Benthic Gouge Marks in the Canadian Beaufort Sea: Associations between whales and methane seeps?

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ABSTRACT

Numerous distinctive depressions of unknown origin were observed on the seafloor during remotely operated vehicle (ROV) dives to sites in the Canadian Beaufort Sea. The video footage recorded by the ROV during dives was later analyzed to document depression characteristics and determine their origin. ROV lasers were used to estimate the width, length, and depth of the depressions. Depressions observed at potential methane seep-sites were tallied and compared to those seen at sites not suspected of seeping gas. Water depths of depression estimates were calculated by averaging ROV dive data. Recorded ship coordinates were used to estimate total area of seafloor observed by the ROV. Finally, literature was reviewed to see if similar findings had been documented before. Most of the depressions had an oval-shaped appearance with raised ridged edges that extended laterally along the flanks. The depressions measured between 10-50 cm across, up to 20 cm deep, and between .5-1.5 m long. All of the depressions were within 800m water depth, with most being within 100 m depth. Depressions were also found 2.25 times more often at suspected methane seep-sites when normalized for depth and area. Similar depressions have been called “gouge marks” and attributed to bottom feeding whales. Depression width and water depths matched well with the beak size and feeding depth of *Delphinapterus leucas,* the Beluga Whale.

Further research is needed to positively determine if whales are preferentially foraging around methane seep-sites.

INTRODUCTION

1.0 Geohazards in the Canadian Beaufort Sea

The Canadian Beaufort Sea lies in the Arctic Ocean and covers a 50,000 Km^2 area. This area has been a popular site for oil and gas exploration since the 1970's, due to the high abundance of natural resources that lie underneath the seabed (Blasco et. al, 2010). The Geologic Survey of Canada has been conducting surveys since 1969, looking for possible geohazards to future structures that may be placed on the seafloor. There are many features in the Canadian Beaufort Sea that have been previously cited as being a geohazards, and we have recently discovered another possible mechanism that may need to be accounted for during future exploration in this area.

Ice scours have been stored in a database by The Geological Survey of Canada since 1978. The marks are created by the contact of sea-ice with the seabed, forming long or multi-keeled striations on the seabed. Documented scours have a mean depression depth of 5.5m and measure around 2m wide. Most of the scours are found in 5m to 30m water depths. As of 2010, 17,000 ice scours have been documented (Blasco et. al 2010). The threat of ice scouring is prevalent in the Canadian Beaufort Sea, and it stands as a process that has major impacts on the morphology of the seafloor. Large scale scouring of the seafloor erases previous geomorphologic features on the seabed in the Canadian Beaufort Sea. This process will be reviewed again later in the paper when discussing other morphologic features seen on the seabed in the Canadian Beaufort Sea.

Pockmarks and Pingo-like features (PLFs) are commonly found around sites where exploration efforts take place. Pockmarks are circular shaped depressions that form by the venting of a fluid from the seafloor. (Blasco et. al, 2010). Venting gas represents high-pressure conditions that must be present below the seabed. The forces that are causing the fluid to escape are also making the seabed itself unstable. Unstable conditions in the seabed are of high interest to surveyors who want to document geohazards. Pingo-like features are circular mounds that also form by the venting of a fluid into the water column. As the fluid escapes, it carries with it sediment from the seabed and displaces it around the venting site (Paull et. al 2007). Over time, this build up becomes great enough to form a mound. Large mounds formed in this way are commonly called mud volcanoes.

1.1 Geologic Setting

The Mackenzie River is the main channel that transports sediment into the Canadian Beaufort Sea, bringing in $1.5 * 10^8$ tons of fine-grained sediment per year (Hill et. al 1991). Sediment transport from smaller rivers, and the erosion of coastal plains, also contribute to the processes that work to overly the seabed with sediment. In the shallow areas around the shelf, ice-bearing permafrost sometimes bonds with the sediment, creating topographically rough seafloor (Blasco et. al, 2010). Permafrost develops deeper in the shelf, usually under thin silt layers that appear as you move westward throughout the Canadian Beaufort Sea and into the Mackenzie Bay.

Gas hydrates are ice-like substances that are composed of water and natural gas. They form in geologic environments under high pressure and low temperature conditions. Well log data taken during previous exploration efforts infers that gas hydrates are present in the Canadian Beaufort Sea (Blasco et. al 2010). No actual strata bearing gas hydrates have been collected from the Beaufort shelf edge, and little is known about the occurrence of gas hydrates on the Beaufort slope. Ongoing research is being conducted to determine the feasibility of extracting the natural gas from the hydrates.

1.2 Diving to the Beaufort Sea Shelf Edge and Slope

Multi-beam bathymetric mapping surveys were started in 2009 in an effort to provide the first detailed bathymetry for a section of the shelf edge and upper slope of the Canadian Beaufort Sea. Large circular morphologic features were observed in the data, with the most prominent ones being observed at water depths of ~282 m, ~420 m, ~740 m (*Paull et. al 2014). The identification of water column acoustic anomalies over these sites indicated that they are sites of active gas venting. This led to the interpretation that these sites were actually large mud volcanoes (Blasco et al, 2013; Saint-Ange et al., 2014). Observations made by remotely operated vehicles (ROVs) would later confirm that these were indeed mud volcanoes.

The Monterey Bay Aquarium Research Institute (MBARI) led 2010, 2012, and 2013 ROV dives to sites on the shelf edge on upper slope of the Canadian Beaufort Sea. These sites were chosen to investigate potential methane venting sites and to collect sediment cores. The ROVs were equipped with HD cameras that were used to record video footage of the seafloor. Parallel lasers were also equipped on the ROV used in the 2012 and 2013 dives. These lasers were fixed 8cm apart. Sites identified to be actively seeping methane, inferred by the detection of the water column acoustic anomalies, were visited to collect gas samples. The samples were later analyzed in labs after returning to shore. Scientists were able to confirm that indeed the identified sites were seeping methane.

While searching for methane sites and places to collect stratigraphic samples, the ROVs recorded something unusual. Seafloor depressions of similar characteristics were repeatedly seen on the seafloor (figure 1). Initial observation pointed to an origin of either ship nets or geophysical survey instruments marking up the seafloor. Due to the natural resources found in the Canadian Beaufort Sea, it would not be unusual for oil and gas companies to have explored this area before. However, research in the Canadian Beaufort Sea is difficult due to the harsh weather conditions, and most of the exploration efforts stopped in the late 1970's. Thus, previous thoughts on possible sources of the depressions did not face scrutiny. For this project, the ROV video footage recorded by the ROV during dives was reanalyzed in an effort to try and determine the origin of the seafloor depressions.

MATERIALS AND METHODS

2.0 Identifying depressions

Seafloor depressions were identified as being distinct gouges in otherwise flat seafloor. Figure 8(a) shows a seafloor depression seen in turbid water. Observed depressions were documented and stored in a MBARI video reference database. Depressions with similar physical characteristics were tallied and grouped together for later analysis. Some of the depressions were seen in permafrost areas. Others were seen on top pockmarks or mud volcanoes. Both of these features create natural seafloor depressions that could easily be misinterpreted as being created by an outside source. Due to this, depression environment observations were made and accounted for when documenting depressions. Depressions seen around permafrost or pockmark areas were heavily scrutinized before being stored in the database.

2.1 Measuring physical depression characteristics

The ROV used in the 2010 dives did not have lasers attached to it for measuring of benthic features. Depression dimension measurements were taken by using the 8-cm spacing between the lasers attached to the ROV used in the 2011 and 2012 dives. This allowed for estimation of each documented depression's width, length, and depth. Because seafloor depressions were not features initially looked for when doing the surveys, it was difficult at times to make precise measurements. The ROV would usually disregard a seafloor depression when in route to a mission site. This led to laser positioning that was not always directly a range of possible values was taken for each depression and refined using statistical methods.

Maximum and minimum depression measurements were averaged to determine a precise data point. To deal with variations in the data, 30 of the documented depressions were randomly selected when determining the true mean width, length, and depth of the depressions. Documented depressions that measured outside of two standard deviations from the mean were discounted and presumed to be created by an uncommon mechanism. This allowed us to make a strong case for one particular mechanism for the creation of most of the observed seafloor depressions.

2.2: Ship navigation data to determine depth and seafloor observed

None of the ROVs used during the dives were equipped with GPS. Ship navigation data collected during the surveys was used to estimate depression locations. Line transects were connected using the software ArcGIS and used to determine the amount of seafloor that was covered by the ROV during dives. A line of best fit was placed between points that existed along a path of low curvature (figure 2). Adding up the line segments allowed for the estimation of the distance the ROVs covered on the seafloor during dives. We determined that, on average, the ROVs could observe a 4m swath. This figure was multiplied by the dive transects to determine the area of seafloor observed by the ROVs during dives.

Knowing the ship's position during dives allowed us to determine a radius in which ROVs were located. The ROVs were tethered, and thus forced to be within a radius of where the ship was. The ROVs are estimated to be located within +-50m of the ship at all times. ROV depth locations were determined by analyzing data taken by the ship crew. The ROVs were equipped with a pressure gauge that allowed for determination of the water depths they entered. Ship crew estimated the ROVs dive depth when it reached the bottom of the seabed, and also the depth at which the ROV was at when it was pulled from the bottom of the seabed. This data was used to determine the depths at which the documented depressions were located.

2.3: Depressions at different bottom types

Not all dives were taken to sites suspected of seeping gas. Some dives were taken to sites simply to collect stratigraphic samples. The ROVs used on all dives were equipped with a mechanical arm. Sediment samples were taken by using a push core, a cylinder manipulated by the ROVs mechanical arm. Pushing the cylinder into the seabed allows soft sediment to be trapped into the container. The samples were collected and later analyzed in labs. Push core analysis, along with methane vent site analysis, were used to understand the geology of the region.

Sites visited solely to collect stratigraphic samples had no suspected presence of methane gas. Other sites were visited to determine if gas was expulsing from the seafloor. These sites were identified by the detection of water column acoustic anomalies in the sonar of surveying ships. To determine if the documented depressions had a relationship with seeping gas, comparisons were made between depressions frequencies at stratigraphic sampling sites against those identified at gas expulsion sites. Normalizing the depressions found at each site per unit area helped to determine if there was a relationship with seeping methane. This was done by comparing different depression sites at similar depths (within 20m) and extrapolating to number of depressions found per kilometer squared.

RESULTS

3.0 Documented Depressions

186 depressions were documented in total. The depressions were found in turbid water, around both permafrost and chemosynthetic communities, and on tops of sites identified as being mud volcanoes (Paull et. al). Of the 186 depressions documented, 152 shared common features. Similar oval-shaped depressions were seen and were most easily identifiable on tops of mud volcanoes and in clear (not turbid) water. These depressions

were sometimes found in close proximity to traces of newly exposed sediment, as evident by the dark, un-oxidized composition of the sediment (citation here). Distinct ridged edges that extended laterally along the flanks of the depressions were also common features. Displaced sediment could be seen (figure 2(a)) in mounds around some of the depressions.

3.1 Depression width, length, and depth measurements

Accurate measurements could only be made for 74 of the documented depressions. The ROVs had lasers pointed directly in the depressions for most of these measurements. The lasers were pointed close enough to the depressions to make the remaining measurements without losing too much accuracy. The depressions measured between 10-50 cm wide, up to 20 cm deep, and between .5-1.5 m long.

3.2 ROV dive depths found of the depressions

The ROVs dive to sites up to 900m depth. Only 3 depressions were observed at these extreme depths. The depressions here were compared to the other depressions seen elsewhere and looked at for some things that need to be known.

DISCUSSION (Heading 3, Times New Roman, 12 pt, bold)

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CONCLUSIONS/RECOMMENDATIONS (Heading 3, Times New Roman, 12 pt, bold)

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ACKNOWLEDGEMENTS (Normal, Times New Roman, 12 pt, bold)

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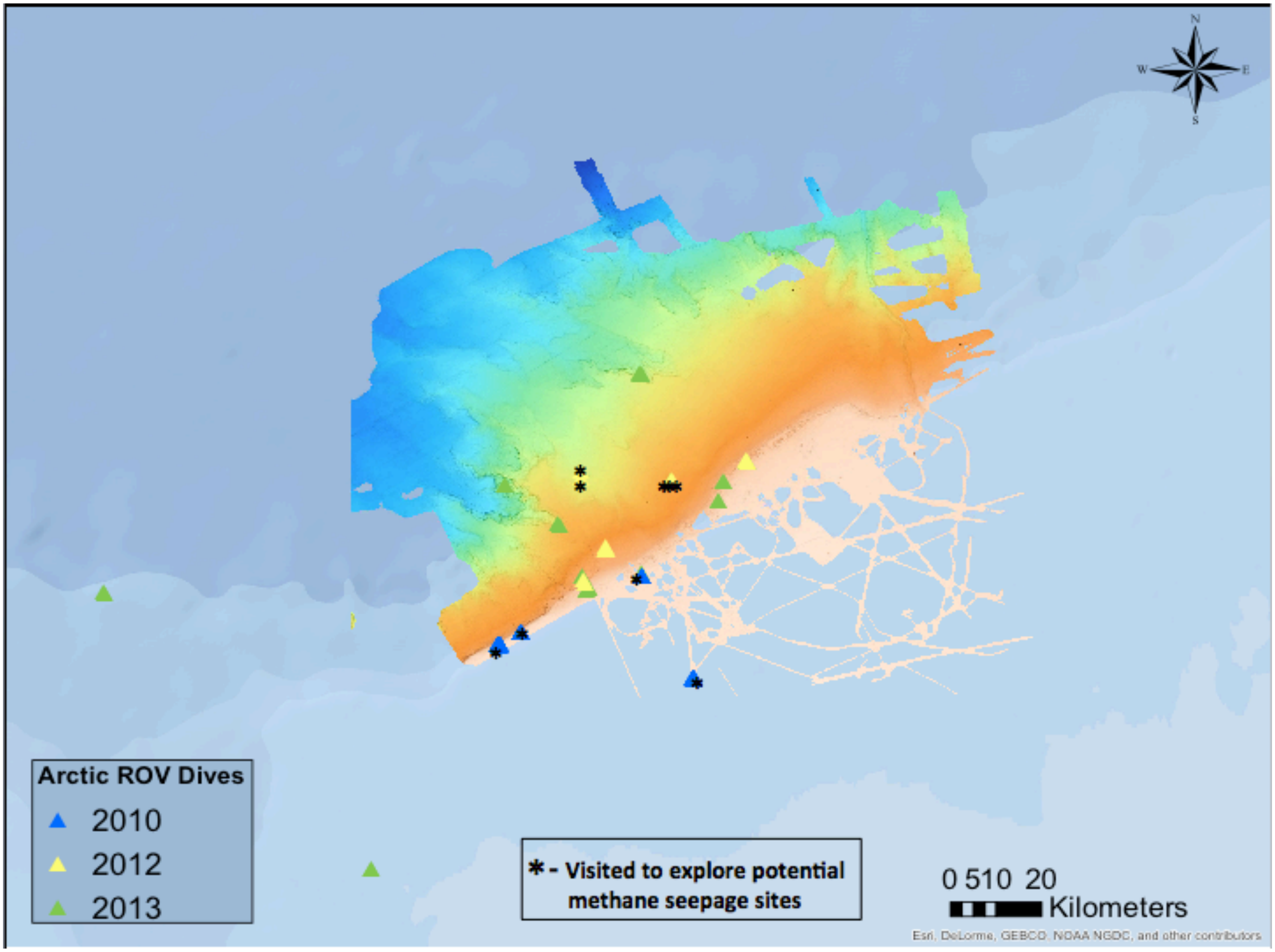
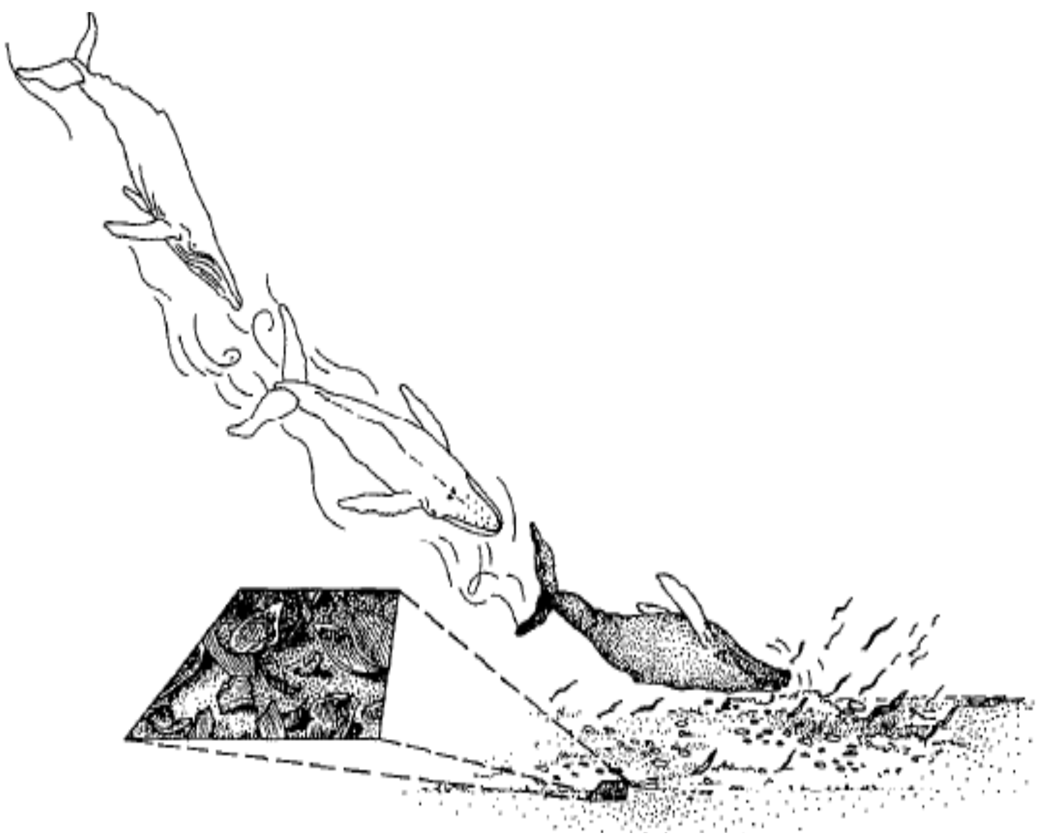
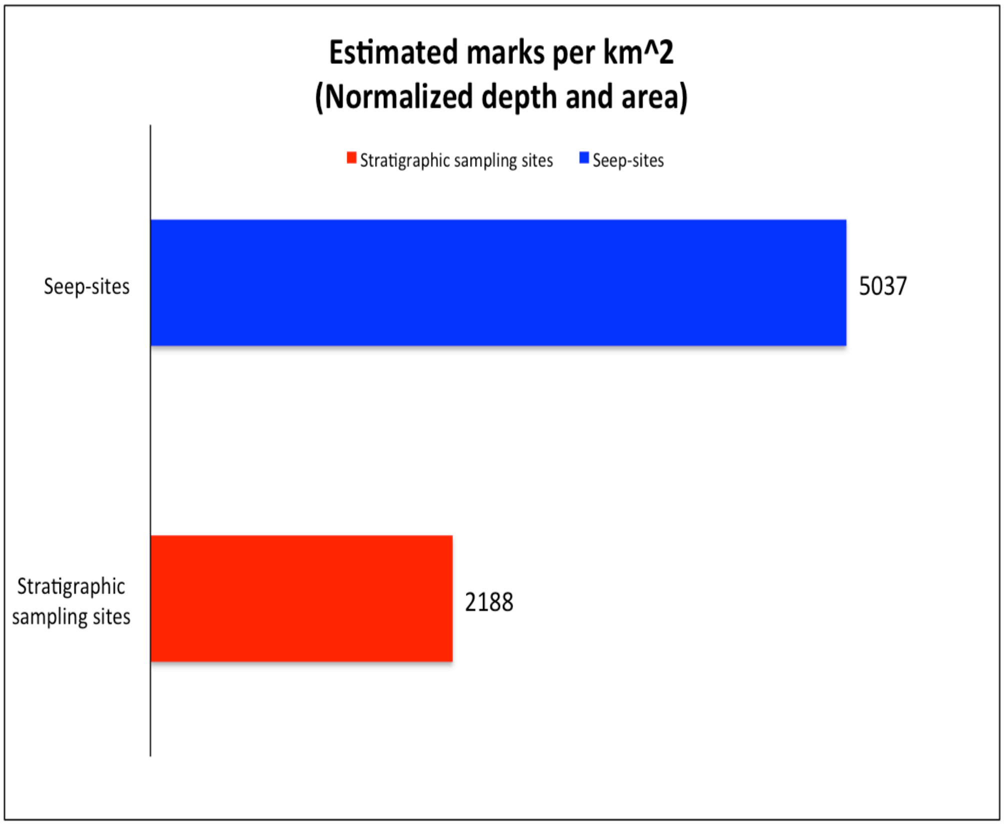
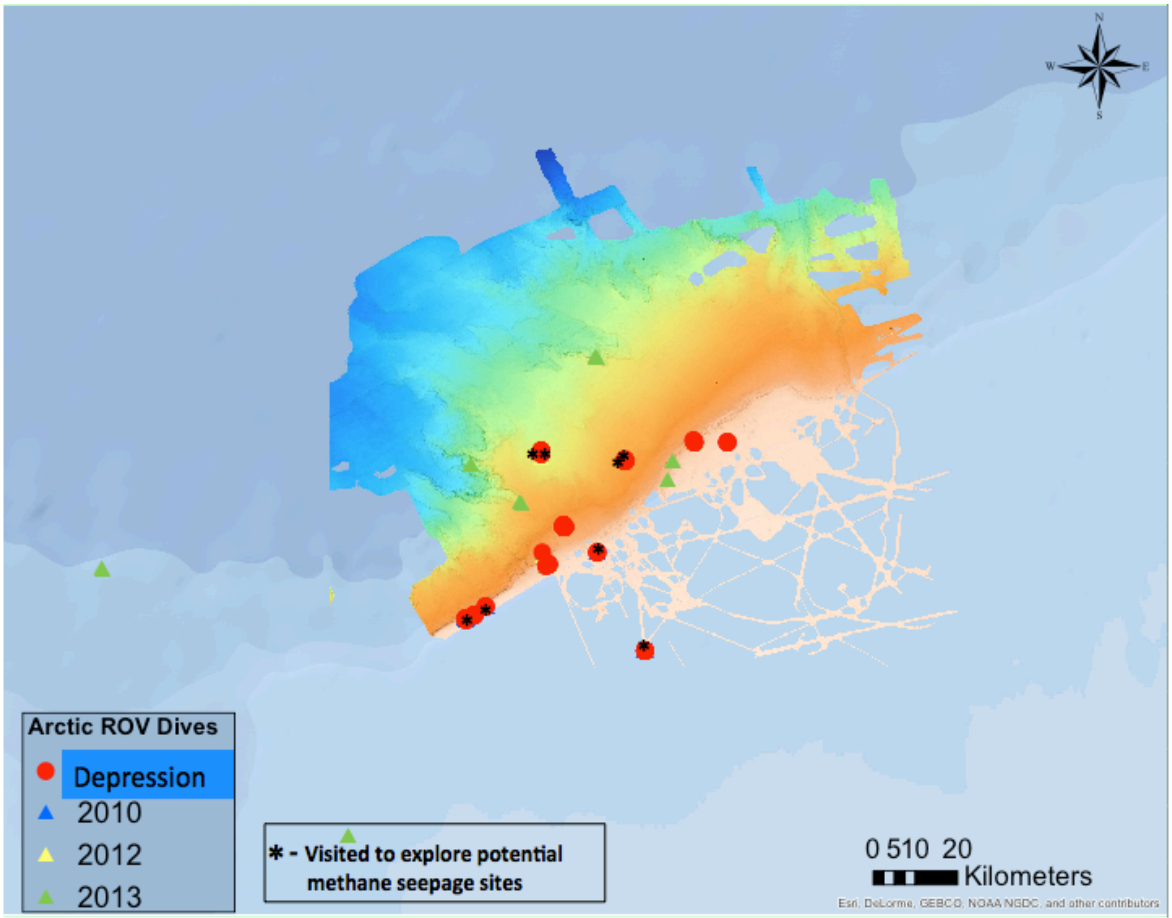


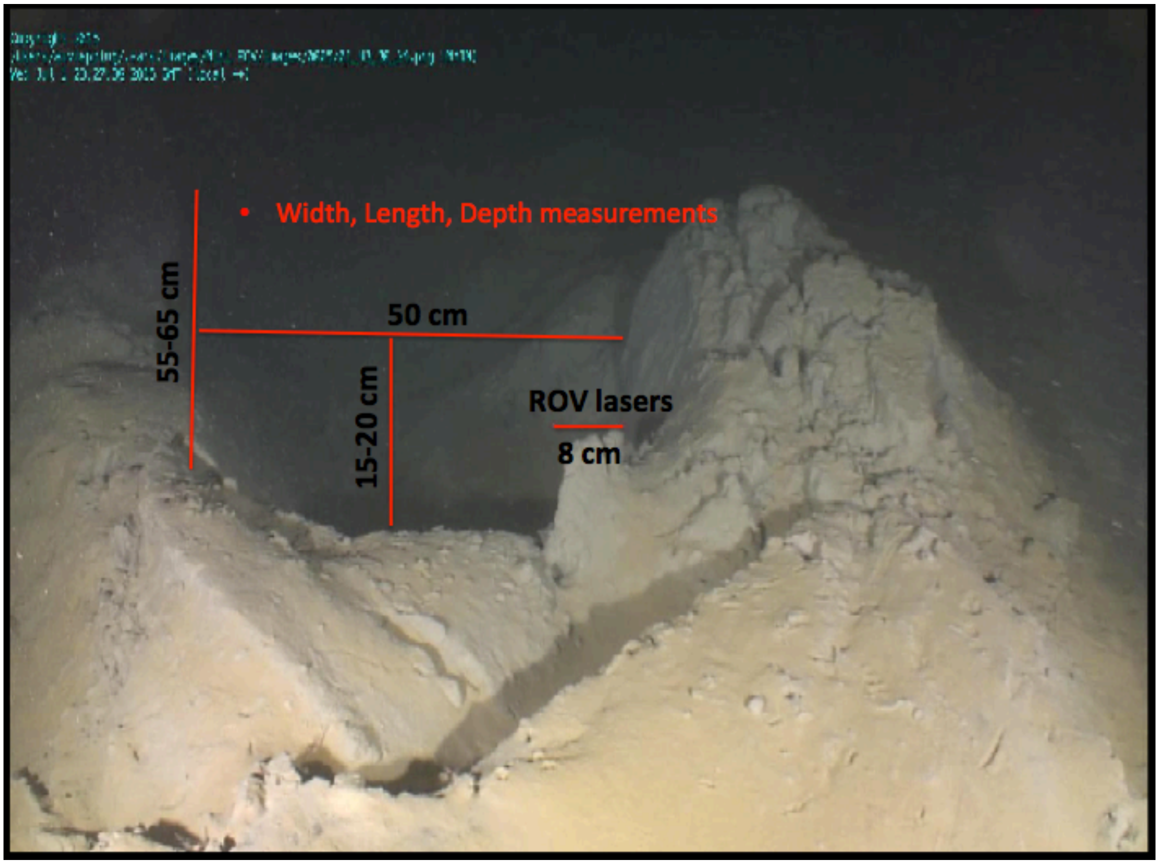
Figure 1:

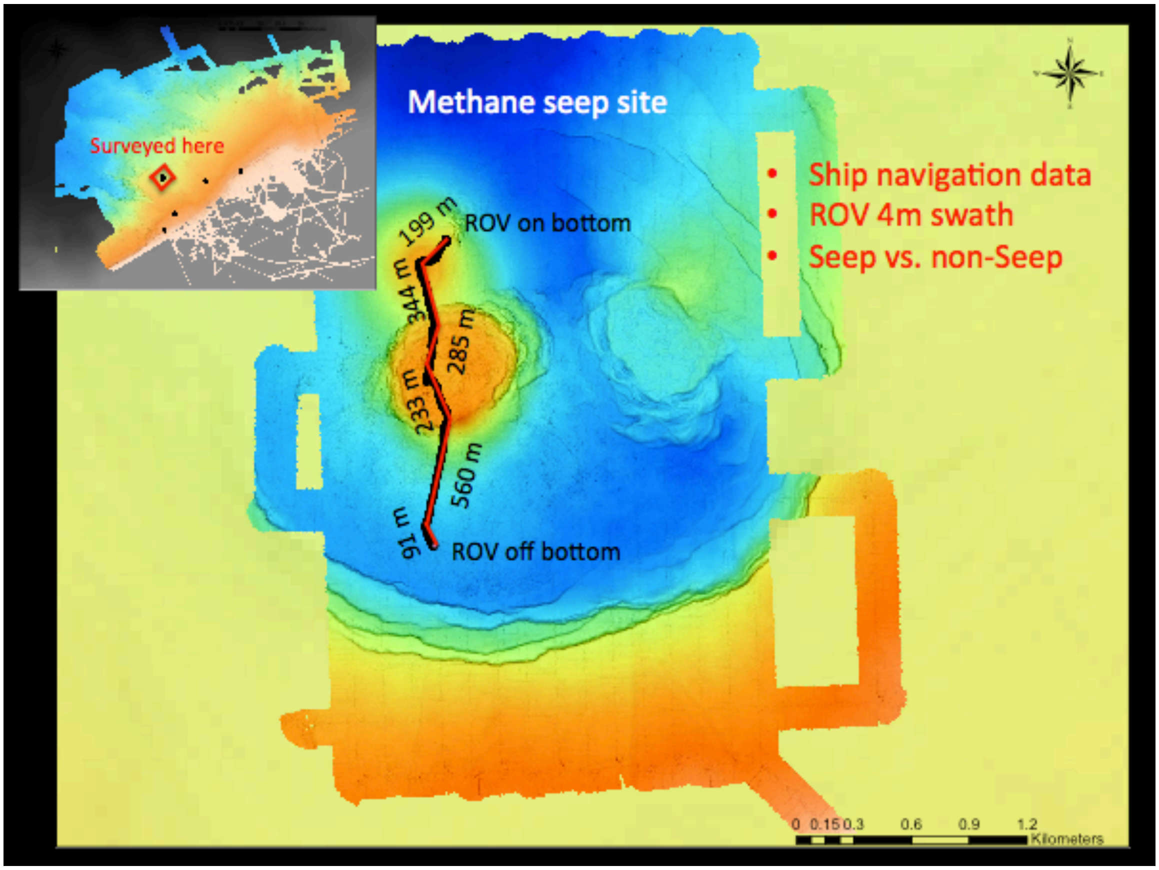
Multi-beam bathymetric map created by Canadian surveyors in 2009-2010. This map was created to provide the first detailed bathymetry for a 100km long section of the Beaufort Sea Shelf Edge and Slope (Paull et. al 2013). The warmer colors indicate sites closer to sea level. Depth to seafloor increases as the color gradient moves closer to the cooler colors. The sites visited by the ROVs deployed by the Monterey Bay Aquarium Research Institute in 2010, 2012, and 2013 are indicated by triangles. A black asterisk is placed above specific sites thought to be actively seeping methane gas.

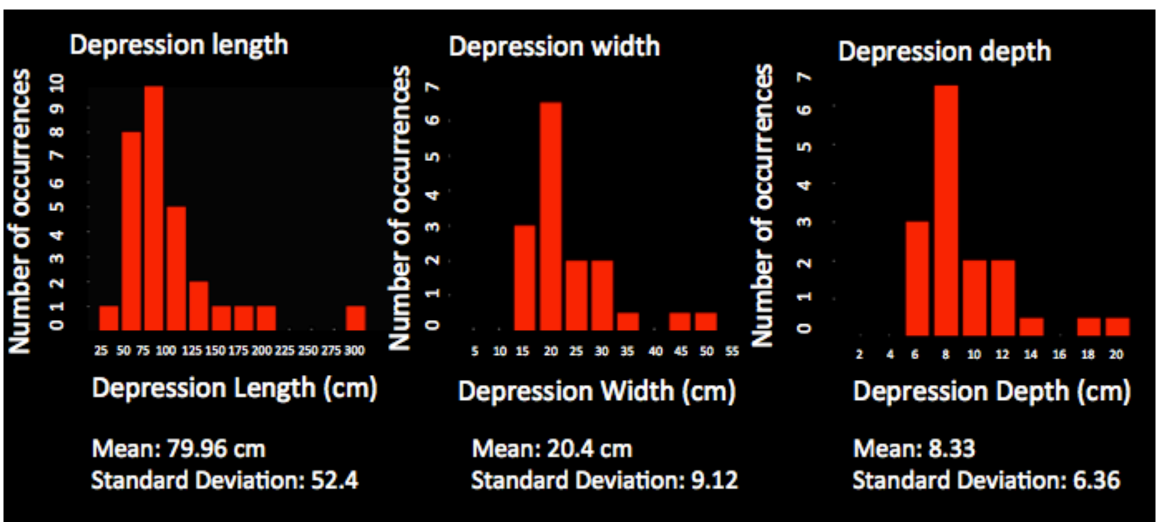


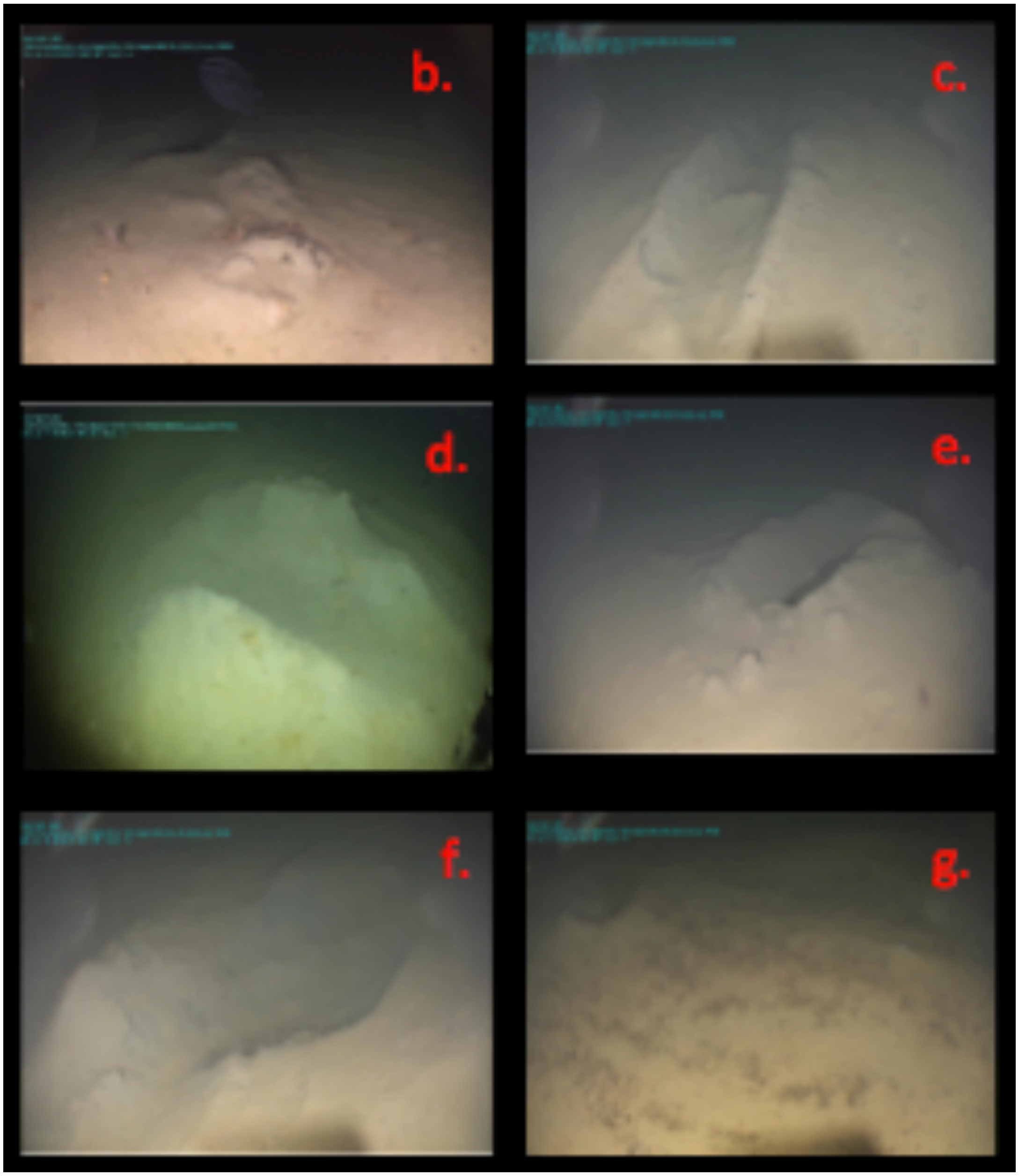

Estimated marks per km^2
(Normalized depth and area)
Stratigraphic sampling sites
Seep-sites
Seep-sites
5037
Stratigraphic
sampling sites
2188


Arctic ROV Dives
Depression
2010
2012
2013
✱ - Visited to explore potential
methane seepage sites
0 5 10 20
Kilometers
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


• Width, Length, Depth measurements
55-65 cm
50 cm
15-20 cm
ROV lasers
8 cm


Methane seep site
Surveyed here
Ship navigation data
ROV 4m swath
Seep vs. non-Seep
ROV on bottom
199 m
344 m
285 m
233 m
560 m
91 m
ROV off bottom
0 0.15 0.3 0.6 0.9 1.2
Kilometers


Depression length
Number of occurrences
Depression Length (cm)
Mean: 79.96 cm
Standard Deviation: 52.4
Depression width
Number of occurrences
Depression Width (cm)
Mean: 20.4 cm
Standard Deviation: 9.12
Depression depth
Number of occurrences
Depression Depth (cm)
Mean: 8.33
Standard Deviation: 6.36


b.
c.
d.
e.
f.
g.