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GEOLOGICAL SURVEY OF CANADA
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CCGS Hudson Expedition 2018042 GEM-2 Baffin marine survey activity report with preliminary results

C.D. Jauer

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Publications in this series have not been edited; they are released as submitted by the author.

Foreword

The Geo-mapping for Energy and Minerals (GEM) program is laying the foundation for sustainable economic development in the North. The Program provides modern public geoscience that will set the stage for long-term decision making related to responsible land-use and resource development. Geoscience knowledge produced by GEM supports evidence-based exploration for new energy and mineral resources and enables northern communities to make informed decisions about their land, economy and society. Building upon the success of its first five-years, GEM has been renewed until 2020 to continue producing new, publically available, regional-scale geoscience knowledge in Canada's North. During the 2018 field season, research scientists from the GEM program successfully carried out 18 research activities, 17 of which will produce an activity report and 14 of which included fieldwork. Each activity included geological, geochemical and geophysical surveying. These activities have been undertaken in collaboration with provincial and territorial governments, Northerners and their institutions, academia and the private sector. GEM will continue to work with these key partners as the program advances.

Introduction

The presence of offshore petroleum in the eastern Canadian Arctic has been broadly studied for over forty years, starting with research into studies of seafloor oil seepage off Scott Inlet, Baffin Island indicated by oil slicks on the surface of the ocean (Loncarevic and Falconer, 1977). Subsequent studies have found petroleum in shallow seafloor rock drill cores from the Davis Strait area (MacLean and Srivastava, 1981) and seafloor pock marks typically associated with gas seepage have been identified via seismic mapping off Cape Chidley (Fader, 1991). Recently the use of synthetic aperture radar aboard the Radarsat 1 & 2 satellites has been studied in detail to map persistent areas of reduced radar reflectivity on the ocean's surface that are interpreted as oil slicks. These oil slick features, when mapped over long periods of time in the same location and filtered for weather effects, are interpreted as originating from seafloor oil seepages (Jauer and Budkewitsch, 2010).

Investigation into the validity of these oil slick sites offshore eastern Baffin Island is the primary purpose of the Baffin Marine Survey component of the Geo-mapping for Energy and Minerals (GEM-2) program science cruise for 2018. The Geological Survey of Canada (Atlantic) (GSC-A), as the operator, was unable to conduct any research cruises the previous year (2017) because of the unavailability of a science vessel due to circumstances beyond their control.

The cruise program aboard the *CCGS Hudson* took place from August 17th to September 10th, 2018 and is shown on Figure 1. A larger geographic area that included Cumberland Sound was originally planned for the cruise in 2017, but due to budgetary restrictions in 2018, intended operations were cut from seven days to only two. Operations were therefore focussed on the Cape Dyer site in order to make best use of limited ship time and to maximise the chance of encountering an active oil seep based on previous SAR data.

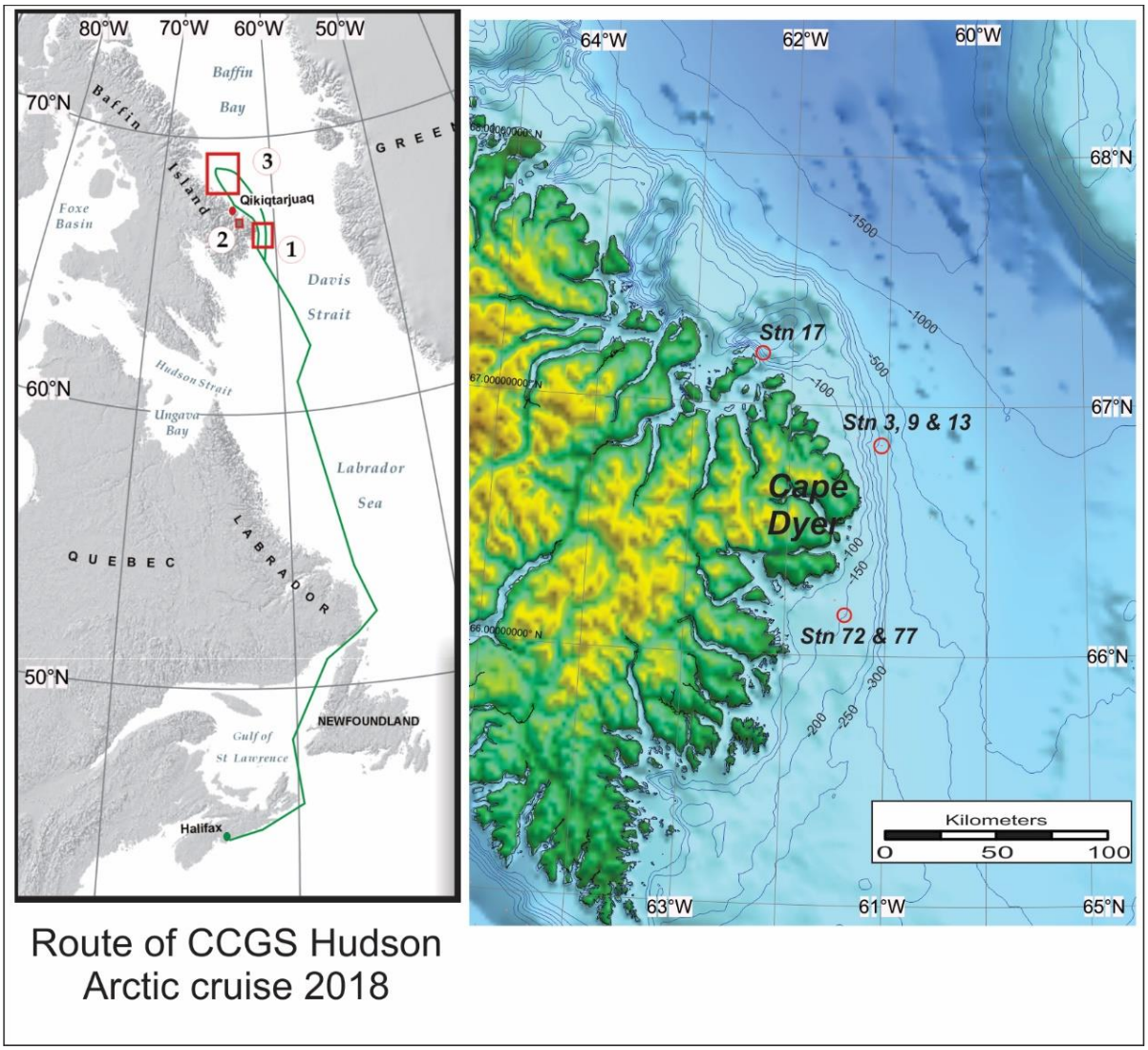

Figure 1. Smaller red box labelled 1on route map is enlarged at right. The middle site includes stations 1 through 15, the southern site covers stations 70 through 77. Station 17 to the north was intended as a control site where no methane anomaly was expected.

Objectives

Oil slick features mapped in the regional offshore from satellite radar data have been previously confirmed as bona fide petroleum occurrences from off Cape Dyer, Baffin Island, as well as off Cape Chidley, Labrador. Excessive amounts of dissolved methane near the seafloor off Cape Dyer were measured from a hydro-chemical transect of water column with conductivity, temperature and density (CTD) water sampling done by the Department of Fisheries and Oceans (DFO) in 2014 that indicates active hydrocarbon seepage on the seafloor (Punshon et al., 2014). Further south, about 100 kilometres off the Cape Chidley headland, Labrador, oil slicks were visually confirmed by the 2016 Amundsen cruise (Fustic et al., 2017). The Amundsen cruise also recovered seafloor grab samples containing sediment and assorted surficial biota. Of note, was

the recovery of thyasirid bivalves, a clam species closely associated with seafloor environments that host hydrocarbon seeps as these clams are thiotrophic; they feed on reduced sulfur compounds generated by methanotrophic bacteria consuming hydrocarbons within the seafloor (Levin, 2005).

The two sites in this cruise are investigated as a follow-up to physically sample evidence of oil seepage based on previous regional studies of satellite radar imaged oil slicks and marine petroleum geophysics and geology by the author (Jauer & Budkewitsch, 2010, Budkewitsch et al., 2013). A first pass of multibeam profiling was followed by an underwater camera drift survey to determine whether seafloor sampling by Van Veen grabs or piston core would be operationally feasible. Site 1 is located 28 km northwest of the 2014 hydro-chemical transect conducted by DFO in 2014 (Punshon et al., 2014) and geophysical mapping indicates that it is near the edge of a newly discovered subsurface sedimentary basin beneath the seafloor (Jauer and Oakey, 2018). Site 2 is 75 kilometres south of the Site 1 and was chosen based on the occurrence of two radar slick features in close proximity to one another as well as the fact that it is adjacent to the same sedimentary basin as Site 1. The final source of data would be the CTD water sample casts, this apparatus was operated and provided by DFO. Please see Table 1 for details regarding the activities conducted at each site.

An unmanned aerial vehicle (UAV) was flown from the ship as a proof of concept for aerial imaging of oil slicks as well as for UAV flight operations from a Coast Guard vessel. The visual recognition of oil slicks by observers from a ship or aircraft is known to be problematic due to ambient light conditions, sea state and the observer's viewing angle; ideally an infrared (IR) video camera would be used to unequivocally identify thin surface oil slicks based on current practices (Fingas & Brown, 2017). Due to budgetary constraints, this equipment was not available and the standard video camera was used.

Table 1: Individual shipboard activities were logged as stations, as shown below for the study areas

Station	Sample Type	Day & Time (UTC)	Latitude	Longitude	Water Depth (m)
1	Grab - Van Veen	235/10:02:26	66.84958	-61.071963	326
2	Camera - GSCA 4K	235/10:53:36	66.84842	-61.074881	326
3	CTD Rosette	235/12:45:30	66.84903	-61.070455	331
4	Plankton Net	235/14:20:27	66.85959	-61.070227	337
5	Plankton Net	235/14:35:46	66.86052	-61.066802	337
6	Plankton Net	235/15:54:25	66.84312	-61.061525	?
7	Grab - Van Veen	235/15:44:04	66.84246	-61.058558	340
8	Camera - GSCA 4K	235/16:24:52	66.84267	-61.05673	346
9	CTD Rosette	235/18:04:46	66.84335	-61.064522	339
10	Grab - Van Veen	235/19:31:10	66.8353	-61.030575	372
11	Grab - Van Veen	236/09:55:39	66.89072	-61.359212	104
12	Camera - GSCA 4K	236/10:25:36	66.89033	-61.357748	?
13	CTD Rosette	236/11:28:10	66.89089	-61.356818	105

14	Grab - Van Veen	236/12:39:43	66.86452	-61.388117	103
15	Camera - GSCA 4K	236/13:13:03	66.86423	-61.387186	102

Station activities for Site 2 study area

70	Camera - GSCA 4K	247/13:42:34	66.19126	-61.454136	146
71	Grab - Van Veen	247/15:20:58	66.19279	-61.449468	146
72	CTD Rosette	247/16:08:01	66.19367	-61.460433	146
73	Drone	247/15:48:00	66.19299	-61.453287	
74	Camera - GSCA 4K	247/17:09:50	66.16466	-61.398761	153.5
75	Grab - Van Veen	247/18:21:08	66.16539	-61.394087	153.5
76	CTD Rosette	247/19:02:43	66.16485	-61.406783	153
77	CTD Rosette	247/19:34:18	66.16626	-61.406279	154

At each site operations commenced with a site specific multibeam survey (Fig.2) to search for the presence of noteworthy seafloor features, e.g., pockmarks or iceberg scours, that would indicate potential oil seep sites. This was followed by a camera drift traverse taking multiple still images that identified the type of seafloor and occurrence of marine biota. The pervasive “pebble pavement”, a seafloor consisting of packed pebbles and cobbles, is present throughout the area and is not suitable for piston coring; a Van Veen grab sampler was used instead. Sediment samples from the grab were collected, labelled and stored in the onboard freezer for later geochemical and biological analysis.

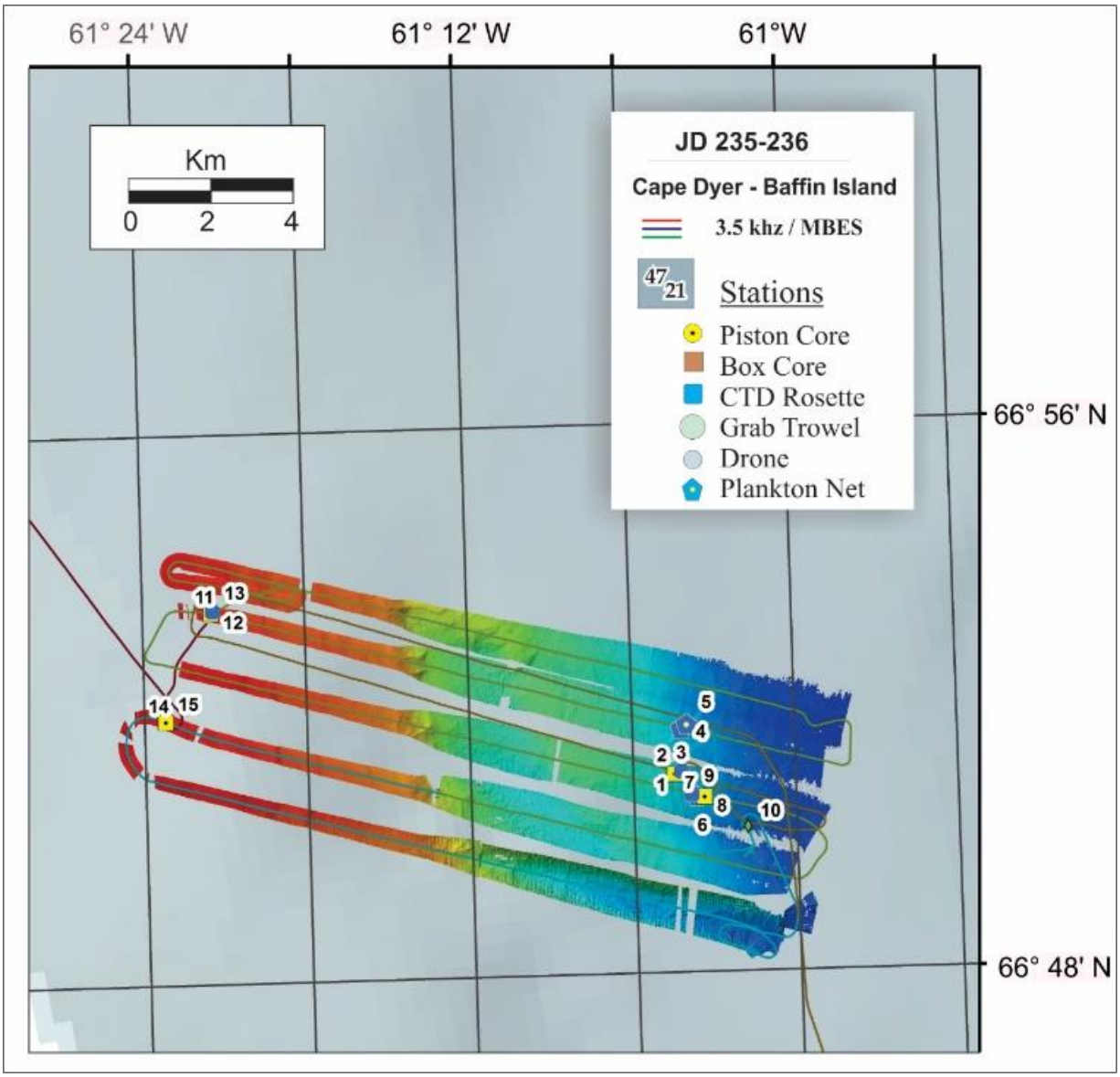

Figure 2. Site 1 covering stations 1 to 15 in cruise report (Normandeau et al., 2018) August 23rd, 2018. The area off Cape Dyer shown with station details and the high resolution multibeam bathymetric data collected prior to the underwater camera drift survey. Several semi-circular pockmark like features are visible in the centre of the survey and just under the numbered stations which show the areas that were targeted for grab and water sampling. Note the mapping coverage is sparse due to time considerations, the use of the pole-mounted multibeam system required significant cruise time as the *CCGS Hudson* can only survey at about 4 knots speed with this configuration.

CTD Results

Co-incident with the grab sampling sites, the CTD rosette water sampler was cast to sample for water depth profiles with respect to chemistry, conductivity (to determine salinity), temperature and density. The CTD results at stations 3 and 9 (Fig. 3), stations 13 and 77 (Fig. 4) and station 17 (Fig. 5) are shown with data for methane concentration, temperature and salinity.

A description of the CTD instrument an oceanographic tool is provided by one manufacturer (http://www.oceannetworks.ca/sites/default/files/pdf/learning/community_observatories/instrument_overivew_CTD_19Aug2014.pdf).
The chemical data from the water samples was later determined from onshore laboratory analysis conducted post-cruise that provided values for dissolved methane, oxygen and acidity (ph).

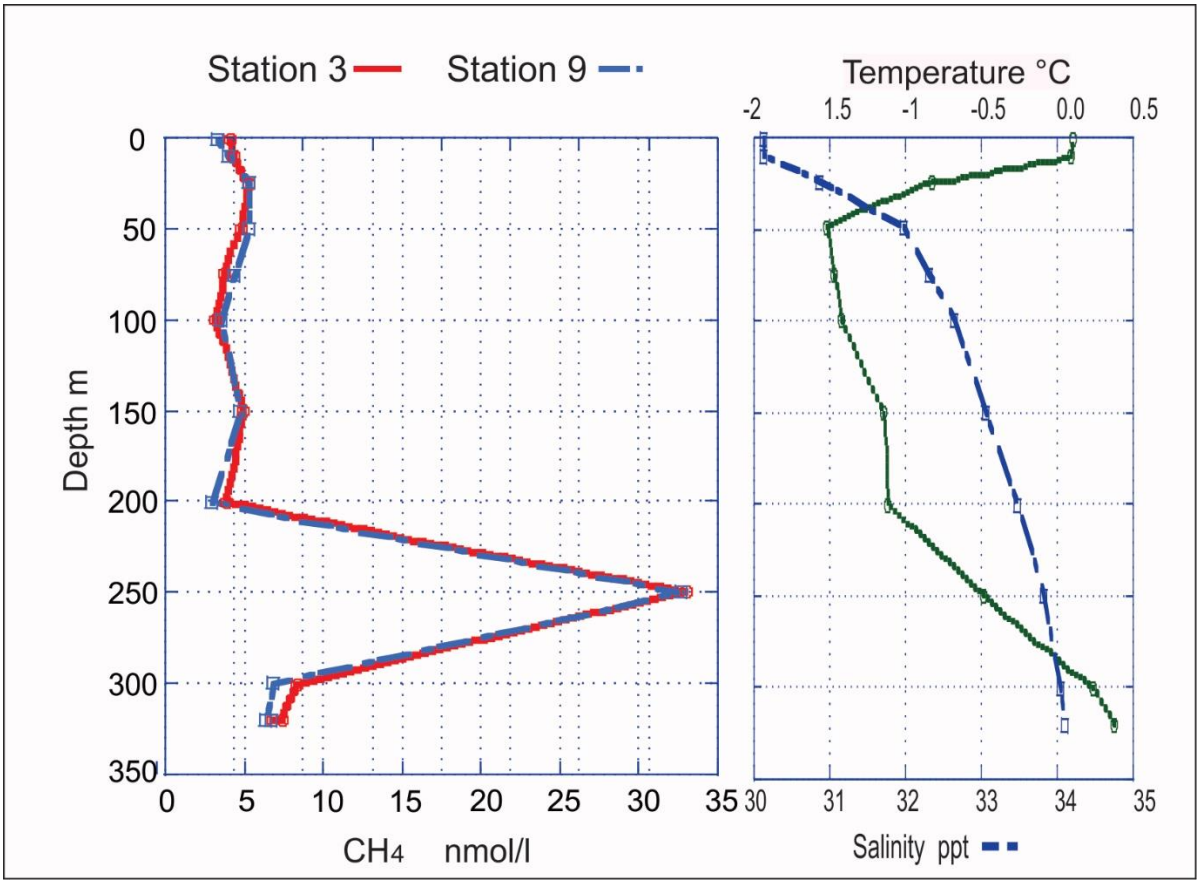

Figure 3. CTD data for stations 3 and 9. Note that these two stations are 685m apart, however only one temperature and salinity profile (for station 3) is shown as the observed values are essentially identical. The high dissolved methane "spike" measured at both stations is not actually at the seafloor and may be an indication that these stations were only close to an active petroleum seep site.

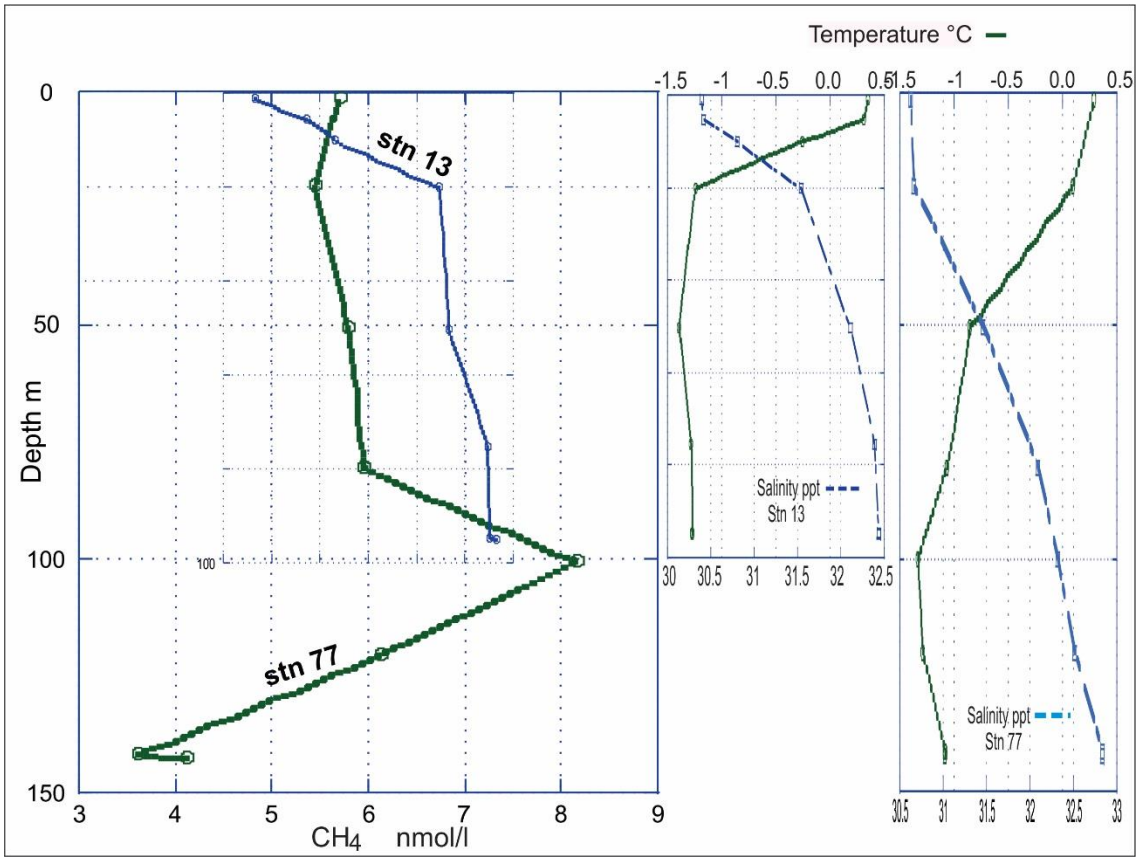

Figure 4. CTD data for Station 13 at Site 1 compared with Station 77 at Site 2. These two stations are about 90 kilometres apart, but are in comparable water depths. Although both stations were believed to be near an active oil seep, based on proximity to vintage Radarsat images of oil slick features, the low values of dissolved methane measured do not indicate any anomalous petroleum presence.

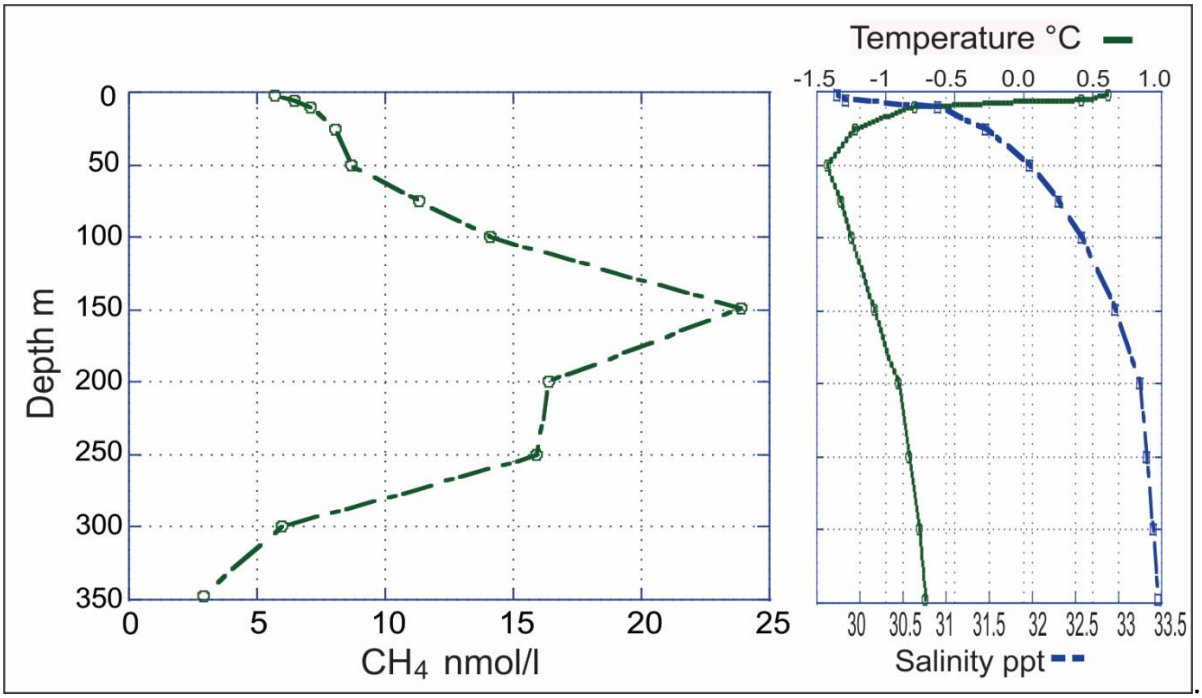

Figure 5. CTD data for Station 17, north east of Site 1. CTD profiles shown in Figs. 3-5 represent preliminary data from the Cape Dyer CTD casts at Site 1 and Site 2 with a "control" measurement at station 17. The measurements at stations 3 and 9 were closely spaced, only 685m apart, and the near identical results are plotted together (Fig. 3). The plot shows anomalously high dissolved methane content, very similar to the measurements taken by DFO in the 2014 transect, approximately 28 km to the southeast (Punshon et al., 2014).
Station 77 at Site 2 is approximately 150 km south of the stations at Site 1, but is in waters of a similar depth range to station 13 and are plotted together (Fig. 4). Both these stations were anticipated to be within another area of high dissolved methane, similar to stations 3 and 9, based on the nearby presence of Radarsat oil slick features. The relatively moderate methane values present may indicate that the inferred oil seep is actually farther away (i.e., has been navigationally missed) or the inferred seep site may not have been active during the sampling period.

The data from Station 17 (Fig. 5) was collected near the mouth of the fjords opening to the north of Cape Dyer, where only nominal methane levels were expected as this area shows no apparent signs of hydrocarbon seepage (there being no Radarsat slick features present). The elevated methane values at 150m depth are enigmatic, and have yet to be explained. The presence of this mid water methane anomaly raises questions about alternative methane sources, as there may be enough organic matter being swept out from the drainage areas feeding into the fjords to provide a biological source.

Drop Camera Surveys

The Geological Survey of Canada-Atlantic's (GSC-A) 4k drop camera is sled mounted, deployed form the ship winch-room and lowered to the ocean bottom using a metal shackle as the drop

weight trigger, which is then raised and lowered as the ship drifts. The camera operation is monitored using a 12 kHz OIS pinger mounted on the sled and used for bottom trigger closure using the Knudsen 12 kHz sounder in pinger mode. A high-powered 4000m Applied Acoustics beacon, also mounted on the sled, enabled subsea positioning by using the Trackpoint 3 USBL system installed in the General Purpose lab moon pool. The following images from station 2 (Fig. 6), station 8 (Fig. 7), station 12 (Fig.8) and station 15 (Fig. 9) are shown with the metal trigger shackle (approximately 18 centimeters in length) for scale. Preliminary descriptions of the physical environments as well as biological components are made with the kind assistance of V. Kostylev.

Figure 6. Site 1, Station 02 (image 0047), 326 m water depth. Metal shackle is approximately 18 cm in length.

This image is approximately 185 m southwest of Station 3 where a CTD profile was measured (Fig. 3). The water column is quite clear (low turbidity) and the seafloor is classified as a well sorted gravel lag (dominated by subangular pebble-sized particles) covering fine sand with some fine shell debris. Angular cobbles are infrequent, most are rounded. The benthic community is dominated by the polychaete worm *Nothria conchylega*, seen as the ~ 4 to 6 cm long tubes, followed by high abundances of brittle stars (likely *Ophiura* sp. and *Ophiocantha* sp.). Also noted, though in lesser abundances, are sabellid polychaete worms, sea urchins (*Strongylocentrotus* sp.) at lower left, burrowing sea cucumbers (*Psolus* sp.), egg cases of whelks (*Buccinum* sp.) and moon snails (*Lunatia* sp.), jellyfish, *Hernicia* (sea star), and unidentified ctenophores.

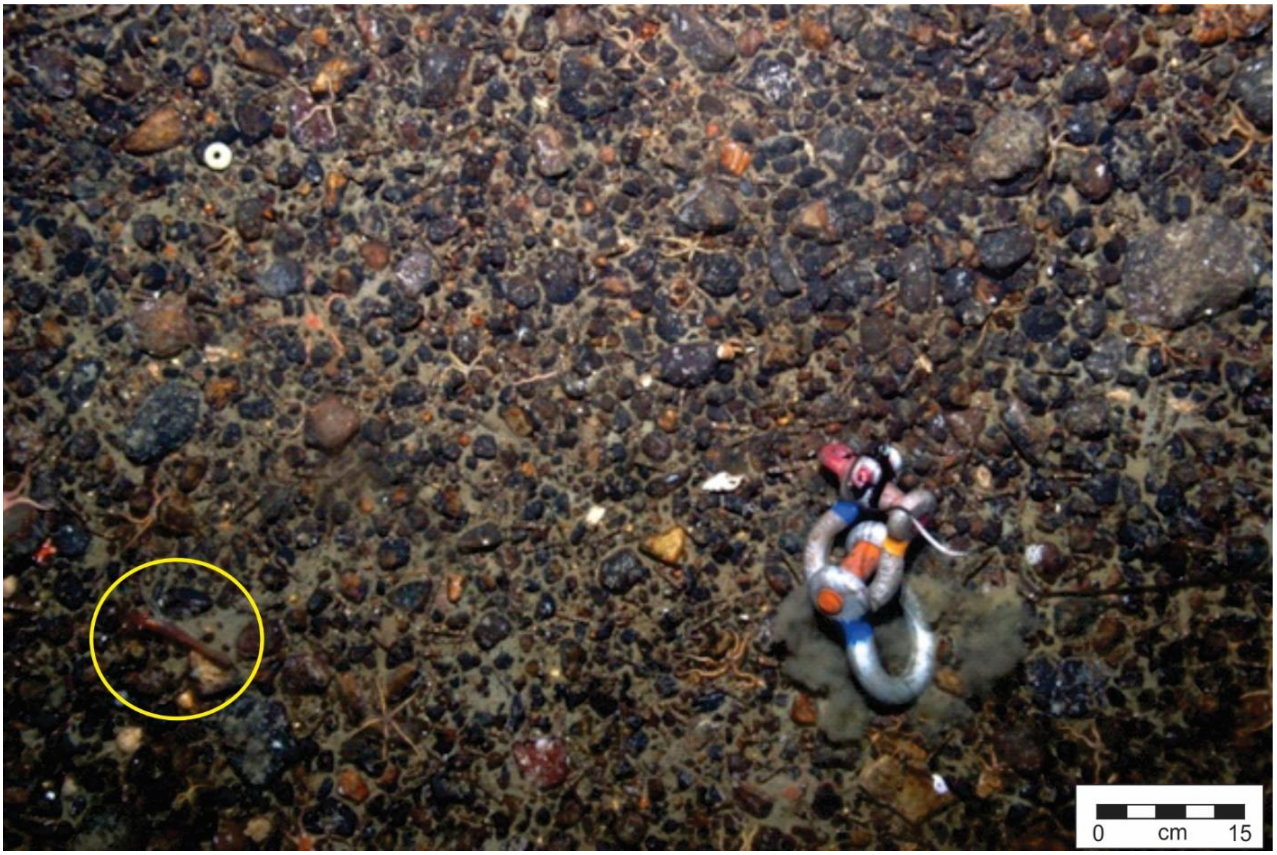

Figure 7. The drop camera image at Station 8 (Site 1; image 026), in 346m water depth with high clarity. The substrate is a cobbly, pebbly gravel lag with small patches of fine sand (seen rising from the shackle) and some shell hash. The benthic community is dominated by the polychaete worm *Nothria conchylega*, visible as numerous tubes ~5 to 7 cm in length, followed by high abundances of brittle stars (likely *Ophiura* sp. and *Ophiocantha* sp.). Infrequent conspicuous crinoids (*Heliometra glacialis*), shrimp (*Pandalus* sp.; lower left corner of photograph, circled), whelks (*Buccinum* sp.), whelk egg masses, sea stars (*Crossaster* sp.), encrusting worm tubes, sabellid polychaete worms, tests of sea urchins and burrowing sea cucumbers (*Psolus* sp).

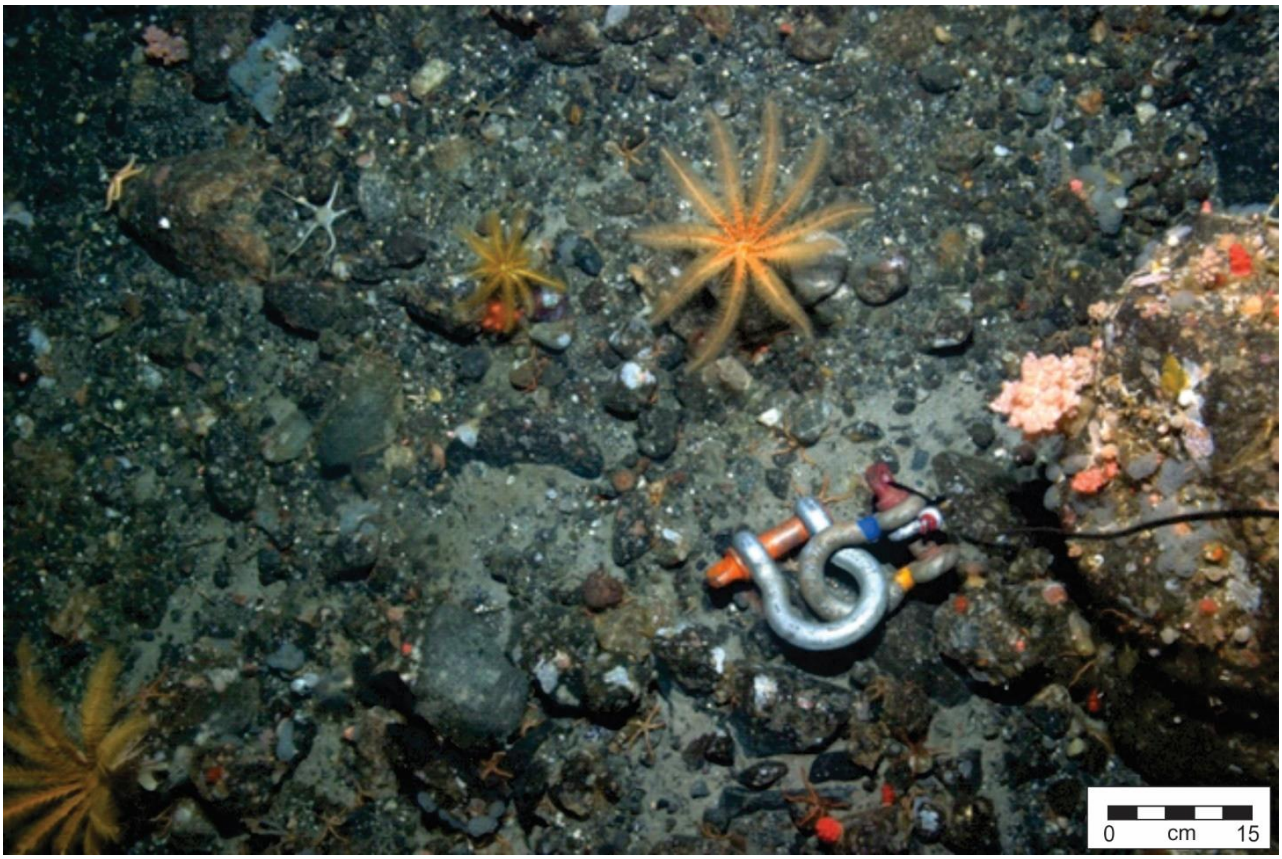

Figure 8. Site 1, Station 0012 (image 016), water depth ~100m. Bouldery to cobbly subangular gravel varying to angular, pebble-sized lag. Brittlestars (*Ophiura* sp., *Ophiopleura* borealis, *Ophiocten gracilis*) and polychaete *Nothria conchylega* are numerically dominant, with conspicuous branching and foliose bryozoans. Crinoids (*Heliometra glacialis*) are very common seen above the shackle and at left. Larger boulders, e.g., at right of the shackle, have several species of encrusting tunicates, sponges and soft corals (*Duva* sp.). On finer particles there is a moderate amount of incrusting animals. Glass sponges present (possibly *Asconema* sp., seen as small white blobs). Few sea stars (*Henricia* sp., *Crossaster* sp.). Sea urchins (*Strongylocentrotus* sp.) are common. Burrowing sea cucumber (*Psolus* sp.). Aphrodita. Whelks (Buccinum sp.) and whelk egg masses as are several tests of barnacles and shells of Icelandic scallop.

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Figure 9. Station 0015 (Site 1 image 018) is at 102m water depth and is approximately 3.3 km southwest of the Station 13 CTD water profile (Fig. 4). The polychaete worm, *Nothria* sp., visible from their tubes, and brittle stars (*Ophiura* sp., *Ophiopleura* borealis, *Ophiocten gracilis*) are both dominant and highly visible amid abundant disarticulated or broken shell debris (*Modiolus sp.*, oysters, *Mya truncate (*?) suggesting the presence of nearby bivalve beds. The substrate is diverse, ranging from granules and pebbles in coarse sand with abundant shell debris, to a gravel lag with infrequent cobbles and boulders. Encrusting coralline algae can be seen on some boulders (within the circle to left of the shackle). Burrowing sea cucumbers (*Psolus* sp.) and sea urchins (*Strongylocentrotus* sp., *Echinus* sp.) are also common. Infrequent occurrences of sea spiders, several species of sea stars (*Asterias* sp., *Leptasterias* sp., *Solaster* sp., *Crossaster* sp., as well as unidentified species), egg cases of whelks, barnacles, and nemertean worms have also been noted. Orange sponges are possibly *Acanella arbuscula,* the white glass sponges possibly *Asconema* sp., as well as soft corals (*Duva* sp.), and crinoids (*Heliometra* sp.) are observed encrusting boulder-dominant habitats.

UAV Ship Operations

The UAV flights were conducted as activities for stations 18, 34 and 73, principally to gain experience in shipboard UAV operation, as well as as a test to determine whether thin oil slicks could be visually identified using the standard UAV equipped video camera, which has a 1/2.3" CMOS sensor creating a 12.4 M effective pixel image. The UAV deployed is a DJI Phantom 4 (Fig. 10 right), a standard unmodified unit that weighs 1388 grams, and was operated using an operator (pilot) and an observer (spotter). The UAV flights were all conducted using Department of Transport approved protocols and licencing under a specific Special Flight Operations Certificate.

Thin oil slicks on the sea surface from natural seepages, as opposed to massive slicks associated with major oil spills, are often difficult to spot even in good conditions (Fig. 10 Left). Aerial surveillance was tested on this cruise to determine the effectiveness of using supplemental UAV imaging to precisely spot oil slicks. The UAV was flown from the aft helicopter deck of the *Hudson*, which provided a good wind break and a secure launch and recovery area.

Figure 10. (Left) A thin naturally occurring oil slick encountered at short range from a dinghy launched from R/V Nuliajuk of the Government of Nunavut's 2018 science cruise in Scott Inlet, an area with known marine oil seeps, under calm and bright daylight conditions. (Right) DJI Phantom 4 drone with operator on the aft helicopter deck aboard *CCGS Hudson* with typical overcast weather conditions

Important lessons in UAV operation obtained by judicious experimentation demonstrated that the launch and recovery location aboard the ship is critical; electrical interference from heavy winch motors on the fore deck of the ship almost resulted in loss of the UAV on one occaission. After this incident all further flights were done from the aft helicopter deck, which was free of heavy electrical machinery and also provided a clear working space. The ship's weather radar is a known source of radio interference and was shut down for the duration of all flight opeerations.

Operating temperature range for this UAV is specified as 0 to 40 degrees Celcius; however, during our operations temperatures were at or below the lower limit (~ -2 C). Battery life of the UAV made flight times in below freezing temperatures shorter than normal; 15 to 18 minutes

instead of the 25 to 28 minute duration possible in temperatures above freezing. Recovery of the UAV was found to work best with a manual grab and hold by the spotter as opposed to letting the UAV land and spin down, a process that requires several seconds during which time a stray gust of wind could result in the UAV being damaged.

The original strategy for planning the oil seep site work was to use recently acquired IR images taken by the National Aerial Surveillance Program Dash 8 aircraft to precisely spot the active oil slicks, but poor weather and local sea ice coverage during their scheduled flights prevented any useable data from being collected. Consequently our site selection was essentially an estimate based on the old Radarsat mapped slick features. Use of the shipborne UAV was attemped to pinpoint any seep activity, but was prejuidiced by the lack of any IR imaging equipment. The oblique angle (Fig. 11 a) and vertical (Fig. 11 b) views of the sea surface taken with our UAV show some of the issues inherent to imaging thin oil slicks in visible light. Imaging with visible light requires ambient conditions of calm seas and bright sunlight; cloud cover and sea state are thus major factors in viewing oil slicks. Our experience using the standard visible light video camera on the UAV proved to be unsatisfactory for the purpose of spotting the active slicks.

Figure 11. (a upper) Oblique view taken from aft of *CCGS Hudson*, at approximately 30m altitude. Winds are light and the skies are clear and sunny. UAV pilot and observer are visible for scale on the helicopter deck. Note the lack of any visible signs of oil slicks.

Fig. 11 (b lower) is a more vertically oriented image of *CCGS Hudson* taken with the UAV at approximately 50m altitude. The winds here are light with overcast skies. Again, no visible indications of an oil slick can be seen. The small white object directly off the stern of the ship is a seabird with a wingspan of approximately 0.5m.

Figure 11 (a,b)

Discussion of preliminary results

The most significant initial result of this cruise is the confirmation of high amounts of dissolved methane over a large, but discrete region of the seafloor east of Cape Dyer. These near seafloor measurements recorded dissolved methane at up to 1000% saturation over a span of 30 kilometres (including the DFO 2014 data points) which presents as a large region where hydrocarbons are leaking from the seafloor. There is insufficient data at this time to determine whether the elevated dissolved methane concentrations are originating from one or more petroleum seep sites, but these measurements suggest that they were in close proximity to at least one hydrocarbon source originating from the seafloor.

The images of the seafloor show a great deal of biological activity and diversity. An inventory of the species present in the seafloor images will be conducted by biologists to determine if the excess dissolved methane has had any inferred environmental effects. Note that dissolved methane in sea water is biologically accessible as compared to actual methane bubbles which immediately rise to the surface and leak out to the atmosphere (Levin, 2005). The predominance of filter feeders indicates an abundant supply of microscopic biota in this cold water, high latitude environment. This raises the question of whether the presence of high levels of dissolved methane are having any environmental effects.

The ultimate source of this methane is either from thermogenic generation (thermal cracking of organic matter) from buried sedimentary source rock that forms a working petroleum system, or biologically created by methanogenic microbial action. A third possibility exists, that of abiotic methane generation from water – rock chemical interaction, as the geology of the region has a major mafic volcanic component associated with the transform rift system here (Jauer et al., 2018; Etiope and Lollard, 2013).

Methanogenesis or biomethanation is limited to one domain of microbes, the Archea, which use specific metabolic pathways to generate methane either by chemolithotrophic means from CO_2 and H_2 in the rocks of the geological environment or by organotrophic processes that involve the decomposition of organic matter (Kietavainen and Purkamo, 2015). Because only this one group of microbes is capable of generating methane; a metagenomic sequence analysis of genetic material isolated from centrifuged sediment samples may be able to determine their presence in the seafloor. This same analysis may also identify other microbes which are methanotrophic, these are methane oxidising bacteria that make use of aerobic or anaerobic biological processes.

The surficial sediments collected from the Van Veen grab samples will be analysed for any petroleum content by the GSC Calgary geochemical laboratory at a later date. This may involve testing by pyrolysis and chromatography to determine the nature of any hydrocarbons present in the sediment samples.

Conclusions

These initial results show that previously unrecognised petroleum seepage is flowing from the seafloor in at least one broad area of the Cape Dyer region. Our attempts to position the ship directly over the inferred active seep site failed due to the technical limitations of conventional video imaging, but the utility of a ship borne UAV was demonstrated. The rather short amount of ship time that was spent in multibeam surveying to map seep related seafloor structures such as

pockmarks or bioherms such as deep water coral build ups was another factor that shows that finding the exact location of these seafloor seeps requires the acquisition of more data.

Acknowledgements

Thanks are given to our colleagues from DFO, whose Aquatic Climate Change Adaptation Services Program funded the work of principal investigator Kumiko Azetsu-Scott, Stephen Punshon and Melissa Faulkner. The marine engineering and technical support staff from the GSC-A, led by chief scientist Dr. Alexandre Normandeau, were essential to the successful outcomes of this cruise as was the skill and enthusiasm of the crew of *CCGS Hudson* under Captain Fergus Francie, who are all gratefully acknowledged. Thanks are also given to the GEM-2 Baffin program office who provided financial support.

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