OFG

Ocean Floor Geophysics Inc.

Ocean Mining Exploration Services

Learning More About the Gaps - OFG's Integrated Approach

GEBCO Symposium: Busan, South Korea

15th November, 2017

Helen Anderson, Matthew Kowalczyk, Alison Proctor, Peter Kowalczyk

Outline of Talk

Company Overview and History

OFG's Involvement in GEBCO-NF Alumni Shell XPRIZE Challenge Team

OFG's Complementary Services and Technologies for Bathymetry and Ocean-Floor Mapping

- OFG Self-Compensating Magnetometer
- Electromagnetics (CSEM) – Deep Tow and AUV
- Gravimetry, E-Field Measurements

Company History

OFG was formed in 2007 to develop and deploy advanced sensors for use in seafloor mineral exploration and has served clients worldwide

Business lines: (a) deep water AUV survey operations and technical support, and (b) development of new marine geophysical systems (primarily EM and magnetic)

2007: First commercial mapping of SMS deposit by OFG patented EM system

2008: ROV-borne EM Mark II and magnetometers deployed in commercial survey; Agreement with Canadian Microgravity for AUV-borne gravity surveys;

2009: EM Mark III and magnetometers deployed in commercial SMS survey

2010 – Present:

- Continued commercial ROV borne survey and exploration services
- Operations support, geophysics and hydrography services

2012 – Present:

- AUV Operations
- Geophysical, geochemical and hydrography services.

2014 – Present:

- Vulcan CSEM towed array
- 3D Vertical Cable Seismic (VCS)
- Towed Array Marine Induced Polarization System
- Improved AUV Magnetics

2015 – Present:

- AUV with Synthetic Aperture Sonar and pipeline inspection technology
- Release of OFG Self-Compensating Magnetometer for AUVs
- Purchase of Hugin "Chercheur"
- AUV CSEM
- Production and sale of low impedance Ag/AgCl marine electrodes

OFG Core Competencies

Strong geophysical and AUV background (company founders)

Highly experienced in mobilising geophysical systems onto local vessels of opportunity globally

Strong technical alliances

- Cellula Robotics, Scripps Institution of Oceanography, Fukada Salvage and Marine Works, Woods Hole Oceanographic Institution, Zonge, CMG, RSI, Mira Geoscience, JGI, Integrated Subsea Inspection Services

Specialised expertise in sensor design and integrating instrumentation (e.g. EM systems, geochemical sensors, sonars, navigation systems etc)

Team of highly experienced AUV and ROV operators

Specialise in providing bespoke subsea geophysical solutions from planning, implementing, data processing and interpretation

OFG Ocean Floor Geophysics

Selected Relevant Project Experience

- **Autonomous High Resolution Bathymetry Mapping**
  - 2017 Shell XPRIZE Challenge
    - OFG “Chercheur” AUV a key component of the GEBCO-NF Alumni challenge
- **Gas Hydrate Mapping and Definition – Towed CSEM + inversion**
  - 2014, 2015, 2017 Japan - AIST
    - Vulcan Deep Tow CSEM Array (Scripps Institution of Oceanography)
- **SMS and Gas Hydrate Deposit Mapping – AUV + Acoustic Mapping (MBES, SSS, SBP) + Magnetic Data + Water Chemistry**
  - 2012-2017 Japan – Fukada Salvage and Marine Works
    - AUV “Deep1”
- **Poly-metallic nodes - AUV Operational Support + Acoustic Mapping (MBES, SSS, SBP) + Water Chemistry**
  - 2015, 2017 CCZ North Pacific
  - 2012 CCZ, North Pacific
    - AUV WHOI Sentry
- **SMS Deposit Mapping – ROV OFG-EM Mk 1, 2, 3 + Precision bathymetry + Magnetic Data**
  - 2007-2009 Manus Basin - Nautilus Minerals, Teck Cominco
    - ROV Perry Slingsby T200 and ROV Fugro FCV 3000
  - 2010 and 2012 Japan (2 projects) – Fukada Salvage and Marine Works
    - ROV ISE Hysub 150 -3000
    - Also included sidescan sonar and subbottom profiling
- **Seafloor Search (downed aircraft)**
  - 2017 confidential (but successful!)








Core OFG Personnel AUV Experience - Operations, System Integration and Design

OFG Ocean Floor Geophysics

- **OFG owned - Kongsberg Hugin “Chercheur”, 3000m with SAS**
- **ISE Explorer “Deep1”, 3000m**
- **WHOI Remus 6000m “Ginger”**
- **WHOI “Sentry” 6000m**
- **Teledyne Gavia**
- **USM Seabed “MolaMola”**
- **Bluefin 12**
- **ISE ARCS**

Shell OCEAN DISCOVERY XPRIZE

OFG involvement in the GEBCO-NF Alumni Team

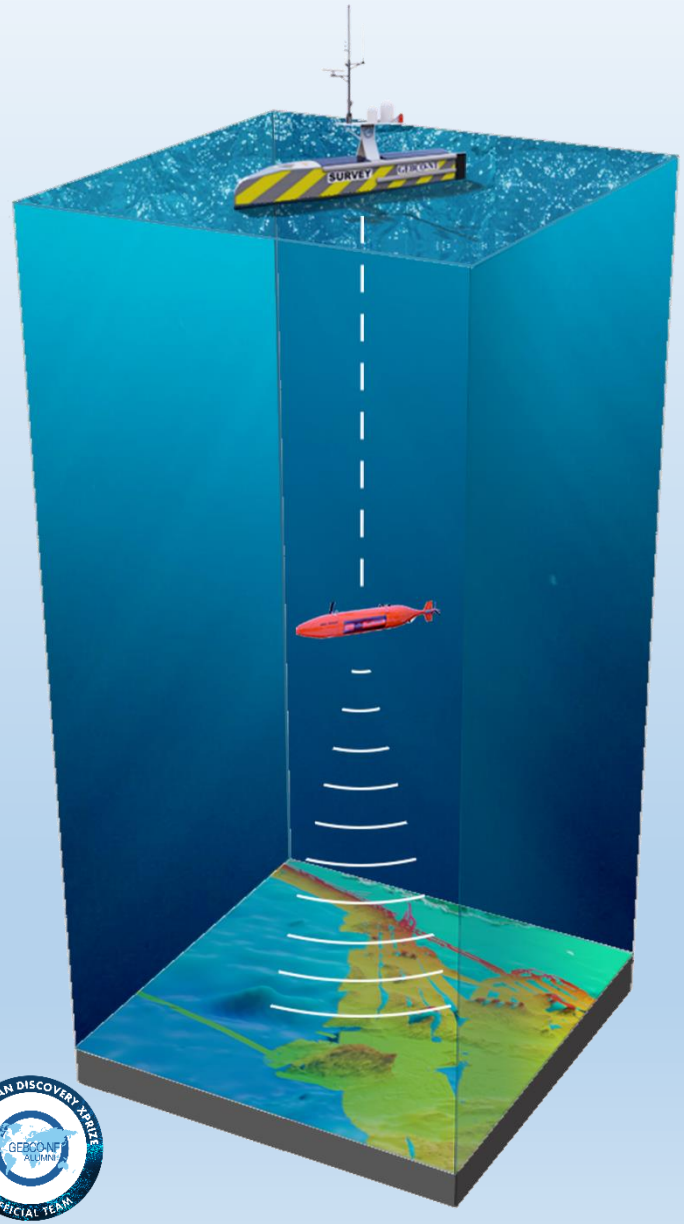
General Bathymetric Chart of the Oceans GEBCO

GEBCO-NF ALUMNI

THE NIPPON FOUNDATION

The GEBCO-NF Alumni Team concept

Integrates existing technology with innovative new ideas



Hushcraft Limited USV

- Sea-Kit XP with KM HiPAP 351P-MGC
- Unmanned operations by KM

Kongsberg Maritime HUGIN 1000 AUV

- OFG Chercheur AUV (3,000 m)

TELEDYNE CARIS esri

High quality seafloor bathymetry and imagery

- Combination of EM2040 MBES, HISAS side-scan wide-area and HISAS bathymetry & spot-focused HiSAS imagery

WHY OFG:

- OFG Personnel have diverse AUV Experience - Operations, System Integration and Design
- Mission Planning
- Selection, Design, and Integration of Sensors
- R&D background
- Similar philosophical approach



OFG Involvement in GEBCO-NF Challenge

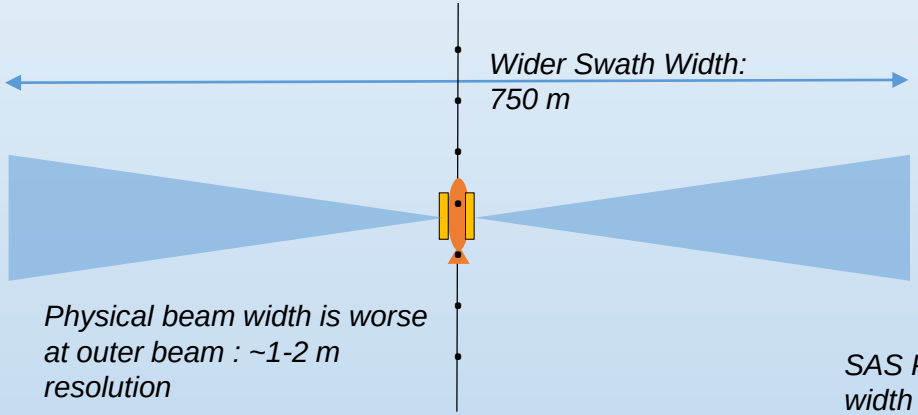
Chercheur HUGIN 1000 AUV equipped with:

- **Synthetic Aperture Sonar (HISAS 1032)**
  - Produces constant resolution imagery over the entire swathe width, offering an ability to interpret features and geology not possible with typical sidescan sonar systems.
  - Interferometric bathymetry
- EM2040 Multibeam Echo Sounder (MBES)
- EdgeTech DW 106 Sub-Bottom Profiler (SBP)
- Also equipped with high resolution camera, ADCP, water chemistry suite and the OFG Self-Compensating Magnetometer (SCM) system.

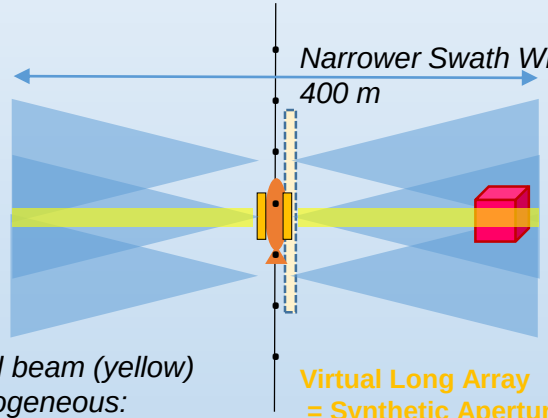
OFG actively involved in development of operations planning, data collection parameters, system integration, acquisition of bathymetry, SAS, side-scan data and sub-bottom profiles.

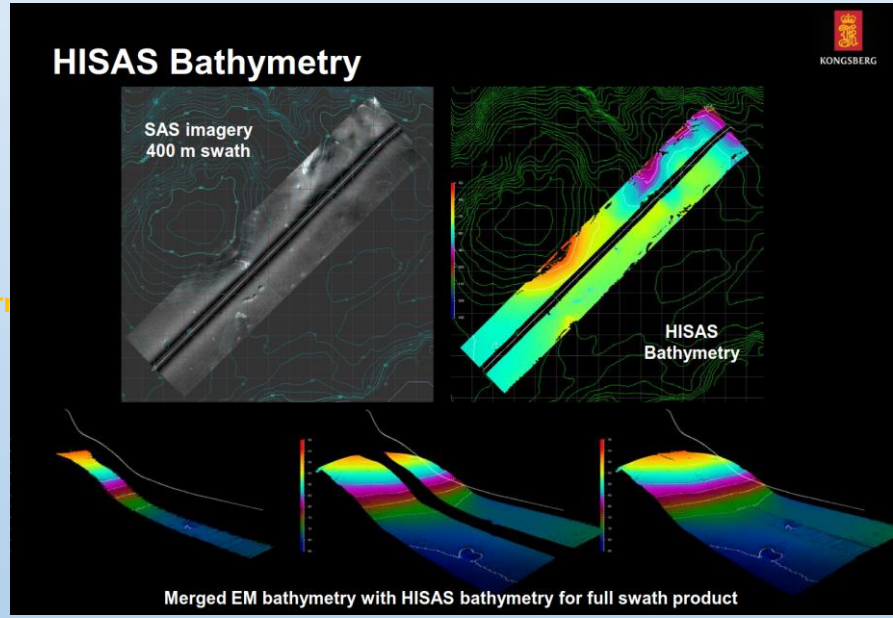
HUGIN 1000 with HISAS 1032
Data Collection

WIDE AREA MODE
Bathymetric Side-Scan Method

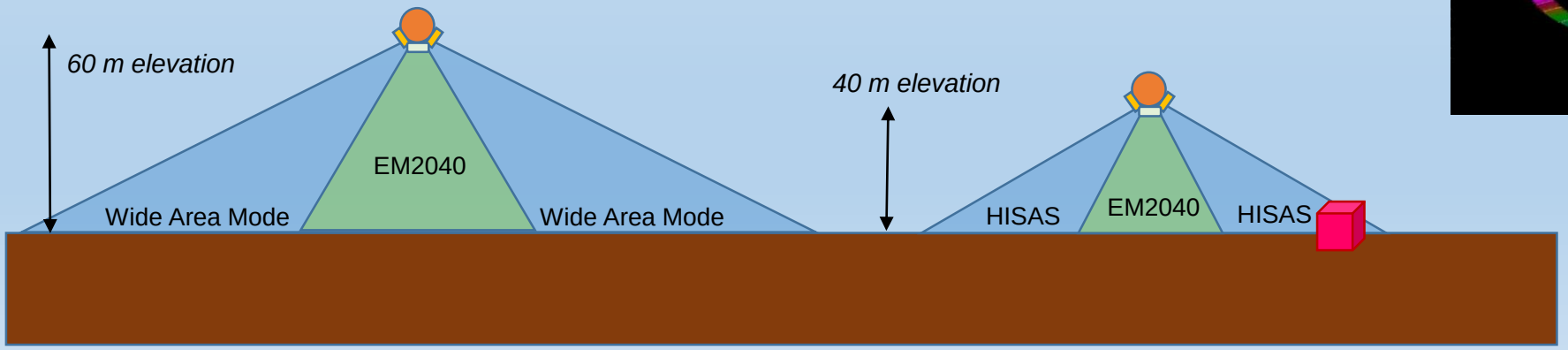


HISAS MODE
Synthetic Aperture Sonar (SAS) Method



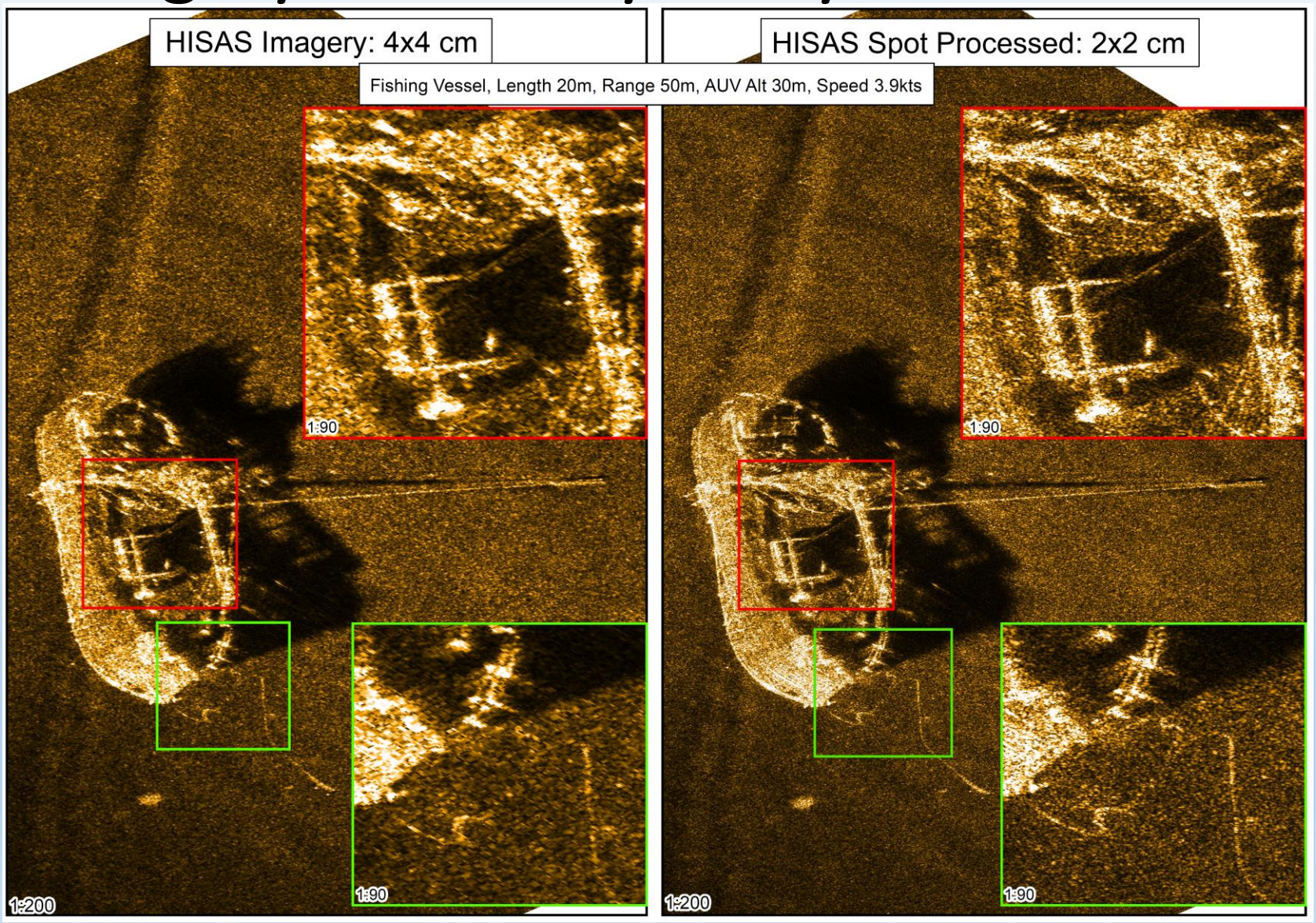


For wide area bathymetry



For seafloor feature detection

HISAS Imagery and Bathymetry

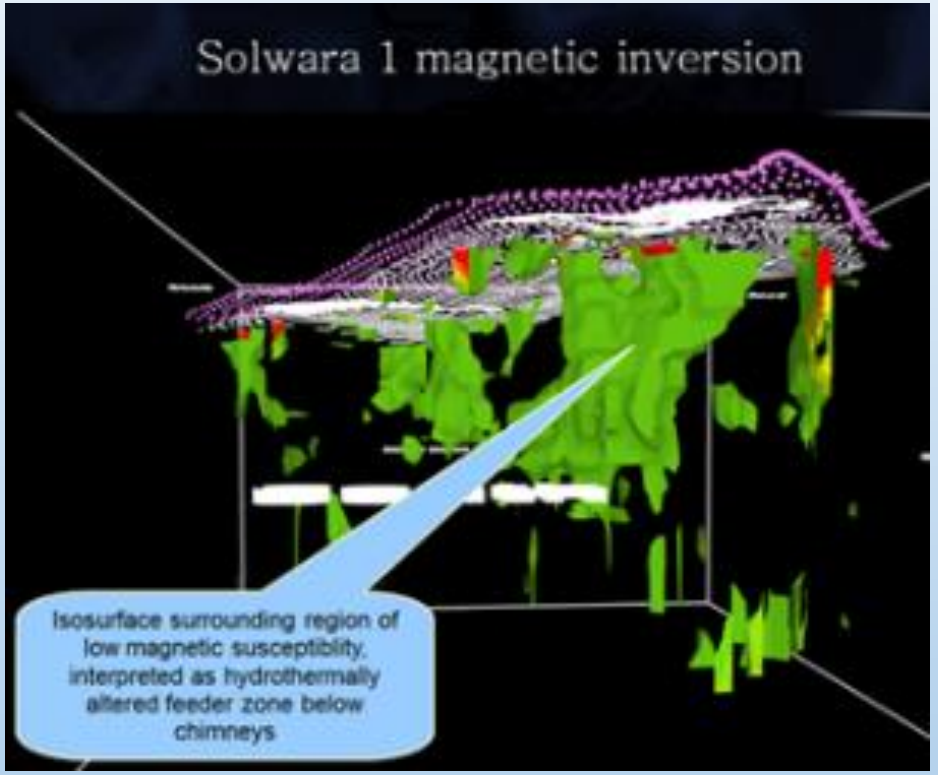


OFG Complementary Technologies and Services for Bathymetry and Ocean Floor Mapping

Why Record Subsea Magnetic Data?

Applications:

- Supplementary data for mapping of seafloor and subsurface features:
  - Hydrothermal vents (demagnetisation often associated with hydrothermal fluids)
  - Associated massive sulphide deposits (increased magnetite associated with subsea sulphide accumulations)
  - Detection of areas of alteration, such as associated with gas seepage
  - Mapping and further definition of near-surface geology
  - Confirmation on pockmark areas, carbonate reefs etc
  - Detailed information on magnetic polarity
- Mine-hunting, unexploded ordinance applications, pipeline/cable following and inspections



Issues:

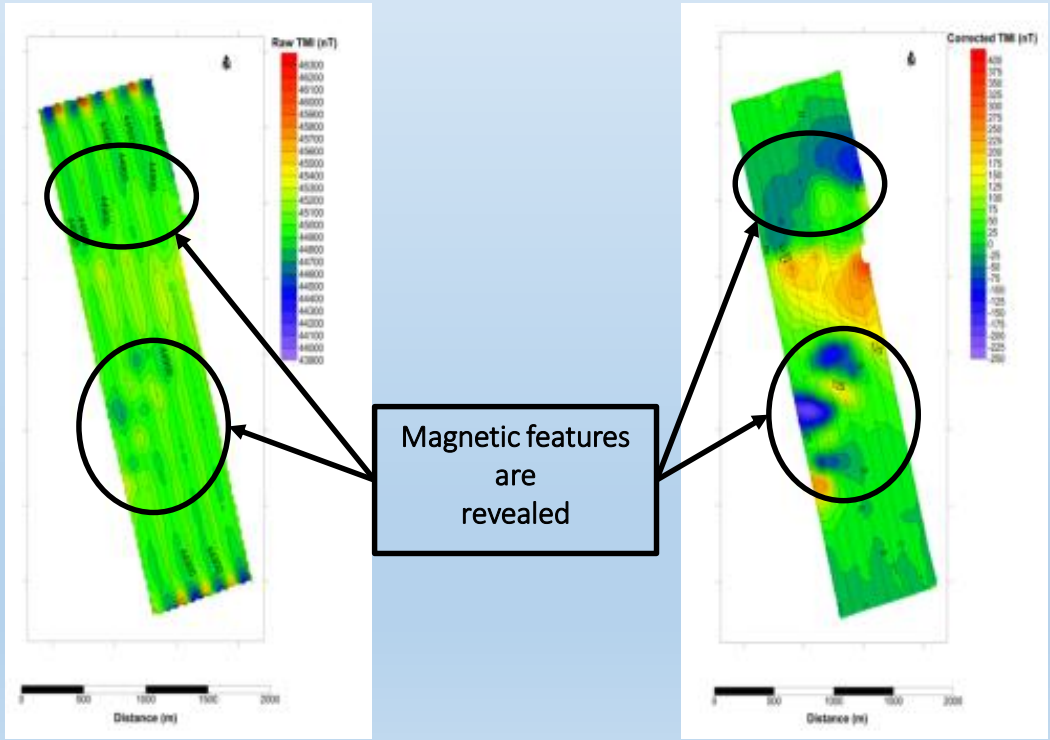
- Generally magnetometers are towed behind vessels or pole-mounted. Vessel-towed magnetometers can have high noise levels, and difficult to get detail near sea-floor
- Mounting magnetometer in AUV previously difficult due to high magnetic interference from AUV system

Solution - Self-Compensating Magnetometer (SCM)

- OFG designed and built - small, robust, 3-axis fluxgate magnetometer

- Only system able to be installed *WITHIN* AUV. Proprietary algorithm automatically handles real-time compensation for:
  - AUV attitude and heading effects
  - Secondary effects derived from AUV propulsion and control circuits

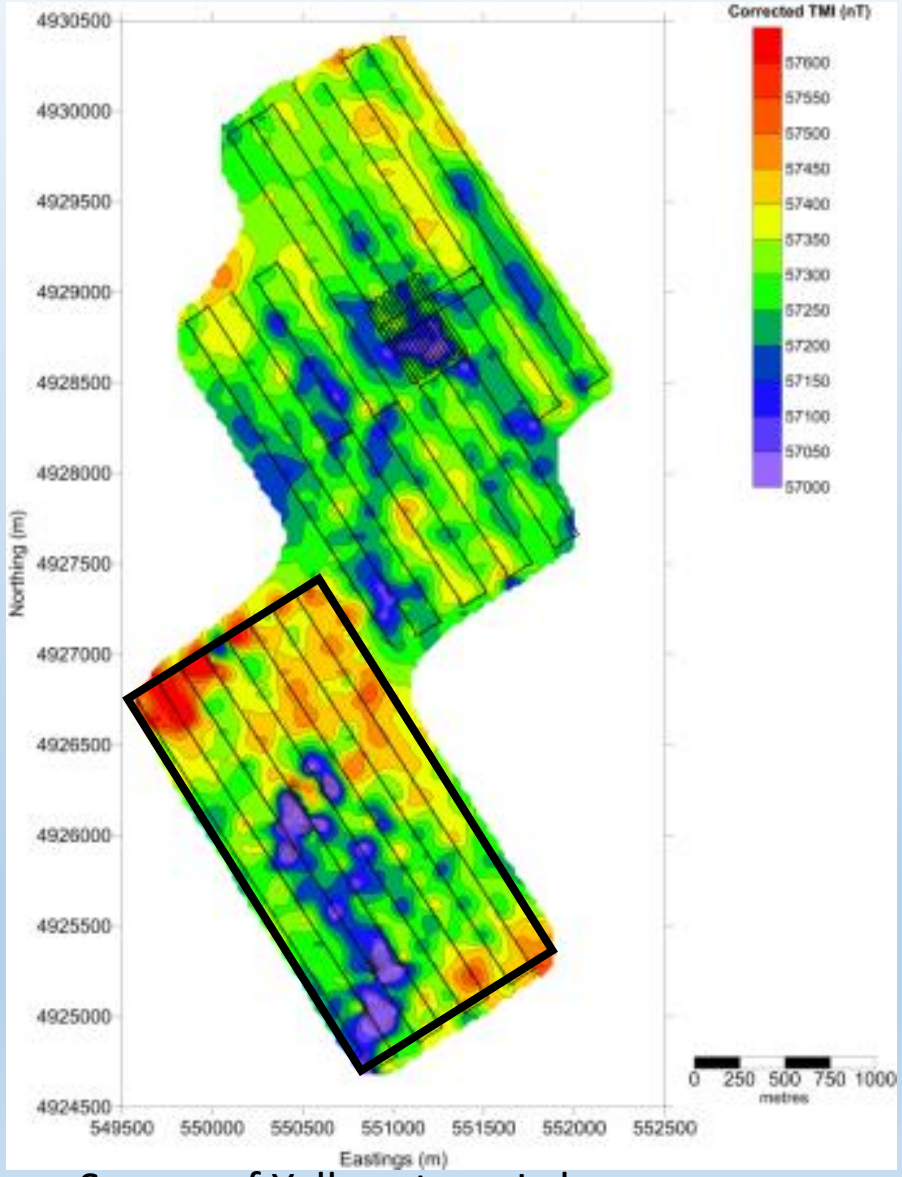
- Only such system commercially available
  - OFG-SCM installed on Remus, IVER3, Gavia, ISE Explorer AUV's and several Hugins (including OFG Chercheur)



Magnetic Map Before Compensation

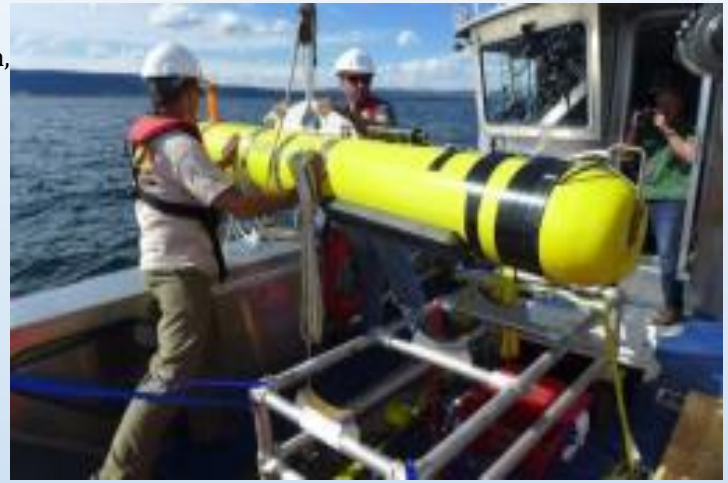
Magnetic Map After Compensation

SCM – Data Example

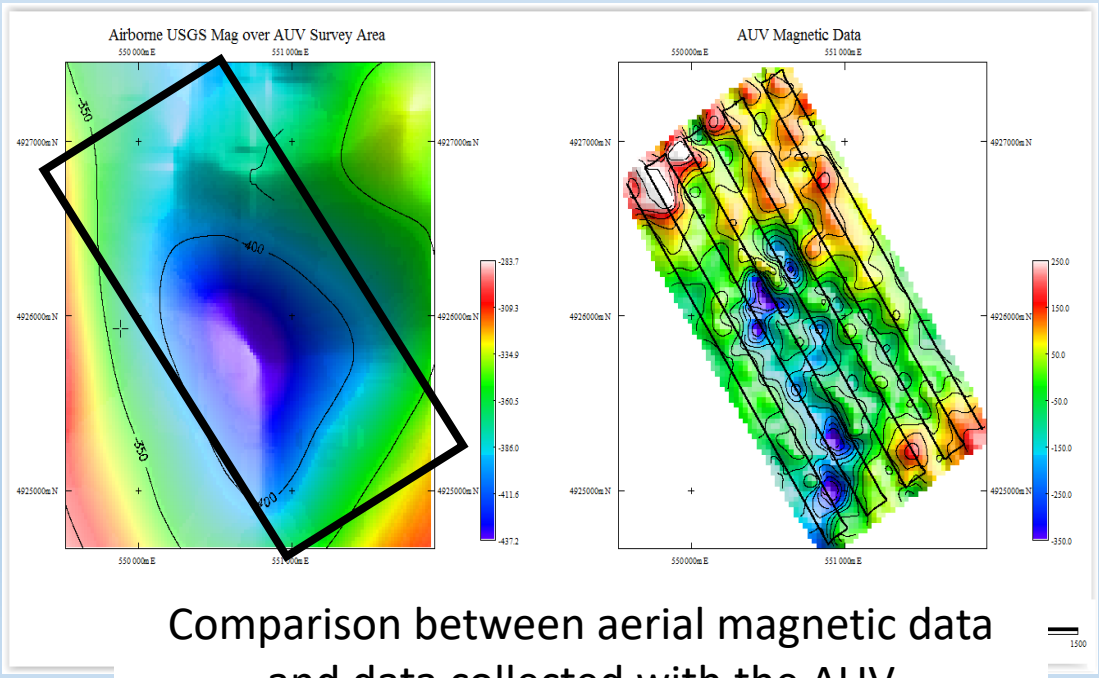


Survey of Yellowstone Lake

Photograph courtesy of Rob Sohn, Woods Hole Oceanographic Institution



- Installed on REMUS 600
- Four survey areas combined; no levelling between surveys required
- **Magnetic lows correspond to seeps and pockmarks on lake bottom**



Comparison between aerial magnetic data and data collected with the AUV

Why Use Marine EM?

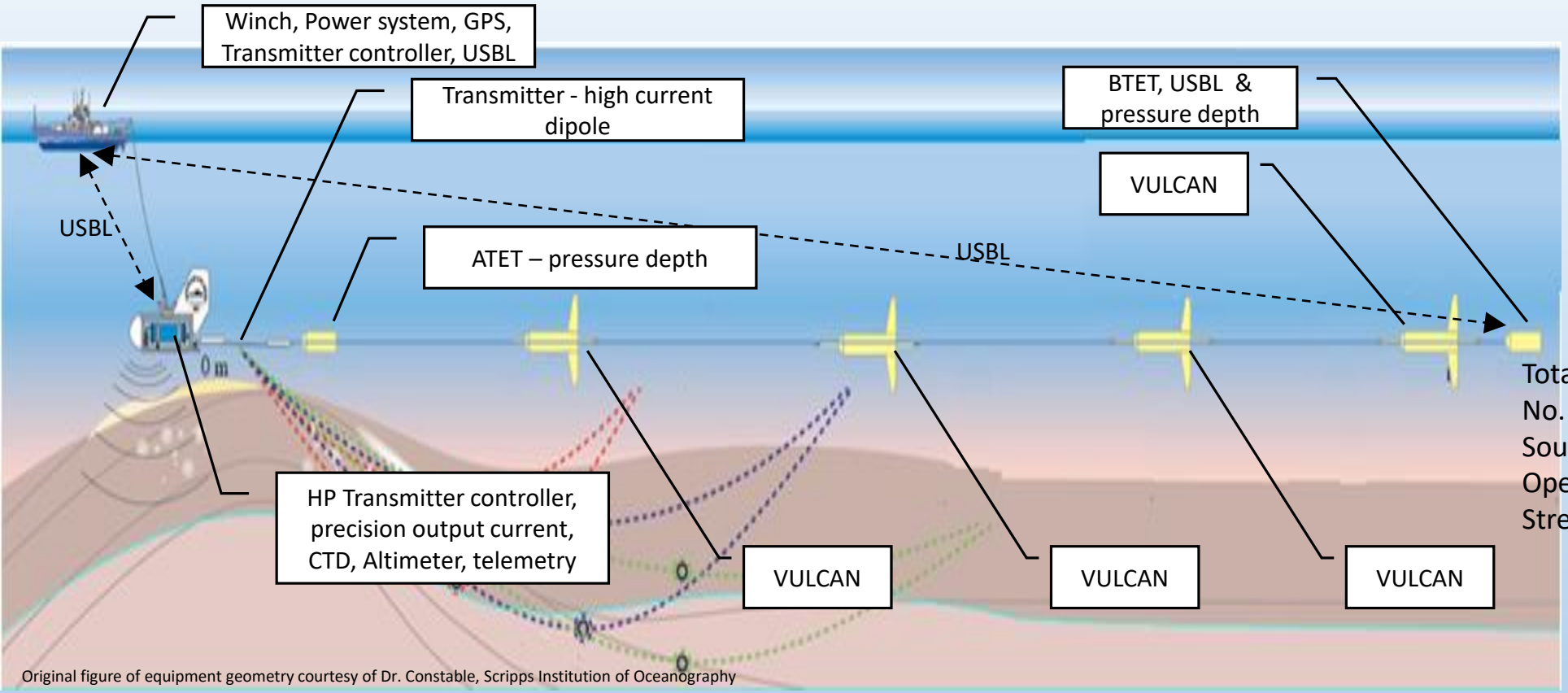
Applications:

- Maps variations in near-surface geology (basalts, sediments, alteration) due to variations in resistivity. Assists with better understanding of MBES, SSS, and SBP data
- Mapping of seafloor conductors (e.g. Seafloor Massive Sulphide (SMS) deposits)
- Detection, mapping and assessment of shallow resistive responses:
  - methane hydrate layers and pods
  - Other gas seepage
  - Natural seabed domes can be generated by the accumulation of gaseous methane in soft cohesive sediments - such structures can lead to seafloor instability.

OFG Systems:

- **Delineation of shallow resistivity (gas hazards) - VULCAN Towed EM system (shipborne)**
- **Detailed mapping of resistivity or conductivity - CSEM AUV**
- 2D/3D EM/MMT monitoring - CSEM seafloor receivers
- CSEMP/MIPS Towed system – mapping shallow resistivity in shallow water (minerals, dredging, construction)
- OFG EM Mark III (ROV) – mapping of conductive mineralisation and alteration

Towed EM Vulcan System – Specifications



Original figure of equipment geometry courtesy of Dr. Constable, Scripps Institution of Oceanography

Total streamer length:	500m – 1.5km
No. of towed receivers:	3 – 5
Source power:	250 - 500A
Operating depth:	3,000m
Streamer flying height:	~ 50m

- Towed EM streamer provides continuous mapping without the need for deployed seabed node receivers.
- Can be containerised and mobilised throughout the world onto vessels of opportunity, and data acquired as a complementary dataset with other geophysical or geotechnical surveys
- Developed by Scripps Institution of Oceanography – modified and operated by OFG

Published results from OFG CSEM gas hydrate survey (Japan, 2014)

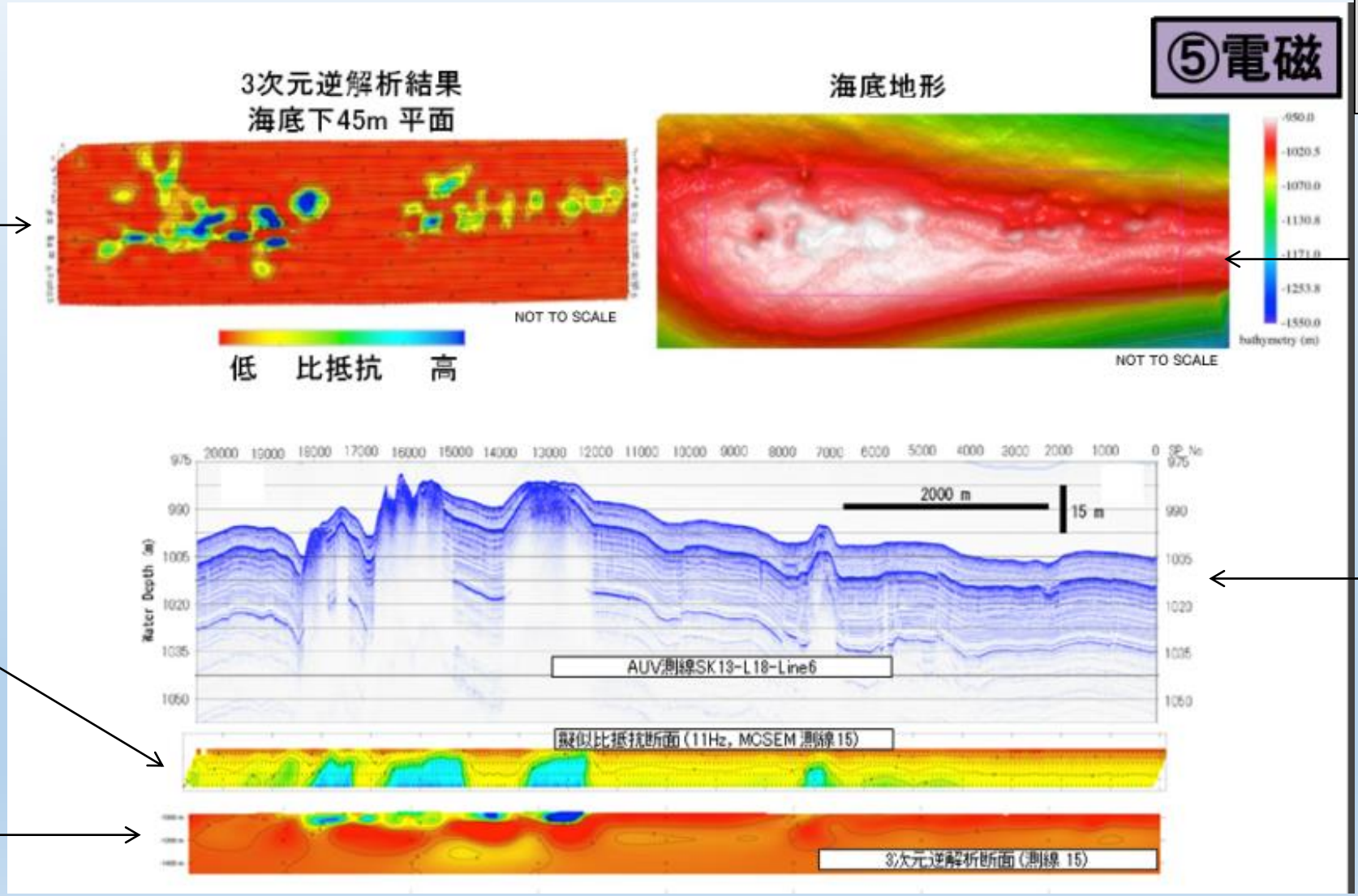
OFG Ocean Floor Geophysics

Deep-tow EM

Constant depth slice through EM inversion – plan view

Initial Pseudo-sections CSEM data

3D EM inversion profile of CSEM data. Thickness of compact gas hydrate bodies (blue) ~300m



AUV + Acoustic Mapping (MBES, SSS, SBP)

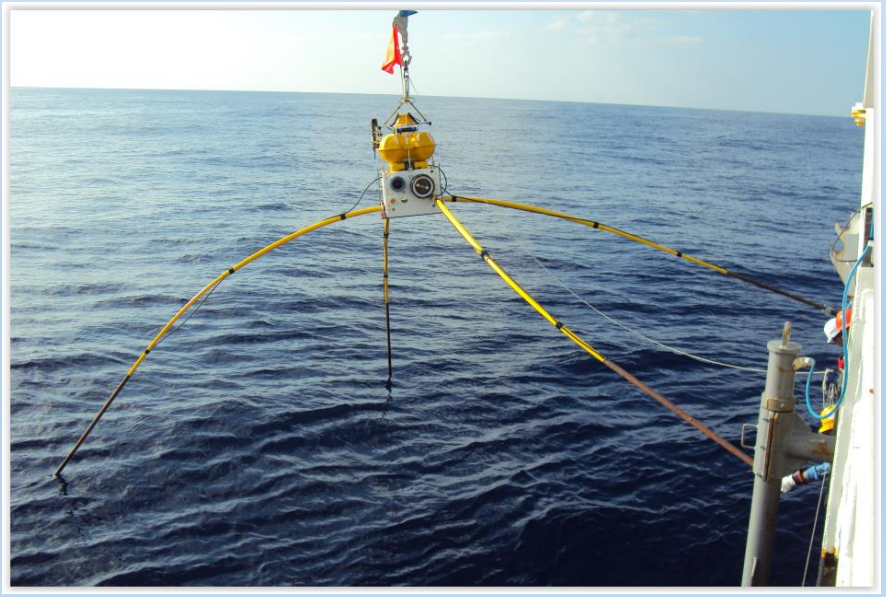
High resolution AUV bathymetry mapping – plan view

Sub-bottom profiling for gas chimneys and structures (note the blanking in the gas chimney areas)

A new system – AUV CSEM

- Designed, tested and now commercially available through OFG/Fukada/Scripps
- High resolution CSEM system using EM receivers on a AUV and fixed seafloor transmitters
- Successfully operated all AUV systems (Bathymetry, sidescan sonar, water chemistry, sub-bottom profiler, magnetometer, and turbidity) while making CSEM measurements
- Provides direct indications of seafloor and buried conductors and resistors. All data can be combined to make a 3D deposit model.

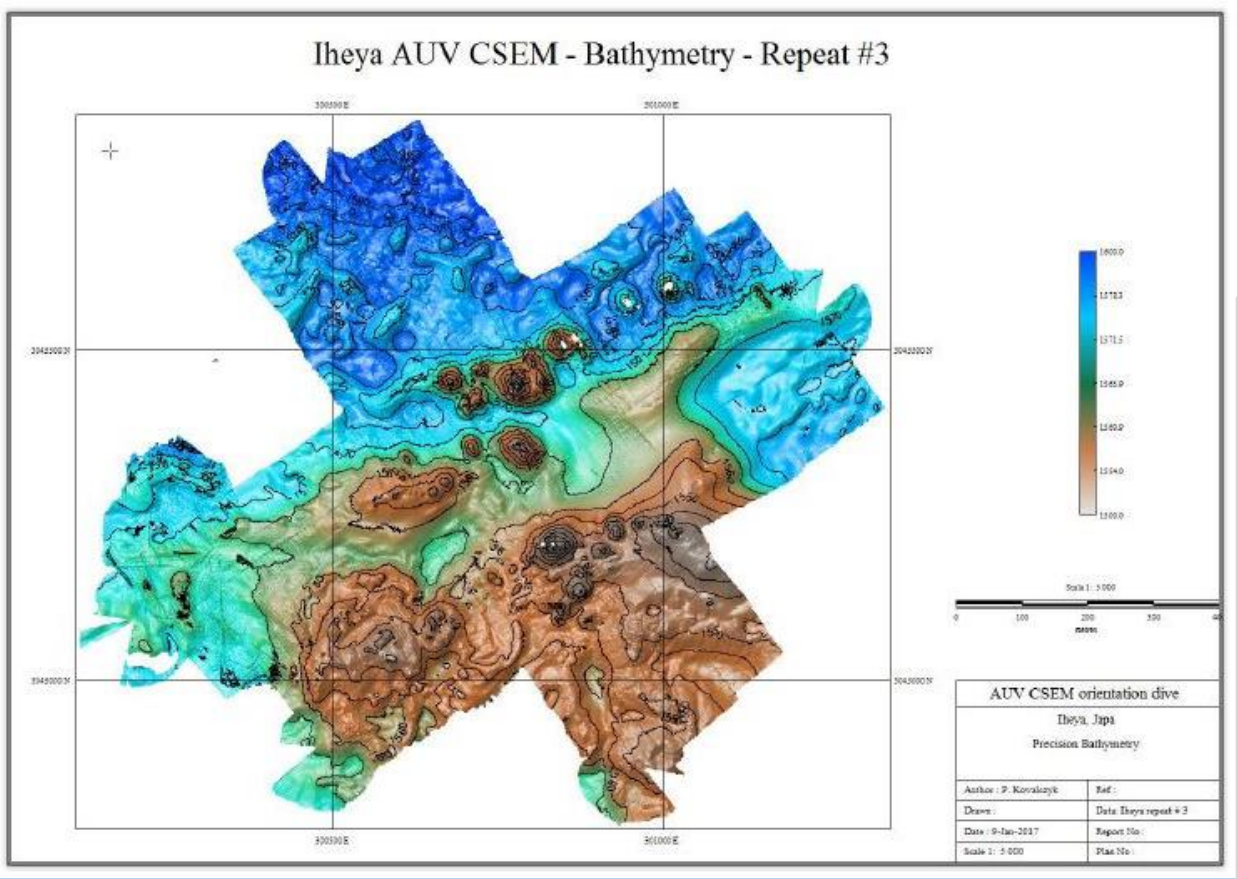
AUV CSEM Receiver system prelaunch tests using Fukada Deep 1 AUV (Nov 2016)



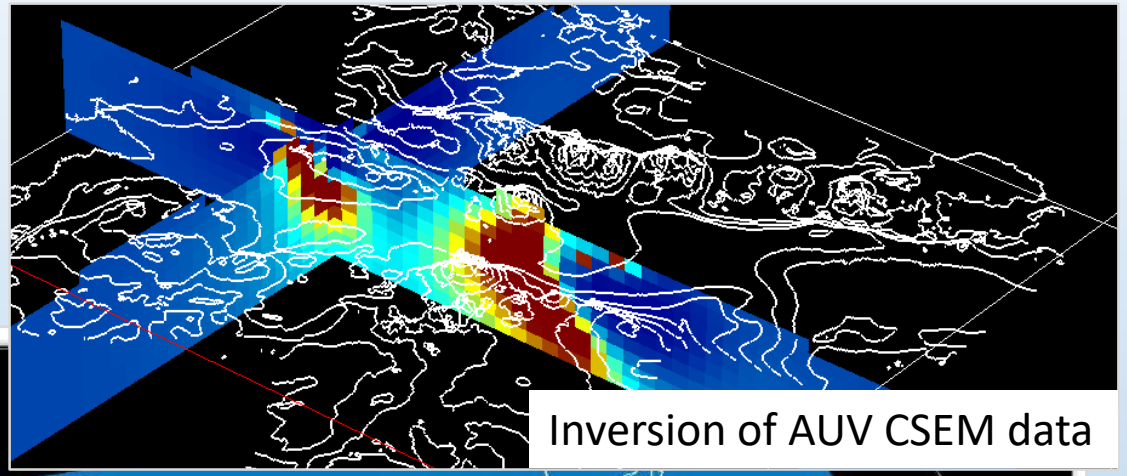
Seafloor DUESI CSEM transmitter being deployed

OFG Ocean Floor Geophysics

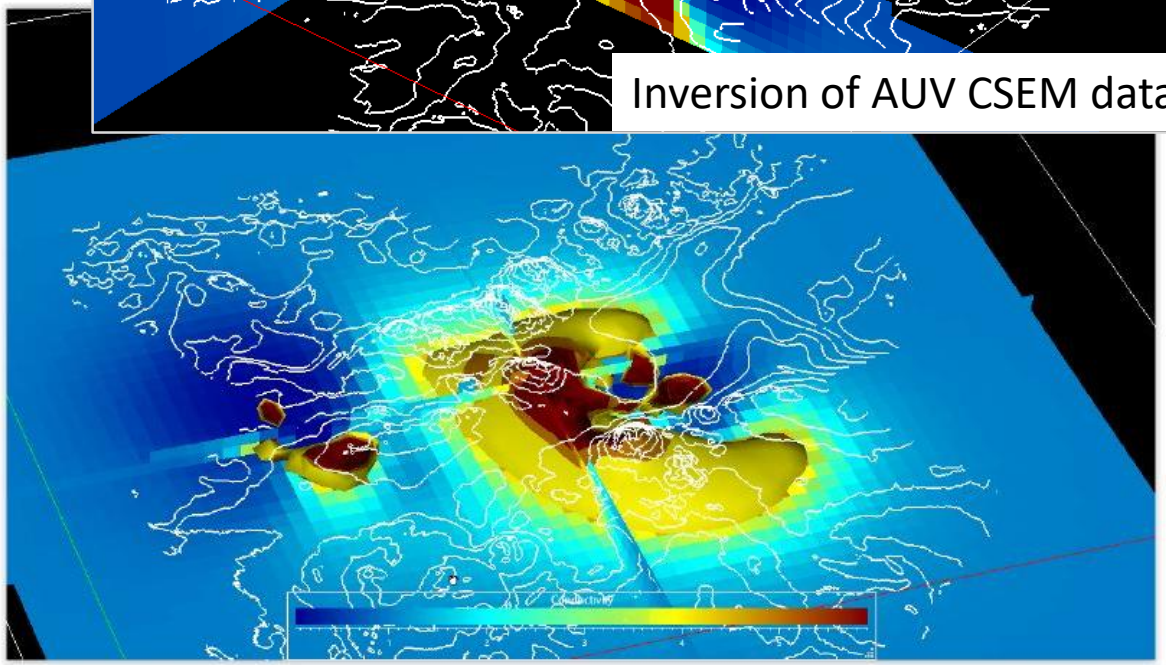
AUV CSEM data over Iheya SMS Deposit (Japan)



Bathymetry acquired during AUV CSEM dive



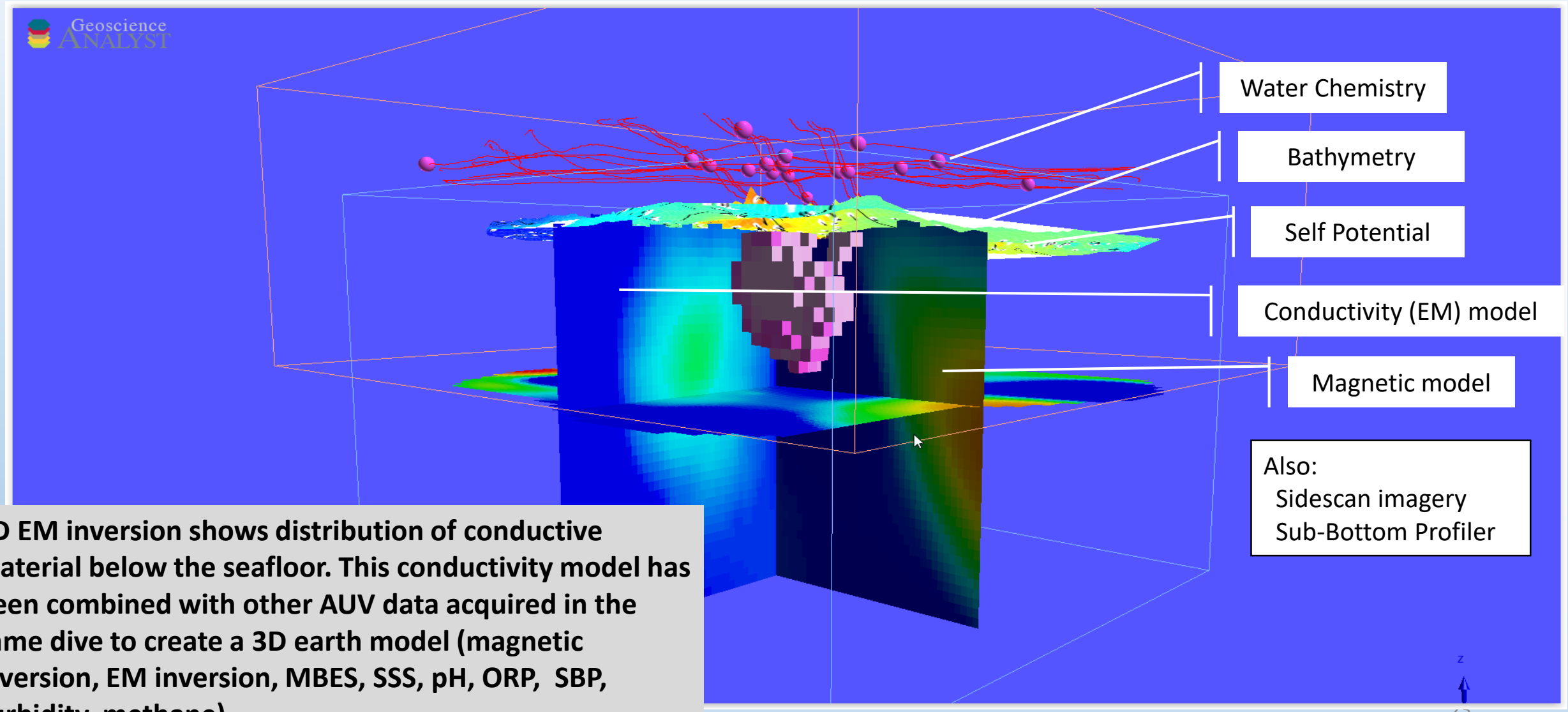
Inversion of AUV CSEM data



3D inversion shows conductivity anomalies - interpreted to be massive sulfides. Note the bodies center under the seafloor mounds, but are shown to be extensive, linking the two larger mounds and extending towards the east. [*3D inversion by CGI, Vancouver*]

OFG Ocean Floor Geophysics

Outcome: 3D Data Model from a Single AUV Dive



3D EM inversion shows distribution of conductive material below the seafloor. This conductivity model has been combined with other AUV data acquired in the same dive to create a 3D earth model (magnetic inversion, EM inversion, MBES, SSS, pH, ORP, SBP, Turbidity, methane).

OFG Ocean Floor Geophysics

Further AUV-CSEM applications

Finding the needle in the hay stack - tracing seabed gas seepages using hullborne multibeam echo sounder, and AUV based sonar and optical systems

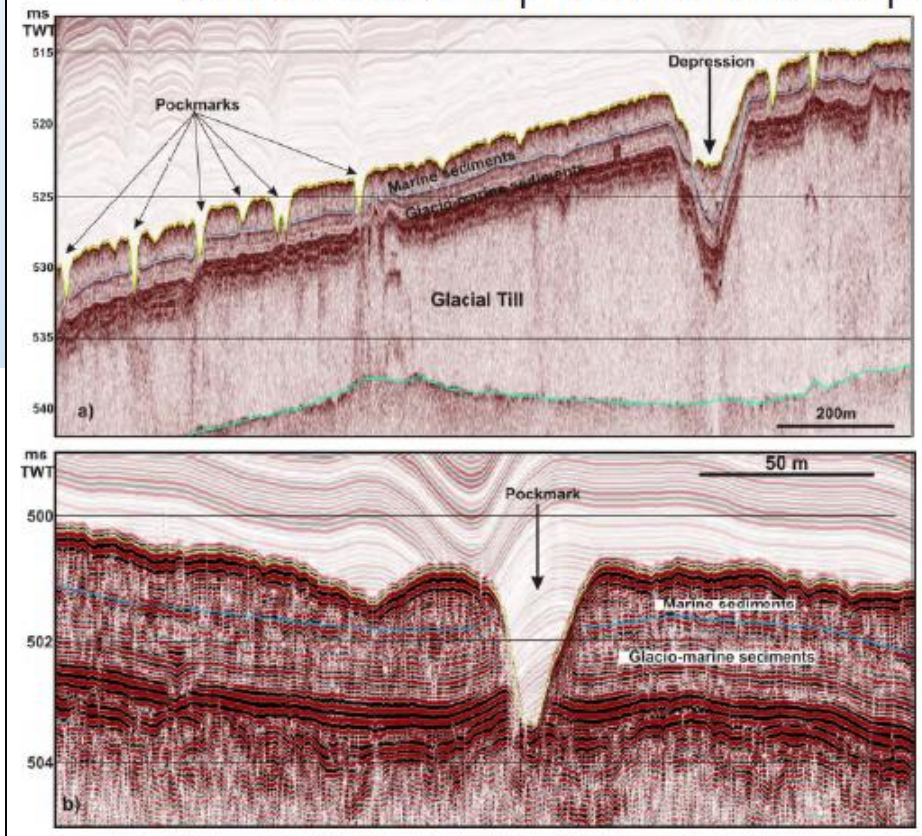
Terje Thorsnes[1], Harald Brunstad[2], Petter Lågstad[3], Shyam Chand[1], Aivo Lepland[1] and Arnfinn Karlsen[3]
[1] – Geological Survey of Norway; [2] – Lundin Petroleum; [3] – Norwegian Defence Research Establishment

Conclusions and experiences

- Multi-scale approach: Hullborne MBE – AUV with HiSAS and Tfish - ROV
- Water column data indicates gas flares (beware of fish shoals!)
- Note – gas flares are episodic events – on and off
- Hullborne MBE data give too low resolution for identifying seep-related structures
- HiSAS may, or may not, identify carbonate crust structures
- Visual documentation is necessary to verify carbonate crust structures, and related phenomena like depressions with algal mats
- Sampling carbonate crusts with grabs and box corers is challenging – ROV...

Combination of hullborne hi-res acoustic tools with AUVs fitted with dedicated sensors provides excellent opportunities to increase the scientific understanding of shallow geological processes, and for more applied investigations related to natural or anthropogenic gas seepages

Hi-res seismic of pockmarks and depressions



Hullborne TOPAS – H.U.Sverdrup II

Internal structure of pockmarks and depressions

Sub-bottom profiler – HUGIN HUSII AUV

OFG Ocean Floor Geophysics

Other AUV geophysical systems under development

AUV Gravity:

Applications:

- Satellite gravity currently used for regional bathymetry
- Potential for more detailed gravity to be acquired in conjunction with bathymetry? Enable better resolution on geology which may affect ocean heights and currents
- Improved geological mapping

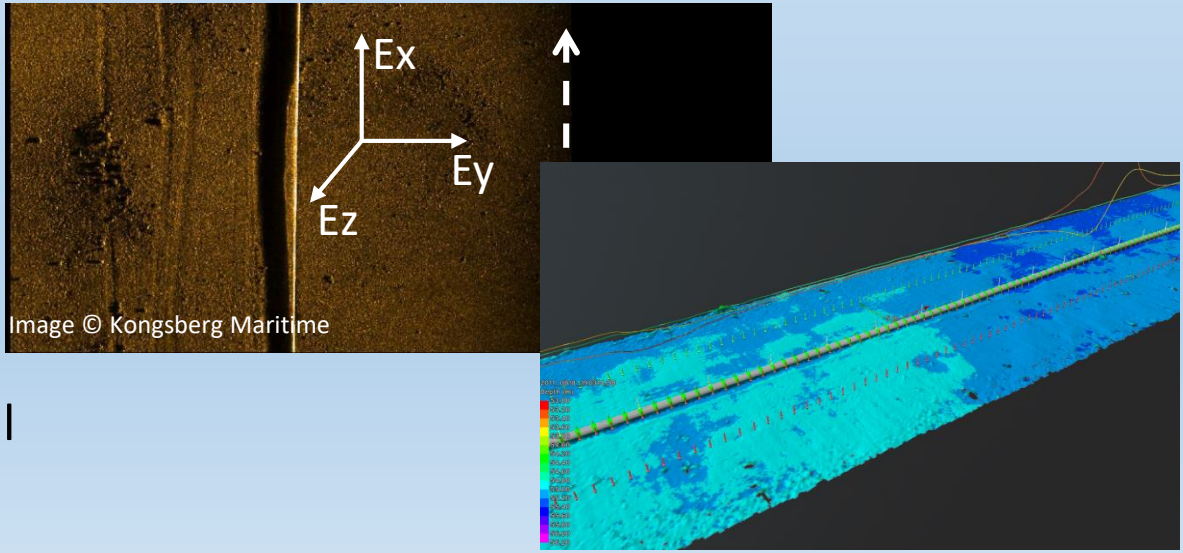
System status: Concept studies and modelling undertaken for modified GT-2A (Airborne Gravimeter) for ISE Explorer AUV

AUV E-Field Gradient:

Applications:

Pipeline tracking + integrated Cathodic Protection surveys

System status: Initial noise trials on Hugin 1000 successful



What complementary data would be of value for YOUR bathymetry or ocean mapping project?

Ocean Floor Geophysics Inc.
B108 – 9000 Bill Fox Way
Burnaby, BC
Canada V5J 5J3

E: mako@OceanFloorGeophysics.com

T: +1-778-654-7781