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Regional landslide occurrences and possible post-glacial earthquake activity in northwest Western Norway: Phase A2; Penetration echosounding in 5 lakes in Sunnmøre and Nordfjord

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REPORT

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Title:
Regional landslide occurrences and possible post-glacial earthquake activity in northwest Western Norway: Phase A2; Penetration echosounding in 5 lakes in Sunnmøre and Nordfjord.

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Client:
NGU, Norsk Hydro ASA, UiB and HSF

County:
Møre&Romsdal and Sogn&Fjordane

Commune:
Nordfjordeid, Volda and Ørsta

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Ulsteinvik

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1218.1 Nordfjordeid , 1119.2 Volda

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Summary:

Five lakes in Ørsta, Volda, and Nordfjordeid communes are mapped using a Knudsen 320 M/P 12 Khz echo-sounder. From the echo-sounding profiles there are made bathymetric maps for the lakes.

The acoustic profiles are interpreted at NGU with regard to disturbances of the lake-sediments - like slides or tectonic shaking. Slides are registered in all lakes. In four of the lakes these slides may have been generated from steep slopes surrounding the lakes, while in the fifth – Storesetervatnet in Nordfjordeid – the disturbances seen, have happened entirely within the lake sediments themselves. Based on the interpretation, we suggest a coring program covering all five lakes to verify the genesis of these disturbances and to date them. Adjustments to the program must be expected during coring when seismic data and cores can be related.

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1. INTRODUCTION

NGU together with Norsk Hydro ASA, the University of Bergen and the Sogn and Fjordane College has set up a project with the following aims;

- Regional compilation of occurrences of slides, avalanches and gravitational faults that may have resulted from earthquakes in northwestern Norway
- Date single events and periods of instability in fjord- and lake sediments

Questions in focus will be:

- Can the Storegga event be recognized in fjord- and lake sediments?
- If so, are there traces in the sediments of similar, younger regional events?
- Are the traces seen in the sediments due to tsunamis, earthquakes or both?
- Do data indicate large earthquakes to be more frequent shortly after the regional deglaciation than recently?

The work will be done by identification and coring of regional seismic reflectors in fjords, near-coastal waters and lakes from Sogn&Fjordane and Møre&Romsdal (Longva et. al 2001). Slide deposits in the cores will be dated. In addition, avalanches and collaps-structures onshore will be tried fitted into the same chronologic framework. The project is done during phases A-E (table) that are reported individually and compiled in a final report.

Phase	Task
A1	Compile a regional seismo-stratigraphy based on interpretation of high-resolution seismic records collected by NGU and Norsk Hydro in near-coastal waters and fjords
A2	Collect and interpret penetration echo-sounding registrations in lakes in the actual area
B1	Sample sea-bottom sediments in near-coastal areas and fjords and collect complementary seismic registrations
B2	Core lake(A2)-sediments
C	Lab.analyses; multi-logger, XRI, sedimentology and dating
D	Compilation of data on rock-avalanches and gravitational faults onshore
E	Final reporting

In this report we present interpreted penetration echo sounding profiles, waterdepth maps and suggest coring localities (Phase A2) from five lakes. The hypothesis behind the study is that if large earthquakes have triggered slides in the fjords, they may also have triggered slumping or sliding in lakes in the area. In one of the lakes, Storesætervatnet in Nordfjordeid, it has previously been documented a repetition of the Vedde ash bed – a 10500 year old layer of tephra – which indicates disturbances of the lake sediments (Mangerud et. al 1984). The aim of this study is thus to find and date possible disturbances in lake sediment and correlate events between lakes and fjords.

2. FIELD MEASUREMENTS/FIELD WORK

2.1 Penetration echosounding

Penetration echo-sounding profiles were run in five lakes in Ørsta, Volda and Nordfjordeid communes. The profiling was done by GeoCore A/S with a Knudsen 320 M/P 12 Khz echo-sounder (Bjerkli 2001, See APPENDIX). Data were registered in analogue and digital format (as *.keb-file i binary format).

The following information was stored in analogue and digital format:

- Fix-no. (about 10 sec. interval on analogue) records
- Date
- Time (local time)
- Water depth (12 KHz transducer)
- Sound Velocity, 1430 m/s (provided by NVE)
- Position, lat/long (degree/decimal/minute)

2.2 Positioning

Positioning was carried out with a GPS receiver type MLR-DGPS-FX412. The Svinøy 293.5 KHz was used as differential reference station. The GPS-antenna was placed at the echosounder transducer, and the positions were logged in WGS 84. The DGPS-coverage was satisfying at Rotevatnet, Hovdevatnet, Storesetervatnet and Medvatnet. In Nedstevatnet, the DGPS-coverage was satisfying for lines in NS-direction, but bad for lines in EW-direction due to low azimuth satellites and signal shading by high mountains.

3. BATHYMETRIC MAPS AND INTERPRETATION OF PENETRATION ECHOSOUNDER PROFILES

From the depth measurements, NGU has made contour maps (Maps 1-4). Since a low frequency echo-sounder was used during the profiling, the first reflector is not always the top of the mud. Thus, the maps are not very precise, especially in the lakes were the lake-bottom reflector is weak.

The seismic profiles have been interpreted at NGU with emphasis on disturbances of the sediments, which may have been caused by slides or tectonic movements. Slides are observed in all lakes. In four of the lakes these slides may have been generated from steep slopes surrounding the lakes, while in the fifth – Storesetervatnet in Nordfjordeid – the area around the lake is flat and the disturbances seen must have happened entirely within the lake sediments themselves. Based on the interpretation, we suggest a coring program covering all five lakes to verify the genesis of these disturbances and to date them.

3.1 Rotevatnet

Rotevatnet (47 meter above sea level) has quite steep slopes to the south-southwest, while rather flat terrain surround the rest of the lake (Map 1). Fig. 1 shows a seismic profile across the lake. The upper 3-4 meters of the sediment sequence shows distinct reflectors draping the underlying sediments or bedrock. Hyperbolic reflections (probably due to blocks from slides on the steep slopes) are found at several levels in the sediment sequence. Disturbances in the sediments are found in the south-southwestern end of the lake, but generally there is little disturbance in the stratified sediments in this lake.

3.2 Hovdevatnet

Hovdevatnet is situated 73 meter above sea level (Map 2). The lake-bottom reflector over most of this lake is quite weak (Figs. 2, 3, 4, 5), and the sediments belonging to the upper sequence are acoustically very transparent. A strong, acoustically dark reflector separate an upper and lower sequences in this lake. The lower sequence may be quite transparent with internal reflectors or it may be acoustically dark with limited penetration. On top of this lower sequence, in the western part of the lake, we find frequent "hyperbolic" features interpreted to reflect blocks. Map 2 shows a map with profile lines and bathymetry from the lake.

3.3 Storesætervatnet

Storesætervatnet is a small lake situated 277 meter above sea level (Map 3). Over most of the lake, the bottom reflector is weak (Figs. 6 – 11) and the upper 1-1.5 meters of sediments have an acoustically very transparent character (i.e. Figs. 6, 9), while in other areas the upper sequence is thicker and shows internal reflectors (Fig. 7). A strong reflector separates the two uppermost sequences (i.e. Figs. 8, 9). In Fig. 9 the profile shows penetration down to an acoustically dark and dense layer with a quite hummocky surface. This hummocky surface may reflect disturbed sediments. Fig. 6 shows an acoustically rather transparent sequence wedging out and getting disturbed towards the south. "Blacking" of the penetration echo-sounding records, as shown in Fig. 11, most probably is due to gas in the sediments.

3.4 Nedstevatnet and Medvatnet

Nedstevatnet (9 m a.s.l.) and Medvatnet (12,5 m a.s.l.) are linked trough a narrow "channel" (Map 4). The two lakes together are called Kilsvatna (The Kil-lakes) and are situated between Bjørkedalsvatnet (25 m a.s.l.) and Kilspollen, at sea level. Map 4 shows profile lines and bathymetry from the two lakes.

Nedstevatnet.

This is the northern part of Kilsvatna. The lake is surrounded by steep hillsides to the east and partly to the west. Over most of the lake, the bottom reflector is quite distinct, but in places (as also seen at loc. no. M1 in Fig. 12) it may be weaker. In the upper 2 meters of the sediment sequence there are several reflectors, some of them with clear signs of disturbances (Fig. 12). Under this sequence, an acoustically transparent lower sequence follows. An up to 1 meter thick sediment sequence shaped as a wedge, is found in the southern part of the lake. This sequence may represent slide material. The reflector underlying this relatively thin sequence is over most of the lake acoustically quite dark and even. There is little penetration below this reflector.

Medvatnet.
This lake makes up the southern part of Kilsvatna. The hillside at the western end of the lake is quite steep, but rather flat at the southern and eastern side. The lake-bottom reflector is quite distinct and strong over most of this lake (Figs 13, 14). A profile from the deepest, northern part of the lake shows a c. 3 meters thick sequence with 2-3 reflectors overlying an acoustically dark sequence with limited penetration (Fig. 13). This acoustically dark layer seems to be disturbed, e.g. at loc. no. M2, Fig.13. There are no clear indications of disturbed sediments in the overlaying sequence in this area. Fig. 14, which is a profile from the south-eastern part of Medvatnet, shows disturbed sediments in the upper sediment sequence. The disturbed sediments seem to wedge out towards the southwestern end of the profile.

4. CORING LOCATIONS

Table 1 shows the suggested coring locations in the lakes. The locations are chosen with the aim to uncover the general stratigraphy and the age of the sediments, the age of slide- or sediment-disturbances and to locate and date tsunami-sediments in the cores, if present. One location is chosen in Rotevatnet (Fig. 1), four locations in Hovdevatnet (Figs. 2-5), seven locations in Storesetervatnet (Figs. 6-11), one location in Nedstevatnet (Fig. 12) and two locations in Medvatnet (Figs. 13-14). There is little experience with acoustic profiling in lakes and interpretation of lake sediments from acoustic profiles. Adjustments will thus probably be necessary during the coring program.

Loc. no.	Longitude	Latitude	Location
R1	6° 06.4190'	62°08.5244'	Rotevatnet
H1	6° 03.2487'	62° 11.0390'	Hovdevatnet
H2	6° 03.1908'	62° 11.3807'	Hovdevatnet
H3	6° 02.6682'	62° 11.1813'	Hovdevatnet
H4	6° 02.5207'	62° 11.3291'	Hovdevatnet
S1	6° 08.3268'	61° 56.7473'	Storesætervatnet
S2	6° 08.3007'	61° 56.7635'	Storesætervatnet
S3	6° 08.2806'	61° 56.7769'	Storesætervatnet
S4	6° 08.2036'	61° 56.7869'	Storesætervatnet
S5	6° 08.5251'	61° 56.6126'	Storesætervatnet
S6	6° 08.3160'	61° 56.4800'	Storesætervatnet
S7	6°08.5320'	61° 56.6058'	Storesætervatnet
N1	6° 02.8215'	62° 02.2226'	Nedstevatnet/(Kilsvatnet-N)
M1	6° 02.8210'	62° 01.8951'	Medvatnet/(Kilsvatnet-S)
M2	6° 02.8431'	62° 01.9324'	Medvatnet/(Kilsvatnet-S)
M3	6° 02.5915'	62° 01.7113'	Medvatnet/(Kilsvatnet-S)

Table 1

5. CONCLUSIONS

Five lakes in Ørsta, Volda, and Nordfjordeid communes have been mapped using a Knudsen 320 M/P 12 Khz penetration echo-sounder. From the echo-sounding profiles bathymetric maps of the lakes have been made.
The acoustic profiles were interpreted at NGU. Slides are observed in all lakes. In four of the lakes, these slides may have been generated from steep slopes surrounding the lakes, while in the fifth – Storesetervatnet in Nordfjordeid – the terrain around the lake is flat and the disturbances seen, must have happened entirely within the lake sediments themselves. Based on the interpretation, we suggest a coring program covering all five lakes to verify the genesis of these disturbances and to date them. So far there is little experience with acoustic profiling of lake sediments. Therefore, adjustments to the program must be expected during coring when the seismic data and the cores can be related.

6. REFERENCES

Bjerkli, K. 2001: Akkustisk profilering (penetrasjonsekkolodd) i 5 ferskvann, Sunnmøre/Nordfjord. *GeoCore rapport*, oppdr.nr. 034-01-B, 11 s.

Longva, O., Blikra, L. H. Olsen, H. A. and Stalsberg, K. 2001: Regional landslide occurrences and possible post-glacial earthquake activity in northwest Western Norway: Phase A1; Interpretation of seismic data and proposal of core-locations in fjords and along the coast. *NGU Report* 2001.048

Mangerud, J., Lie, S. E., Furnes, H., Kristiansen, I. L. and Lømo, L. 1984: A Younger Dryas ash bed in western Norway, and its *possible correlations with tephra in cores from the Norwegian Sea and the North Atlantic. Quaternary Research* 21; 1, Pages 85-104.

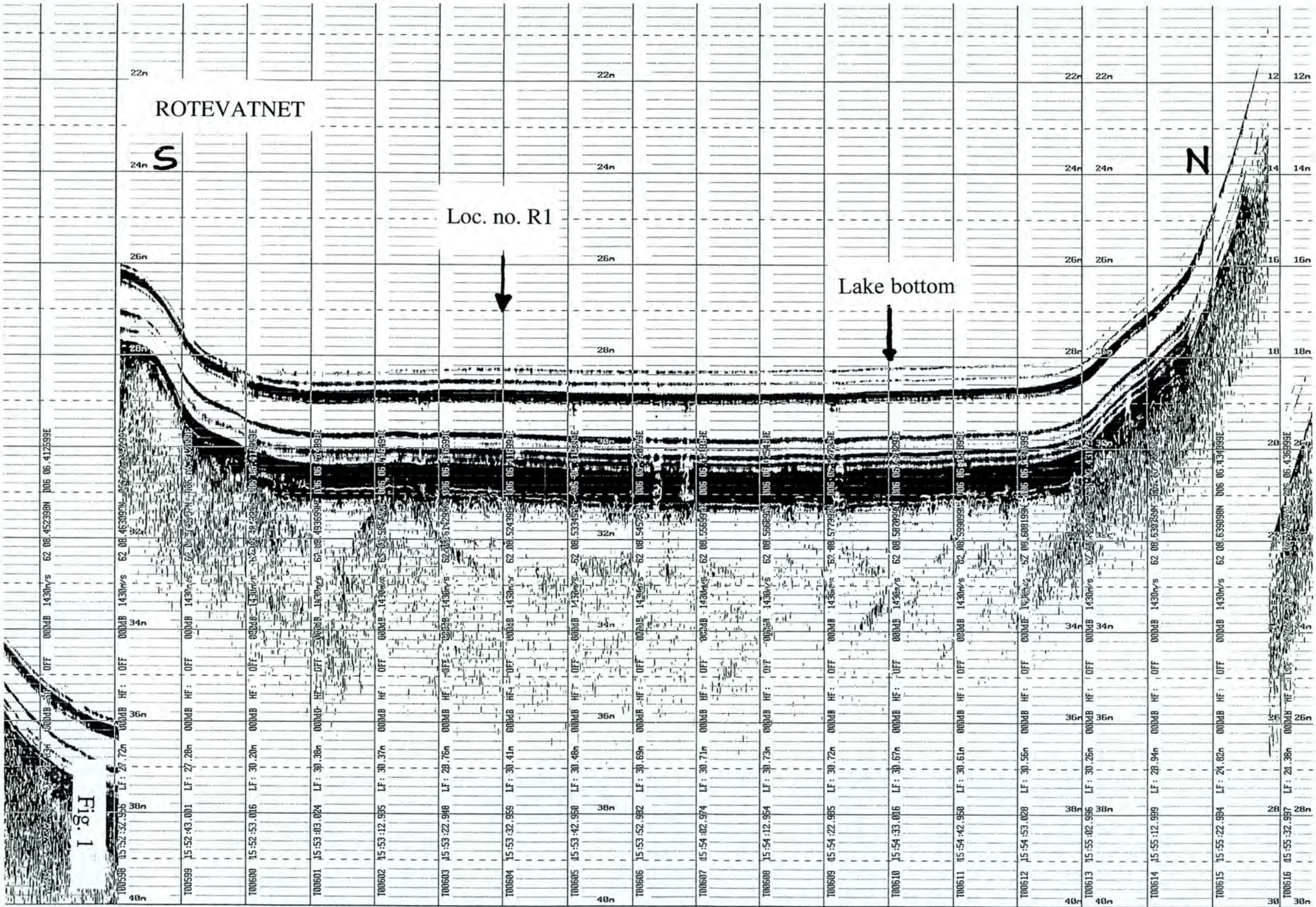


Fig. 1

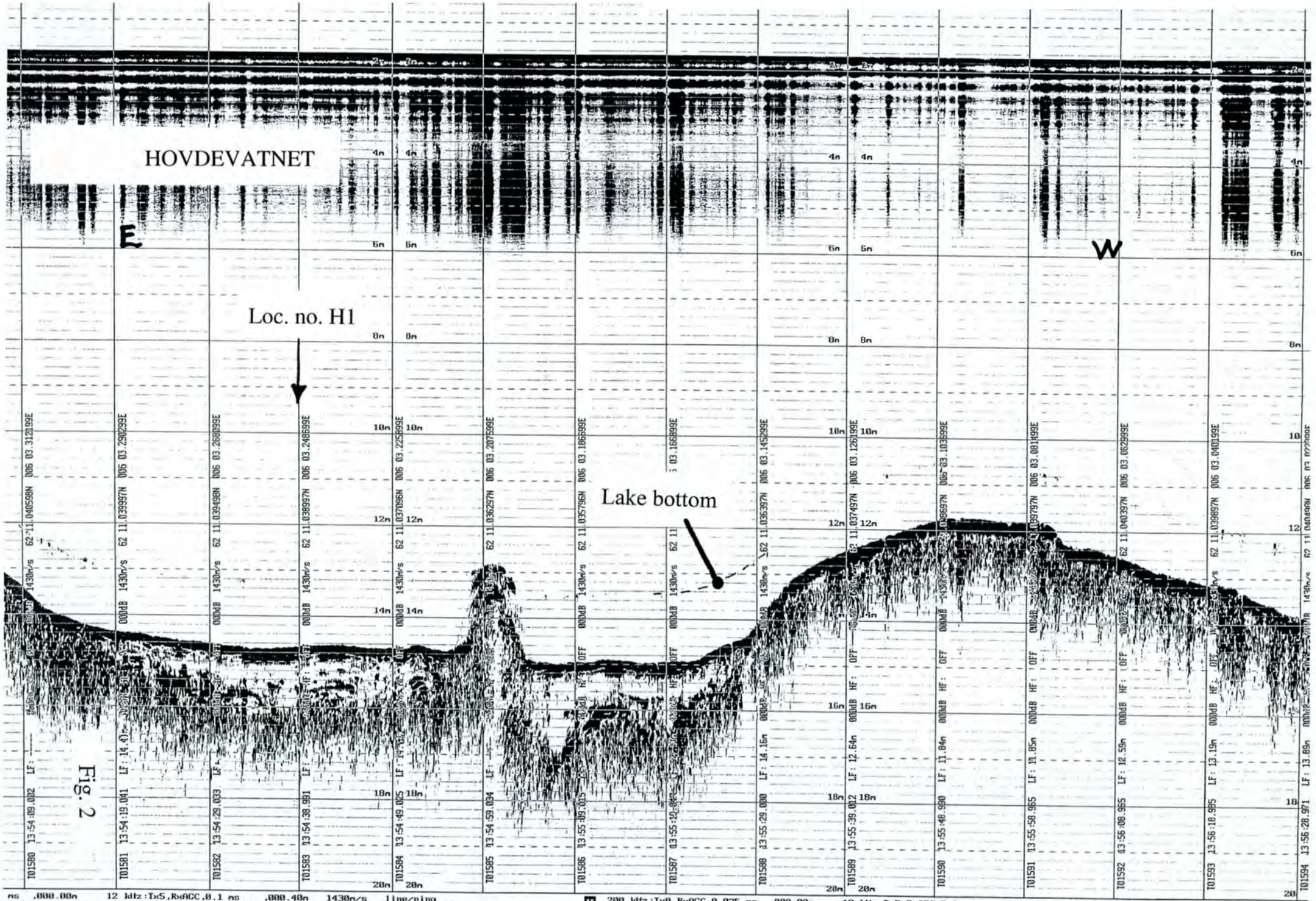
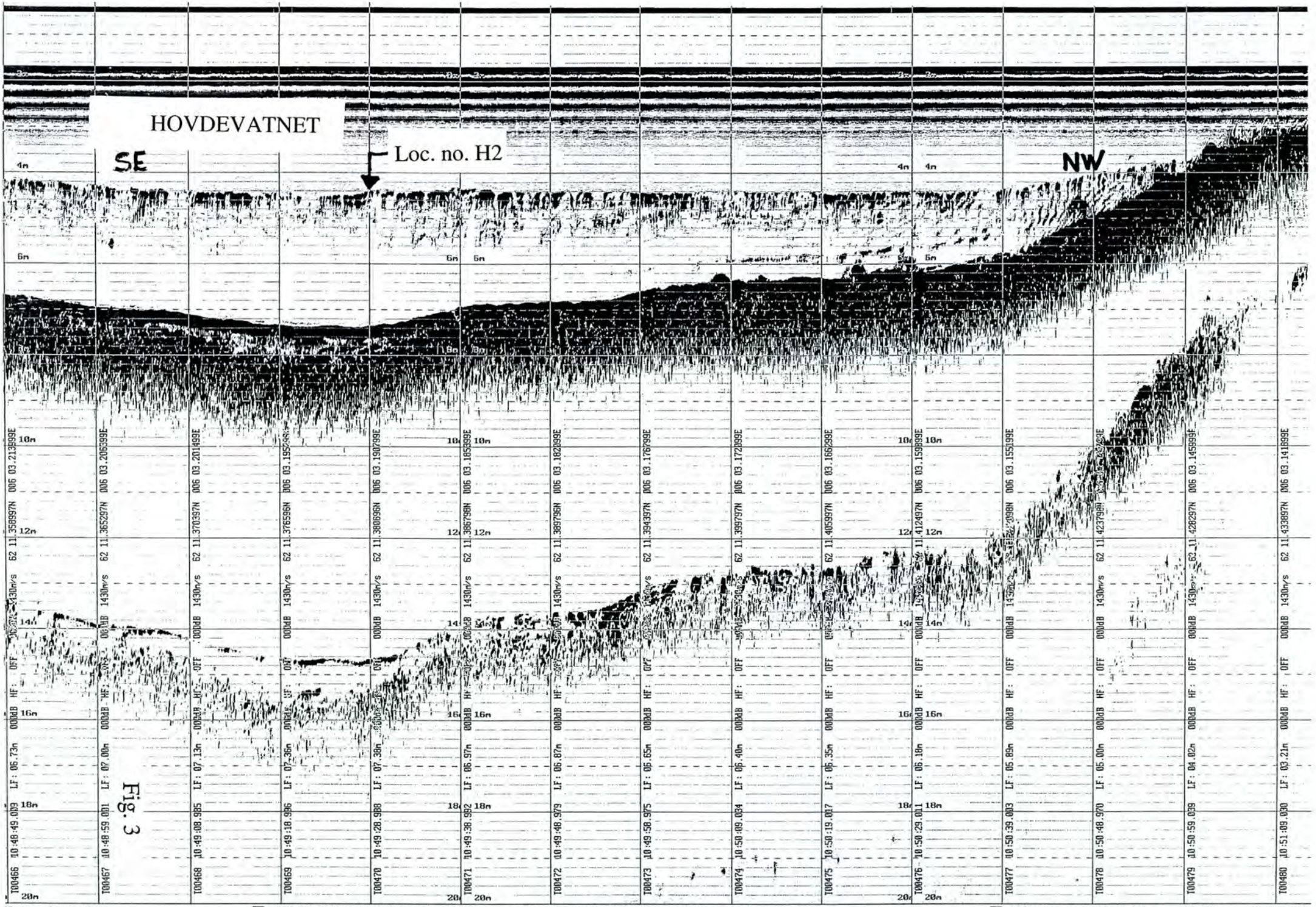


Fig. 2



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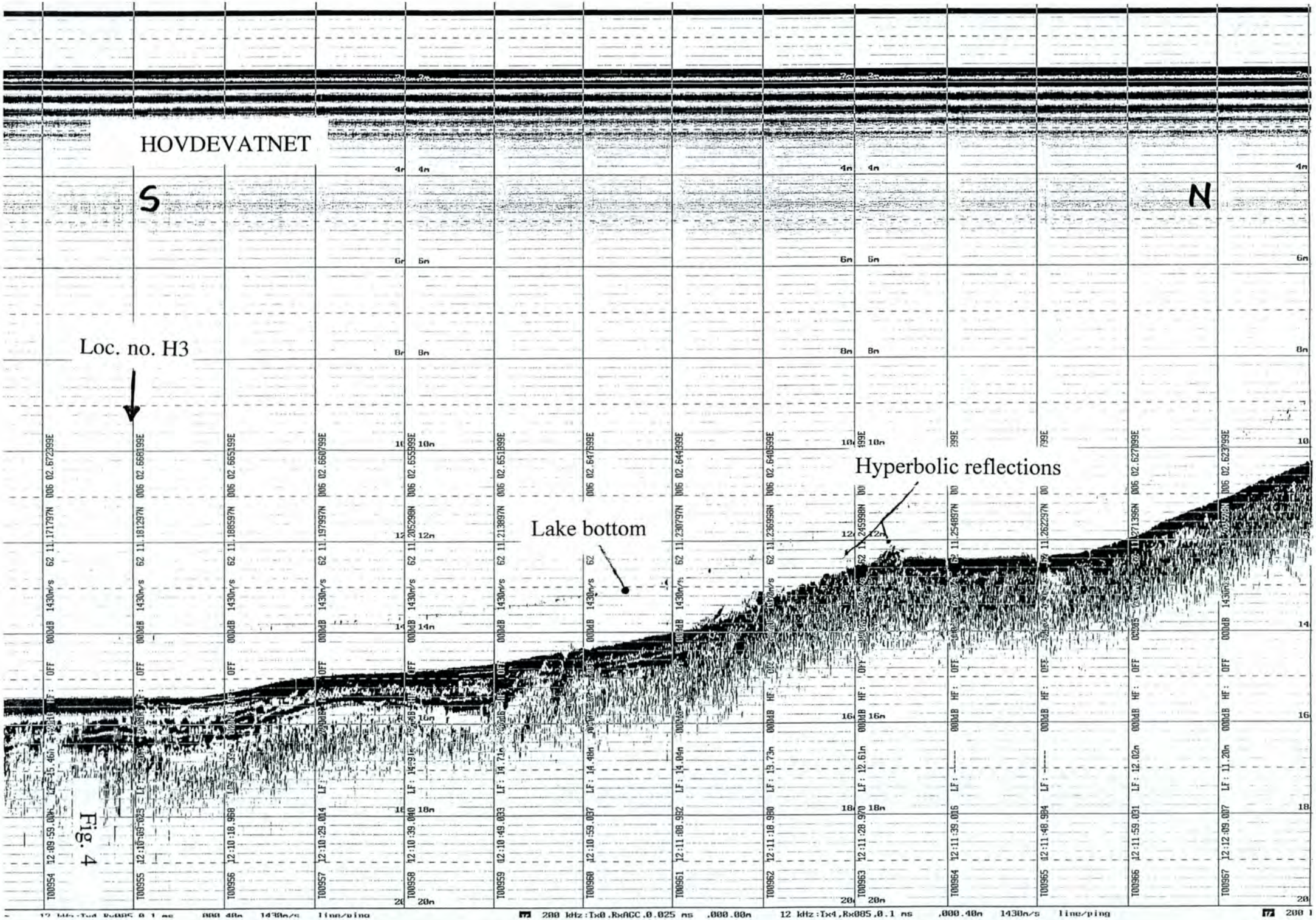
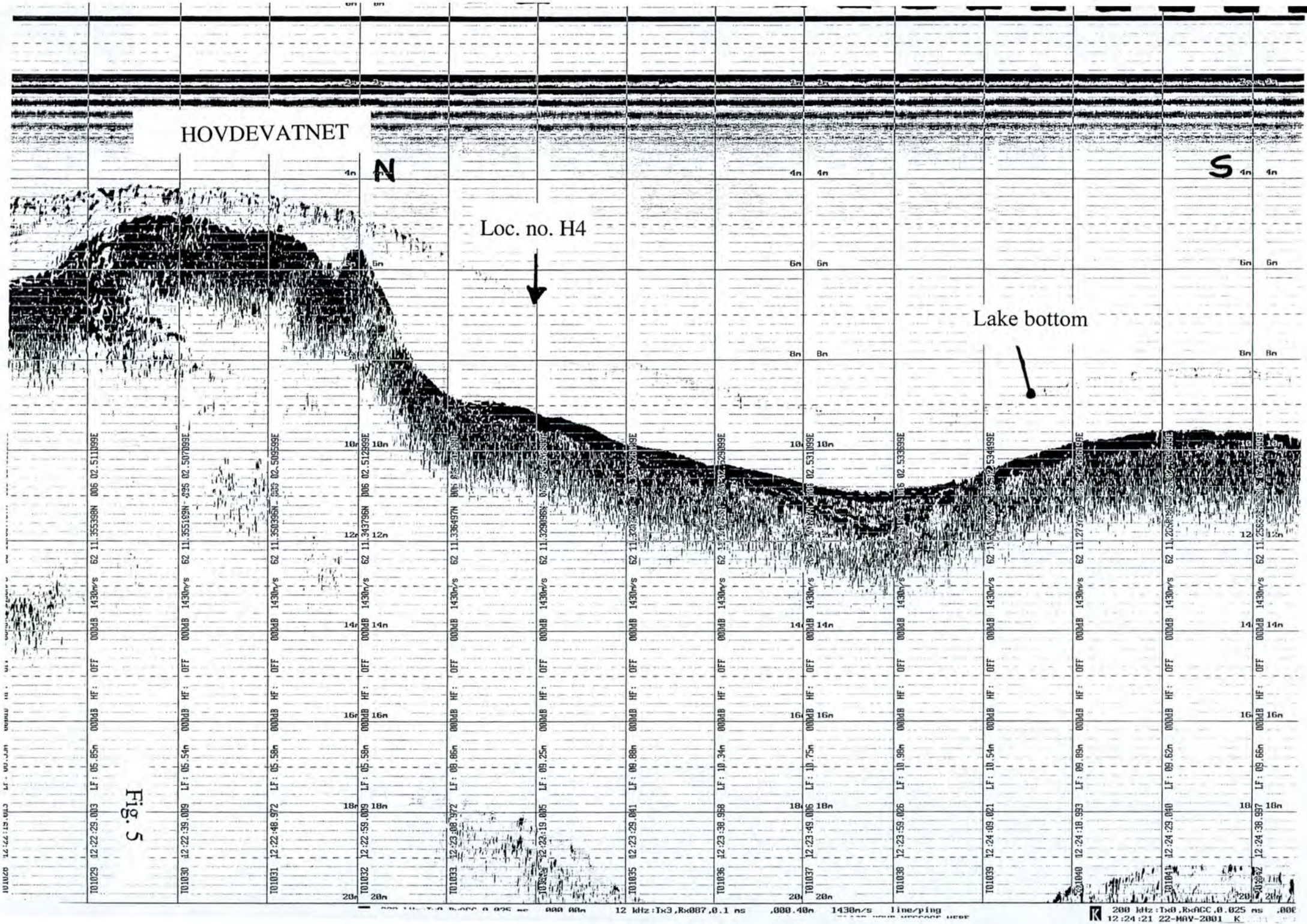

HOVDEVATNET
S
N
Loc. no. H3
Lake bottom
Hyperbolic reflections

Fig. 4



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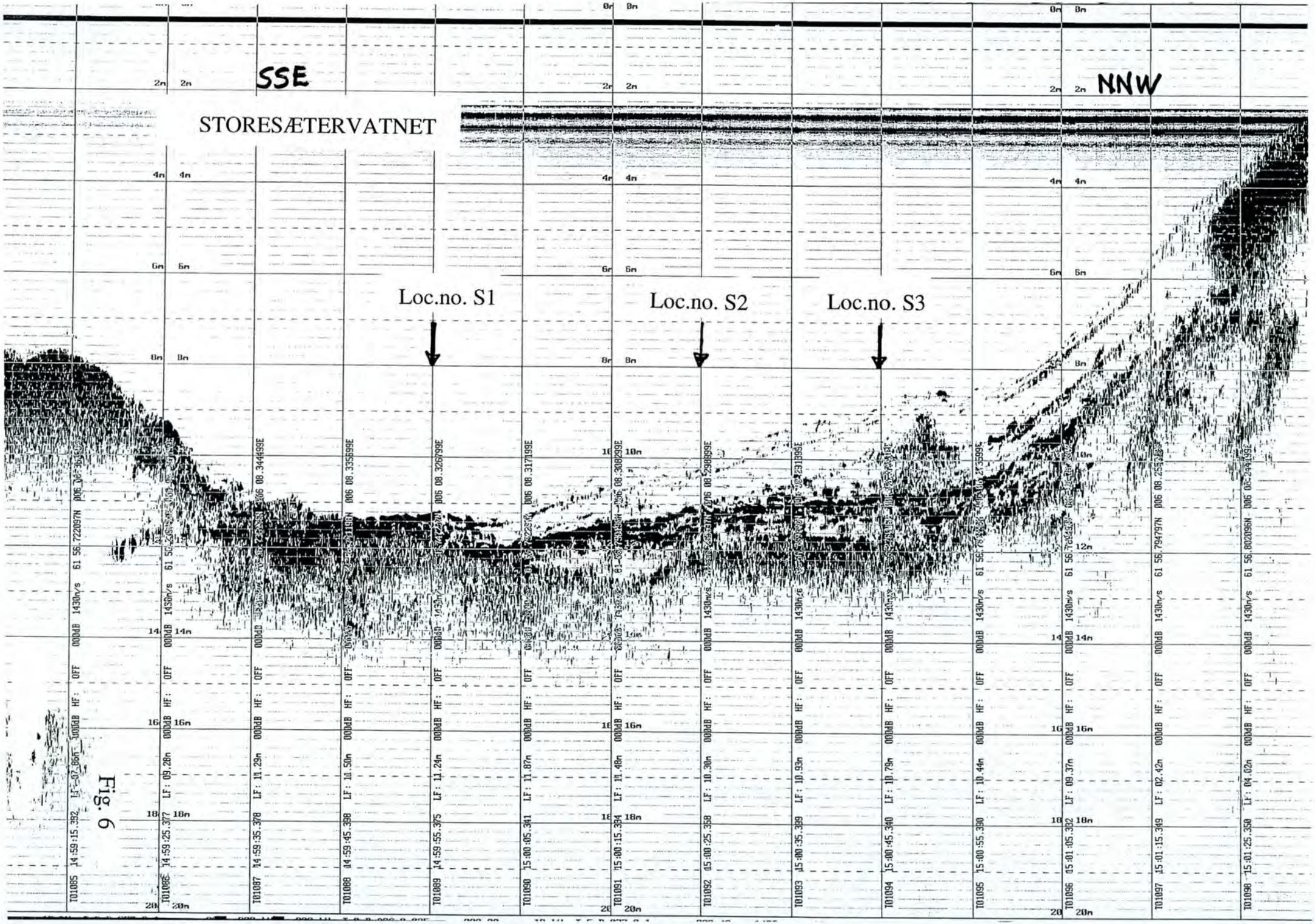

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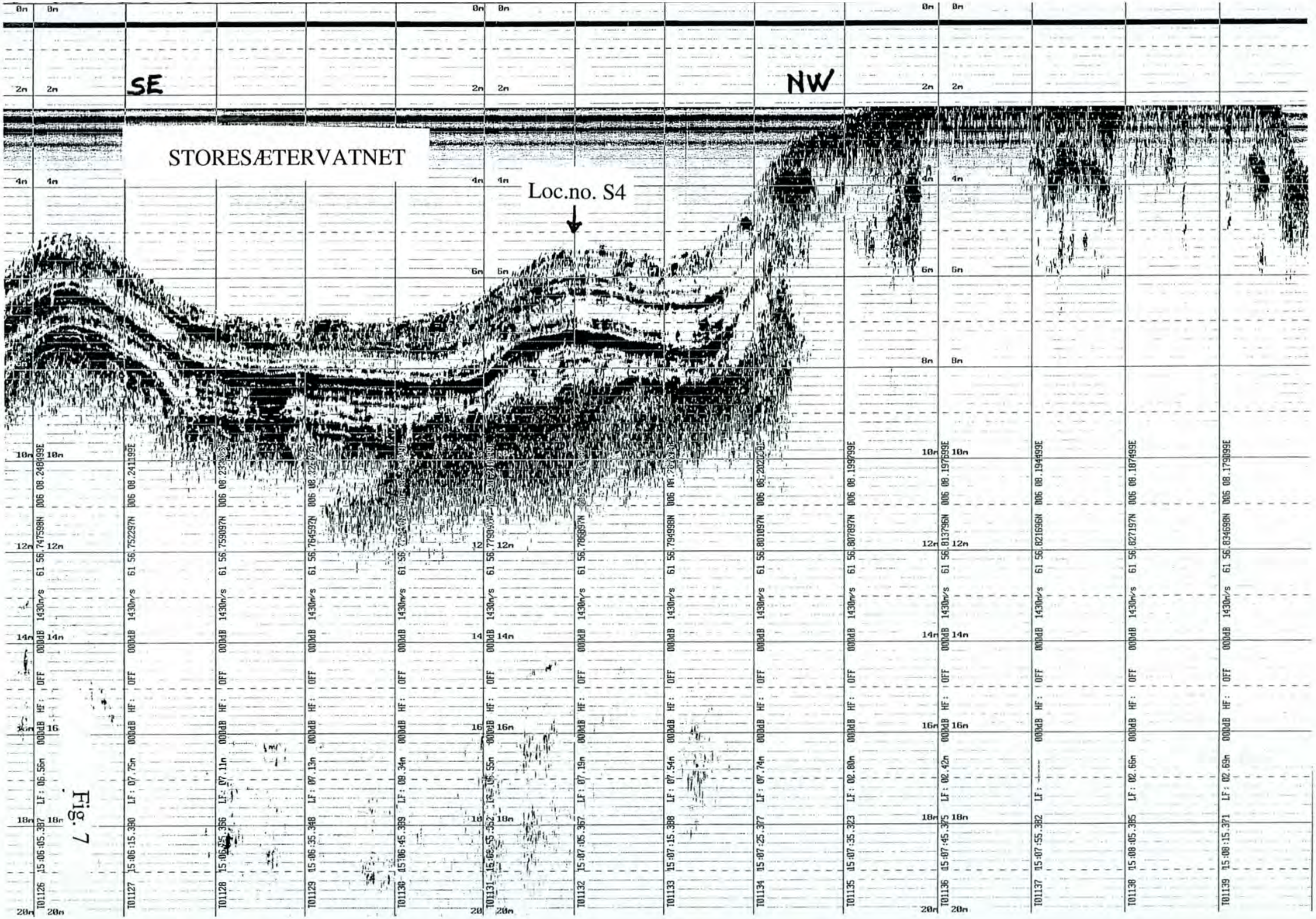
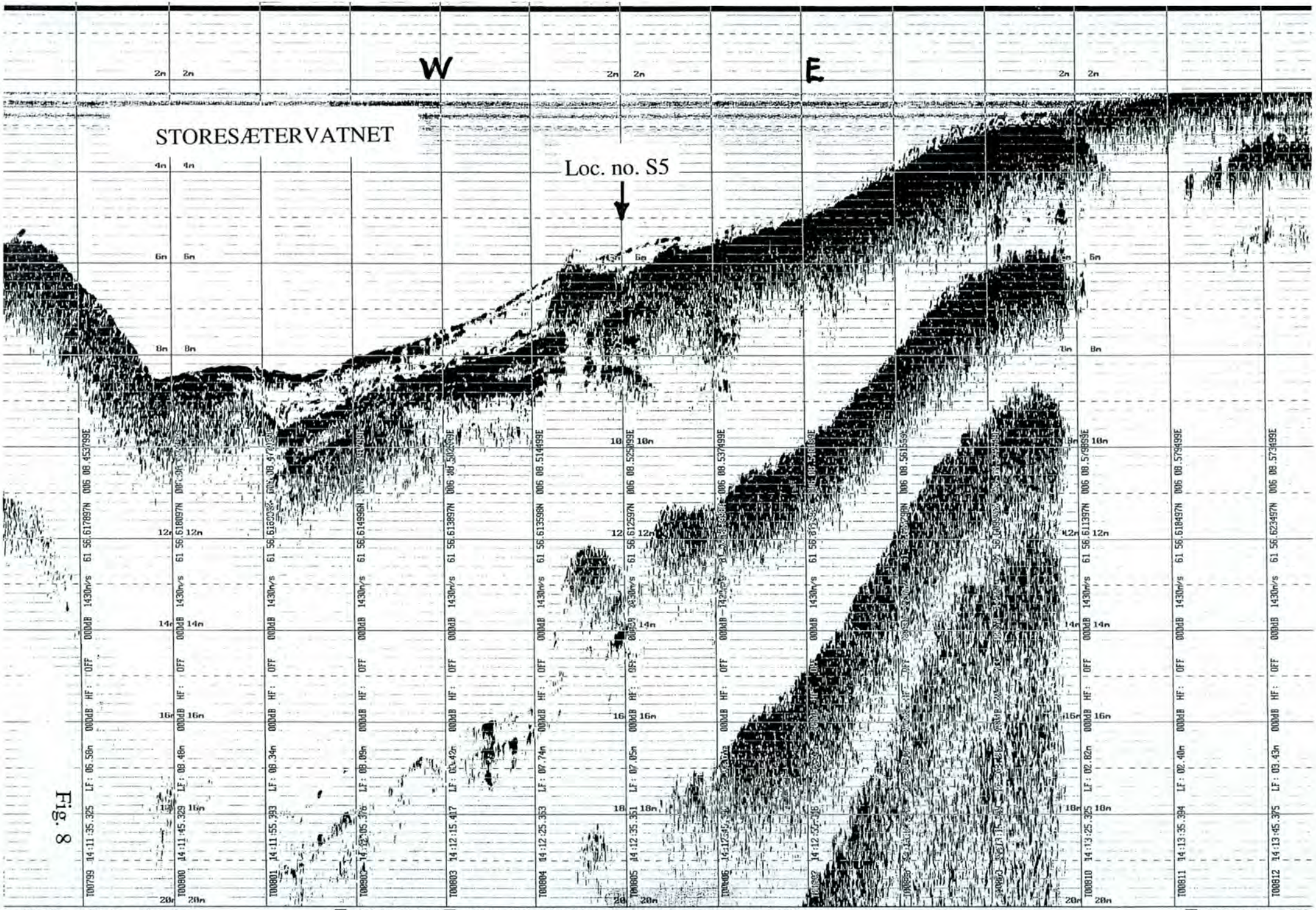


Fig. 7



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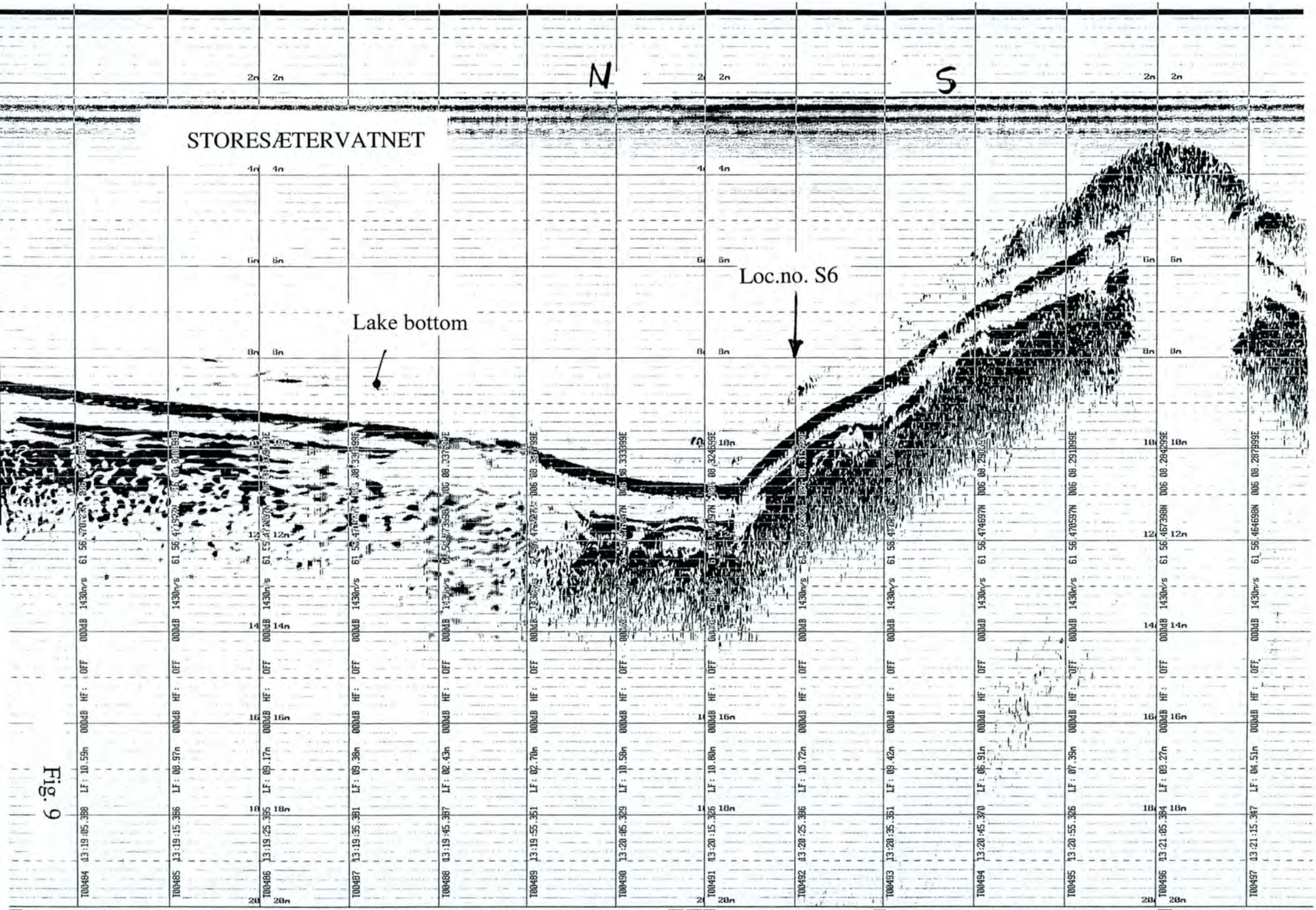
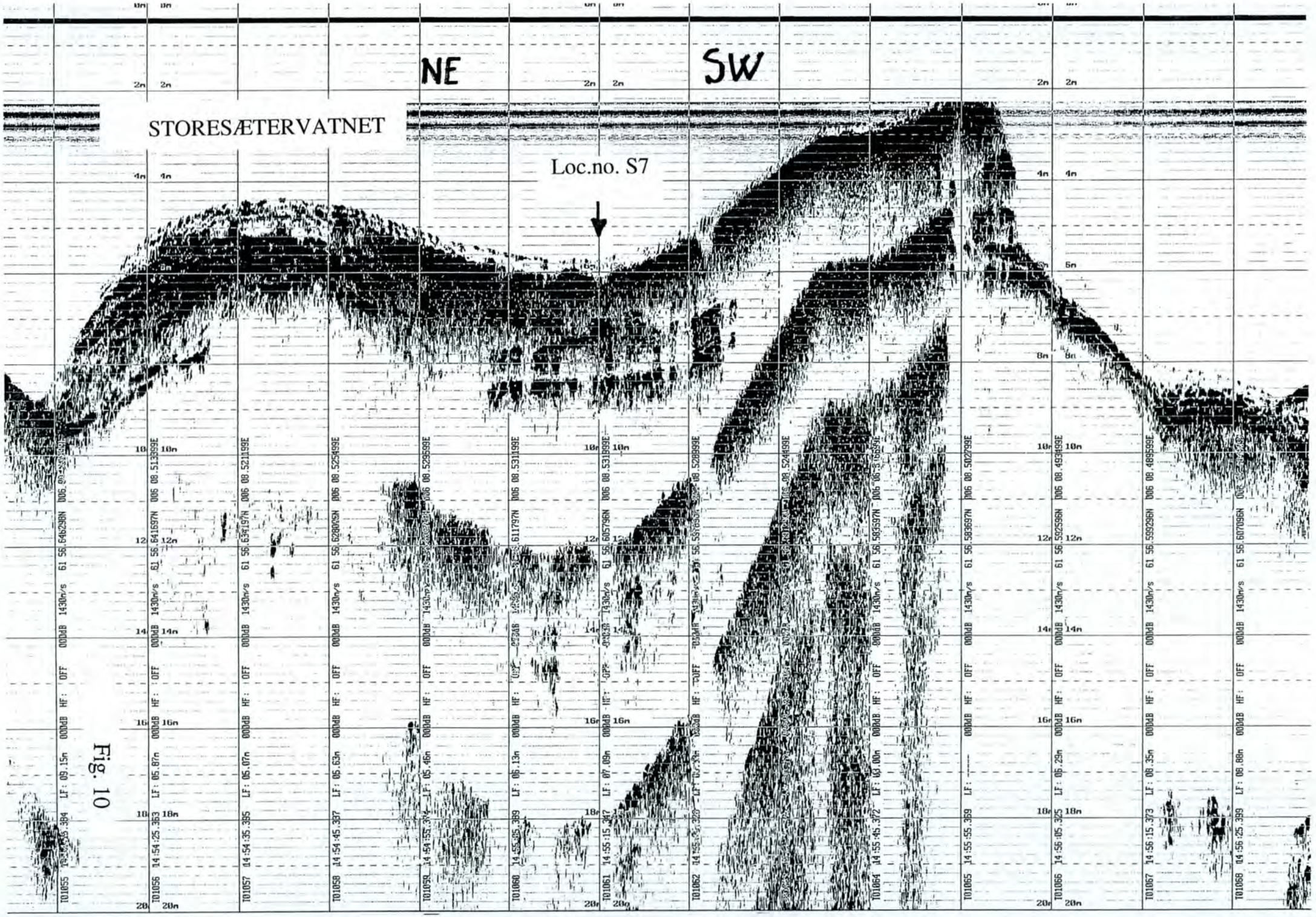


Fig. 9



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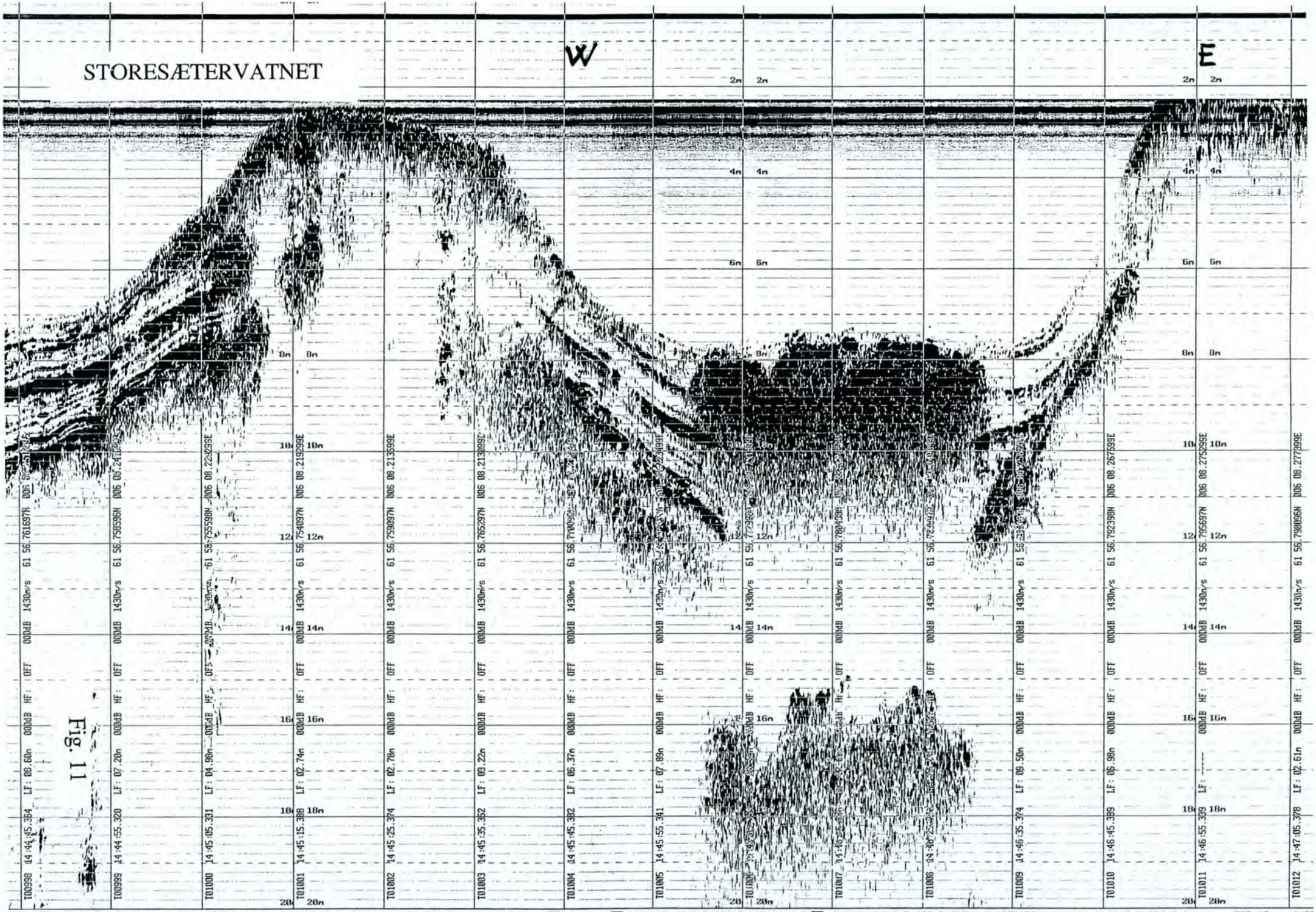

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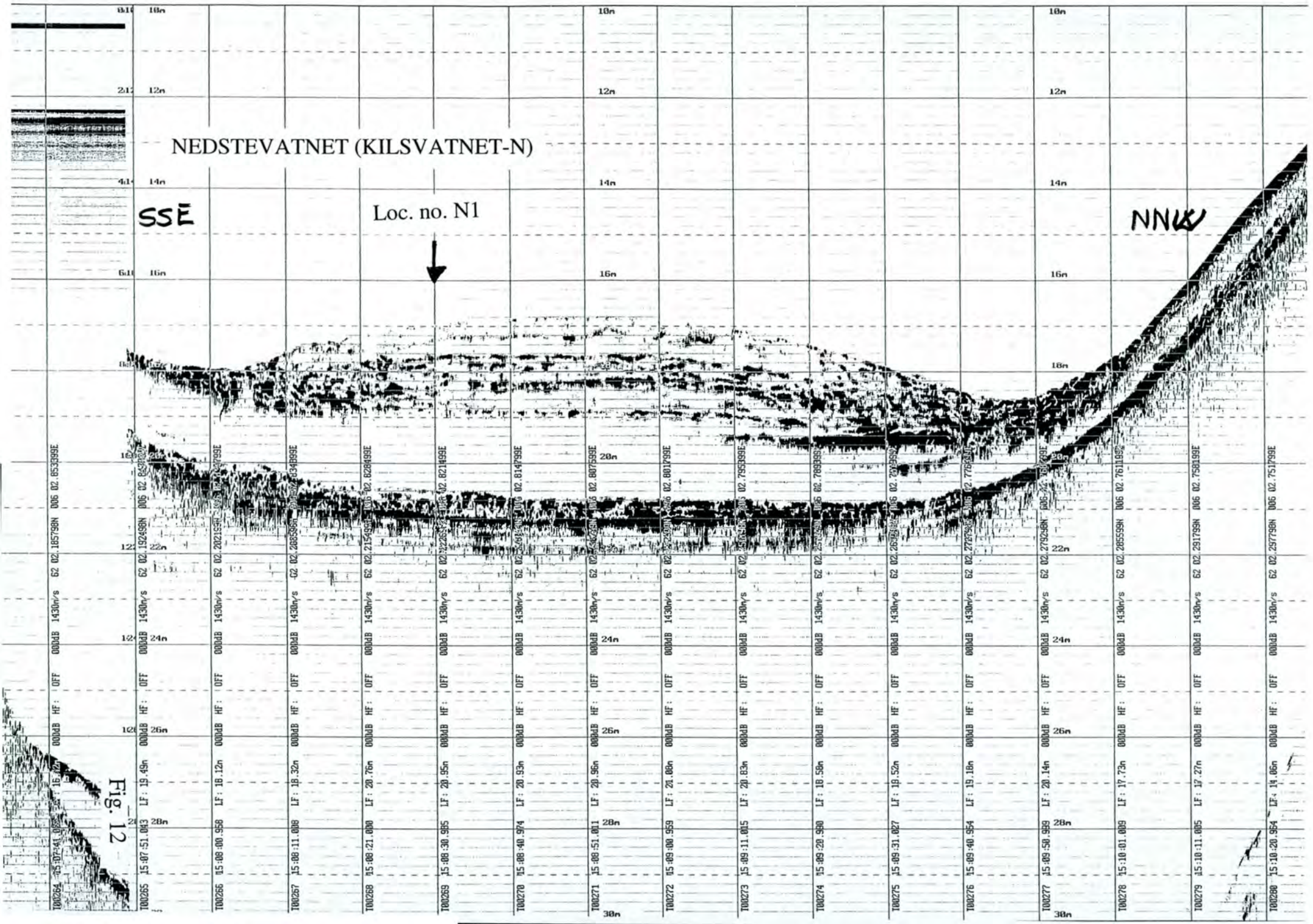

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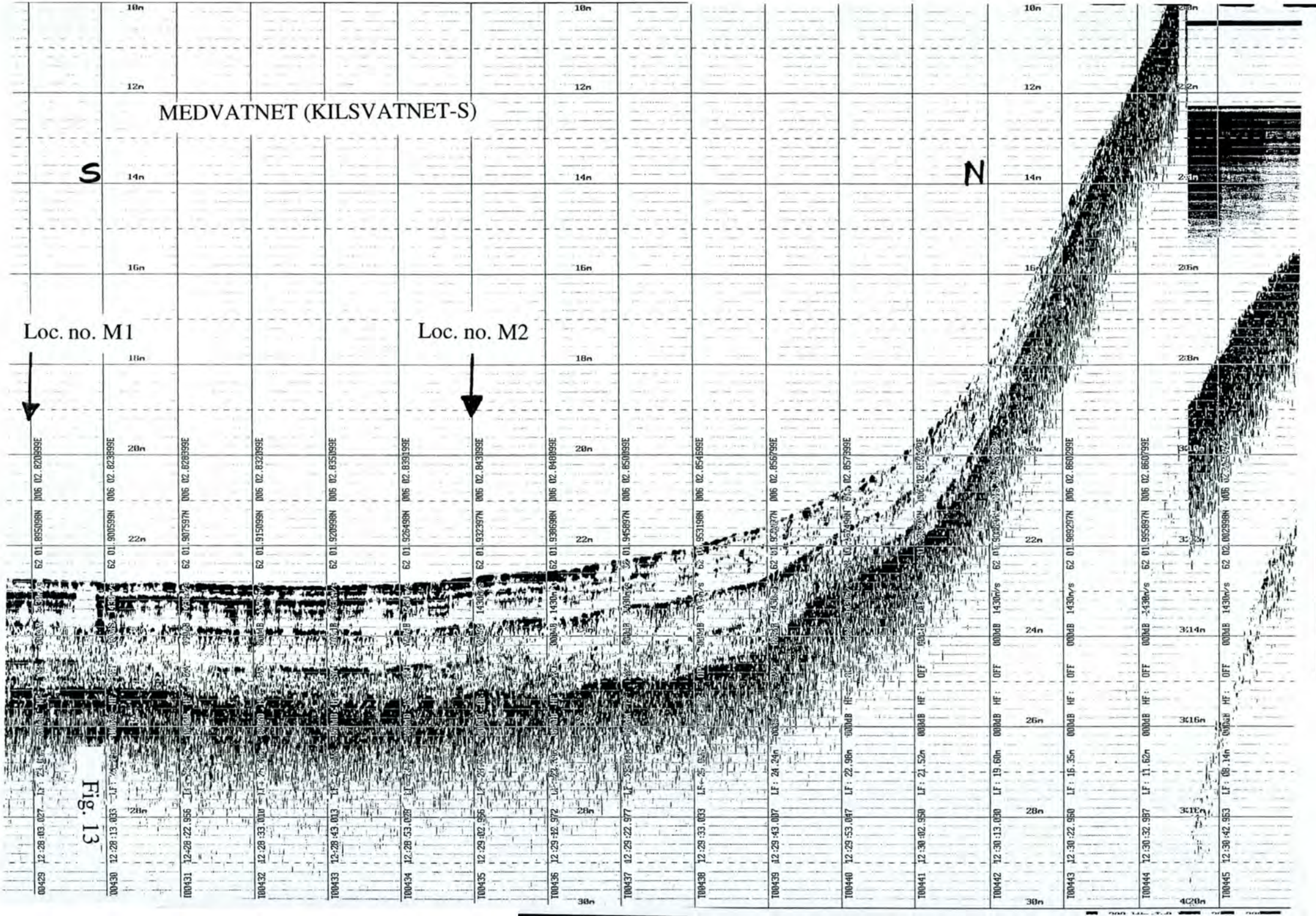

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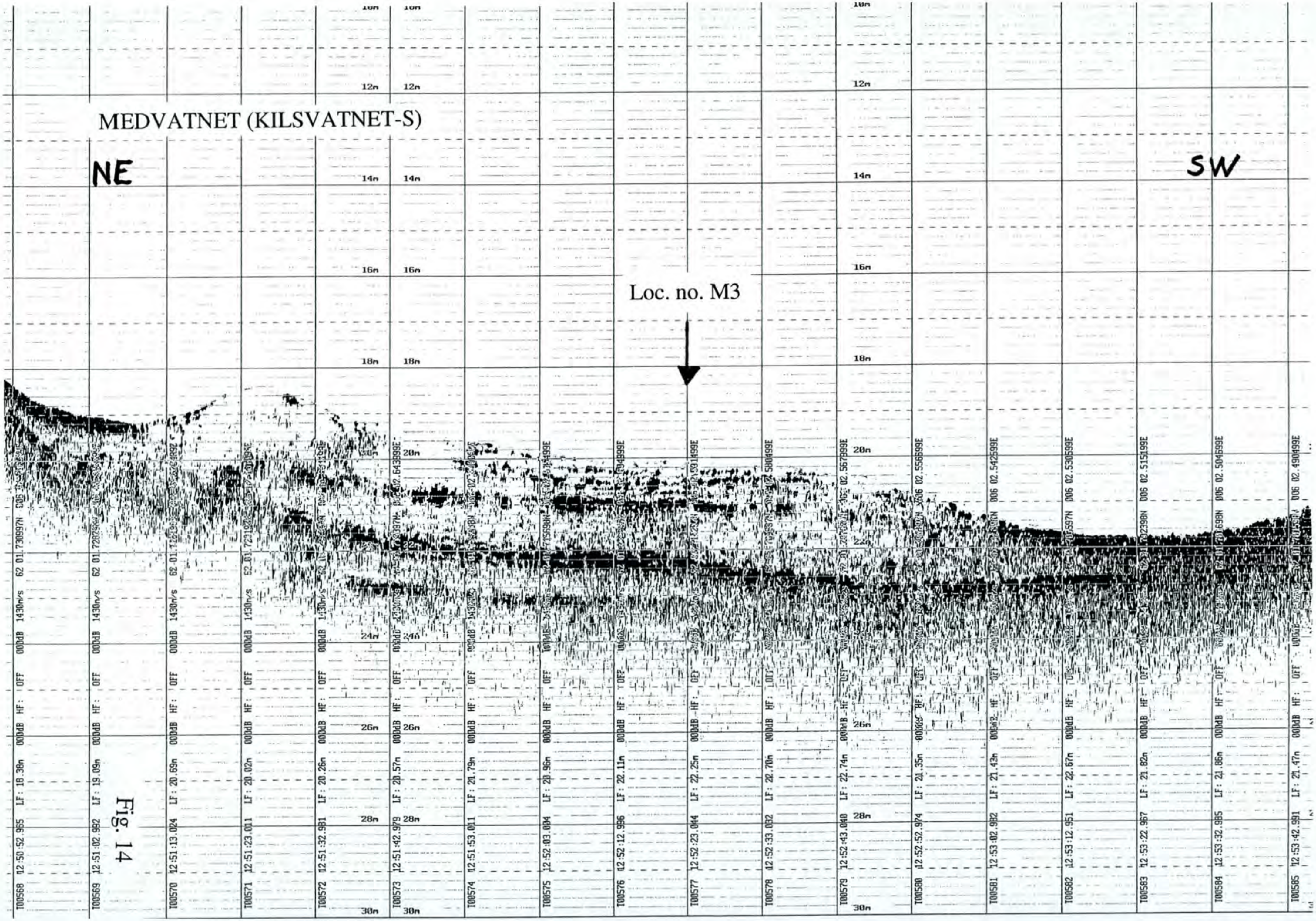

Fig. 14

APPENDIX

GeoCore as
ANVENDT MARIN GEOLOGI OG GEOKJEMI
MILJØTEKNISKE GRUNNUNDERSØKELSER
TEKNOLOGI FOR SEDIMENTPRØVETAKING

NORSK AKKREDITERING P156
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Akustisk profilering (penetrasjonsekkolodd) i 5 ferskvann i Sunnmøre/Nordfjord

NGU oppdrag nr. 293100
GeoCore oppdrag nr. 034-01-B

INNHOLD

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GeoCore as
ANVENDT MARIN GEOLOGI OG GEOKJEMI
MARINE MILJØTEKNISKE GRUNNUNDERSØKELSER
TEKNOLOGI FOR MARIN SEDIMENTPRØVETAKING

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GRADERING: Fortrolig til oppdragsgiver

RAPPORT

TITTEL/FORFATTER

Akustisk profilering (penetrasjonsekkolodd) i 5 ferskvann, Sunnmøre/Nordfjord

FORFATTER	OPPDRAGSGIVER		OPPDRAGSGIVERS REF./KONTAKTPERSON	
Kristian Bjerkli	Norges geologiske undersøkelse		NGU oppdragsnr. 293100 Oddvar Longva	
OPPDRAGSNR.:	ARKIV	ANT.SIDER/VEDLEGG	STED/DATO	GODKJENT AV
034-01-B	034-01-B NGU	11 / akust.. registr.	Trondheim, 27.05.2001	Per Th. Moen

Sammendrag

GeoCore har i mai 2001utført akustisk profilering (penetrasjonsekkolodd) for Norges geologiske undersøkelse i følgende 5 ferskvann i Sunnmøre/Nordfjord:

- Hovdevatnet, Ørstad kommune
- Rotevatnet, Volda kommune
- Medvatnet (Kilsvatnet syd), Volda kommune
- Nedstevatnet (Kilsvatnet nord), Volda kommune
- Storesætervatnet, Eid kommune

Målingene ble utført med Knudsen ekkolodd m/ 12 KHz sender/mottaker og DGPS-posisjonering. Posisjonsbestemmelsene har gjennomgående god diff-dekning med unntak av deler av målingene i Nedstevatnet.

Data er levert NGU i form av papirutskrift av akustikk-registreringene (termisk skriver), CD-ROM med akustikkdata i binærfil-format og CD-ROM med posisjonsdata i *.xls-format.

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Besøksadresse: Transittgt. 10 B Trondheim
Telefon 73 92 19 76 73 92 19 66
Telefax 73 92 13 02
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E-post: geocore.as@c2i.net

2. INNLEDNING

GeoCore as har på oppdrag fra Norges geologiske undersøkelse (NGU) utført akustisk profilering med penetrasjonsekkolodd i 5 ferksvann i Sunnmøre/Nordfjord. Oppdraget er utført i henhold til avtale mellom NGU og GeoCore av 15.05.2001.

Målingene er utført i følgende ferskvann:

Møre og Romsdal:

Ørstad kommune: Hovdevatnet

Volda kommune: Rotevatnet
Medvatnet (Kilsvatnet syd)
Nedstevatnet (Kilsvatnet nord)

Sogn og Fjordane:

Eid kommune: Storesætervatnet

Tidrom for samlet utførelse av oppdraget (mobilisering, feltarbeid, demobilisering og rapportering) var 14. – 28.05.2001.

3. FELTMÅLINGER

3.1 Ekkolodd

Målingene ble utført med Knudsen 320 M/P ekkolodd med 12 KHz svinger (sender/mottaker). Måledata registreres i analog form på termisk papir og digitalt som *.keb-fil i binærfil-format.

Det annoteres følgende informasjon både analogt og digitalt:
- Fix-nr. (på analog registrering: pr. ca. 10 sek.)
- Dato
- Klokke (lokal tid)
- Vanndyp LF (12 KHz)
- Lydhastighet, oppgitt av NVE til 1.430 m/s
- Posisjon grad/desimalmin. lengde og bredde

Det ble utført testing/innstilling av penetrasjonsekkoloddet i Rotevatnet, Volda kommune, den 20.05.2001, uten registrering av posisjonsdata i *GeoCore-logg*. Posisjonsdata er imidlertid annotert på de analoge registreringene. Disse registreringene er ikke vedlagt denne rapporten, men de kan fritt stilles til NGU's disposisjon etter ønske.

3.2 Posisjonering

Posisjonering er utført med GPS mottaker type MLR-DGPS-FX412.

Som differensiell referansestasjon er benyttet Svinøy 293,5 KHz. GPS-antennen er plassert over senter av ekkolodd-svingeren.

Posisjonsdata, som logges i programmet *GeoCore-logg*, er hentet fra en NMEA 182 GGAD-streng. Det lagres følgende informasjon:

- GPS-tid
- desimalgrad øst lengde/nord bredde
- HDOP-verdi
- diffkode (2=diff, 1=ikke diff blank=ikke satelitt-fix)

Posisjoner logges i datum WGS 84.

Vedlagte posisjonsfiler (CD-ROM) tilsvarer annotering på de analoge registreringene og inneholder:

- Desimalgrader øst lengde
- Desimalgrader nord bredde
- Lokal tid

Det var gjennomgående god DGPS-dekning i Hovdevatnet, Rotevatnet, Medvatnet og Storesætrevatnet.

I Nedstevatnet var det tilfredsstillende DGPS-dekning for profil-linjer i NS-retning. Posisjonering av profil-linjene i ØV-retning ble usikre på grunn av overgang til satelitt-plassering med lav asimuth kombinert med signalskjerming av høye fjell.

Det ble oppdaget svikt i *GeoCore-log* under rapporteringen av data. Alle posisjonsdata er imidlertid logget som **.kea*-filer (leses som tekst-filer) i Knudsen-systemet. Posisjonsfil for Nedstevatnet merket "sikker" er logget i *GeoCore-logg* og manuelt plukket fra annotering pr. 10 sek. i de analoge registreringene. Posisjonsfil merket "usikker" er logget i Knudsen-systemet hvor tidsangivelsen er gitt i tall-format og ikke tids-format.

3.3 Utførelse i felt

Måleinstrumentene ble montert ombord i en 14 fots aluminiumsbåt med 4 hk utenbordsmotor. Feltopplegget er vist i Foto 1 - 3.

Adkomst til Rotevatnet, Medvatnet og Nedstevatnet foregikk uten problemer i jevnt skrånende terreng. For adkomst til Hovdevatnet måtte båten uten utstyr fraktes over en ca. 2 meter lang strandsone med store steiner. For ankomst til Storesætervatnet ble båt uten utsyr transportert ca. 50 meter på traktorvei over bløt, men steinsatt myr til og fra vannkanten.

Foto 1. GPS-antenne montert over ekkoloddets sender/mottaker

Foto 2. Plassering ombord av ekkolodd, GPS-mottaker og PC for operasjon av samlet målesystem

Foto 3. Tilhenger med målebåt rygges ut i Nedstevatnet

4. OVERSIKT OVER DATA

De analoge akustiske registreringene (termisk printer) er merkert:

Hovdevatnet Fra 09:35:24 - Til 12:41:58
Hovdevatnet Fra 12:51:58 - Til 14:26:09

Rotevatnet Fra 14:41:24 - Til 18:14:23
Rotevatnet Fra 18:19:50 - Til 18:51:50

Medvatnet (Kilsvatnet – S) Fra 11:44:02 - Til 13:39:02

Nedstevatnet (Kilsvatnet – N) Fra 14:33:11 - Til 15:20:01
Nedstevatnet (Kilsvatnet – N) Fra 15:26:41 - Til 16:10:40

Storesætervatnet Fra 13:11:14 - Til 14:29:25
Storesætervatnet Fra 14:37:35 - Til 15:19:35

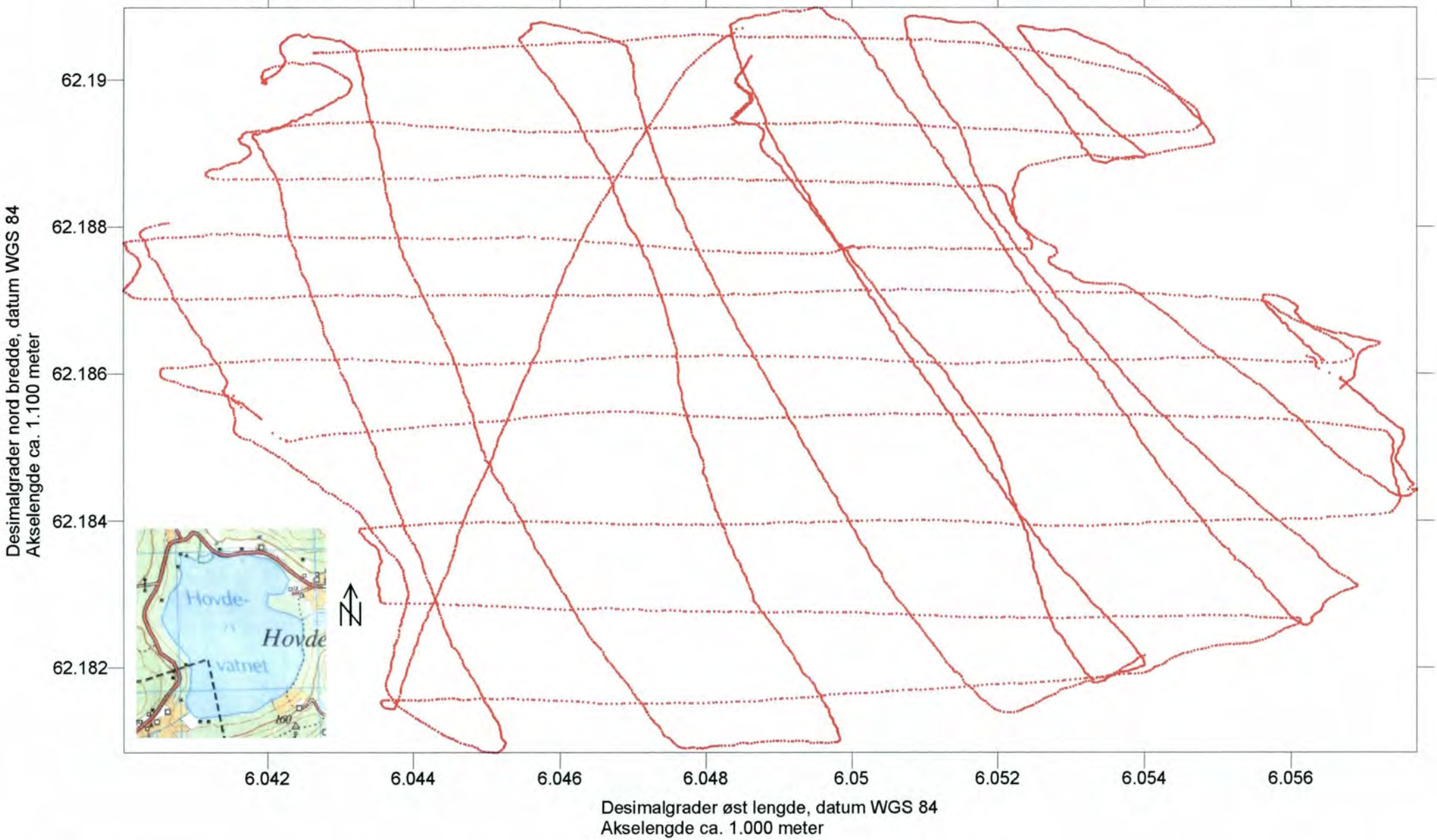
Følgende posisjonsfiler ligger på vedlagte CD-ROM:

Hovdevatnet-posisjon.xls
Rotevatnet-posisjon.xls
Medvatnet (Kilsvatnet S)-posisjon.xls
Nedstevatnet (Kilsvatnet N) – sikker posisjon.xls
Nedstevatnet (Kilsvatnet N) – usikker pos.xls
Storesætervatnet-posisjon.xls

Fig. 1 – 5 viser orienterende linjekart for hvert av ferskvannene. Posisjonene er plottet i desimalgrader øst og nord og kartbildet er strukket noe i ØV-retning i forhold til NS-retning.,

Fig. 1 HOVDEVATNET, Ørstad kommune
Orienterende linjekart - penetrasjonsekkolodd

GeoCore as
034-01-B



07

Fig. 2 ROTEVATNET, Volda kommune
Orienterende linjekart - penetrasjonsekkolodd

GeoCore as
034-01-B

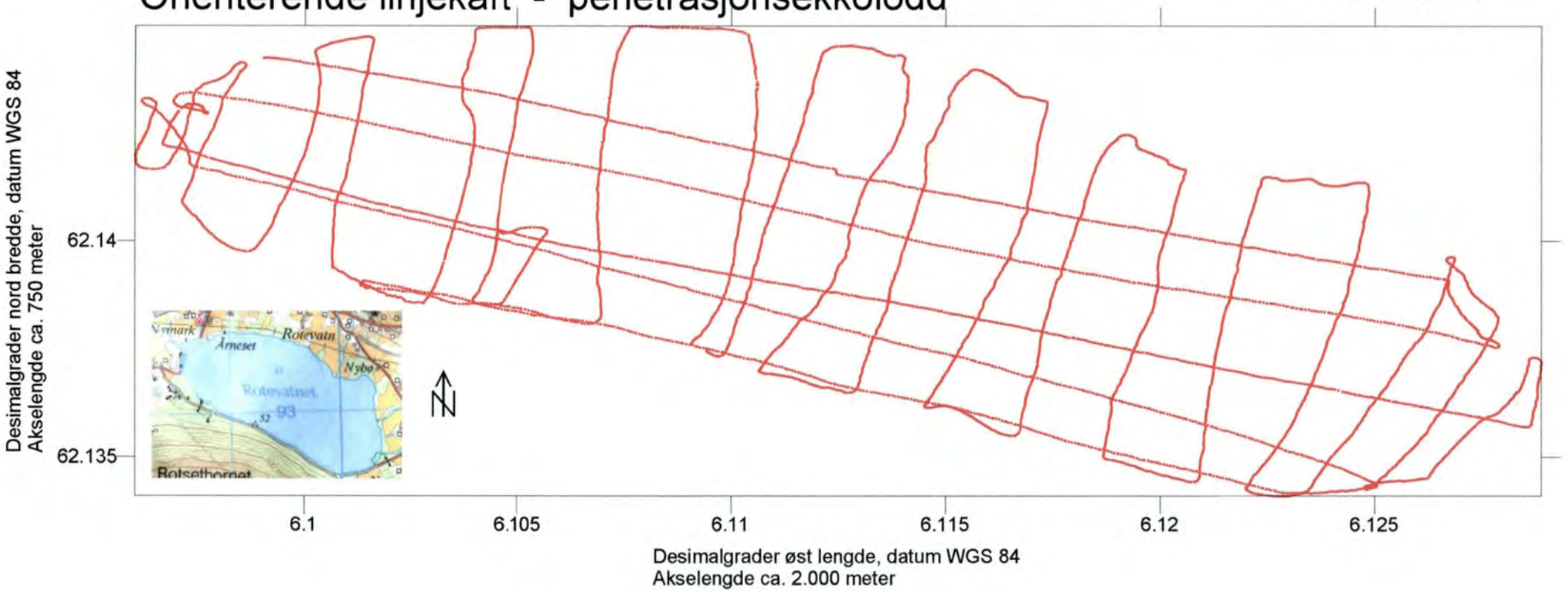


Fig. 3 MEDVATNET (Kilsvatnet syd), Volda kommune
Orienterende linjekart - penetrasjonsekkolodd

GeoCore as
034-01-B

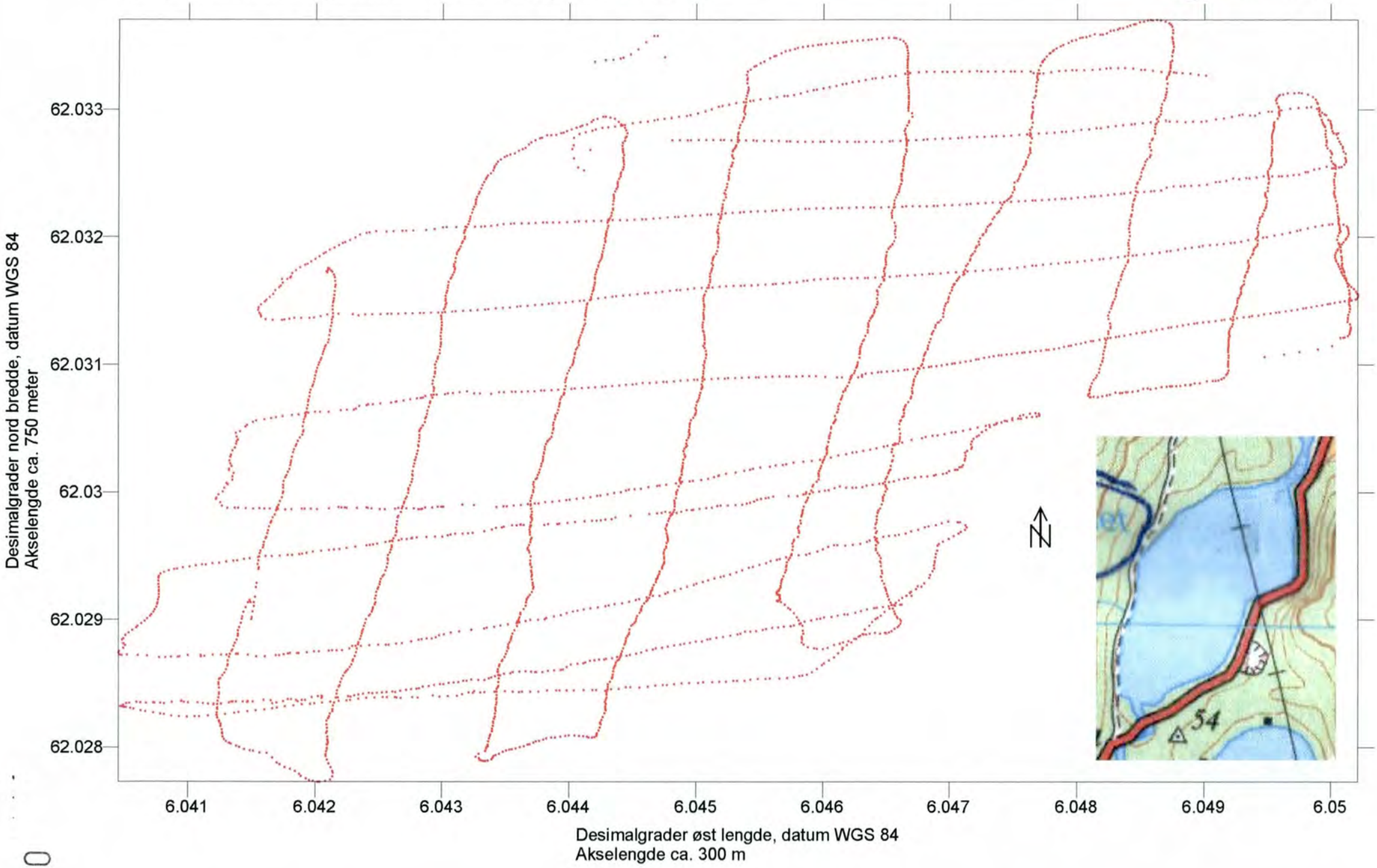


Fig. 4 NEDSTEVATNET (Kilsvatnet nord), Volda kommune
Orienterende linjekart - penetrasjonsekkolodd

GeoCore as
034-01-B

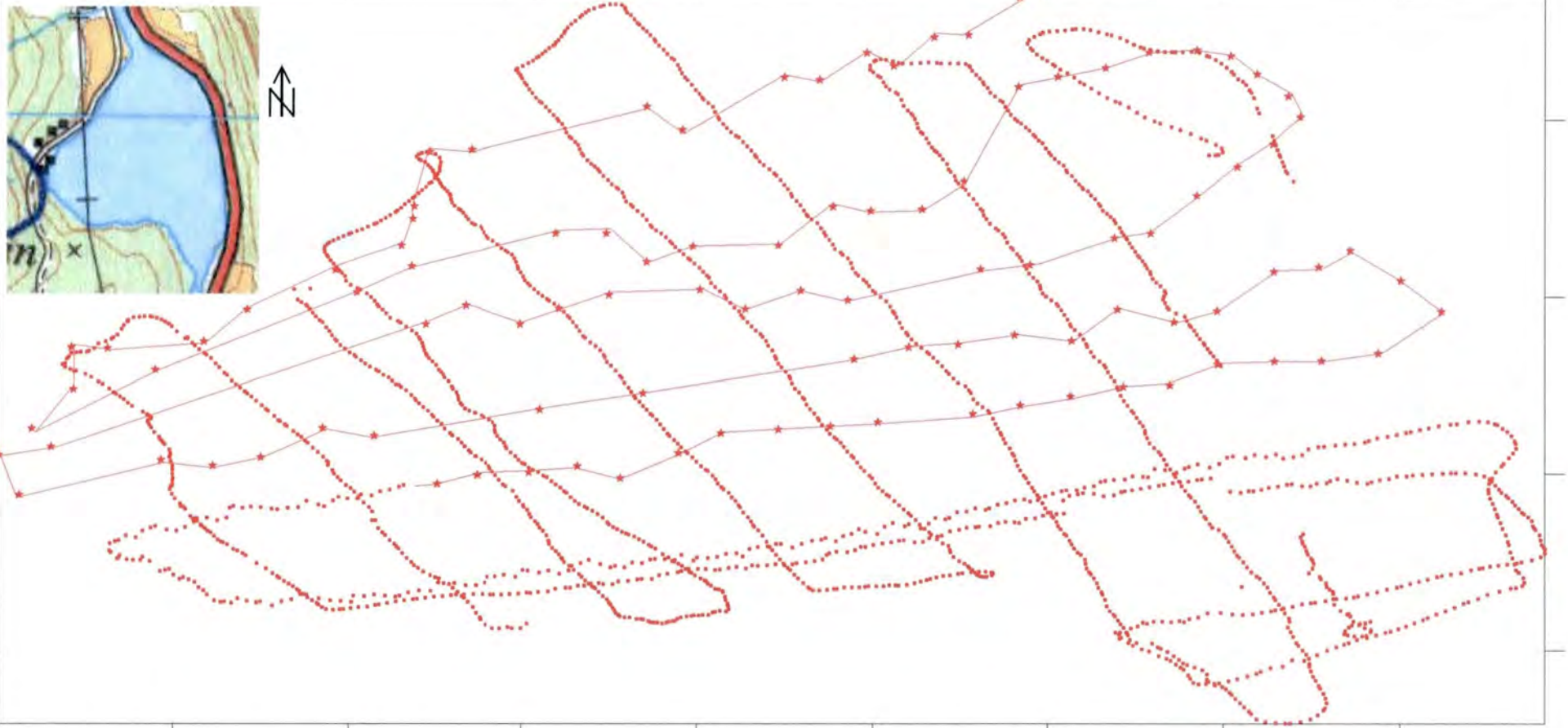
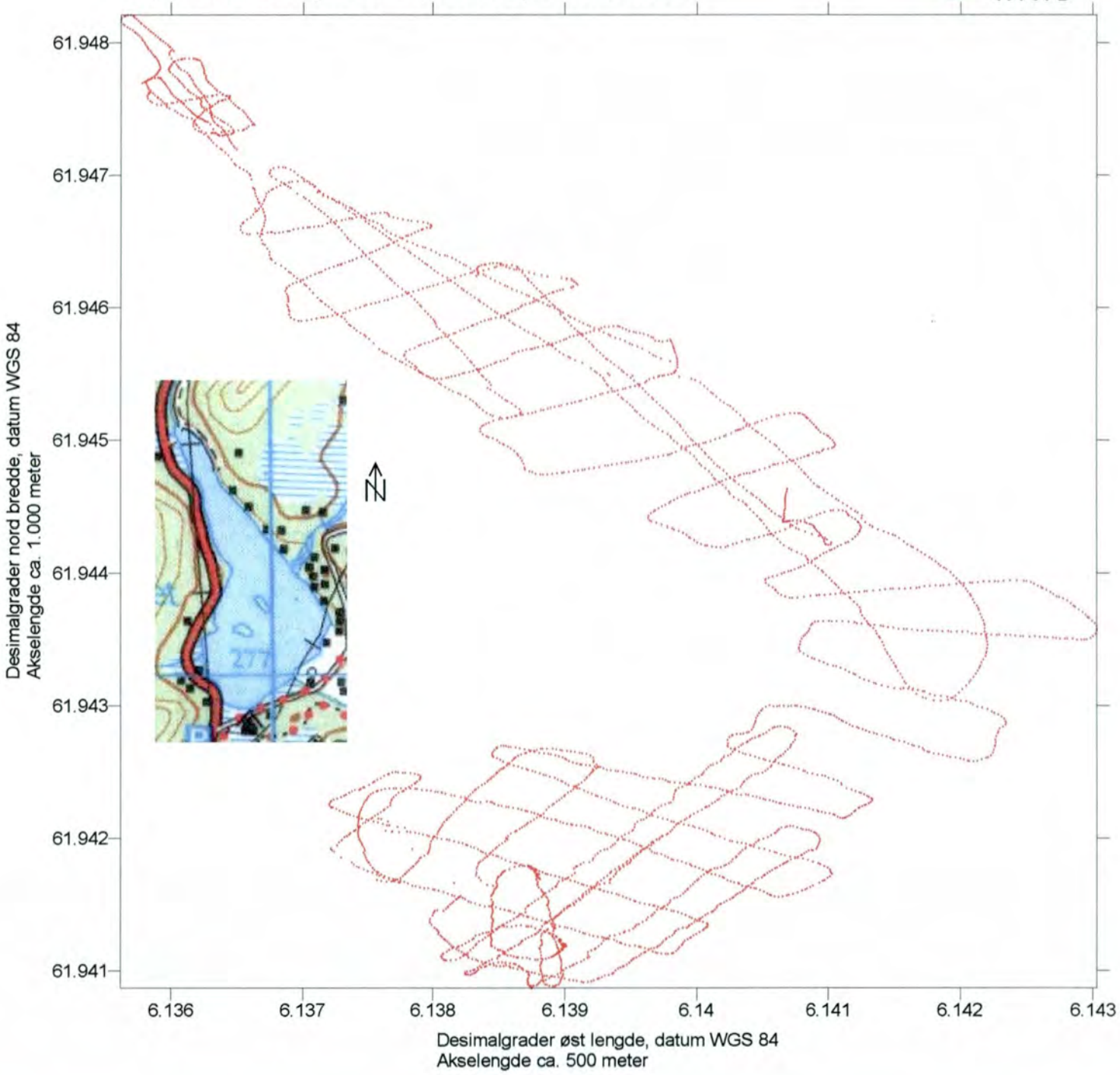


Fig. 5 STORESÆTERVATNET, Eid kommune
Orienterende linjekart - penetrasjonsekkolodd

GeoCore as
034-01-B



348500 349000 349500 350000 350500

6693500 6693000 6692500

Fig.1

NGU
Geology for Society since 1858

Scale 1:2500

50 0 50 100 150

meters

WGS 84 / UTM zone 32N

Contour interval 2meter

6 Depth contour (meter)

Profile lines with time and figure segments marked

Fig. 1

NGU / Norsk Hydro ASA / UiB / HSF

Map 1 **ROTEVATNET**
VOLDA
SEISMIC LINES

BATHYMETRY

346000

346500

6899000

6898500

6898000

Fig.2

Fig.3

Fig.4

Fig.5

NGU
Geology for Society since 1858

Scale 1:2500

50 0 50 100 150

metre

WGS 84 / UTM zone 32N

Contour interval 2 meter

2 Depth contour (meter)

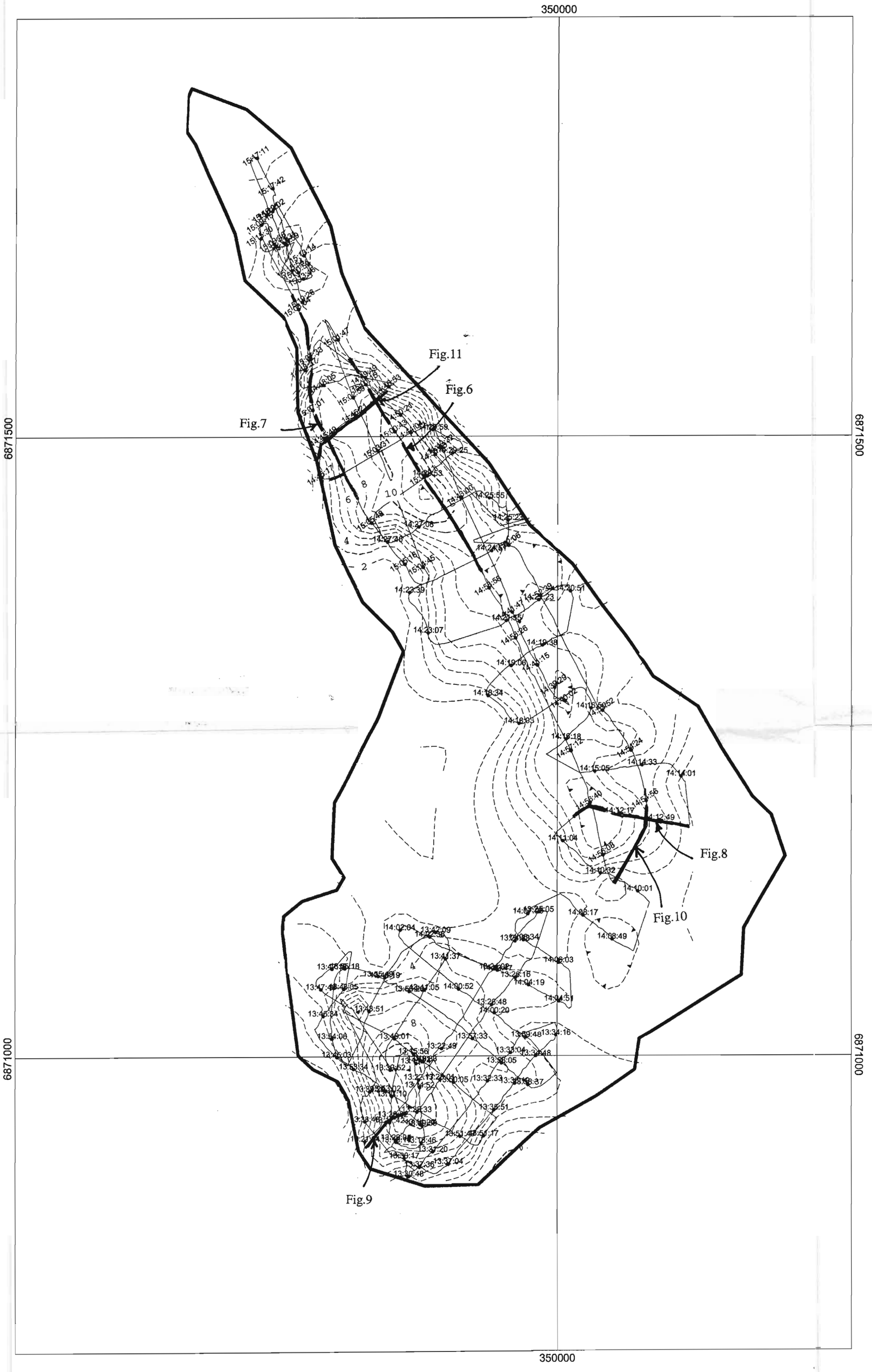
Profile lines with time and figure segments marked

Fig. 1

NGU / Norsk Hydro ASA / UiB / HSF

Map 2 **HOVDEVATNET VOLDA SEISMIC LINES**

BATHYMETRY



NGU
Geology for Society since 1858

Scale 1:2500

25 0 25 50 75 100 125 150 175
metre
WGS 84 / UTM zone 32N

Contour interval 1meter

6 Depth contour (meter)

Profile lines with time and figure segments marked

Fig. 1

NGU / Norsk Hydro ASA / UiB / HSF	
Map 3	**STORESETERVATNET** **VOLDA** **SEISMIC LINES**
BATHYMETRY	

345500

6882000

6881500

6881000

Fig.12

Fig.13

Fig.14

NGU
Geology for Society since 1858

Scale 1:2500

50 0 50 100 150

metre

WGS 84 / UTM zone 32N

Contour interval 2meter

4 Depth contour (meter)

Profile lines with time and figure segments marked

Fig. 1

NGU / Norsk Hydro ASA / UiB / HSF

Map 4

KILSVATNET
VOLDA
SEISMIC LINES

BATHYMETRY