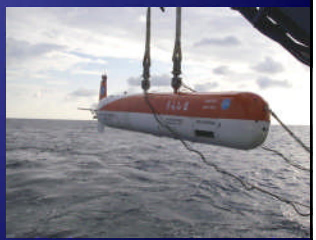
MARINE CONTROLLED-SOURCE ELECTROMAGNETIC SOUNDING ON SUBMARINE MASSIVE SULPHIDES USING AUTONOMOUS UNDERWATER VEHICLE

Tada-nori Goto*, Naoto Imamura,
Junichi Takekawa and Hitoshi Mikada

Kyoto University, Japan

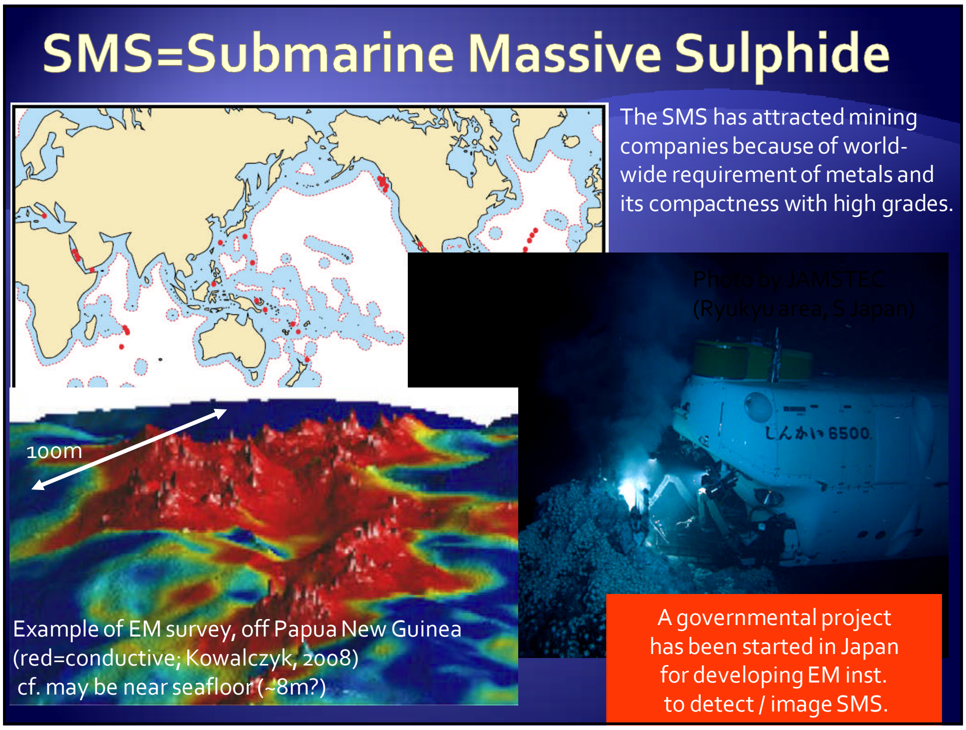


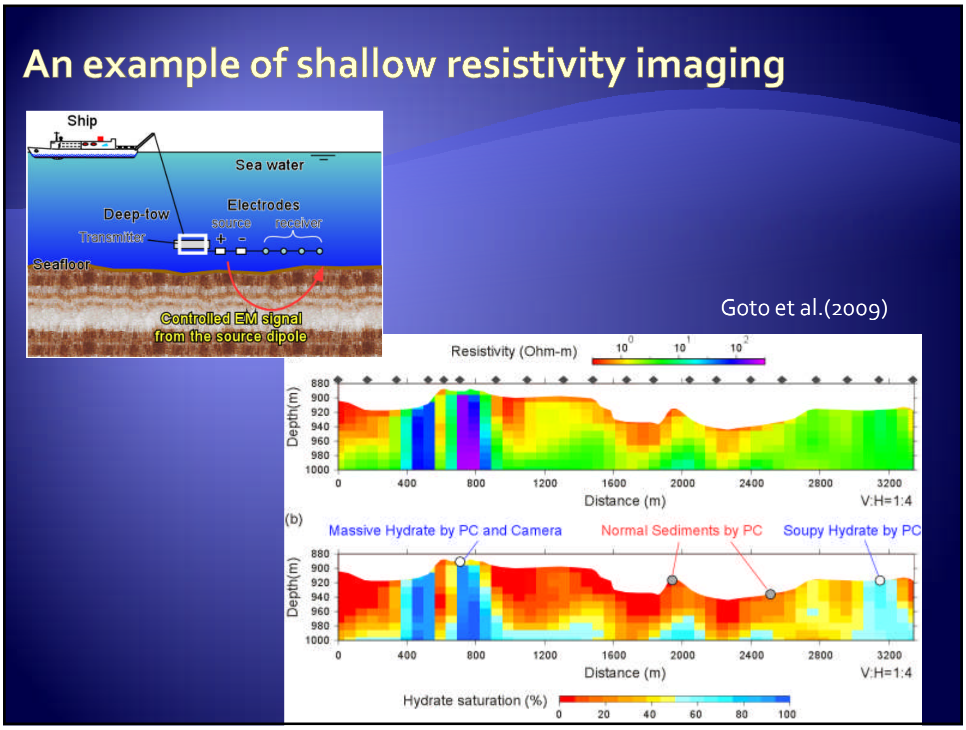
Summary of today's talk

- Proposal of AUV-CSEM:
  A new survey technology for shallow
  sub-seafloor structure imaging
  such as seafloor massive sulphide (SMS)
- Numerical studies show us that AUV-CSEM is feasible even with a shorter source-dipole length , positioning (navigation) errors and so on.

- Proceeding the real AUV-CSEM survey, we applied ROV-based DC resistivity survey for testing instruments.
- The obtained surface resistivity /IP distribution corresponds to the camera image/coring results.

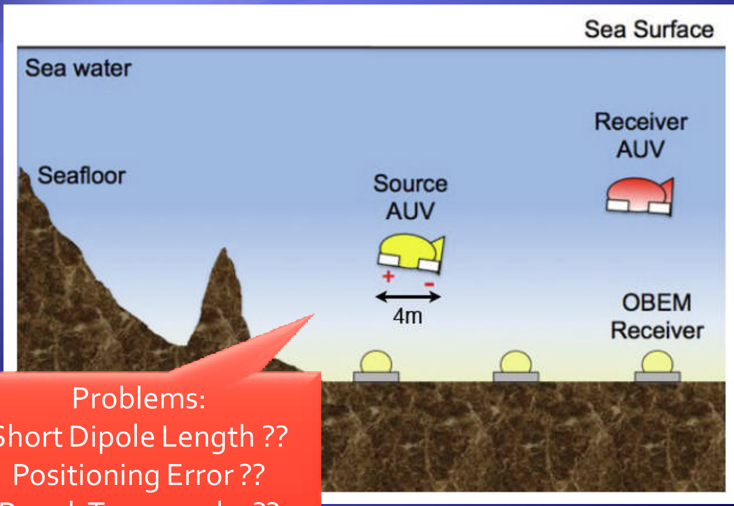
Related cruises:KR08-10, KR09-16, KR11-02


SMS=Submarine Massive Sulphide
The SMS has attracted mining companies because of world-wide requirement of metals and its compactness with high grades.
Photo by JAMSTEC
(Ryukyu area, S Japan)
しんかい6500
100m
Example of EM survey, off Papua New Guinea
(red=conductive; Kowalczyk, 2008)
cf. may be near seafloor (~8m?)
A governmental project has been started in Japan for developing EM inst. to detect / image SMS.


An example of shallow resistivity imaging
Ship
Sea water
Deep-tow
Transmitter
Electrodes
source
receiver
Seafloor
Controlled EM signal
from the source dipole
Goto et al.(2009)
Resistivity (Ohm-m)
Depth(m)
Distance (m)
V:H=1:4
(b)
Massive Hydrate by PC and Camera
Normal Sediments by PC
Soupy Hydrate by PC
Hydrate saturation (%)

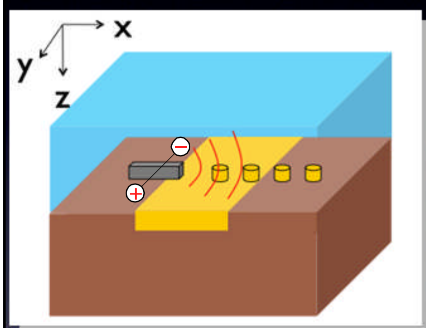
Proposal: CSEM survey with AUV

- AUV=Autonomous Underwater Vehicle



Problems:
Short Dipole Length ??
Positioning Error ??
Rough Topography ??

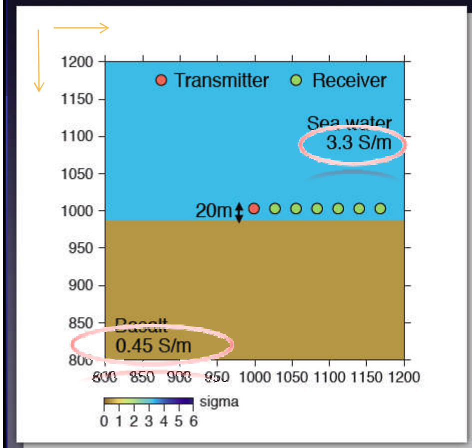
Feasibility: 2.5 D numerical simulation

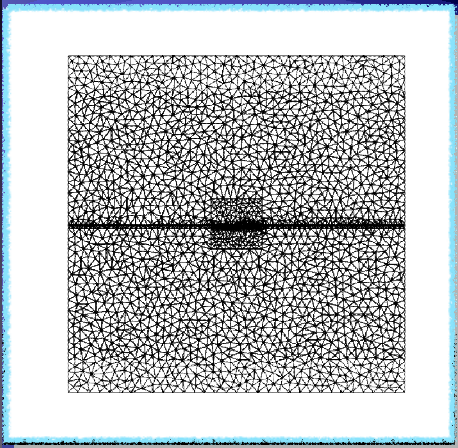


$$\nabla \times E = -\hat{z}H - \hat{z}M_s$$
$$\nabla \times H = \hat{y}E + J_s$$
$$(\hat{z} = i\mu\omega, \hat{y} = \sigma + i\epsilon\omega)$$

- Fourier transform of Maxwell's Eq. is applied to y-axis.
- 2D equation for Ey and Hy is solved.
- Inverse Fourier transform gives us 3D distribution of EM field.
- Source configuration (y-direction):
  4m dipole length, 1A amp. with freq of 10Hz.

Feasibility: 2.5 D numerical simulation

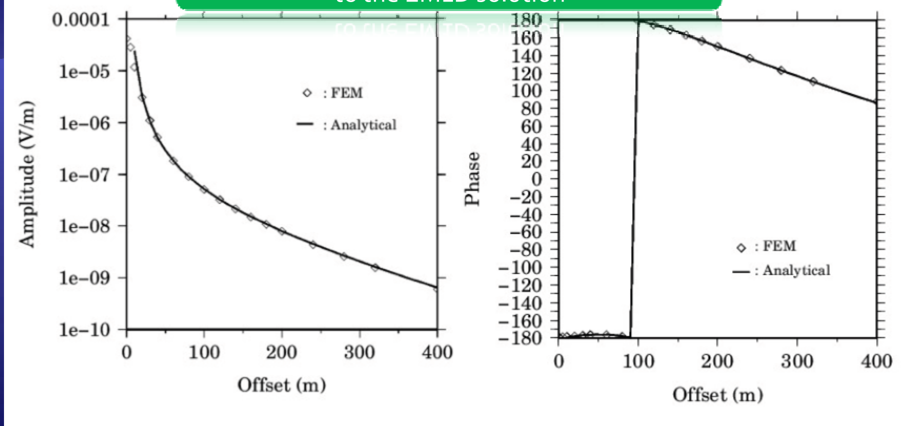




- Source-AUV & Receiver-AUV with altitude of 20m.
- Jy source – Ey, Hx, Hz receiver
- Resistivity values comes from Von-Herzen at al.(1996)

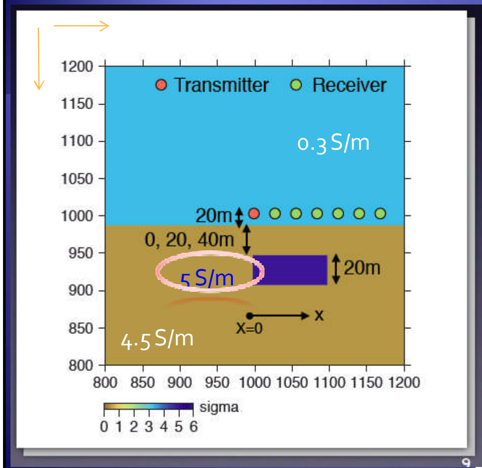
Feasibility: 2.5 D numerical simulation

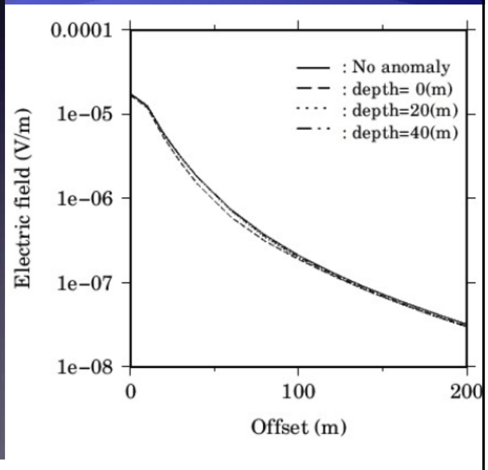
Pretty nice correspondence
to the EM1D solution



- Source-AUV & Receiver-AUV with altitude of 20m.
- Jy source – Ey, Hx, Hz receiver
- Resistivity values comes from Von-Herzen at al.(1996)

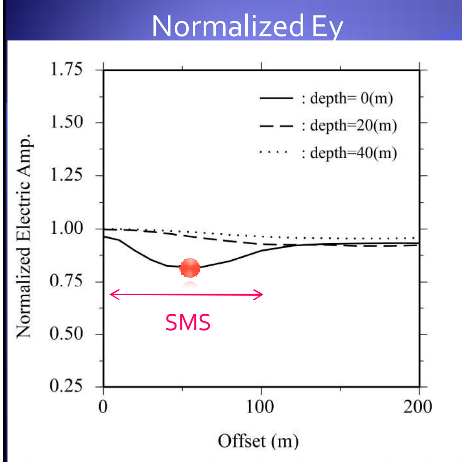
Feasibility: 2.5 D numerical simulation

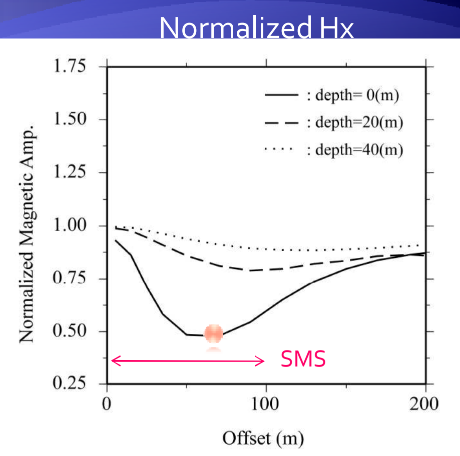




- The numerical results predict that depth changes of SMS (0-40m) make slight variation of received electric field.

Feasibility: 2.5 D numerical simulation

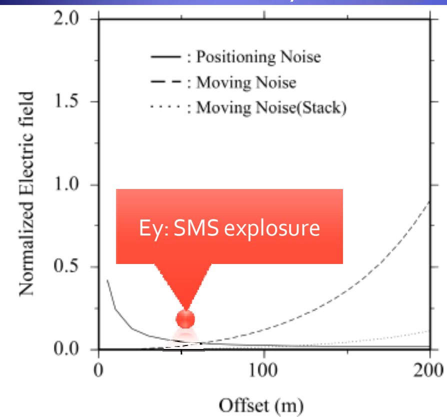




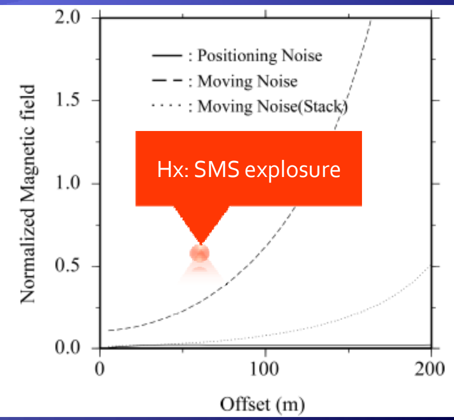
- In case of 0m depth (SMS is exposed to the seafloor), max. Ey decrease = 20%, and max. Hx decrease = 55%.
- Hz change (15%) is relatively smaller than Hx.

Positioning Error and Moving Noise

Normalized Ey noise



Normalized Hx noise



- Positioning Error: 1m shortening of source-receiver distance
- Moving noise @ 100A amplitude:
  Ey = 2.5μV/m, Hx = 1.0nT with 1 stacking
  Ey = 0.31μV/m, Hx = 0.13nT with 64 stacking

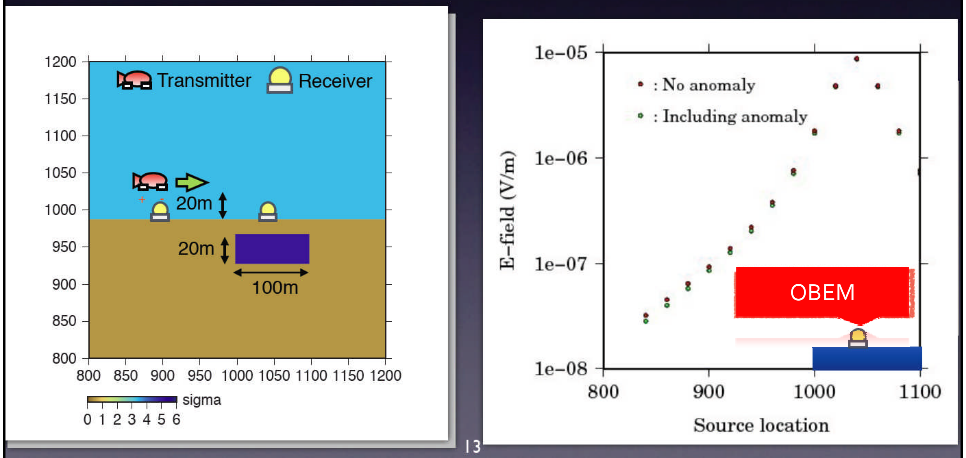
Summary of Numerical Simulation

Imamura et al.(2011)

Model	Receiver Direction	Maximum Normalized Amp. with the Offset	Positioning Noise	Moving Noise (stack)	Tilt Noise
Thickness 20m Depth 20m	Ey	8% at 200m	1.8%	90% (11%)	0.4%
	Hx	22% at 100m	1.8%	61% (7.7%)	0.4%
	Hz	10% at 200m	4.3%	750% (94%)	0.4%
Thickness 40m Depth 20m	Ey	14% at 200m	1.8%	90% (11%)	0.4%
	Hx	29% at 110m	1.8%	74% (9.3%)	0.4%
	Hz	14% at 200m	4.3%	750% (94%)	0.4%
Thickness 20m Depth 0m	Ey	19% at 60m	4.0%	3.4% (0.4%)	0.4%
	Hx	52% at 70m	2.0%	34% (4.3%)	0.4%
	Hz	10% at 160m	2.9%	187% (23%)	0.4%

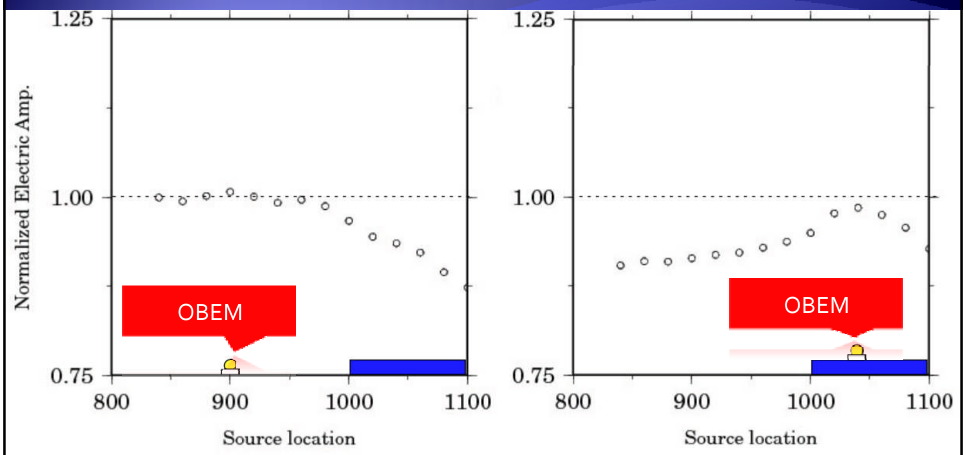
- Jy source-Ey, Hx receiver can be used.

AUV-OBEM combination (Num. Cal.)

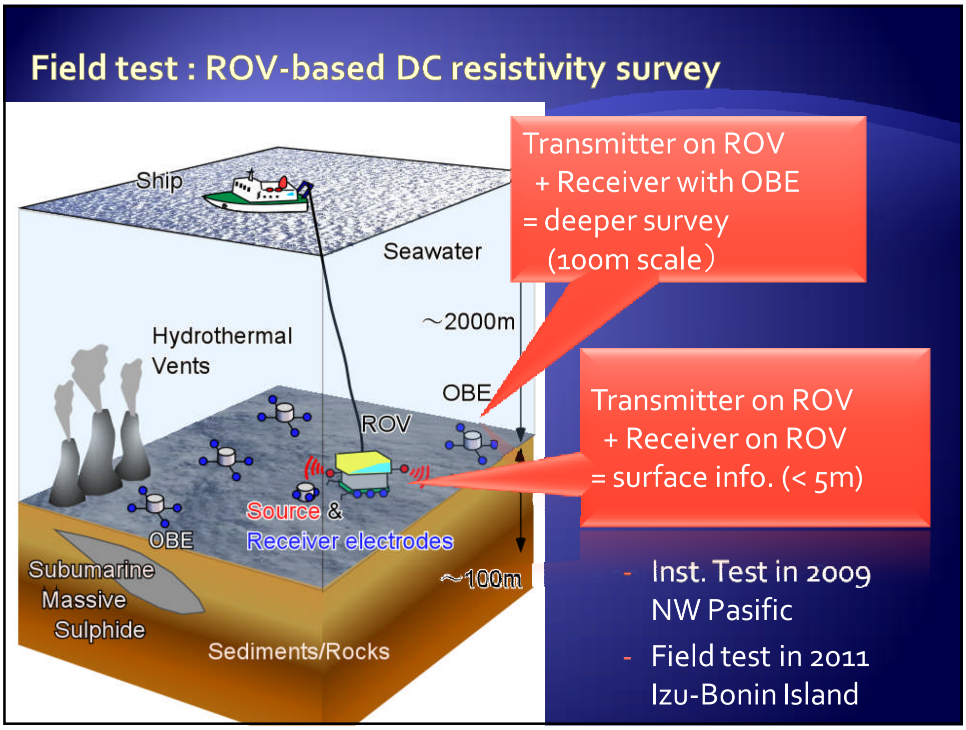


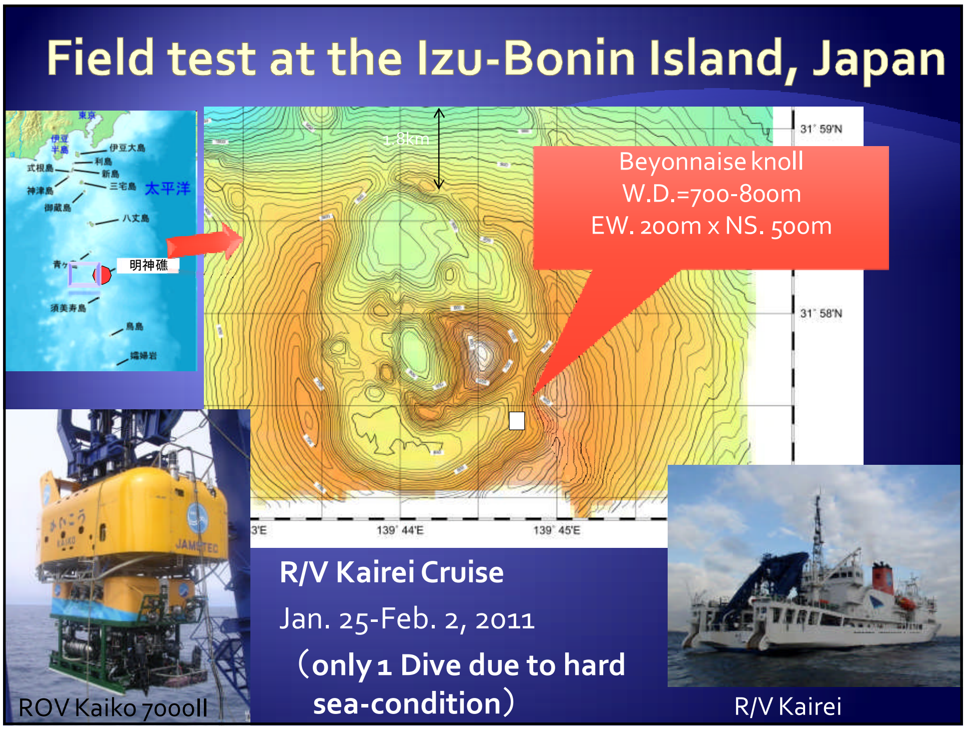
- Source-AUV and receiver OBEMs can be also available for SMS imaging.

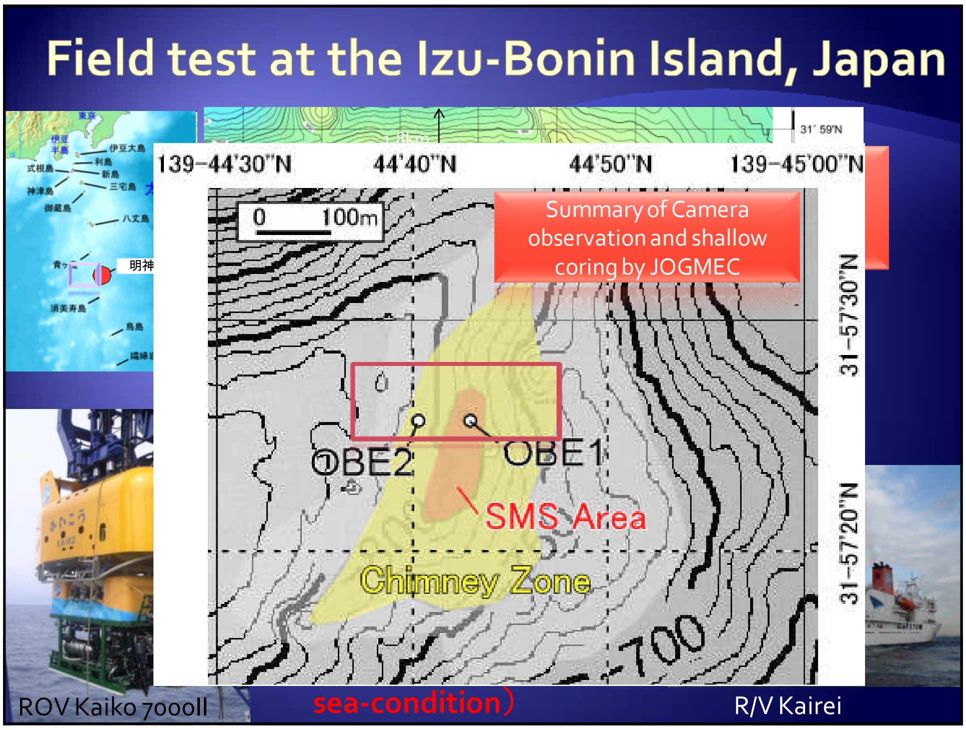
AUV-OBEM combination (Num. Cal.)

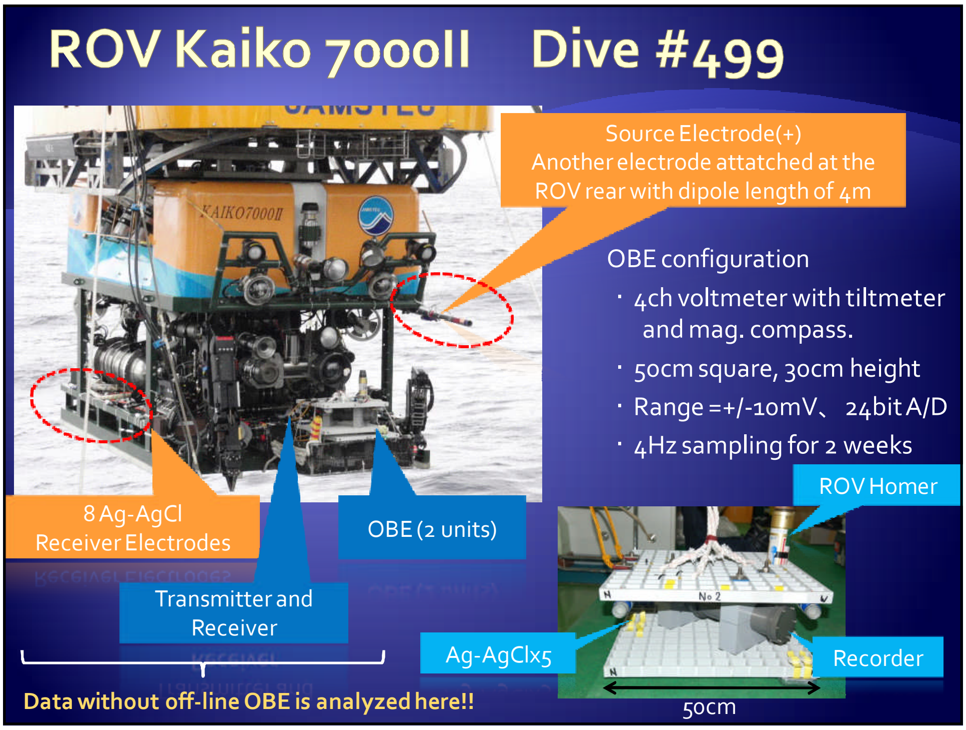


- If source-AUV or OBEM is located on the SMS, anomalous attenuation of EM field will be observed.

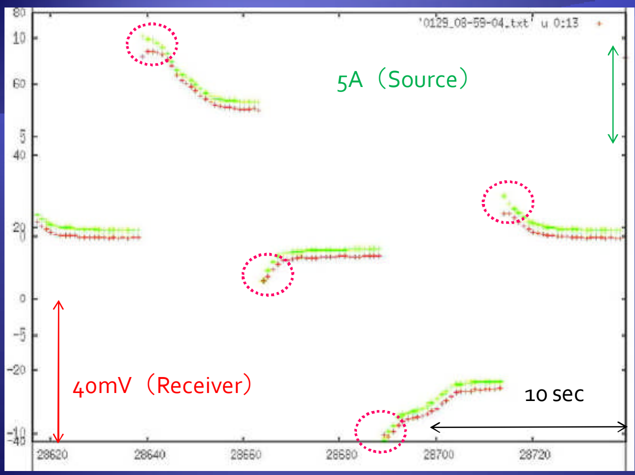

Field test : ROV-based DC resistivity survey
Ship
Seawater
Hydrothermal
Vents
～2000m
OBE
ROV
Source &
Receiver electrodes
OBE
Subumarine
Massive
Sulphide
Sediments/Rocks
～100m
Transmitter on ROV
+ Receiver with OBE
= deeper survey
(100m scale)
Transmitter on ROV
+ Receiver on ROV
= surface info. (< 5m)
- Inst. Test in 2009
NW Pasific
- Field test in 2011
Izu-Bonin Island

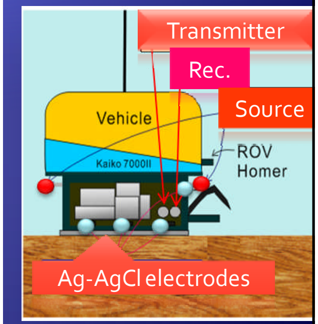

Field test at the Izu-Bonin Island, Japan
太平洋
明神礁
Beyonnaise knoll
W.D.=700-800m
EW. 200m x NS. 500m
31° 59'N
31° 58'N
139° 44'E
139° 45'E
R/V Kairei Cruise
Jan. 25-Feb. 2, 2011
(only 1 Dive due to hard
sea-condition)
ROV Kaiko 7000II
R/V Kairei


Field test at the Izu-Bonin Island, Japan
139-44'30"N
44'40"N
44'50"N
139-45'00"N
0 100m
Summary of Camera observation and shallow coring by JOGMEC
31-57'30"N
31-57'20"N
OBE2
OBE1
SMS Area
Chimney Zone
700
ROV Kaiko 7000II
sea-condition)
R/V Kairei


ROV Kaiko 7000II Dive #499
Source Electrode(+)
Another electrode attatched at the ROV rear with dipole length of 4m
OBE configuration
・4ch voltmeter with tiltmeter and mag. compass.
・50cm square, 30cm height
・Range =+/-10mV、24bit A/D
・4Hz sampling for 2 weeks
ROV Homer
8 Ag-AgCl Receiver Electrodes
OBE (2 units)
Transmitter and Receiver
Ag-AgClx5
Recorder
Data without off-line OBE is analyzed here!!
50cm

Example of Wave Form

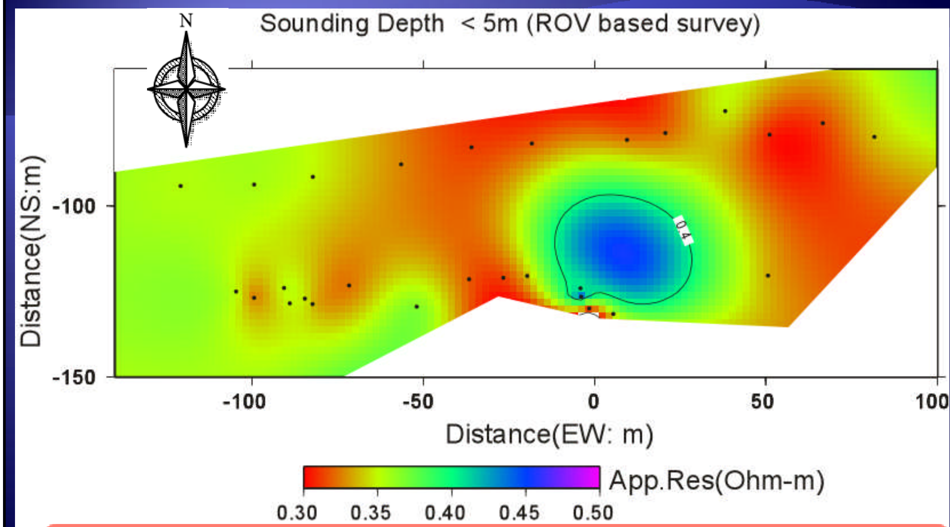




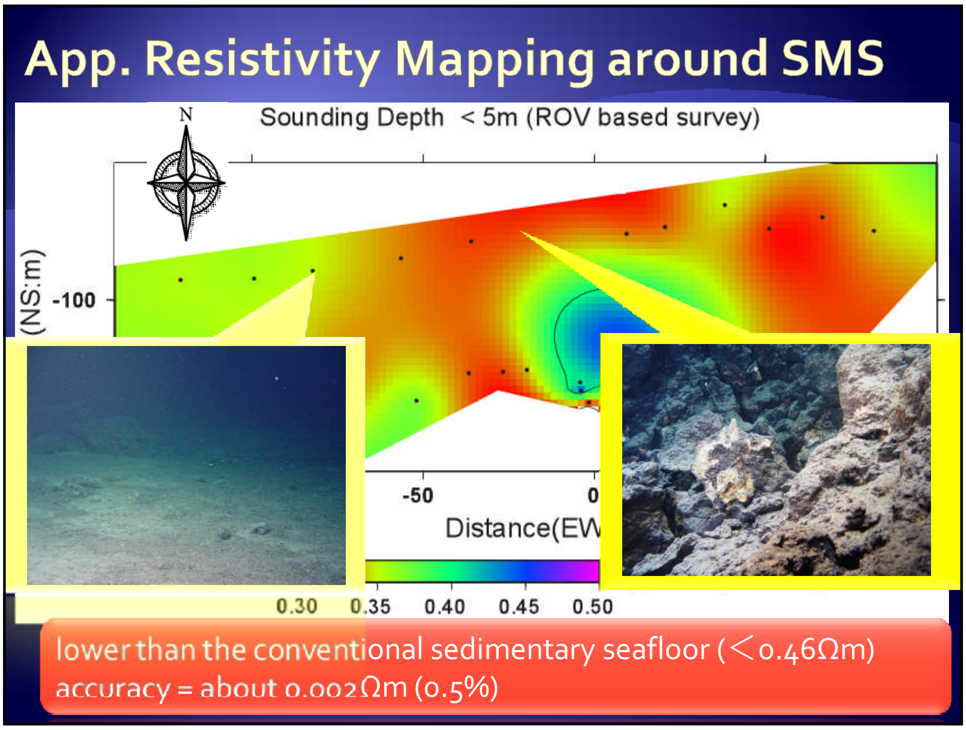
Time series for Source (I) and Receiver (V)

- Square wave (+on/off/-on/off every 6.25sec duty cycle)
- Induced Polarization is observed clearly.

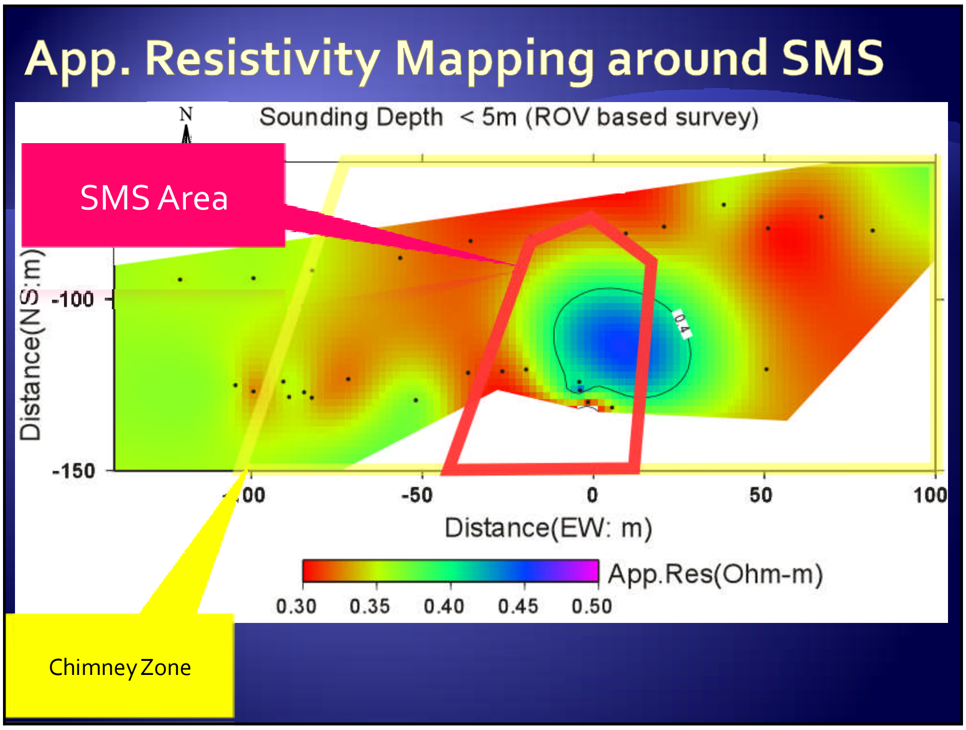
App. Resistivity Mapping around SMS



lower than the conventional sedimentary seafloor (＜0.46Ωm)
accuracy = about 0.002Ωm (0.5%)

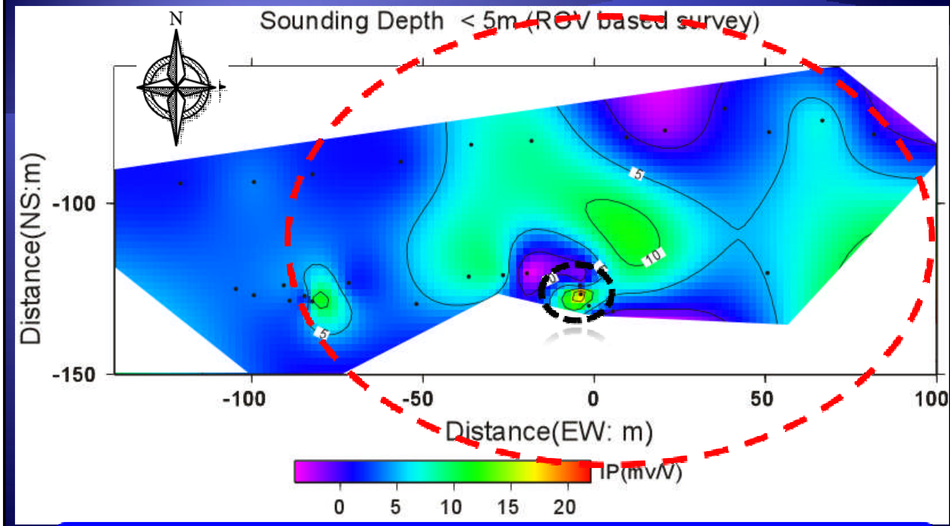


App. Resistivity Mapping around SMS
N
Sounding Depth < 5m (ROV based survey)
(NS:m)
-100
-50
0
Distance(EW
0.30
0.35
0.40
0.45
0.50
lower than the conventional sedimentary seafloor (<0.46Ωm)
accuracy = about 0.002Ωm (0.5%)



App. Resistivity Mapping around SMS
N
Sounding Depth < 5m (ROV based survey)
SMS Area
Distance(NS:m)
-100
-150
0.4
-100
-50
0
50
100
Distance(EW: m)
App.Res(Ohm-m)
0.30
0.35
0.40
0.45
0.50
Chimney Zone

Induced Polarization Mapping

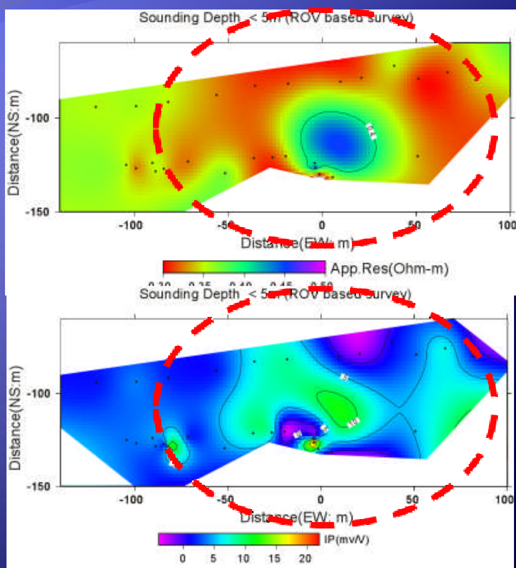


High IP anomaly (with large charge) was observed in the Chimney and SMS areas.

App. Res. and IP mapping

Low App.Resistivity
at the Chimeney Zone
(0.35-0.4Ωm
 for sediments/rocks)
* Partly high app. res.

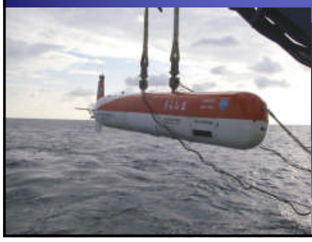
High IP effect
at the Chimney Zone



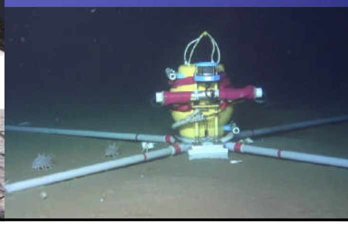
Summary

- AUV-CSEM survey is feasible.
- Source-AUV and receiver-OBEM will be a realistic combination for the survey.
- The developed instruments test is successful at a SMS.
- The in-situ test shows low resistivity/high IP features of SMS.
- The Japanese AUV "Urashima" is ready to go. The AUV experiment with OBEM is conducted around the real SMS in Dec., 2011.

AUV "Urashima"



Japanese OBEM



Izu-Bonin SMS