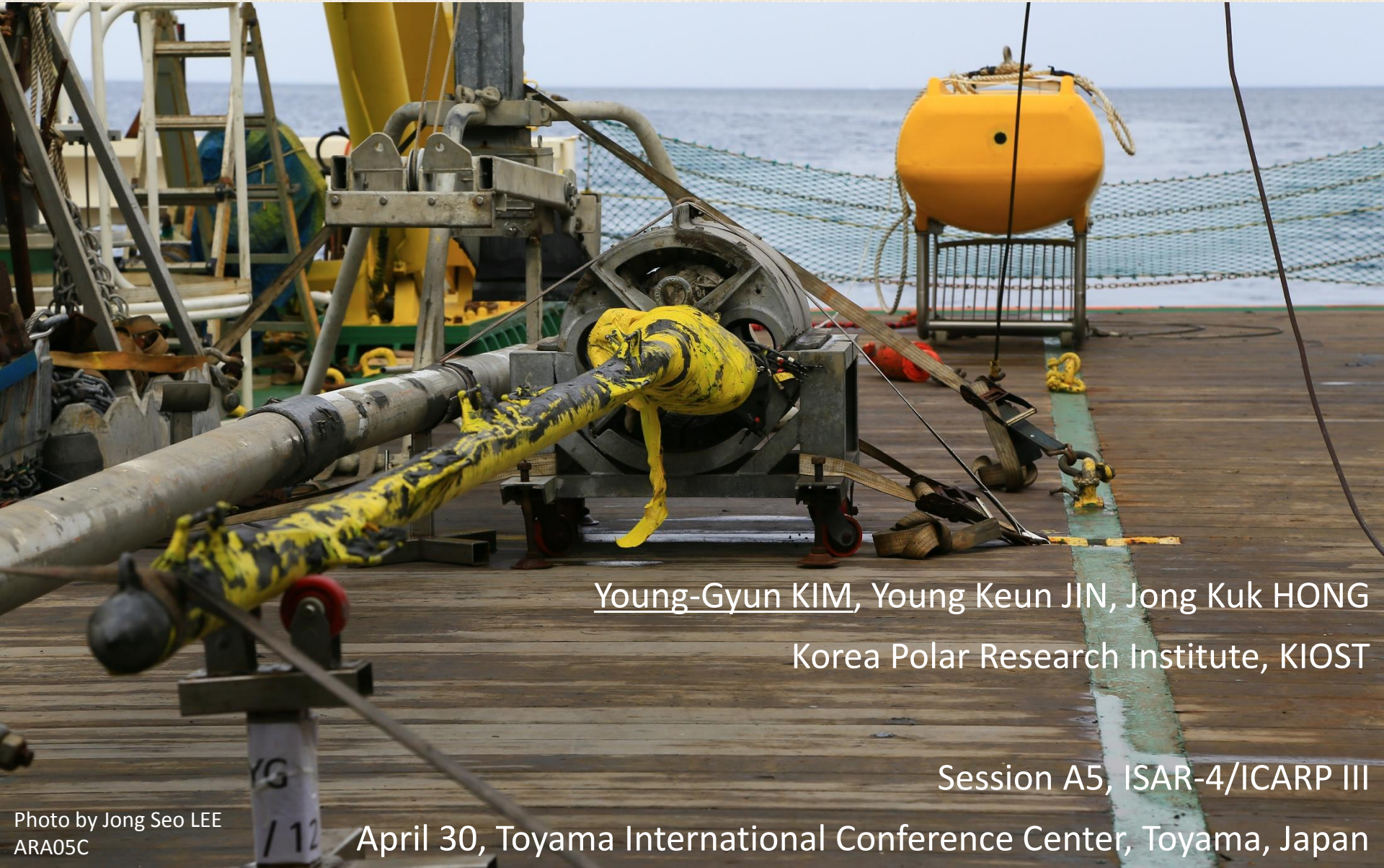
Gas Hydrate Stability Zone Associated With Subsea Permafrost Thawing In the Canadian Beaufort Sea Inferred From Marine Heat Flow Measurements



Young-Gyun KIM, Young Keun JIN, Jong Kuk HONG

Korea Polar Research Institute, KIOST

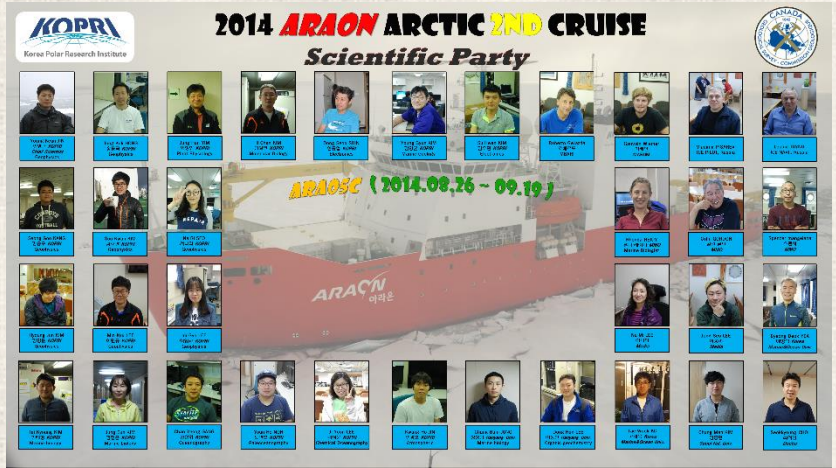
Session A5, ISAR-4/ICARP III

April 30, Toyama International Conference Center, Toyama, Japan

Photo by Jong Seo LEE
ARA05C

Thanks to

- Initiative
  - “Research Proposal to Investigate Degrading Gas Hydrate and Melting Permafrost on the Beaufort Shelf”
  - **Young Keun JIN** (Korea Polar Research Institute), **Scott Dallimore** (Geological Survey of Canada), **Charles Paull** (Monterey Bay Aquarium Research Institute), **Timothy Collett** (U. S. Geological Survey), **Humfrey Melling** (Fisheries and Oceans Canada)
- Research Fund
  - Korea-Polar Ocean in Rapid Transition (PM13040 and PM14040)
  - Characteristics of Gas Hydrate and Reconstruction of Paleo-environment Changes in the Western Arctic (PE14060)
- Expedition
  - Icebreaker R/V Araon
  - ARA04C (2013) and ARA05C (2014) Scientific Teams

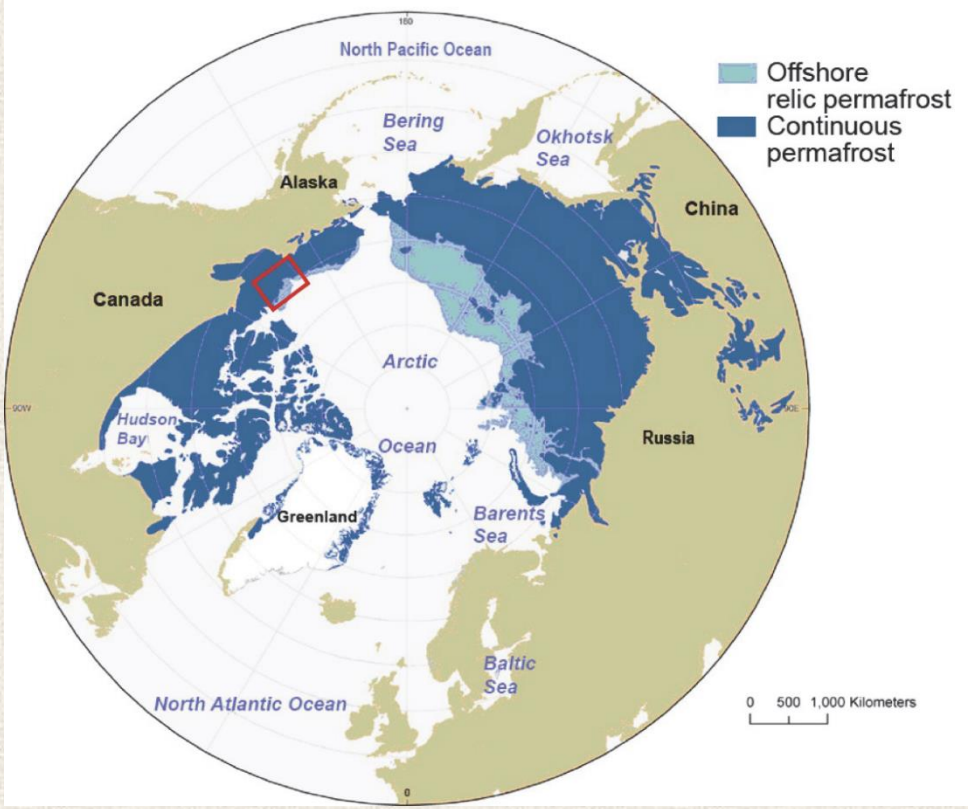


Outlines

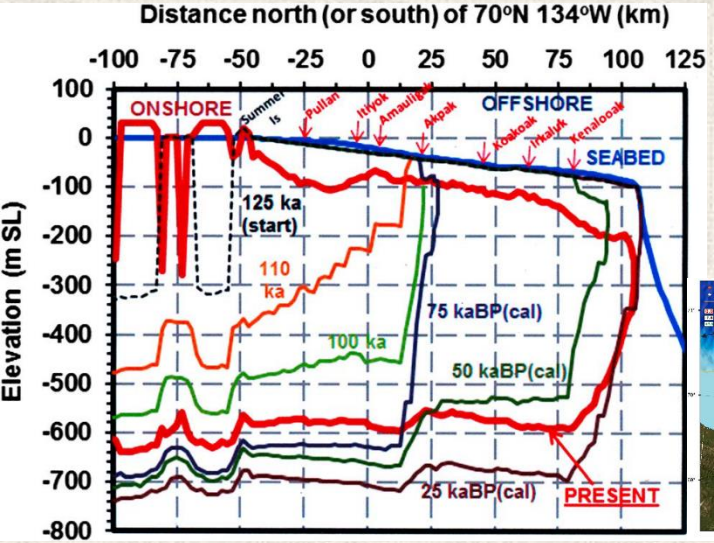
- Canadian Beaufort Sea as a promising area for researches related to degradation of permafrost and gas hydrate
- Icebreaker RV Araon and her expeditions in the Canadian Beaufort Sea in 2013 and 2014
- Marine heat flow measurements in the continental shelf and slope of the Canadian Beaufort Sea
- Distinction of three thermal regimes based on our geophysical observations: permafrost below the seafloor, normal seafloor, and mud volcano
- Implications from heat flow measurements: 1) steady-state heat flow condition through sediments, and 2) possibility of permafrost limit reaching up to the upper continental slope
- Plan for future expeditions and analyses
- Summary

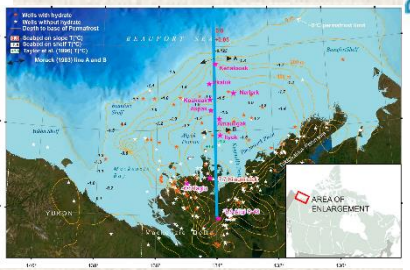
Canadian Beaufort Sea #1

- Degradation of offshore permafrost and gas hydrate
- Environmental considerations:
  - Nature of methane venting
  - Linkage to climate change
  - Active seafloor processes and marine habitat associated with venting
  - Geohazards due to increased slope instability
  - Various fundamental sciences

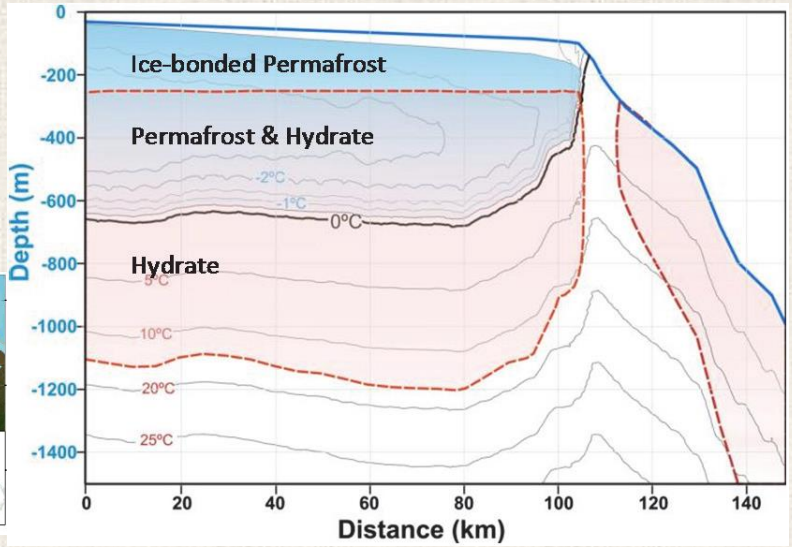


IODP pre-proposal 806 by Dallimore et al, 2012





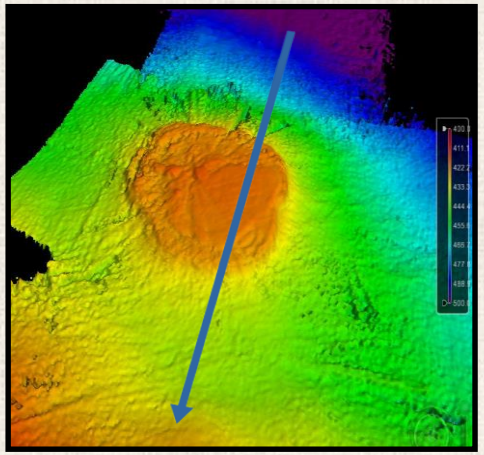
Taylor et al., 2013

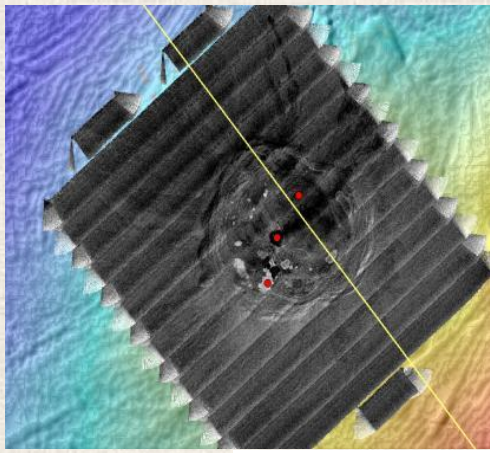


ARA04C Cruise Report

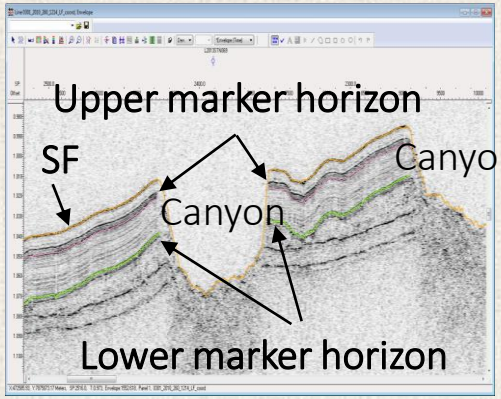
Canadian Beaufort Sea #2

- Fluid expulsion features
  - Active methane-rich fluid emission
  - Unique microbiology setting
- Slope failure
  - Around shelf edge and in the continental slope
  - Slope instability
  - Seismic stratigraphy and chronology
- IODP pre-proposals
  - #753 and #806



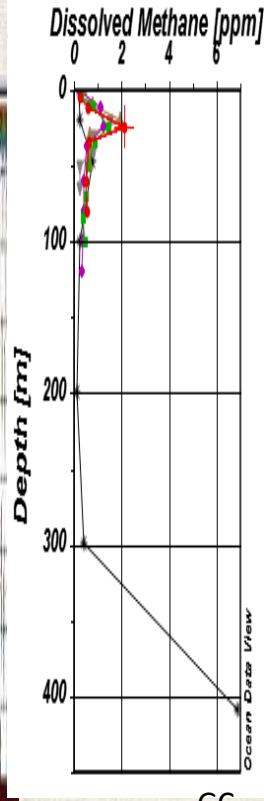


MB (bathy an BS) of ship and AUV

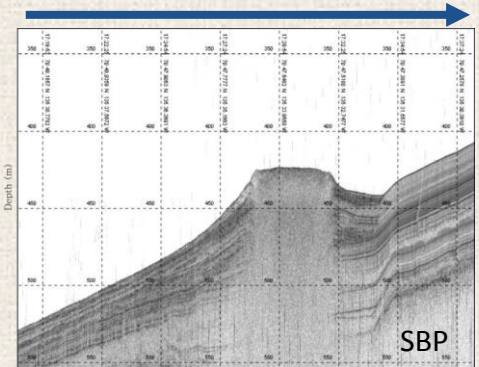


Courtesy of Michael Riedel

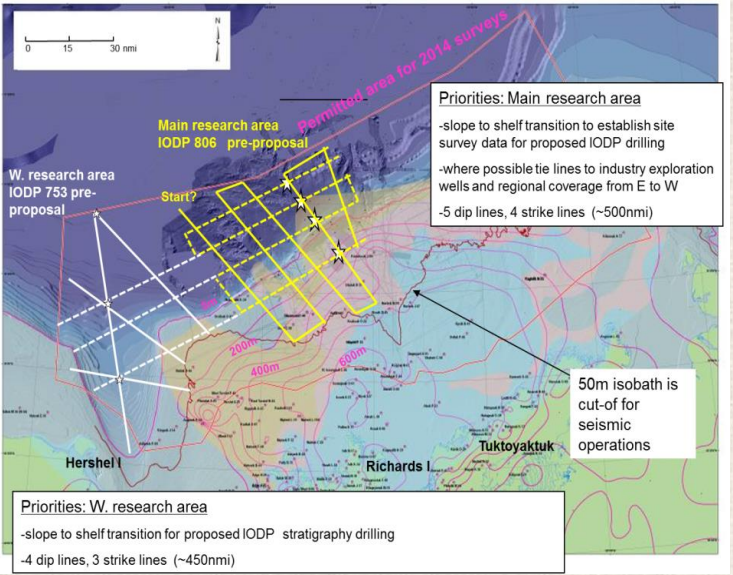
ES



GC



SBP



2013 & 2014 Araon Expeditions #1

Research Proposal to Investigate Degrading Gas Hydrates and Melting Permafroat on the Beaufort Shelf

By: Young Keun Jin[1], Scott Dallimore[2], Charles Paull[3], Timothy Collett[4], and Humfrey Melling[5]

Executive Summary:

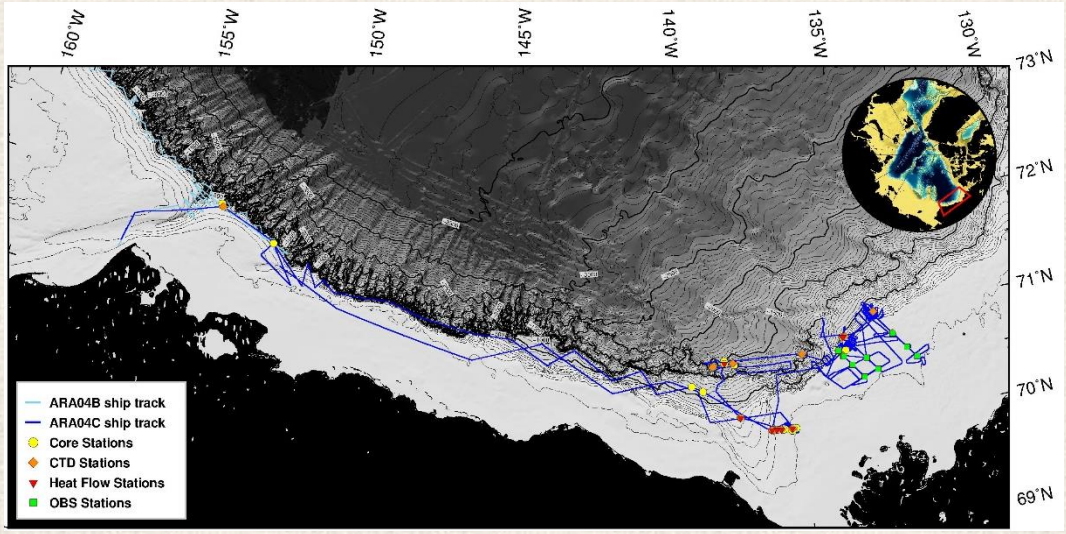
We propose to conduct geological and geophysical investigations of the near sea floor environment of the Beaufort Shelf to establish whether and how methane gas escapes from decomposing permafrost and associated gas hydrates. This area is ideal because: **(1)** significant amounts of decomposing gas hydrates are known to occur in the subsurface, **(2)** the surface sediments in this area are fine-grained enough to permit collection of good sediment cores to enable stratigraphic, biostratigrahic and geochemical studies (which is rare in the Arctic Ocean), and **(3)** gas venting has been documented in association with unique physical features on the sea bed (i.e., active submarine pingos, pock mark fields and permafrost taliks), suggesting there are unique point source conduits for fluid and gas movements from decomposing gas hydrates.

Our strategy is to conduct integrated geophysical, geological, and oceanographic surveys along several cross shelf transects. The location of these transects would be chosen to intersect known sea floor features of interest such as pingo like features and shelf break landslides. Three transects are proposed across the shelf each located with varied Quaternary transgression histories and permafrost properties. This work will be conducted from the Korean icebreaker Araon with a joint scientific team from Korea, Canada and the USA.

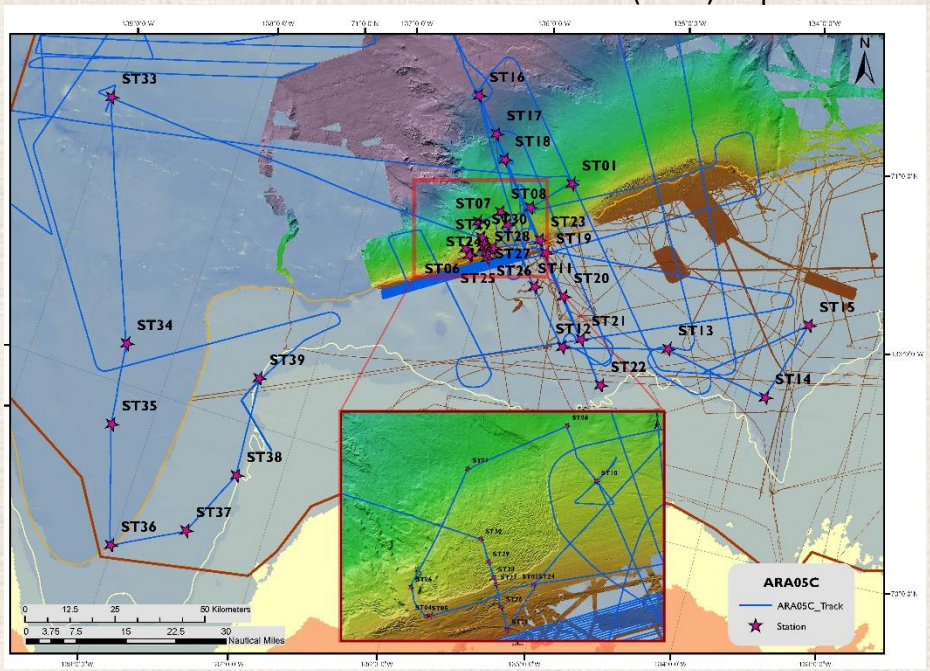
2013 & 2014 Araon Expeditions #2

- Icebreaker RV Araon
  - Class DNV Polar 10
  - 110 m * 19 m * 9.9 m
  - 6950 tons (gross)
  - 25 crews + 60 scientists
- Research Tasks
  - Multi-channel seismic survey
  - Swathy mapping + subbottom profiling
  - Coring (gravity + box)
  - Heat flow
  - Seawater and microbiological sampling
  - CH4 and CO2 sampling from ocean and atmosphere

IBRV Araon



ARA04C (2013) shiptrack and stations



ARA05C (2014) shiptrack and stations

2013 & 2014 Araon Expeditions #3

- Quick photo tour


Helicopter


CPT


MCS (tail buoy and floater)


MCS (airgun array)


MCS (streamer with birds)

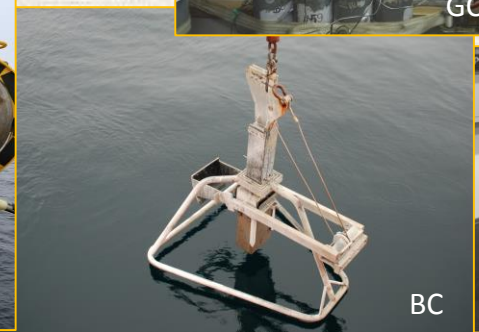

MC


MSCL


GV


CTD with sensors


GC


BC

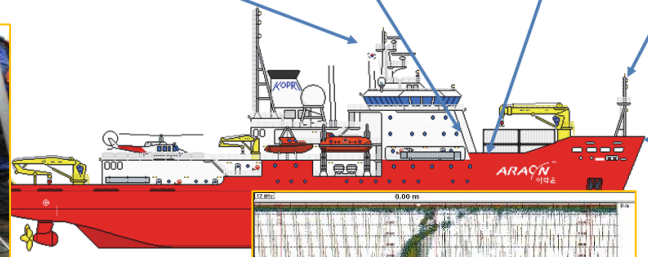
Radarmast (38m)
Short-wave radiometer (PSP)
Long-wave radiometer (PIR)
Temperature & RH (HMP45D)
Pressure sensor (PTB100)
Quantum sensor (LI-200)
Data logger (CR3000)
2D sonic anemometer

Atmospheric Sciences Lab. (03Deck)
CPC
CCN Counter
Aethalometer
HVTDMA
Nephlometer

CRDS Shelter 02Deck (15m, Port)
CRDS (G2301-f)
Data logger (CR3000)
Motion Sensor (MPII)

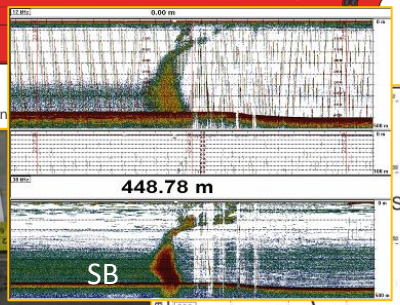
Foremast (29.8m)
Windmill Anemometer (031050-L)

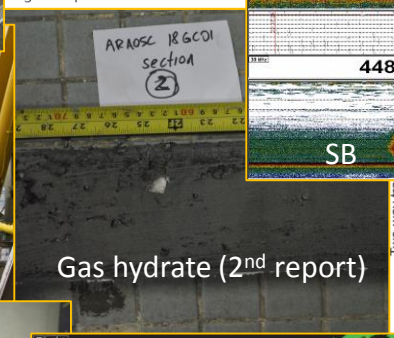
Various atmospheric observation tools



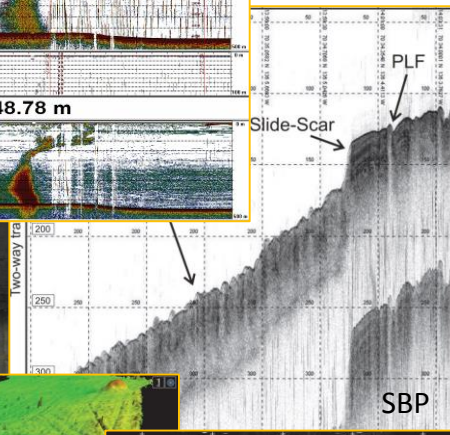
Bow (19m)
Sonic Anemometer (CSAT3)
Infra-red gas analyzer (LI7500)
Motion Sensor (MPII)
Net radiometer (CNR1)
CRDS intake

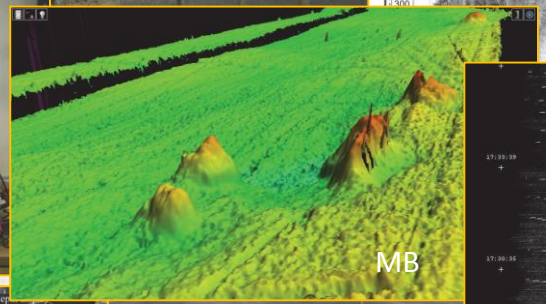
Heights in parenthesis are the distan

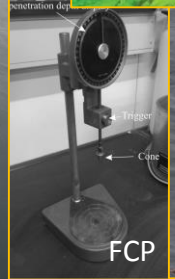




Gas hydrate (2nd report)

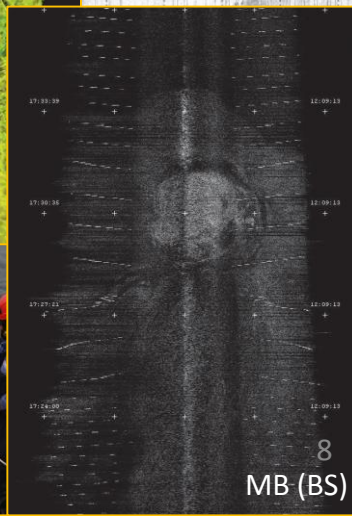



MB



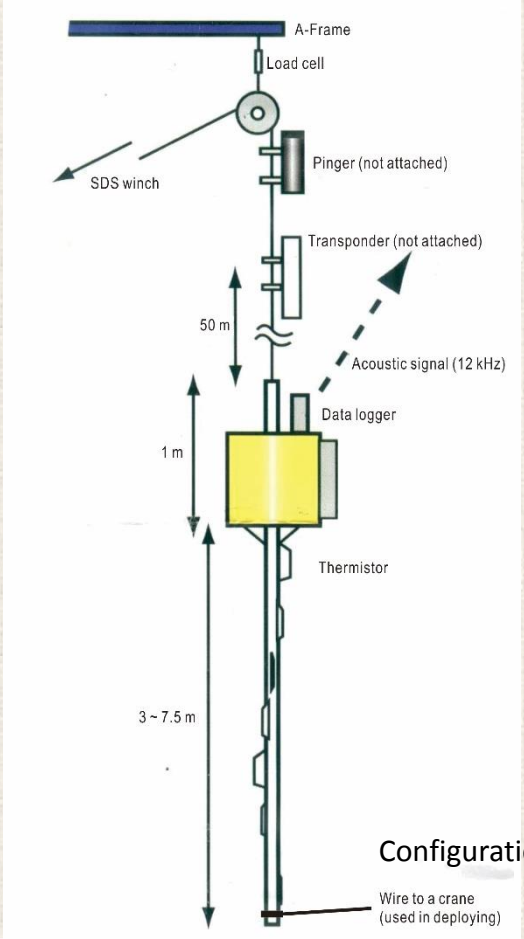
FCP


OBS

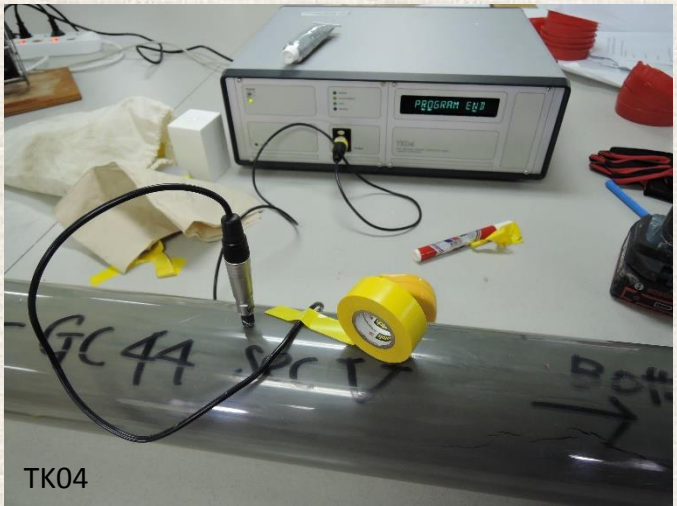

MB (BS)

Marine Heat Flow Measurements #1

- Lister-type heat probe
  - 4.5 m, 700 kg, maximum 8 thermistors
  - Ability of heat generation
  - Acoustic modem, tilt meter, shock sensor, depth sensor
  - At least two penetrations per a station
- TK04 thermal conductivity meter
  - Product of TeKa
  - Needle probe into a sediment core
  - Measurement intervals depending on lithology change



Configuration of HP

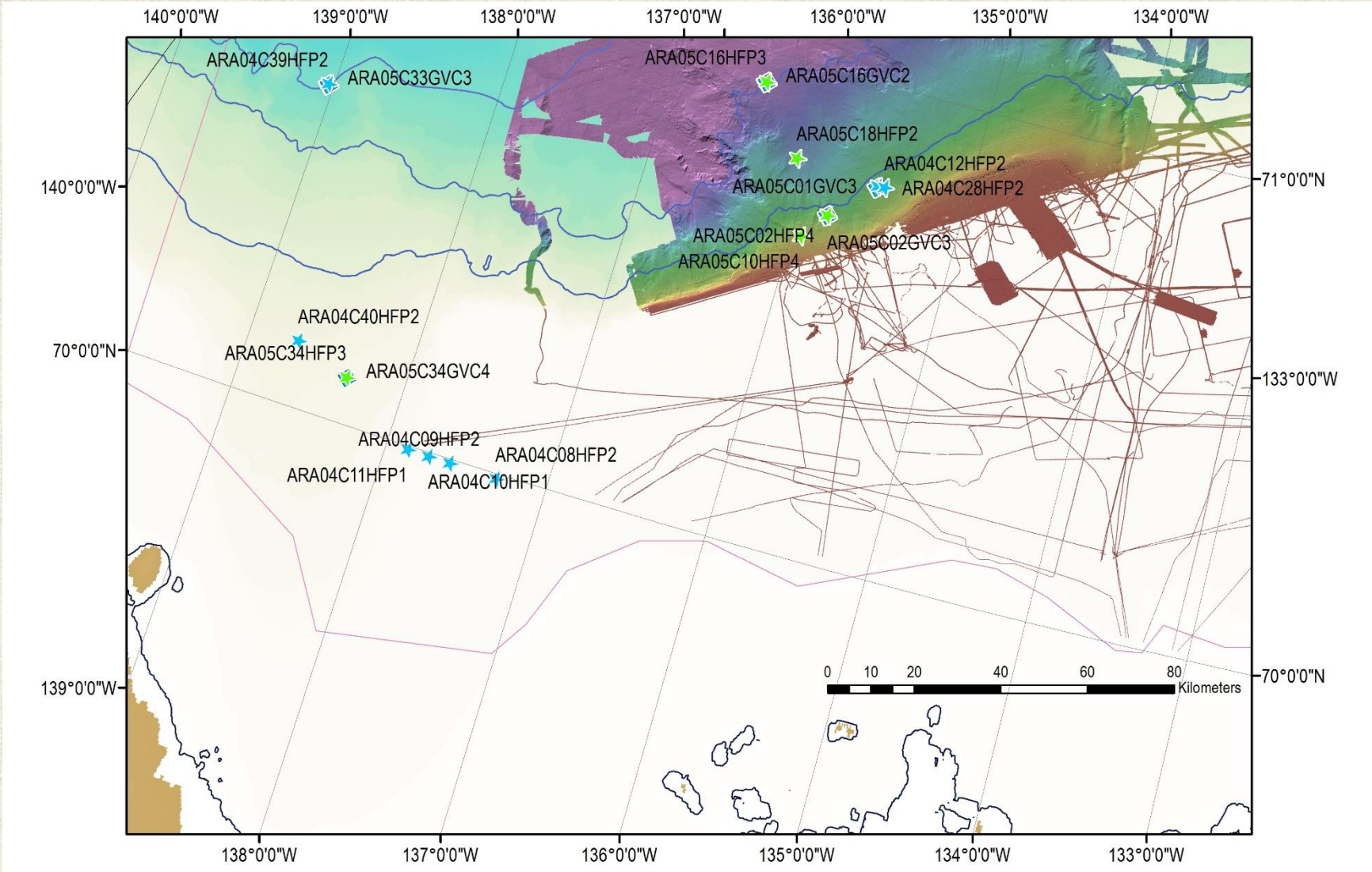


TK04

HP

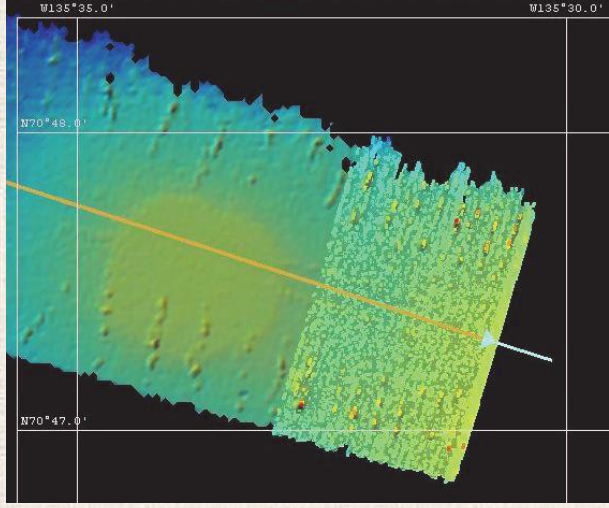
Marine Heat Flow Measurements #2

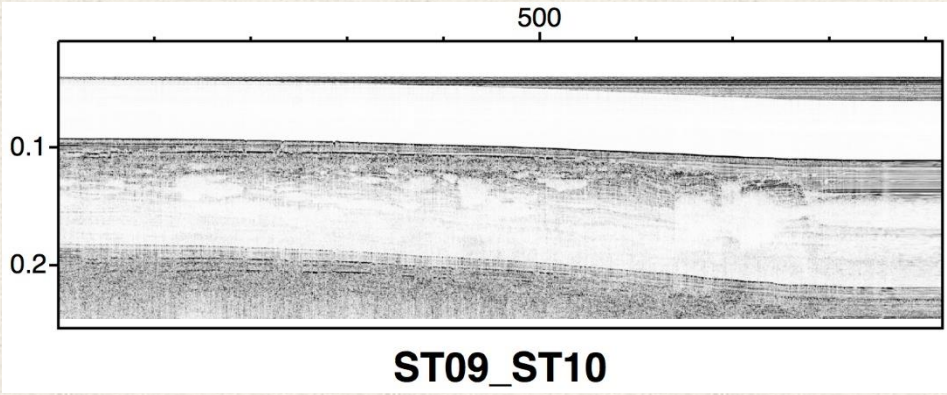
- ARA04C: geothermal gradient (☆)* 8
- ARA05C: geothermal gradient (☆)* 5 + thermal conductivity (□) * 5



Three Thermal Regimes #1

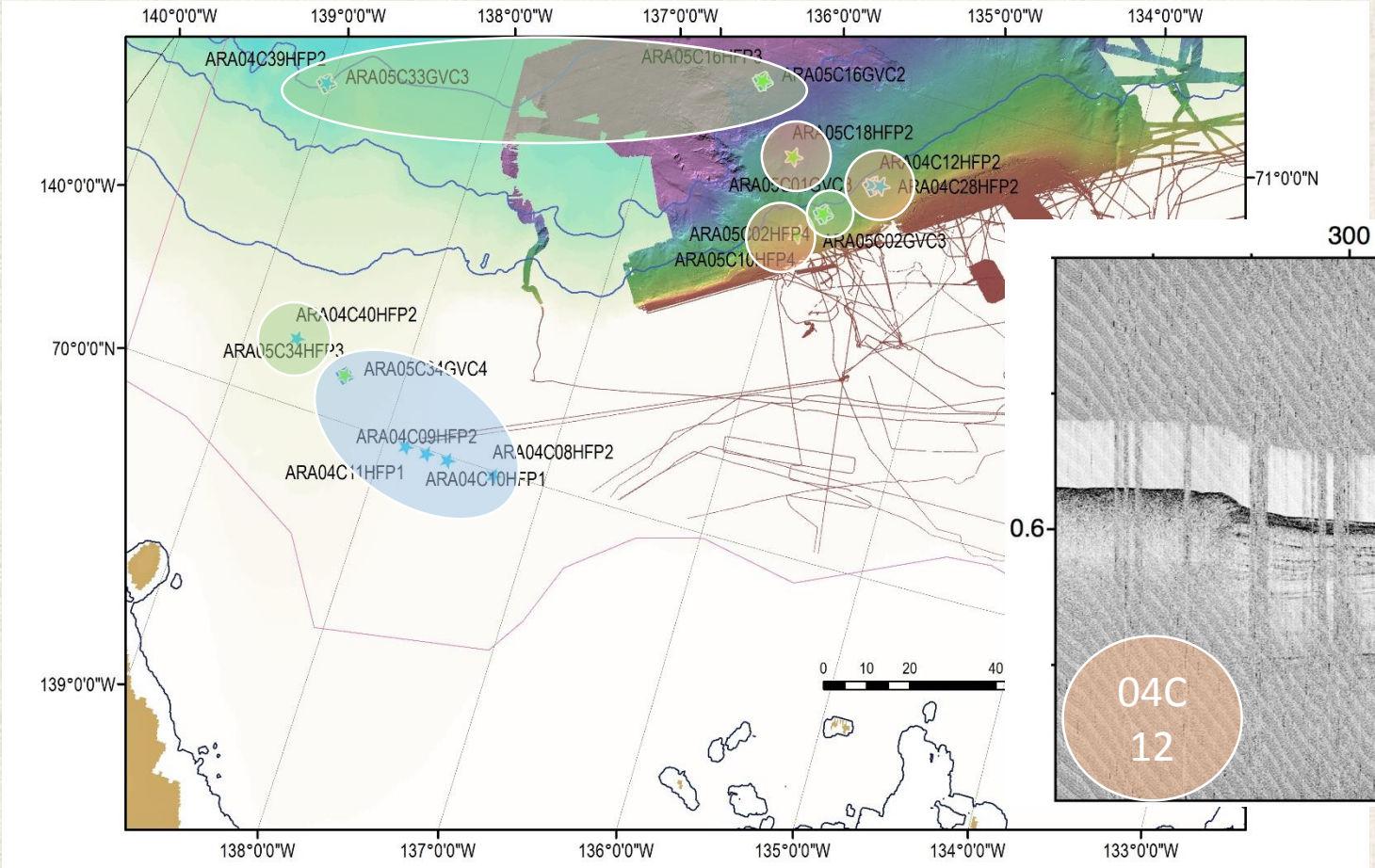
- Criteria
  - Geothermal gradient (GG)
  - Temperature difference at seafloor (TD)
  - Subbottom profile
  - Morphology
- Three thermal regimes
  - Normal seafloor: 42-75 mK/m in GG, 0.1 °C in TD, well-laminated
  - Permafrost below: lower GG, higher TD, ice occurrence
  - Mud volcano: Much higher GG, higher TD, acoustic turbidity below flat top

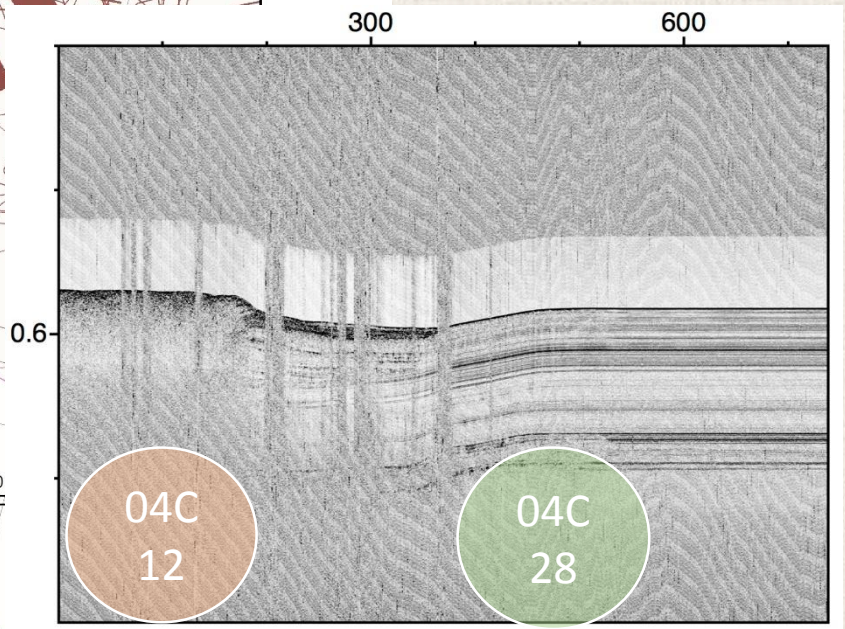




Exp. St.	04C 08	04C 09	04C 10	04C 11	05C 34	04C 40	04C 39	05C 02	05C 16	04C 28	04C 12	05C 10	05C 18
Temp. diff. at seafloor (°C)	0.1	0.2	0.4	0.1	0.5	0.2	0.1	0.1	0.1	0.0	1.4	2.3	0.1
GG (mK/m)	16.8	55.3	-73.9	30.1	22.4	41.5	66.1	75.1	44.3	28.9	557.9	517.7	104.3
WD (m)	59	73	88	129	246	330	1540	410	1016	430	419	278	740
TC (W/m/K)					0.968		1.037	0.995	0.955		0.905		
Thermal Regime	McKenzie Trough; Permafrost below					Normal seafloor				Out of MV	Flat-top mud volcano		

Three Thermal Regimes #2

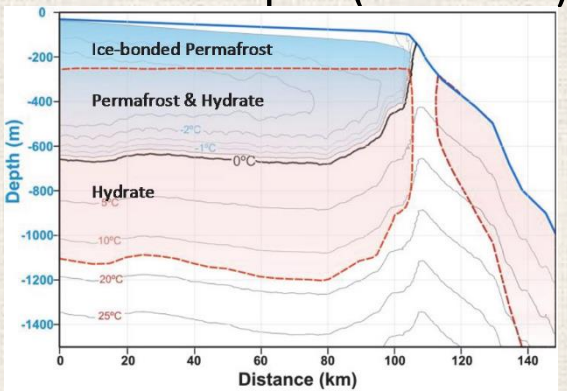


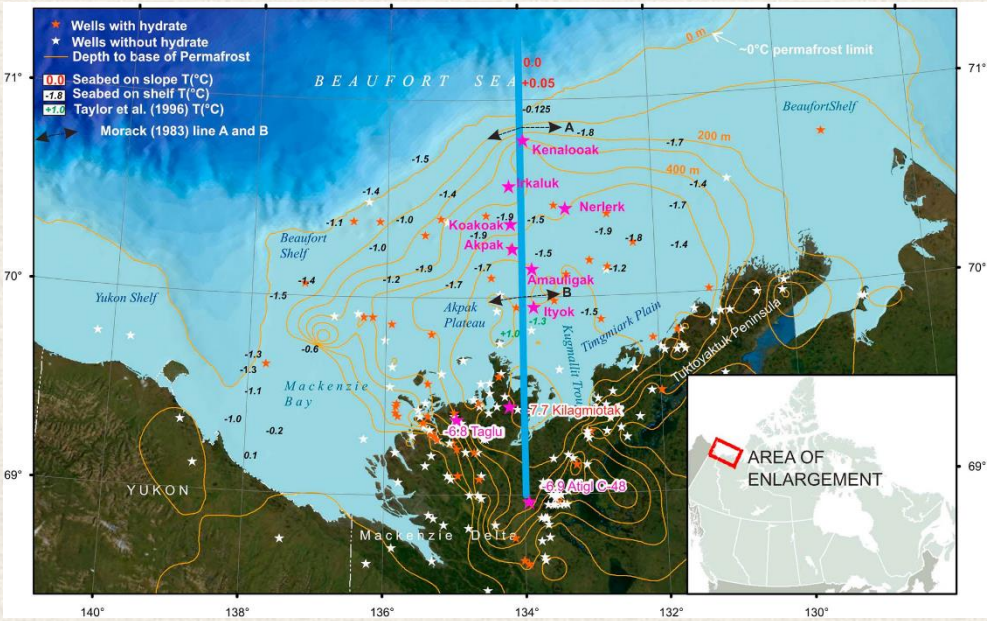


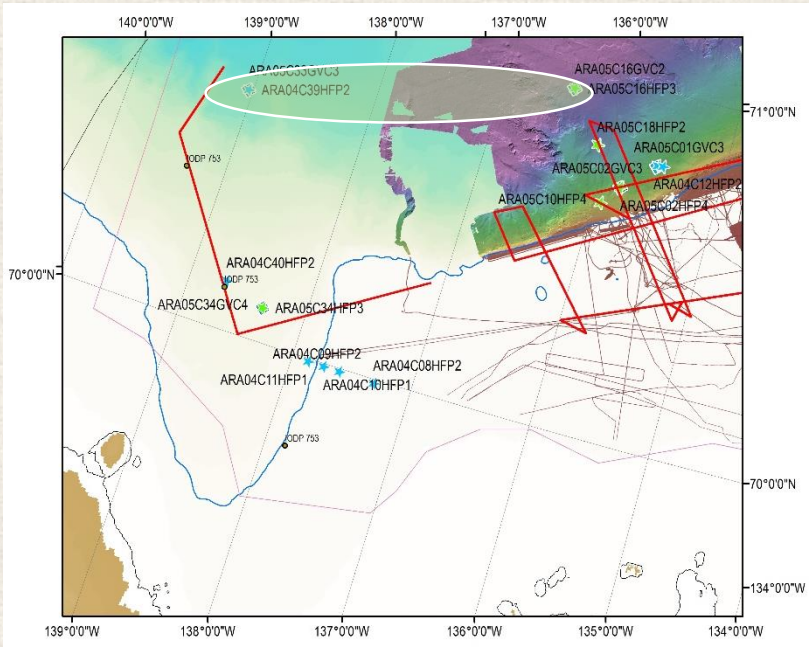
Exp. St.	04C 08	04C 09	04C 10	04C 11	05C 34	04C 40	04C 39	05C 02	05C 16	04C 28	04C 12	05C 10	05C 18
Thermal Regime	McKenzie Trough; Permafrost below					Normal seafloor				Out of MV	Flat-top mud volcano		

Implication of Steady-state Heat Flow Condition

- First report of heat flow in the continental slope and normal seafloor in this region
- Similar heat flow values from deep and shallow sedimentary sections
  - 43-69 mW/m^2 from the normal seafloor in continental slope
  - ~60 mW/m^2 for onshore to 50 mW/m^2 for the outer shelf from deep boreholes (Majorwicz et al., 1996)
- Need to compare BSR-derived heat flow (by industry) at deep water depth (~1500 m)

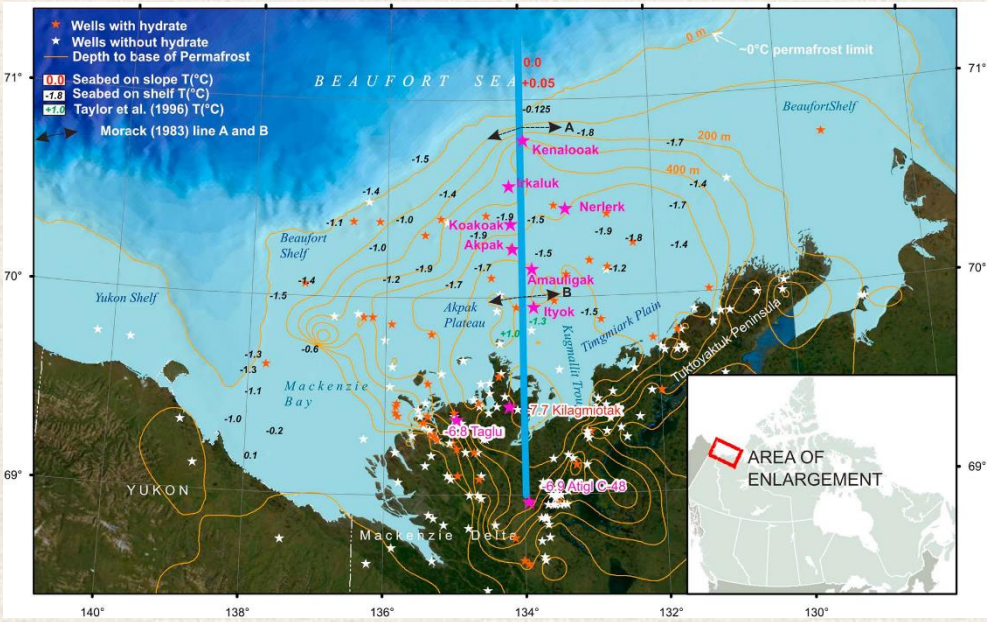


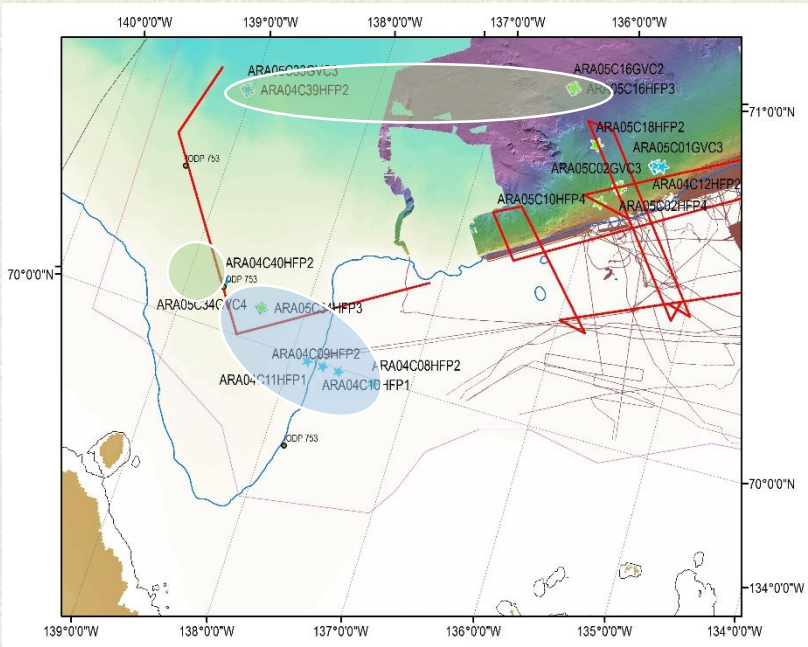




Permafrost Limit, Farther Basinward

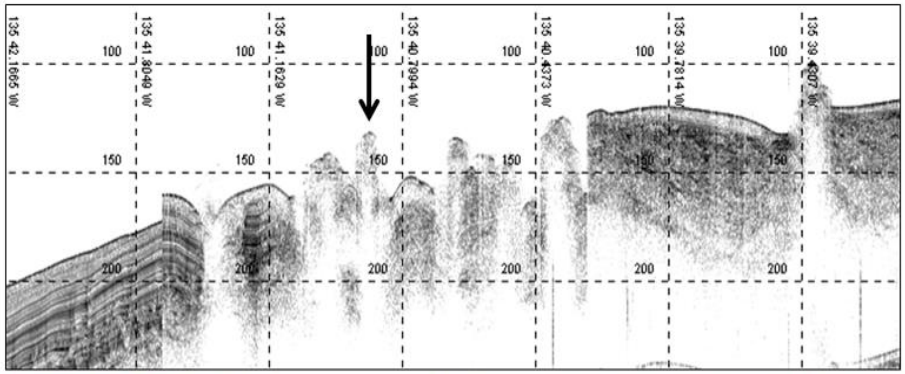
- Permafrost limit appears to be restricted within the continental shelf based on borehole observation (Issler et al., 2011)
- Our observation indicates that permafrost limit reaches farther at least in the McKenzie Trough
- Further analysis of both multi-channel seismic and subbottom profiles obtained during the two expeditions will delineate distribution of permafrost in the continental slope

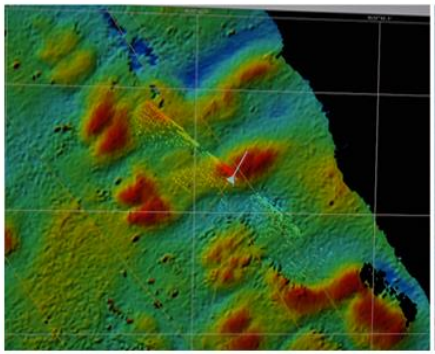




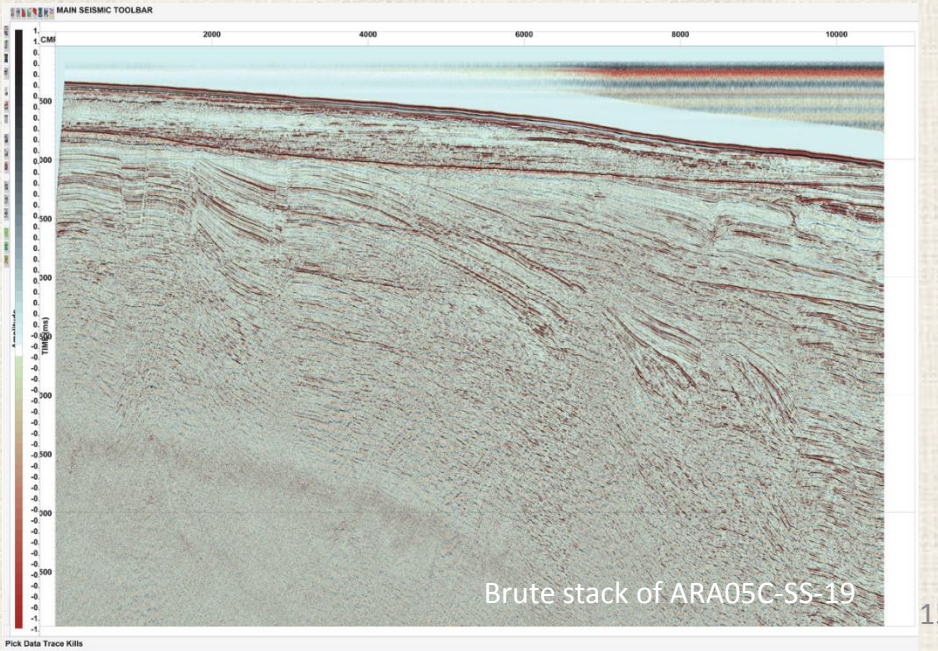
Future Plans

- Limitation of this research
  - Small number and restricted area of heat flow measurements
  - Lack of detailed information on sedimentary structure below the seafloor
  - Assumption of heat conduction
- Expeditions
  - Proposal of the Araon expeditions during 2016-20 to the western Arctic seas including East Siberian, Chuckchi seas as well as Canadian Beaufort Sea (by Young Keun JIN)
  - To understand dynamics of degrading of gas hydrate and permafrost in the western Arctic through multidisciplinary approaches
  - Tentative plan of implementation multi-purposed mooring instruments for long period (> 1 yr)
- Analyses
  - Multi-channel seismic and subbottom profiles to depict distribution of permafrost and BSR
  - Thermal effect modeling due to vertical fluid advection





Ice from Cyan unit at 114 mbsl



Brute stack of ARA05C-SS-19

Summary

- We made marine heat flow measurements at thirteen stations using a heat probe during 2013-14 Araon Expeditions. This was the first attempt to observe the marine heat flow in the continental slope where it is expected that there is no permafrost below the seafloor.
- Three thermal regimes reflecting subsurface geological processes can be identified based on our geophysical observations, in particular subsurficial heat flow measurement results: permafrost area below the seafloor, normal seafloor, and mud volcanos.
- Preliminary heat flow result may support steady-state heat flow condition through sediments, which us allow to estimate the gas hydrate stability zone in the continental slope.
- Subsea permafrost in the McKenzie Trough apparently reaches up to the upper continental slope, implying the possibility where permafrost limit in this region is farther basinward than our expectation.
- Subsurficial heat flow measurement using a heat probe seems to be useful and efficient approach to depict a rough picture of permafrost distribution.
- We need more observations and analyses in this region to tell detailed status and dynamics of subsea permafrost thawing, and to establish/test the subsurficial heat flow approach as a key criteria to distinguish permafrost area.

Thank you for attention! Your input is highly welcomed!

Email: ygkim@kopri.re.kr

Photo by Rhonda Reidy
ARA04C
70°47.4’N 135°33.9’W