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Reconnaissance Mapping of Suspect Oil Seep Occurrences in Hudson Bay and Foxe Basin Using Satellite Radar

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

Cover Image
Radarsat-1 mosaic created by CCRS in partnership with CSA with bathymetry from GEBCO, NOAA, National Geographic, DeLorme, and ESRI. Image spans across 1250 km.

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Attached Annexes

Annex 1: a series of plates consisting of index maps, RADARSAT-2 images and figures outlining the dark targets selected for the regions of interest with accompanying meta-data.

Annex 2: Geodatabase available as an ESRI shape or KML files.

Introduction

Exploration success and understanding petroleum systems in offshore basins require significant investment in a geosciences knowledge base. In many offshore basins around the world where hydrocarbon exploration or oil producing wells are in operation, satellite radar data has been employed to detect the presence of oil slicks on the ocean surface which emanate from natural sea-bottom seeps. These remote sensing tools can be employed to examine large offshore areas rapidly and in a cost-effective manner (e.g., Hood et al., 2002), however very little data of this kind are available from potential oil producing basins in arctic waters. Exploration for hydrocarbons in some of these remote areas, including Hudson Bay and Foxe Basin, has been limited due to incomplete geoscience information and the high cost of working and collecting data in these marine and harsh environments. Space-borne radar data, however, can be just as easily collected and obtained for these areas and at the same cost as elsewhere in the world. Based on initial results obtained in the offshore areas of Davis Strait and Baffin Bay under a pilot study with RADARSAT-1 data (Budkewitsch et al., 2013), the work was expanded to evaluate the potential of detecting dark targets on the sea surface for monitoring and assessing the hydrocarbon potential of Hudson Bay and Foxe Basin with RADARSAT-2 satellite data (Figure 1).

The approach taken in this work included a more aggressive data acquisition campaign to provide a larger dataset for detecting repeat appearances of dark targets which are often more strongly correlated with the presence of persistent hydrocarbon seeps. This collection of new data improves the very limited knowledge we have of these major interior sea regions. The ability to identify new hydrocarbon seeps and to further our understanding of the widespread distribution of seeps can contribute towards a greater understanding of the hydrocarbon potential of these two basins.

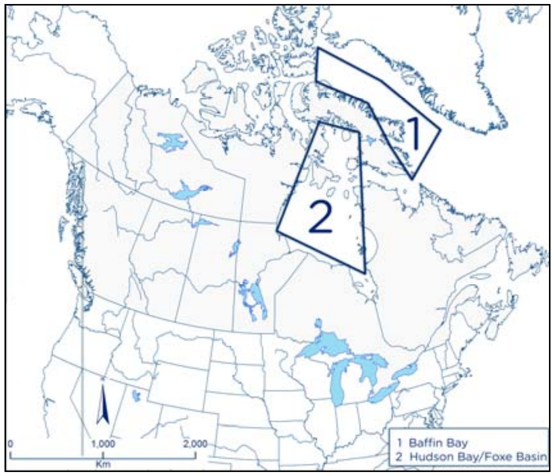


Figure 1 – Regions of interest in offshore basins examined with satellite radar. (1) Previous work over Baffin Bay/northern Davis Strait and (2) the area of Hudson Bay and Foxe Basin investigated in this report.

This study provides new data to suggest where natural oil seeps may be occurring, which may be able to direct other geoscience work aimed at assessing the hydrocarbon potential of these two Phanerozoic sedimentary basins in Canadian waters.

Approach

Satellite radar technology is employed for the detection of natural seeps in petroleum basins around the world because of the association of natural hydrocarbon seepage and subsurface accumulations of oil. Although the relationships are variable, the nature and location of seepages, such as those found offshore Nigeria, Brazil and in the Gulf of Mexico, has proven to be significant in terms of their proximity to discovered oil fields (Sassen, 2000). The location of seeps and suspected seeps enables these features to be placed within a regional interpretive framework of offshore geologic and seismic data sets. Satellite-based tools enable an evaluation of wide areas of the offshore for seep detection as evidence of active hydrocarbon systems at relatively low cost (e.g., MacDonald et al., 1993; Williams and Lawrence, 2002; Miranda et al., 2004). The data collection strategy and rationale follow the approach described in Budkewitsch et al. (2013). Compared to actively explored and producing offshore oil fields worldwide, arctic waters in Canada (with the exception of the Beaufort Sea) have not seen active exploration in over thirty years.

This contribution to the Geo-Mapping for Energy and Mineral Program focuses on the Hudson Bay and Foxe Basin project. The objective was to plan and utilize new RADARSAT-2 Wide mode images in VV polarization mode covering Hudson Bay and Foxe Basin to provide a background set of image data for this study and future investigations. A preliminary search for potential natural oil seeps was made possible with this data set. The new RADARSAT-2 data were acquired during ice-free conditions, yielding almost complete and repeat coverage of the basins annually in 2010, 2011 and 2012. Only partial repeat coverage was possible in 2011 due to conflicts with other user requests. This Open File presents results of image analysis for the detection of dark targets and a database describing these features from the individual scenes employed. The two study areas combined represent over 900,000 square kilometers of sea surface where no previously published examinations of this kind have been carried out.

Dark target detection in Hudson Bay and Foxe Basin

Almost the entire area occupied by Hudson Bay and Foxe Basin was imaged and the pattern of orbital tracks acquired is illustrated in Figure 2. The results presented in the database as part of this report are based on these images (Annex 1 and 2). The dark targets identified can assist with determining background conditions of the sea state and where natural seep occurrences may exist. The study is based on three years of observations that may serve as a foundation for further studies, including environmental monitoring.

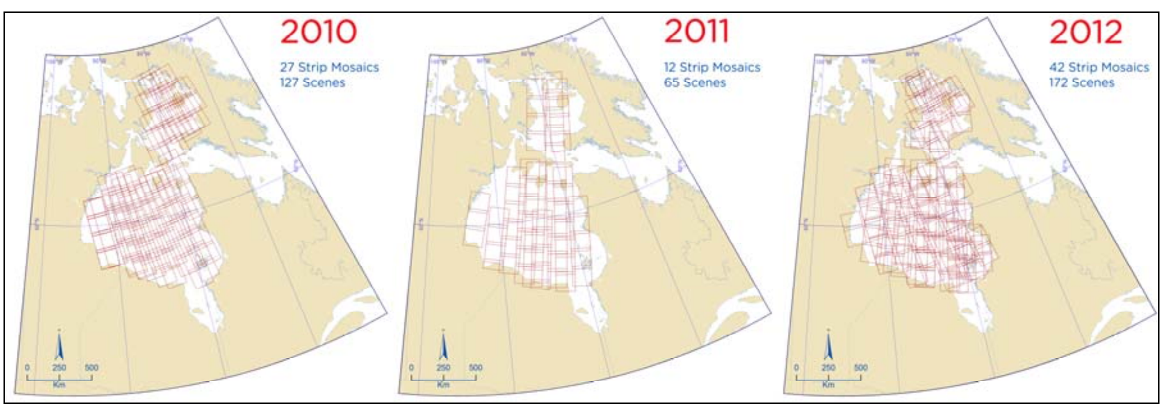


Figure 2 – Outlines of the RADARSAT-2 scenes collected and examined over Hudson Bay and Foxe Basin. The majority of the data was collected in the fall of 2010 (ascending passes), 2011 (descending passes) and 2012 (both ascending and descending passes). Each strip or scene outline shown (in red) is 150 km wide.

A long term observational data set from these two regions has an important role to play in contributing to the detection of any potential seeps and understanding their presence and characteristics over time. The results presented in the database are focused on small dark targets, which represent a shift in the presentation of results from Budkewitsch et al. (2013) where both large (significantly greater than 1,000 ha or several thousand ha) and small (less than 100 ha) dark targets were presented. Many large slick like features are most often associated with ocean current or surface wind related phenomena, which increases the number of suspect occurrences that require follow-up investigation. In this examination over Hudson Bay, a very large number of images were collected and the smaller dark targets were considered to be more consistent and anomalous in appearance to merit follow-up monitoring.

In contrast to previous work where wind speed information is used to screen for radar images ideal for detecting slicks, wind velocity data was not collected from other sources such as QuikScat or determined from the RADARSAT-2 data itself. All images were analyzed since they were available to us under the Government of Canada RADARSAT-2 data allocation. Qualitatively, radar images with wind speeds to high or too low can be reasonably deduced by inspection. Follow-up for wind velocity could be done for the much smaller subset of images where dark targets have been identified.

Approximately 75% of the requested data collections from 2010-12 were accepted from the initial submissions. Over 360 images were examined as part of this study. Satellite passes for data collection were selected with significant overlap with adjacent passes whenever possible (Figure 3). This eliminated gaps in coverage and permitted multiple observations over many parts of the study area within the same season. This strategy would help to confirm if a dark target remained a persistent feature over more than one day. The period of acquisition was chosen seasonally between early September and early November, which has the least amount of sea ice. Sea-ice or melting remains of residual ice otherwise clutter the ocean surface for most of the year and confounds image interpretation. Later than mid- to late-November, grease ice begins to develop with the falling temperatures. Most of the data in this study were acquired in 2010 and 2012.

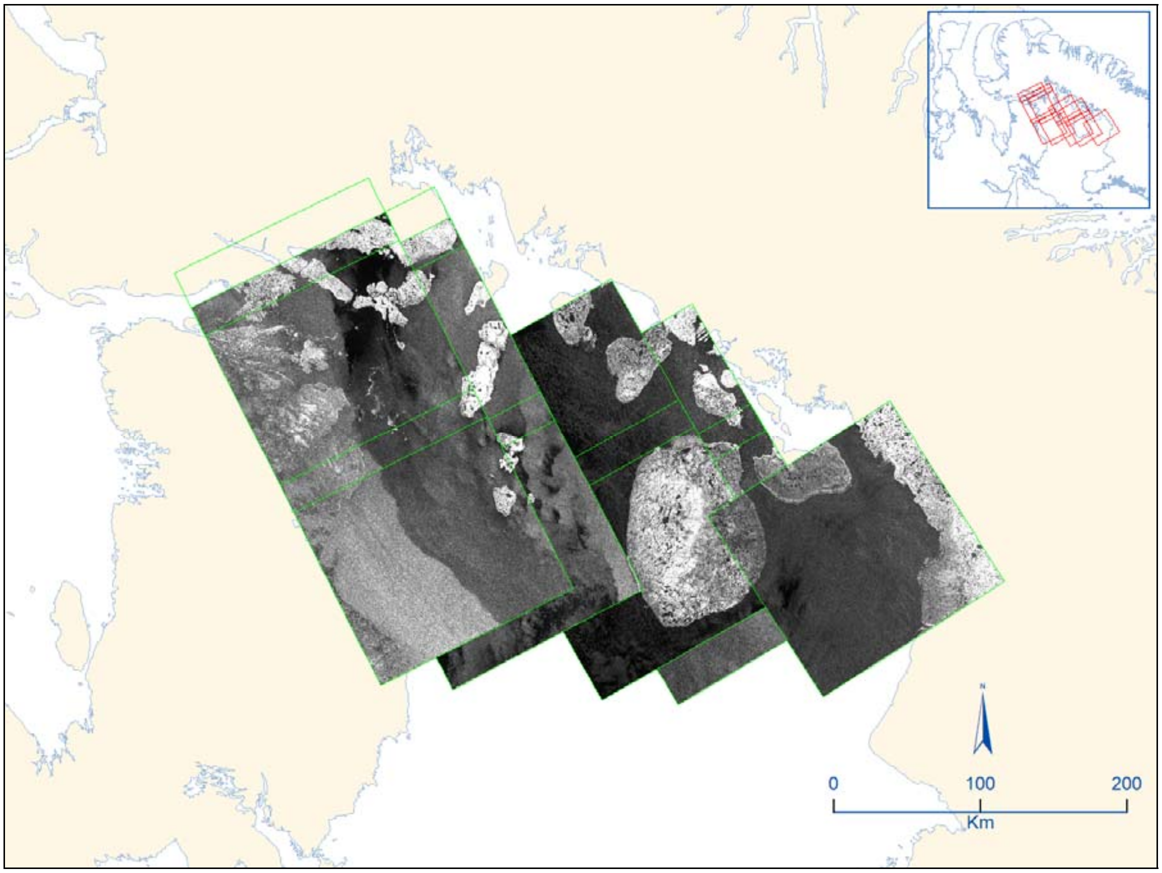


Figure 3 – A series of strip mosaics across the northern part of Foxe Basin illustrating the side-lap of successive ascending passes. Some parts are imaged at two or three different dates.

For the purpose of providing all possible suspected seep locations in the database presented in this report, the authors were not concerned with trying to make determinations on the origin of dark targets that appear in the satellite SAR images. It is well known that dark features in SAR ocean images can be caused by a number of surface phenomena, including biogenic activity (algal blooms), wind or current conditions, and other non-petroleum related natural surfactants (e.g., MacDonald et al., 1993). Backscatter contrast and shape characteristics are the main features that govern the appearance of dark targets or suspect seeps. In our study, a dark target was included if (i) a backscatter contrast of about -10 dB between target and background exists, and in order for it to be isolated from the surrounding sea state, (ii) a sufficiently well defined shape or boundary characteristics of the target area is present. A typical example of these identified dark targets is given in Figure 4.

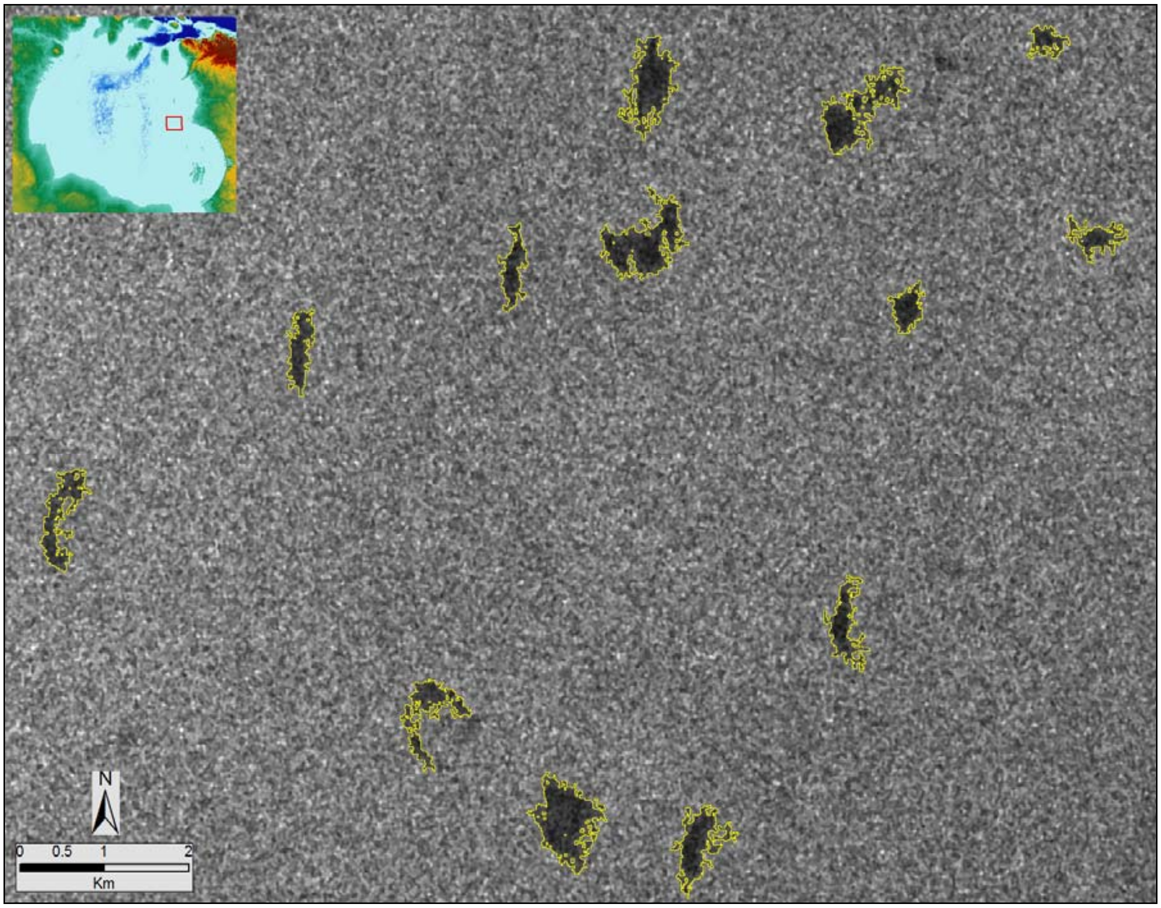


Figure 4 – The appearance of a cluster of dark targets in a RADARSAT-2 image selected as a potential oil seep from the Hudson Bay area (Annex 1, seep Id: HUD-2012_002).

From an examination of the best ice-free scenes, a total of 40 dark targets were identified and subject to image processing with semi-automated procedures to define the perimeter of the feature (edge detection). One or more closed polygons may be included in a target area of identified interest. Multiple targets that appear to cluster (without specifying a cut off distance of separation) are considered as one region of interest for the purpose of this database. The results are presented as a series of visual representations in Annex 1 and the geospatial attributes of the dark targets are included as digital files contained in Annex 2.

Relationship of geological features to dark targets identified on the ocean surface

A summary map of the location of the dark targets superimposed on bathymetry and known pockmarks locations is given in Figure 5 and also in context of the regional offshore geology (Figure 6). It has to be stressed out that the coverage of seafloor mapping with high-resolution side scan bathymetry (pockmark identification) is less than 1% (Roger et al., 2011).

The dark target locations present some intriguing spatial relationships. Multiple coverage and annual repeat observations of persistent dark targets over the same area may suggest the presence of significant and persistent seeps, increasing the likelihood that the basin contains an active petroleum system. From the 2010-2012 data sets available in this study, one occurrence in the southern part of Foxe Basin and three occurrences in Hudson Bay (west, north and central regions) exhibited repeat observations of dark targets. These regions with these repeat characteristics, warranting further monitoring and investigation to determine the origin of these dark targets.

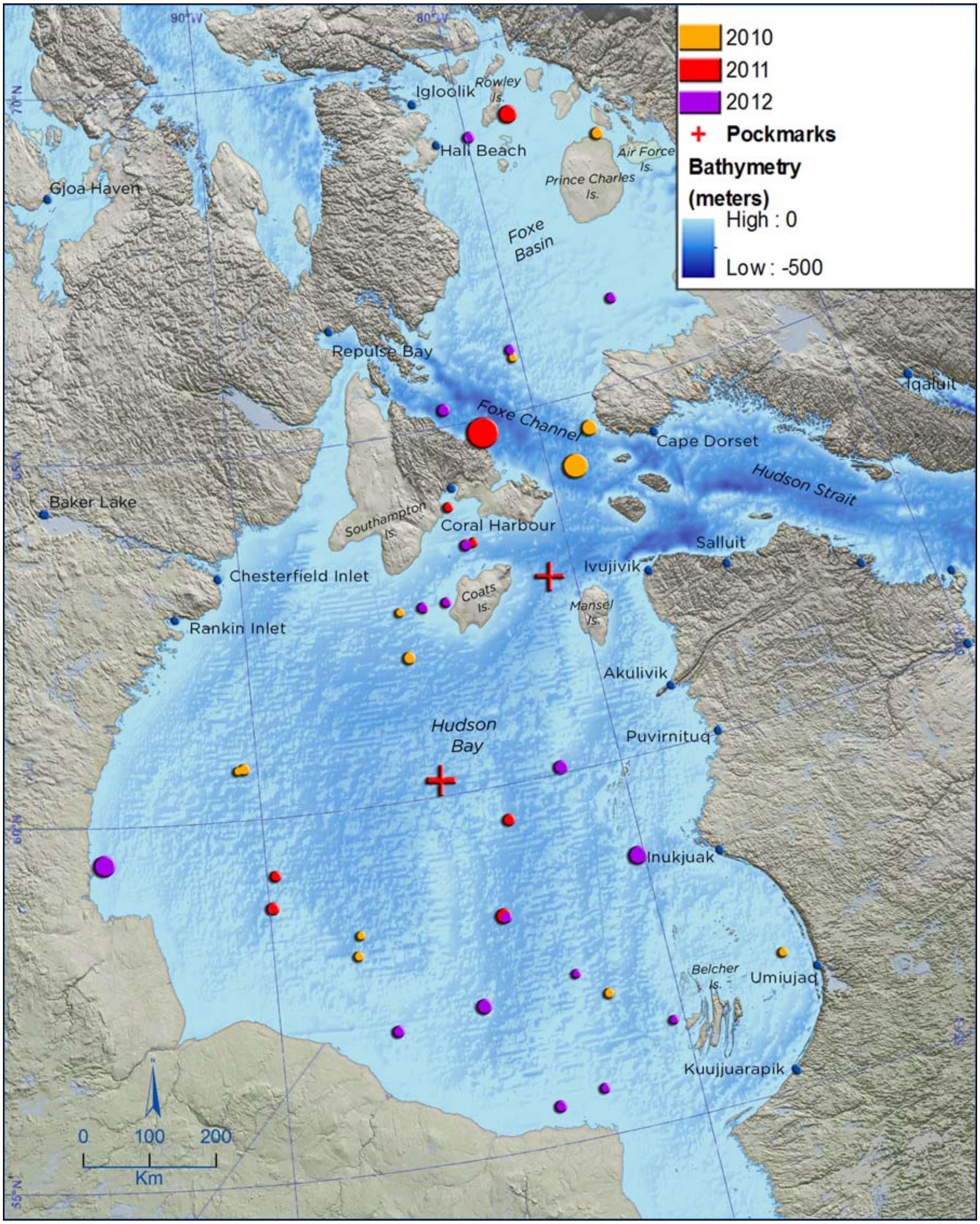


Figure 5 – Bathymetry of Hudson Bay and Foxe Basin with the location of pockmarks from limited seafloor high resolution bathymetry (Roger et al., 2011). Dark targets identified from RADARSAT-2 images indicated by year. Relative symbol sizes displayed are exaggerated and not to the scale of the map.

Whereas Jauer and Budkewitsch (2010) recognized a spatial correlation between seismically visible sea floor mounds with dark targets observed in SAR images at the epicenter in the Davis Strait area, a similar coincidence of radar dark targets in Hudson Bay with known pockmarks is not observed in Figure 4. However, in Hudson Bay both datasets are limited and no high-resolution seafloor side scan bathymetry is available in the Foxe Basin. The three pockmark fields identified through side scan sonar surveys, only covers less than 1% of the Hudson Bay seafloor. Scores of other examples undoubtedly exist. Roger et al. (2011) postulated that some petroleum seepage from deeper bedrock sources may be occurring from these pockmarks. These paired surface and sub-surface features in close proximity could indicate that hydrocarbon seeps are active in the area.

As indicated above, a small number of the dark targets identified on different dates within the same season and from different years appear to occur in close proximity. Repeat observations of discrete dark targets of this kind have a greater likelihood of being related to a hydrocarbon seep origin and are promising evidence in support of an active petroleum system in the region. The higher likelihood of these dark targets being related to a hydrocarbon origin is reflected by a higher confidence level, a parameter assigned to these features in the database. These qualitative parameters used to describe the identified features are discussed more fully below (see Database parameters section).

For the Hudson Bay region, there are a number of observations and hypotheses that can be made from Figure 6 which illustrates where dark targets are located with respect to interpreted seafloor map distribution of geological units. A large number of dark targets seem to be found at the interpreted geological contacts; this may indicate hydrocarbon escape along formational boundaries if the dark targets are indeed related to seeps. However, given the relative imprecision of the submarine geological map, this is a very speculative comment. Some others, on the other hand, are hardly explained by interpreted geology. For example there are features located on the east side of Hudson Bay, within the Proterozoic Nastapoka Arc, where no Paleozoic strata are known to underlie this part of the Bay. West and North of the Belcher Islands, a few dark targets are localized near the Proterozoic-Paleozoic contact. These may also be dark targets unrelated to a hydrocarbon origin (false-positive), however if they were, they could signal fluid escape along the basin margin or the presence of potential hydrocarbon source rock(s) in the Proterozoic succession of the Belcher Islands.

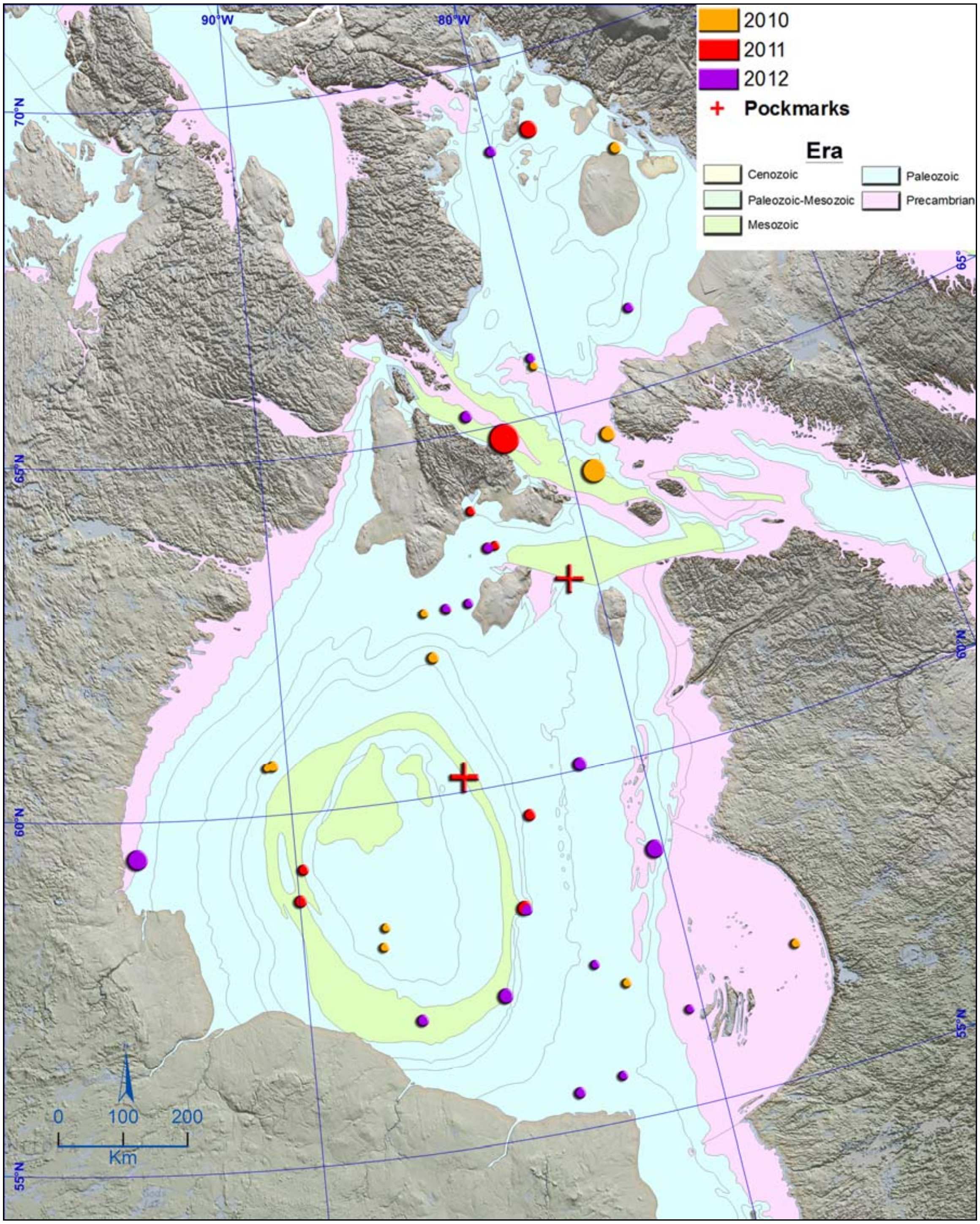


Figure 6 – Simplified geological map of Hudson Bay and Foxe Basin with location of pockmarks and dark targets identified from RADARSAT-2 images indicated by year. Relative symbol sizes displayed are exaggerated and not to the scale of the map.

Near Southampton Island at the northern end of Hudson Bay, some dark targets observed in data sets from 2011 appear close to onshore areas where exposures of Upper Ordovician oil shale are known to occur. One field exposure close to the shoreline is in proximity to the Sixteen Mile Brook (Nelson and Johnson 1966, 1976) south of Coral Harbour, and the other one on the north side of the island at Cape Donovan (Zhang, 2008) are matched with offshore features in SAR that were independently recognized as dark targets. Nowhere else around Southampton Island are these associations observed, suggesting likelihood that these dark targets may have a hydrocarbon origin.

Database parameters

Ten parameters, in addition to the geospatial extents, are recorded for each dark target identified from the RADARSAT-2 data. Each of the 46 dark targets identified from the RADARSAT-2 data are contained in Annex 1 of this report as a series of figures outlining the dark targets selected and listing the meta-data associated with each. Digital geospatial data can be found in Annex 2 as a compressed ESRI shape file "OF7070_NOS.zip" or alternatively as a kml file

Each parameter associated with the dark targets in the database is described below. Most of these pertain to the data collection parameters selected for the RADARSAT-2 C-band radar system. This information can be used to source the original data stored in the RADARASAT-2 archive, available to Government of Canada users through the National Earth Observation Data Framework (NEODF) and to the general public and commercial clients through MacDonald, Dettwiler & Associates Ltd.

The **satellite** identifies the data collection platform for the SAR images examined, which for all data is RADARSAT-2 in this report.

For most SAR systems, there are prescribed **beam modes** that can be selected. We chose the Wide mode, beam position 2 for its resolution, area of coverage and incidence angle range best suited for the detailed ocean imaging desired for this application.

VV **polarisation** was selected over HH and HV polarisations because of the superior clutter to target ratio obtained in ocean images with the vertical transmit and vertical receive (VV) radar polarisation.

The orbital track, or **pass direction** of the satellite, can be either ascending (north bound) or descending (south bound). The imaging difference is largely expressed as function of look direction, however this effect becomes unimportant for the case of flat ocean surfaces (only significant with respect to wind direction, which is not known before acquisition). The main outcome of ascending or descending passes is how they cover the area of interest with as few gaps as possible. Best geometrical coverage is achieved if all the accumulated strips are in the same direction with some side lap. From Figure 2, it can be seen that ascending passes were used in 2010; descending passes chosen in 2011; and a pattern of both in 2012.

The **acquisition date** indicates the year month and day of the image that the dark target was derived from.

The **dark target ID** is simply a short descriptive alpha-numeric string used to index the database, composed a location prefix (Hudson Bay or Foxe Basin), year and incremental number of the features identified.

The **area-ha** parameter is the area in hectares of the dark target enclosed by its polygonal vector outline. For the cases where a group of multiple features are shown, it represents the total aggregate area. To provide a quantitative tracking of the size of the features, segmentation of the dark target was performed and area (in hectares) is recorded. These values in turn can be used to provide estimates of the oil volume these features may contain, should these dark targets be of hydrocarbon origin.

The **orientation** is the principal or long axis direction of dark ocean features. An angle from north, in degrees is given as a non-directional line.

In the browse image provided in the database, a **diameter** value is describe the overall size of the feature or extent of the group of features of interest. The unit of the numbers given is in metres.

From observations of radar images made over the years by a number of workers in different areas around the world, it has been noted that oil or hydrocarbon slicks on the sea surface tend to have similar characteristics in certain environments. Although these characteristics are not universal throughout ocean basins around the world, it has been beneficial to describe the dark targets as variety of **class** types to aid in their interpretation. Thus, in this study, the dark features observed in the ocean RADARSAT-1 images were characterized as objectively as possible to provide some qualitative description on the appearance of the features. This was carried out visually by two independent reviewers according to the size, shapes and abundance of dark features identified and examined in each image. The classification scheme used is divided into eight types of dark targets, illustrated in Table 1.

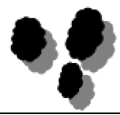
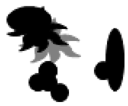
	Linear (string)		Areal (patch)	
Rectilinear Regular				
Curvi-linear Irregular				
Database Code	SL	ML	SR	MR
	SC	MC	SI	MI
	single	multiple	single	multiple

Table 1 – Descriptive matrix illustrating the morphological types of dark target shapes and patterns observed and the corresponding classification codes employed in the database of features observed (Annex 1).

Using a binary decision, dark features with a high aspect ratio are “linear” or string-like and those with a low aspect ratio are classed as “areal” or patch-like. Linear features are either straight “rectilinear” features or “curvi-linear”; similarly, areal features are simple with broadly convex boundaries and “regular” in shape or have complex boundaries and thus exhibit “irregular” shapes. For a given target area of interest an isolated linear or areal dark target is a “single” feature and several occurrences of the main type of dark target grouped in a cluster is classed as a “multiple” feature. Using this approach, a two letter **class** code was employed to describe the slick type observed.

The last parameter is one that provides a three level **confidence** ranking of probability that the dark target could be of hydrocarbon origin. A weak feature or one resembling ocean surface or biological processes are given a lower rank (3); most are assigned an intermediate rank (2) by default as a result of meeting the extraction criteria; and those of highest rank (1) appears to have the best chances and merit further investigation and validation. An example of confidence level 1 would be those dark targets that appear in the same general area in more than one image. The ranking is in part subjective, but are included to highlight the likelihood or relative potential of each dark target to be a naturally occurring hydrocarbon slick.

1. Best candidate – a location either known to be related to an active seep or has characteristics such as a repeated observations.

2. Unknown origin – a dark target that could be equally explained by the presence of a seep or other phenomena. Repeat observations are required to infer its origin.

3. Unlikely to be of hydrocarbon origin – a dark feature that could be the result of phenomena other than a hydrocarbon seep but is included until more information (additional observations) can rule it out with greater confidence as a false positive.

Summary

Forty distinct, anomalous dark targets derived from a visual interpretation of RADARSAT-2 data are further quantified and stored in a database for Hudson Bay and Foxe Basin. This geospatial information can be used as a baseline for supporting further targeted investigations and as an aid in understanding the subsurface geology and hydrocarbon potential of these basins. Whereas many dark features in SAR ocean images may have origins other than from oil slicks, the total number of all targets identified represents a greatly reduced area of interest which merits further investigation as compared to the more than 900,000 square kilometres the two basins occupy.

The long-lived and persistent nature of hydrocarbon seeps is one distinguishing trait that suggests repeat detection of dark features on overlapping images from different dates or similar observations made from year to year enables one to more confidently ascribe the potential origin of these dark features to natural hydrocarbon seeps. Establishing a record of persistence dark target features in SAR images from Hudson Bay and Foxe Basin provides clues to support the hypothesis that presence of an actively discharging petroleum system may exist within these basins. The information extracted from RADARSAT-2 data presented in this database identifies a number of key areas where follow-up investigations should be directed. Results presented in this work should be considered as preliminary findings and independent verification of seep activity in the region requires additional work.

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