DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2008/73

Geophysical investigation of archaeological artefacts in NordHavn harbour

Zyad Al-Hamdani & Jørgen O. Leth

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2008/73

Geophysical investigation of archaeological artefacts in NordHavn harbour

Zyad Al-Hamdani & Jørgen O. Leth

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

Table of contents

1. Introduction

GEUS was approached by Vikingeskibsmuseet for conducting a survey in the area surrounding the proposed new port and terminal in the northern part of the Copenhagen Nordhavn port, Fig 1. The results of this survey are presented in this report.

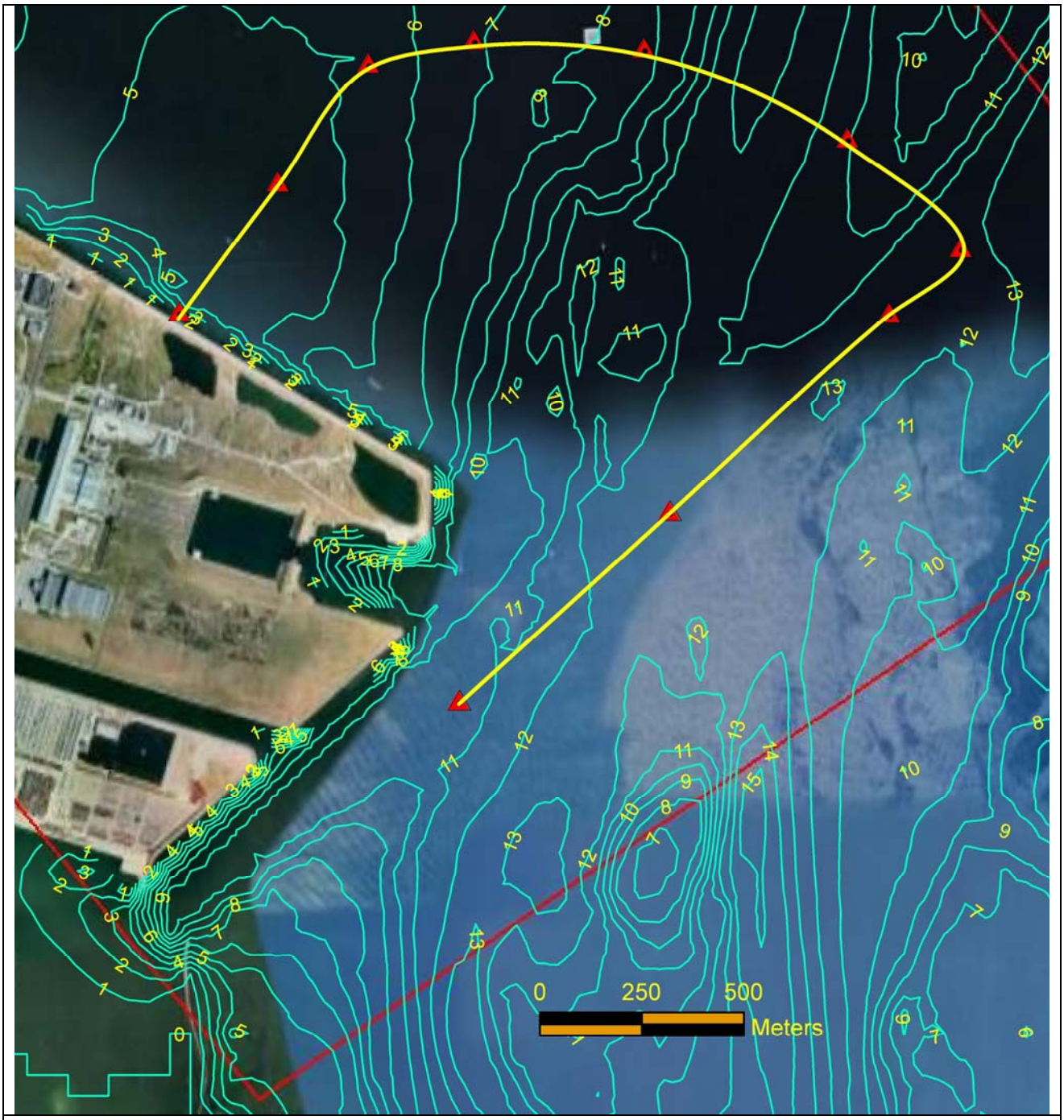


Figure 1. Survey area (yellow line) in the Copenhagen Nordhavn.

The survey consists of two parts:

1. The magnetometer part.
2. The sidescan mosaicing part.

Both parts were conducted simultaneously in the same survey vessel.

2. The survey

The survey was conducted at the 28th October 2008 using the survey ship CAT1, Fig 2, to cover the area of ~1.3x1.3km as shown in Fig 3. The surveyed region is located at the Nordhavn harbour. The area was surveyed at 30m interval with a Northwest Southeast survey lines. A total of ~ 55 line-km were surveyed during the work. The ship is equipped with a GPS system and NaviPac software for navigation. They survey was conducted at a speed of about 4.5knots which is very adequate for such kind of work where two survey equipment (the magnetometer and the sidescan) are towed behind the ship.

Figure 2. The survey ship CAT1.

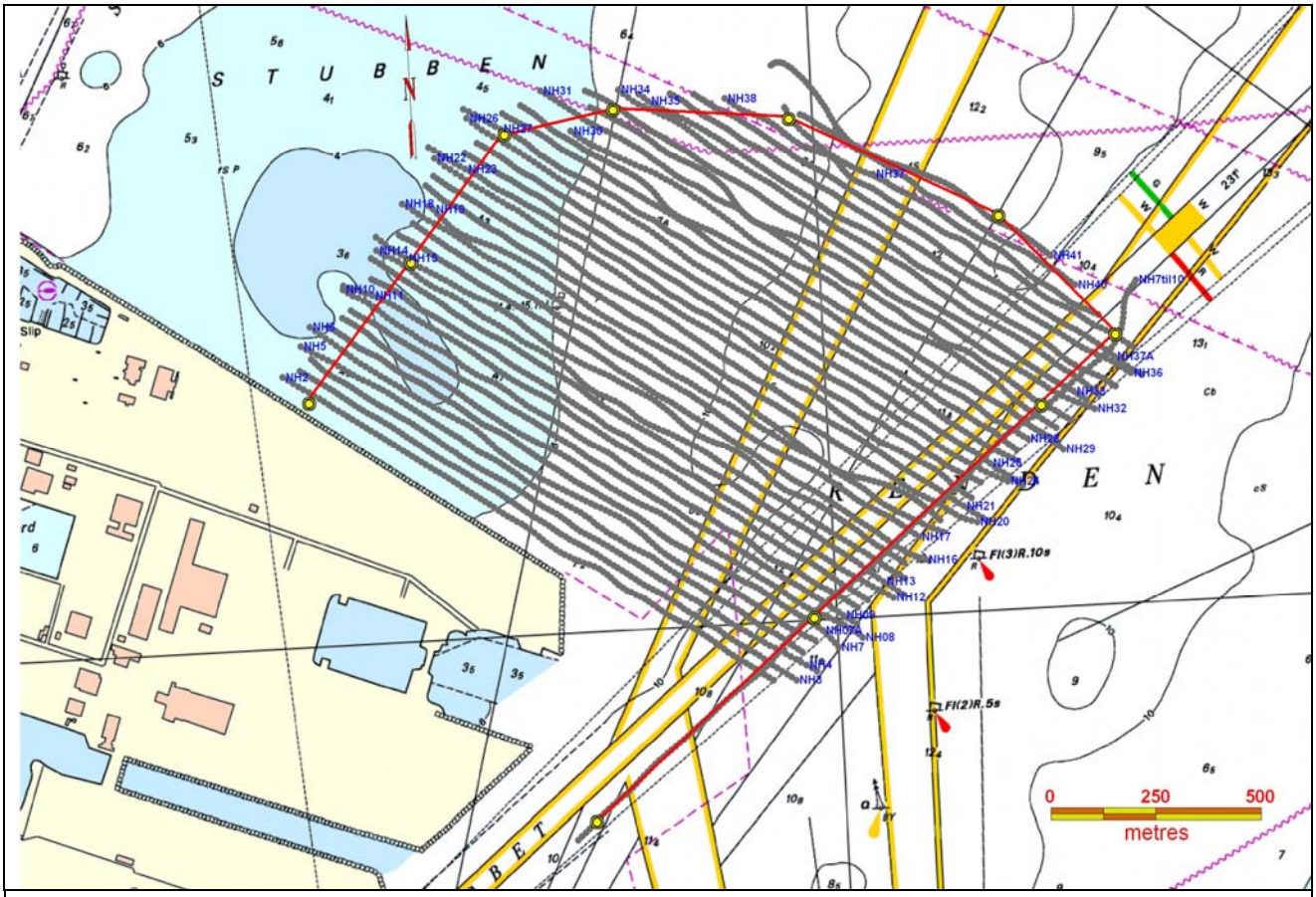


Figure 3. The survey region with survey lines indicated.

3. The equipment

To conduct such a survey three types of instruments were deployed:

1. The Geometrics G882 magnetometer.
2. The Teledyne Benthos SIS-1600 Seafloor imaging system.

The technical description of these instruments is found in Annex IV.

4. Results

4.1 The magnetic survey data

The magnetic data was processed and cleaned first from noise and spikes and the resulting magnetic data was tested for anomalies. Then the background magnetic field was extracted from the data and the local anomalies were deduced.

The resulting magnetic distribution map was gridded and is shown in Fig 4. On the map the magnetic anomalies at each survey line was shown. Some of these anomalies are caused by artificial structures in the survey vicinity or they could be caused by a passing ship. The surveyed area is located near the Nordhavn so traffic is expected all the time. A generally high magnetic filed response is noticed in the North-eastern part of the area as compared with the near shore South-western area.

A spread sheet with target positions and values are given in Annex I.

Each anomaly was plotted on a separate graph. Some samples are shown in Annex II.

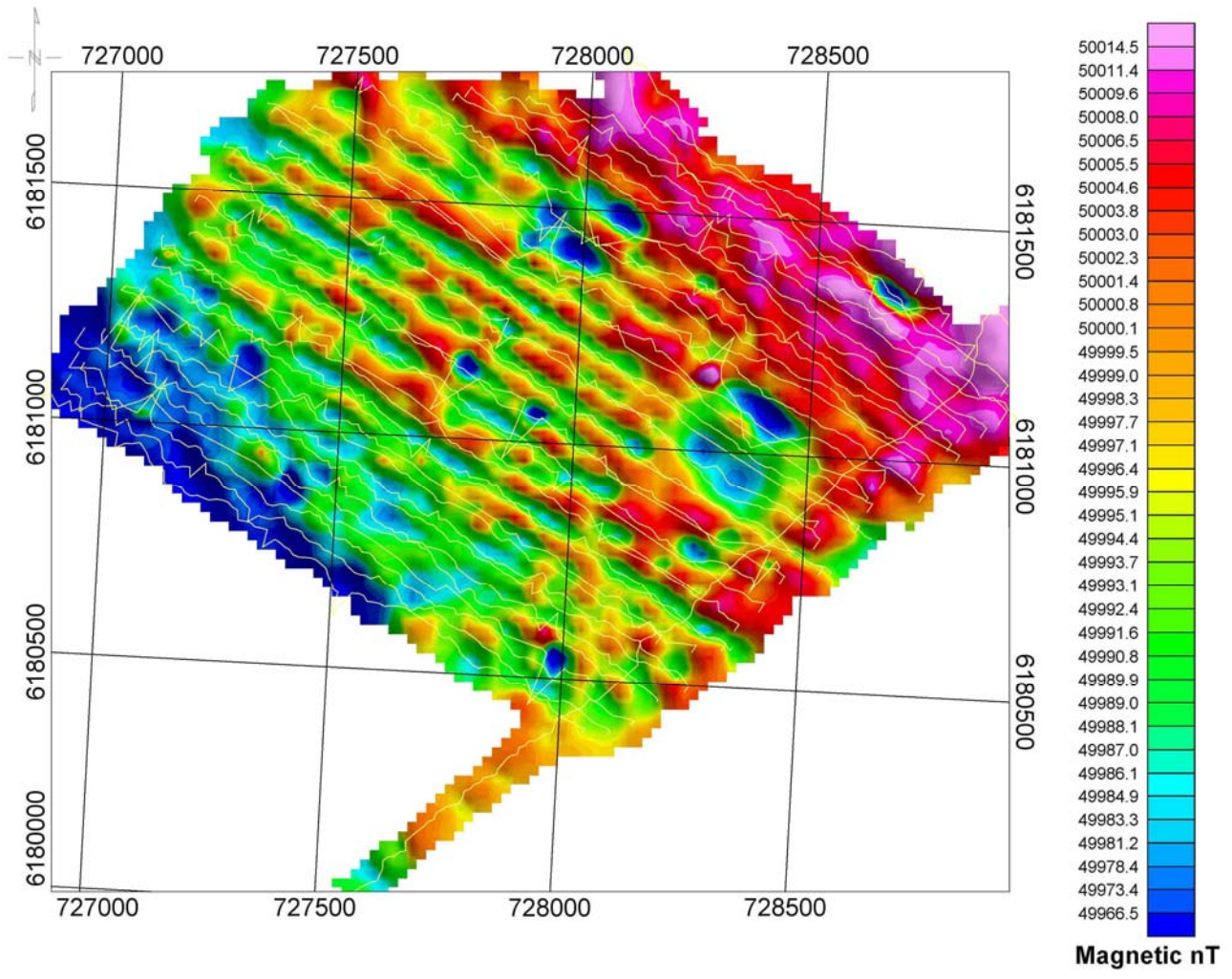


Figure 4. The magnetic distribution map of the surveyed area.

Figure 5 shows the position of each anomaly and the depth of the seabed at that position.

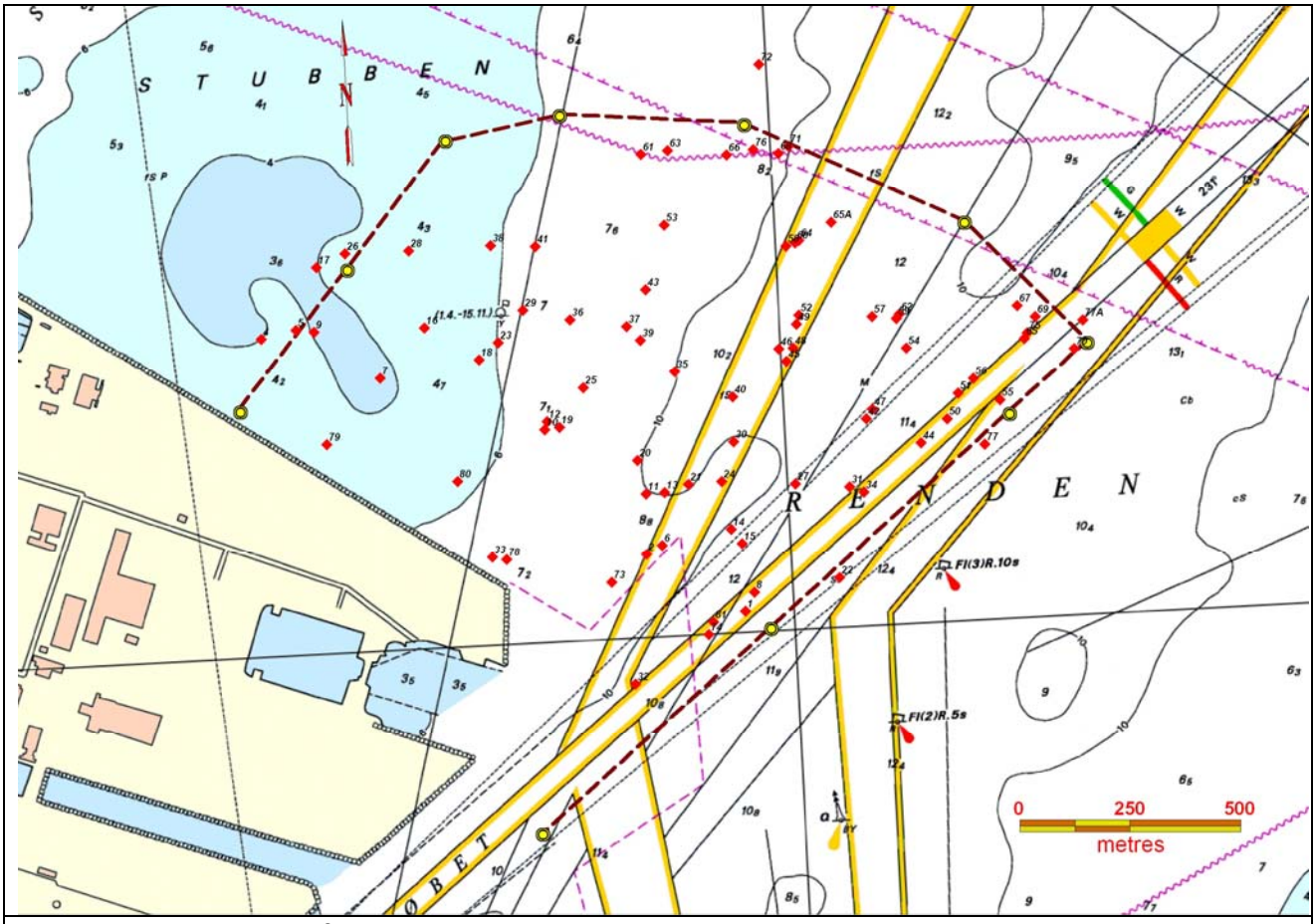


Figure 5. Distribution of the magnetic anomalies (red diamonds) in the survey area.

4.2 The sidescan survey data

The sidescan data for the survey area was processed, mosaiced and presented in Fig 6. Backscattered data was played back for each survey line, and then they were mosaiced using dedicated software to give a complete picture of the seabed sediment and bedforms.
For each magnetic anomaly position a sidescan image was scrutinised for targets and snap shots were taken for further documentation. Examples from these images are presented in Annex III.
As for the general description of the survey area one can observe from the sidescan image that the area can almost be divided into three main parts, one to the west which is a hard sediment area where stones where noticed, and one to the middle composed mostly of soft sediment and the third to the east where mixed sediment can be seen clearly. One can also notice the different marks on the seabed which can be related to man made activities.

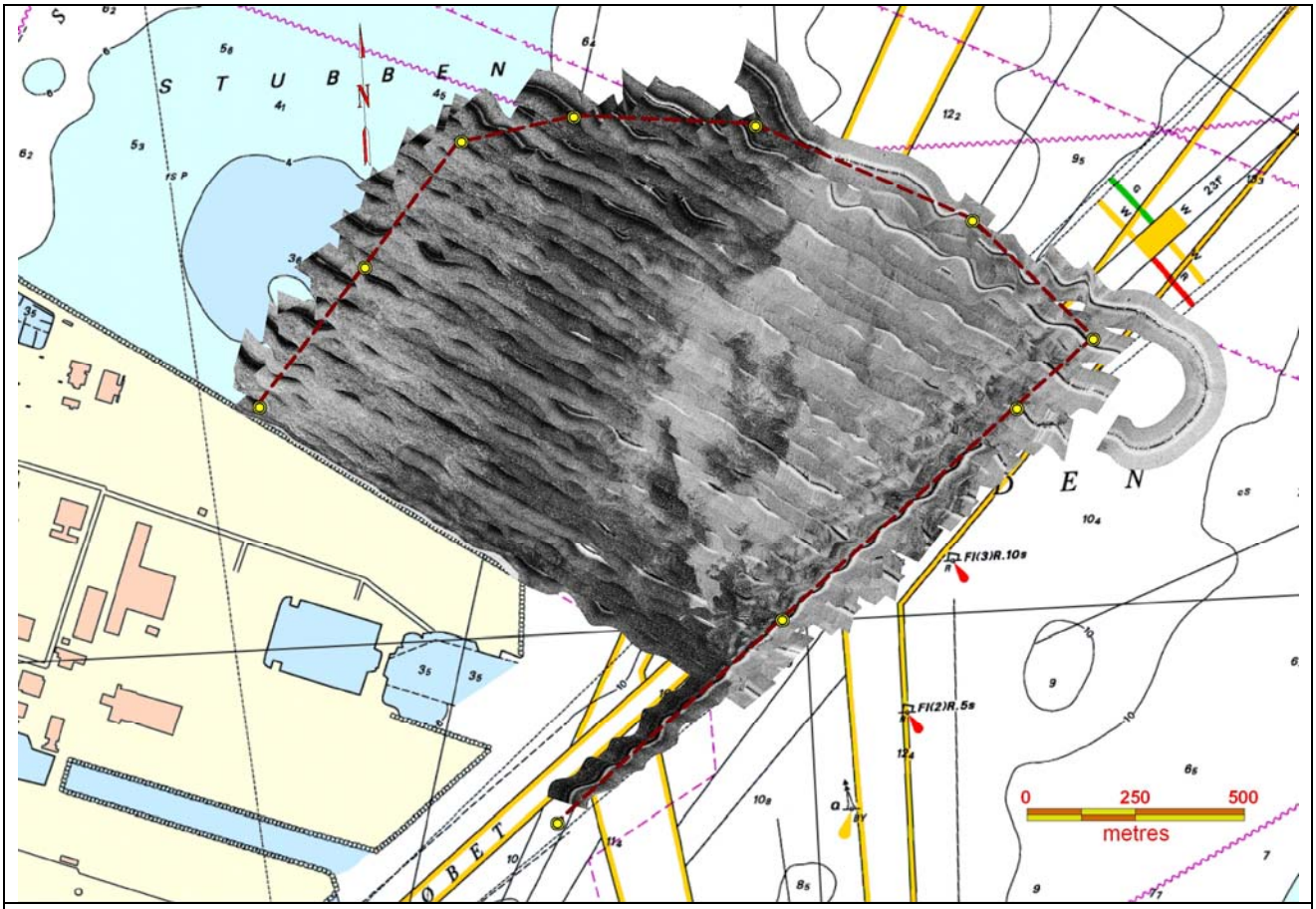


Figure 6. The sidescan mosaic of the survey area.

4.3 The further work

The results from the survey presented here will be further processed by Vikingeskibsmuseet. On this basis the marine archaeologists subsequently decide which of the anomalies should be inspected by divers.

Annex I

Magnetic targets and positions (WGS84-Zone32N)

Anomaly#	Longitude	Latitude	Mag. nT	Image File#	Mag-Back Ground
1	728090	6180568	50007	NH8_Anom1	22
2	727866	6180697	50006	NH8_Anom2	21
3	727454	6480903	50000	NH7A_Anom3	15
4	726993	6181183	50003	NH7A_Anom4	18
5	727072	6181203	49990	NH9_Anom5	5
6	727901	6180717	50005	NH9_Anom6	20
7	727262	6181094	50001	NH9_Anom7	16
8	728110	6180611	50014	NH10_Anom8	29
9	727113	6181199	50004	NH10_Anom9	19
10	727635	6180978	50000	NH11_Anom10	15
11	727864	6180834	49996	NH11_Anom11	11
12	727640	6180996	50020	NH12_Anom12	35
13	727906	6180837	50009	NH12_Anom13	24
14	728057	6180754	50008	NH12_Anom14	23
15	728082	6180722	50001	NH13_Anom15	16
16	727363	6181209	50000	NH13_Anom16	15
17	727118	6181344	49990	NH13_Anom17	5
18	727486	6181136	50022	NH14_Anom18	37
19	727668	6180984	50006	NH14_Anom19	21
20	727845	6180909	50009	NH14_Anom20	24
21	727960	6180855	50012	NH14_Anom21	27
22	728303	6180644	50012	NH14_Anom22	27
23	727530	6181175	50001	NH15_Anom23	16
24	728036	6180862	50010	NH16_Anom24	25
25	727722	6181073	50009	NH16_Anom25	24
26	727183	6181376	50005	NH16_Anom26	20
27	728203	6180856	50000	NH17_Anom27	15
28	727327	6181382	50027	NH18_Anom28	42
29	727585	6181249	50009	NH18_Anom29	24
30	728063	6180951	50013	NH18_Anom30	28
31	728325	6180850	50004	NH19_Anom31	19
32	727841	6180403	50001	NH02_Anom32	16
33	727517	6180691	49983	NH02_Anom33	-2
34	728358	6180838	50008	NH20_Anom34	23
35	727929	6181110	50008	NH20_Anom35	23
36	727692	6181227	50008	NH20_Anom36	23
37	727820	6181212	49995	NH21_Anom37	10
38	727512	6181394	50014	NH22_Anom38	29
39	727852	6181181	50019	NH22_Anom39	34
40	728061	6181053	50014	NH22_Anom40	29
41	727614	6181392	49999	NH23_Anom41	14
42	728363	6181003	50005	NH24_Anom42	20
43	727863	6181295	50011	NH24_Anom43	26

44	728487	6180949	50000	NH25_Anom44	15
45	728182	6181133	49996	NH25_Anom45	11
46	728165	6181161	50013	NH26_Anom46	28
47	728377	6181025	49999	NH26_Anom47	14
48	728197	6181163	50007	NH27_Anom48	22
49	728205	6181217	50055	NH28_Anom49	70
50	728546	6181003	50018	NH28_Anom50	33
51	728571	6181061	50006	NH29_Anom51	21
52	728210	6181238	50006	NH29_Anom52	21
53	727905	6181440	50000	NH29_Anom53	15
54	728454	6181163	50013	NH30_Anom54	28
55	728666	6181046	50009	NH31_Anom55	24
56	728606	6181095	50009	NH32_Anom56	24
57	728376	6181235	50011	NH32_Anom57	26
58	728181	6181393	50013	NH32_Anom58	28
59	728431	6181230	50014	NH33_Anom59	29
60	728202	6181400	50007	NH33_Anom60	22
61	727853	6181601	50000	NH33_Anom61	15
62	728437	6181240	50013	NH34_Anom62	28
63	727913	6181609	50038	NH35_Anom63	53
64	728210	6181406	50038	NH35_Anom64	53
65	728721	6181185	50019	NH36_Anom65	34
65A	728283	6181447	50027	NH36_Anom65A	42
66	728046	6181600	50016	NH36_Anom66	31
67	728705	6181259	50018	NH37_Anom67	33
68	728164	6181603	50018	NH38_Anom68	33
69	728746	6181235	50022	NH38_Anom69	37
70	728834	6181162	50017	NH38_Anom70	32
71	728187	6181619	50015	NH40_Anom71	30
72	728120	6181803	50014	NH41_Anom72	29
73	727787	6180633	50002	NH04_Anom73	17
74	728007	6180515	49999	NH05_Anom74	14
75	728727	6181198	50016	NH37A_Anom75	31
76	728107	6181612	50016	NH37A_Anom76	31
77	728631	6180946	50018	NH7til10_Anom77	33
77A	728853	6181227	50028	NH7til10_Anom77A	43
78	727549	6180685	50000	NH3_Anom78	15
79	727142	6180945	49991	NH3_Anom79	6
80	727438	6180862	50002	NH6_Anom80	17
81	728017	6180543	50028	NH6_Anom81	43

Table 1. Magnetic target positions and values in nT.

Annex II

Selected magnetic anomaly profiles[1]

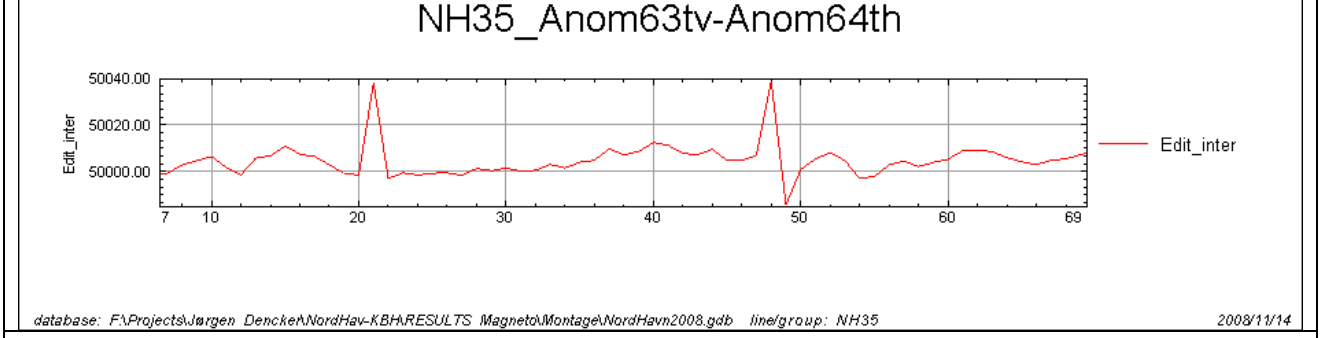


Fig. 1 Anx II. Magnetic profiles of anomaly 63,64.

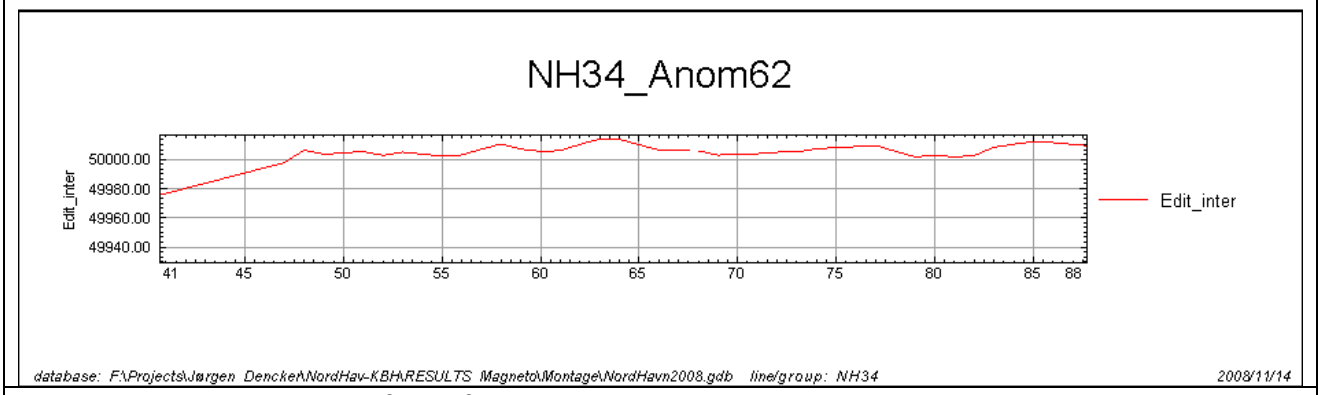


Fig. 2 Anx II. Magnetic profiles of anomaly 62.

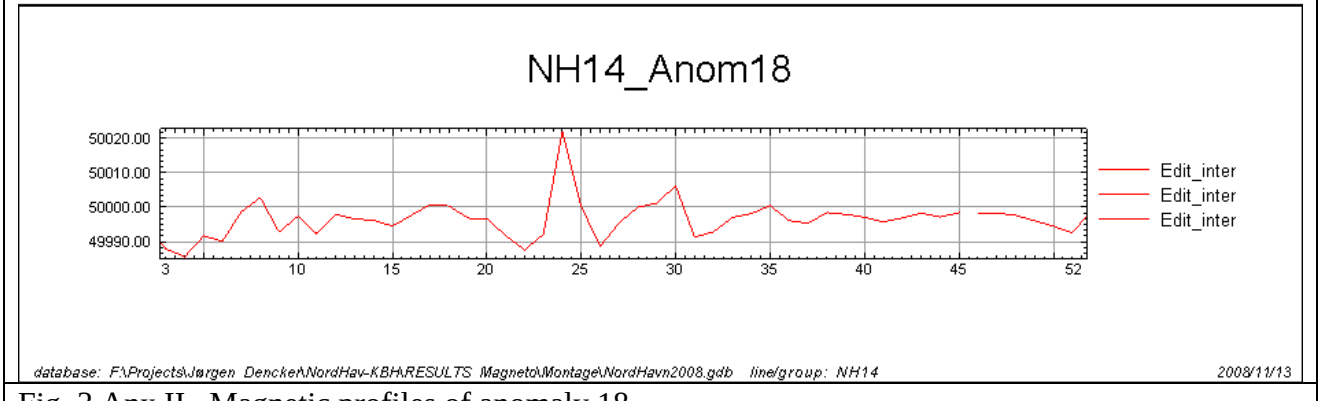


Fig. 3 Anx II. Magnetic profiles of anomaly 18.

[1] The complete anomaly profiles are found in the accompanied CD.

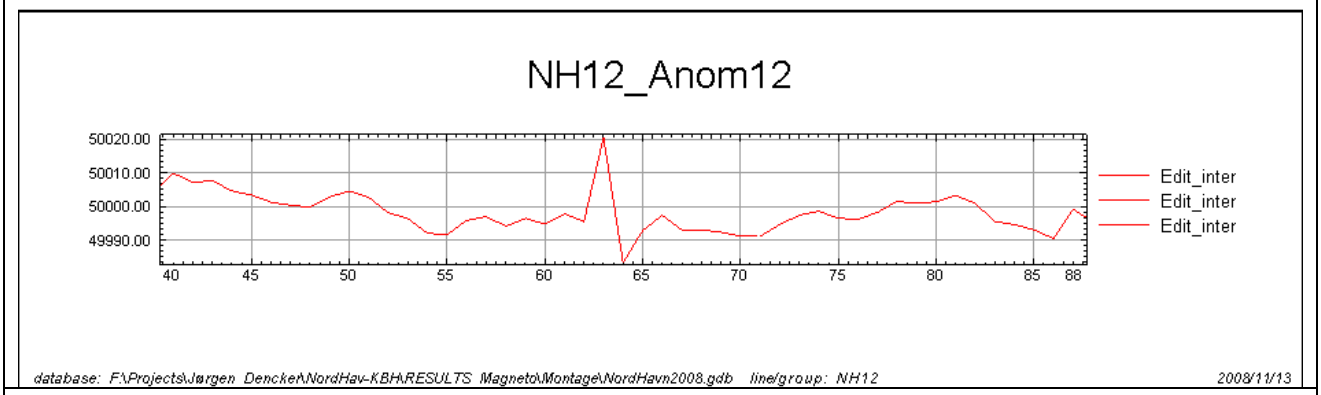


Fig.4 Anx II. Magnetic profiles of anomaly 12.

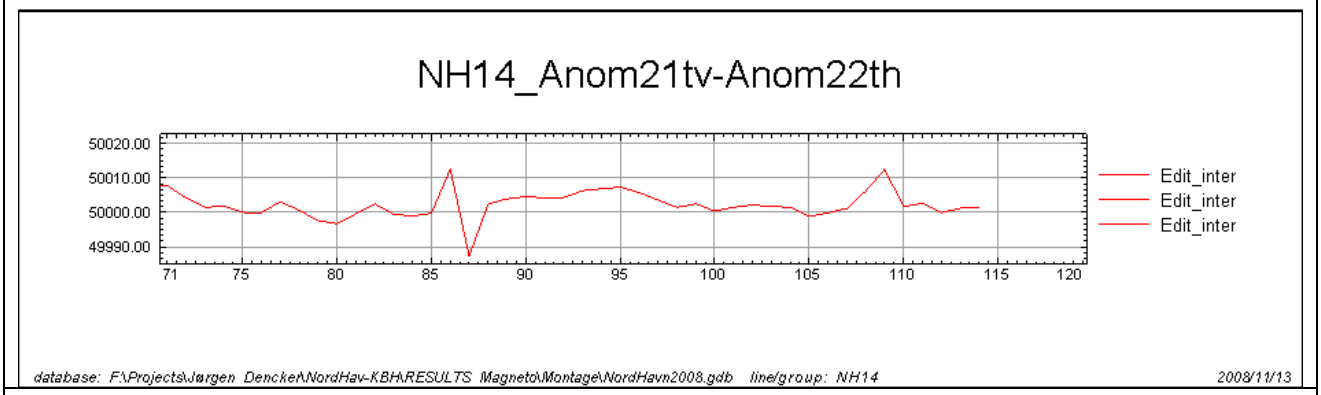


Fig. 5 Anx II. Magnetic profiles of anomaly 21, 22.

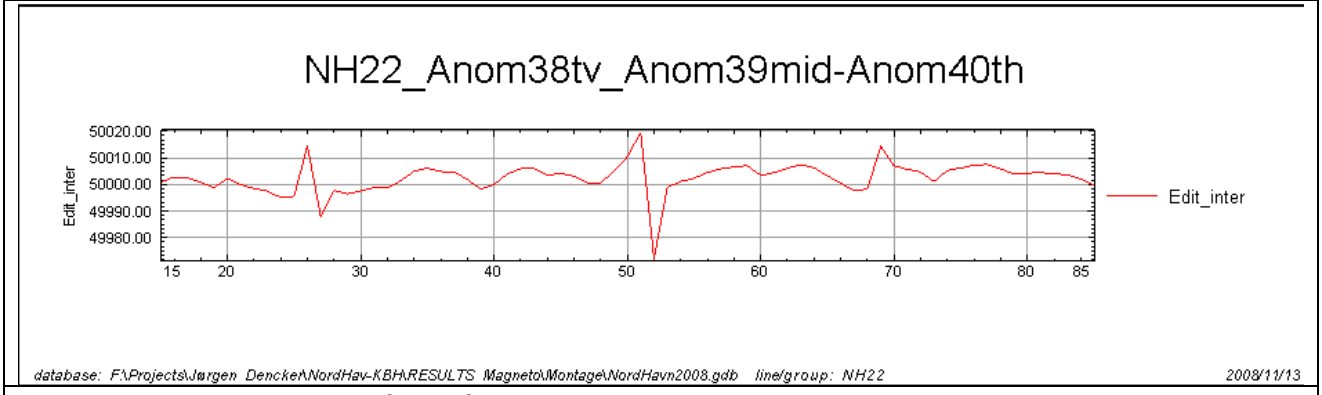


Fig. 6 Anx II. Magnetic profiles of anomaly 38,39,40.

Annex III

Selected Sidescan images

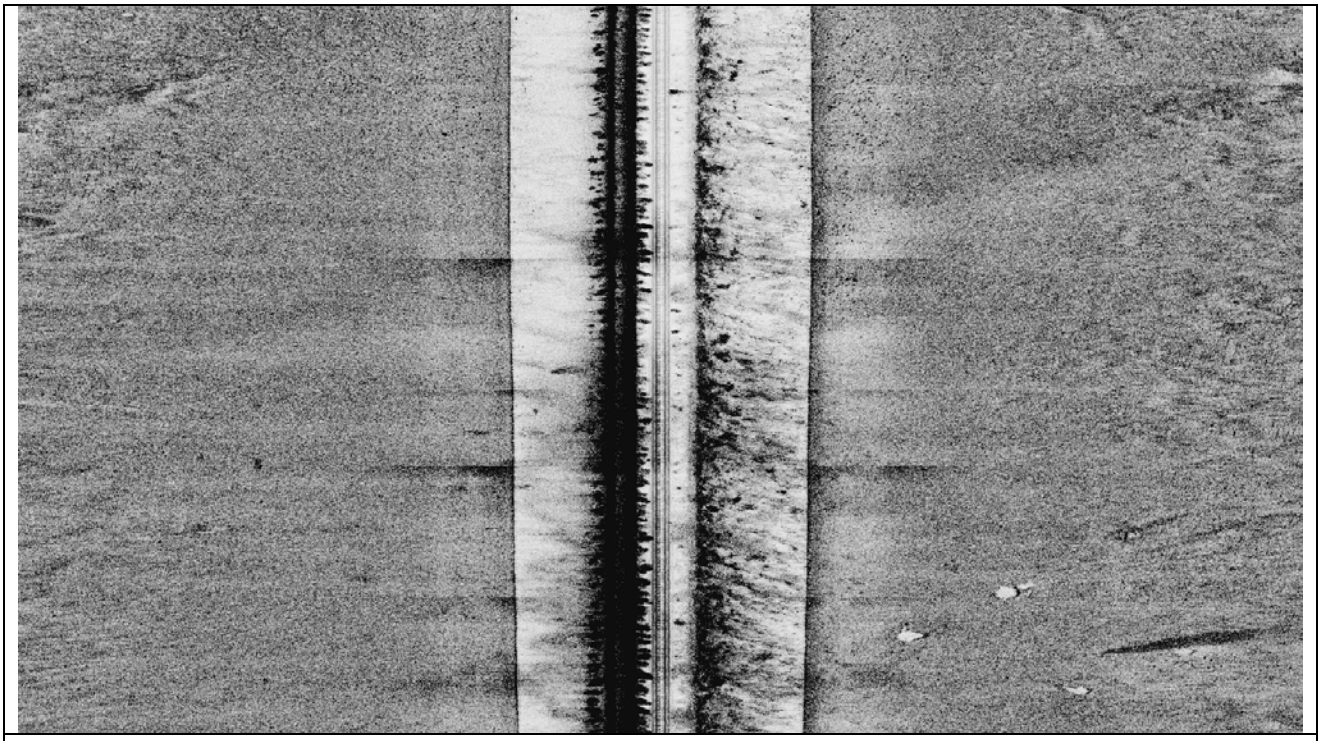


Fig. 1 Anx III. Sidescan image of anomaly 64

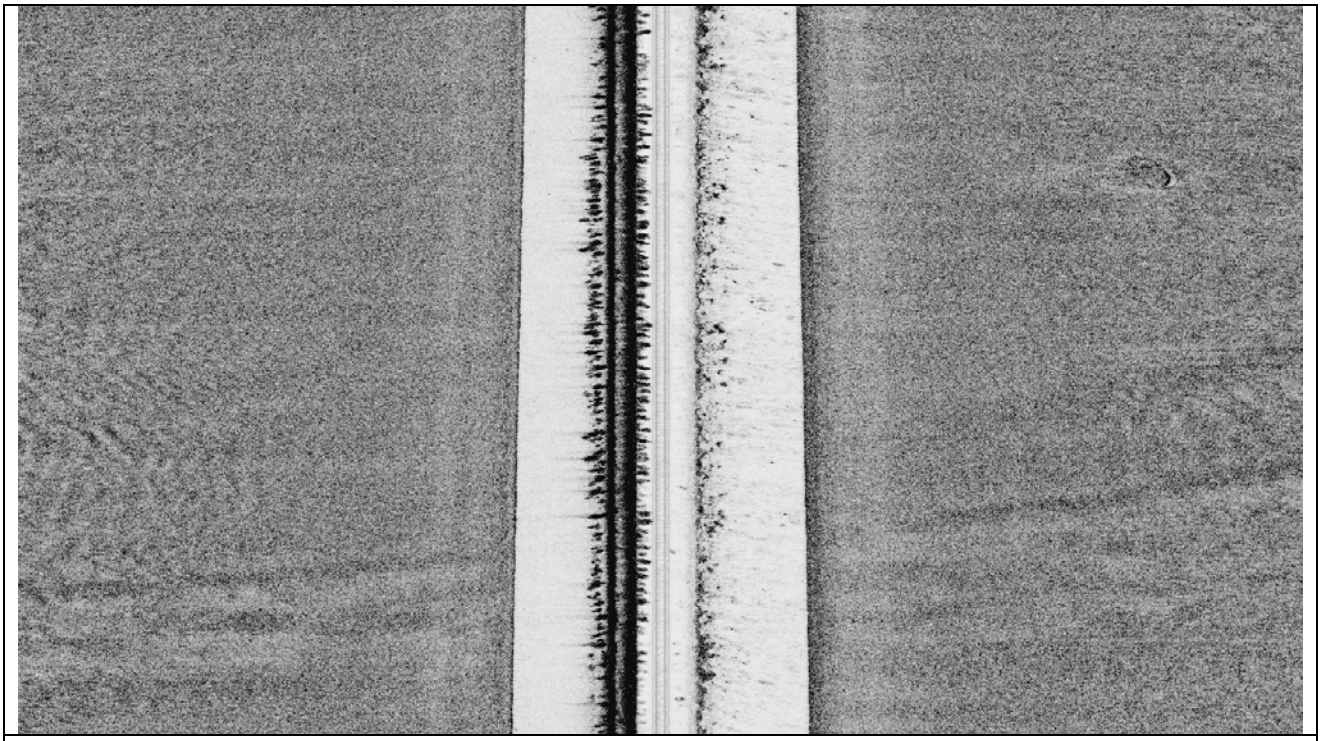


Fig. 2 Anx III. Sidescan image of anomaly 62

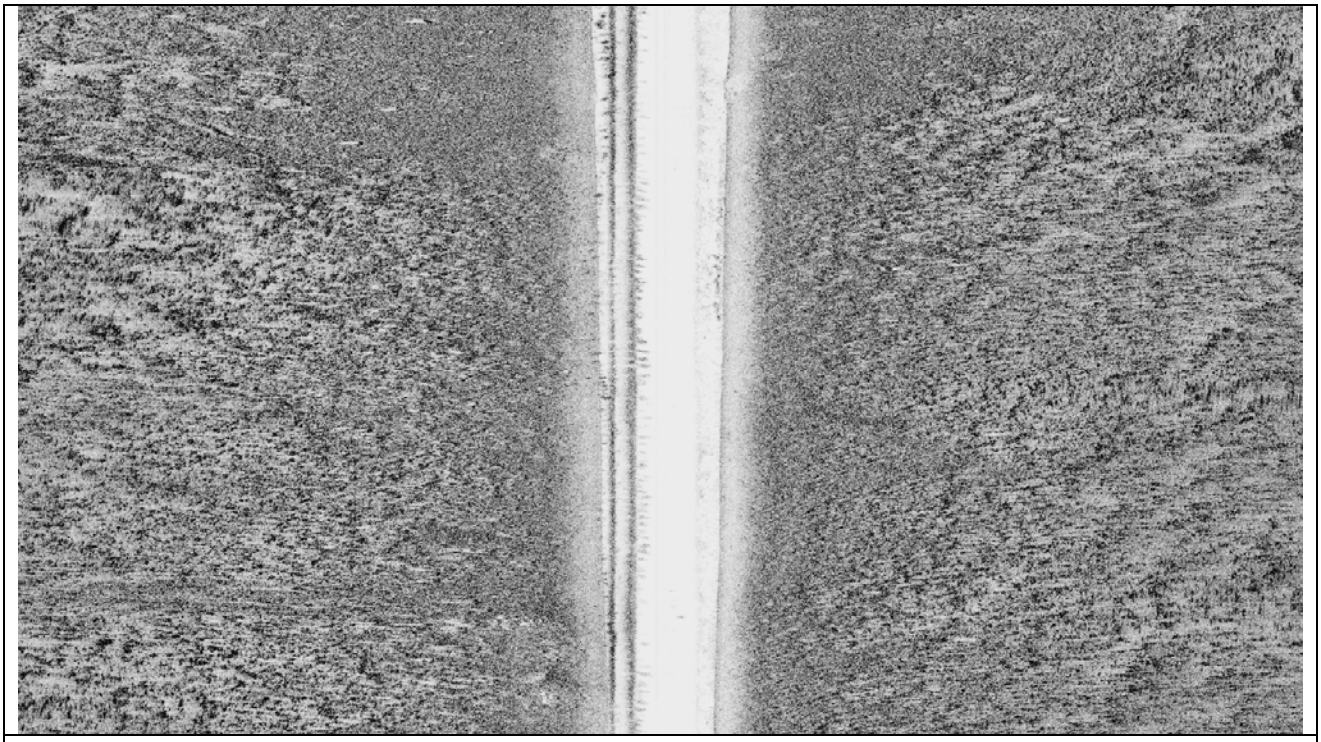


Fig. 3 Anx III. Sidescan image of anomaly 18

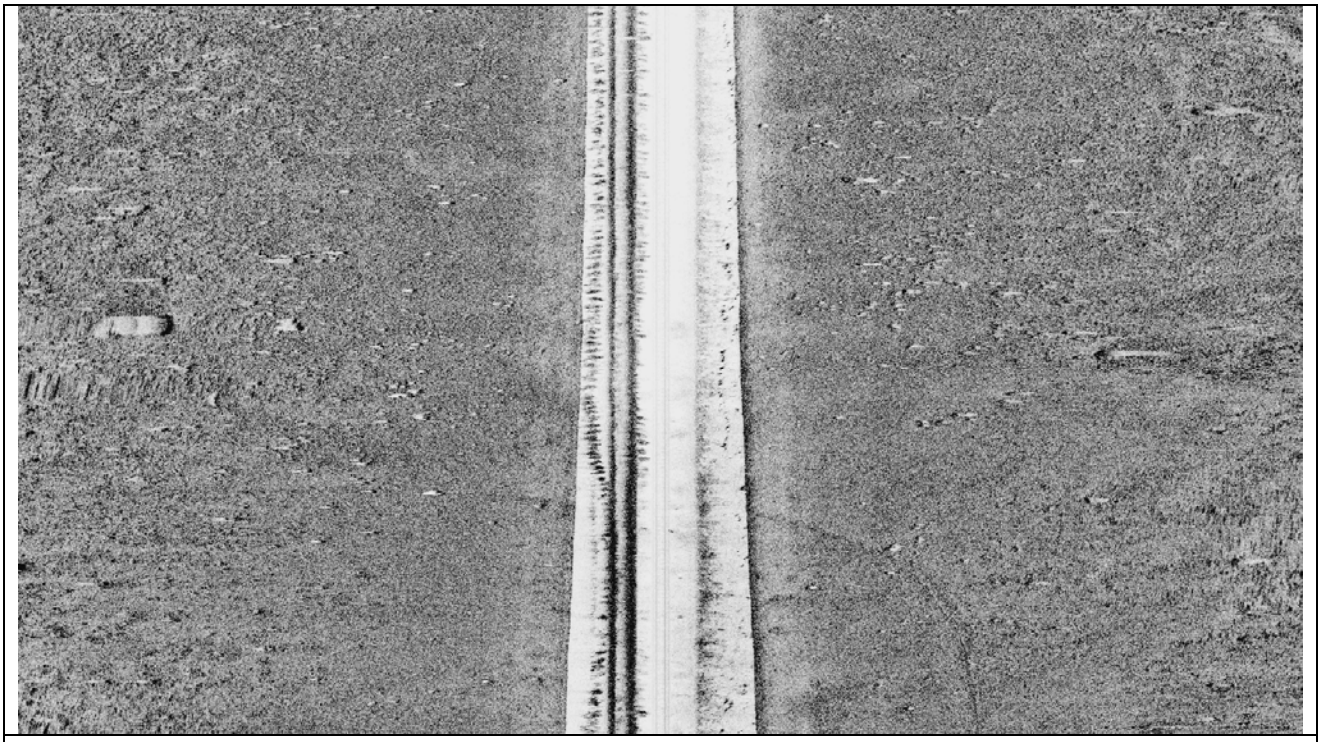


Fig. 4 Anx III. Sidescan image of anomaly 12

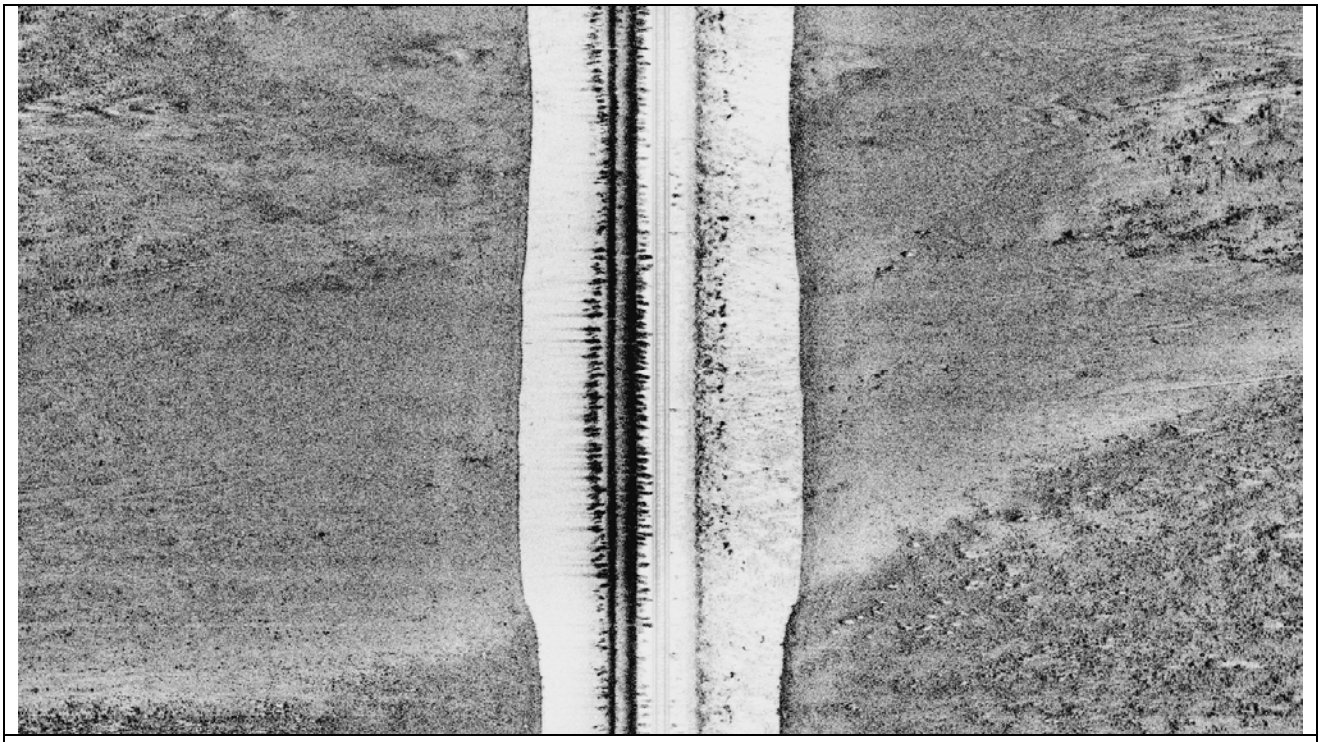


Fig. 5 Anx III. Sidescan image of anomaly 21

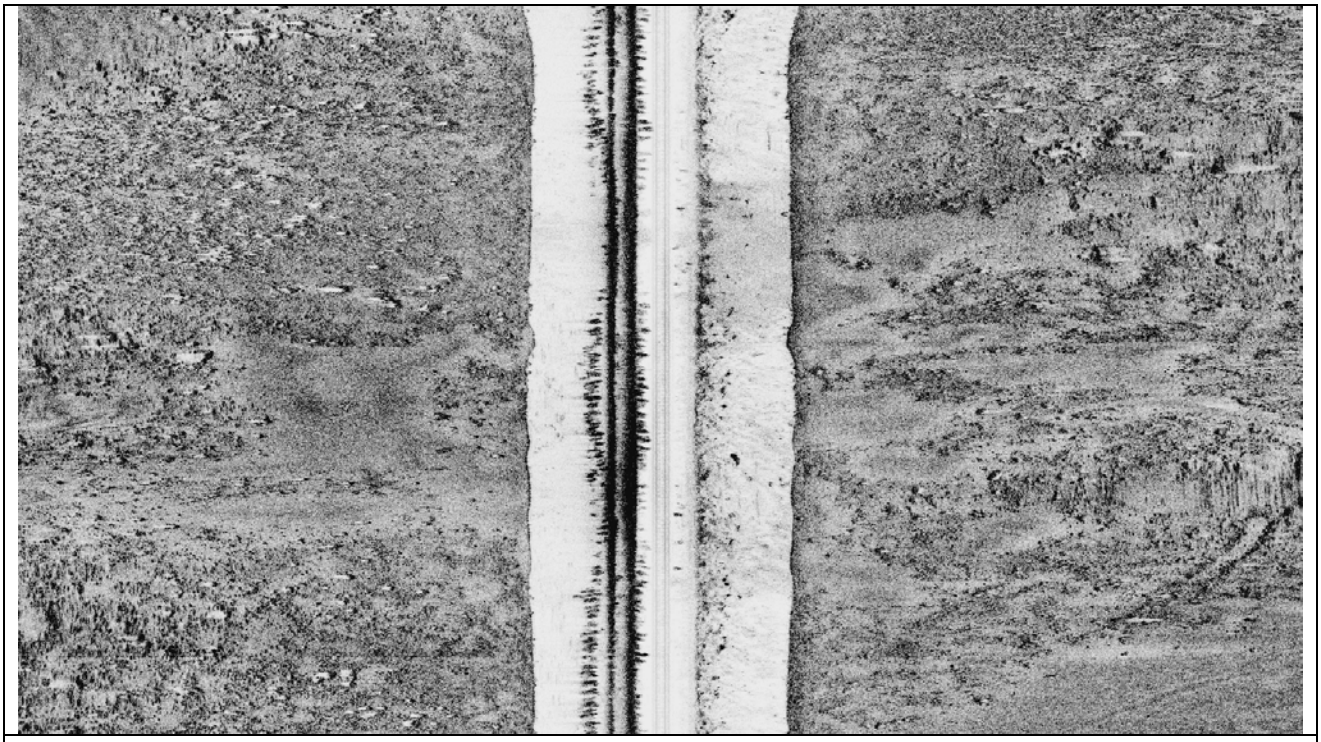


Fig. 6 Anx III. Sidescan image of anomaly 40

Annex IV

Equipment specifications

1. The Seafloor imaging system, SIS1600

The Benthos SIS-1600 Series Side Scan Sonar is a fully integrated system that uses both advanced Chirp and conventional continuous wave (CW) technologies—single frequency or dual frequency—and an advanced high-speed communications link to acquire high resolution side scan sonar images.

The Benthos SIS-1600 is a complete side scan sonar survey system that includes a topside acquisition system and software, a 100-meter tow cable, the CL-160 Communications Link, and one of two available tow vehicles: the TTV-196 Tow Vehicle, which acquires long range, high resolution Chirp side scan sonar images in a single frequency band; and the TTV-196D Tow Vehicle, which acquires long range, high resolution Chirp side scan sonar images in two frequency bands simultaneously.

Benthos Side Scan Sonar.

System Highlights

▲ CL-160 Communications Link
▲ 100 kHz, 100 meter range
▲ 400 kHz, 100 meter range

▲ Topside sonar processor

System Features

The TTV-196D Tow Vehicle includes the transceiver electronics, the processing and communications electronics, the port and starboard side scan transducer arrays, the pitch, roll and heading sensors, and the optional sensors. The optional sensors include a water temperature sensor, a pressure sensor, a magnetometer, and a responder. Hydro dynamically stable tow vehicle with operating depth up to 1,750 meters.

Features

■ Dynamic range - high frequency data up to 150 meters
■ Enhanced resolution
■ Repeatable transmitted waveforms
■ Constant temporal resolution
■ The pulse characteristics are programmable
■ Stainless steel construction
■ Seaconnet shipwreck, 400 kHz, 75 meter range

SYSTEM SPECIFICATIONS

Software
Application: Third party data acquisition and display (i.e.TEI “Isis Lite”, Chesapeake, “Sonarmap”)
Operating System: Microsoft® Windows® XP Professional

Hardware
Processor CPU: Intel® Pentium® 4 processor
Memory: 512 DDR SDRAM
I/O Ports: Wireless keyboard/mouse
RS-232 serial
Parallel

Ethernet 10/100 BaseT

Graphics Processor: Integrated high resolution graphics

Data Sorage: High capacity hard drive, CD/DVD-RW drive

CL-160 Communications Link

Physical Characteristics

Construction: 316 stainless steel

Dimensions: 11.4 cm (4.5 in.) outside diameter by 177.8 cm (70 in.) long

Weight in Air: 34 Kg (75 pounds)

Weight in Water: 25 Kg (55 pounds), approx.

Operating Depth: 1,750 meters

Towing Speed: 1 to 8 knots operational

Input Power: 144 VDC, 32 watts nominal

Side Scan Sonar

Acoustic Source Level: +225 dB re 1uPa @ 1 meter

Range: 25 to 500 meters each channel

Frequency Range

Chirp Frequency Range:

(TTV-196D): Simultaneously sweeps in the 110 kHz to 130 kHz and 370 kHz to 390 kHz bands

CW Frequency

(TTV-196D): Simultaneous 123 kHz and 383kHz

Transducer Radiation

(TTV-196D): 0.5 degrees horizontal, 55 degrees vertical (110 kHz to 130 kHz band), 0.5 degrees horizontal, 35 degrees vertical (370 kHz to 390 kHz band)

SIS-1625 Seafloor Imaging System

One Cable—CL-160 Communications Link

The comm link was designed through a program to develop a full ocean depth telemetry module for a multisensor seafloor mapping system.

- Two-way communication with tow vehicle over single coax with digital high speed multiplexor. Standard cable length—up to 10,000 meters.
- Digital multiplexor for single coaxial tow cables. Communication rates: sonar data—up to 5 megabit/sec; uplink status—9600 bits/sec; downlink command—9600 bits/sec.

SPECIFICATIONS

CL-160 Shipboard Sub-System

Chirp Processing:	Sonar/status control PC based workstation; 5-DSP based sonar matched filter processing channels.
Display:	High resolution video display.
Recording:	Large capacity hard drive, DVD writable, other..
Status Display:	Vehicle pitch, roll, heading (standard); speed, altitude, and depth (optional). Customer input ship position, vehicle position, event marks; all status data recorded.
Sonar Display:	Side scan port, starb; dual channel sub-bottom; all sonar data recorded.
Corrections:	Slant range and speed; beam angle/grazing angle.
Multiplexor:	Digital MUX for coaxial cables (ADSL).
Sonar Data:	up to 5 megabit/sec.
Uplink Status:	9600 bit/sec.
Downlink Command:	9600 bits/sec.
Power Supply:	110/220 VAC autosensing.

Side Scan

Side Scan Transducers:	Multi-element array, dual channel 100/400 kHz 0.5° horizontal beam; 60° vertical beam.
Frequency:	100/400 kHz band swept FM; 4.5 cm resolution.
Processing:	Calibrated transmit waveform stored in ROM; match filter FFT digital signal processing.
Swath Selection:	25 meters to ±500 meters.

Sub-Bottom

Transducer:	Transmit projector array; line array receiving hydrophone; 30° conical radiation pattern.
Frequency:	1 kHz to 10 kHz swept FM (4 KW output), synchronous with side scan.
Resolution:	5 cm.
Processing:	Calibrated transmit waveform stored in ROM; matched filter FFT digital signal processing.
Scale Selection:	25 meters to 500 meters full scale.

TTV-290 Tow Vehicle Sub-System

Depth rating:	2000 meters.
Vehicle Dimensions:	18 inches (45 cm) OD x 64 inches (162.6 cm) long.
Weight:	In air: 300 lbs (136 Kg); in water: 170 lbs (77 Kg).

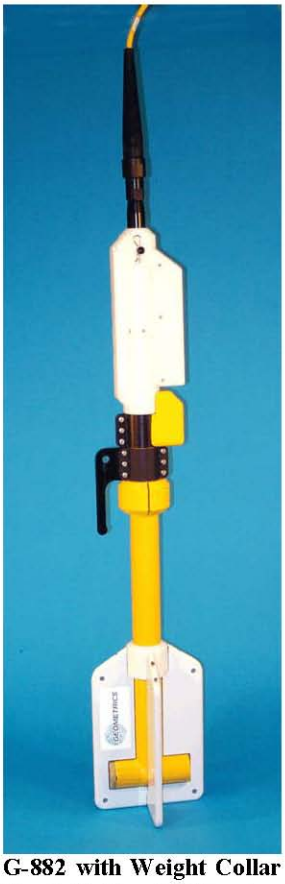
TELEDYNE BENTHOS
A Teledyne Technologies Company
49 Edgerton Drive • North Falmouth, MA 02556 USA
Tel: 508 563-1000 • Fax: 508 563-6444 • E-mail: info@benthos.com
www.benthos.com

2. The G882 marine magnetometer

GEOMETRICS

G-882 MARINE MAGNETOMETER

- *CESIUM VAPOR HIGH PERFORMANCE – Highest detection range and probability of detecting all sized ferrous targets*
- *NEW STREAMLINED DESIGN FOR TOW SAFETY – Low probability of fouling in lines or rocks*
- *NEW QUICK CONVERSION FROM NOSE TOW TO CG TOW – Simply remove an aluminum locking pin, move tow point and reinsert. New built in easy carry handle!*
- *NEW INTERNAL CM-221 COUNTER MODULE – Provides Flash Memory for storage of default parameters set by user*
- *NEW ECHOSOUNDER / ALTIMETER OPTION*
- *NEW DEPTH RATING – 4,000 psi !*
- *HIGHEST SENSITIVITY IN THE INDUSTRY – 0.004 nT/Hz RMS with the internal CM-221 Mini-Counter*
- *EASY PORTABILITY & HANDLING – no winch required, single man operation, only 44 lbs with 200 ft cable (without weights)*
- *COMBINE TWO SYSTEMS FOR INCREASED COVERAGE – Internal CM-221 Mini-Counter provides multi-sensor data concatenation allowing side by side coverage which maximizes detection of small targets and reduces noise*



G-882 with Weight Collar Depth Option & Altimeter

Very high resolution Cesium Vapor performance is now available in a low cost, small size system for professional surveys in shallow or deep water. High sensitivity and sample rates are maintained for all applications. The well proven Cesium sensor is combined with a unique and new CM-221 Larmor counter and ruggedly packaged for small or large boat operation. Use your computer and standard printer with our MagLogLite™ software to log, display and print GPS position and magnetic field data. The G–882 is the lowest priced high performance full range marine magnetometer system ever offered.

The G-882 offers flexibility for operation from small boat, shallow water surveys as well as deep tow applications (4,000 psi rating, telemetry over steel coax available to 10Km). The G-882 also directly interfaces to all major Side Scan manufacturers for tandem tow configurations. Being small and lightweight (44 lbs net, without weights) it is easily deployed and operated by one person. But add several streamlined weight collars and the system can quickly weigh more than 100 lbs. for deep tow applications. Power may be supplied from a 24 to 30 VDC battery power or the included 110/220 VAC power supply. The tow cable employs high strength Kevlar strain member with a standard length of 200 ft (61 m) and optional cable length up to 500m with no telemetry required.

A rugged fiber-wound fiberglass housing is designed for operation is all parts of the world allowing sensor rotation for work in equatorial regions. The shipboard end of the tow cable is attached to an included junction box or optional on-board cable for quick and simple hookup to power and output of data into any Windows 98, ME, NT, 2000 or XP computer equipped with RS-232 serial ports.

The G-882 Cesium magnetometer provides the same operating sensitivity and sample rates as the larger deep tow model G-880. MagLogLite™ Logging Software is offered with each magnetometer and allows recording and display of data and position with Automatic Anomaly Detection and automatic anomaly printing on Windows™ printer! Additional options include: MagMap2000 plotting and contouring software and post acquisition processing software MagPick™ (free from our website.)

The G-882 system is particularly well suited for the detection and mapping of all sizes of ferrous objects. This includes anchors, chains, cables, pipelines, ballast stone and other scattered shipwreck debris, munitions of all sizes (UXO), aircraft, engines and any other object with magnetic expression. Objects as small as a 5 inch screwdriver are readily detected provided that the sensor is close to the seafloor and within practical detection range. (Refer to table at right).

The design of this high sensitivity G-882 marine unit is directed toward the largest number of user needs. It is intended to meet all marine requirements such as shallow survey, deep tow through long cables, integration with Side Scan Sonar systems and monitoring of fish depth and altitude.

Typical Detection Range For Common Objects

Ship 1000 tons	0.5 to 1 nT at 800 ft (244 m)
Anchor 20 tons	0.8 to 1.25 nT at 400 ft (120 m)
Automobile	1 to 2 nT at 100 ft (30 m)
Light Aircraft	0.5 to 2 nT at 40 ft (12 m)
Pipeline (12 inch)	1 to 2 nT at 200 ft (60 m)
Pipeline (6 inch)	1 to 2 nT at 100 ft (30 m)
100 KG of iron	1 to 2 nT at 50 ft (15 m)
100 lbs of iron	0.5 to 1 nT at 30 ft (9 m)
10 lbs of iron	0.5 to 1 nT at 20 ft (6 m)
1 lb of iron	0.5 to 1 nT at 10 ft (3 m)
Screwdriver 5 inch	0.5 to 2 nT at 12 ft (4 m)
1000 lb bomb	1 to 5 nT at 100 ft (30 m)
500 lb bomb	0.5 to 5 nT at 50 ft (16 m)
Grenade	0.5 to 2 nT at 10 ft (3 m)
20 mm shell	0.5 to 2 nT at 5 ft (1.8 m)

MODEL G-882 CESIUM MARINE MAGNETOMETER SYSTEM SPECIFICATIONS

OPERATING PRINCIPLE:	Self-oscillating split-beam Cesium Vapor (non-radioactive)
OPERATING RANGE:	20,000 to 100,000 nT
OPERATING ZONES:	The earth's field vector should be at an angle greater than 6° from the sensor's equator and greater than 6° away from the sensor's long axis. Automatic hemisphere switching.
CM-221 COUNTER SENSITIVITY:	<0.004 nT/ $\sqrt{Hz}$ rms. Up to 20 samples per second
HEADING ERROR:	±1 nT (over entire 360° spin)
ABSOLUTE ACCURACY:	<2 nT throughout range
OUTPUT:	RS-232 at 1,200 to 19,200 Baud
MECHANICAL:	
Sensor Fish:	Body 2.75 in. (7 cm) dia., 4.5 ft (1.37 m) long with fin assembly (11 in. cross width), 40 lbs. (18 kg) Includes Sensor and Electronics and 1 main weight. Additional collar weights are 14lbs (6.4kg) each, total of 5 capable
Tow Cable:	Kevlar Reinforced multiconductor tow cable. Breaking strength 3,600 lbs, 0.48 in OD, 200 ft maximum. Weighs 17 lbs (7.7 kg) with terminations.
OPERATING TEMPERATURE:	-30°F to +122°F (-35°C to +50°C)
STORAGE TEMPERATURE:	-48°F to +158°F (-45°C to +70°C)
ALTITUDE:	Up to 30,000 ft (9,000 m)
WATER TIGHT:	O-Ring sealed for up to 4,000 psi (9000 ft or 2750 m) depth operation
POWER:	24 to 32 VDC, 0.75 amp at turn-on and 0.5 amp thereafter
ACCESSORIES:	
Standard:	View201 Utility Software operation manual and ship kit
Optional:	Telemetry to 10Km coax, gradiometer (longitudinal or transverse), reusable shipping case
MagLog Lite™ Software:	Logs, displays and prints Mag and GPS data at 10 Hz sample rate. Automatic anomaly detection and single sheet Windows printer support

SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE ***12/03***

GEOMETRICS

GEOMETRICS, INC. 2190 Fortune Drive, San Jose, California 95131
408-954-0522 □ Fax 408-954-0902 □ Internet: sales@mail.geometrics.com

GEOMETRICS Europe Manor Farm Cottage, Galley Lane, Great Brickhill, Bucks, England MK179AB □ 44-1525-261874 □ Fax 44-1525-261867

GEOMETRICS China Laurel Industrial Co. Inc. - Beijing Office, Room 2509-2511, Full Link Plaza #18 Chaoyangmenwai Dajie, Chaoyang District, Beijing, China 100020
10-6588-1126 (1127..1130), 10-6588-1132 □ Fax 010-6588-1162