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Saglek Basin Macro- and Micro- Hydrocarbon Seeps – New Evidence, Reinterpretation, and Emerging Exploration Tools

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Summary

In 2016, a search for macro- and micro- hydrocarbon seeps aboard Canadian Coast Guard Ship (CCGS) *Amundsen* in Saglek Basin included integration of multi-beam sonar bathymetric survey with data and samples collected by a remotely operated vehicle (ROV) and box-cores. Although the focus of research is on the interdependance of various earth system constituent elements, the observation and findings are potentially relevant to petroleum exploration.

Two sites previosly described as potential macro-seeps by Jauer and Budkewitsch (2010) were investigated. Seep locations are documented as research stations ROV2 and ROV2b (Fig. 1). At ROV2 site, the presence of a potential macroseep was inferred by a synthetic aperture radar (SAR) image, supported by direct visual observation of an oil surface slick and from the abundance of thyasirid bivalves that may contain chemoautotrophic sulfur-oxidizing and/or methanotrophic bacteria in their gills. At the ROVb site, a mound-like structure, previously interpreted as cold-seep precipitated carbonates, is re-interpreted to be a long side-berm (submarine lateral morraine) of a large gouging iceberg, also referred to as ploughmark (Dowdeswell et al., 2016).

Additionally, we propose that observed and mapped biogeochemical anomalies related to metabolism of hydrocarbons of some species might be utilized as a novel petroleum exploration tools. These may include: (i) the presence of hydrocarbon oxidizing microbes in sea bottom sediments, an emerging geomicrobiology exploration concept (Hubert and Judd, 2010); (ii) increased concentrations of polycyclic aromatic hydrocarbons (PAH) in sea stars (Gaden et al., 2016); (iii) elevated concentrations of hydrocarbon degrading microbes in carnivorous sponges (Verhoeven et al, 2016); and (iv) thyasirid bivalves that contain chemoautotrophic bacteria in their gills. Routinely conducted, and in most cases publicly available baseline microbiological and marine biology studies may be used as a powerful screening tool for identifying otherwise hard to detect petroleum micro-seeps and thus as potential indicators of underlying reservoirs. This provides a new dimension to previously suggested relationship between seabed geologic features, macro-seeps and benthic environments (Blasco et al., 2010).

Overall, the results and proposed novel exploration concepts allow for revising exploration strategies in the Saglek Basin, and indicate the potential utility of geomicrobiology and marine biology for offshore petroleum exploration worldwide.

Introduction

Petroleum exploration of the Saglek Basin (Northern Labrador, NW Atlantic; Fig. 1) includes (i) five exploratory wells drilled 1976-1980, (ii) regional 2D seismic and bathymetric surveys, and (iii) recent synthetic aperture radar (SAR) remote sensing from the RADARSAT-1 Earth observation satellite. The Hekja O-71 gas discovery of 1979 confirmed the presence of an active gas-prone petroleum system. Across the basin, the close proximity of (i) "pockmarks" and mound like features (interpreted as seep related authigenic carbonates), revealed by bathymetry and seismic surveys, (ii) slick-like features on the sea surface revealed by satellite images, and (iii) the presence of significant amount of cold water corals potentially related to petroleum seepage, was considered promising evidence for an additional oil-prone petroleum system in otherwise under-explored Saglek basin (Jauer and Budkewitsch, 2010).

Here we report some aspects of ongoing research that attempts to integrate geology, bathymetry, geochemistry, geomicrobiology and marine biology to advance the understanding of dynamic processes related to petroleum seeps and their products through space and time. The ultimate aim is to provide new directions for exploration activities in Saglek Basin and offshore exploration worldwide.

Theory and/or Method

Multi-beam sonar survey is used to map the ocean bottom three-dimensionally and identify anomalous geomorphic features. The Remotely Operated Vehicle (ROV) was used to visualize and photograph sea-bottom morphology as well as to sample selected sediments and living organisms such as cold water corals.

Box coring was used to acquire the top 0.5-0.8m of sea-bottom sediments for bulk and DNA microbial studies as well as collection of thyasirids. In areas with no evidence of macro-seeps, identification of hydrocarbon oxidizing microbes and chemosymbiotic thyasirids may suggest the presence of active micro-seeps, even if these are not detectable by classical organic geochemical trace hydrocarbon, isotopic and biomarker methods. For example, the elevated concentration of hydrocarbon degrading microbes in carnivorous sponges and polycyclic aromatics in sea stars may be related to their proximity to hydrocarbon seeps.

Examples

<u>Macro-seep 1 (Station ROVb)</u>: a previous study based on a 2D seismic suggested that a 10 m thick and 400 m wide sea-bottom feature was an authigenic microbial carbonate mound formed around the hydrocarbon seep. The lack of oil in the water column and on the ocean surface at this locality was thought to be caused by self-sealing activity by biological agents such as bacterial matting and associated carbonate hard-ground formation (Jauer and Budkewitsch, 2010). An alternative interpretation would be cessation of charge and/or oil depletion from the underlying reservoir. Both scenarios favor the presence of active petroleum system and potential subsurface accumulations. However, results from a three-dimensional multibeam survey revealed that the studied feature is not circular, mound-like, but rather a multi-kilometer long linear feature. Additionally, the first attempt to sample using a box core resulted in impacting very hard ground and consequent serious damage to box-coring tool. The second attempt also damaged the box core, but succeeded in retrieving rock specimens. Contrary to expectation for unconsolidated pelagic mud and/or semi-hard recent authigenic carbonates and microbial mats, five decimeter-scale glacial boulders including granite and various metamorphic rocks were recovered (Fig. 2).

A multi-kilometer long, about 10m thick and up to 400 meters wide sea-bottom feature comprised of glacial boulders suggests that it likely represents a long side-berm (submarine lateral morraine) created by a large gouging iceberg. Although its occurrence at a current water depth of 281m is not supportive of this suggestion, it is likely that it was formed during one of the recent ice periods when sea level was significantly lower. Analogues include Pleistocene age gouging iceberg features encountered at even greater depths (450 – 850m) offshore Svalbard (Weeks, 2010; Dowdeswell et al., 2016). The absence of post-glacial pelagic sediments covering the interpeted side-berm in the box core is likely due to a combination of (i) low sedimentation rates typical for offshore environments in cold water settings, and (ii) fine sediment wash-out during box core retrieval.

<u>Macro-seep 2 (Station ROV2</u>): a previous study using synthetic aperture radar (SAR) images suggested that changes in image contrast are actual surface water anomalies caused by the presence of oil, which dampens waves and lowers backscatter (Jauer and Budkewitsch, 2010; Budkewitsch et al. 2014*)*. The mapped aerial extent of the anomaly was used to find the site and from there to search for the suspected seabed hydrocarbon seep. While oil sheen on the surface of the water was obvious, the search for its source at the sea bottom was challenging. A multibeam sonar and sub-bottom profile survey did not detect any oil and gas actively seeping from the seafloor. Neither pockmarks nor carbonate mounds were detected. However, the absence of these types of evidence is not conclusive evidence of absence of seeps. The ROV experienced significant mechanical problems and was not employed.

Visual observation of an oil sheen supports radar image interpretation and suggests the presence of an active oil-prone petroleum system. Additionally, high abundances of relatively large thyasirid bivalves were collected in box cores from this location. Thyasirids may harbour chemoautotrophic symbionts in their gills, which they depend on as a source of nutrients; chemosymbiotic thyasirids have been sampled from numerous cold seeps around the world. Transmission electron microscopy, stable isotope analyses, and DNA sequencing are being undertaken to confirm whether the thyasirids from Saglek Bank contain symbionts that use petroleum compounds as an energy or autotrophic carbon source.

Future investigation at this location should include sampling and geochemical characterization of oil from surface water. Since multibeam sonar was ineffective in finding an anomaly, future ROV dive planning should include oceanographic data on sea and tide currents in the area. Finally, finding seep locations might be assisted by the documenting presence or absence of oil ("seeps halo effect") through relatively closely spaced water profiles (Farwell et al., 2009). Water characterization and sampling from multiple depths is routinely done in a single run using a CTD (Conductivity Temperature Depth) Rosette. The presence of oil in the water can be rapidly detected using gas-chromatography in the onboard lab. Multi-depth samples would also allow for potentially detailed characterization of oil from different water depths to establish directional trends such as alteration intensity as oil migrates away and upward from the seep (Farwell et al., 2009). This will moreover contribute to establishing hydrocarbon alteration rates in cold Arctic waters which are hitherto poorly documented.

<u>Emerging and Potential Microbiology and Marine Biology Hydrocarbon Seep Identification Tools</u>:

In addition to ongoing research on the utility of hydrocarbon oxidizing microbes in sea-bottom sediments as exploration tools (Hubert and Judd, 2010), baseline environmental studies that document increased concentration of hydrocarbon oxidizing microbes in both thyasirid bivalves and carnivorous sponges, and increased polycyclic aromatic hydrocarbons in sea stars, suggests that these organisms might be used as a screening tool for petroleum exploration.

Geomicrobiology of sea-floor sediments: Although, the main aim is to establish baseline concentrations of different microbial communities in pristine environments (i.e. not anthropogenically contaminated) that may be utilized as an effective natural agent for mitigating potential future oil spills, recognition of hydrocarbon consuming microbes may indicate the proximity of a natural hydrocarbon seep and thus the presence of an active petroleum system (Hubert and Judd, 2010). Since microbial metabolism of hydrocarbons is rapid, relatively small seepages are likely to remain non-detectable by classical geochemical isotope and biomarker screening methods. In these cases, the presence of hydrocarbon metabolizing microbes in sea floor sediments might be the only convincing indicator of active micro-seeps and thus of an underlying petroleum reservoir, suggesting the importance of utility of geomicrobiology as an emerging petroleum exploration tool.

The elevated concentration of hydrocarbon degrading or chemoautotrophic bacteria in a wide range of species including thyasirids bivalves and carnivorous sponges may indicate the proximity to an oil seep. Carnivorous sponges such as methanotrophic *Cladorhiza methanophila* are a potential analogue *(*Hestetun et al., 2016)*.*

Gaden et al. (2016) noted the enormous variability in concentration of polycyclic-aromatic hydrocarbons (PAH), ranging from 6 to 497 ng/g, in widely dispersed sea stars in Baffin Bay. Although, PAH anomalies are not correlated with presence of documented seeps the increased concentration might be related to proximity of active petroleum seeps.

A potential challenge of using hydrocarbon degrading microbes and PAH concentration in sea floor sediments and stationary or non-migrating marine organisms such as sponges and sea stars, is other sources of hydrocarbons. Thus, following identification of an anomaly, a follow up study for distinguishing hydrocarbon sources should be undertaken. This may include routine Carbon Preference Index (CPI) which based on odd versus even carbon-number ratios distinguishes biogenic and pyrogenic from petroleum hydrocarbons.

Contrary to previous reports, observed occurrences of cold water corals were not related to proximity of hydrocarbon seeps.

Conclusions

Investigation of two previously inferred offshore natural hydrocarbon seep localities allowed for their re-interpretation. In the first case, at the ROVb station, a three-dimensional multibeam survey and box coring identified a multi-kilometer long, 400m wide, and 10m high sea-bottom feature comprised of glacial gravel as a side-berm of a large gouging iceberg. This overturns the previous interpretation based on two-dimensional seismic line of an elevated feature that may be an authigenic carbonate mound related to a hydrocarbon seep. In the second case, at the ROV2 station, the presence of a potential macro-seep inferred from synthetic aperture radar (SAR) image is further supported by direct observation of an oil surface slick and potentially from the abundance of thyasirid bivalves that may contain chemoautotrophic sulfur-oxidizing and/or methanotrophic bacteria in their gills.

Ongoing environmental studies in the Canadian Arctic including the Saglek Basin are focusing on the interdependance of various earth system constituent elements and the establishment of biological, microbiological and benthic baselines in pristine (un-spilled) environments. However, the presence of hydrocarbon degrading microbes in sea floor sediments and carnivorous sponges, chemoautotrophic symbionts in thyasirids, as well as elevated concentrations of polycyclic hydrocarbons in widely spread sea stars, provide new directions for exploration strategies in Saglek Basin and have a potential to be utilized as a screening tools in offshore petroleum exploration worldwide.

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References

Blasco, K. A., Blasco, S. M., Bennett, R., MacLean, B., Rainey, W. A., & Davies, E. H. (2010). Seabed geologic features and processes and their relationship with fluid seeps and the benthic environment in the Northwest Passage. *Geological Survey of Canada, Open File*, *6438*, 57.

Budkewitsch, P, Pavlic, G, Oakey, G, Jauer, C, and Decker, V. (2013) Geological Survey of Canada, Open File 7068.

Dowdeswell, J.A. & Hogan, K.A, (2016), The variety and distribution of submarine glacial landforms and implications for ice-sheet reconstruction, In: Dowdeswell, J.A., Canals, M., Jakobsson, M., Todd, B.J., Dowdeswell, E.K. and Hogan, K.A. (eds) Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient. Geological Society, London, Memoirs, 46, 519-552.

Farwell, C., Reddy, C. M., Peacock, E., Nelson, R. K., Washburn, L., & Valentine, D. L. (2009). Weathering and the fallout plume of heavy oil from strong petroleum seeps near Coal Oil Point, CA. *Environmental science & technology*, *43*, 3542-3548.

Hestetun,T.J., Håkon Dahle, Steffen L. Jørgensen, Bernt R. Olsen, and Hans T. Rapp, (2016), The Microbiome and Occurrence of Methanotrophy in Carnivorous Sponges, Frontiers in Microbiology, p. 1-14.

Hubert C, Judd A. (2010). Using microorganisms as prospecting agents in oil and gas exploration. In: Timmis KN (ed). Handbook of Hydrocarbon and Lipid Microbiology. Springer-Verlag: Berlin, Heidelberg.

Gaden, Ashley, A. Burt, J. Ritchie, Z. Z. Kuzyk and G. Stern, (2016), Petroleum Hydrocarbons in Baffin Bay Sediments and Sea Stars, (abs.) ArcticNet Annual Meeting, Winnipeg, Canada.

Jauer, C.D., and Budkewitsch, P. 2010. Old marine seismic and new satellite radar data: Petroleum exploration of north west Labrador Sea, Canada. Marine and Petroleum Geology. 27: 1379-1394.

Verhoeven, Joost and S. Dufour, 2016, Exploring the Microbiome of two Carnivorious Sponge Genera (*Chondrocladia*, *Cladorhiza*) from Baffin Bay, (abs.) ArcticNet Annual Meeting, Winnipeg, Canada.

Weeks W.F., 2010, *On Sea Ice*, University of Alaska Press, 664 p.

Wilhelmina A., Z. Z. Kuzyk, J. Ritchie, M. Kamula, R. Macdonald and G. Stern, Concentrations and Accumulations Rates in Arctic Sediments, Kivalliq Region, Nunavut, (abs.) ArcticNet Annual Meeting, Winnipeg, Canada.

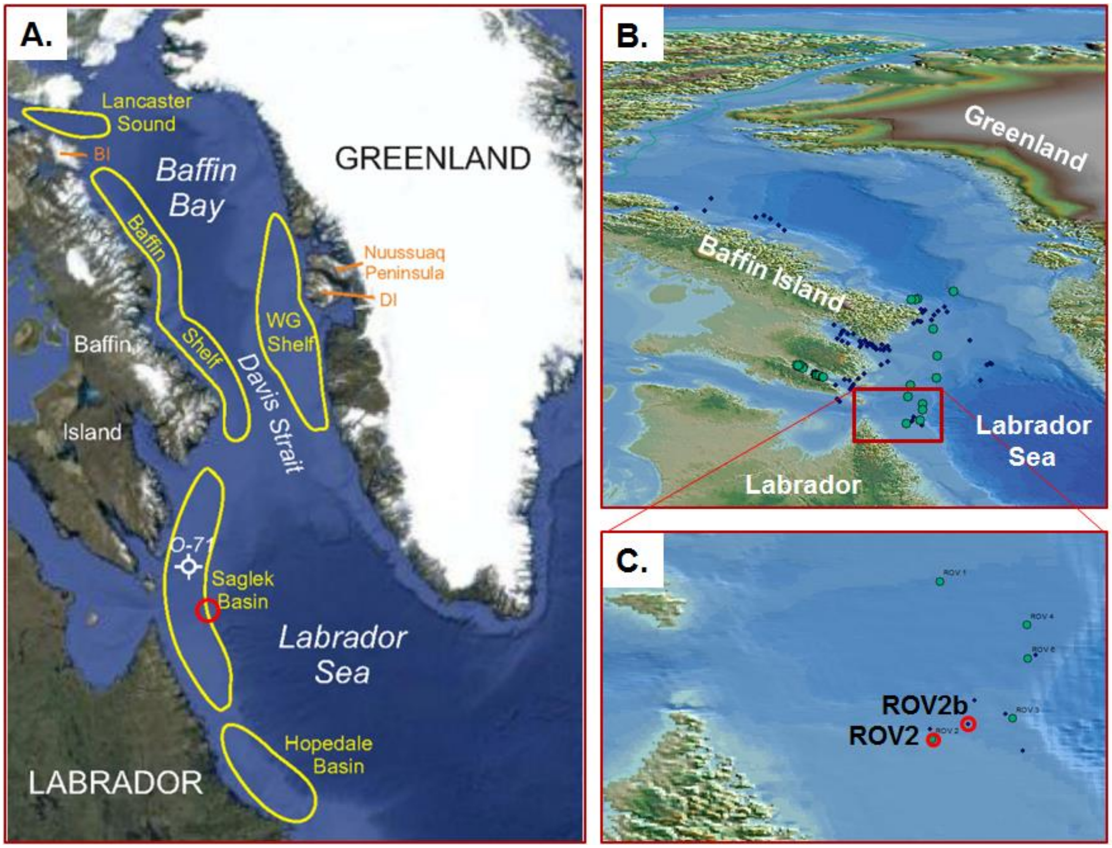

Figure 1. Stations ROV2 and ROV2b. A) red circle, B-C) ROV dive sites (green circles) and slick-like features (blue dots)

Figure 2. Boulders (>0.05m diameter) retrived in box core at ROVb station.