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Regional landslide occurrences and possible post-glacial earthquake activity in northwest Western Norway: sediment cores from five lakes in Nordfjord and Sunnmøre (Phase B2)

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REPORT

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Title:
Regional landslide occurrences and possible post-glacial earthquake activity in northwest Western Norway: sediment cores from five lakes in Nordfjord and Sunnmøre (Phase B2)

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Summary:

NGU, Norsk Hydro ASA, the University of Bergen and Sogn and Fjordane College collaborate on a project aiming to identify regional slide/mass-movement events and to interpret triggering factors for such slides (Regional landslide occurrences and possible post-glacial earthquake activity in northwest Western Norway).

Evidences for such slides have been searched for in five lakes in Nordfjord and Sunnmøre by penetration echosounding profiling and bathymetric mapping. From these lakes, 26 sediment cores, with a combined length of 70 m, have been sampled with a modified 110 mm Livingstone piston corer.

This field report (Phase B2) gives a summary of the sediment sampling, including the geographical location of the cores and their stratigraphic location compared to the echosounding profiles.

Keywords: Marine Geology	Core	Slide
Lake sediment	Holocene	Neotectonism
Tsunami		

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1. INTRODUCTION

High resolution seismic reflection profiles from fjords along the coast between Sognefjorden and Kristiansund show seismic reflectors that apparently can be recognized and correlated from fjord to fjord (Longva et al. 2001). In some cases, submarine slides or avalanches/rock fall deposits from the surrounding land areas are related to these regional reflectors. The appearances of regional reflectors could be a result of sedimentary/environmental changes caused by climatic changes, earthquakes, or tsunamis generated by large submarine slides.

An 8.5 m long core of fjord sediments from Voldafjorden shows distinct turbidite beds (Sejrup et al. 2001). The uppermost 3 turbidites have been dated to approximately 2000, 7000 and 9000 radiocarbon years BP. The two youngest of these have been correlated to seismic reflectors that occur at the same stratigraphic level as massive debris-flow deposits along the slopes of the fjord basin. The 7000 years BP event is interpreted to be related to the Storegga Slide (Fig. 1) tsunami (Bondevik et al. 1998, Grøsfjeld et al. 1999, Sejrup et al. 2001), suggesting that the 2000 years BP event possibly could be related to another large tsunami caused by an offshore mega-slide.

There are indications that major earthquakes may have triggered slides on a regional scale at several occasions during late-glacial and Holocene times. To invetigate this, and to understand the origin of the 2000 years BP layer, NGU, together with Norsk Hydro ASA, the University of Bergen and Sogn og Fjordane College run a project with the following aims:

- Regional compilation of slide occurrences, avalanches and gravitational faults that may have resulted from earthquakes or tsunamis in northwest Western Norway.
- Date single events and periods of instability in fjord- and lake sediments.

This field report summarises the work carried out during Phase B2 (sediment coring in 5 lakes in Nordfjord and Sunnmøre).

2. CORING EQUIPMENT

The coring equipment used was a modified Livingstone 110 mm piston corer (Fig. 2, Nesje et al. 1987, Nesje 1992). The cores were taken from a raft (Fig. 3). Cores up to 5.7 m long may be taken by the Livingstone corer. The longest core obtained was 5.40 m, from Nedstevatnet (Table 1).

In addition, a Russian half cylinder corer, taking half cylinder samples 5 cm in diameter and up to 1 m long, was used for inspection of the lake bed sediments prior to sampling with the Livingstone piston corer. The maximum water depth range for the Russian corer was 10-12 m. All the Russian cores (11) were discarded after visual inspection.

3. POSITIONING

Coring sites were chosen from echosounder profiles (Longva and Olsen 2001), and a GPS, type MLR SP24 XC, was used for positioning (WGS 84, accuracy ± 5 m). Water depths were registered by echo sounding (Skipper 417 with printer) from the raft. When possible, the coring sites within each lake were chosen according to the suggestions in Longva and Olsen (2001). There are some exceptions, for instance in the large lakes Rotevatnet and Hovdevatnet, where weather conditions did not allow coring exactly at the suggested localities. Also, 26 coring localities were sampled, compared to the 16 suggested.

4. LAKES CORED

Sediment cores were taken from the following lakes, cited from south to north (Figs. 4 and 5, Table 1):

Eid commune, Nordfjord, Sogn & Fjordane

- Storsætervatnet, Eid — Map sheet Nordfjordeid (1218I), scale 1:50 000

Volda commune, Sunnmøre, Møre & Romsdal

- Medvatnet, Volda, — Map sheet Volda (1119II), scale 1:50 000
- Nedstevatnet, Volda — Map sheet Volda (1119II), scale 1:50 000
- Rotevatnet, Volda — Map sheet Volda (1119II), scale 1:50 000

Ørsta commune, Sunnmøre, Møre & Romsdal

- Hovdevatnet, Ørsta — Map sheet Volda (1119II), scale 1:50 000

5. FIELD WORK

The field work was executed during weeks 26 and 27 by Connie Hovland, Runar Sandnes, Eivind Sønstegaard, Torbjørn Stokke (week 26) and Stein Joar Hegland (week 27).

The uppermost part of the lake sediments are normally very soft, and the piston corer will in most cases penetrate some centimeters or a few desimeters into top gyttja before sampling starts. Nevertheless, the uppermost part of the core was often more or less floating and disturbed, due to the high water content.

The cores were cut into maximum 1.5 m long sections, which is the maximum length accepted by the multisensor core logging (MSCL) equipment. Several of the cores were inspected in the field by slicing through the core liner. In many of them, the Vedde Ash Layer (a ca. 10 500 ^{14}C years old tephra layer) and the Younger Dryas-Holocene boundary were identified. The Younger Dryas- Holocene boundary can usually be identified by a change from silt in the Younger Dryas to gyttja in the Holocene.

Generally, there is good accordance between our water depth measurements and those given in the penetration echosounder profiles (Longva and Olsen 2001).

The total number of collected cores are 26, compared to 16 recommended, and the combined core length is 70 m. The location of the cores on maps and on penetration echosounder profiles are shown in Figs. 6-25.

6. REFERENCES

Bondevik, S., Svendsen, J. I. and Mangerud, J. 1998: Distinction between the Storegga Tsunami and the Holocene marine transgression in coastal basin deposits of western Norway. *Journal of Quaternary Science 13*, 529-537.

Grøsfjeld, K., Larsen, E., Sejrup, H. P., de-Vernal, A., Flatebø, T., Vestbø, M., Haflidason, H. and Aarseth, I. 1999: Dinoflagellate cysts reflecting surface-water conditions in Voldafjorden, western Norway during the last 11 300 years. *Boreas 28*, 403-415.

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Nesje, A. 1992: A Piston Corer for Lacustrine and Marine Sediments. *Arctic and Alpine Research 24*, 257-259.

Nesje, A., Søgnen, K., Elgersma, A. and Dahl, S.O. 1987: A piston corer for lake sediments. *Norsk Geografisk Tidsskrift 41*, 123-125.

Sejrup, H.P., Haflidason, H., Flatebø, T., Klitgaards Kristensen, D., Grøsfjeld, K. and Larsen, E. 2001: Late-glacial to Holocene environmental changes and climate variability: evidence from Voldafjorden, western Norway. *Journal of Quaternary Science 16*, 181-198.

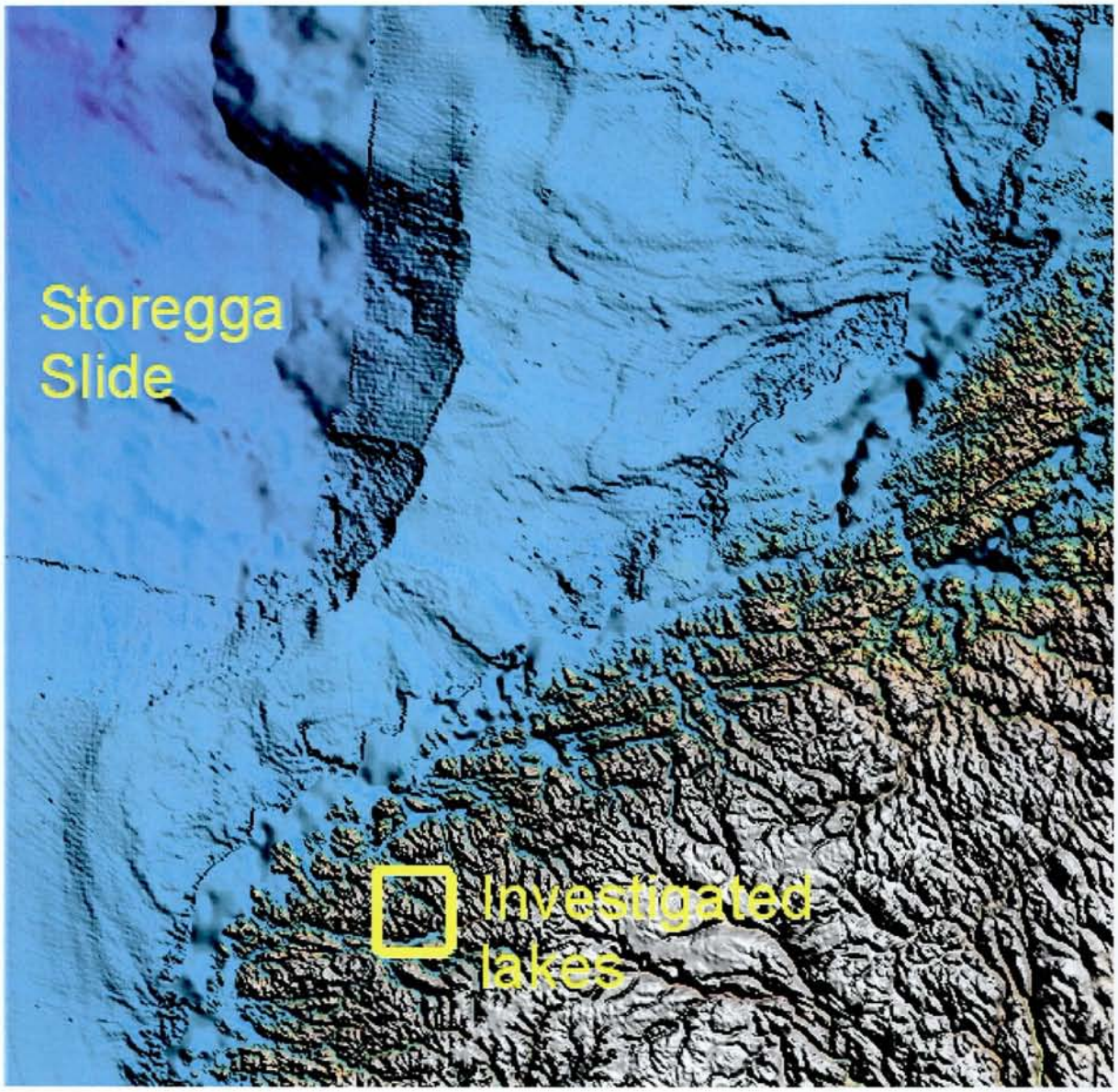
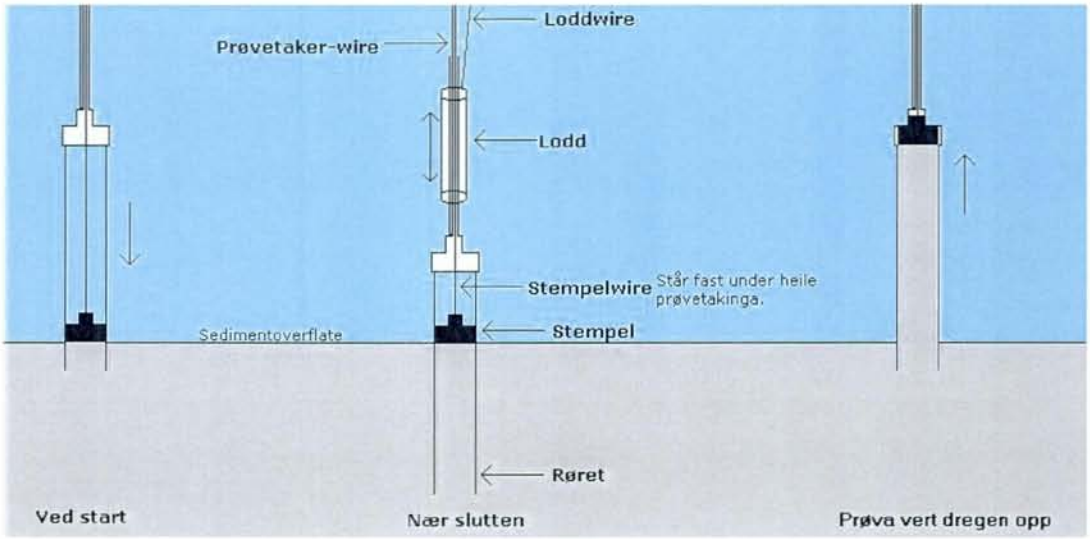


Figure 1. Overview map showing the location of the investigated lakes in relation to the location of the Storegga Slide.



Figur 2. Livingstone piston corer sampling principle.

Raft transport

From Storsætervatnet

The core is hauled up by means of a jack

Sample from Rotevatnet taken by Russian corer. Vedde Ash close to the bottom

Fig. 3. Photos from the coring activities.

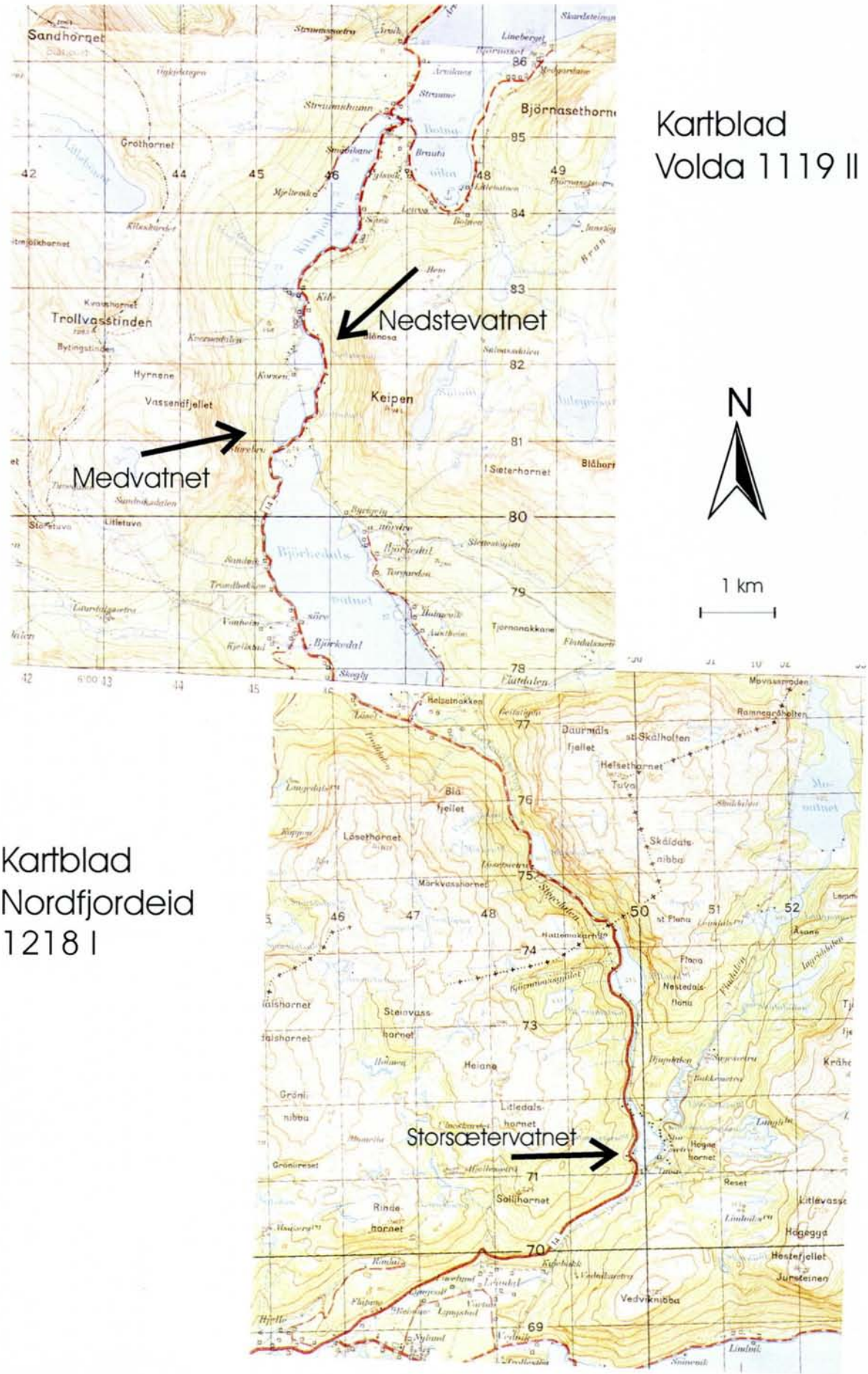


Fig. 4. Mapshowing the location of Storsætervatnet, Medvatnet and Nedstevatnet.

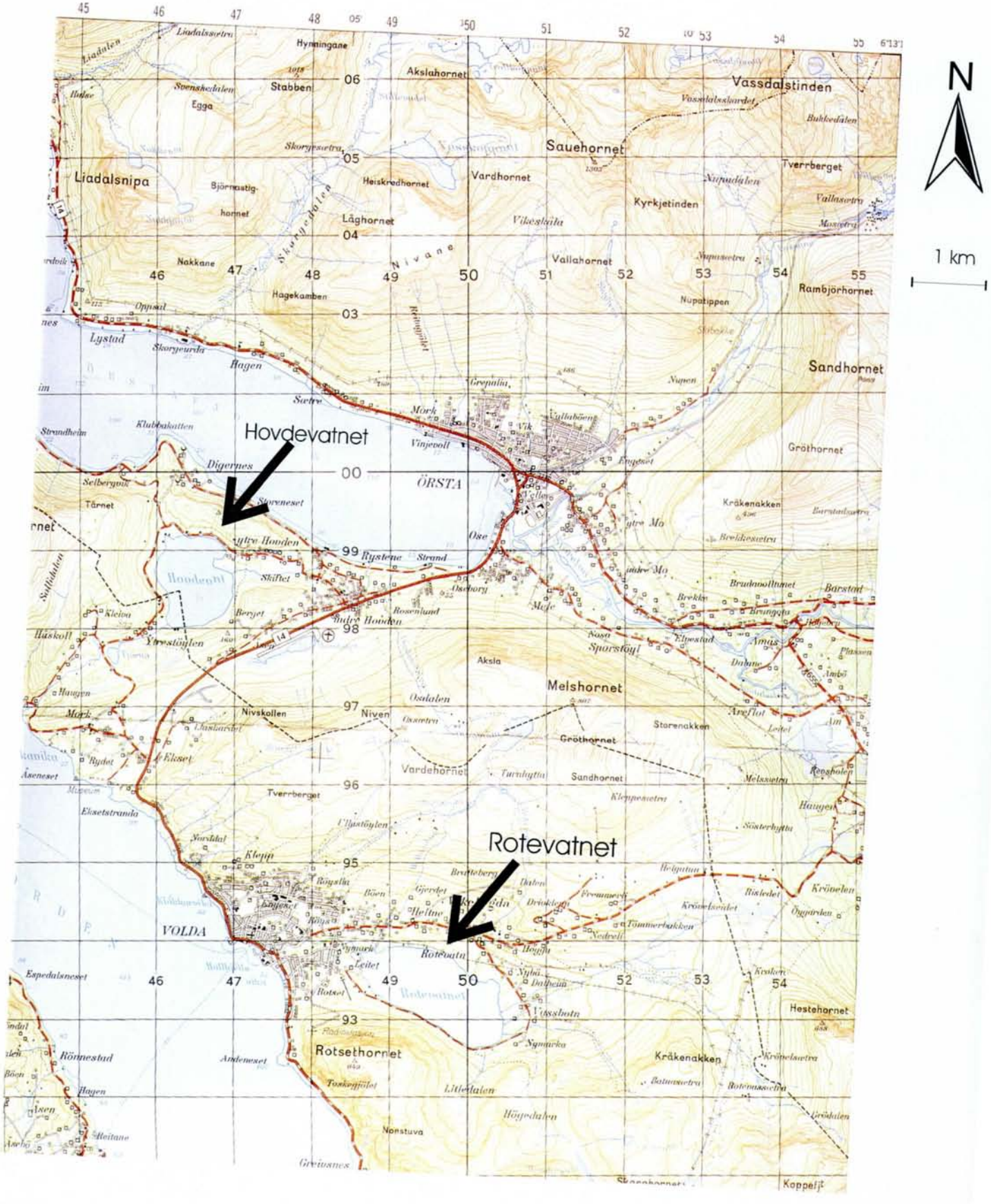


Fig. 5. Map showing the location of Rotevatnet and Hovdevatnet.

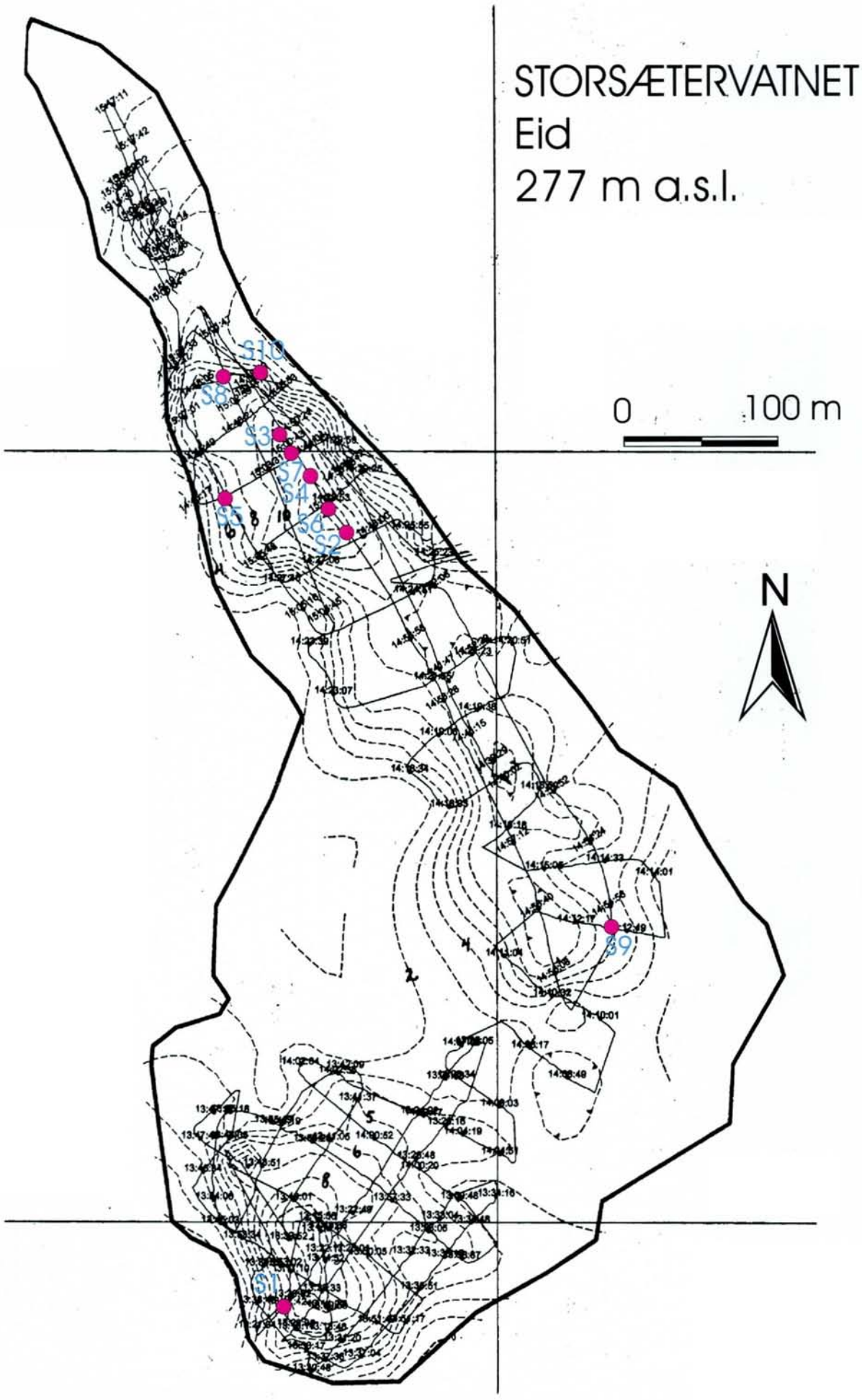


Fig. 6. Storsætervatnet. Map showing bathymetry, seismic profiles and core locations.

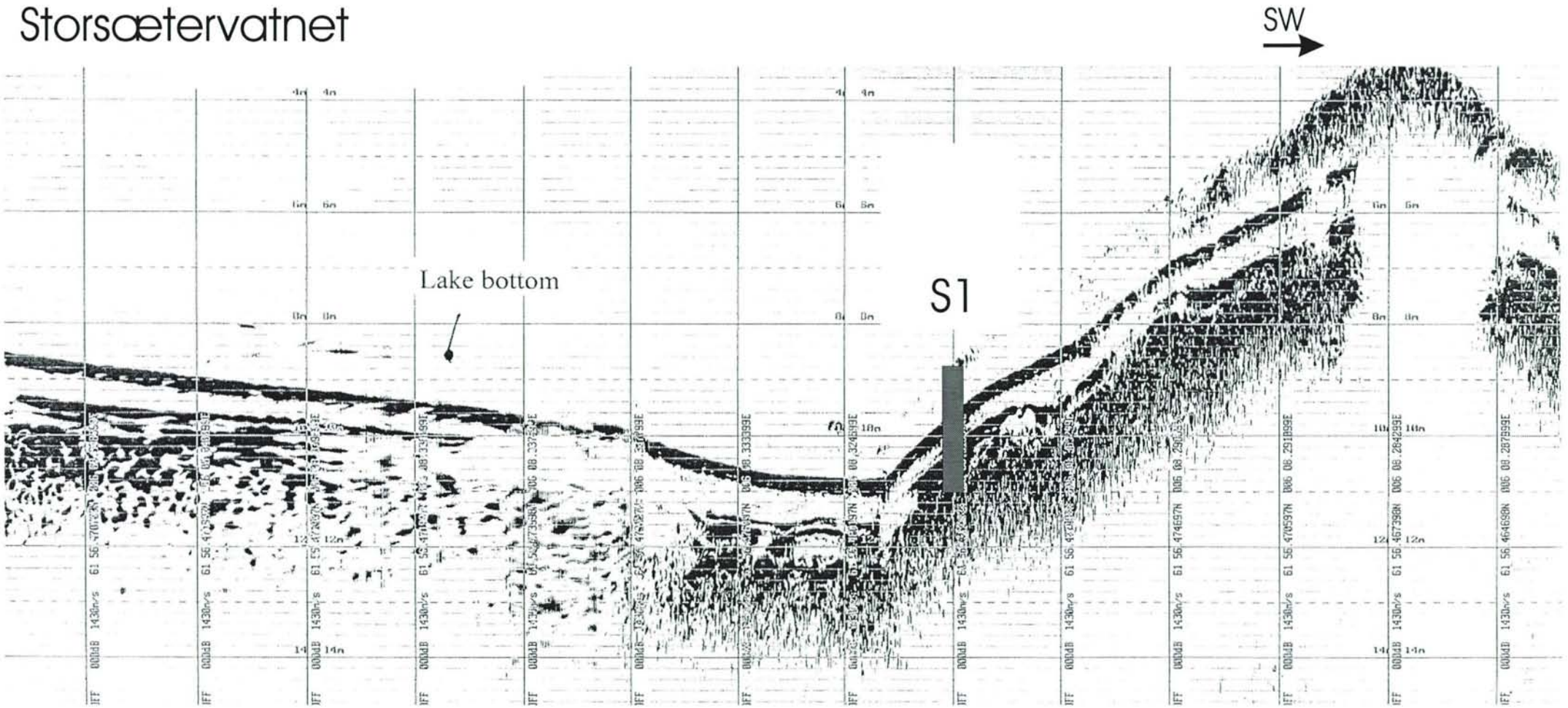


Fig. 7. Storsætervatnet. Seismic profile showing the location of core S1.

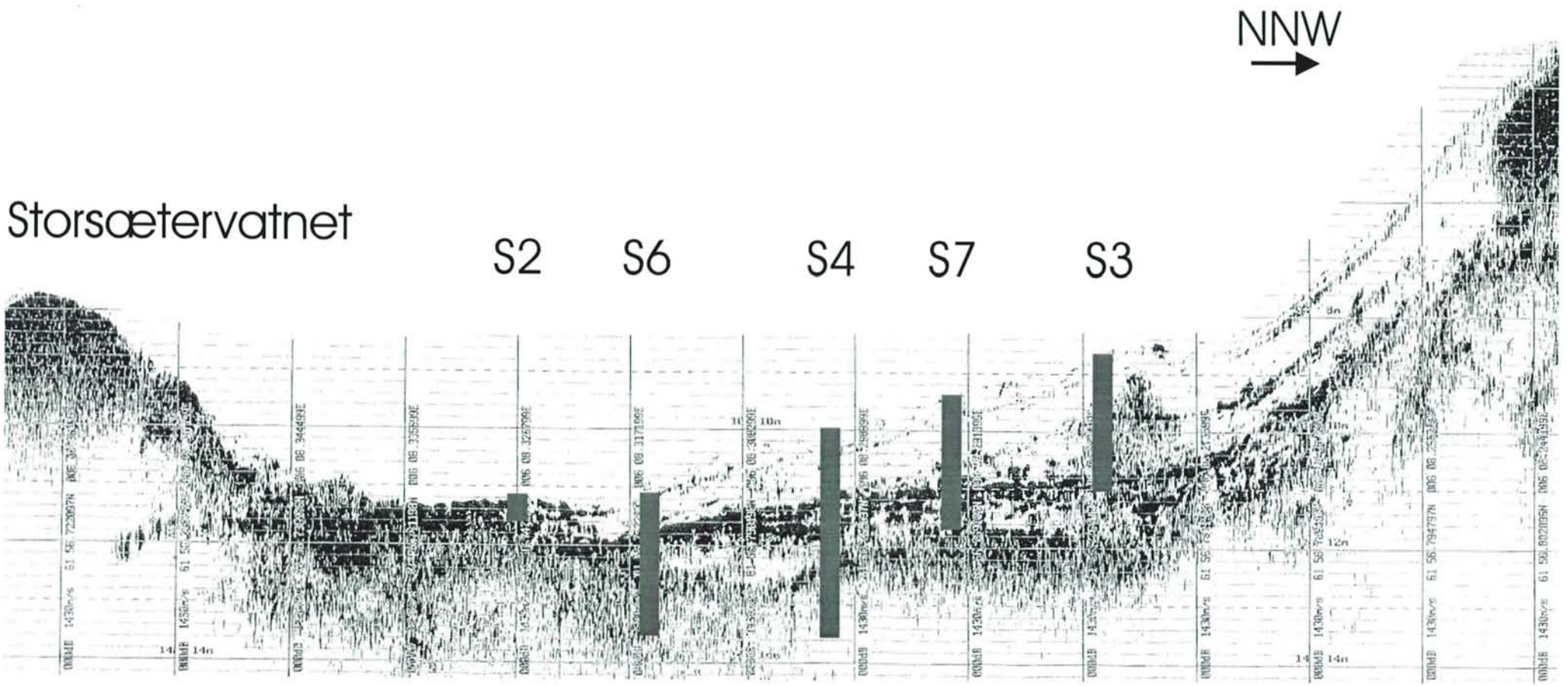


Fig. 8. Storsætervatnet. Seismic profile showing the locations of cores S2, S3, S4, S6 and S7.

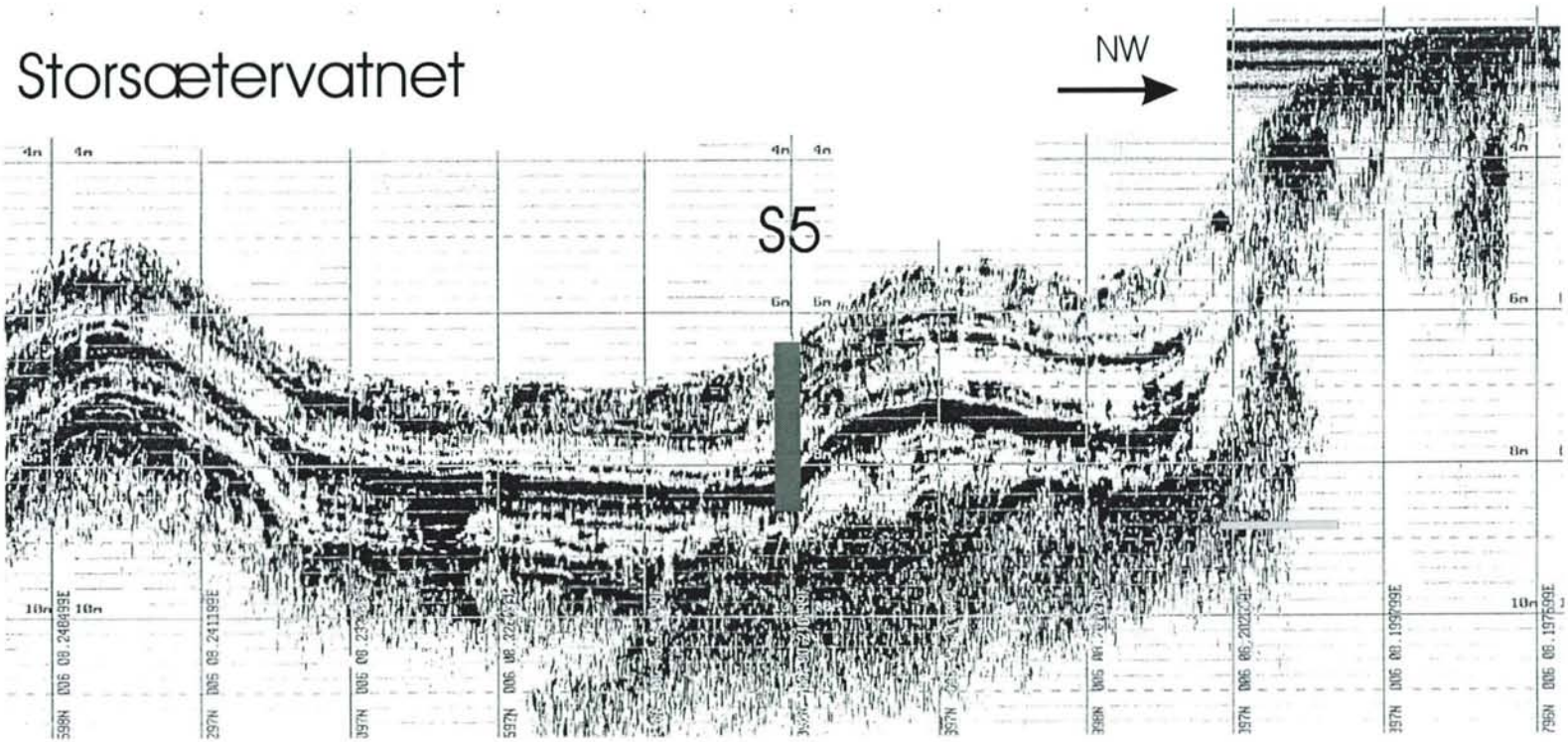


Fig. 9. Storsætervatnet. Seismic profile showing the location of core S5.

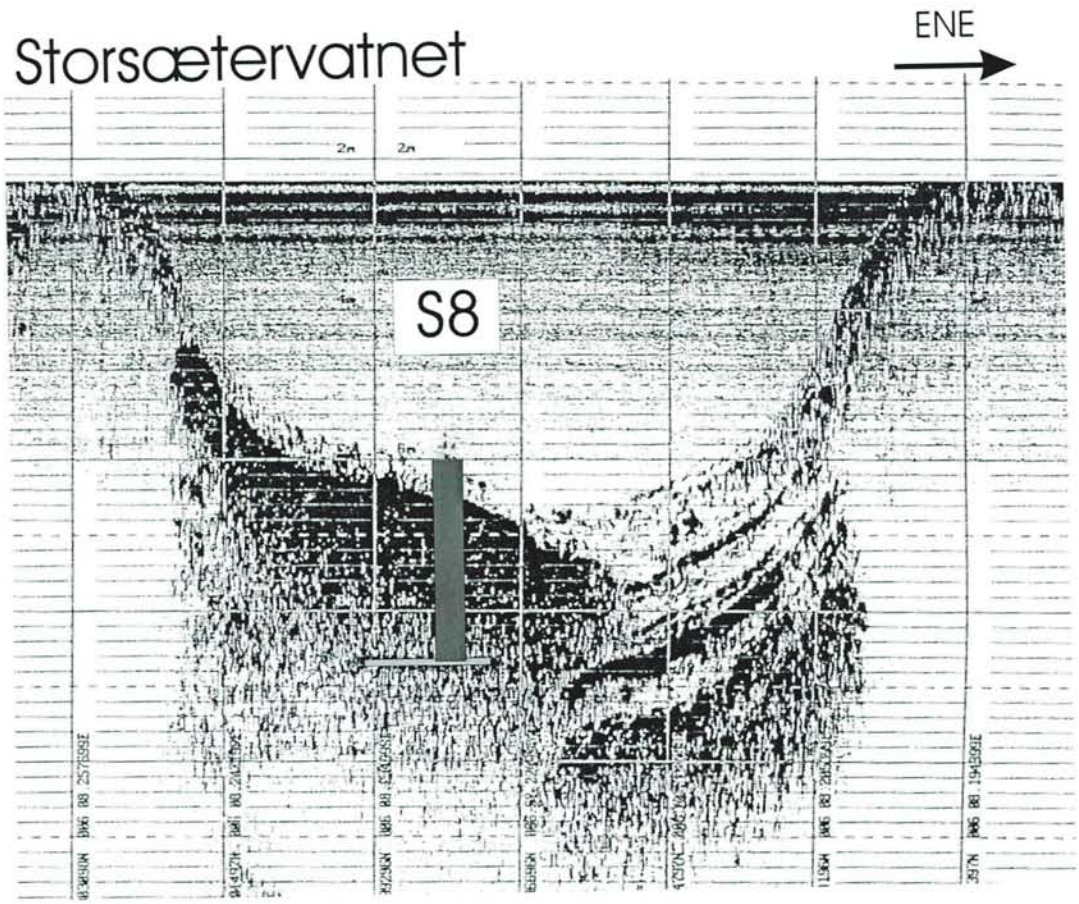


Fig. 10. Storsætervatnet. Seismic profile showing the location of core S8.

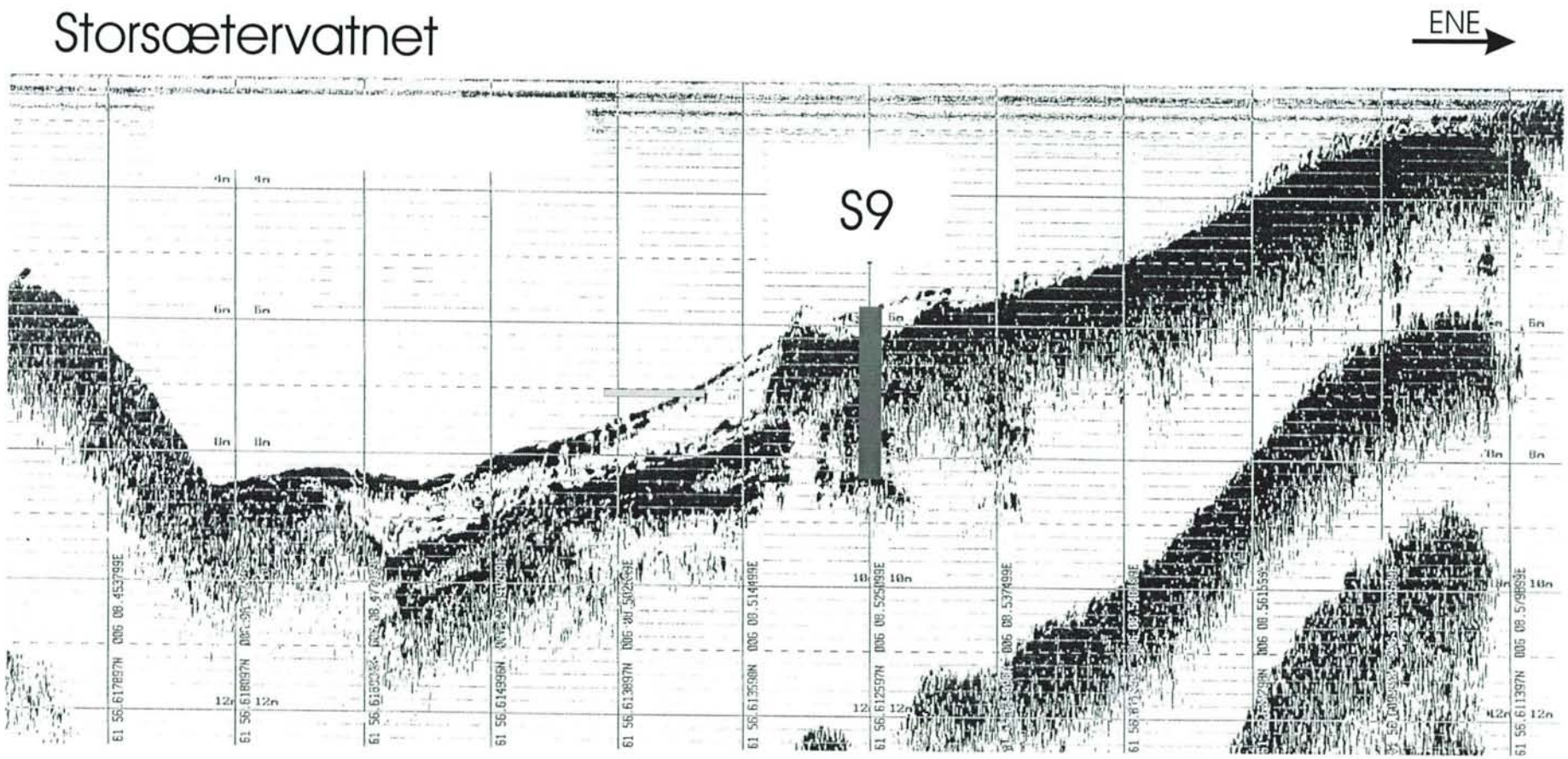


Fig. 11. Storsætervatnet. Seismic profile showing the location of core S9.

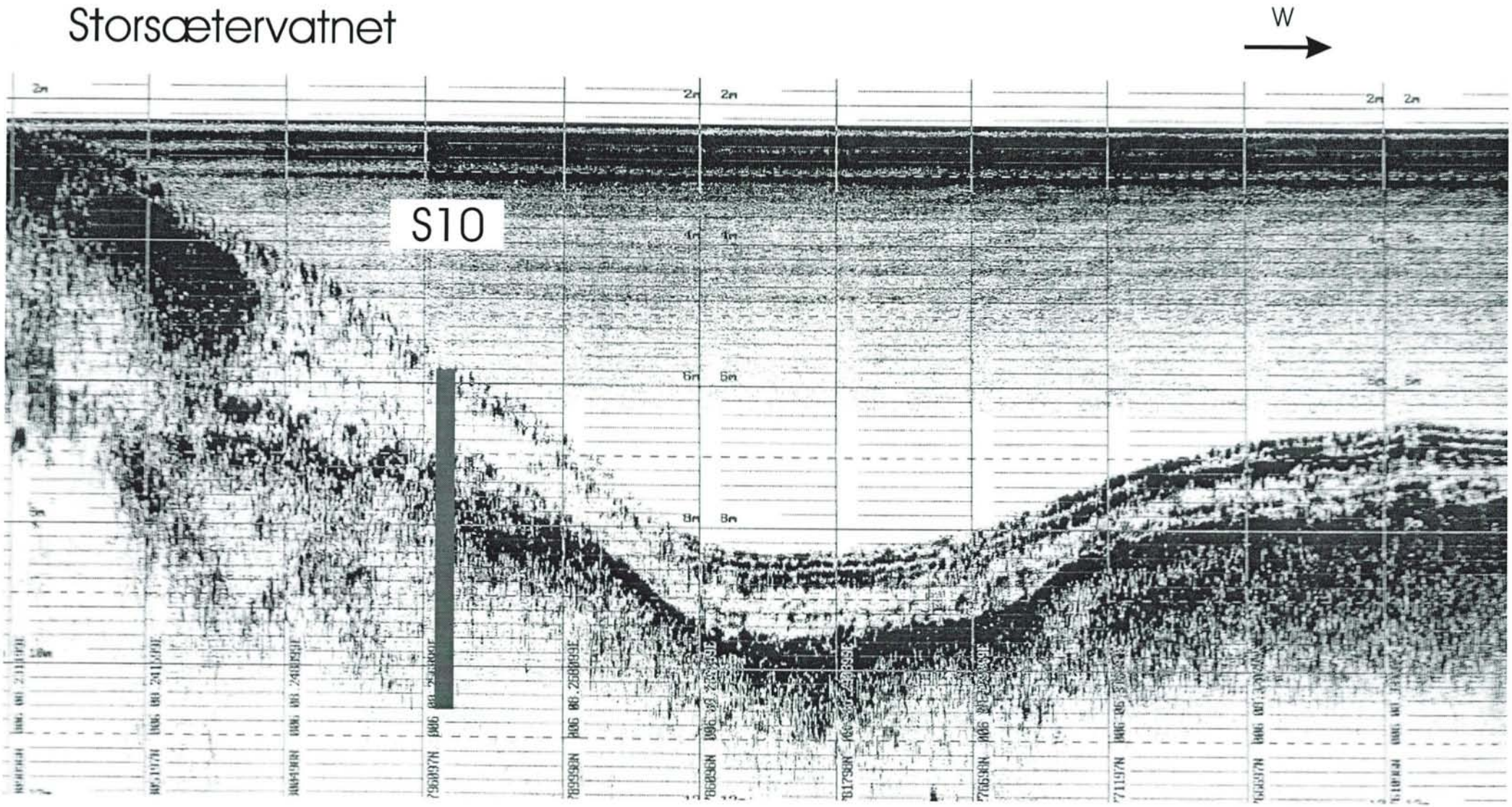


Fig. 12. Storsætervatnet. Seismic profile showing the location of core S10.

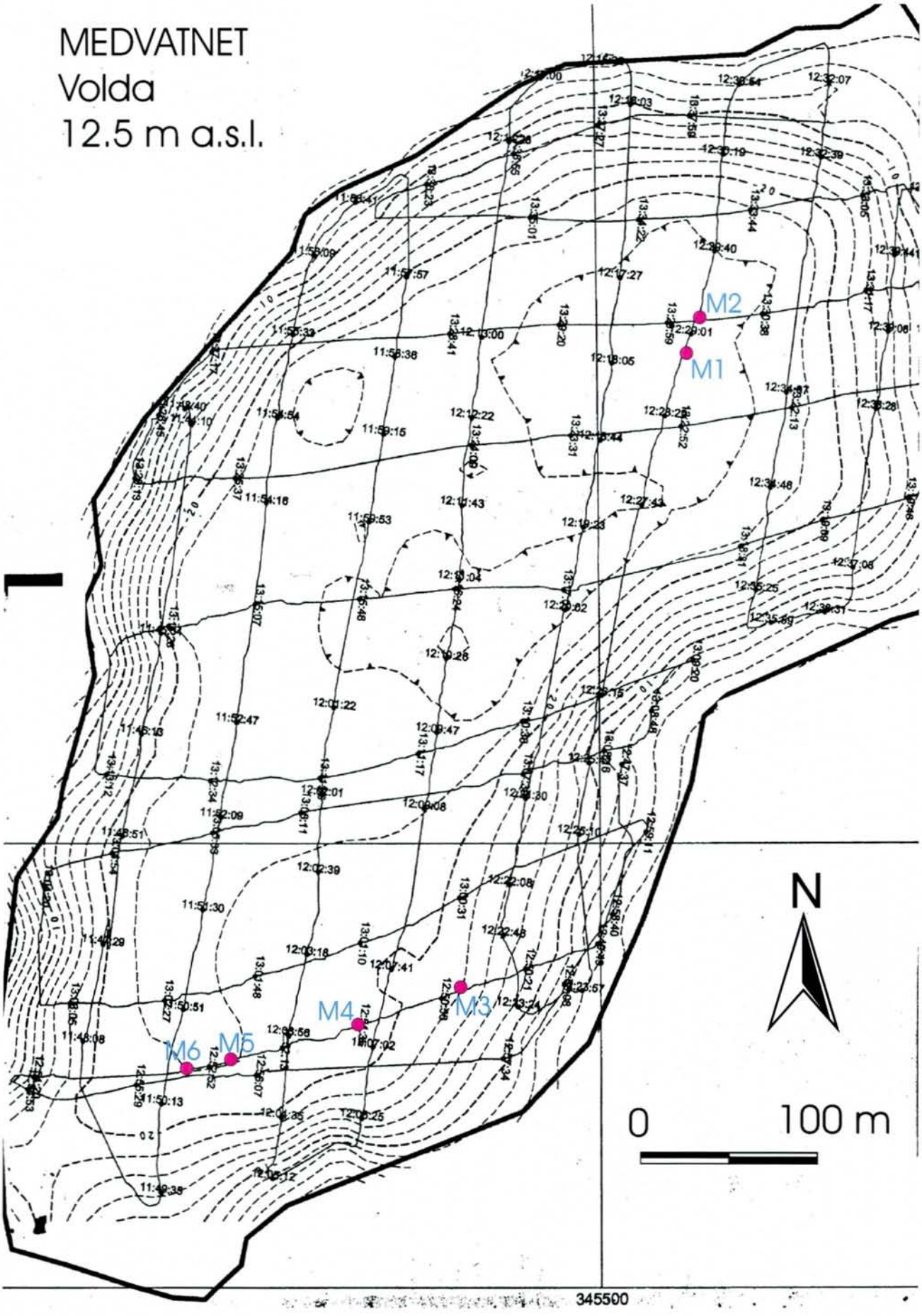


Fig. 13. Medvatnet. Map showing bathymetry, seismic profiles and core locations.

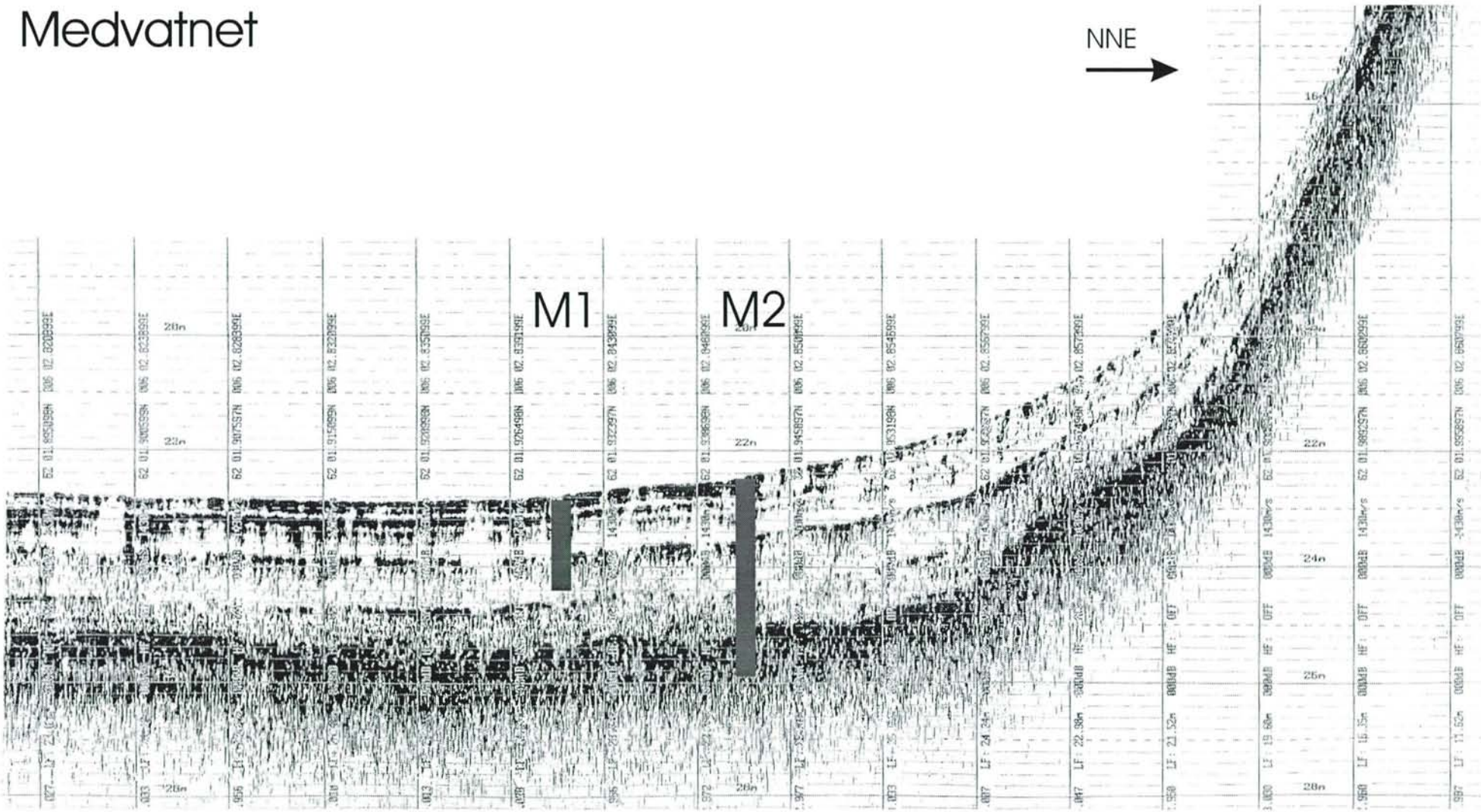


Fig. 14. Medvatnet. Seismic profile showing the locations of cores M1 and M2.

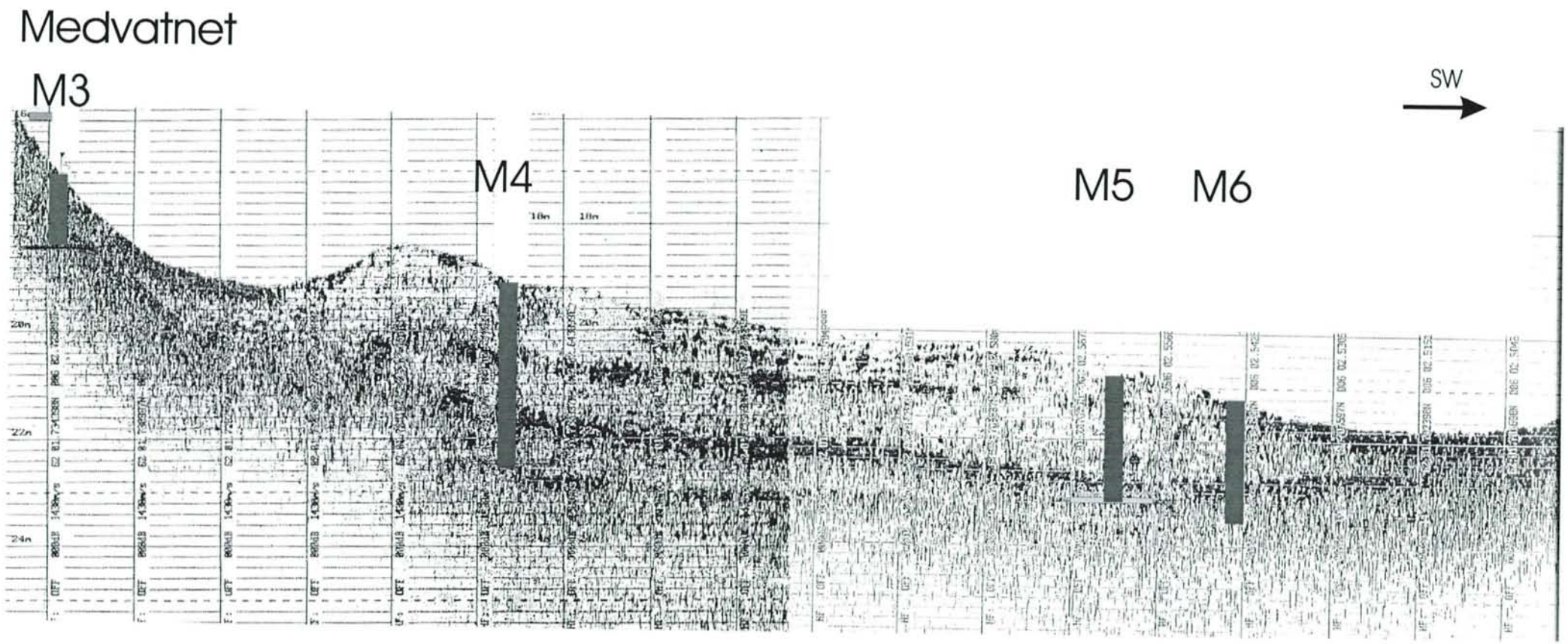


Fig. 15. Medvatnet. Seismic profile showing the locations of cores M3, M4, M5 and M6.

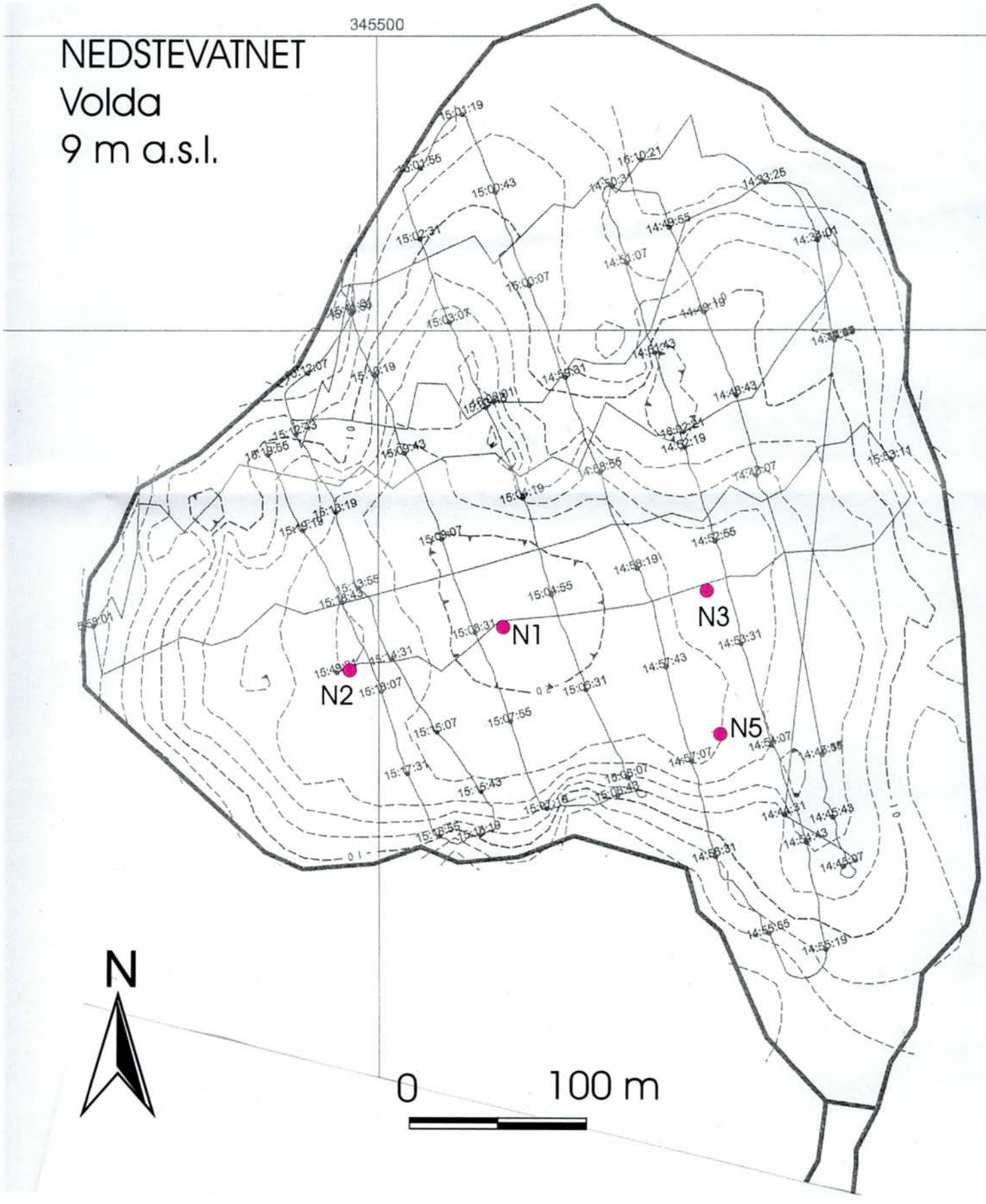


Fig. 16. Nedstevatnet. Map showing bathymetry, seismic profiles and core locations.

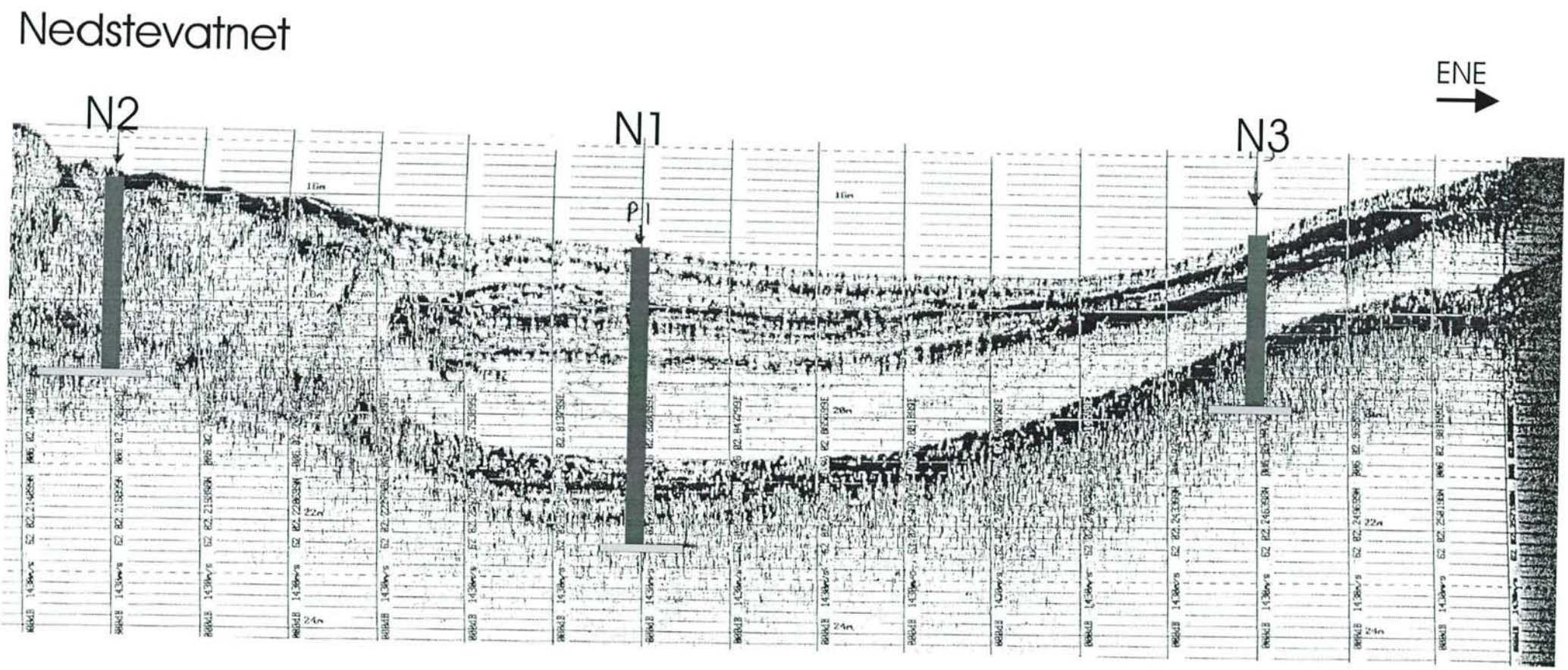


Fig. 17. Nedstevatnet. Seismic profile showing the locations of cores N1, N2 and N3.

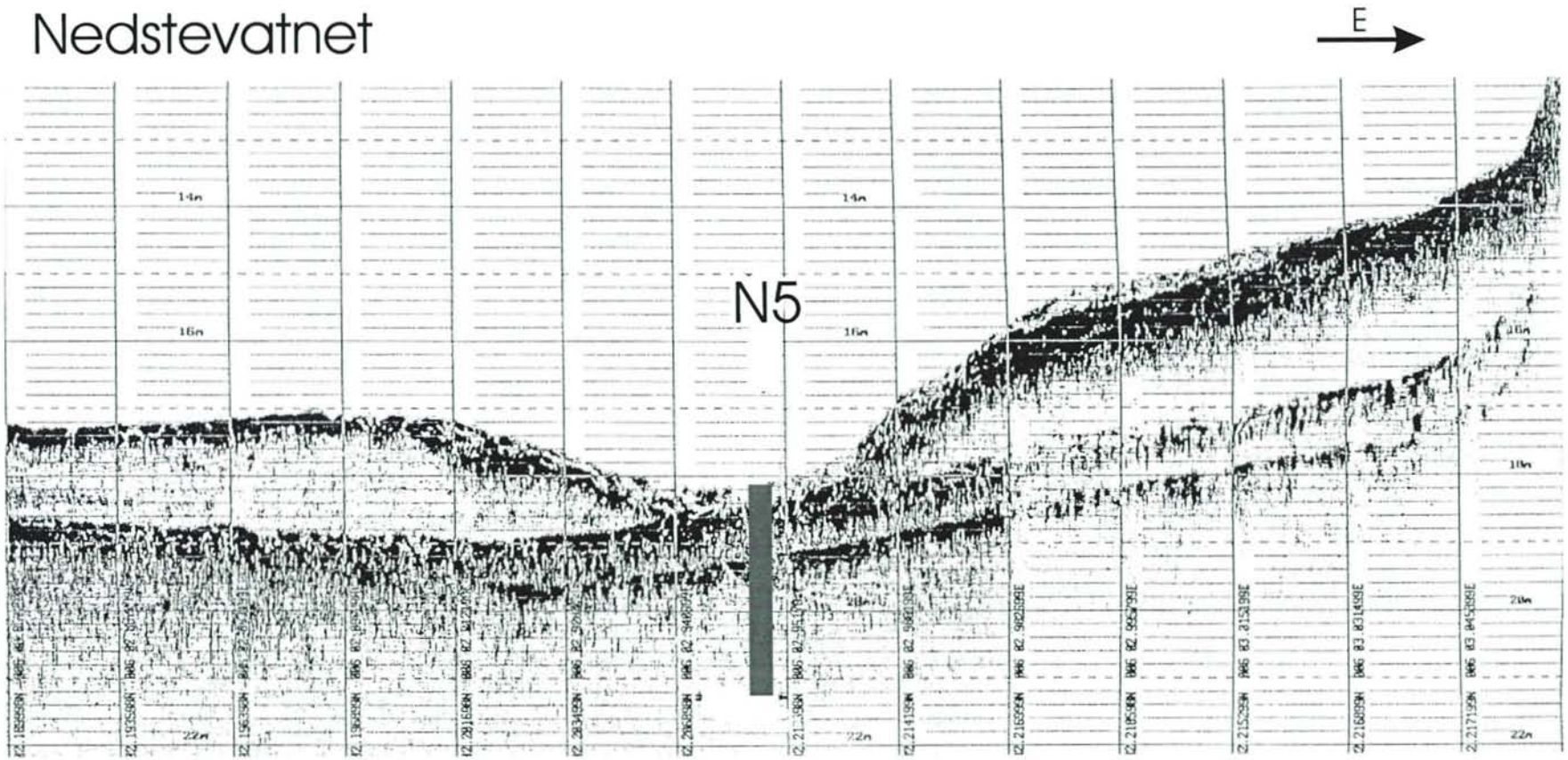


Fig. 18. Nedstevatnet. Seismic profile showing the location of core N5.

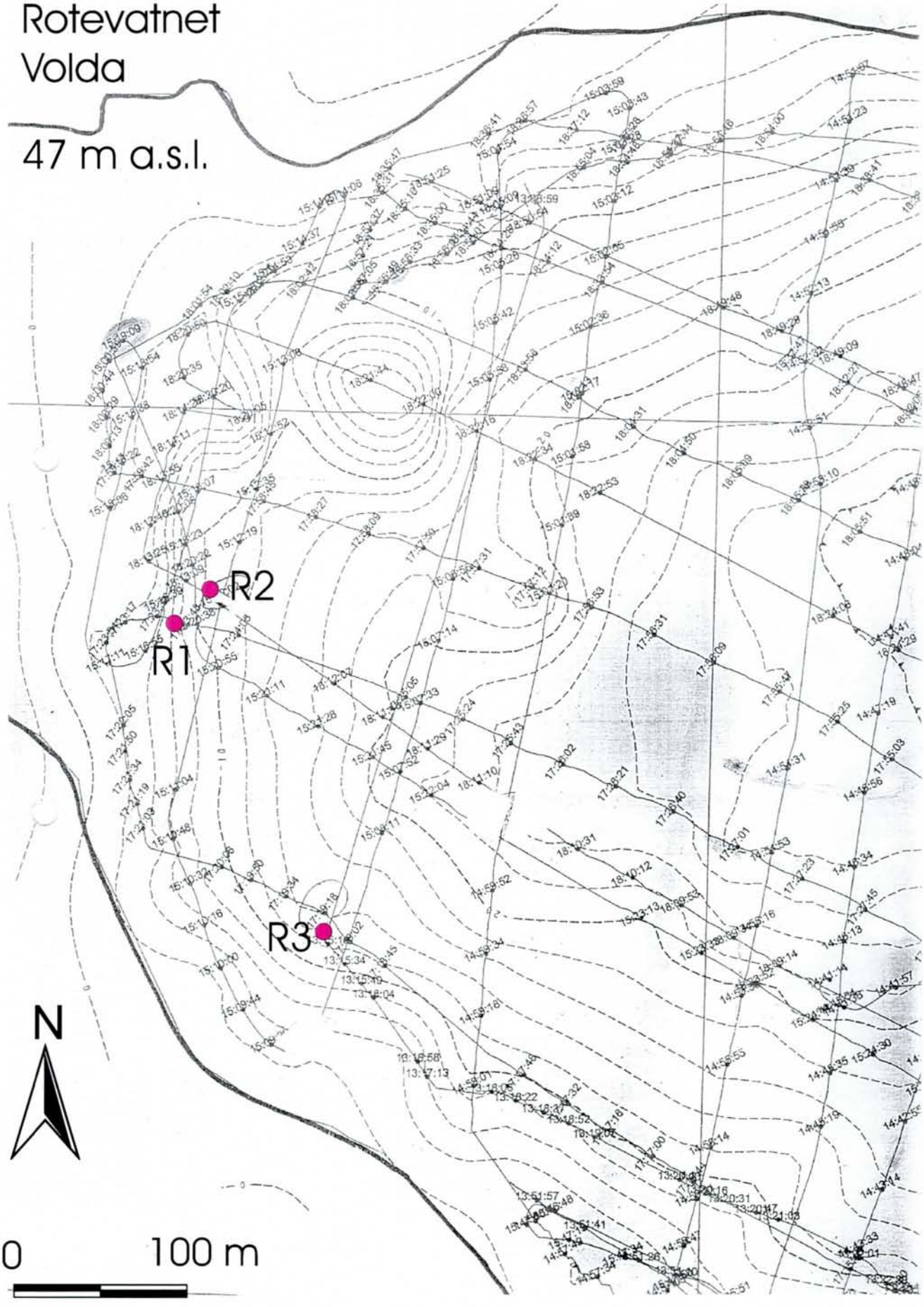


Fig. 19. Rotevatnet. Map showing bathymetry, seismic profiles and core locations.

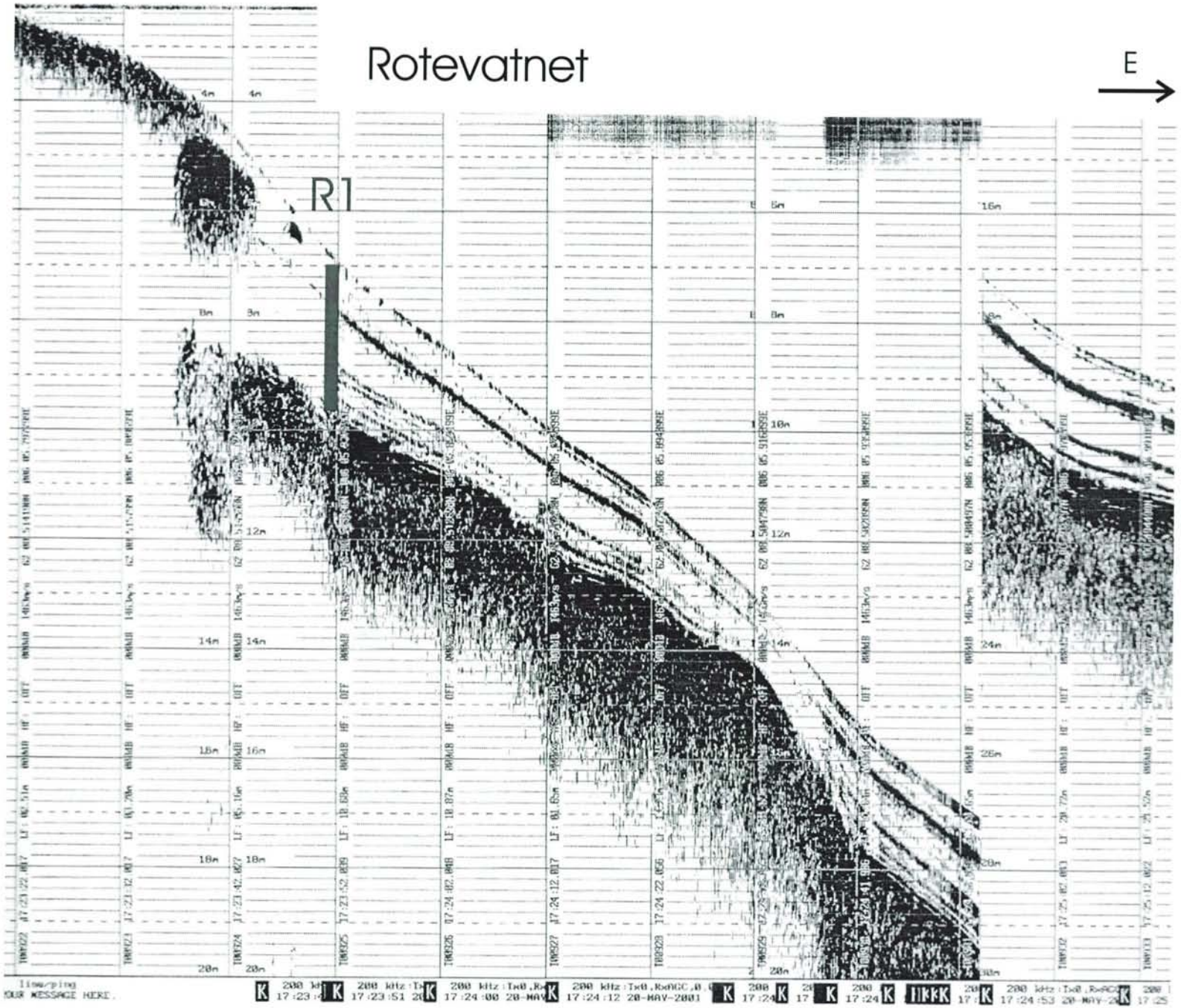


Fig. 20. Rotevatnet. Seismic profile showing the location of core R1.

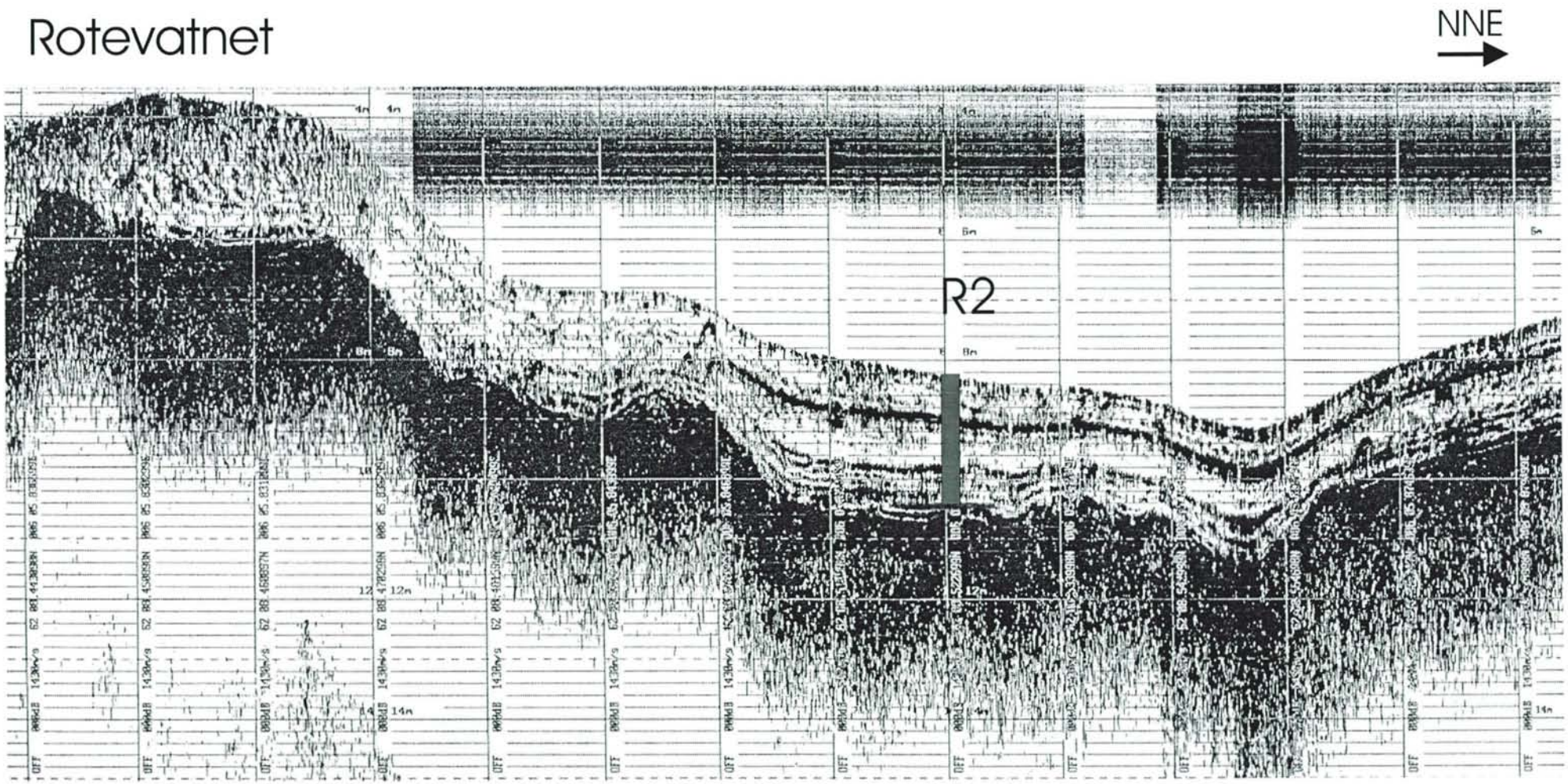


Fig. 21. Rotevatnet. Seismic profile showing the location of core R2.

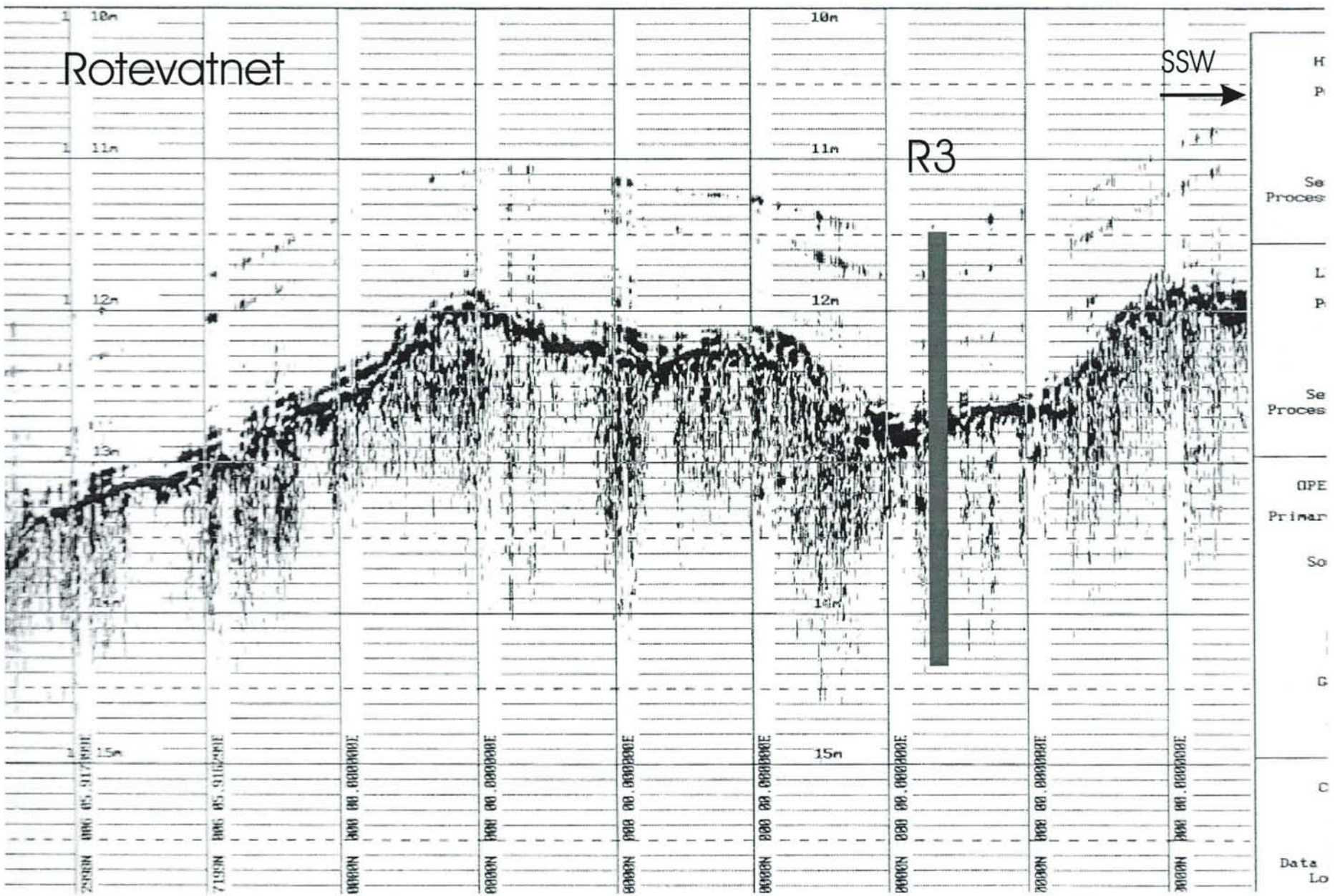


Fig. 22. Rotevatnet. Seismic profile showing the location of core R3.

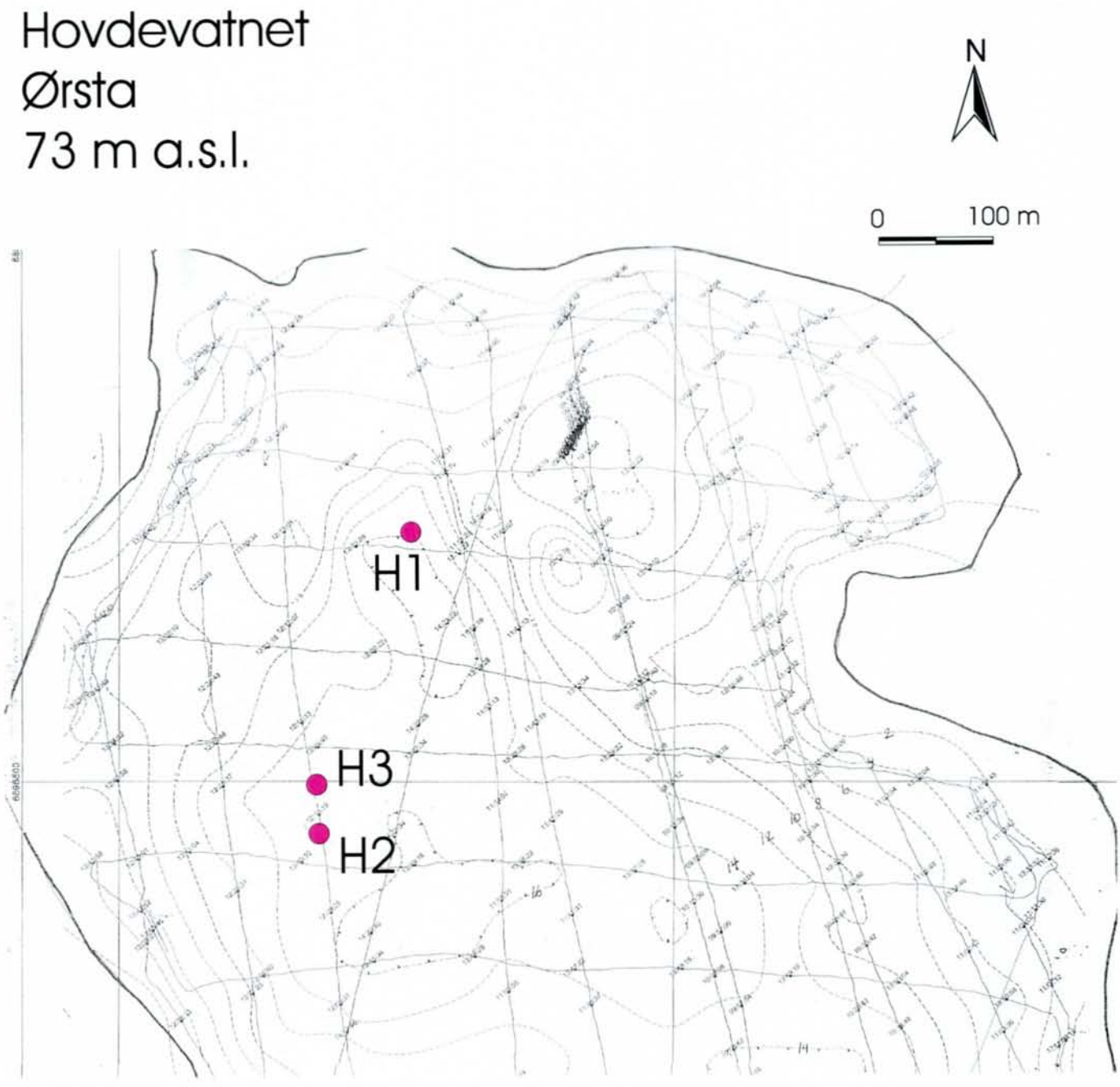


Fig. 23. Hovdevatnet. Map showing bathymetry, seismic profiles and core locations.

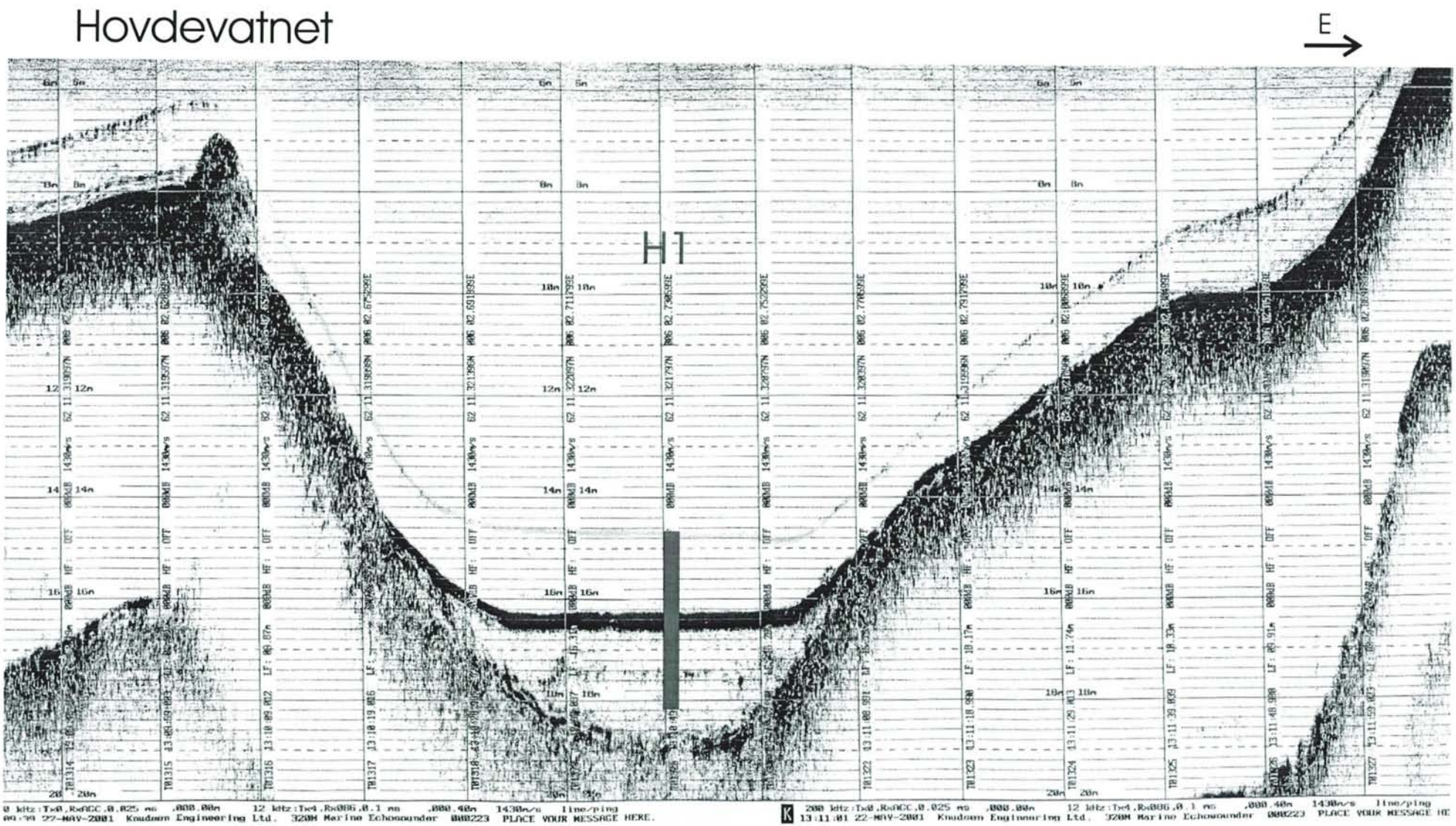


Fig. 24. Hovdevatnet. Seismic profile showing location of core H1.

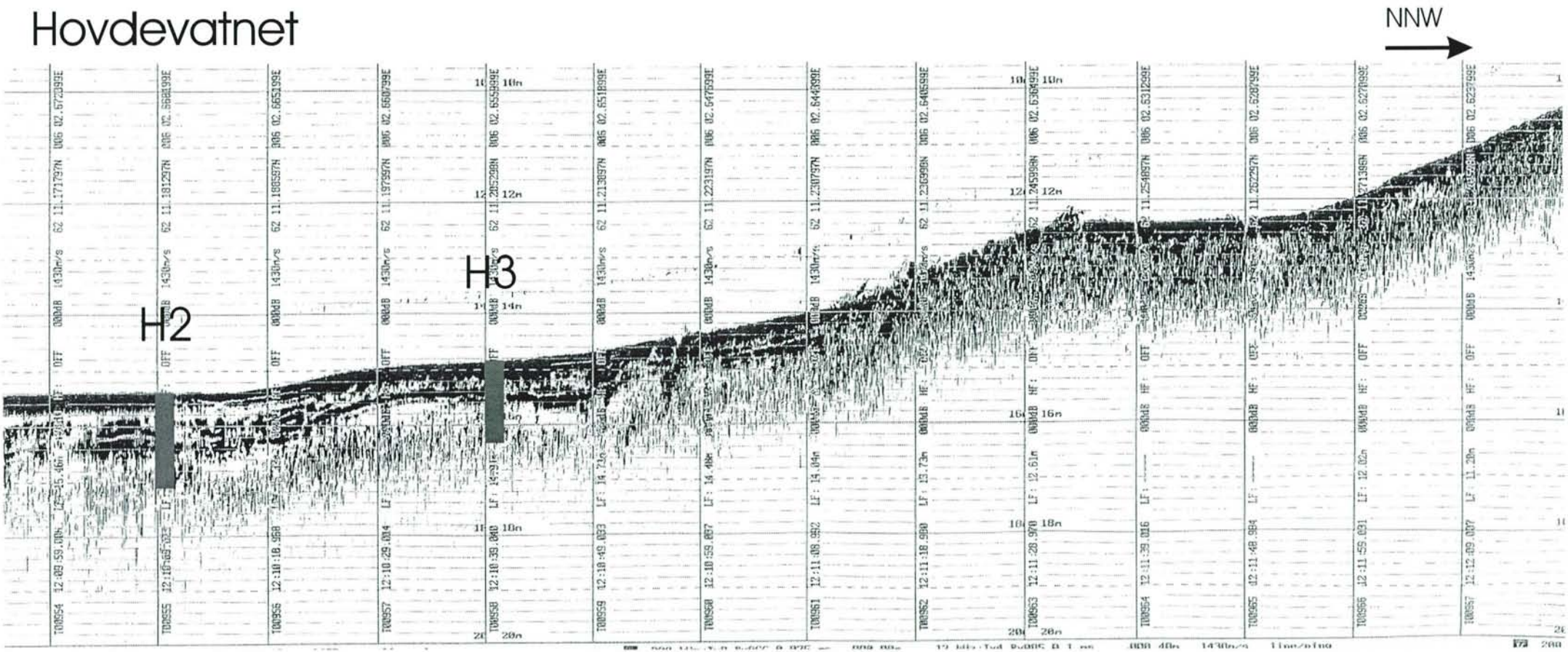


Fig. 25. Hovdevatnet. Seismic profile showing the locations of cores H2 and H3.

Table 1. Cores collected from lakes in Sunnmøre and Nordfjord

Lake name	Metres a.s.l.	Core number	Latidude (WGS84)	Longitude (WGS84)	Time	Water depth (m)	Core length (cm)
Storsetervatnet	277	S1	61 56 481	06 08 312	13:20:25	9	220
Storsetervatnet	277	S2	61 56 740	06 08 328	14:59:53	11	49
Storsetervatnet	277	S3	61 56 778	06 08 282	15:00:47	9	234
Storsetervatnet	277	S4	61 56 772	06 08 302	15:00:23	9	350
Storsetervatnet	277	S5	61 56 778	06 08 213	15:06:55	6	219
Storsetervatnet	277	S6	61 56 758	06 08 315	15:00:07	10	264
Storsetervatnet	277	S7	61 56 776	06 08 292	15:00:33	9	214
Storsetervatnet	277	S8	61 56 798	06 08 218	14:47:50	6	251
Storsetervatnet	277	S9	61 56 615	06 08 525	14:12:35	6	250
Storsetervatnet	277	S10	61 56 800	06 08 249	14:47:00	6	484
Medvatnet	12,5	M1	62 01 929	06 02 923	12:28:58	21	160
Medvatnet	12,5	M2	62 01 941	06 02 887	12:29:17	22	350
Medvatnet	12,5	M3	62 01 740	06 02 726	12:50:45	19	125
Medvatnet	12,5	M4	62 01 717	06 02 650	12:51:37	19	350
Medvatnet	12,5	M5	62 01 700	06 02 562	12:52:48	21	242
Medvatnet	12,5	M6	62 01 733	06 02 544	12:53:02	22,5	242
Nedstevatnet	9	N1	62 02 223	06 02 833	15:50:20	17	540
Nedstevatnet	9	N2	62 02 217	06 02 730	15:49:21	15	383
Nedstevatnet	9	N3	62 02 246	06 02 934	15:51:30	17	330
Nedstevatnet	9	N5	62 02 209	06 02 944	15:36:25	18	313
Rotevatnet	47	R1	62 08 517	06 05 831	17:23:52	6	290
Rotevatnet	47	R2	62 08 524	06 05 853	15:12:02	8	231
Rotevatnet	47	R3	62 08 434	06 05 928	13:14:45	12,5	290
Hovdevatnet	73	H1	62 11 315	06 02 732	13:10:49	15	290
Hovdevatnet	73	H2	62 11 183	06 02 664	12:10:09	14	170
Hovdevatnet	73	H3	62 11 207	06 02 666	12:10:40	14	150

Appendix 1

Field core log

Storsætervatnet (277 meters above sea level)

Core S1

Latitude: 61°56,481 N
Longitude: 06°08,312 E
Coring site (time) from seismic data: 13:20:25
Water depth: 9 m
Core length: 220 cm

Light brown to grey silt/clay at the base. Loose gyttja in the upper part.

Core S2

Latitude: 61°56,740 N
Longitude: 06°08,328 E
Coring site (time) from seismic data: 14:59:53
Water depth: 11 m
Core length: 49 cm

Barrel stopped in hard clay. Inspection of the core by slicing through the core liner showed the presence of the Vedde Ash Layer and the Younger Dryas-Holocene boundary. Fine lamination above Vedde Ash Layer.

Core S3

Latitude: 61°56,778 N
Longitude: 06°08,282 E
Coring site (time) from seismic data: 15:00:47
Water depth: 9 m
Core length: 234 cm

Loose clay/gyttja. Lower part of core possibly disturbed by sliding. Inspection of the core by slicing through the core liner showed no Vedde Ash Layer.

Core S4

Latitude: 61°56,772 N
Longitude: 06°08,302 E
Coring site (time) from seismic data: 15:00:23
Water depth: 9 m
Core length: 350 cm. Top section 169 cm. Bottom section 181 cm.

Gyttja at 169 cm depth. Inspection of the core by slicing through the core liner showed no Vedde Ash Layer. Sharp boundary between gyttja and silt in the upper part of the core.

Core S5

Latitude: 61°56,778 N
Longitude: 06°08,213 E
Coring site (time) from seismic data: 15:06:55
Water depth: 6 m
Core length: 219 cm

Loose, glaciolacustrine clay/silt. Inspection of the core by slicing through the core liner showed the Younger Dryas-Holocene boundary, and the Vedde Ash Layer to be present. The lower part of the core contains 35 cm silt.

Core S6

Latitude: 61°56,758 N
Longitude: 06°08,315 E
Coring site (time) from seismic data: 15:00:07
Water depth: 10 m
Core length: 264 cm. Top section 132 cm. Bottom section 132 cm.

Gyttja in top section and upper 2 cm of bottom section. Sandy silt in remaining part of bottom section.

Core S7

Latitude: 61°56,776 N
Longitude: 06°08,292 E
Coring site (time) from seismic data: 15:00:33
Water depth: 9 m
Core length: 214 cm. Top section 76 cm. Bottom section 138 cm.

Silt with gyttja.

Core S8

Latitude: 61°56,798 N
Longitude: 06°08,218 E
Coring site (time) from seismic data: 14:47:50
Water depth: 6 m
Core length: 251cm. Top section 105 cm. Bottom section 146 cm.

Gyttja in upper part. The core was cut 10 cm below the sediment surface.

Core S9

Latitude: 61°56,615 N
Longitude: 06°08,525 E
Coring site (time) from seismic data: 14:12:35
Water depth: 6 m
Core length: 250 cm

Core S10

Latitude: 61°56,800 N
Longitude: 06°08,249 E
Coring site (time) from seismic data: 14:47:00
Water depth: 6 m
Core length: 484 cm. Top section 189 cm. Middle section 142 cm. Bottom section 153 cm.

Silt in lower section.

Medvatnet (12.5 meters above sea level)

Core M1

Latitude: 62°01,929 N
Longitude: 06°02,923 E
Coring site (time) from seismic data: 12:28:58
Water depth: 21 m
Core length: 160 cm

Shell fragments and gravel particles up to 1.5 cm in diameter in the lower part. The core was opened (split in two) in the field. Inspection of the core showed a 7 cm thick sand layer supposed to be a tsunami deposit.

Core M2

Latitude: 62°01,941 N
Longitude: 06°02,887 E
Coring site (time) from seismic data: 12:29:17
Water depth: 22 m
Core length: 350 cm. Top section 165 cm. Bottom section 185 cm.

Smells H_2S.

Core M3

Latitude: 62°01,740 N
Longitude: 06°02,726 E
Coring site (time) from seismic data: 12:50:43
Water depth: 19 m
Core length: 125 cm

Gravelly in lower part, with unbroken shells and carbonate worm tubes.

Core M4

Latitude: 62°01,717 N
Longitude: 06°02,650 E
Coring site (time) from seismic data: 12:51:37
Water depth: 19 m
Core length: 350 cm. Top section 160 cm. Bottom section 190 cm.

Glaciomarine silt in lower part.

Core M5

Latitude: 62°01,700 N
Longitude: 06°02,562 E
Coring site (time) from seismic data: 12:52:48
Water depth: 21 m
Core length: 242 cm.

Fine grained sediments with shell fragments at the base of the core. Very loose gyttja in the upper part of the core. The uppermost 18 cm of the originally 260 cm long core was cut off and discarded to get the core into the car.

Core M6

Latitude: 62°01,733 N
Longitude: 06°02,544 E
Coring site (time) from seismic data: 12:53:02
Water depth: 22.5 m
Core length: 242 cm. Top section 32 cm. Bottom section 210 cm.

First attempt of coring failed due to gravel at lake bed. Fine grained sediments with shells in lower part of core.

Nedstevatnet (9 meters above sea level)

Core N1

Latitude: 62°02,223 N
Longitude: 06°02,833 N
Coring site (time) from seismic data: 15:50:20
Water depth: 17 m
Core length: 540 cm. Top section 130 cm. Middle section 200 cm. Bottom section 210 cm.

Lower part of top section contains loose gyttja. Lower part of middle section contains gyttja. Lower part of bottom section contains glaciomarine silt and clay with small shells.

Core N2

Latitude: 62°02,217 N
Longitude: 06°02,730 E
Coring site (time) from seismic data: 15:49:21
Water depth: 15 m
Core length: 383 cm. Top section 181 cm. Bottom section 202 cm.

Friction marks on the outside of the tube up to 46 cm above the bottom due to the penetration of a gravel/cobble horizon.

Core N3

Latitude: 62°02,246 N
Longitude: 06°02,934 E
Coring site (time) from seismic data: 15:51:30
Water depth: 17 m
Core length: 330 cm. Top section 119 cm. Bottom section 211 cm.

Several friction marks on the outside of the lowermost 2 m of the tube. Twigs in upper part of lower section. Smells H_2S.

Core N5

Latitude: 62°02,209 N
Longitude: 06°02,944 E
Coring site (time) from seismic data: 15:36:25
Water depth: 18 m
Core length: 313 cm. Top section 150 cm. Bottom section 163 cm.

Clay in lower part of bottom section. Silt with shells and large pebbles in lower part of top section and upper part of bottom section. Loose gyytja in upper part of top section.

Rotevatnet (47 meters above sea level)

Core R1

Latitude: 62°08,517 N
Longitude: 06°05,831 E
Coring site (time) from seismic data: 17:23:52
Water depth: 6 m
Core length: 290 cm. Top section 144 cm. Bottom section 146 cm.

Silt in the lower part of the core.

Core R2

Latitude: 62°08,524 N
Longitude: 06°05,853 E
Coring site (time) from seismic data: 15:12:02
Water depth: 8 m
Core length: 231 cm. Top section 86 cm. Bottom section 145 cm.

Loose gyttja in upper part. Consolidated gyttja at 86 cm core depth. Silt in lower part of core.

Core R3

Latitude: 62°08,434 N
Longitude: 06°05,928 E
Coring site (time) from seismic data: 13:14:45
Water depth: 12,5 m
Core length: 290 cm. Top section 145 cm. Bottom section 145 cm.

GPS-coordinates are missing on the echosounder profile (Fig. 22), and hence the position of the core in relation to this profile is somewhat uncertain. Loose gyttja in upper part. Consolidated gyttja at 145 cm core depth. Silt in lower part of core.

Hovdevatnet (73 meters above sea level)

Core H1

Latitude: 62°11,315 N
Longitude: 06°02,732 E
Coring site (time) from seismic data: 13:10:49
Water depth: 15 m
Core length: 290 cm. Top section 145 cm. Bottom section 145 cm.

Gyttja in top of core. Clay at 145 cm core depth. Silt/sand in lower part of core.

Core H2

Latitude: 62°11,183 N
Longitude: 06°02,664 E
Coring site (time) from seismic data: 12:10:09
Water depth: 14 m
Core length: 170 cm.

Sandy silt in lower part of core.

Core H3

Latitude: 62°11,207 N
Longitude: 06°02,666 E
Coring site (time) from seismic data: 12:10:40
Water depth: 14 m
Core length: 150 cm.

Silty sand in lower part of core.