TOBI SURVEY CRUISE REPORT ON THE NORWEGIAN MARGIN:

Upper North Sea Fan, Storegga Slide, Vøring Plateau and Trænadjupet Slide

RRS "CHARLES DARWIN"
Cruise No. CD116-97
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A contribution to the
ENAM II project

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BACKGROUND AND SCIENTIFIC OBJECTIVES

During the last decade the scientific community research interest and activities have increasingly focused on sedimentary processes, sediment fluxes, geometry of sediment bodies, as well as environmental changes in high and mid latitude margin areas. Through the research effort of the ENAM I project (**E**uropean **N**orth **A**tlantic **M**argin: sediment pathways, processes and fluxes) and the on-going ENAM II project (**E**uropean **N**orth **A**tlantic **M**argin: quantification and modelling of large-scale sedimentary processes and fluxes) both supported by the EU Commission this research work has seen the need for a better seabed imagery data from a selection of critical sites along the Norwegian margin. Up-to-date deep sea technologies (swath bathymetry and deep towed seismic profiler, high-resolution sidescan sonar and sea floor imagery) allow the determination of the large-scale sediment pathways and recognition of areas of mass wasting and deep-sea fan developments. TOBI (Towed Ocean Bottom Intrument) imagery sidescan sonar survey along the Norwegian margin is expected to be of a considerable benefit for our understanding of the dynamics of the margin system.

This marine geological/geophysical survey on the Norwegian margin off North Sea and off midwest Norway is the first TOBI sidescan sonar survey to the Norwegian margin. The use of the TOBI vehicle for this purpose has been funded by the European Commission under the Training and Mobility of Researchers (TMR) programme. This will be Cruise **No. CD116-97** from the Geological Institute and Cruise **No. 106C** for the research ship chartered, RRS Charles Darwin.

Objectives for Cruise CD116-97

The objectives of this cruise are to run the TOBI sea floor imaging vehicle to provide a suite of geological observations on the detailed morphology and shallow seismic character of the sea floor within three key target areas on the Norwegian margin, south of 68°N (Figs. 1 and 2). These new observations are aimed to complement existing data from earlier cruises into these areas, where synoptic-scale morphological data, along with seismic architecture and core material were acquired.

The specific objectives for the three key areas are:

Area I. Upper North Sea Fan.

The glacigenic debris flows/processes. Debris flows associated with glaciated trough mouth fans have been recognised in a number of North Atlantic margin locations and their flow mechanism addressed. One of the major problems in understanding the glacigenic debris flows mechanism/processes is reconciliation of the massive volumes of these debris flows and the failure to recognise corresponding zones of mass wasting with characteristic failure scarps, failure planes, or even topographic depressions reflecting their source area on the North Sea Fan. Previously collected data from the site chosen include air gun, Deep-Tow Boomer and echosounder grid surveying which demonstrated presence of numerous debris flow lenses/lobes of various sizes associated with the Last Glacial Maximum. This technique has not confirmed the presence of buried and surficial lenses/lobes nor failure scars at or near the seabed. Therefore a broad yet continuous survey technique, which can identify features of different scale, together with some shallow sub-bottom control, such as provided by the TOBI system is necessary to shed light on this problem.

Area II. The Storegga Slide/southern Vøring Plateau.

The Storegga Slide, northern escarpment. Bugge et al. (1987) suggested rapid sedimentation, shallow gas and gas-hydrate decomposition, and earthquakes as possible triggering mechanisms for the three Storegga Slides; the earthquakes as their preferred mechanism. Recent studies have, however, pointed out that gas or gas-hydrates could have been the most important mechanism in this area (e.g. Evans et al. 1966; Mienert et al. in press). The steepness of the slope, which is in part tectonically controlled, may also be an important factor on the northern flank of the Storegga Slide. A specific objective will be to study the nature and character of the northern Storegga Slide escarpment, meant to be the oldest of the slide events, and its relation to the bathymetrical and the stratigraphical character of the autochtonous slope sediments north of the slide scarp.

Fluid-escape features. The existence of gas hydrates at the same depth as the glide plane on the northern flank of the Storegga Slide has been proposed by Bugge et al. (1987). Recently, an abundance of gas-hydrate/fluid-release features has been revealed in this area north of the Storegga Slide found to disrupt the stratigraphical character of the autochtonous sediments (Evans et al. 1996). The TOBI survey is aimed to map these features to better understand their role in the slope stability.

Area III. Trænadjupet Slide/northern Vøring Plateau.

The Trænadjupet Slide complex. The main slide feature has its origin on the continental slope with a well defined termination on the lower continental rise as mapped on the GLORIA long-range sidescan sonar data (Dowdeswell et al. 1996). The age and volume of sediments involved in this failure is little known so far and the size of the features requires detailed study in separate areas where number of events has been recognised. In order to evaluate the slope stability on the northern Vøring Plateau the objective of the TOBI survey is to study the modern sedimentary processes in the southern Trænadjupet Slide area by elucidate the sediment failure processes, the relative age and volume of the slide events and to understand the geometry and architecture of the distal slide deposits.

Figures 1 and 2 show the outline of the general survey area and the track lines between the survey areas, and Figures 3-6 detailed trackplots of the three target areas. The general survey log is provided in Table I.

Funding

Funding of the cruise was by the University of Bergen (UiB), the EU Commission through the management of the ENAM II project (EU MAST III Contract: MAS3-CT 95-0003), the Norsk Hydro ASA on behalf of the Seabed Project and through a grant from the Training and Mobility of the Researchers (TMR-EU Commission) for running the TOBI vehicle free of charge. The cruise was also supported by the Southampton Oceanography Centre (SOC), GEOMAR Kiel, University of Tromsø, University of Oslo, British Geological Survey (BGS) and the University of Wales (Aberystwyth).

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Vessel

The research vessel RRS Charles Darwin was chartered for this cruise. RRS "Charles Darwin" has a length of 69.4 m, a beam of 14.4m and a displacement of 2556 tonnage (1936 gross tonnage). The ship is aptly suited to multidiciplinary geological/geophysical surveying and coring up to 20 m in length. Due to its special design, the acoustic noise signature (including the propulsion system) has been minimised. The facilities include a number of scientific laboratory spaces and sufficient offices and storage rooms. The centrally positioned laboratory facilities conveniently face aft on the main working deck level. The ship also features large handling systems as "A" frames both stern and starboard and cranes for handling large/heavy scientific equipment. A delay in the delivery of a new coaxial conducting tow cable for the ship winch required an installation of an external winch on the main deck specially designed for carrying a 10 km of conducting tow cable for the TOBI operation. We thank captain Robin C. Plumley and the crew of RRS "Charles Darwin" for their help in collecting the data on this cruise.

METHODS

Data Logging and Shipboard Data Processing

The distributed data acquisition and processing system used on board RRS Charles Darwin is built on a three layer architecture. The bottom layer (Level A) consists of a group of intelligent instrument interfaces which are responsible for collecting, conditioning and time stamping data from associated instruments. Each Level A interface constructs and transmits datagrams that conform to a common Ship Message Protocol (SMP). The transmitted SMP datagrams are collected using a secure V24 protocol transfer by the next layer in the architecture (Level B). The Level B data logger "funnels" data into a single stream that is written to two "mirrored" hard disk FIFO queues. Data in the queues are checked and cross-checked for error and time-out conditions and an appropriate system state display is provided for watch keepers. Data are also copied to 150 megabyte cartridge tapes which form a baseline backup from which all products could be re-worked should a disaster occur. The level B also forwards data via ethernet to the next layer (Level C). The Level C data processing system compress a suite of software which reside on a SUN Sparc Station IPC. Incoming Level A SMP datagrams sent on by the Level B are parsed out into associated binary data files for processing and archiving. The Level C is connected to the ships Ethernet LAN and has access to a number of plotting and output devices.

1) Level A instrument interfaces logged

GPS_4000 : Trimble 4000AX GPS
(using Racal DeltaFix LR differential corrections)
GPS_GLOSS : Glonass & GPS combination navigation receiver
LOG_CHF: Ships speed log
BIN_GYRO : Ships gyro-compass
DECKMK53G : Decca mk53G GPS navigator
EA500D1 : SIMRAD Single beam EA500 echosounder

2) Level B data logger

The Level B data logger operated without fault during the cruise. Ten 150 megabyte tapes were used. The tapes were read back onto the Level C system, compressed and archived.

3) Level C data processing system

The Level C system was operated using the Solaris 2.x operating system for the first time. No problems occurred. Navigation was taken from the differentially corrected Trimble 4000 system and processed into a bestnav file at 10 second intervals. Echosounder data was subsampled at 30 second intervals and Carter area corrected. A program for TOBI layback time processing was e-mailed from the base, and combined with an awk script written on board, to calculate the along track position offset of the TOBI vehicle behind the ship. The resulting TOBI navigation was plotted on ships track plots, and used as an input to the Trackmm program enabling generation of anamorphically correct strips of image data for mosaicing. Data was produced in ASCII format on IBM PC readable floppy disks. 150 Mbyte data tapes were produced for archiving at RVS (Table III).

Track plots for each target area were produced at a 1: 50 000 scale for creating mosaic map of the survey area (tick marks every 10 minutes, with labelled event numbers). All time annotations (navigation, profiles, samples, etc.) are in GMT. The ships track showing locations of the TOBI side scan and the 3.5/10 kHz seismic transects, together with hourly fix points with Julian day/time annotation are shown in Figures 1-6. The start and end of line co-ordinates are provided in Table II. During surveying, the ship travelled at a speed between 2 and 3 knots.

Geophysical Equipments and Procedures

a) TOBI

<u>Equipment</u>

TOBI (Towed Ocean Bottom Instrument) system is a deep-towed geophysical surveying vehicle build at the Institute of Oceanographic Sciences Deacon Laboratory (IOSDL), UK (now Southampton Oceanographic Centre). It is capable of operating in 6000 m of water although on this cruise the depth requirement was only up to 2000 m, most of the area under investigation was significantly less than this. The vehicle is connected by a 200 m neutrally buoyant umbilical cable to a 600 kg depressor fish, which terminates the main conducting tow cable and the vertical ship´s frequency movements. With this two bodied tow system the TOBI sidescan sonar unit is provided with a highly stable platform for recording. The TOBI vehicle is during surveying kept at a height between 350-400 m above the seabed by varying wire out and/or ship speed. Ship speed was usually kept between 2-3 knots depending on water depth and fine adjustments carried out by using the winch.

Data from the two side-channels are corrected for geometric distortion before being displayed on both a high resolution monitor and a thermal paper recorder. Sub-bottom profiler data are displayed directly to a linescan recorder as a measure of vehicle altitude, and in an expanded form, to reveal sub-bottom reflections. All data recorded are stored on magneto-optical discs which may be replayed to produce a corrected and geographically indexed mosaic of the working area.

The vehicle is designed in an open rectangular structure, ballasted for neutral buoyancy, consisting of a 4.25 m long, 1.1 m wide and 1.45 m high frame whereas (in which) the sidescan transducers are mounted along both sides angled down at 20 degrees. The array of transducers operates at a frequency of 30.37 kHz on the starboard side and 32.15 kHz on the port side to minimise cross-talk. These frequencies allows the acoustic arrays (3.0x0.12 m) to generate a beam maintaining a good signal to noise ratio out to 3000 meters. This array produces an acoustic sea bed footprint that varies from about 4x7 m at ca. 300 m off track to 40x2m at 3000 m range. Although TOBI is primarily a sidescan sonar vehicle a number of other instruments are fitted to make use of the stable platform TOBI provides. For this cruise the instrument complement in addition to the 30 kHz sidescan sonar was a 7.5 kHz sub-bottom profiler producing a continuous profiling below the vehicle (giving a resolution of <1 m and a penetration of up to 70 m), a three axis fluxgate magnetometer, thermistor, CTD, Gyrocompass and Pitch & Roll sensor. Although the gyrocompass was installed it was not operated due to power supply overload and noise problems.

The TOBI system uses a two bodied tow system to provide a highly stable platform for the onboard sonars. The vehicle weighs two and a half tonnes in air but is made neutrally buoyant in water by using syntactic foam blocks. A neutrally buoyant umbilical connects the vehicle to the 600 kg depressor weight. This in turn is connected via a conducting swivel to the main armoured coaxial tow cable. All signals and power pass through this single conductor.

For this cruise the SOC TOBI winch system, purchased using European funding, was utilised. This system combines tow, launch and umbilical winches onto one container sized baseplate enabling one driver to control all operations. The winch was secured to the aft deck using mounting plates designed and fitted by RVS. During the surveys the winch was controlled by a remote station in the main laboratory.

TOBI Deployments

TOBI was launched and recovered three times during the cruise. The logging times are listed below along with relevant comments:

Run	Start time/Julian day	End time/Julian day	Comments
1	16:40/185	14:41/187	Area 1.
2	11:48/188	19:16/193	Area 2.
3	10:11/194	05:53/195	Area 3 TOBI recovered to replace CTD unit
3	09:18/195	10:52/199	Area 3.

The disks used and their relevant times are listed in Table III

Data Recording and Replay

Data from the TOBI vehicle is recorded onto 1.2 Gbyte magneto-optical (M-O) disks. One side of each disk gives approximately 16 hours 10 minutes of recording time. All data from the vehicle is recorded along with wire out and ship position taken from a GPS receiver. The wire out did not function automatically due to winch wire out signals not being decoded correctly in the logging interface box. Manual entry was done throughout the cruise whenever winch movements occurred.

Data was recorded using TOBI programme LOG.C. The profiler data was corrected for the depth of the vehicle and replayed in programme PROFRAY.C. The CTD data was copied off the M-O disks and onto floppy disk in ASCII format for importation into a spreadsheet using programme CTDCOPY.C. Positions for the TOBI vehicle derived from the wire out and depth of the vehicle. 1/2 hour distance travelled for the vehicle could be calculated or measured. These were integrated into the TOBI replay system and correctly scaled sidescan sonar replays were generated at a scale of 1:50.000 using programmes ERASDISC.C and DISSCRAY.C. BLOWUP.C was used to generate large images of areas of interest.

TOBI Watchkeeping

TOBI watchkeeping was split into three four hour watches repeating every 12 hours. Watchkeepers kept the TOBI vehicle flying at a height of between 350 to 400m above the seabed by varying wire out and/or ship speed. Ship speed was usually kept between 2.0 and 3.5knts, depending on wire out, with fine adjustments carried out by using the winch.

As well as flying the vehicle and monitoring the instruments watchkeepers also kept track of disk changes and course alterations.

b) 3.5 kHz sub-bottom profiler

The 3.5 kHz profiling system with the transducer fish deployed at the starboard quarter were routinely recording high-resolution sub-bottom profiles both during the surveying in the three target areas and along the passage lines between these areas. For recording of the seismic signal an Waverley 3710 Recorder was set up and the archived data consists of paper records printed to in real time with a fixed annotations every 6th minute. No taped backup was made.

c) 10 kHz echosounder

A SIMRAD EA500 echosounder system connected with a 10 kHz transducer fish deployed at the port side was run continuously throughout the cruise, from the start of Survey area I and to the end of Survey area III. It has a colour monitor (CF 140) with colour output to an HP inkjet printer together with date/time annotations every 6th minute.

FIELD OPERATIONS

A summary of ship-board operations is provided in Table I.

Weather Conditions

Weather conditions during the entire cruise were extremely good for surveying with a calm weather although fog was experienced for a major proportion of the cruise. Deploying or recovering of the TOBI vehicle was therefore not disturbed by any sea state conditions. During a one calm spell the TOBI sidescan recording even suffered from surface reflection which resulted in a reduced range on the side scan sonar.

Equipment performance

The TOBI sidescan sonar performed well with some spectacular images obtained over the rougher terrain. Far range noise was present on run #1 and some of run #2 and to a much lesser extent on run #3. This was mainly caused by the vehicle chassis coming into contact with the 0V vehicle line and generating noise. The most likely sources of this contact were the swath hydrophone arrays (Area I) and a slight leak in the hydro electronics tube (Area II). By Area III both of these sources had either been eliminated or its effect minimised.

The CTD used in Areas I & II was a repaired unit brought in to replace our usual unit which had been delayed in returning from a previous cruise. In Area I the unit operated satisfactorily however on deployment in Area II the unit stopped working. The vehicle was recovered and the system tested on deck. No obvious reason could be found for the fault and the vehicle was redeployed, the CTD working reliably for the rest of the deployment. Prior to deployment in Area III the CTD was found to be giving occasional spurious readings that were crashing the interface programme in the vehicle. A change to the spare unit was not immediately possible as the output formats did not match so deployment went ahead with the original unit. The unit stopped working soon after deployment and could not be made to respond. It was decided to complete the first line during which a modification to enable use of the spare unit was worked out. The vehicle was recovered at the end of Line 24 and the spare unit installed and tested. The vehicle was relaunched on Line 25 but again the CTD stopped simultaneously with the magnetometer - see below. This time the unit responded to a restart and continued to operate satisfactorily for the remainder of the cruise.

The magnetometer performed well throughout the trip apart from a short period of down time during the start of Line 25. This problem was likely to have been caused by a small leak in the hydro tube as it also stopped the CTD readings at the same time. The fault cleared itself after about 1 hour. The only other noteworthy incident was that the magnetometer casing took a nudge from the ship during recovery at the end of Line 24 resulting in the unit being knocked out of its locating clamps. The unit was replaced prior to redeployment.

The TOBI winch system performed excellently mechanically. The wire out meter showed that there was some asymmetry in the haul and veer readings with the overall effect being that the actual wire out was more than indicated. This difference reduced during the cruise after being worked on by the technical engineers. The wire rate indicator seemed satisfactory. The wire tension meter gave readings they were not believably accurate.

The Swath system. The swath arrays, two each side of the vehicle, had been rebuilt since cruise CD100 using fibre glass rather than PVC tubes. A copper mesh had been buried in the tubes to provide extra electrical screening for the arrays of sensors inside but we discovered that this was in contact with the mounting bolts and hence the sea. This connection contributed to noise on both the side-scan and swath signals and had to be removed.

The tubes had originally been filled with hydraulic oil, whose sound velocity is greater than that of sea water, and this had been replaced by castor oil, with a sound velocity very nearly the same as water's. This improved the response of the arrays looking straight down but it or some other, not fully understood phenomena, has resulted in the vertical beam pattern being too narrow. We were only able to receive a useable signal out to about 1 km. After careful checking all the signal channels, 6 each side, before run #3 we were surprised to find that only four were working acceptably during that run. We suspect that there is a flooded connector somewhere.

The 3.5 kHz profiling system with the transducer fish deployed at the starboard quarter were routinely recording high-resolution sub-bottom profiles both during the surveying in the three target areas and along the passage lines between these areas. Archived data consists of paper records printed to in real time.

The 10 kHz echosounder provided some limited penetration, displaying some layering in the authoctonous sediments on the Vøring Plateau and in the Trænadjupet on occasional surficial units. Even with a limited penetration the intensity of the backscatter signal as record on the SIMRAD EA500 echosounder printout gave a useful information on the surface sediments. Archived data consists of paper records printed to in real time.

General Cruise Performance

The cruise was very successful both according to fairly good weather conditions and data retrieving having gathered over with about 1950 km of TOBI sidescan surveying covering 4150 km^2. The 3.5 kHz profiling system and the 10 kHz echosounder were also run successfully along the same track lines (1950 km) and in addition 667 km profiles were retrieved on the transits between the target areas. Equipment "down time" was insignificant due to failure on the CTD sensor and caused three times at least a full stop in operations. The main cruise objectives were addressed by the data collected, but answers for many of the more specific problems addressed in the Objectives will be forthcoming with further analysis of the data.

PRELIMINARY RESULTS

Area I. Upper North Sea Fan

Over 1150 km^2 TOBI sidescan coverage (4 km line spacing) was obtained, stretching from the outermost Norwegian Channel to ca. 750 m water depth on the upper North Sea Fan, with the attempt to help delineate the geometry and features of a series of debris flow deposits associated with glacial ice maximum conditions (Fig. 3). In the outer Norwegian Channel, randomly oriented iceberg scours were registered, giving way on the uppermost slope to a relatively featureless seabed with thin, late-post glacial sediment cover in the upper ca. 450 m water depth (Enclosure Map 1; CD-ROM). No obvious surficial contour current features were revealed. The thin surficial sediment cover is believed responsible for the general diffuse character of the sonograms across the entire survey site. A general decrease in seabed reflectivity with water depth probably reflects the decrease in sand content with depth in this sediment (presumably due to diminished winnowing action). Water column inhomogeneities (due to temperature differences) produced artefacts in the far range, effectively reducing the sidescan range to just over 3 km.

All surficial features on the slope, though relatively subtle, portray aspects of the downslope flow, owing either to the flow surfaces themselves or to the affect their slight topographic relief (lensoid in cross-section) had on distribution of the overlying hemipelagic sediment. Rather diffuse downslope-oriented lineations arising from seabed textural contrasts vary from broad bands (up to km wide) to narrow (75-100m), sub-parallel lineations. These textural contrasts are generally located along the flanks of the mounded debris flow bodies as opposed to along their downslope oriented crestlines. This pattern of alternating moderate to weak backscatter becomes more marked in the deeper part of the survey area. This is thought to be due to the presence of finer grained infill between flow crests, as deduced from slight sediment ponding observed on the profiler data. Rare continuous, narrow, linear bands can be traced upwards of 15 km downslope following a slightly sinuous path.

The TOBI data confirm inferences from previous (seismic profiling) investigations that the downslope mass wasting begins immediately at the uppermost slope (shelf break). The sinuous pattern is attributed to a degree of meandering of the debris flow path. No surficial expression of failure scarp, erosional cavity, or blocks is observed at any scale, helping confirm interpretations from previously collected Deep-Towed Boomer data (Haflidason et al. 1996) that these glacigenic debris flows contrast from the more "classic" (e.g. Prior et al. 1984) bottle-neck type of debris flow feature.

Area II. The Storegga Slide

The area covered by TOBI sidescan sonar data is approximately 3000 km^2, (totally 634 km of transect lines, 5 km in spacing), and stretches from the northern part of the Storegga Slide across the slide escarpment and into the Helland Hansen Field area on the Vøring Plateau (Fig. 4). The TOBI imagery maps enclosed are based on near 100% sidescan sonar coverage (Enclosure Maps 2-5). The morphology of the area surveyed is dominated by two distinctive seafloor characteristics (Enclosure Map 2; CD-ROM). In the north and in the central part of the area, i.e. on the Vøring Plateau, the seafloor imagery is characterised by a generally undisturbed low acoustic backscatter features, whereas in the south, i.e. inside the Storegga Slide, the seafloor imagery is characterised by a heavily disturbed area composed of several distinctive types of hummocky like features with linear, arcuate and random zones of contrasting backscatter (Enclosure Map 2). The boundary between these two morphologically distinctive areas is confined by a continuous escarpment features with a headwall may be up to 50 m high.

The seafloor dips ca. 0.8° towards Southwest, from depths around 700 m in the north to 1100 m in the south characterised by relatively featureless backscatter though gradually increasing to higher backscatter values to the north and east where the water depth is shallower and the current rates higher. The northern part of the area, i.e. the one covered by 3D-seismic (Fig. 4; Enclosure Maps 2 & 5), shows downslope elongated areas with lower backscatter than the adjacent areas. This may reflect textural differences of the sediments due to sediment filling of debris flow channels or differential sorting of sediments by contour currents. In the central part of the area, the backscattering is lower and more uniform than in the northern areas only interrupted by a number of patches/spots with higher backscattering than the surrounding areas. Most of these patches are uniformly circular in size and shape with a diameter of 200-300 m. Further east in the central part of the area similar patches occur, but these are smaller (up to 130 m in diameter), more irregular in shape and have lower backscattering than the surrounding high backscatter area. In this part the features also have a higher concentration. The size and the acoustic characteristics of these patches (i.e. the presence of acoustic shadows and strong acoustic signals) suggest that they might be pockmarks or mudvolcanoes. The 3.5 kHz data retrieved on the TOBI cruise show that the sediments possibly contain gas. Some of these patches are also surrounded with a number of high backscatter spots with a diameter of 20-40 m. The size, morphological character and the high backscatter value indicates that these small seafloor features can represent coral assemblages/Lophelia reefs?

The present slide escarpment is almost continuous across the surveyed area characterised with a pronounced arcuate scarps forming numerous collapse depressions. At some places it has also a character of a slightly gradual transition between the undisturbed Vøring Plateau area and the sediment failure area. The general dip inside the slide area is 1.1-1.4°, but locally within the slide scar zone the dip can be locally up to 11.5° (Bugge 1983). The height of the headwall (up to 50 m) is according to the 3.5 kHz profiles often nearly the same or slightly less than the thickness of the acoustically parallel bed sediments recorded on the Vøring Plateau area (see also e.g. Evans et al. 1996).

The seafloor morphology inside the sediment failure area is characterised by many discontinuous elongated sinuous bands of contrasting backscattering consisting of pressure ridges, lateral ridges, rafted blocks and longitudinal shear zone. Among these complex structures there are some zones with broader bands with less spectacular surface patterns. These bands are continuous and can be followed over long distances. They might represent channels, probably filled with sediments after the slope failure. In this area there are also some zones with small scale featureless surfaces, which can be interpreted as thick slabs of sediment that have moved downslope from the scarp, without much disintegration.

In the eastern part, where the headwall extends much further north than else recorded in the area, the structures are also much more pronounced. Just north of the scarp, there are bands of low backscattering oriented subparallell to the scarp. These are interpreted as active fractures or crack zones, and constitute a part of the transition between the continental slope and the slide area. The most pronounced of these fractures continue 6 km westwards far into the apparently undisturbed and stable area on the southern Vøring Plateau. Further, another one can be traced up to 13 km further west (clearly seen at 64°42´ N and 4° 57´ E). The size and location of these open fracture/crack zones far inside this apparently stable area means that the present slide scarp and the adjacent stable areas appear more unstable than earlier assumed.

According to the studies by Bugge (1983) and Bugge et al. (1987, 1988) the slide scarp mapped on the TOBI cruise is interpreted to be the northern boundary of the first Storegga Slide event tentatively dated to be about 30-50,000 years BP (Bugge et al. 1987, Jansen et al. 1987). The morphological character of the slide area and the high preservation of the structures must lead to the conclusion that the present slide scarp and the features downslope can not be as old as predicted by Bugge (1983). In the absence of groundtruth data other than the sidescan sonar imagery and the seismic profiles the interpretation of a Holocene age of these features is based on comparison with the seismic signature of the undisturbed units on the Vøring Plateau. The present slide scarp zone and the associated undisturbed (seismically bedded) areas are therefore much more unstable than earlier understood.

Area III. Trænadjupet Slide

Over 2900 km^2 TOBI sidescan coverage (5 km line spacing) was obtained including the northern, upper Vøring Plateau and the southern part of the continental slope off Trænadjupet (Figs. 5 & 6). Near 100% TOBI sidescan sonar coverage was obtained for this area (Enclosure Maps 6-10; CD-ROM 2). The survey area is characterised by a north-eastward/westward dipping continental slope, the water depth increases from about 1200 m to c. 2000 m. Target Area III has been divided into two main areas; the Trænadjupet Slide (north-eastern area) and the northern Vøring Plateau (south-western area) based on seismic signature and acoustic backscatter.

The Trænadjupet Slide. Within the slide affected area the 3.5 kHz records is characterised by prolonged bottom echoes with no subbottom reflections and regular, overlapping hyperbolae with varying vertex elevations above the sea floor and no subbottom reflections. The TOBI record covering the slide shows an overall high backscatter (Enclosure Maps 6-10). Linear bands of contrasting backscatter as well as streamlined flow pattern have been identified. Both the TOBI record and 3.5 kHz data indicates relatively young multiple downslope sediment transport within the Trænadjupet Slide.

The northern Vøring Plateau. On the TOBI image data the upper slope of the Vøring Plateau immediately south of the Trænadjupet Slide is an area dominated by downslope trending lineations within an area of relatively low backscatter. The 3.5 kHz records reveals continuous, sharp bottom echoes with one or two sharp, unconformable, wedging subbottom reflections. The area is inferred to be dominated by glacigenic debris flow deposits overlain by a thin drape of hemipelagic sediments. A downslope oriented escarpment seems to define the south-western limit of the glacigenic debris flows.

Continuous, sharp bottom echoes with several continuous, sharp parallel subbottom reflections has been found within the southernmost part of the study area (south-west of the escarpment). The TOBI sidescan sonar data in this area in general display relatively low backscatter most probably due to hemipelagic sediment coverage. The hemipelagic sediments are, near the southern limit of the study area, disturbed by diapiric structures characterised by a transparent seismic facies. Several of them can be identified up to the sea floor which pull up above them. Based on the above characteristics these features probably represents mud diapers.

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FIGURES

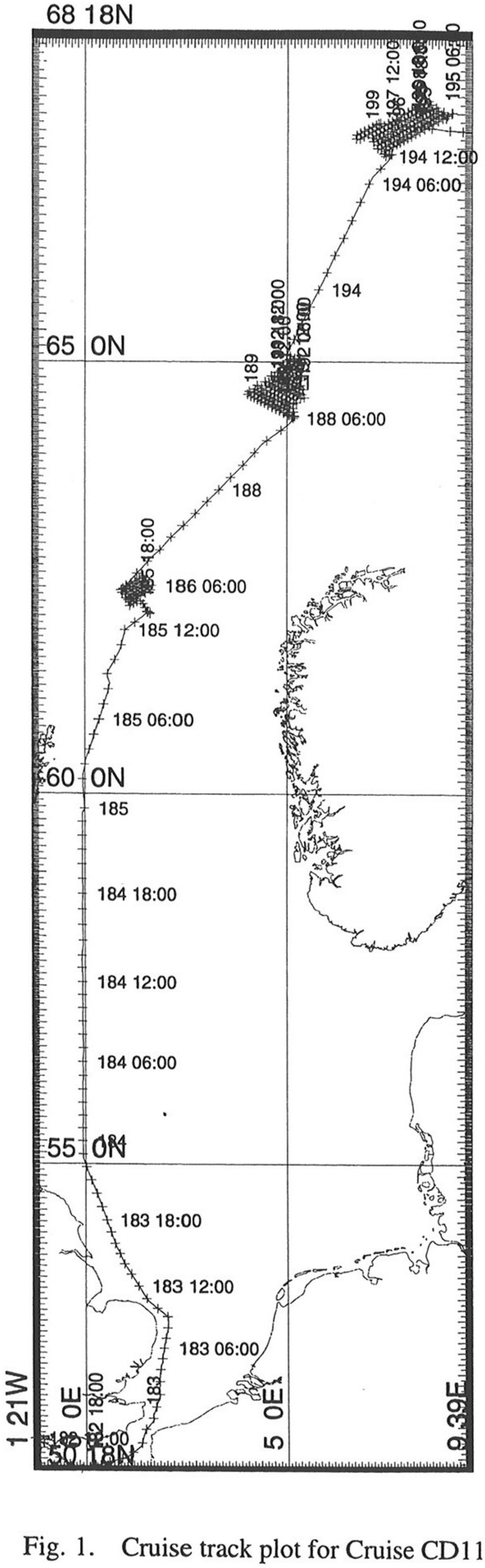

Fig. 1. Cruise track plot for Cruise CD116-97. Scale 1: 9 000 000 (Mercator Projection-natural scale at latitude 60°N). Detailed maps of the three survey areas are in Figs 3-5.

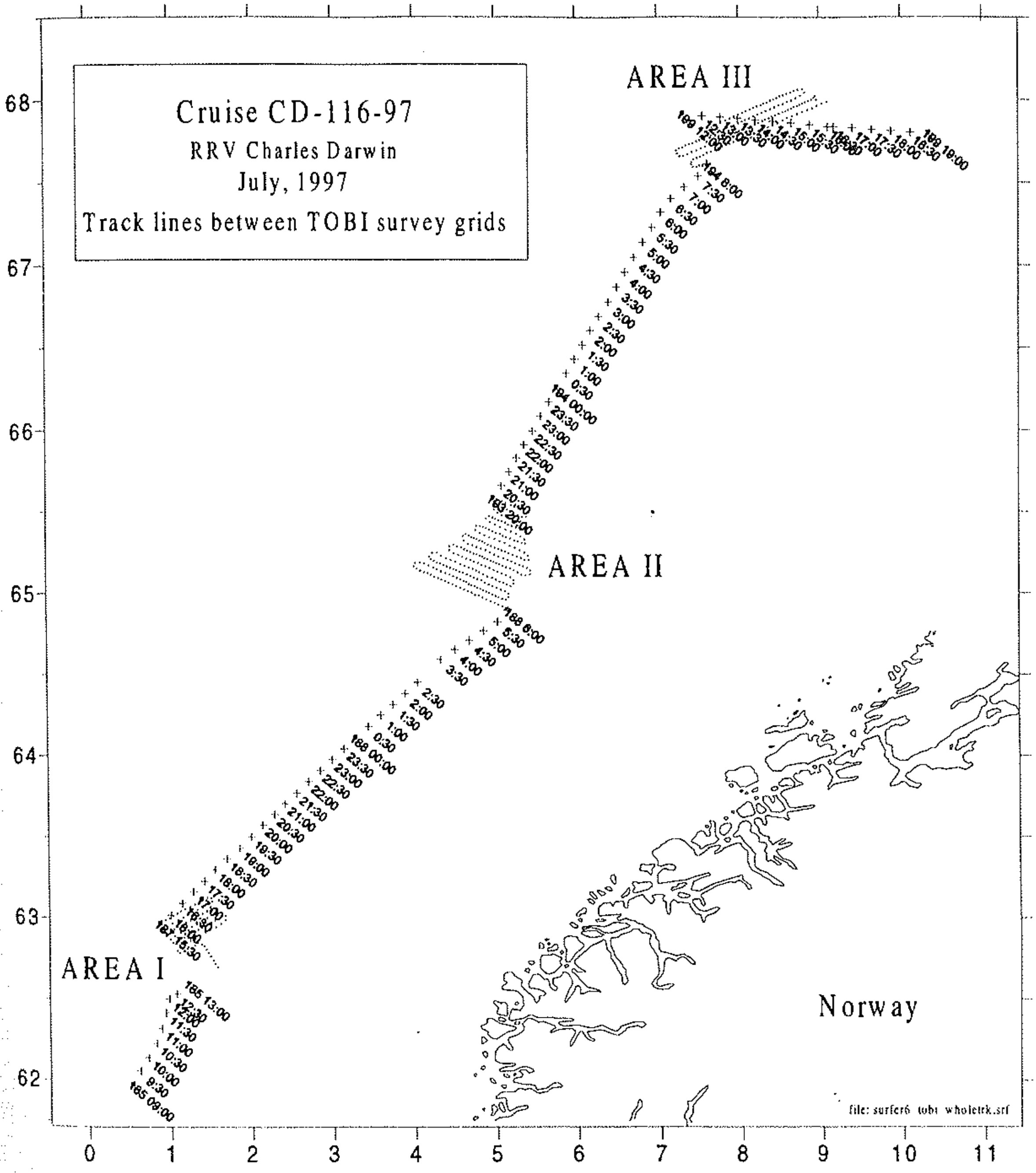

Fig. 2. Track lines between TOBI survey grids. Annotation with Julian Day and GMT is labelled.

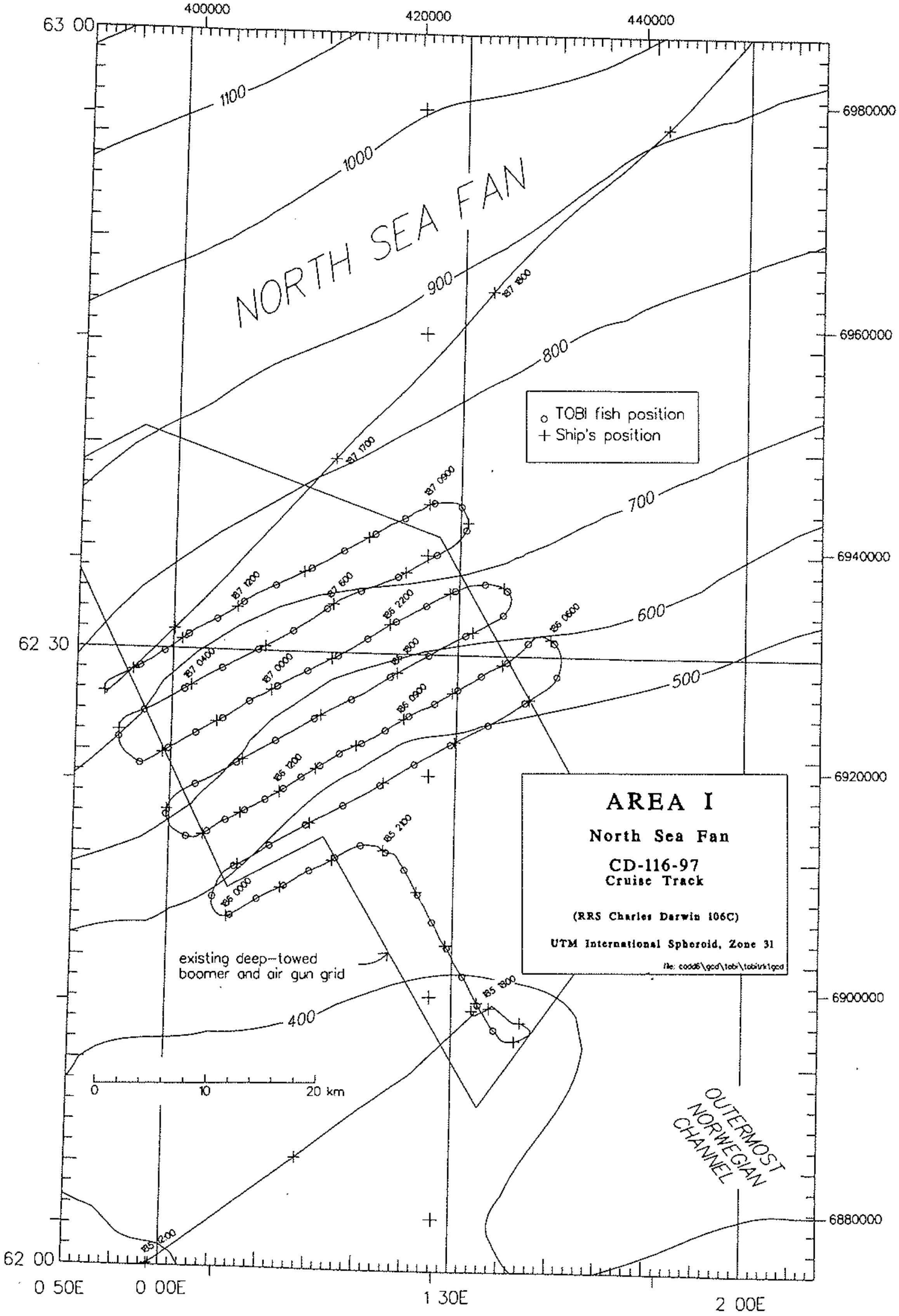

Fig. 3. TOBI survey Area I on the North Sea Fan. Annotation with Julian Day and GMT for the ships position is labelled. TOBI fish position is also shown and the existing Deep-Towed Boomer and air gun grid.

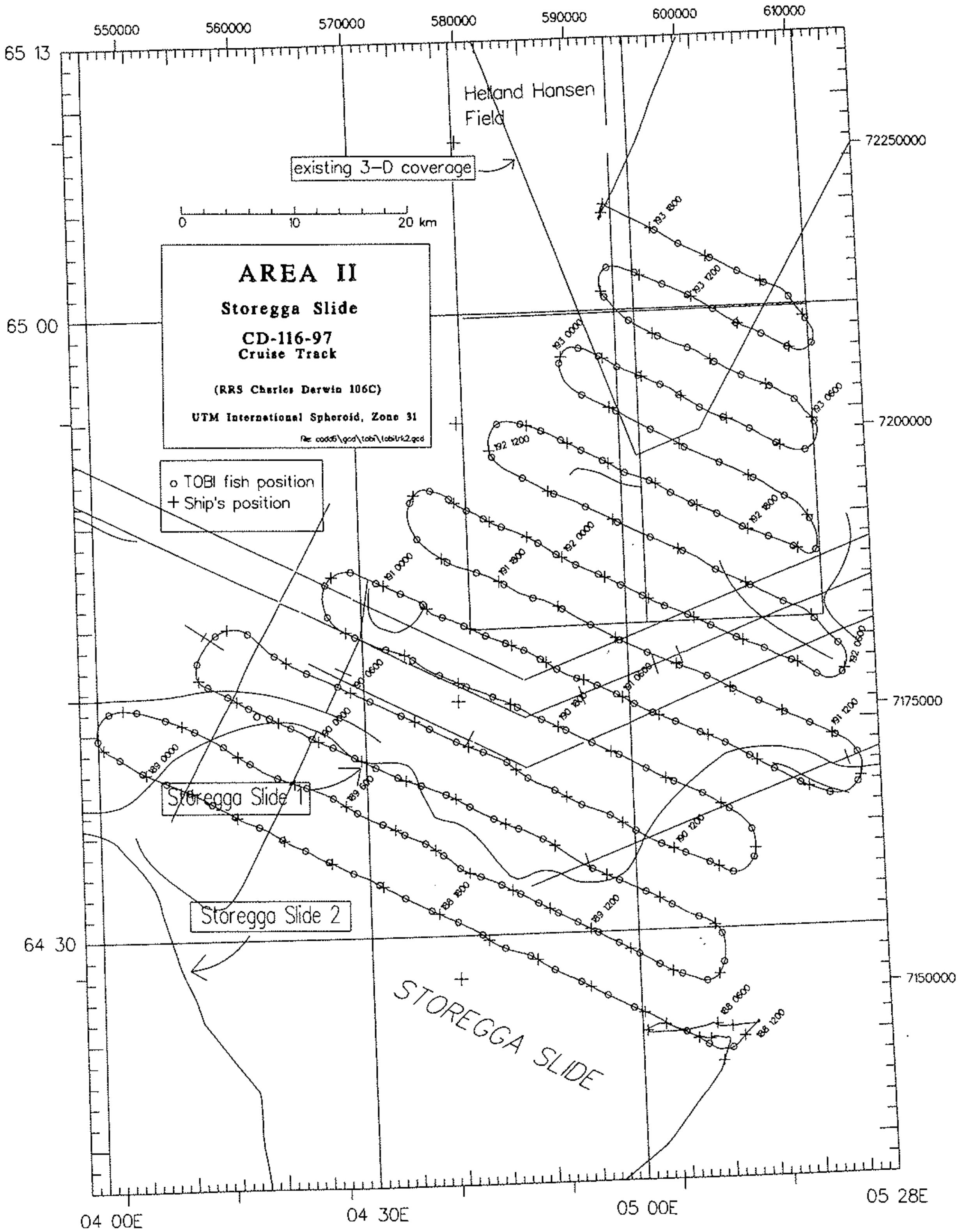

Fig. 4. TOBI survey Area II on Storegga Slide and Helland Hansen Field. Annotation with Julian Day and GMT for the ships position is labelled. TOBI fish position is also shown and the existing 3D coverage on the Helland Hansen Field.

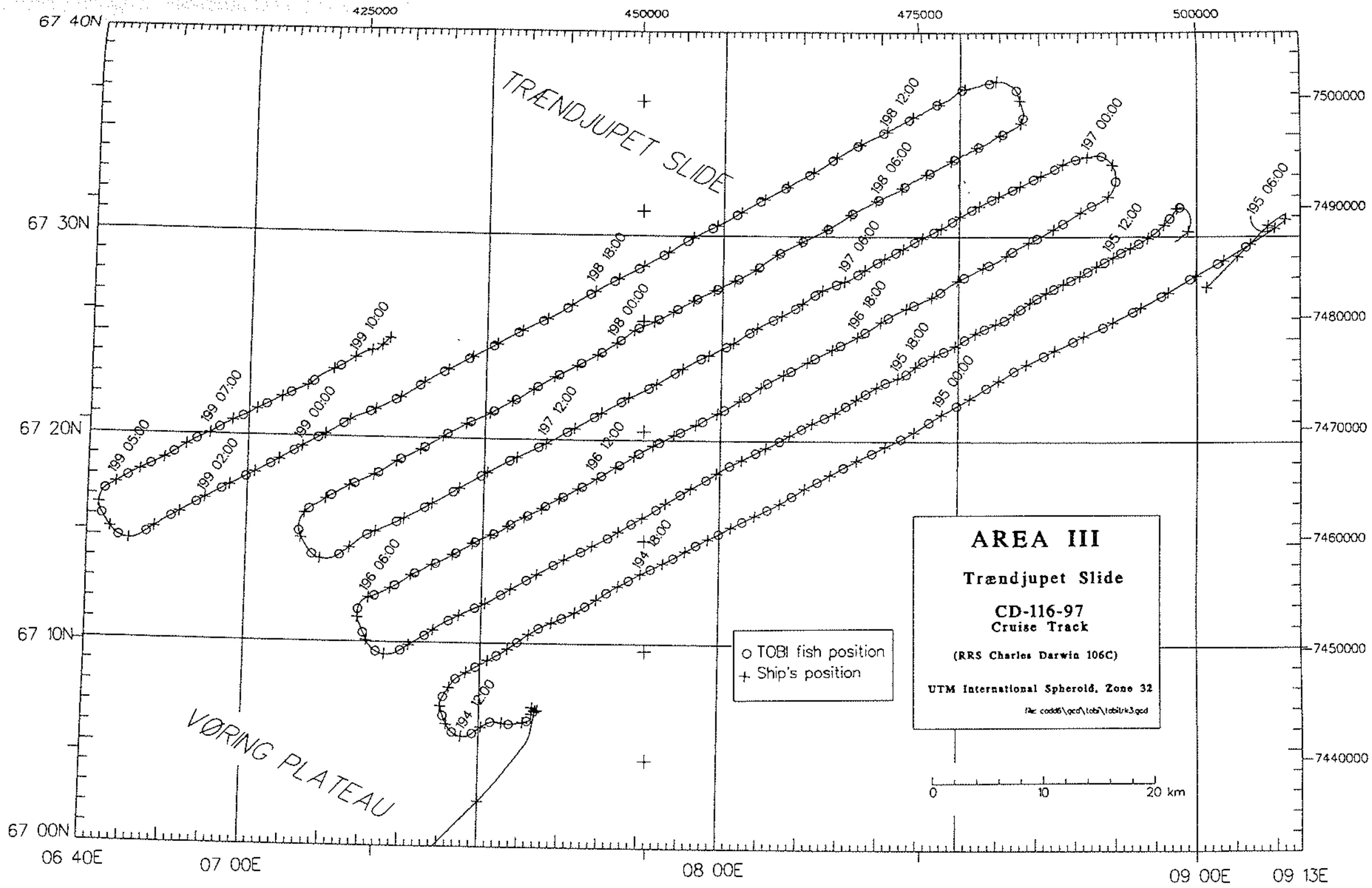

Fig. 5. TOBI survey Area II on the Trænadjupet Slide. Annotation with Julian Day and GMT for the ships position is labelled. The TOBI fish position is also shown.

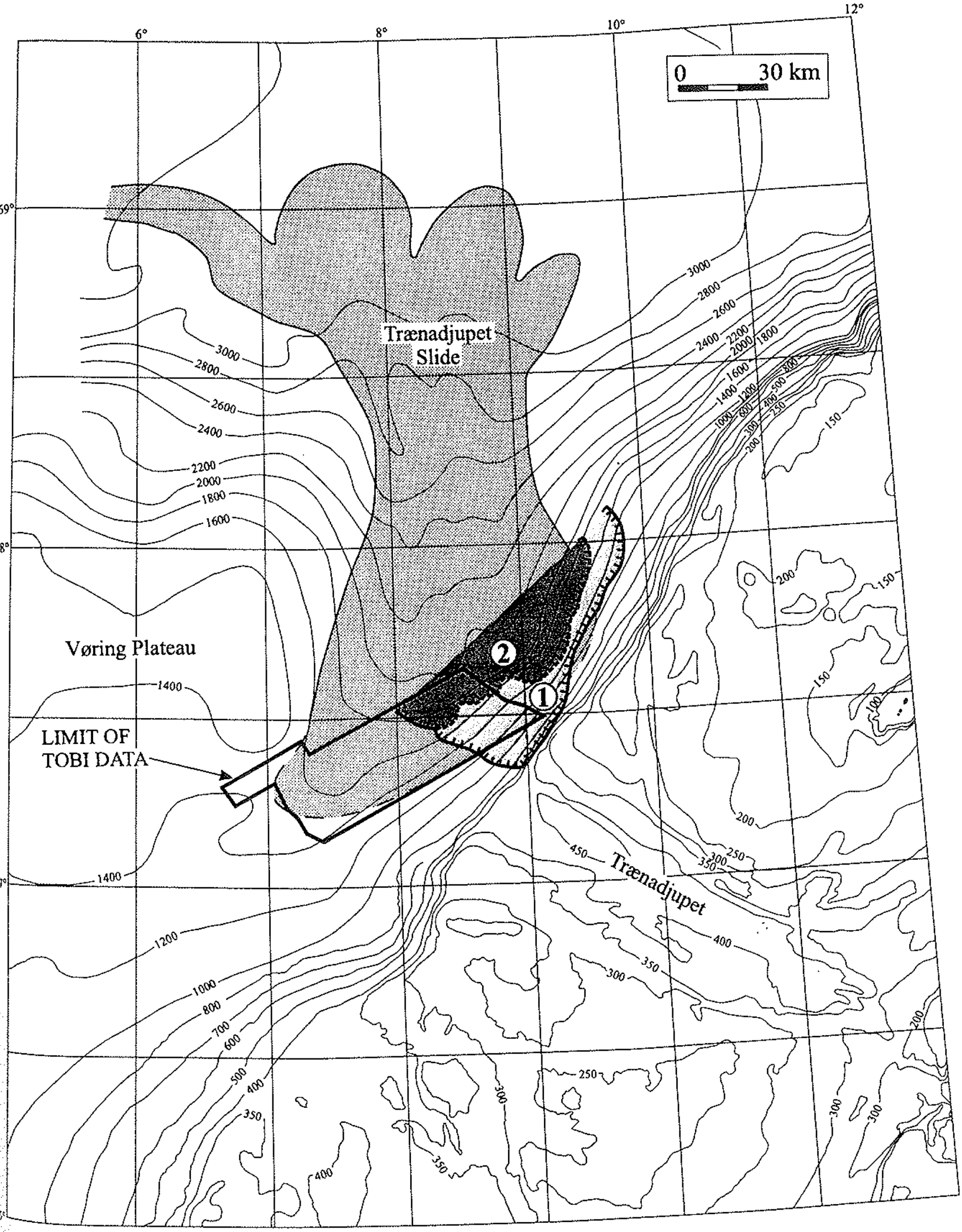

Fig. 6. Outline of the TOBI survey on the Trænadjupet Slide. Location of the two most recent sediment failures areas inside the main Trænadjupet Slide is shown.

TABLE I
GENERAL SURVEY LOG

TABLE 1.

GENERAL SURVEY LOG

CRUISE CD116-97

DATE	Julian Day	TIME (GMT)	COMMENTS
30.06.1997	181	11:00	Mobilization and preparation.
01.07.1997	182	08:00	Security meeting.
01.07.1997	182	09:30	Lifeboat drill.
01.07.1997	182	11:00	Departure Southampton
02.07.1997	183	12:00	Scientific goals meeting.
03.07.1997	184	09:30	Emergency drill.
04.07.1997	185	12:00	3.5 kHz & 10 kHz tow fishes deployed
04.07.1997	185	14:00	In position to deploy TOBI
04.07.1997	185	16:35	TOBI deployed
04.07.1997	185	17:40	SOL 1 (Survey Area I)
04.07.1997	185	20:42	EOL 1
04.07.1997	185	21:22	SOL 2
04.07.1997	185	23:41	EOL 2
05.07.1997	186	00:45	SOL 3
05.07.1997	186	04:57	EOL 3
05.07.1997	186	06:58	SOL 4
05.07.1997	186	14:00	EOL 4
05.07.1997	186	15:12	SOL 5
05.07.1997	186	19:14	EOL 5
05.07.1997	186	20:47	SOL 6
06.07.1997	187	02:06	EOL 6
06.07.1997	187	03:15	SOL 7
06.07.1997	187	07:32	EOL 7
06.07.1997	187	09:10	SOL 8
06.07.1997	187	14:25	EOL 8
06.07.1997	187	15:25	TOBI recovered
06.07.1997	187	15:36	SOTransit to Survey Area II (3.5 kHz+10 kHz profiling)
07.07.1997	188	06:08	On station for deploying TOBI in Survey Area II
07.07.1997	188	07:50	In position for SOL 9 - TOBI not working properly
07.07.1997	188	08:50	TOBI recovered
07.07.1997	188	11:23	TOBI deployed again after repair
07.07.1997	188	13:26	SOL 9 (Survey Area II)
08.07.1997	189	00:27	EOL 9
08.07.1997	189	02:49	SOL 10
08.07.1997	189	14:12	EOL 10
08.07.1997	189	16:18	SOL 11
09.07.1997	190	02:30	EOL 11
09.07.1997	190	05:12	SOL 12
09.07.1997	190	12:48	EOL 12
09.07.1997	190	14:55	SOL 13
09.07.1997	190	21:39	EOL 13
10.07.1997	191	00:08	SOL 14
10.07.1997	191	00:46	Diverting course to avoid nearby ship
10.07.1997	191	01:10	Back on Line 14
10.07.1997	191	10:09	EOL 14

TABLE 1. cont. **GENERAL SURVEY LOG**

DATE	Julian Day	TIME (GMT)	COMMENTS
10.07.1997	191	11:54	SOL 15
10.07.1997	191	18:58	EOL 15
10.07.1997	191	20:30	SOL 16
11.07.1997	192	05:21	EOL 16
11.07.1997	192	07:25	SOL 17
11.07.1997	192	11:30	EOL 17
11.07.1997	192	13:39	SOL 18
11.07.1997	192	19:06	EOL 18
11.07.1997	192	20:22	SOL 19
11.07.1997	192	23:18	EOL 19
12.07.1997	193	01:00	SOL 20
12.07.1997	193	05:07	EOL 20
12.07.1997	193	06:38	SOL 21
12.07.1997	193	09:30	EOL 21
12.07.1997	193	10:49	SOL 22
12.07.1997	193	13:50	EOL 22
12.07.1997	193	15:46	SOL 23
12.07.1997	193	18:24	EOL 23
12.07.1997	193	19:39	TOBI recovered
12.07.1997	193	19:50	SOTransit to Survey Area III (3.5 +10 kHz profiling)
13.07.1997	194	09:35	TOBI deployed
13.07.1997	194	13:42	SOL 24
14.07.1997	195	04:10	EOL 24
14.07.1997	195	06:00	TOBI recovered for CDT repair
14.07.1997	195	08:57	TOBI redeployed
14.07.1997	195	11:29	SOL 25
15.07.1997	196	03:44	EOL 25
15.07.1997	196	06:19	SOL 26
15.07.1997	196	22:30	EOL 26
16.07.1997	197	01:00	SOL 27
16.07.1997	197	15:35	EOL 27
16.07.1997	197	17:05	SOL 28
17.07.1997	198	08:14	EOL 28
17.07.1997	198	10:21	SOL 29
18.07.1997	199	02:50	EOL 29
18.07.1997	199	05:22	SOL 30
18.07.1997	199	11:00	EOL 30
18.07.1997	199	11:37	TOBI recovered
18.07.1997	199	12:00	SOTransit to Bodø (3.5 kHz+10 kHz profiling)
18.07.1997	199	12:00	SOL 31
18.07.1997	199	16:05	EOL 31
18.07.1997	199	16:10	3.5 kHz fish recovered
18.07.1997	199	16:20	10 kHz fish recovered
19.07.1997	200	06:30	Arrival Bodø

TABLE II

START AND END OF LINE COORDINATES

TABLE II
START AND END OF LINE COORDINATES

	START OF LINE							END OF LINE						
LINE NUMBER	DATE	JULIAN DAY	TIME GMT	LATITUDE	LONGITUDE	EASTING	NORTHING	DATE	JULIAN DAY	TIME GMT	LATITUDE	LONGITUDE	EASTING	NORTHING
Area 1: North Sea Fan; UTM Zone 31														
CD-116-01	04-07	185	17:27	62° 11.75′ N	01° 34.48′ E	425814	6896979	04-07	185	20:42	62° 20.10′ N	01° 23.94′ E	417062	6912694
CD-116-02	04-07	185	21:22	62° 20.64′ N	01° 20.47′ E	414095	6913759	04-07	185	23:44	62° 17.40′ N	01° 07.76′ E	402947	6908026
CD-116-03	05-07	186	00:44	62° 19.00′ N	01° 05.61′ E	401177	6911081	05-07	186	05:08	62° 28.23′ N	01° 38.74′ E	430154	6927471
CD-116-04	05-07	186	06:57	62° 29.59′ N	01° 34.76′ E	426787	6930082	05-07	186	14:02	62° 20.91′ N	01° 03.33′ E	399311	6914667
CD-116-05	05-07	186	15:12	62° 22.91′ N	01° 00.85′ E	397297	6918444	05-07	186	19:10	62° 31.48′ N	01° 32.90′ E	425262	6933614
CD-116-06	05-07	186	20:47	62° 33.28′ N	01° 30.31′ E	423124	6937006	06-07	187	02:06	62° 24.72′ N	00° 58.41′ E	395292	6921881
CD-116-07	06-07	187	03:16	62° 26.74′ N	00° 56.02′ E	393360	6925690	06-07	187	07:24	62° 34.93′ N	01° 27.81′ E	421054	6940120
CD-116-08	06-07	187	09:10	62° 37.01′ N	01° 25.40′ E	419080	6944038	06-07	187	14:24	62° 28.37′ N	00° 52.67′ E	390579	6928815
Area 2: Storegga Slide; UTM Zone 31														
CD-116-09	07-07	188	13:26	64° 25.23′ N	05° 03.63′ E	599248	7145635	08-07	189	00:27	64° 38.63′ N	04° 03.11′ E	550254	7169332
CD-116-10	08-07	189	02:49	64° 40.62′ N	04° 08.35′ E	554368	7173119	08-07	189	14:12	64° 27.82′ N	05° 04.84′ E	600066	7150494
CD-116-11	08-07	189	16:18	64° 03.58′ N	05° 06.77′ E	603112	7105524	09-07	190	02:30	64° 42.06′ N	04° 13.52′ E	558426	7175857
CD-116-12	09-07	190	05:12	64° 43.02′ N	04° 23.01′ E	565922	7177808	09-07	190	12:48	64° 33.16′ N	05° 08.45′ E	602630	7160493
CD-116-13	09-07	190	14:55	64° 35.86′ N	05° 10.29′ E	603923	7165555	09-07	190	21:39	64° 44.30′ N	04° 30.45′ E	571782	7180295
CD-116-14	10-07	191	00:08	64° 46.87′ N	04° 33.26′ E	573886	7185146	10-07	191	10:09	64° 36.50′ N	05° 20.94′ E	612371	7167065
CD-116-15	10-07	191	11:54	64° 39.07′ N	05° 23.29′ E	614064	7171900	10-07	191	18:58	64° 48.24′ N	04° 39.26′ E	578573	7187804
CD-116-16	10-07	191	20:30	64° 51.47′ N	04° 39.00′ E	578219	7193804	11-07	192	05:21	64° 42.12′ N	05° 21.24′ E	612223	7177501
CD-116-17	11-07	192	07:25	64° 45.66′ N	05° 17.94′ E	609363	7183964	11-07	192	11:30	64° 52.22′ N	04° 48.06′ E	585328	7195391
CD-116-18	11-07	192	13:39	64° 54.03′ N	04° 52.47′ E	588716	7198835	11-07	192	19:06	64° 48.04′ N	05° 20.40′ E	611141	7188460
CD-116-19	11-07	192	20:22	64° 50.68′ N	05° 18.93′ E	609802	7193306	11-07	192	23:18	64° 55.80′ N	04° 56.61′ E	591875	7202214
CD-116-20	12-07	193	01:00	64° 57.66′ N	04° 58.50′ E	593264	7205726	12-07	193	05:07	64° 53.09′ N	05° 19.09′ E	609769	7197798
CD-116-21	12-07	193	06:38	64° 55.67′ N	05° 19.01′ E	609528	7202592	12-07	193	09:30	64° 59.64′ N	05° 00.92′ E	595048	7209469
CD-116-22	12-07	193	10:49	65° 01.80′ N	05° 02.10′ E	595848	7213522	12-07	193	13:50	64° 58.11′ N	05° 19.01′ E	609362	7207109
CD-116-23	12-07	193	15:46	65° 00.85′ N	05° 18.35′ E	608664	7212196	12-07	193	18:24	65° 04.40′ N	05° 01.93′ E	595549	7218345
Area 3: Trændjupet Slide; UTM Zone 32														
CD-116-24	13-07	194	13:42	67° 08.19′ N	07° 26.86′ E	432689	7447616	14-07	195	04:10	67° 27.56′ N	08° 57.61′ E	498289	7482762
CD-116-25	14-07	195	11:29	67° 29.43′ N	08° 51.59′ E	494007	7486237	15-07	196	03:44	67° 10.21′ N	07° 22.39′ E	429560	7451445
CD-116-26	15-07	196	06:19	67° 12.41′ N	07° 17.45′ E	426113	7455627	15-07	196	22:30	67° 31.11′ N	08° 45.36′ E	489580	7489378
CD-116-27	16-07	197	01:00	67° 32.94′ N	08° 40.17′ E	485912	7492802	16-07	197	15:35	67° 14.44′ N	07° 12.68′ E	422776	7459501
CD-116-28	16-07	197	17:05	67° 16.39′ N	07° 07.79′ E	419373	7463226	17-07	198	08:14	67° 34.62′ N	08° 33.64′ E	481293	7495959
CD-116-29	17-07	198	10:21	67° 37.32′ N	08° 31.60′ E	479889	7500986	18-07	199	02:50	67° 15.69′ N	06° 49.47′ E	406171	7462355
CD-116-30	18-07	199	05:22	67° 18.08′ N	06° 45.83′ E	403708	7466874	18-07	199	11:00	67° 24.49′ N	07° 16.81′ E	426267	7478085
CD-116-31	18-07	199	12:00	67° 24.73′ N	07° 20.00′ E	428564	7478456	18-07	199	16:05	67° 20.33′ N	09° 07.70′ E	505518	7469326

TABLE III

DATA DISCS NO. FOR TOBI SURVEY

TABLE III
Data Discs for TOBI Survey

Disc No.		Start/ Julian Day	End/ Julian Day	Comments
1	500	16:40/184	16:53/184	Stopped logging to correct video card fault and date
	500A	17:04/185	17:52/185	Stopped logging to correct computer clocks
	500B	17:55/185	09:03/185	Start of run #1
2	501	09:03/185	01:12/187	
3	502	01:12/187	14:41/187	End of run #1
	502A	06:59/188	07:48/188	Aborted start to run #2 due to CTD problem
	502B	11:48/188	13:41/188	Start of run #2
4	503	13:41/188	05:50/189	
5	504	05:50/189	21:59/189	
6	505	21:59/189	14:08/190	
7	506	14:08/190	06:17/191	
8	507	06:17/191	22:27/191	
9	508	22:17/191	14:36/192	
10	509	14:36/192	06:45/193	
11	510	06:45/193	19:16/193	End of run #2
	510A	10:11/194	13:55/194	Start of run #3
12	511	13:55/194	05:53/195	TOBI recovered at EOL 24 to replace CTD unit
	511A	09:18/195	09:29/195	TOBI redeployed at SOL 25
13	512	09:30/195	01:40/196	
14	513	01:40/196	17:49/196	
15	514	17:49/196	09:58/197	
16	515	09:58/197	02:08/198	
17	516	02:08/198	18:17/198	
18	517	18:17/198	11:00/199	

ENCLOCURE MAPS

CD-ROMS

CD-ROM 1. CD106 TOBI/Cruise No.116-97 Imagery for North Sea Fan and Storegga Slide (Raw data and Processed maps).

CD-ROM 2. CD106 TOBI/ Cruise No.116-97 Imagery for Trænadjupet Slide (Raw data and Processed maps).