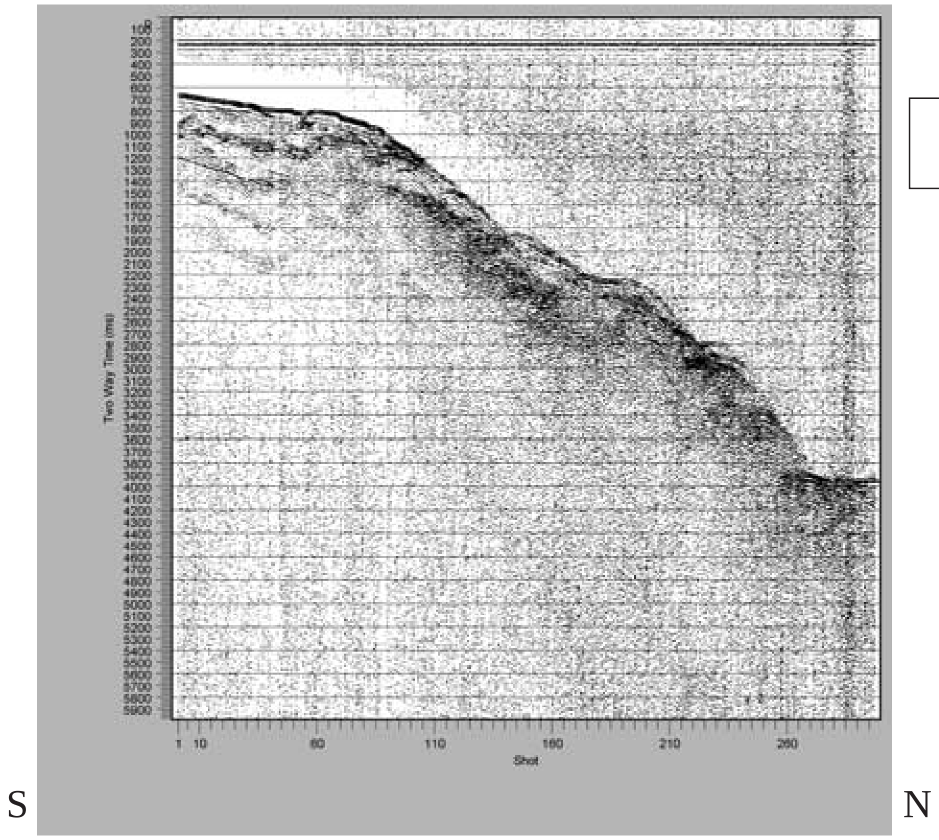


Fig. 3 (Line12)　Seismic profiles along the survey tracks.

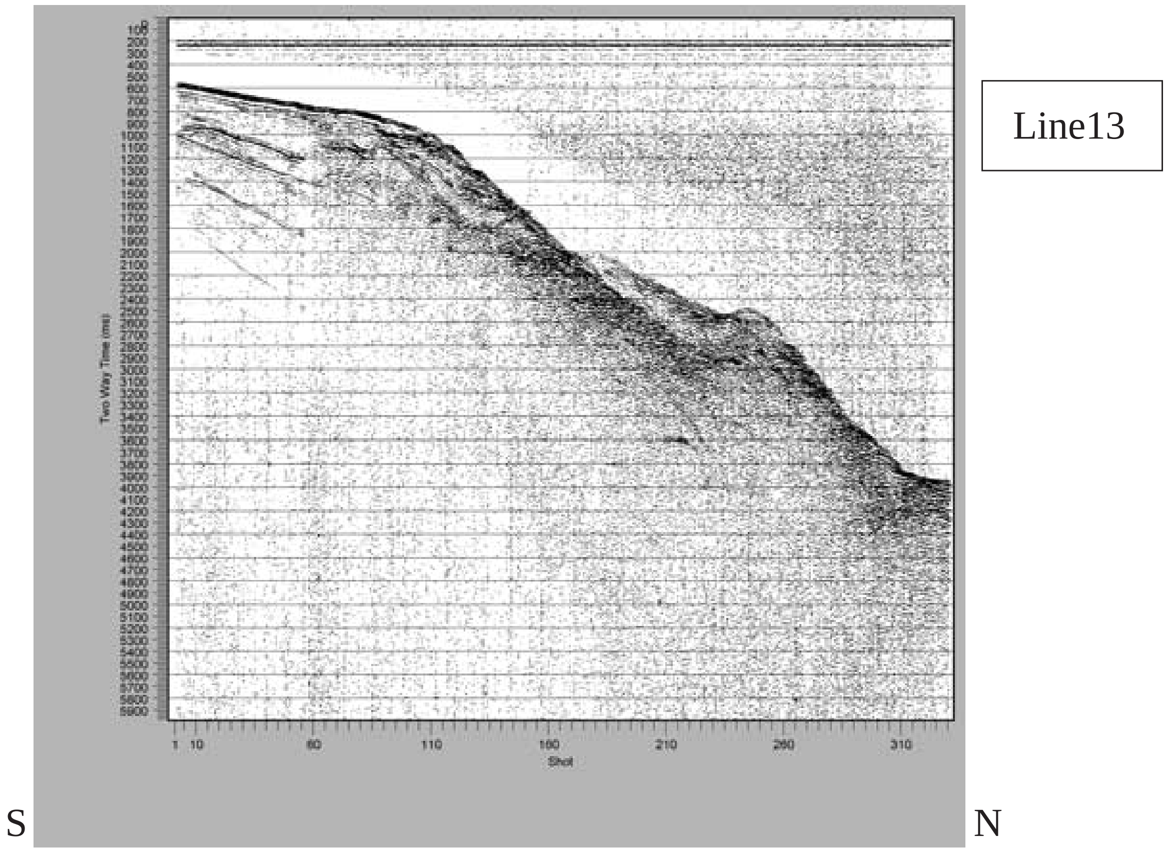


Fig. 3 (Line13)　Seismic profiles along the survey tracks.

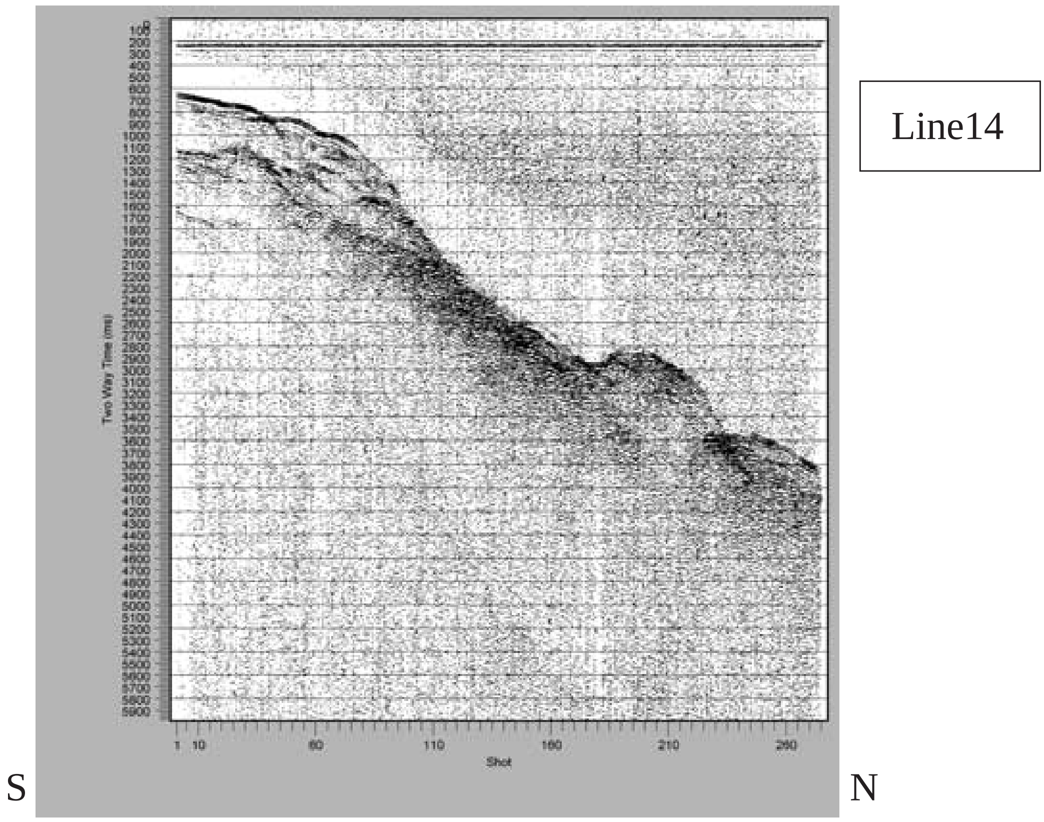


Fig. 3 (Line14)　Seismic profiles along the survey tracks.

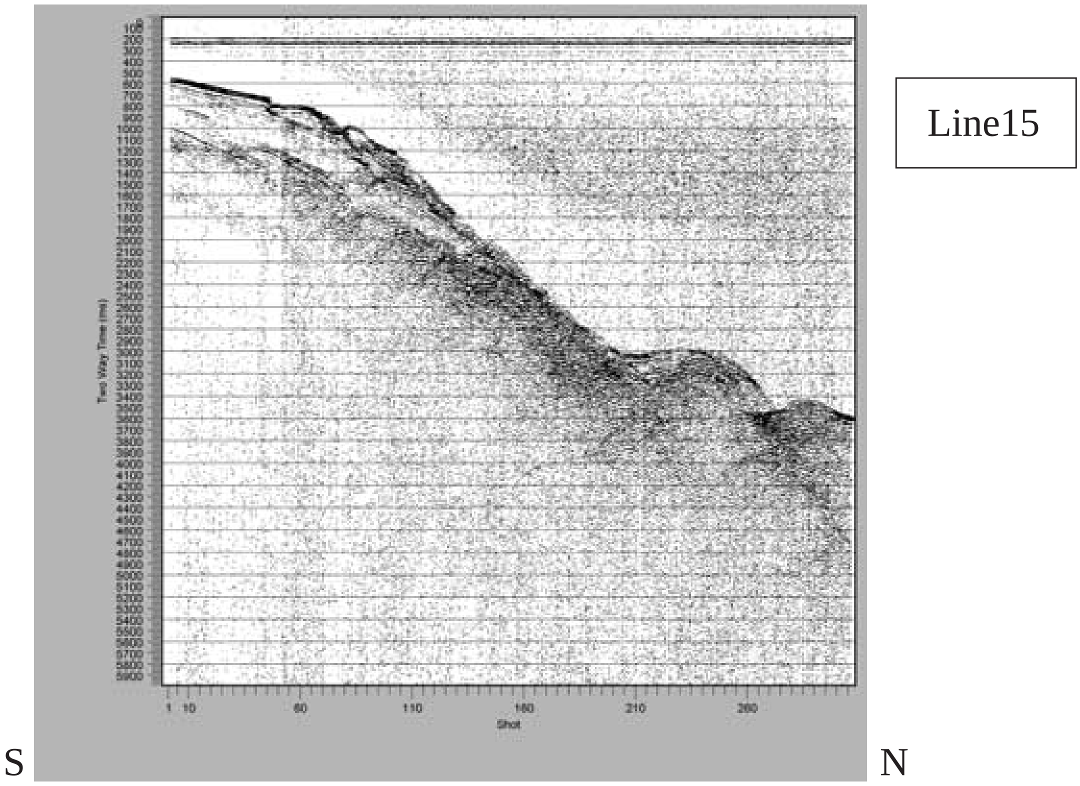


Fig. 3 (Line15)　Seismic profiles along the survey tracks.

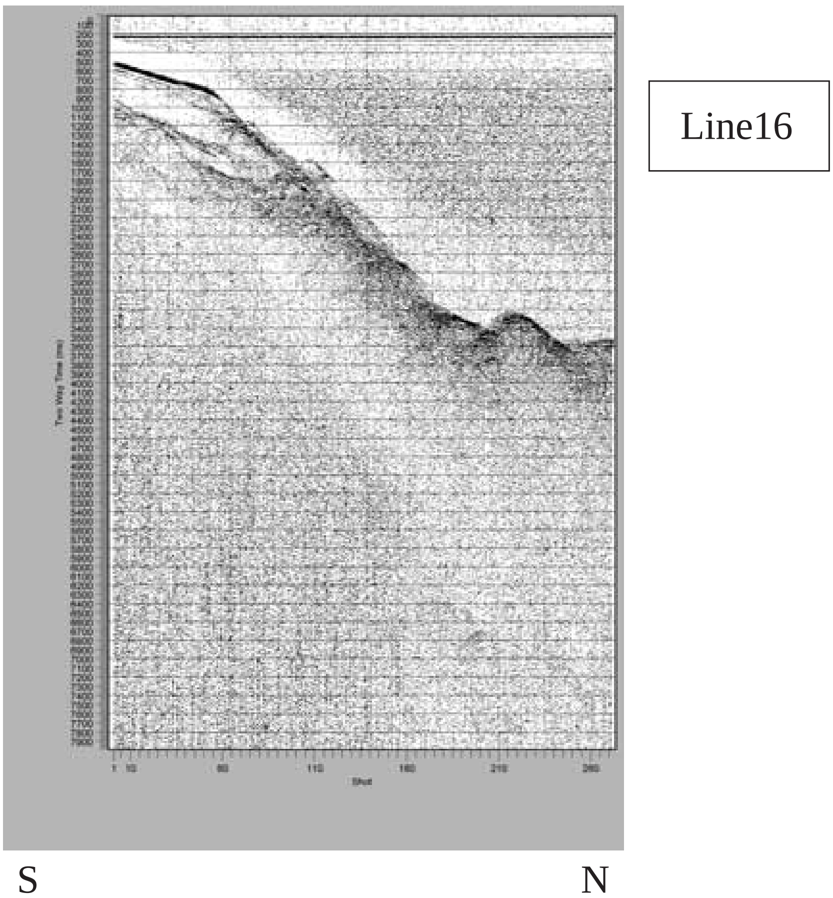


Fig. 3 (Line16)　Seismic profiles along the survey tracks.

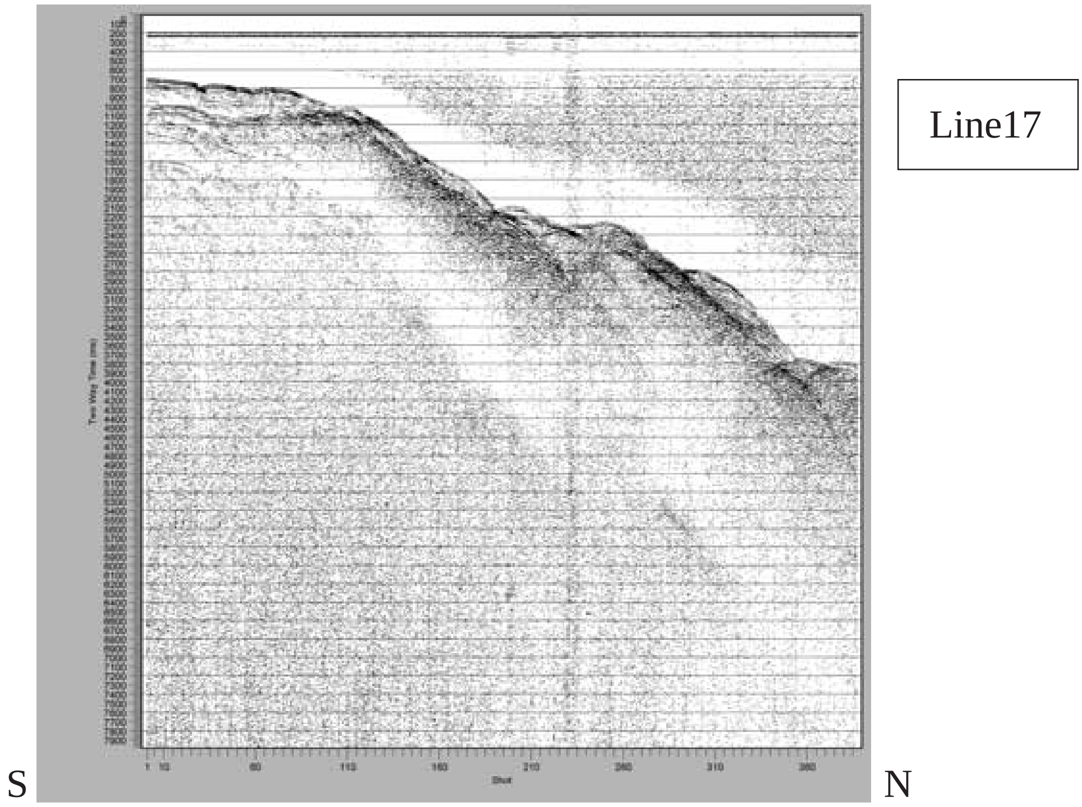


Fig. 3 (Line17)　Seismic profiles along the survey tracks.

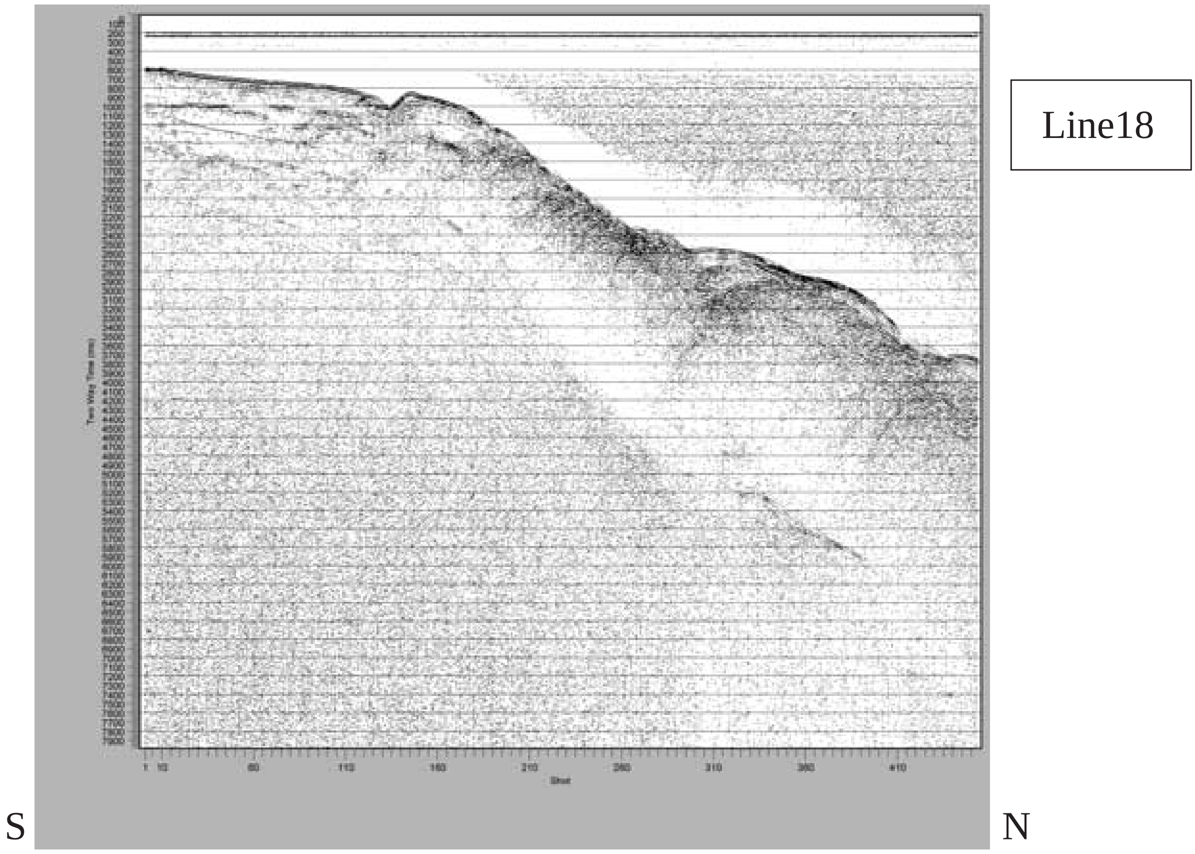


Fig. 3 (Line18)　Seismic profiles along the survey tracks.

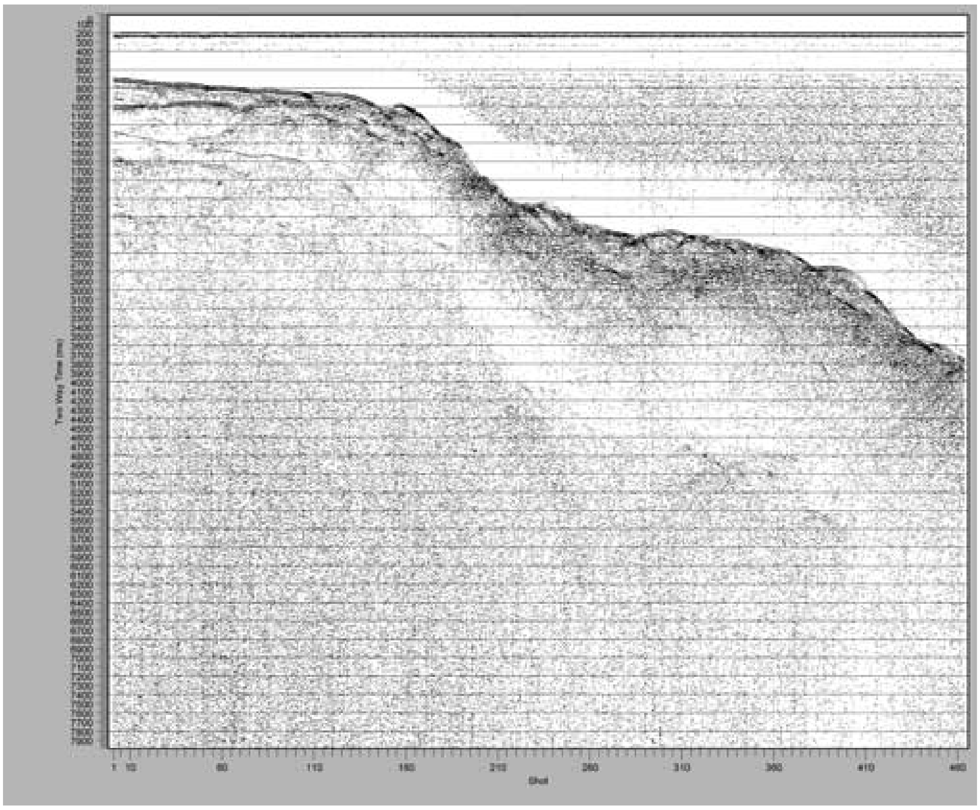


Fig. 3 (Line19)　Seismic profiles along the survey tracks.

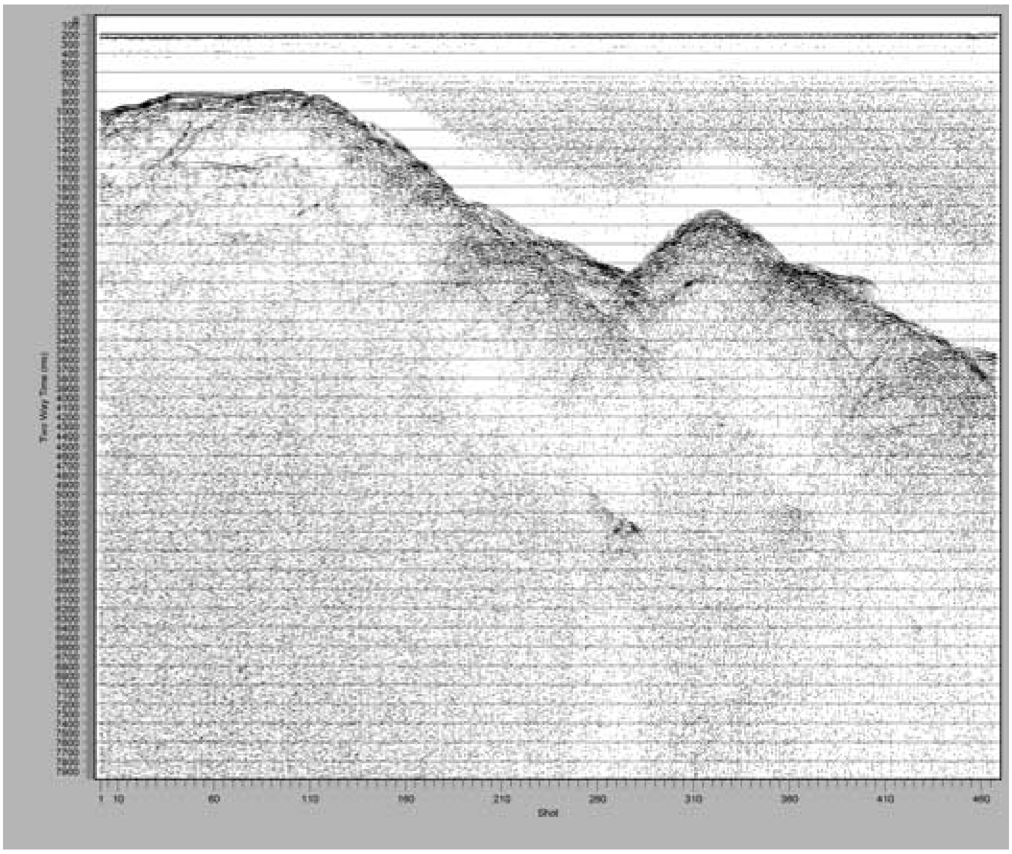


Fig. 3 (Line20)　Seismic profiles along the survey tracks.

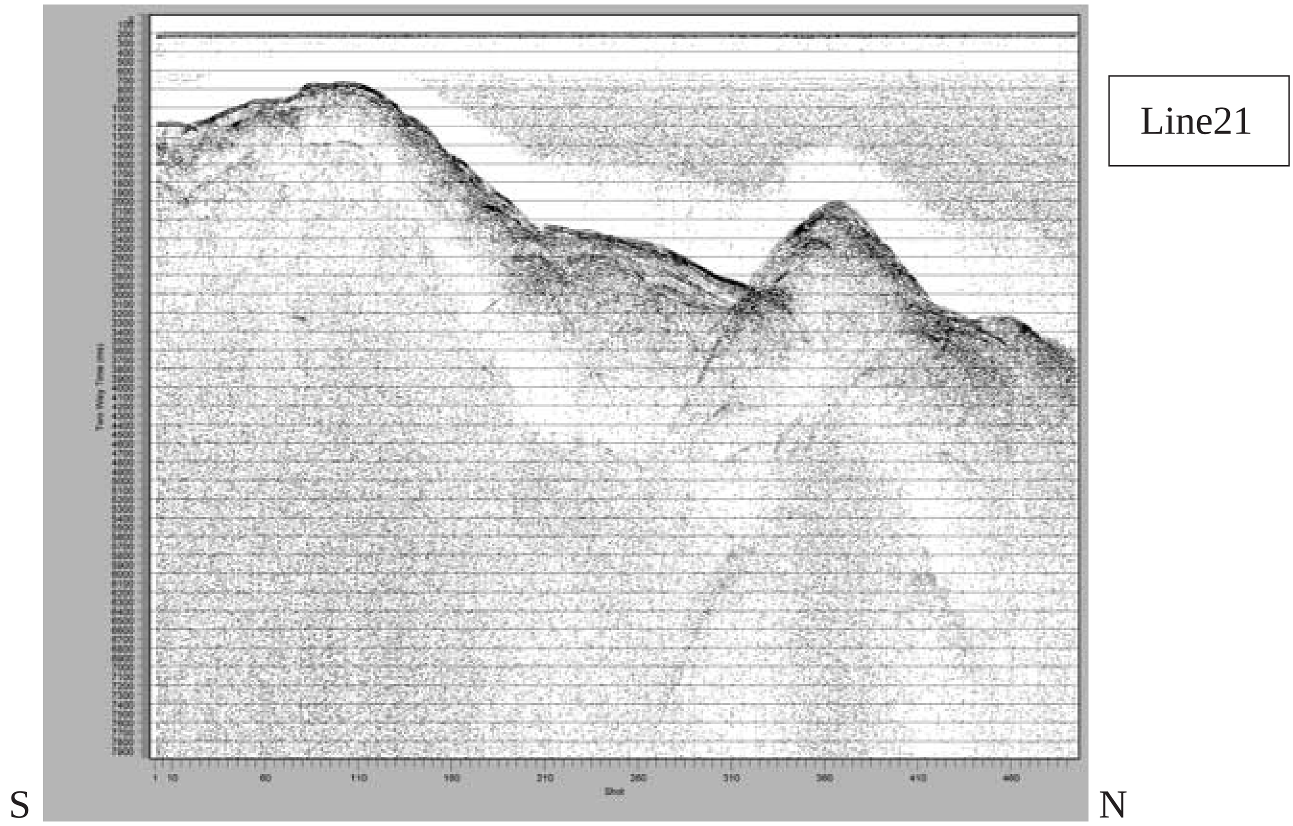


Fig. 3 (Line21)　Seismic profiles along the survey tracks.

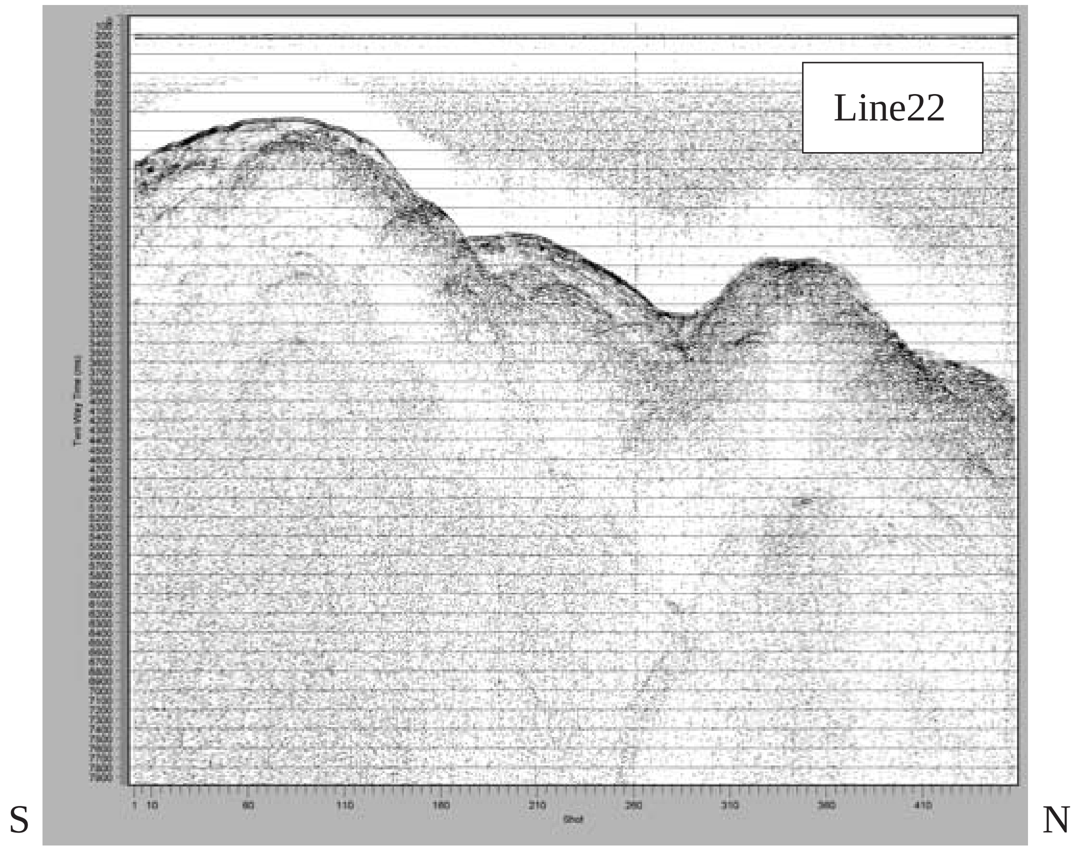


Fig. 3 (Line22)　Seismic profiles along the survey tracks.

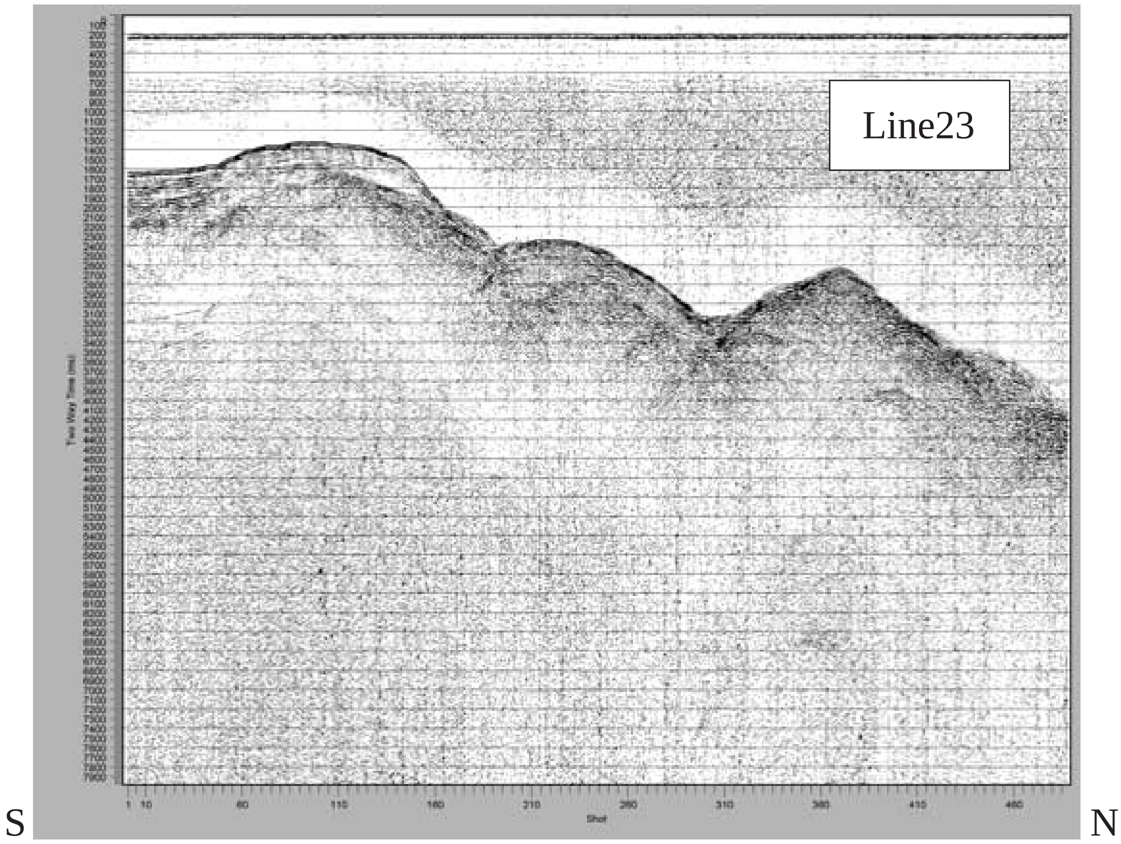


Fig. 3 (Line23)　Seismic profiles along the survey tracks.

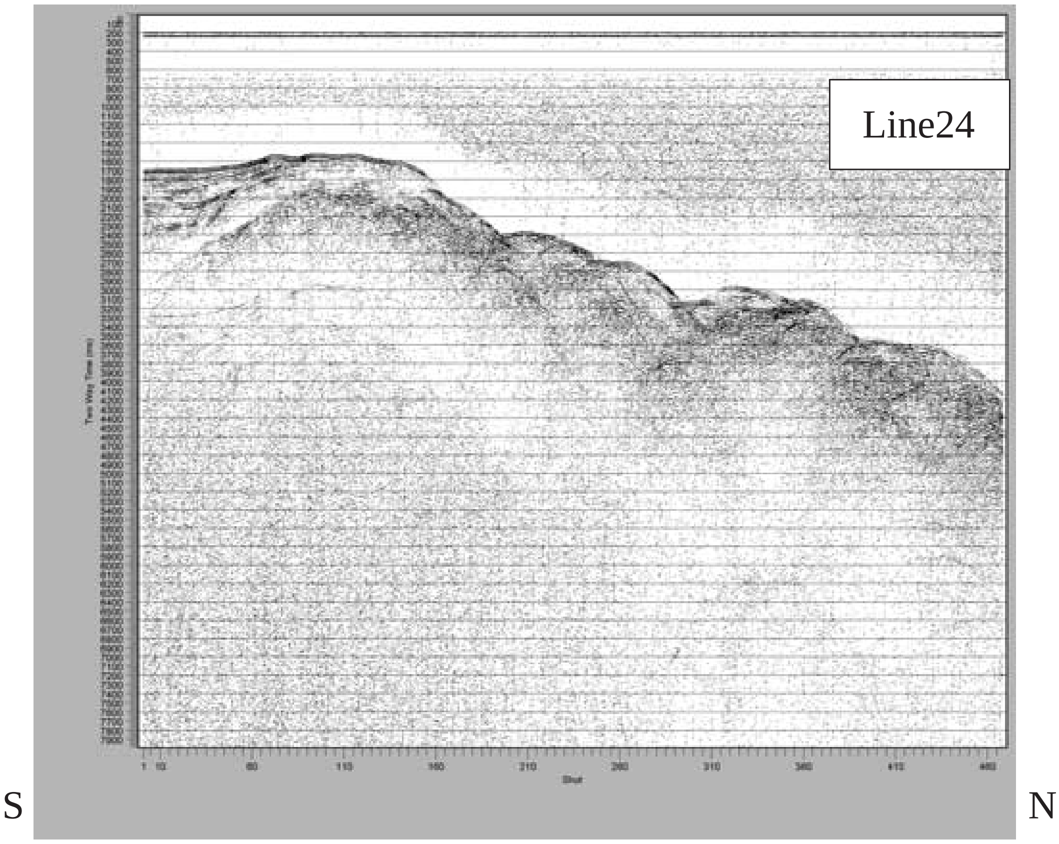


Fig. 3 (Line24)　Seismic profiles along the survey tracks.

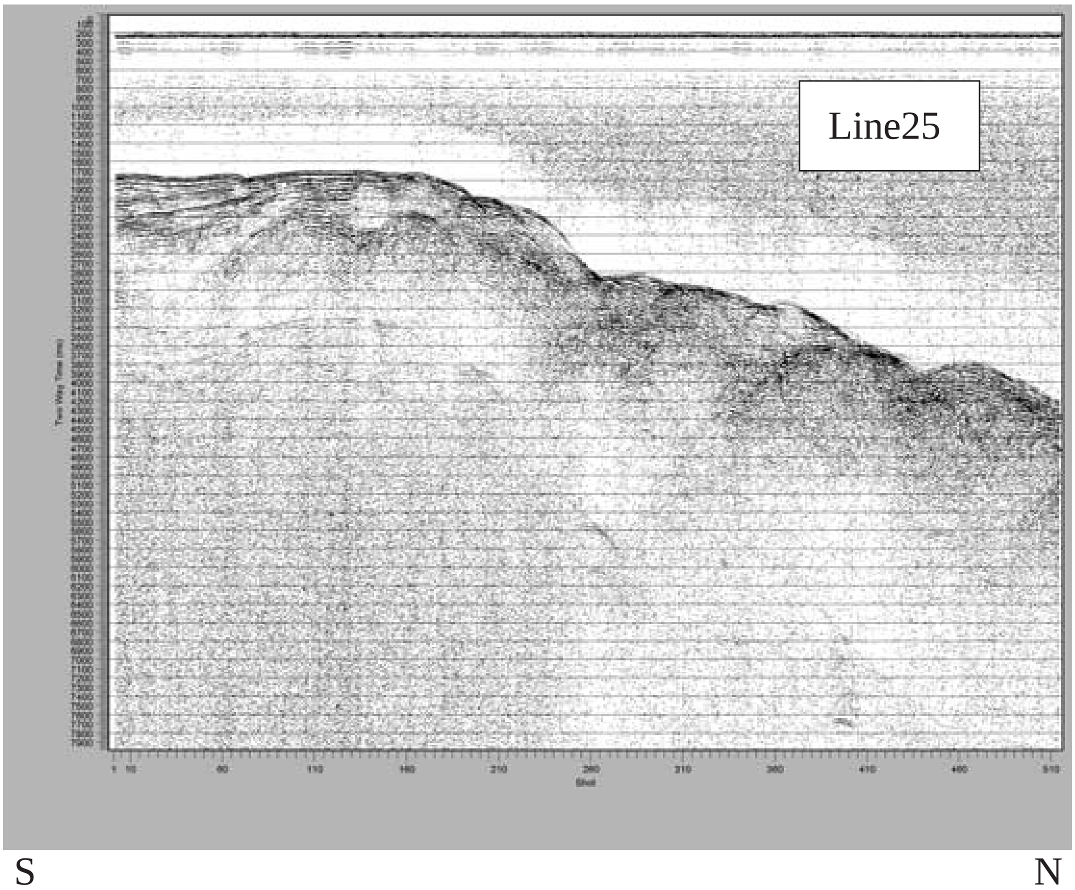


Fig. 3 (Line25)　Seismic profiles along the survey tracks.

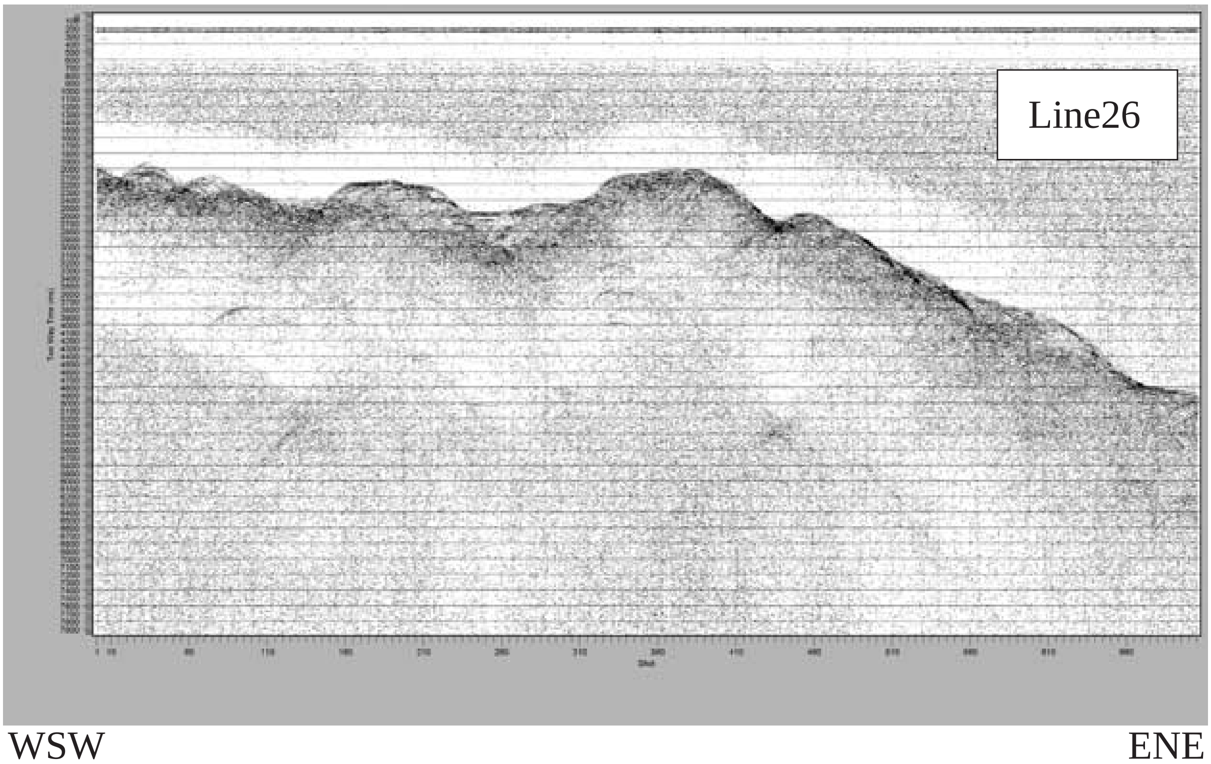


Fig. 3 (Line26)　Seismic profiles along the survey tracks.

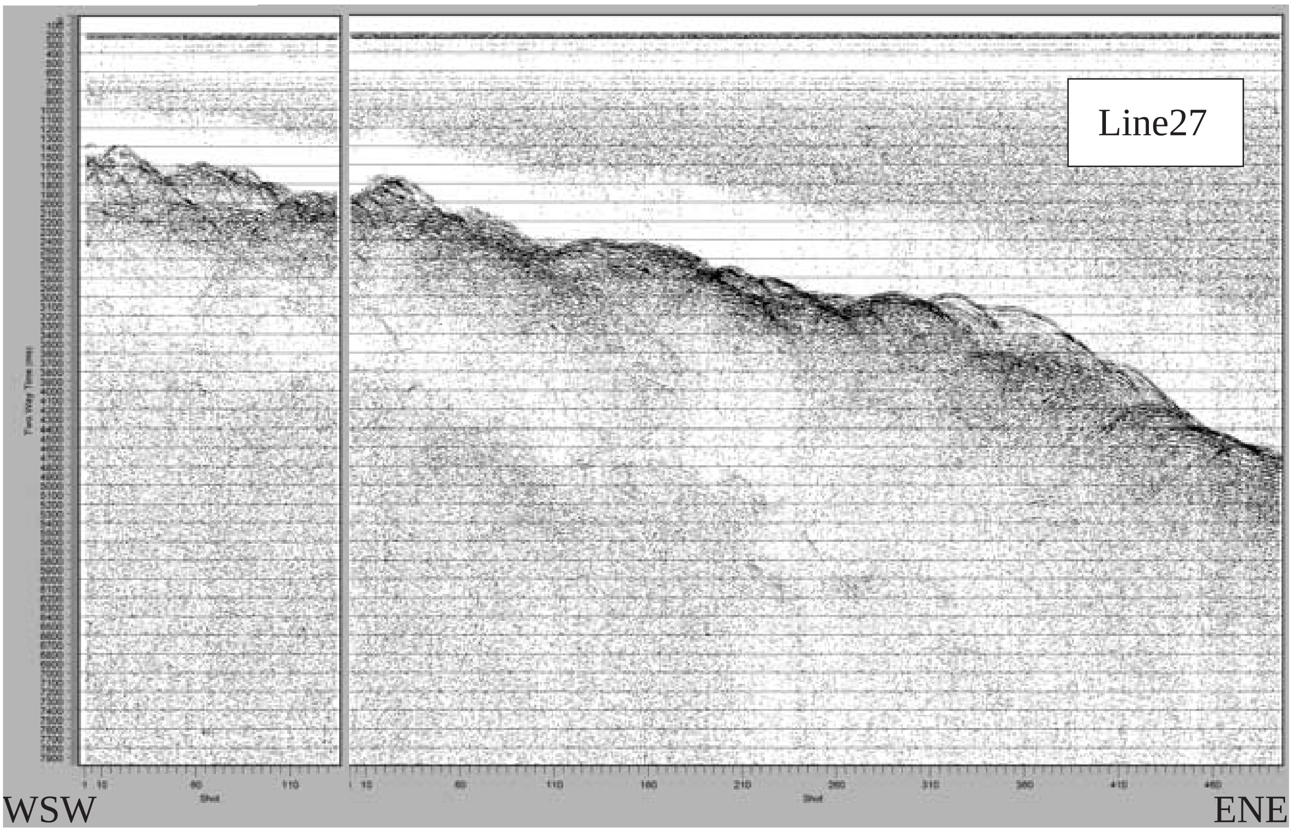


Fig. 3 (Line27)　Seismic profiles along the survey tracks.

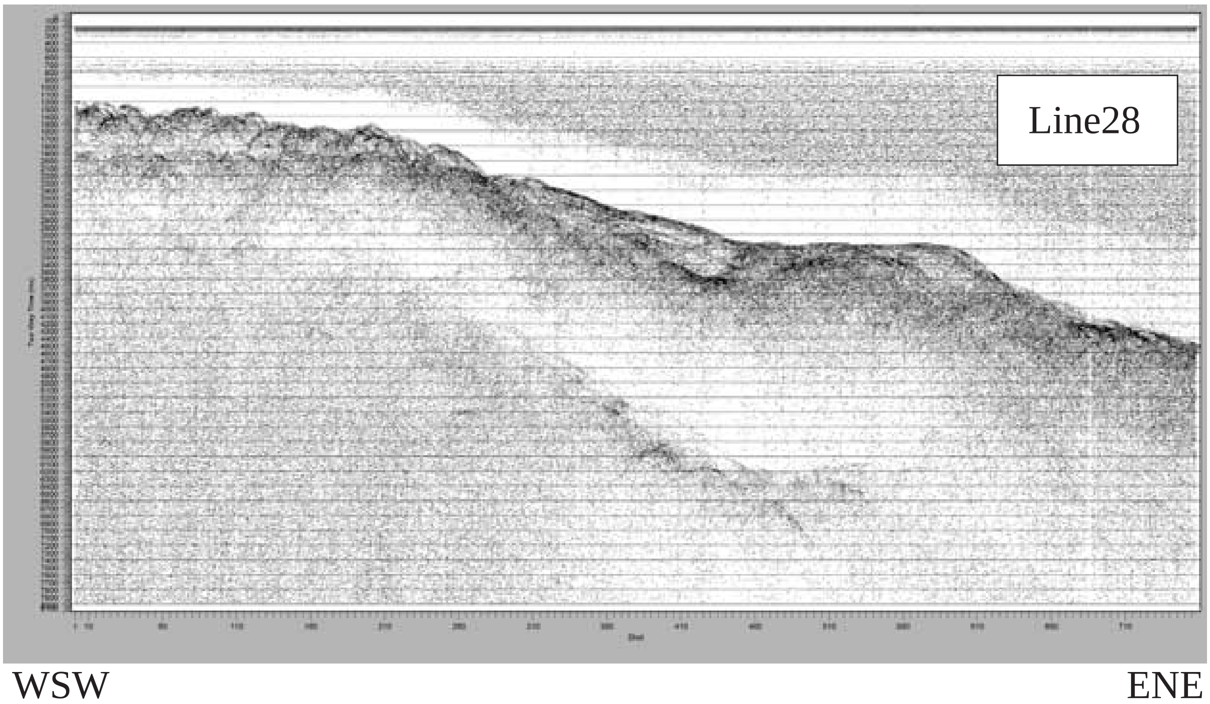
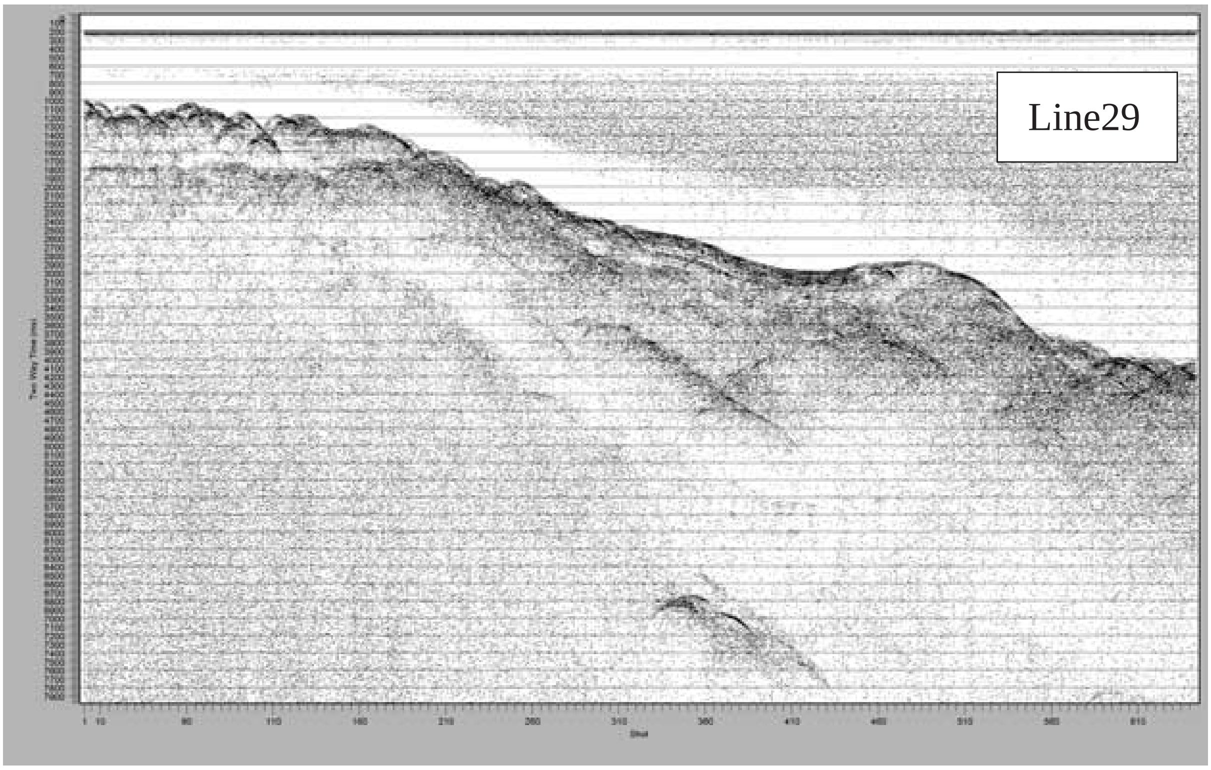
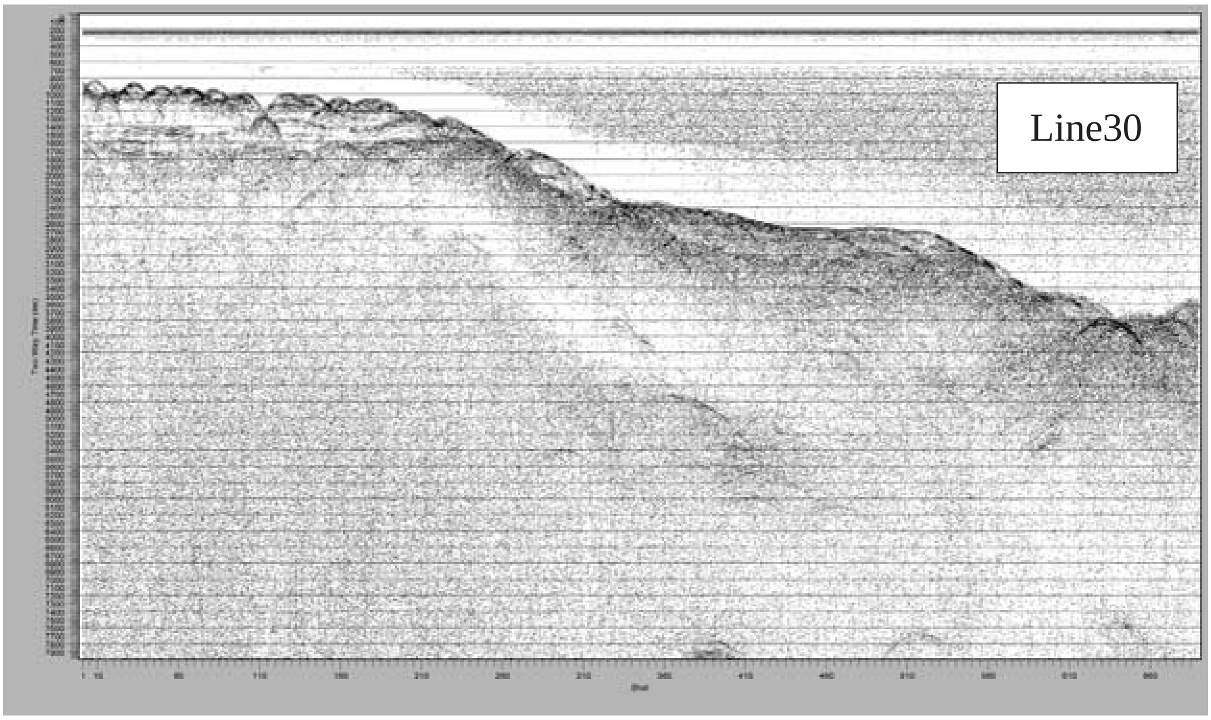


Fig. 3 (Line28)　Seismic profiles along the survey tracks.



WSW ENE

Fig. 3 (Line29)　Seismic profiles along the survey tracks.



WSW ENE

Fig. 3 (Line30)　Seismic profiles along the survey tracks.

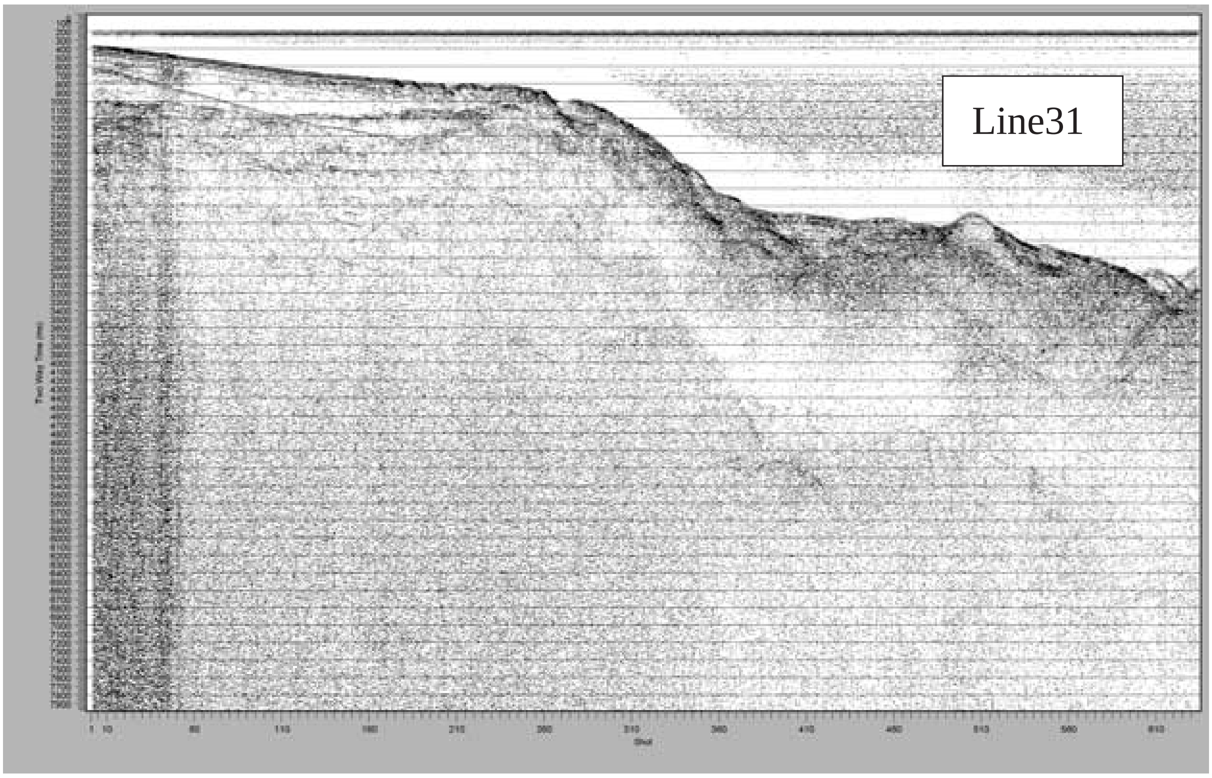


Fig. 3 (Line31)　Seismic profiles along the survey tracks.

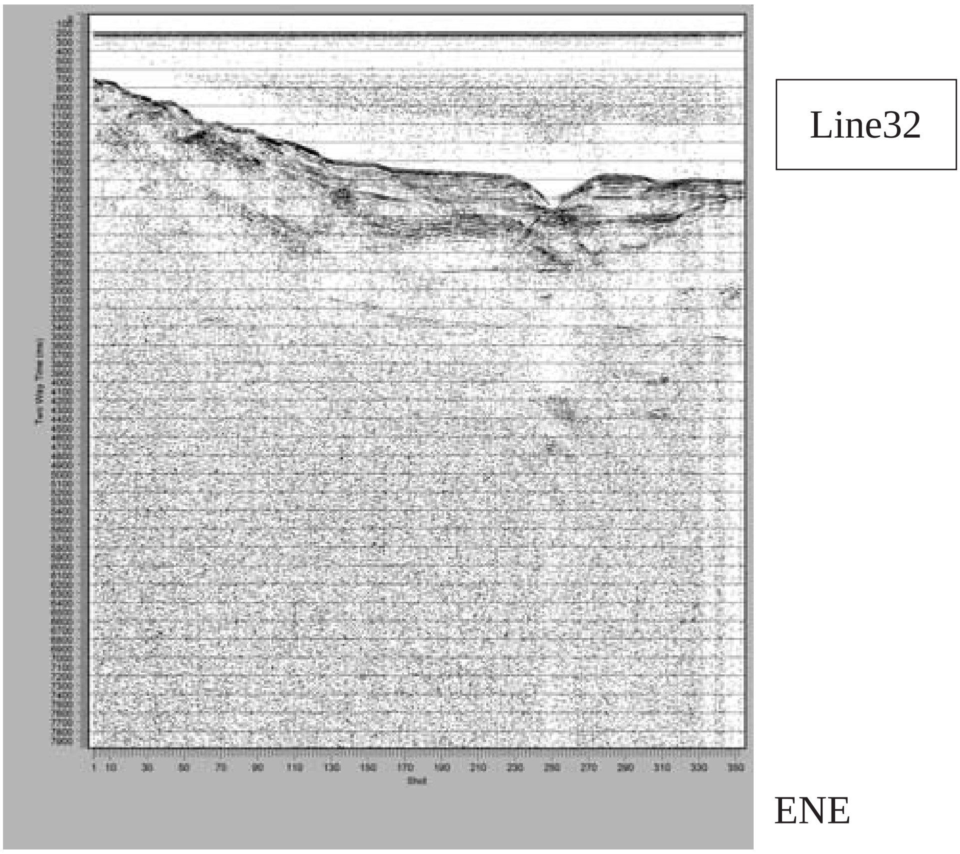


Fig. 3 (Line32)　Seismic profiles along the survey tracks.

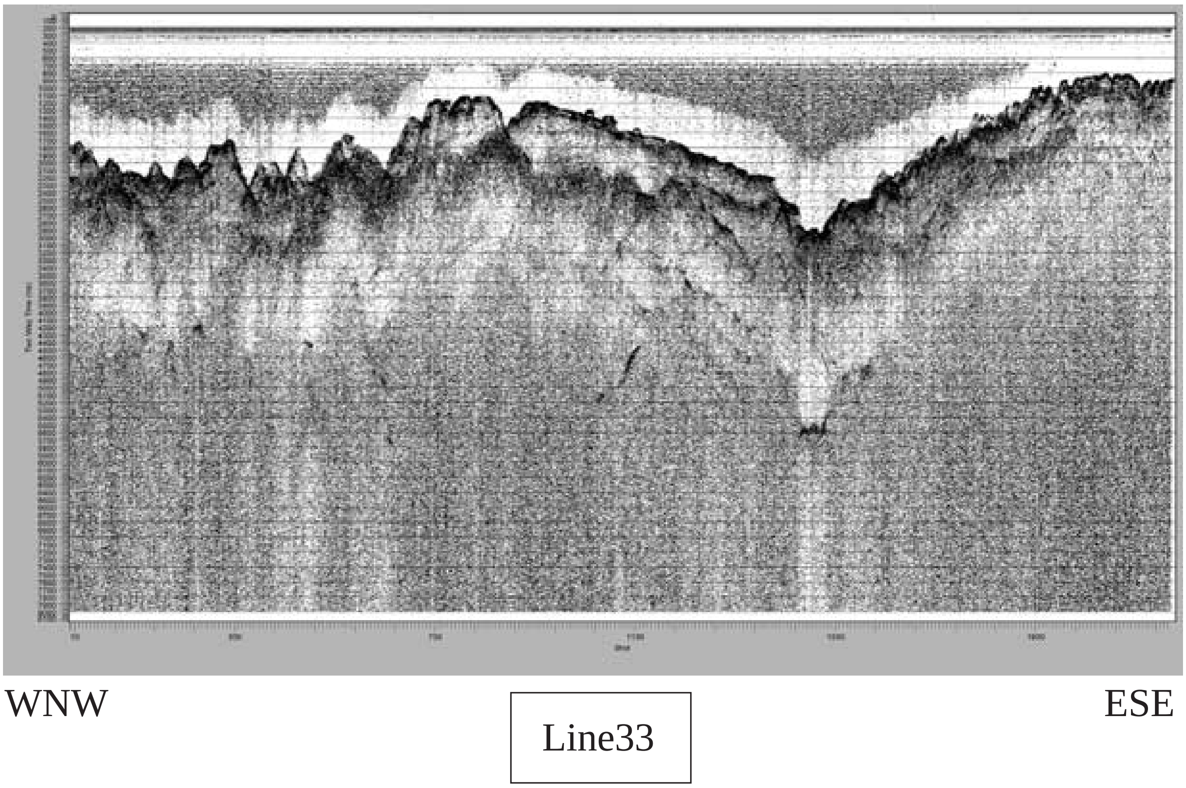


Fig. 3 (Line33)　Seismic profiles along the survey tracks.

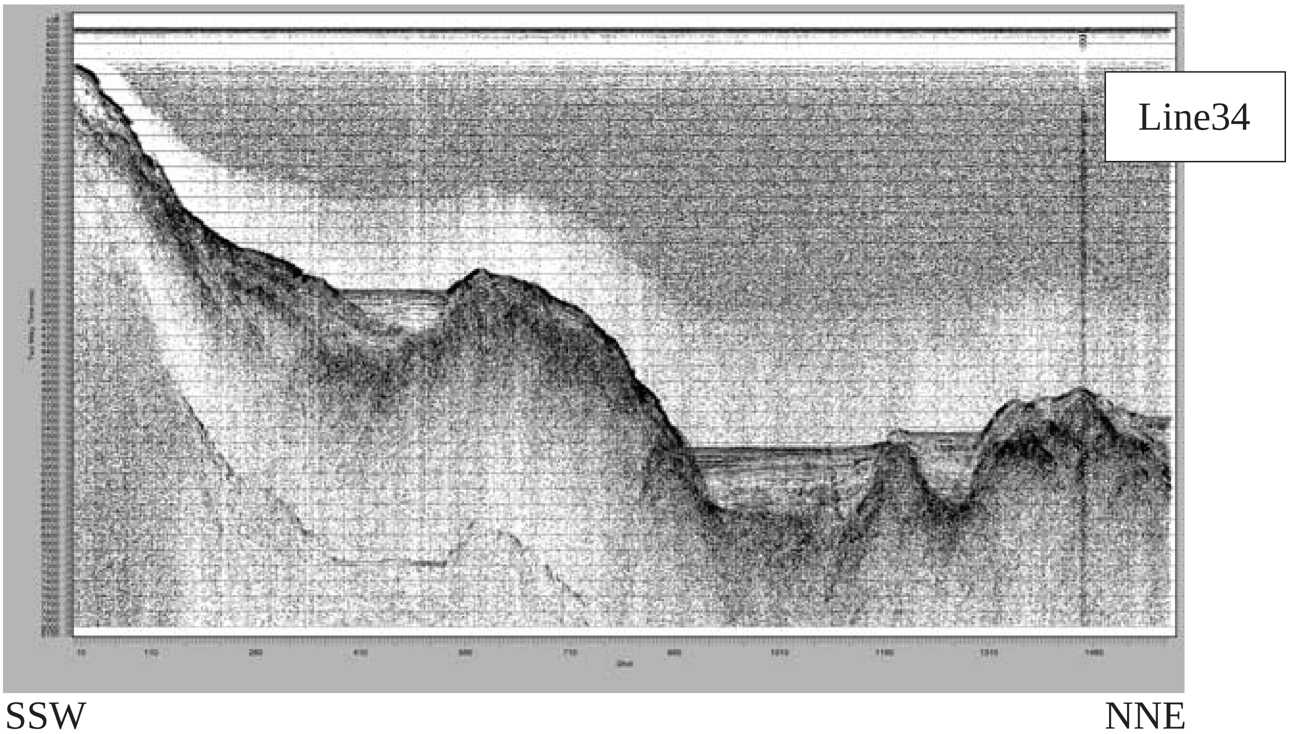


Fig. 3 (Line34)　Seismic profiles along the survey tracks.

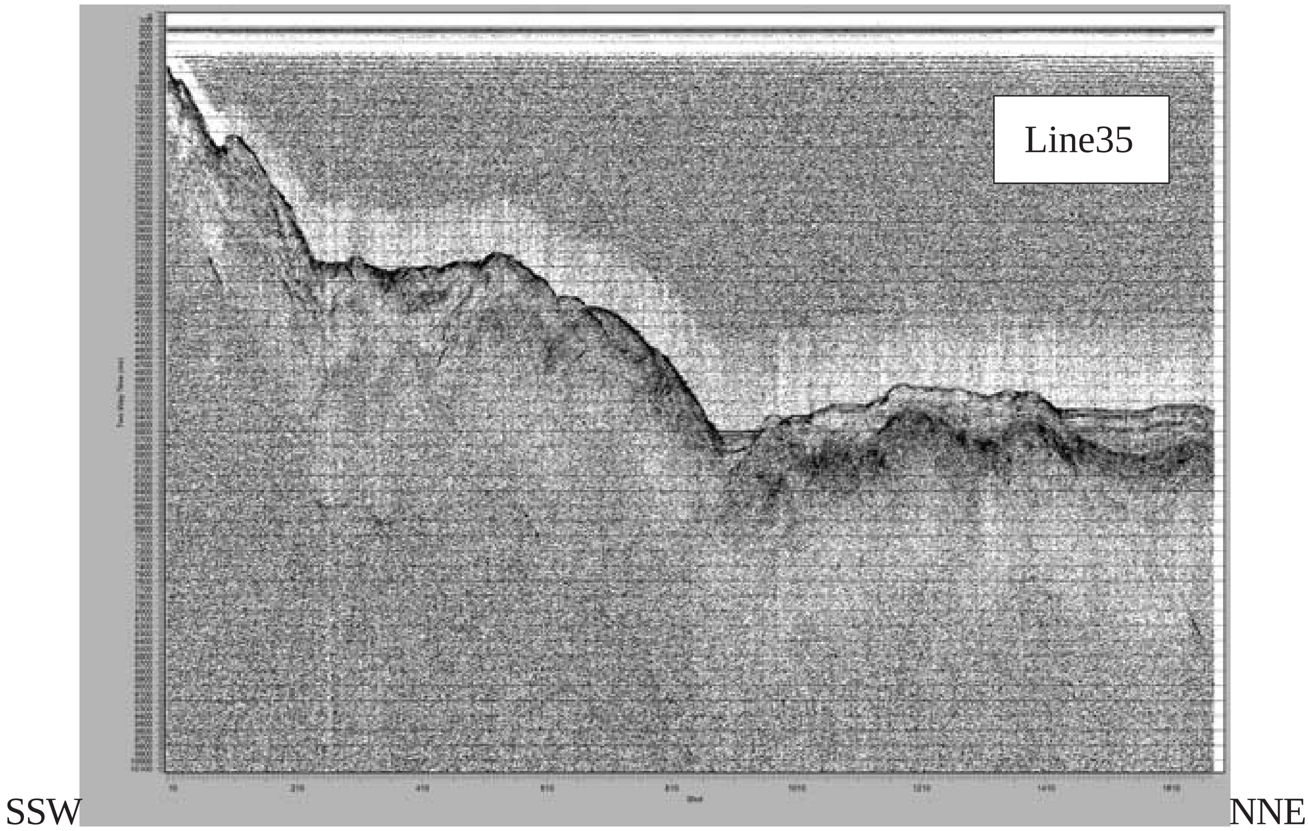


Fig. 3 (Line35)　Seismic profiles along the survey tracks.

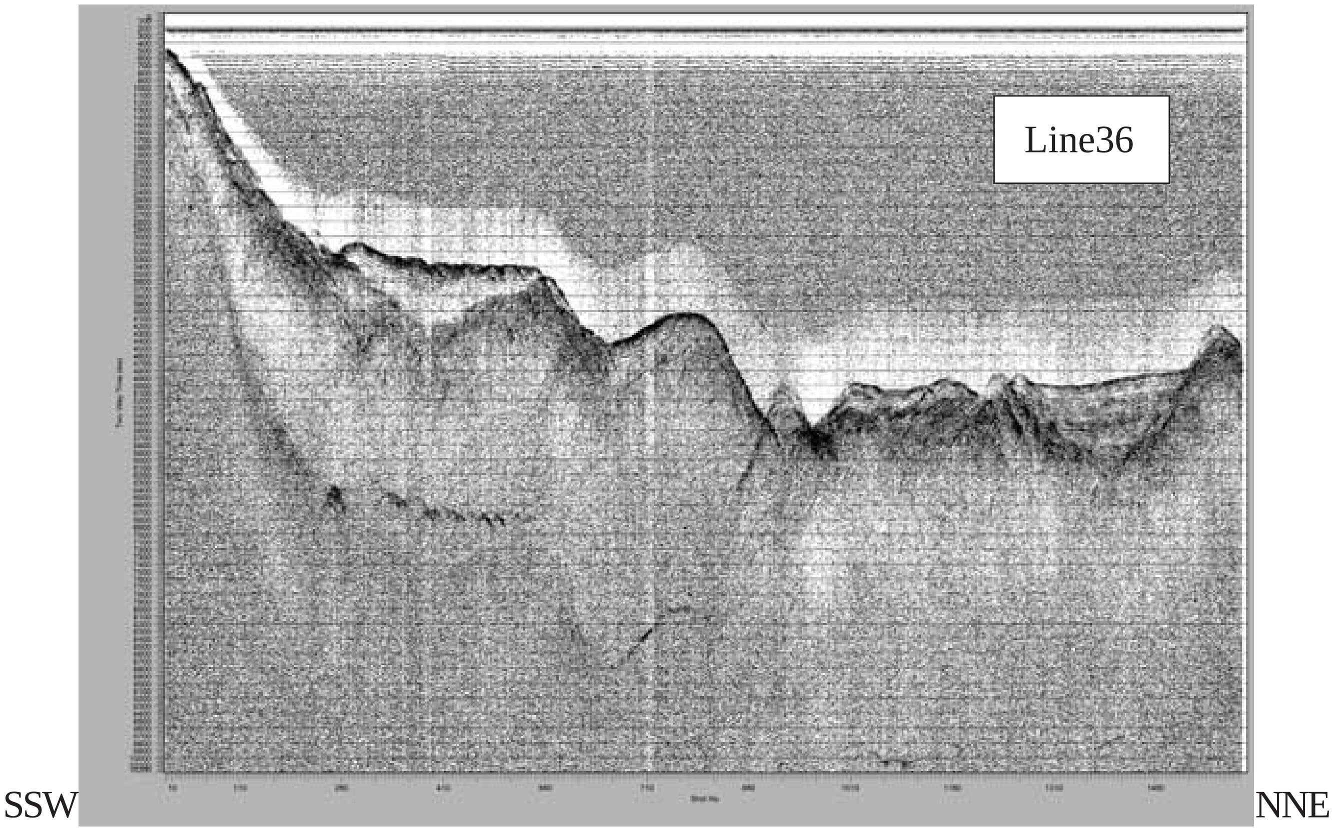


Fig. 3 (Line36)　Seismic profiles along the survey tracks.

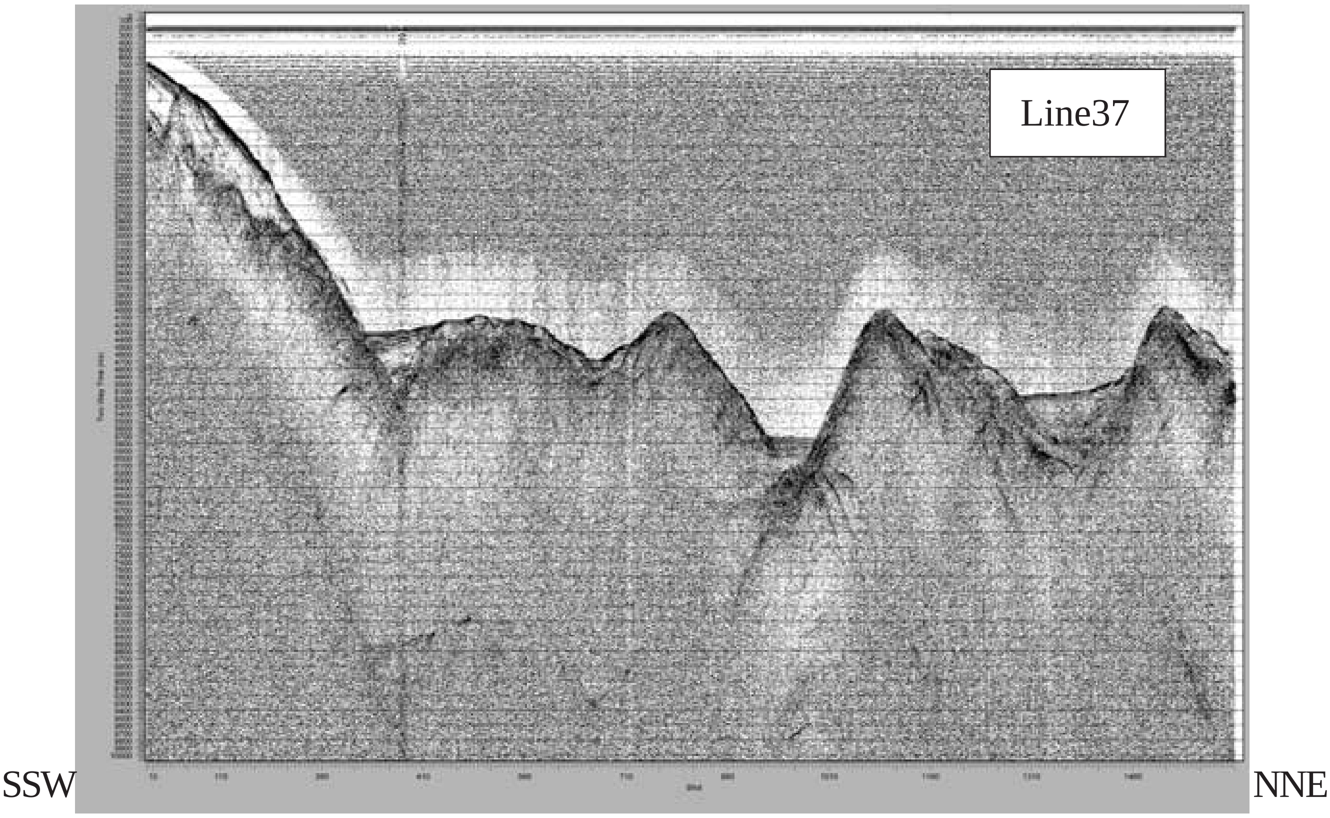


Fig. 3 (Line37)　Seismic profiles along the survey tracks.

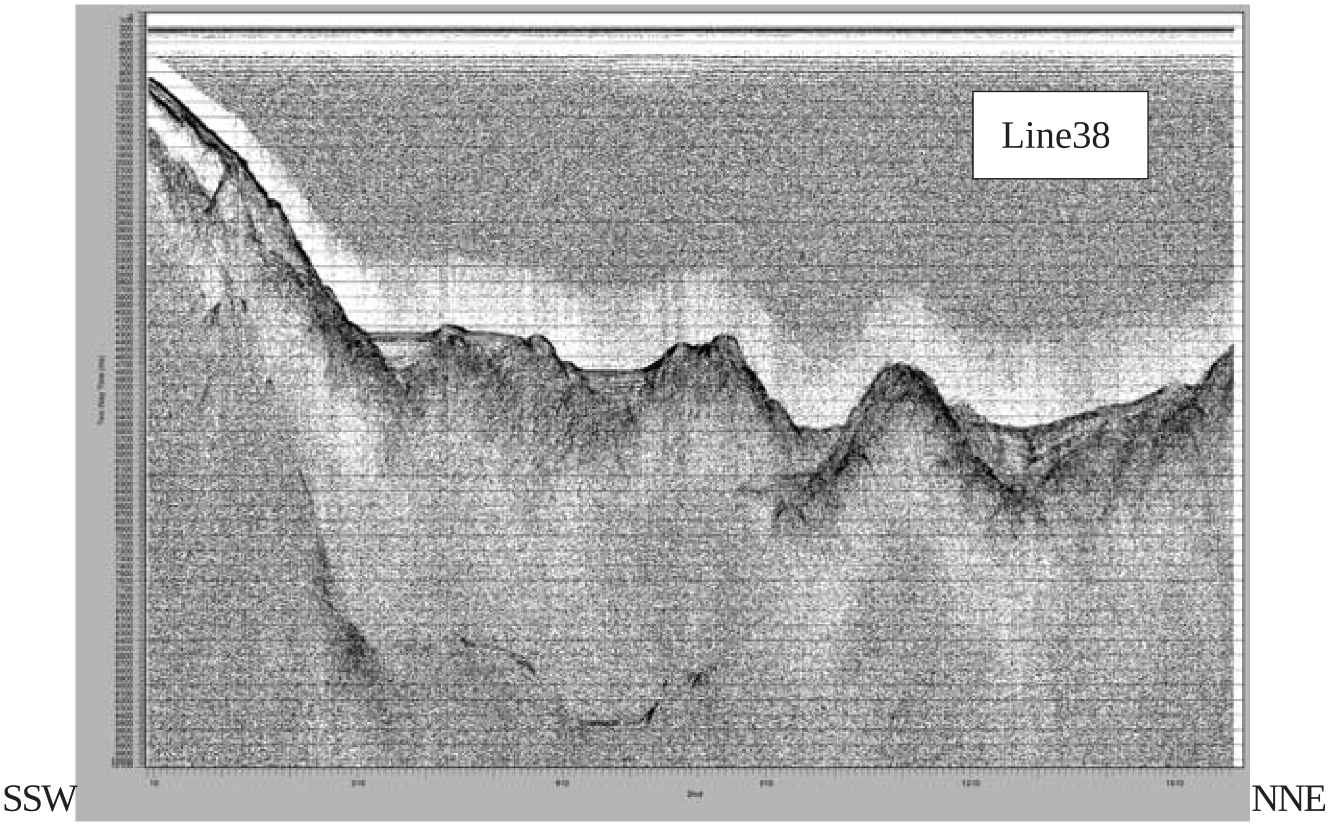


Fig. 3 (Line38)　Seismic profiles along the survey tracks.

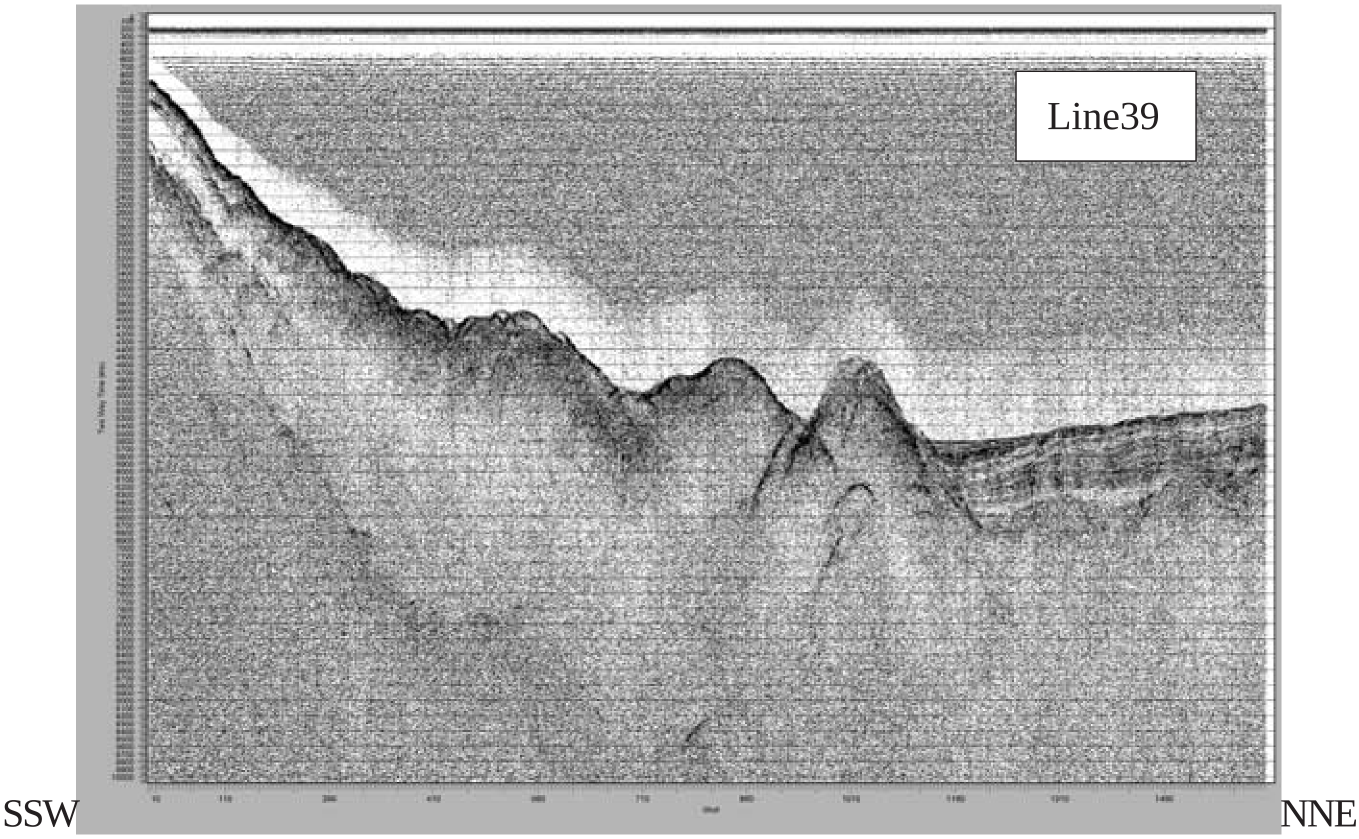


Fig. 3 (Line39)　Seismic profiles along the survey tracks.

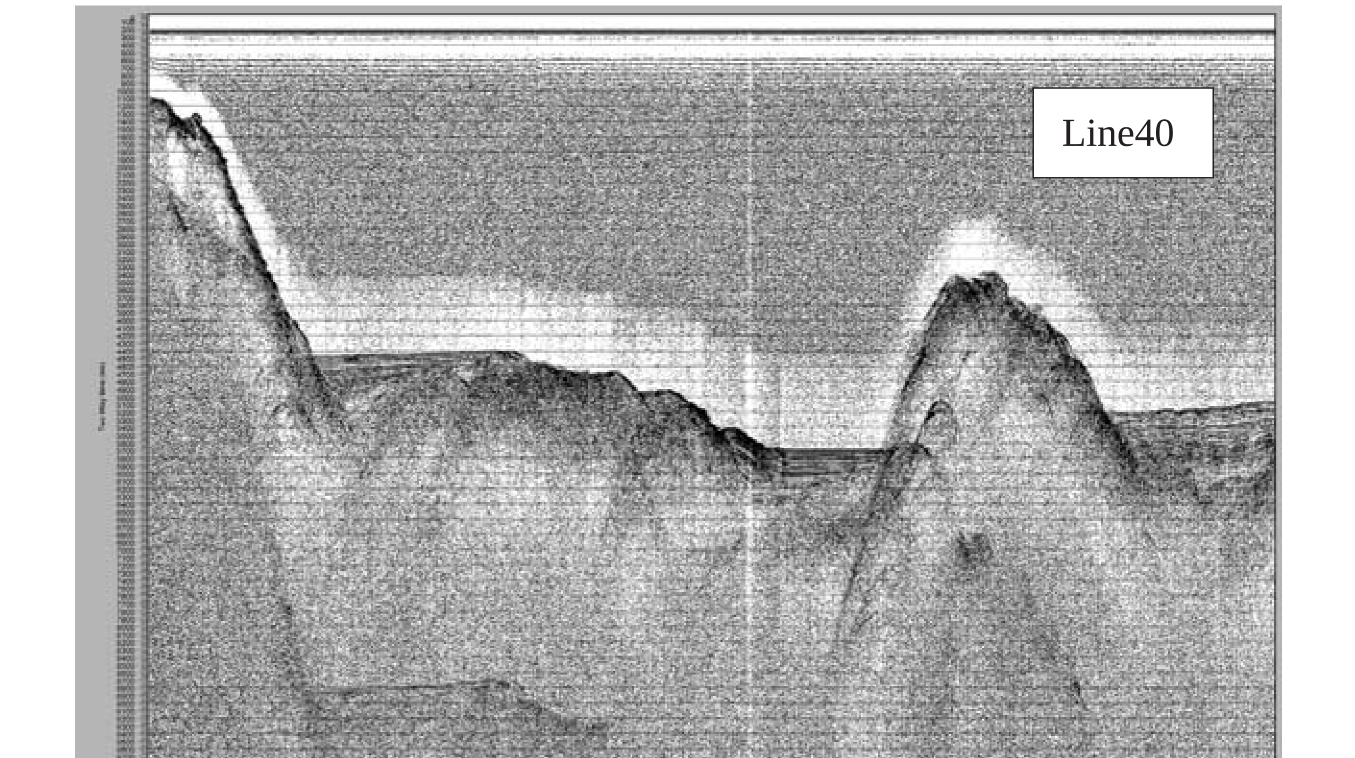


Fig. 3 (Line40)　Seismic profiles along the survey tracks.

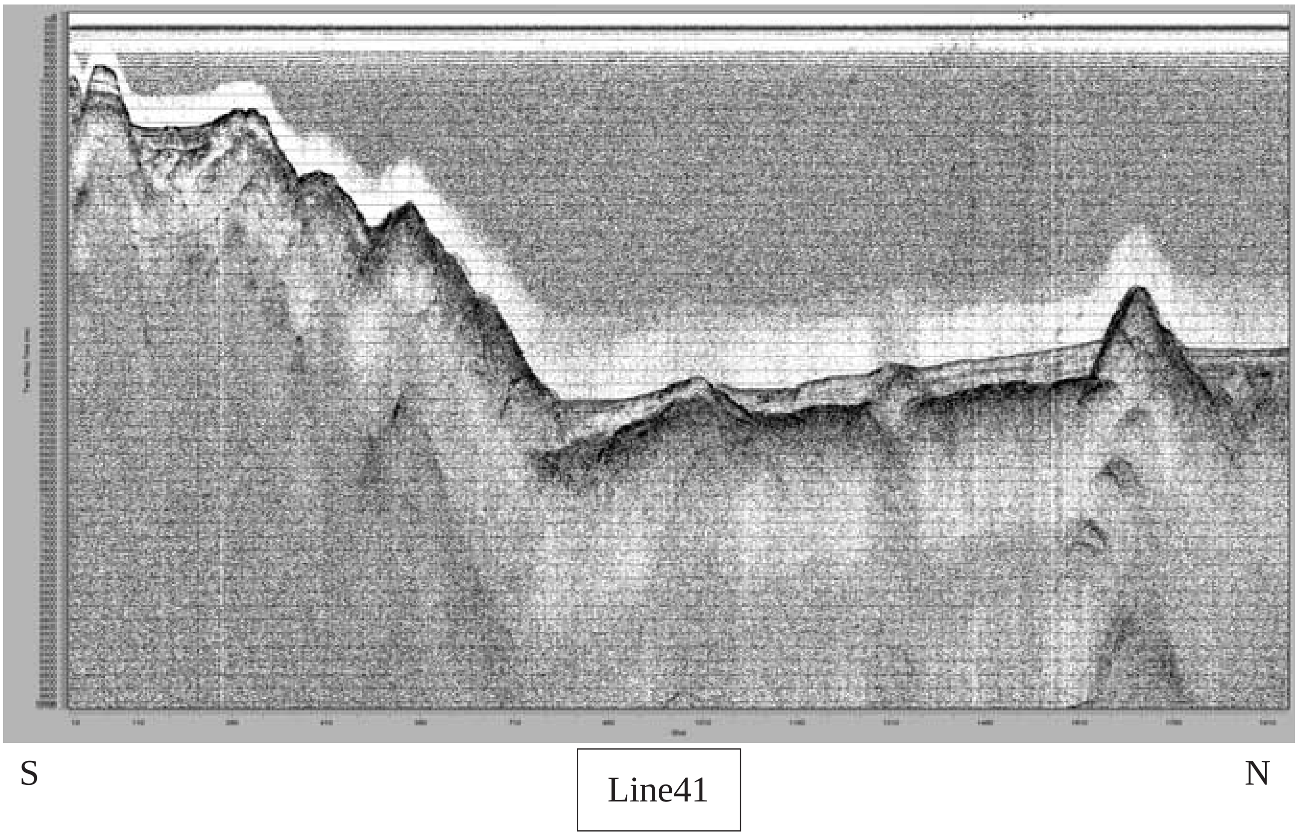


Fig. 3 (Line41)　Seismic profiles along the survey tracks.

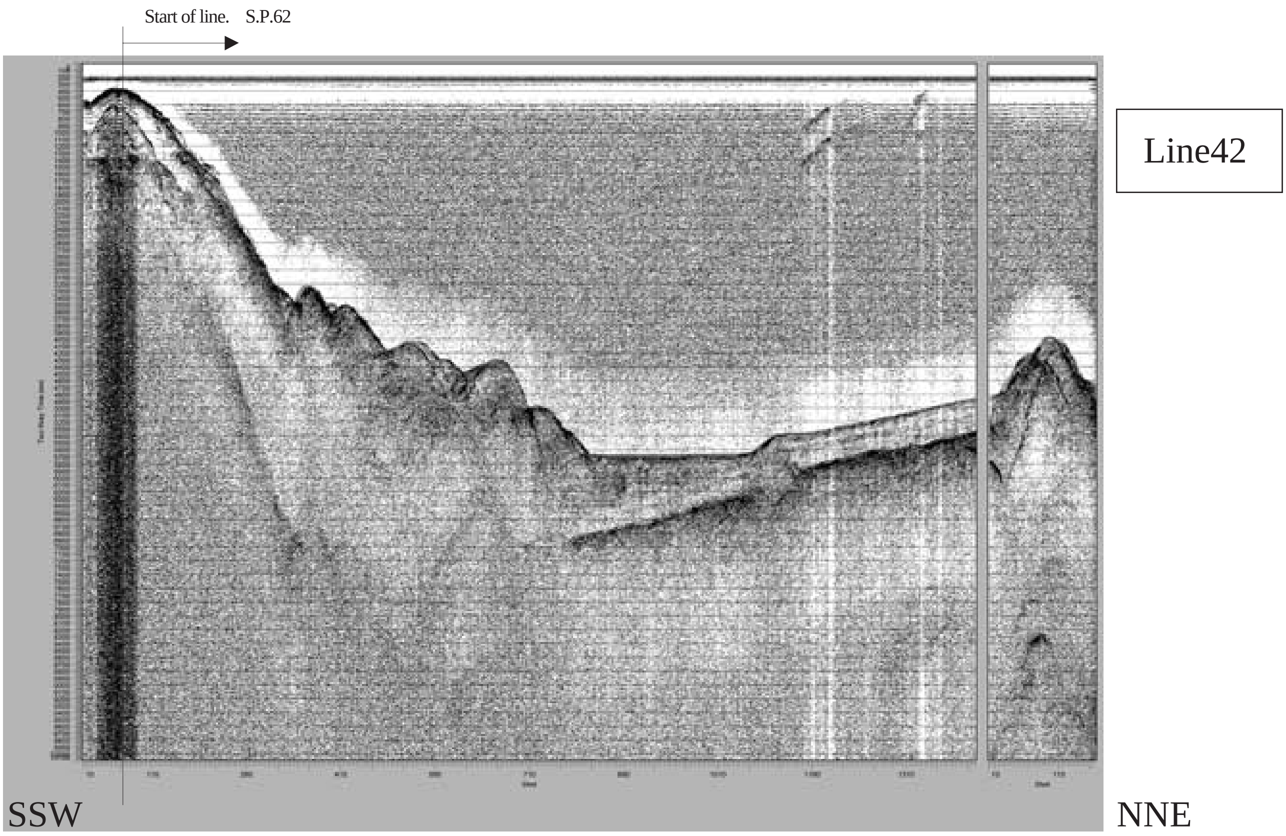


Fig. 3 (Line42)　Seismic profiles along the survey tracks.

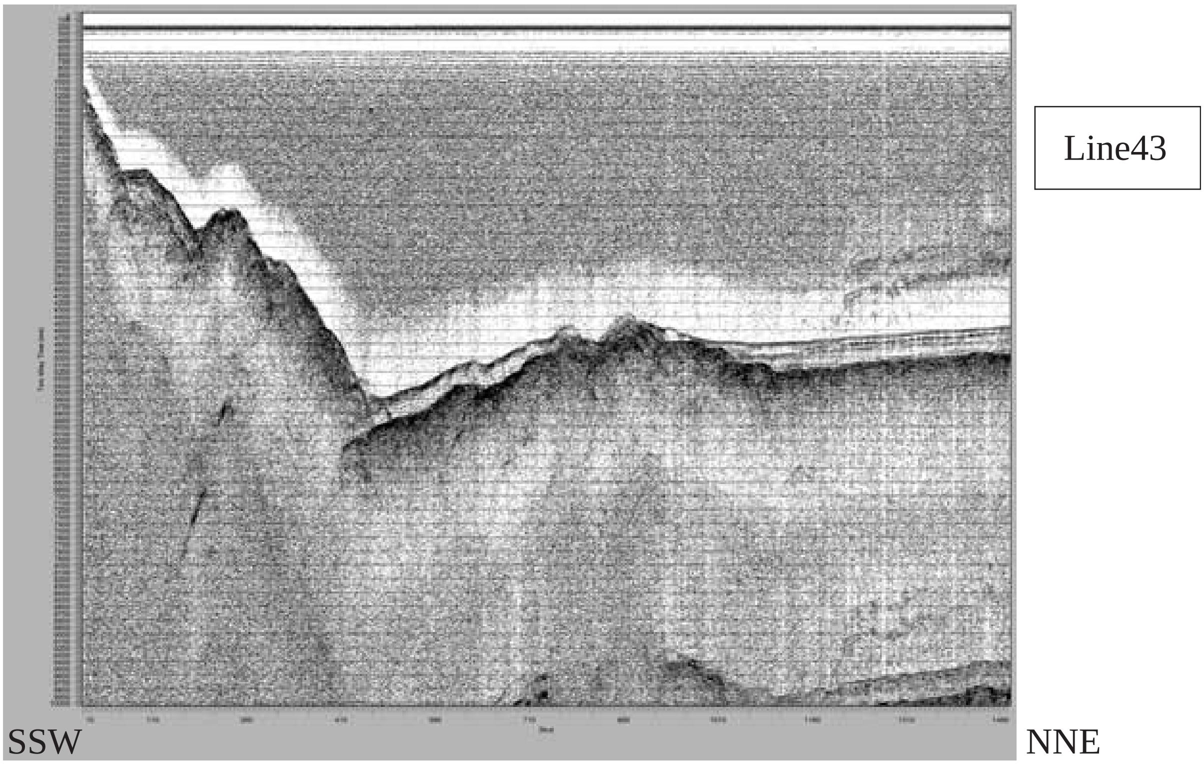


Fig. 3 (Line43) Seismic profiles along the survey tracks.

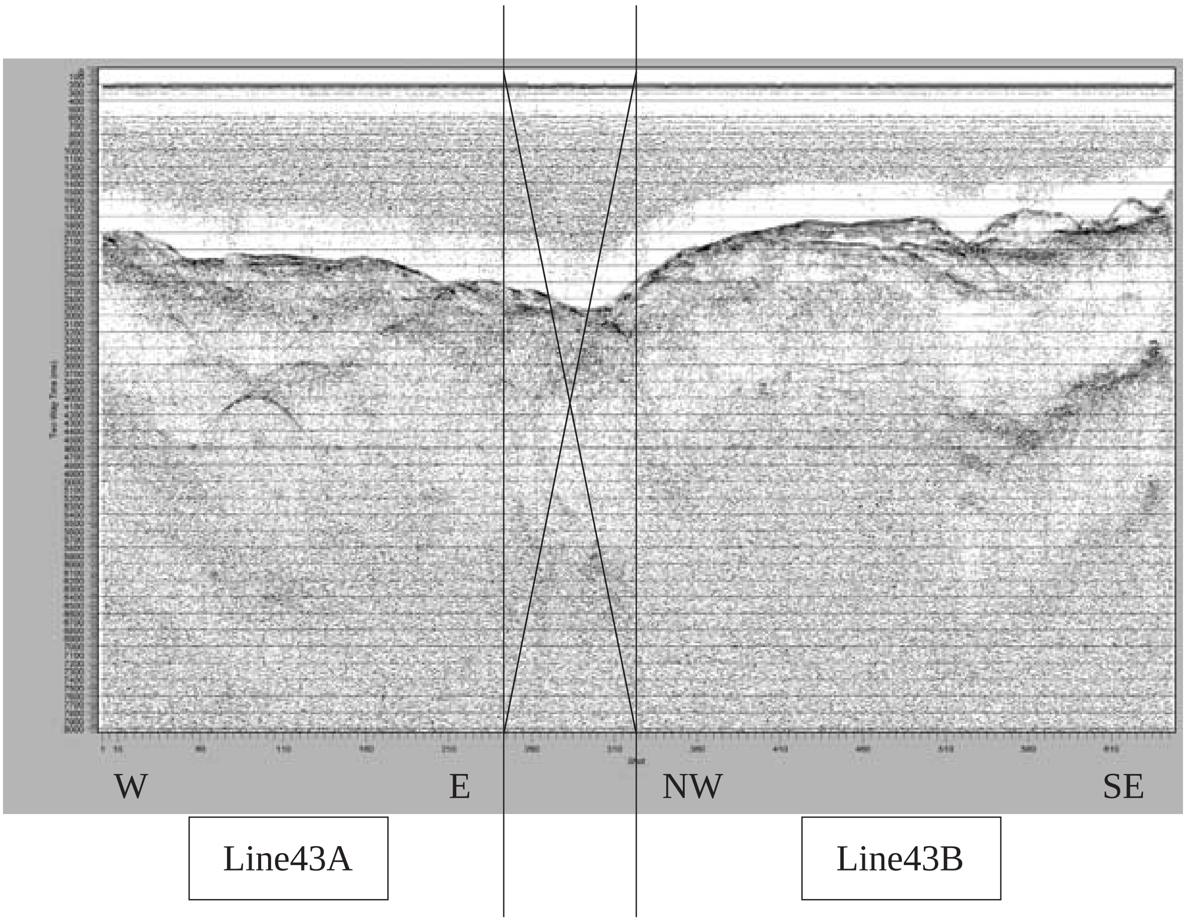


Fig. 3 (Line43AB) Seismic profiles along the survey tracks.

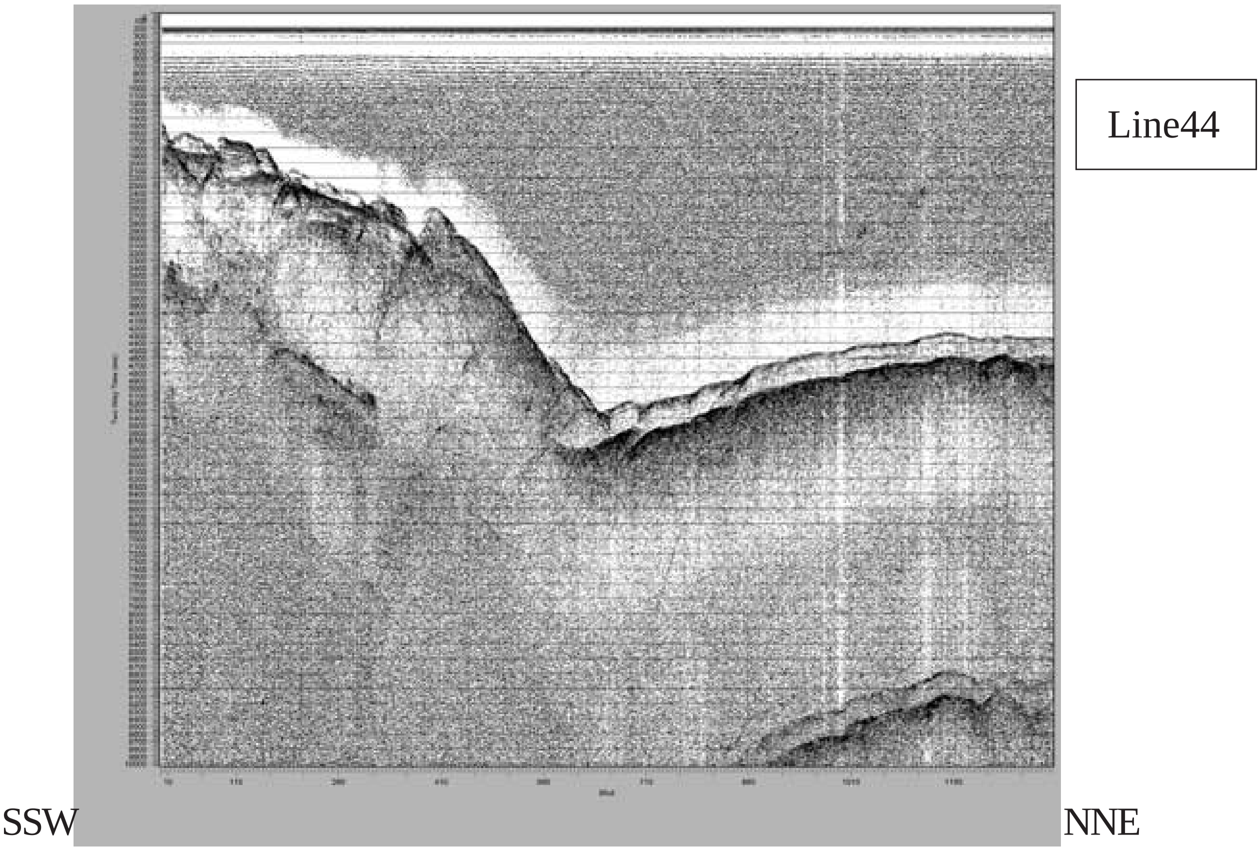


Fig. 3 (Line44)　Seismic profiles along the survey tracks.

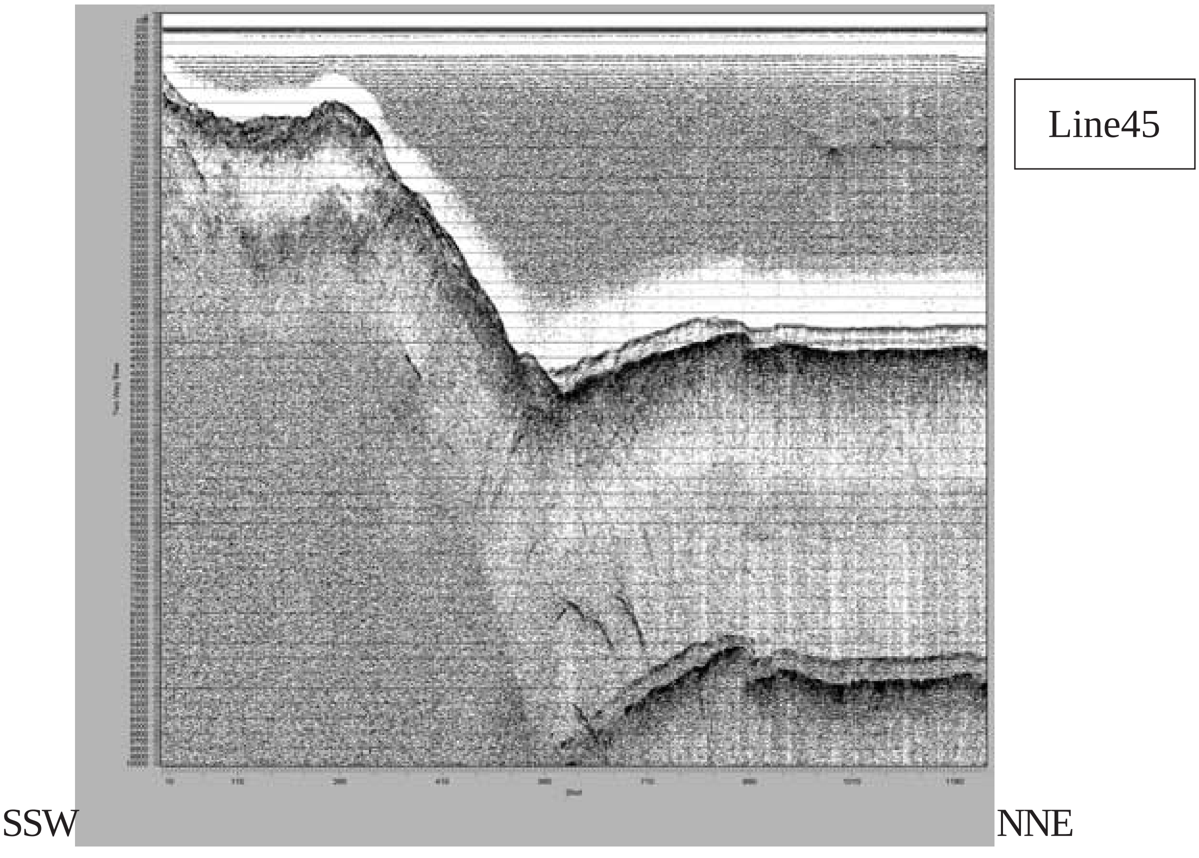


Fig. 3 (Line45)　Seismic profiles along the survey tracks.

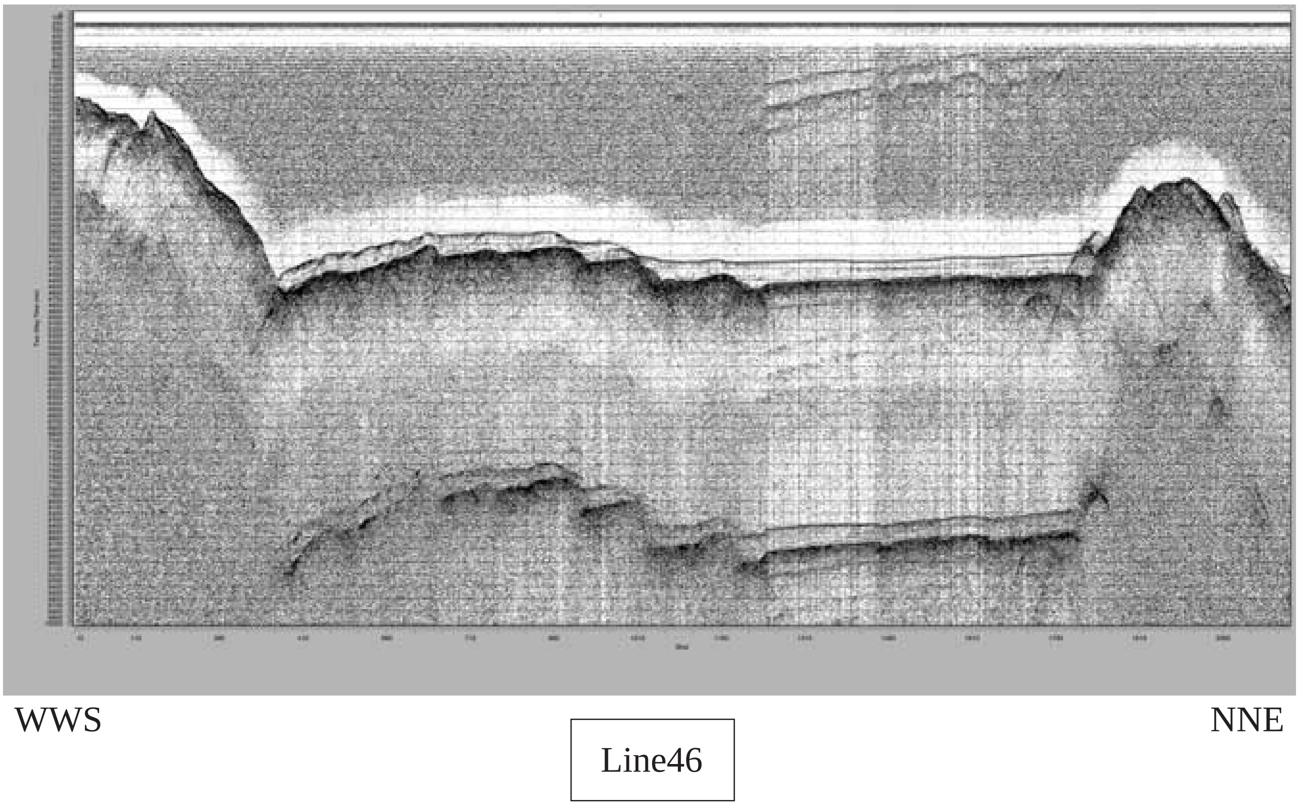


Fig. 3 (Line46)　Seismic profiles along the survey tracks.

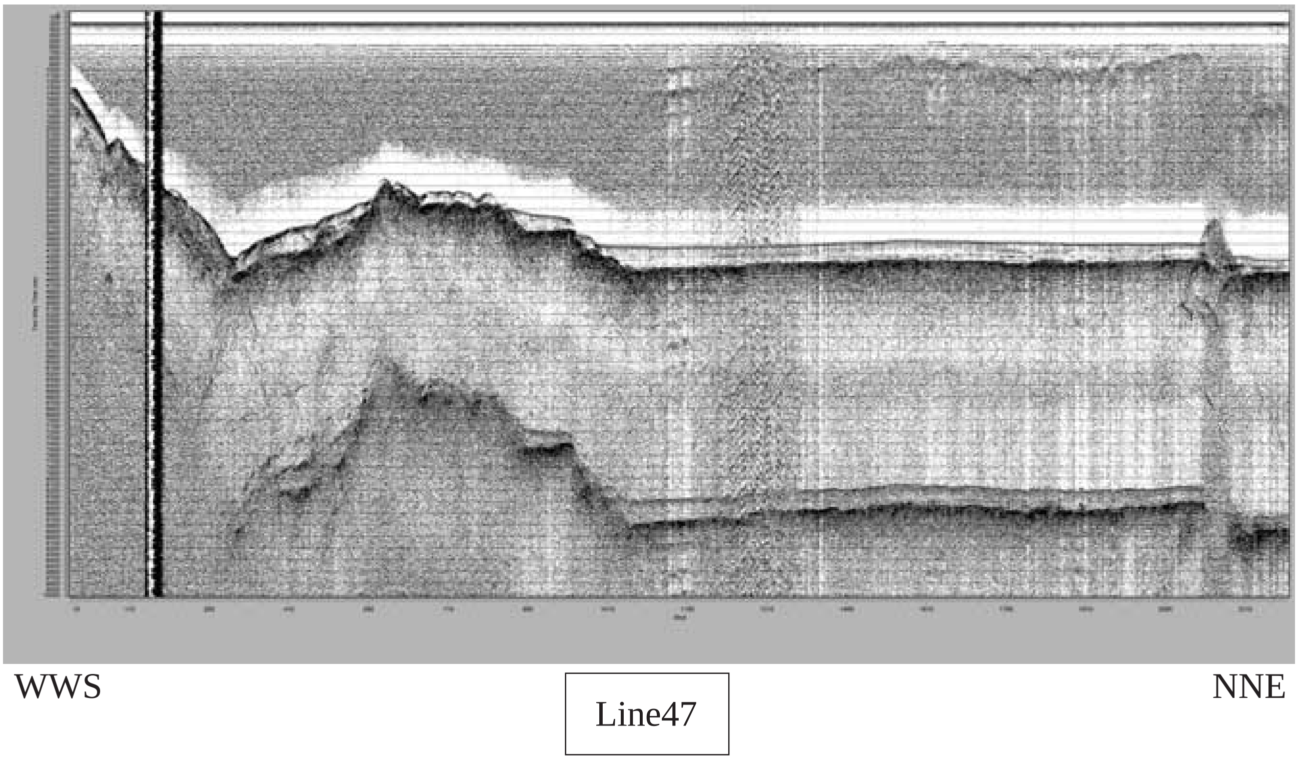


Fig. 3 (Line47)　Seismic profiles along the survey tracks.

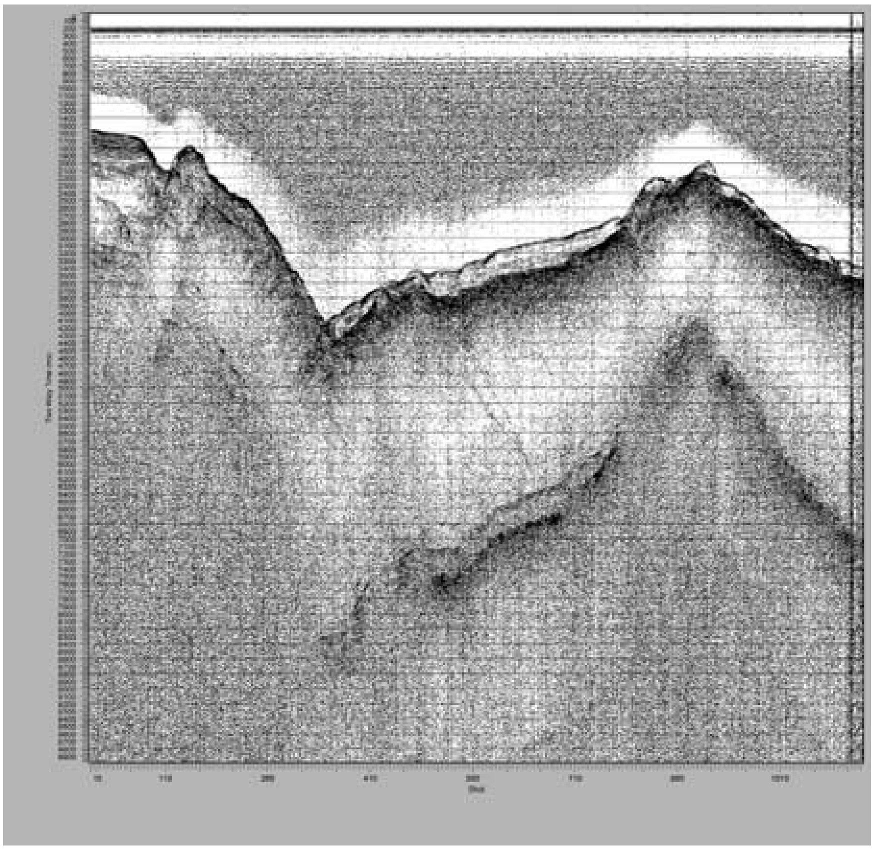


Fig. 3 (Line48)　Seismic profiles along the survey tracks.

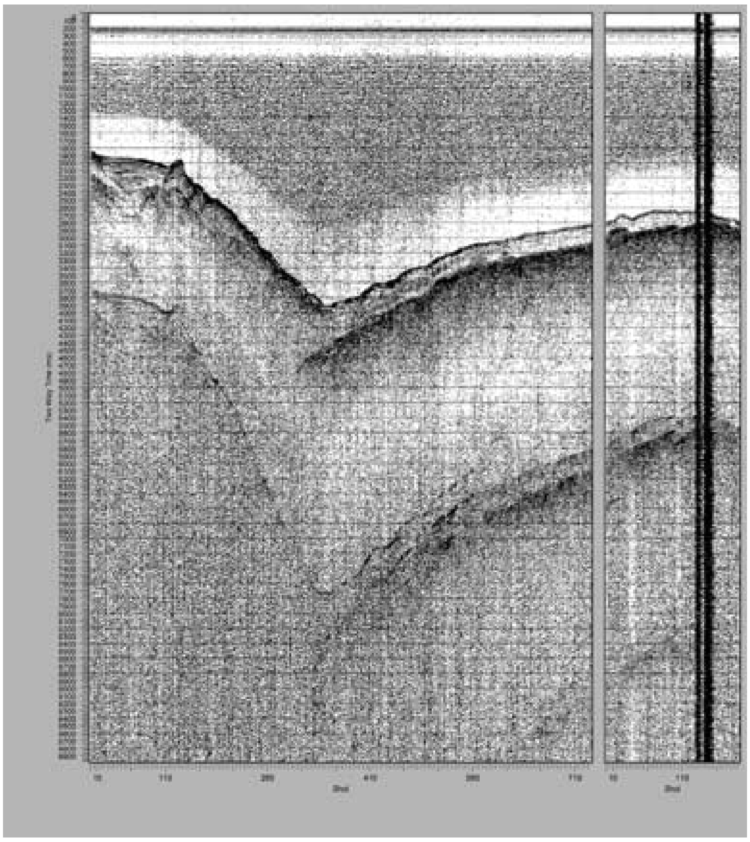


Fig. 3 (Line49)　Seismic profiles along the survey tracks.

Table 3-1 Summary of the single-channel seismic survey lines.

Line No. **NT01-01**	Filename **Line-1**				
Commenced	Lat.	3_02.069S	Finished	Lat.	2_44.667S
2001/02/09 20:34:30	Long.	142_19.977E	2001/02/09 22:47:31	Long.	142_19.989E
	Depth(m)	794		Depth(m)	3734
	Shot No.	1		Shot No.	500
Remarks					

Line No. **NT01-01**	Filename **Line-2**				
Commenced	Lat.	2_45.136S	Finished	Lat.	3_02.385S
2001/02/09 23:14:00	Long.	142_19.016	2001/02/10 01:25:00	Long.	142_18.982E
	Depth(m)	3567		Depth(m)	411
	Shot No.	1		Shot No.	481
Remarks					

Line No. **NT01-01**	Filename **Line-3**				
Commenced	Lat.	3_01.626S	Finished	Lat.	2_14.786S
2001/02/10 01:40:00	Long.	142_17.996E	2001/02/10 04:04:00	Long.	142_17.990E
	Depth(m)	415		Depth(m)	3315
	Shot No.	10		Shot No.	545
Remarks					

Line No. **NT01-01**	Filename **Line-4-2**				
Commenced	Lat.	2_45.025S	Finished	Lat.	3_02.157S
2001/02/10 05:23:57	Long.	142_17.004E	2001/02/10 07:30:13	Long.	142_16.993E
	Depth(m)	3017		Depth(m)	690
	Shot No.	1		Shot No.	472
Remarks					

Line No. **NT01-01**	Filename **Line-5**				
Commenced	Lat.	3_01.656S	Finished	Lat.	2_44.757S
2001/02/10 07:44:02	Long.	142_15.993E		Long.	142_16.606E
	Depth(m)	636		Depth(m)	
	Shot No.	1		Shot No.	491
Remarks					

Line No. **NT01-01**	Filename **Line-6**				
Commenced	Lat.	2_45.067S	Finished	Lat.	3_02.201S
2001/02/10 10:11:00	Long.	142_14.090E	2001/02/10 12:18:00	Long.	142_14.998E
	Depth(m)	2911		Depth(m)	402
	Shot No.	1		Shot No.	476
Remarks					

Line No. **NT01-01**	Filename **Line-7**				
Commenced	Lat.	3_02.176S	Finished	Lat.	2_44.764S
2001/02/10 12:32:00	Long.	142_14.019E	2001/02/10 14:50:13	Long.	142_14.001E
	Depth(m)	202		Depth(m)	2781
	Shot No.	1		Shot No.	517
Remarks					

Total No. of shots (except test shots) **3,482**

Table 3-2 Summary of the single-channel seismic survey lines.

Line No. **NT01-01**	Filename **Line-8**				
Commenced	Lat.	2_44.793S	Finished	Lat.	3_00.196S
2001/02/10 15:04:35	Long.	142_12.985	2001/02/10 17:01:55	Long.	142_13.063 E
	Depth(m)	2579		Depth(m)	280
	Shot No.	1		Shot No.	443
Remarks					

Line No. **NT01-01**	Filename **Line-9**				
Commenced	Lat.	3_00.008S	Finished	Lat.	2_44.845S
2001/02/10 17:17:44	Long.	142_12.012E	2001/02/10 19:09:41	Long.	142_12.002E
	Depth(m)	284		Depth(m)	2637
	Shot No.	1		Shot No.	421
Remarks					

Line No. **NT01-01**	Filename **Line-10**				
Commenced	Lat.	2_44.940S	Finished	Lat.	2_57.169S
2001/02/10 19:23:40	Long.	142_10.987E	2001/02/10 20:52:17	Long.	142_10.993E
	Depth(m)	2717		Depth(m)	372
	Shot No.	1		Shot No.	332
Remarks					

Line No. **NT01-01**	Filename **Line-11**				
Commenced	Lat.	2_57.135S	Finished	Lat.	2_44.770S
2001/02/10 21:06:20	Long.	142_09.996E	2001/02/10 22:40:50	Long.	142_09.995E
	Depth(m)	307		Depth(m)	2831
	Shot No.	1		Shot No.	352
Remarks					

Line No. **NT01-01**	Filename **Line-12**				
Commenced	Lat.	_2_44.885S	Finished	Lat.	2_55.332S
2001/02/10 22:53:03	Long.	142_08.958E	2001/02/11 00:14:00	Long.	142_08.996E
	Depth(m)	2875		Depth(m)	397
	Shot No.	1		Shot No.	297
Remarks					

Line No. **NT01-01**	Filename **Line-13**				
Commenced	Lat.	2_55.239S	Finished	Lat.	2_44.773S
2001/02/11 00:26:10	Long.	142_08.000E	2001/02/11 01:54:00	Long.	142_08.003E
	Depth(m)	352		Depth(m)	2918
	Shot No.	1		Shot No.	329
Remarks					

Line No. **NT01-01**	Filename **Line-14**				
Commenced	Lat.	2_44.761S	Finished	Lat.	2_54.233S
2001/02/11 02:06:45	Long.	142_07.015E	2001/02/11 03:20:54	Long.	142_07.000E
	Depth(m)	2786		Depth(m)	892
	Shot No.	1		Shot No.	274
Remarks					

Total No. of shots (except test shots) **2,448**

Table 3-3　Summary of the single-channel seismic survey lines.

Line No. **NT01-01**	Filename **Line-15**				
Commenced 2001/02/11 03:33:00	Lat. Long. Depth(m) Shot No.	2_54.152S 142_06.006E 341 1	Finished 2001/02/11 04:53:20	Lat. Long. Depth(m) Shot No.	2_44.818S 142_06.018E 2634 305
Remarks					

Line No. **NT01-01**	Filename **Line-16**				
Commenced 2001/02/11 05:10:00	Lat. Long. Depth(m) Shot No.	2_45.021S 142_05.007E 2567 1	Finished 2001/02/11 06:24:58	Lat. Long. Depth(m) Shot No.	2_54.243S 142_05.005E 305 270
Remarks					

Line No. **NT01-01**	Filename **Line-17**				
Commenced 2001/02/11 07:02:47	Lat. Long. Depth(m) Shot No.	2_55.020S 142_9.539E 446 1	Finished 2001/02/11 08:45:53	Lat. Long. Depth(m) Shot No.	2_44.787S 142_9.487E 2884 386
Remarks					

Line No. **NT01-01**	Filename **Line-18**				
Commenced 2001/02/11 08:58:53	Lat. Long. Depth(m) Shot No.	2_44.865S 142_10.454E 2722 1	Finished 2001/02/11 10:59:45	Lat. Long. Depth(m) Shot No.	2_57.245S 142_10.518E 334 452
Remarks					

Line No. **NT01-01**	Filename **Line-19**				
Commenced 2001/02/11 11:11:30	Lat. Long. Depth(m) Shot No.	2_57.172S 142_11.556E 444 1	Finished 2001/02/11 13:15:00	Lat. Long. Depth(m) Shot No.	2_44.779S 142_11.511E 2802 462
Remarks					

Line No. **NT01-01**	Filename **Line-20**				
Commenced 2001/02/11 13:31:45	Lat. Long. Depth(m) Shot No.	2_44.741S 142_12.530E 2584 1	Finished 2001/02/11 15:36:30	Lat. Long. Depth(m) Shot No.	2_57.267S 142_12.506E 643 468
Remarks					

Line No. **NT01-01**	Filename **Line-21**				
Commenced 2001/02/11 15:50:25	Lat. Long. Depth(m) Shot No.	2_57.305S 142_13.490E 812 1	Finished 2001/02/11 18:01:36	Lat. Long. Depth(m) Shot No.	2_44.736S 142_13.501E 2696 493
Remarks					

Total No. of shots (except test shots)　**2,836**

Table 3-4 Summary of the single-channel seismic survey lines.

Line No. **NT01-01**	Filename **Line-22**				
Commenced	Lat.	2_45.997S	Finished	Lat.	2_57.203S
2001/02/11 18:19:05	Long.	142_14.503E	2001/02/11 20:20:52	Long.	142_14.502
	Depth(m)	2997		Depth(m)	1043
	Shot No.	1		Shot No.	456
Remarks					

Line No. **NT01-01**	Filename **Line-23**				
Commenced	Lat.	2_57.228S	Finished	Lat.	2_44.762S
2001/02/11 20:23:21	Long.	142_15.467E	2001/02/11 22:42:25	Long.	142_15.521E
	Depth(m)	1149		Depth(m)	2952
	Shot No.	1		Shot No.	486
Remarks					

Line No. **NT01-01**	Filename **Line-24**				
Commenced	Lat.	2_44.795S	Finished	Lat.	2_57.237S
2001/02/11 22:54:00	Long.	142_16.466E	2001/02/12 00:59:45	Long.	142_16.501E
	Depth(m)	2984		Depth(m)	1207
	Shot No.	1		Shot No.	467
Remarks					

Line No. **NT01-01**	Filename **Line-25**				
Commenced	Lat.	2_57.281S	Finished	Lat.	2_44.786S
2001/02/12 01:14:13	Long.	142_17.527E	2001/02/12 03:30:50	Long.	142_17.501E
	Depth(m)	1230		Depth(m)	3101
	Shot No.	1		Shot No.	513
Remarks					

Line No. **NT01-01**	Filename **Line-26**				
Commenced	Lat.	2_46.880S	Finished	Lat.	2_49.935S
2001/02/12 04:18:09	Long.	142_21.012E	2001/02/12 07:26:33	Long.	142_03.803E
	Depth(m)	3917		Depth(m)	1379
	Shot No.	1		Shot No.	704
Remarks					

Line No. **NT01-01**	Filename **Line-27**				
Commenced	Lat.	2_50.899S	Finished	Lat.	2_50.246S
2001/02/12 07:41:50	Long.	142_04.042E	2001/02/12 08:16:11	Long.	142_07.717E
	Depth(m)	961		Depth(m)	1408
	Shot No.	1		Shot No.	133
Remarks					

Line No. **NT01-01**	Filename **Line-27-2**				
Commenced	Lat.	2_50.75S	Finished	Lat.	2_47.863S
2001/02/12 08:20:30	Long.	142_08.00E	2001/02/12 10:32:00	Long.	142_21.224E
	Depth(m)	1411		Depth(m)	3428
	Shot No.	1		Shot No.	494
Remarks					

Total No. of shots (except test shots) **3,253**

Table 3-5 Summary of the single-channel seismic survey lines.

Line No. **NT01-01**	Filename **Line-28-2**				
Commenced	Lat.	2_48.337S	Finished	Lat.	2_51.417S
2001/02/12 12:30:13	Long.	142_21.311E	2001/02/12 15:51:45	Long.	142_03.786E
	Depth(m)	3254		Depth(m)	848
	Shot No.	1		Shot No.	756
Remarks					

Line No. **NT01-01**	Filename **Line-29**				
Commenced	Lat.	2_51.906S	Finished	Lat.	2_48.865S
2001/02/12 17:38:30	Long.	142_03.991E	2001/02/12 20:28:59	Long.	142_21.178E
	Depth(m)	709		Depth(m)	3161
	Shot No.	1		Shot No.	642
Remarks					

Line No. **NT01-01**	Filename **Line-30**				
Commenced	Lat.	2_49.465S	Finished	Lat.	
2001/02/12 20:42:19	Long.	142_21.124E		Long.	
	Depth(m)	2800		Depth(m)	
	Shot No.	1		Shot No.	
Remarks					

Line No. **NT01-01**	Filename **Line-30-2**				
Commenced	Lat.	2_49.472 S	Finished	Lat.	2_52.341S
2001/02/12 22:11:40	Long.	142_21.228 E		Long.	142_03.780E
	Depth(m)	2717		Depth(m)	605
	Shot No.	1		Shot No.	688
Remarks					

Line No. **NT01-01**	Filename **Line-31**				
Commenced	Lat.	2_54.542S	Finished	Lat.	2_50.964S
2001/02/13 01:40:30	Long.	142_03.727E	2001/02/13 04:29:26	Long.	142_21.219E
	Depth(m)	196		Depth(m)	2075
	Shot No.	1		Shot No.	632
Remarks					

Line No. **NT01-01**	Filename **Line-32**				
Commenced	Lat.	2_57.016S	Finished	Lat.	2_58.046S
2001/02/13 05:24:45	Long.	142_20.976	2001/02/13 06:59:02	Long.	142_11.816E
	Depth(m)	1296		Depth(m)	428
	Shot No.	1		Shot No.	352
Remarks					

Line No. **NT01-01**	Filename **Line-33**				
Commenced	Lat.	2_53.988S	Finished	Lat.	2_34.940S
2001/02/13 07:57:20	Long.	142_12.098E	2001/02/13 17:43:12	Long.	141_19.040E
	Depth(m)	596		Depth(m)	1270
	Shot No.	1		Shot No.	2199
Remarks					

Total No. of shots (except test shots) **5,269**

Table 3-6 Summary of the single-channel seismic survey lines.

Line No. **NT01-01**	Filename **Line-34**				
Commenced	Lat.	2_38.405S	Finished	Lat.	1_57.316S
2001/02/13 18:31:10	Long.	141_19.223E	2001/ 02/14 01:29:20	Long.	141_32.880E
	Depth(m)	438		Depth(m)	3871
	Shot No.	1		Shot No.	1567
Remarks					

Line No. **NT01-01**	Filename **Line-35**				
Commenced	Lat.	1_59.617S	Finished	Lat.	2_40.798S
2001/02/14 02:24:31	Long.	141_39.626E	2001/02/14 09:51:37	Long.	142_25.926E
	Depth(m)	3910		Depth(m)	450
	Shot No.	1		Shot No.	1678
Remarks					

Line No. **NT01-01**	Filename **Line-36-2**				
Commenced	Lat.	2_42.935S	Finished	Lat.	2 _01.823S
2001/02/14 11:00:00	Long.	141_32.693E	2001.02.14 18:02:42	Long.	141_46.353E
	Depth(m)	308		Depth(m)	3393
	Shot No.	1		Shot No.	1586
Remarks					

Line No. **NT01-01**	Filename **Line-37**				
Commenced	Lat.	2_04.966S	Finished	Lat.	2_45.878S
2001/02/14 19:18:10	Long.	141_55.348E	2001/02/15 02:27:17	Long.	141_41.725E
	Depth(m)	3299		Depth(m)	410
	Shot No.	1		Shot No.	1609
Remarks					

Line No. **NT01-01**	Filename **Line-38**				
Commenced	Lat.	2_47.420S	Finished	Lat.	2_06.298S
2001/02/15 03:12:09	Long.	141_46.184E	2001/02/15 10:17:50	Long.	141_59.860E
	Depth(m)	583		Depth(m)	3384
	Shot No.	1		Shot No.	1595
Remarks					

Line No. **NT01-01**	Filename **Line-39**				
Commenced	Lat.	2_08.511S	Finished	Lat.	2_49.554S
200/02/15 11:01:15	Long.	142_04.093E	2001/02/15 18:09:05	Long.	141_51.549E
	Depth(m)	3782		Depth(m)	569
	Shot No.	1		Shot No.	1605
Remarks					

Line No. **NT01-01**	Filename **Line-40**				
Commenced	Lat.	2_51.481S	Finished	Lat.	2_48.703S
2001/02/15 19:02:13	Long.	141_55.771E	2001/02/15 19:29:23	Long.	141_56.679E
	Depth(m)	779		Depth(m)	1548
	Shot No.	1		Shot No.	100
Remarks					

Total No. of shots (except test shots) **9,740**

Table 3-7 Summary of the single-channel seismic survey lines.

Line No. **NT01-01**	Filename **Line-40-2**				
Commenced	Lat.	2_51.699S	Finished	Lat.	2_09.765S
2001/02/15 22:20:27	Long.	141_55.716E	2001/ 02/16 05:30:20	Long.	142_08.892E
	Depth(m)	758		Depth(m)	3317
	Shot No.	1		Shot No.	1611
Remarks					

Line No. **NT01-01**	Filename **Line-41**				
Commenced	Lat.	2_10.011S	Finished	Lat.	3_02.188S
2001/02/16 06:25:48	Long.	142_15.193E	2001/02/16 15:03:30	Long.	142_16.033E
	Depth(m)	3582		Depth(m)	702
	Shot No.	1		Shot No.	1942
Remarks					

Line No. **NT01-01**	Filename **Line-42**				
Commenced	Lat.	2_53.017S	Finished	Lat.	2_48.703S
2001/02/16 17:31:47	Long.	142_02.554E	2001.02.16 23:35:55	Long.	141_56.679E
	Depth(m)	207		Depth(m)	1548
	Shot No.	62		Shot No.	1419
Remarks					

Line No. **NT01-01**	Filename **Line-42-2**				
Commenced	Lat.	2_18.903S	Finished	Lat.	2_14.822S
2001/02/16 23:37:25	Long.	142_14.293E	2001/02/17 00:23:00	Long.	142_15.645E
	Depth(m)	3557		Depth(m)	3563
	Shot No.	1		Shot No.	1419
Remarks					

Line No. **NT01-01**	Filename **Line-43**				
Commenced	Lat.	2_15.773S	Finished	Lat.	2_54.175S
2001/02/17 02:02:15	Long.	142_26.741E	2001/02/17 08:35:33	Long.	142_13.923E
	Depth(m)	4782		Depth(m)	719
	Shot No.	1		Shot No.	1473
Remarks					

Line No. **NT01-01**	Filename **Line-43A**				
Commenced	Lat.	2_51.836S	Finished	Lat.	3_00.213S
2001/02/17 09:21:50	Long.	142_12.113E	2001/02/17 12:13:25	Long.	142_18.810E
	Depth(m)	1471		Depth(m)	1017
	Shot No.	1		Shot No.	645
Remarks	This file has Line 43A and Line 43B records. (Refarence General Info.sheet Line 34A, 34B)				

Line No. **NT01-01**	Filename **Line-44**				
Commenced	Lat.	3_00.0545S	Finished	Lat.	2_29.851S
2001/02/17 12:28:50	Long.	142_18.761E	2001/02/17 18:16:15	Long.	142_28.837E
	Depth(m)	1061		Depth(m)	3182
	Shot No.	1		Shot No.	1303
Remarks					

Total No. of shots (except test shots) **9,812**

Table 3-8 Summary of the single-channel seismic survey lines.

Line No. **NT01-01**	Filename **Line-45**				
Commenced	Lat.	2_31.842S	Finished	Lat.	3_03.487S
2001/02/17 19:22:53	Long.	142_36.321E	2001/ 02/18 00:44:35	Long.	142_25.730E
	Depth(m)	3054		Depth(m)	537
	Shot No.	1		Shot No.	1205
Remarks					

Line No. **NT01-01**	Filename **Line-46**				
Commenced	Lat.	3_03.487S	Finished	Lat.	2_04.805S
2001/02/18 01:54:00	Long.	142_25.730E	2001/02/18 12:14:15	Long.	142_52.966E
	Depth(m)	978		Depth(m)	3165
	Shot No.	1		Shot No.	2325
Remarks					

Line No. **NT01-01**	Filename **Line-47**				
Commenced	Lat.	2_04.768S	Finished	Lat.	3_4.915S
2001/02/18 13:22:10	Long.	143_00.354E	2001.02.18 23:33:20	Long.	142_40.334E
	Depth(m)	3118		Depth(m)	909
	Shot No.	1		Shot No.	2291
Remarks					

Line No. **NT01-01**	Filename **Line-48**				
Commenced	Lat.	3_07.021S	Finished	Lat.	2_39.795S
2001/02/19 00:58:25	Long.	142_47.152E	2001/02/19 05:58:54	Long.	142_56.212E
	Depth(m)	1100		Depth(m)	2426
	Shot No.	1		Shot No.	1130
Remarks					

Line No. **NT01-01**	Filename **Line-49**				
Commenced	Lat.	2_40.022S	Finished	Lat.	2_46.682S
2001/02/19 07:03:32	Long.	143_3.624E	2001/02/19 08:02:40	Long.	143_1.389E
	Depth(m)	2031		Depth(m)	2039
	Shot No.	1		Shot No.	192
Remarks					

Total No. of shots (except test shots) **7,143**

総ショット数 **43,983**

amphitheatre upper and lower scarps, the depression at the base, the subsided reef on the northeast margin of the delta front and the dissected lower delta slope in the west. The consequent regional survey covered an area approximately bounded by latitudes 1 °55'- 3 °10' S and longitudes 141 °30' - 143 °10'E. Approximately 20,000 square kilometres of seismic line data were acquired during the survey by 15 NNE-SSW lines at a spacing of 5-10nm. The application of seismic stratigraphy involves the subdivision of seismic sections into sequences of reflections interpreted as expressions of sedimentary sequences. The principles of this analysis are two-fold: (1) Reflections define the chronostratigraphical units, and (2) Related sedimentary units normally comprise a set of genetically related reflectors that exhibit similar structural patterns with overlying or underlying sequences.

The Amphitheatre

The area covered by the amphitheatre may be described as intensely fractured and folded in the upper continental slope. In contrast, the inner wall of the New Guinea Trench is covered by sediments derived from weathering and erosion of the continental shelf. Terriginous sediments derived from the mountain ranges are transported to this area by the out-flowing rivers.

The inner trench wall is characterised by bench-like features which are intensely folded and, in some places, fractured. The mid-slope wall also has bench-like features. Reflection sequences in the area are not so well defined, especially in the eastern margin. The lack of well defined reflection sequences in this area may indicate transitional lithological units. From this analysis, we infer that these features are not upraised structures, rather they are derived from erosion and sedimentation of the outer shelf, which is an on-going process. The fact that these transitional lithological units have rotational features may indicate movement at several stages. The high angle slopes of the continental margins also encourage these sediment motions.

Sediments within the amphitheatre are not horizontally stratified and show signs of 'deformation'. This suggests the area is highly active due to crustal convergence. This feature is well manifested on Lines 1-3 and 25, especially towards the outer continental shelf.

Towards the west sediments thin out until Line 13, where sedimentation is not so clearly expressed. Further west, more sedimentation is observed, mostly probably sourced from the Pual River.

Sedimentary layers in the north terminate against the southern flank of the upraised block. There is not much contrast between the basement and the sediments, thus making it difficult to clearly and confidently demarcate the overall thickness of the sediments. Hence, thickness values given in this report are only estimates. .

Preliminary estimates of the thickness of slumped sediments within the amphitheatre results in approximately 469 m (Line 41). These calculations are based on the assumptions that the sediments are derived from Pliocene to Holocene reefal limestone (Hutchison and Norvick, 1980). Hill et al. (1996) studied seismic data acquisition within this type of limestone in the Papuan Fold Belt and used an average velocity of 1250 m/s. Such limestone may comprise the shallow weathered low velocity layer in this area.

Regional survey results

On the regional outset the area between Vanimo and Aitape is characterized by stratified sediments of the New Guinea Trench floor. Analysis of the seismic sequences reveals at least two stratified layers in some areas. These layers are disrupted by seamounts, (e.g. Line 34). As these stratified sediments are evidently discontinued by the seamounts, it may be possible to assume that the arrival and attempted subduction of the seamounts occurred after sedimentation. Deformation of horizontal bedding planes in the vicinity of the seamounts reinforce this idea (Line 34).

Estimates of the sediment thickness within this region give a value of approximately 500 m at Shot Point # 1010 (Line 34).

Towards the east (Lines 36-38) there is possible evidence of slumping (Line 36) at the base of the upper slope. Seismic reflections show lineation of the reefal limestone, which may suggest 'recent' activity. Movement of sediments within this area may also be influenced by the Bliri River.

There is a marked difference between the western seismic profiles from those acquired in the east, beginning just north of the amphitheatre (Line 41). The eastern profiles show evidence of subduction of the oceanic crust (Bismarck Sea Plate) beneath the continental crust (Lines

41 and 42), which is not visible on the western profiles. Again visible from the profile is the highly deformed structures to the south of the profiles. There is possible displacement in the seismic sequences further north that may be evidence of faulting (?) caused by the subduction of the oceanic crust beneath the continental crust.

North of the amphitheatre at about Shot Point # 1010 (Line 45), thickness of the sediment has been determined to be approximately 269 m.

Line 34 is planned to get a "typical" slope basin ~ trench slope ~ trench floor profile. The slope basin is filled with soft sediment of 0.6sec TWTT with a disconformity inside it. The ridge between the slope basin and trench floor is made up of a stuff sediment on the basement - maybe consists of sedimentary rocks. The location of the trench axis is not clear because the topographic feature of the trench floor is flat and the width of the trench floor is some 20km. The water depth is 5.65sec TWTT on the southern side and 5.45sec TWTT on the northern side with a step associated with a seamount apparently subducting towards the trench and covered completely with abyssal sediment. Another seamount also subducting towards the trench is located at the end of the profile.

Line 35 is about 7nm east of Line 34. The slope basin is no more filled with soft sediment but some undulations of the bottom with small-scale thrust faults are predominant. A massif of seamounts or the end of a seamount chain is subducting in the trench. Then the trench floor deforms and split into two by the subducting masssif.

Relics of a remarkable underwater landslide were observed along Line 36. The surface of the slope just beneath the shelf is characterised by a sliding with rough undulations and a block of a transparent sedimentary layer is located on the extension of the slope basin. Maximum thickness of the sediment block is some 0.9sec TWTT. The block is corresponding to the topographic high with surface undulations off the canyon. Considering that the area of the topographic high is 14km times 14km, the total volume of the slump sediment block is some 70km3. However, it should be noted that at least three different layering is observed inside the block by the processed record, it is not always concluded that the whole block slided at one time but at least a couple of events of underwater landslide on the slope nearby constructed the slump sediment block. One part of the sediment is flowing to the downslope towards the ridge facing the trench axis. Subducting seamount massif is also existing on the trench floor.

Profiles along Line 37 and 38 present similar features with each other. The slope near the coastline is filled with sediment of 0.8sec TWTT on the basement, apparently derived from the land nearby. The slope basin similar to the figure of amphitheatre is covered with sediment on undulated basement layer. The surface of a seamount located on the trench floor is clearly observed. The seamount is apparently subducting and the surface of the seamount is deformed and collapsed.

Line 40 is crossing the western amphitheatre and the seamount on the trench axis. The trench slope is characterised by a couple of terraces derived from normal faults. The amphitheatre is filled completely with sediment. A couple of series of sedimentary layers were observed inside the amphitheatre. The seamount on the trench floor is not axisymmetric. The gradient of the landward side is higher than that of the seaward side. The basement of the landward side of the seamount can be traced down to 8.4sec TWTT. Therefore, the seamount seems to be inclining towards the landward side and a normal fault runs at the foot of the seamount.

Line 41 is following Line 1a and Line 1b of Sweet and Silver's 48-ch survey, crossing the amphitheatre from far north. The end point is the Yalingi Canyon eroding the fan sediment. The location of the trench axis is clear from the depth profile. The basement of the foot of a sunken seamount is subducting underneath the foot of the Pop-up Block.

Line 43 is crossing the amphitheatre headwall, sediment mound, Pop-up Block, trench axis and the volcanic massif on the North Bismarck Sea Plate. The summit is not covered with sediment but cut towards the trench axis by a fault scarp which is apparently a normal fault. The slope of the volcanic massif is covered with sediment of maximum 0.3sec TWTT. On the slope towards the trench axis three other normal faults are cutting the sedimentary layer and volcanic basement rock. The foot of the massif is apparently subducting underneath the trench slope.

The whole area is characterised by an oblique subduction of the Caroline Plate from ENE to SWS. In this case, relative motion between the two plates is not perpendicular to the strike of the trench. If the lithospheric thickness differs from each other (in most cases lithosphere of the oceanic plate is thicker than that of the continental plate), thicker lithosphere sinks down due to its weight and thinner lithosphere moves towards the thicker lithosphere like a density current. Then the convergent plate boundary (trench) shifts towards the seaward side and rolling buck of the oceanic lithosphere takes place. The surface of the convergent plate boundary area is characterised by tensile stress. Slumping of the surface sediment and normal faults appear remarkably in this case. The findings obtained during the cruise in the study area are described by the simple density current model.

Many seamounts subducting underneath the trench slope are observed in the present study area. If the size of the seamount is smaller than several kilometers, the seamount load is supported by the restoring force of elastic bending of the oceanic crust. However, the load of seamounts or oceanic plateaus the horizontal size of which exceeds 100km is hard to be supported by elasticity and is supported by buoyancy by thick crusts underneath them. Small seamounts subduct easily if they reach the trench axis and the restoring force that supported them disappeares. However, large-scale seamounts supported by buoyancy never subduct at the trench axis because they are stable mechanically. In this case, the seamounts are included into the continental plate and the convergent boundary (trench axis) jumps to the seaward side of the seamounts because the "slab-pull" force is still effective in the collision.

5. Sedimentation description and interpretation

Sedimentation off the northern coast of Papua New Guinea (PNG) is predominantly controlled by the active convergent setting between the Australian plate and the Caroline plate which is a segment of the Pacific plate. The oblique subduction occurring in the New Guinea Trench affects not only the overall marginal architecture, but also the sediment supply, transport and accumulation.

On the other hand, the voluminous rainfall in the rugged and high mountains of PNG combined with the weathering-intensive, tropical environment and frequent seismic activity result in high river sediment loads. As a result of these processes, the northern coast of PNG receives more than 1×10^8 metric tons of sediment per year (SOS-2 Cruise Shipboard Scientist, 1999). In this survey area, there are three big rivers such as the Pual, Bliri and Yalingi Rivers which drain the mountain area northward to the Bismark Sea.

In this preliminary report, we described typical sedimentary bodies and sedimentary structures of the New Guinea Trench area using our seismic records acquired by single channel system. We classified four distinct sedimentary environments of the inner trench area and two canyon systems in the study area.

<u>Continental shelf</u>

The continental shelf narrows from 10 km in the east to 5 km in the west and is widest between the eastern margin of the Serra Hills and Tumileo Islands. According to our seismic data of Lines 1 to 8 from off Sissano, in water depths shallower than 1000 m, there is greater thickness of detrital sediments, 450m in thickness, accumulated on the shelf plain. This is because of the high sedimentation rate and subsidence continuing to the present day (Goldsmith et al., 1999).

<u>Shelf slope</u>

At 1000 to 2000 m water depth, our seismic data of Lines 34 to 45 from off Aitape to Vanimo show that there is a steep slope with little sediment. The natural slope gradient of the upper slope is about 14 to 21 °and maximum 21 °. Many landslide relics are found on this slope, however only a few show the inverted topography (concave-convex topography) indicative of recent landslides.

On the other hand, according to seismic data of Line 33 off Sissano lagoon to Vanimo, there are many V-shaped and short length valleys eroded from the shelf slope. Reliefs of each valley are almost 300 m. Off the mouth of Bliri River, is located the biggest valley that is 1350 m deep. However, because of the steep slope, there are a few valley-fill sediments that are bypassing detrital sediments to the slope basins.

The PC-2 core from 913 m depth (SOS-1 Cruise Shipboard Scientist, 1998) describes the core as consisting of hemi-pelagic olive silty clay, which exhibits a homogeneous, stiff, and cohesive nature. There are no turbidite sands in this core.

Slope basins

Slope basins are prominent from the north of Sissano to the western end of the survey area. Many different sizes and a few different levels of slope basins are recognized in the survey area. The water depth of each basin is 1500 to 2500 m, and the thickness of basin fill sediments is about 50 to 1000 m.

This sedimentation is predominantly controlled by E-W lineaments such as ridges and faults due to oblique subduction. Parts of the big slope basins are gently tilted landward because of possible rapid crustal movement by growth accretionary complex.

According to the description of PC-4 core by Ikehara et al. (2001), there are amount of turbidite sands with forams and shell fragments. Up to now, there are no age data from the core. However turbidite frequency and thickness suggest that at the lower part of the core interbedded turbidites are more frequent then at the upper part.

Inner trench slope

Our seismic data of Lines 34 to 45 from off Aitape to Vanimo show that there is an obvious steep shelf slope with a few covering sediments at 2500 to 4200 m water depth in this survey area. The natural slope gradient of the upper part is about 6 to 17 °, maximum 21 °. The natural slope gradient of the lower part is about 12 to 17 °, maximum 21 °. Many landslide topographies are found on this slope, however only a few show the inverted topography (concave-convex topography) indicative of recent landslides.

Trench floor

The topographic definition of 'trench' is an elongated deep depression more than 6000 m in depth. Sometimes 'trench' also means the subduction boundary of plates, so we use the term New Guinea Trench in this report. The overall strike of the trench is WNW-ESE, however the landward front is a zigzag shape except for the eastern part of the trench. The water depth of the trench is about 3000 m at the eastern end and about 4200 m from the north of Aitape to the western end of the survey area.

Our seismic data of Lines 34 to 43 show that several seamounts on the ocean plate reach the trench floor and break the inner trench area (Lines 34, 35 and 41). Thus these divide the trench floor into several sized sedimentary basins. The depth of each basin is 4100 to 4200 m. The thickness of trench fill sediments range from 400 to 900 m. Furthermore, according to our seismic data of Lines 34 and 35, there are deformed sediments covering the top of seamounts. However, these old? Sediments are overlain by recent trench fill sediments (Lines 34 and 35).

On the other hand, our seismic data of Lines 43 to 46 show that there are no seamounts in the trench floor. The depth of each basin is 3500 to 4000 m. The thickness of trench fill sediments range from 200 to 350 m (Line 45).

More critical description of PC-1 core was carried out by Ikehara et al. (2001) at GSJ. The PC-1 core was described as mainly hemi-pelagic olive silty clay interbedded thin turbidite sands which are 2-5 cm in thickness and very fine to coarse silt grain with wood fragments, shallow marine benthic foraminiferas and turbidite silt. These turbidites were supplied to the trench floor from the shelf margin via the inner trench area. There are no age data, however, the frequency of 3-4 layers/m suggests that these turbidites are not frequently occurring in this earthquake-prone area.

Yalingi Canyon System

Yalingi canyon is the biggest deep-sea channel system in the survey area. It erodes the continental shelf to the north off Aitape according to previous investigations such as the SeaBeam2112 survey (SOS-1 Cruise Shipboard Scientist, 1998). The canyon system at 142 ° 20'E extends onto the continental shelf and continues to the mouth of Yalingi River and the trench floor.

According to seismic data of Line 1 to 5, the upper part of the canyon (shallower than 1500 m water depth) erodes the continental shelf. The natural slope gradient of the upper part is about 10 to 15 °. This part of the canyon is not filled by sediments because of the steep slope, and bypasses detrital sediments to the slope basins or trench floor.

The middle part of the canyon (1500 to 2500 m in water depth) passes through the slope basin and shows obvious meandering channel system like an onshore fluvial system. The natural slope gradient is gentle or flat. According to seismic data of Lines 1 and 2, channel-levee complexes are piled up and buried in this slope basin by more than 1000 m thick due to the high sedimentation rate and subsidence continuing to the present day (Goldsmith et al., 1999).

Furthermore, the lowest part of the canyon (deeper than 2500 m in depth) erodes the lower trench slope and reaches the trench floor. The natural slope gradient of the lower part is about 16 to 21 °. However, there is no obvious submarine fan around the canyon mouth because of slow sedimentation rate and rapid crustal movement, which is controlled by the WNW-ESE trending fault lineaments termed the 40 kilometer-Fault.

For example, the Nankai Sea Channel is situated in and along the Suruga and Nankai Troughs, which are convergent plate boundaries with ridge collision in southwestern Japan (Shimamura, 1989). This channel shows incised meandering and straight channel patterns similar to those of the Yalingi Canyon. These meandering channel systems have been controlled by tectonic movement related to plate subduction. The channel pattern and the channel relief show systematic change with variations in the channel gradient.

Pual Canyon System

Pual canyon is the second biggest deep-sea channel system in the survey area at 141 °30'E and extends onto the continental shelf and continues to the mouth of Pual River and slope basin. The natural slope gradient of the upper part is about 18 °.

Our seismic data of Line 36 show that there is a big slope basin that has accumulated sediments more than 600 m thick and made like a deep-sea fan supplied by the abundant channel. The new channel erodes the old? fan sediments. Thus this canyon has been bypassing much of the detrital sediments to this slope basin.

6. Vulnerability to tsunami off the north coast of Papua New Guinea

Initially, for lines 1 to 15 the ship speed was 8 knots and the data were of sufficient quality in soft, stratified sediments. In the more cohesive, and/or massive sediments, such as the clays sampled in PC-2 on SOS-1, seismic resolution was poor. However, in the context of the MCS line of Sweet and Silver (in press), a slumped sediment body could be identified extending from the upper landward scarp to the foot of the mound and from the eastern margin of the amphitheatre to below the re-entrant located on the upper scarp slope.

Subsequently acquired seismic data (Line 16-25) was at a reduced ship speed of six knots; a reduction that improved data quality sufficiently to improve resolution in all sediments including the cohesive clays. In the amphitheatre headwall two seismic units were identified and correlated with those previously identified by Sweet and Silver (in press). These data confirmed that sediment failure in the eastern part of the amphitheatre upper scarp lines had been by rotational failure. The additional cross Lines 31 and 42A also showed the failure to be complex. A maximum slump width of 5 km and a length of 4 km was mapped. The slump margins are sharp with a maximum thickness of ~600 m, tapering to the northern and southern margins. Dipping reflections in the western part of the amphitheatre and on the lower scarp (below the rotational failure) confirmed a failure (slump) origin of the amphitheatre feature.

The 40-Kilometre Fault was identified on the seismic and, as interpreted from the multibeam bathymetry, has a normal downthrow to the north. The 14-Kilometre Fault was also identified and although earlier suspected to be a thrust fault (with southward directed thrust movement) appeared on the seismic data to have a dominantly normal component of throw to the south. A small slump was identified on the southeastern margin of the Upraised Block.

The depression at the base of the amphitheatre has a thick sediment cover with two phases of infill. The upper surface and internal reflections are horizontal, with little disturbance. The reflections may be traced westward towards the amphitheatre western margin and up dip towards the mound and upper headwall scarp where they comprise the dipping sequence described above.

The heavily dissected western scarp of the amphitheatre exhibits a number of sediment slumps. A moderate sized slump was identified on Line 13. The heavily dissected nature of the western area suggests that failure here is older than in east. An interpretation confirmed by the SHINKAI2000 diving on SOS-3, on which survey older fissures and degraded exposed cohesive sediment bedding planes were identified on the first dive of SHINKAI2000 in SOS-3 cruise (Matsumoto et al., 2001; Tappin et al., 2001a).

Interpretation of the seismic data confirmed that the amphitheatre has been formed by sediment slumping. A dipping lower reflector sequence at the lower amphitheatre scarp is interpreted as downfaulted formation of the rotational failure on the upper scarp. Translational sliding is associated with the downfaulting. The failure of the upper scarp identified during the previous SOS surveys is considered the most recent failure event. This failure is rotational in nature and is a maximum of 5 km wide and 4 long with an estimated maximum thickness of 600m (at a velocity of 2 km/sec). On the multi-channel seismic line of Sweet and Silver the failure has a maximum thickness of 750 m. Depending on the extent and overall thickness of the slumped area as well as the history of slump movement the slump has a volume between 4 and 7.5 cubic km.

Both faults on the southern margin of the amphitheatre appear to be normal with throws to the south (14-Kilometre Fault) and north (40-Kilometre Fault). Neither appears to be a likely source of the 1998 tsunami, as has already been concluded from bathymetric data (Tappin et al., 2001a).

Small slumps are present on the southeastern margin of the Upraised Block and in the west on the upper scarp slope below the Lower Delta slope edge. The slumps on the western margin of the amphitheatre are considered to be older events than the failure in the east. However, it is possible that a spur between two gullies has been dislodged more recently than the surrounding topography suggests.

In the east, in the vicinity of the Yalingi Canyon, the structure is similar to that in the area of the amphitheatre except that basement is deeper and the sedimentary section extends farther trenchward. The basement is an extension of the reef high. The sedimentary sequence is downfaulted towards the trench from the shelf. Parts of the sedimentary sequence are certainly backward rotated, a structure that ties in with the reversal landward of sections of the Yalingi Canyon.

From the seismic data acquired during SOS-4 several conclusions may be drawn:

(1) Slumping of sediment on the steep inner trench slope off northern PNG appears to well distributed, although many of the slumps are small and undoubtedly old.

(2) In the area of the amphitheatre sediment slumping is common and of several ages. It is confirmed that the amphitheatre has been formed over several slumps events. The most recent of these is probably that in the east which has been proposed as the source of the 1998 tsunami that struck the Sissano (Aitape) area,

(3) The sedimentary package on the uppermost part of the inner trench slope is considered to be unstable and prone to failure that may be tsunamigenic. More detailed studies of the data are required before further comment may be made.

(4) The Sissano (Aitape) area is considered to be most susceptible to tsunami attack because of its particular location at the transition zone where the boundary between the Caroline and North Bismarck Sea plates interact with the New Guinea Trench. Additionally, any tsunami wave will be focused on the Lagoon area because of the seaward projecting subsided delta front. Continuing subsidence of the Lagoon will increase its vulnerability.

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