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Regional Assessment of Seabed Geohazard Conditions Canadian Beaufort Outer Shelf and Upper Slope: Legacy Data Synthesis

Évaluation régionale des géorisques du fond marin, plate-forme continentale externe et talus supérieur de la portion canadienne de la mer de Beaufort : synthèse des données existantes

Canada

August 2016

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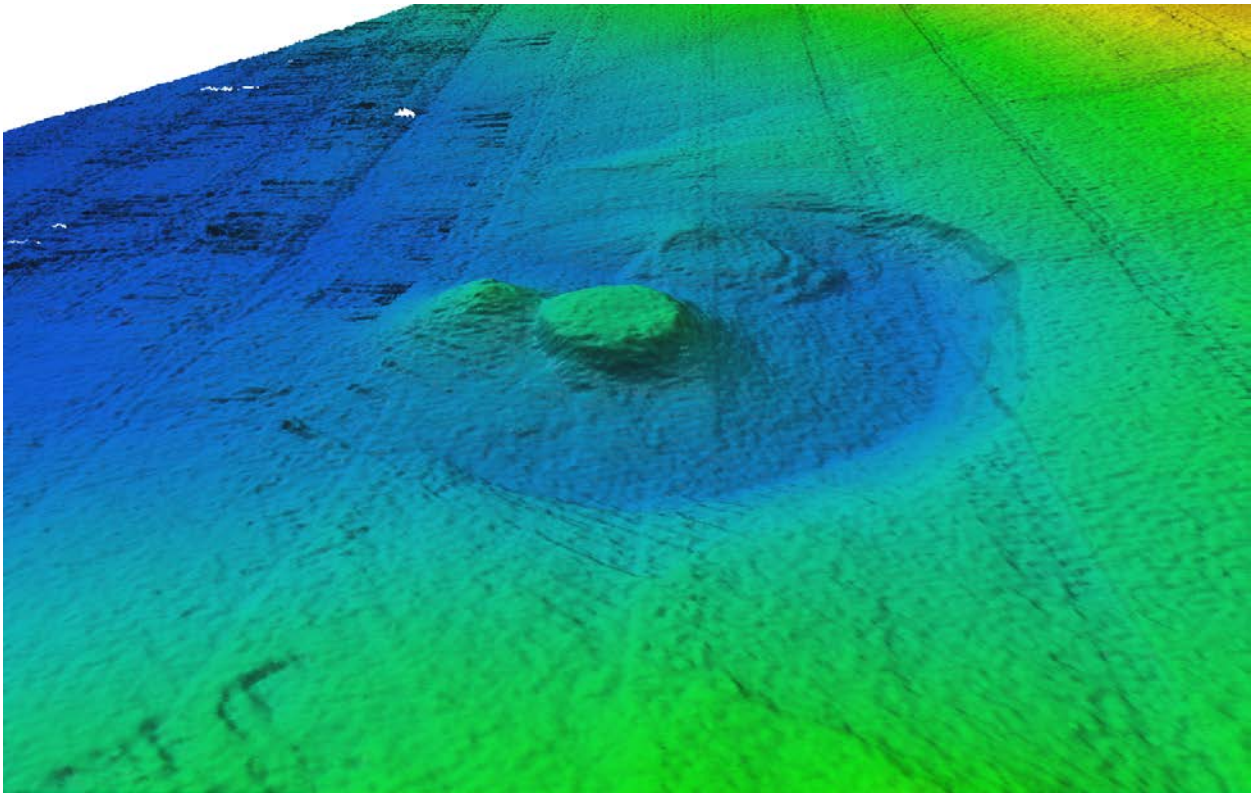
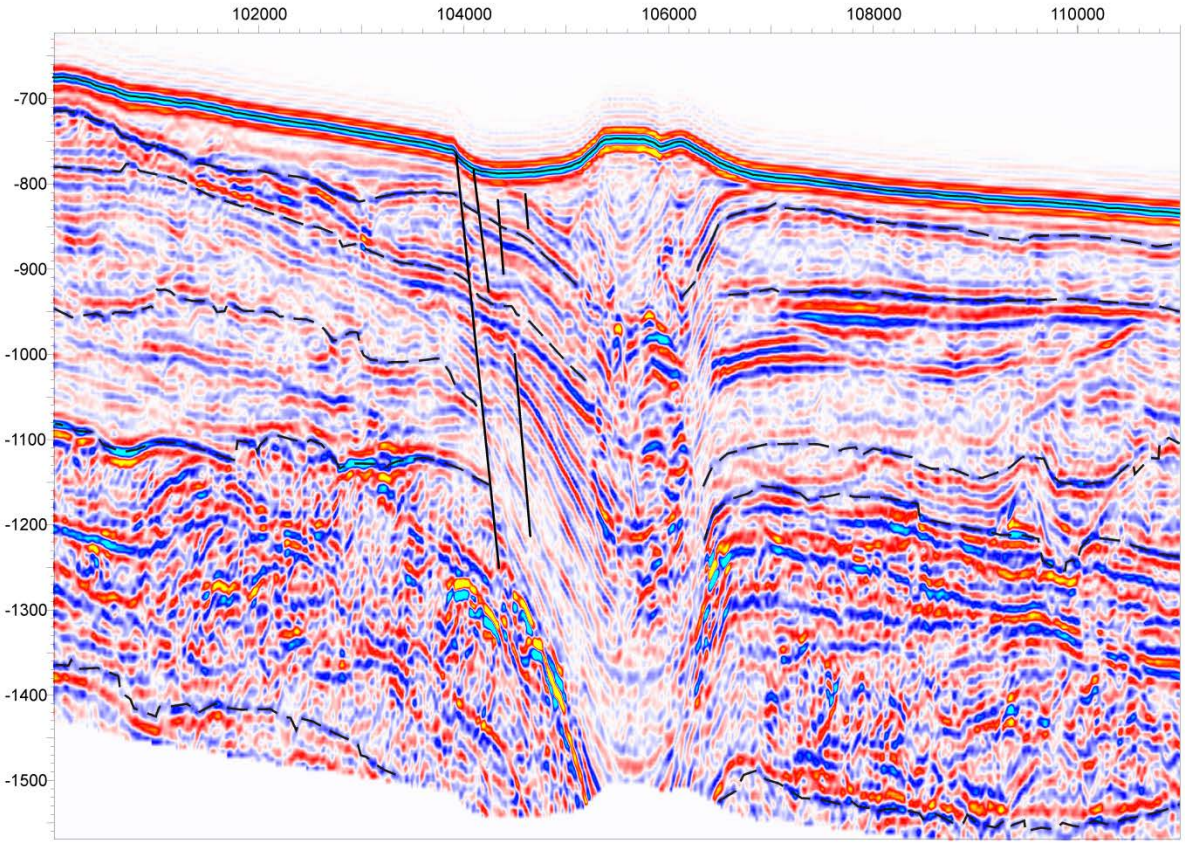
Frontispiece

Left side panel



View to the east of a Fluid Expulsion Feature (FEF) from 3-dimensional multibeam data. The central FEF is flanked by 2 less prominent features, all located in a fault-bound moat. The central FEF is a truncated, planar-toped conical mound with a base diameter up to 900 m and relief of 40 m (vertical exaggeration 5X). See multibeam map view of the FEF Section 2 Plate 5.8 (Arcticnet CCGS Amundsen data URL).

Right side panel (opposite multibeam image)



Two dimension multichannel reflection seismic profile through the same FEF in 750 to 795 m water depth. Note the column of possible gas extending to at least 750 m below the seafloor beneath the FEF, and ring faults that extend to approximately 450 m. See Section 2 Plate 6.6. Seismic data courtesy of ION Geophysical Corporation. Also see Section 2 Plate 5.9 for high resolution subbottom cross-section of the FEF.

Described as seabed/subseabed geohazards affecting hydrocarbon exploration, such instability features can be located and mapped in marine geophysical surveys and avoided during drilling activities. The presence of FEF's (mud volcanoes) can indicate the occurrence of other geohazards including hydrates, shallow gas and formation overpressures (see Section 2 for details).

ABSTRACT

The Environmental Studies Research Funds in collaboration with the Program on Energy Research and Development and the Geological Survey of Canada (GSC) funded a study to investigate the regional distribution of seabed geohazards on the Beaufort outer shelf and upper slope. ArcticNet, Imperial Oil Ltd, BP, Chevron, ConocoPhillips, Shell, ION/GXT, Arctic Institute of North America (AINA) and the GSC provided legacy geological, geotechnical and geophysical data as the basis for the study. The research was conducted both by contract and within the GSC. AINA generated a catalogue of relevant reports, maps and data. Fugro GeoSurveys and the GSC conducted the geological and geophysical research while Michelmore Engineering and the GSC compiled the geotechnical component.

With hydrocarbon exploration extending beyond the shelf edge and down slope, it became evident that little was known about the nature and distribution of seabed and sub-seabed instability conditions in deeper waters. The regional study extended from the outer central Beaufort Shelf and west to include the outer Mackenzie Trough and eastern Yukon margin. Water depths ranged from 100 m at the shelf edge to 1500 m down slope.

Acoustic data included multibeam sonar, subbottom profiles, and single and multichannel 2D and 3D reflection seismic data to 1000 m below seabed. Ground truth data included geotechnical borehole, piston, gravity and box core sediment sample analyses, *in-situ* test results (stratigraphy, sedimentology, physical and dynamic properties) from seabed to 6 m with rare data from 20 to 100 m on the outer shelf. As acoustic and ground truth data sets differed significantly, the approach to reporting results differs.

Data analysis and interpretation led to the identification and mapping of a wide range of geohazard features and processes. These included low strength sediments, slope instabilities and failures, mass transport deposits, ice scouring by glacial, iceberg and sea-ice regimes, fluid venting (fluid expulsion features/mud volcanism, pockmarks), overpressure, faulting, folding, subsea permafrost, gas hydrates, seismicity, and shelf edge erosion. These geohazards occur at and below seabed to depths greater than 1000 m.

A geological and geotechnical stratigraphic and chronologic model of the outer shelf and upper slope for the outer central Beaufort region was developed to provide a spatial and temporal framework to determine the distribution, age and recurrence rates of geohazards. Instability features and processes mapped on the outer shelf and upper slope appear to be less than 25,000 years old.

RÉSUMÉ

Le Fonds pour l'étude de l'environnement, en collaboration avec le Programme de recherche et de développement énergétiques (PRDE) et la Commission géologique du Canada (CGC), a financé une étude visant à étudier la répartition régionale des géorisques du plancher océanique sur la plateforme continentale externe et le talus supérieur de mer de Beaufort. ArcticNet, Imperial Oil Ltd, BP, Chevron, ConocoPhillips, Shell, ION/GXT, l'Institut arctique de l'Amérique du Nord (*Arctic Institute of North America* - AINA) et la CGC ont fourni d'anciennes données géologiques, géotechniques et géophysiques comme fondement de l'étude. La recherche a été réalisée par contrat et par la CGC. L'AINA a produit un catalogue des cartes, des données et des rapports pertinents. Fugro GeoSurveys et la CGC ont réalisé les recherches géologiques et géophysiques alors que Michelmore Engineering et la CGC ont compilé la composante géotechnique.

À mesure que la prospection des gisements d'hydrocarbures s'est avancée au-delà du bord de la plateforme continentale et du bas du talus continental, il est devenu évident qu'on savait peu de choses sur la nature et la répartition des conditions d'instabilité sur et sous le plancher océanique dans les eaux plus profondes. L'étude régionale couvrait une zone partant du centre de la plateforme continentale externe de la mer de Beaufort et s'étendant vers l'Ouest pour inclure la partie extérieure de la dépression du Mackenzie et la partie est de la marge du Yukon. La profondeur de l'eau variait de 100 m au bord de la plateforme continentale à 1 500 m au bas du talus continental.

Les données acoustiques comprenaient des données de sonar multifaisceaux, des données de sondeur de sédiments (*sub-bottom profiler*), et des données de réflexion sismiques en 2D et 3D à canal simple et canaux multiples, jusqu'à 1 000 m sous le plancher océanique. Les données réelles recueillies au sol comprenaient des données issues de trous de forage géotechniques, d'analyses d'échantillons de sédiments prélevés par piston, par gravité ou par carottage, des résultats de tests réalisés *in situ* (stratigraphie, sédimentologie, propriétés physiques et dynamiques) du plancher océanique à 6 m de profondeur, avec de rares données du 20 à 100 m de profondeur sur la plateforme continentale externe. Puisque les jeux de données acoustiques et de données réelles recueillies au sol diffèrent considérablement, l'approche de communication des résultats diffère elle aussi.

L'analyse et l'interprétation des données ont permis de cerner et de cartographier un vaste éventail de caractéristiques et de processus de géorisques. On a entre autres cerné les sédiments à faible résistance, les instabilités et les failles dans le talus, les dépôts de transport de masse, les affouillements glaciaire attribuable aux régimes glaciaires, aux icebergs et à la glace de mer, les écoulements de fluide (expulsions de fluides, volcans de boue, marques d'échappement), les surpressions, la formation de failles et de plis, le pergélisol sous-marin, les hydrates de gaz, la sismicité et l'érosion du bord de la plateforme continentale. Ces géorisques apparaissent sur ou sous le plancher océanique à des profondeurs supérieures à 1 000 m.

On a mis au point un modèle stratigraphique et chronologique géologique et géotechnique de la plateforme continentale externe et du talus continental pour la région externe du centre de la mer de Beaufort afin d'offrir un cadre spatial et temporel permettant de déterminer la répartition, l'âge et le taux de récurrence des géorisques. Les caractéristiques et les processus d'instabilité

cartographiés sur la plateforme continentale externe et le talus continental semblent avoir moins de 25 000 ans.

EXECUTIVE SUMMARY

This ESRF study is a synthesis of Canadian Beaufort Sea seabed and subseabed geological, geophysical and geotechnical data directed towards identifying and describing environmental geohazard conditions that may affect Arctic offshore hydrocarbon exploration drilling in water depths of 100 to 1500 m. The synthesis is divided into 3 sections: (1) Catalogue of industry, government and university data used in the study (2) analysis and interpretation of geological and geophysical data and (3) compilation, analysis and interpretation of geotechnical data. As the cataloguing, geological, geophysical and geotechnical data sets differ significantly, reporting approaches reflect conventional formats familiar to the user. In addition, the 3 sections were conducted simultaneously to accelerate study delivery time. However, the review process took 2 additional years to complete. The following summary highlights the key outputs of each section.

Section 1: Cataloguing of Data

The cataloguing component of this project was undertaken by the Arctic Science and Technology Information System (ASTIS) at the Arctic Institute of North America (AINA), University of Calgary. First, ASTIS identified Canadian Beaufort Sea geological, geophysical and geotechnical publications already listed in the ASTIS database that contained information useful in identifying seabed geohazards. Most of these publications were from the AINA Collection in the University of Calgary Library, but publications from 9 other government and university libraries were also included. Second, ASTIS added to its database geohazard-relevant reports identified in the collections of the Geological Survey of Canada Atlantic. Third, ASTIS prepared a Microsoft Excel workbook describing more than a thousand datasets and reports in the O'Connor collection curate by GSC Atlantic.

Geohazard-relevant publications and datasets were divided into 2 categories: those that were about the geographic “Area of Interest” of this project (Section 1, Figure 8), and those that were about the remainder of the Canadian Beaufort Sea. All of the resulting records were made available to the other project participants and to the public through ASTIS’s Hydrocarbon Impacts database. Detailed instructions for accessing this information are provided in Section 1 of this report. As of July 2016 the database listed 194 geohazard-relevant publications about the “Area of Interest” and 168 publications about the remainder of the Canadian Beaufort Sea. The Excel workbook describing the O’Connor collection listed 48 geohazard-relevant reports and 125 datasets about the “Area of Interest” and 77 reports and 359 datasets about the remainder of the Canadian Beaufort Sea. ASTIS welcomes the opportunity to catalogue additional reports and datasets as they become available.

Section 2: Geological and Geophysical Syntheses

This section describes a wide range of seabed and subseabed geohazards, some for the first time in public literature, that have been identified from acoustic and seismic geophysical data, sediment cores and grab samples collected since the 1970’s up to and including 2010. The result, A ‘Handbook of Geohazard Conditions’, describes and interprets features, processes and anomalies

that represent potential geohazards from the present seafloor to a sediment depth of approximately 1000 m. The well-defined Late Quaternary chronostratigraphy of the shelf is

combined with new knowledge from the continental slope to produce a regional shelf-to-slope evolutionary chronostratigraphic framework presented here for the first time (see Enclosure 9 for synthesis).

Geographically, the focus of the Handbook is on the continental slope, a region that was largely unknown prior to the early 2000s. However, the geohazard problems of subsea permafrost, including acoustic and seismic detection, are also discussed for a portion of the Beaufort Shelf extending from the slope south to the Amauligak F-24 discovery well. At the F-24 location in 1988 a geotechnical borehole was drilled to a depth of 468 m below seafloor, and to date is the only deep ice-bearing permafrost sampled borehole on the shelf. Geohazards on and beneath the outer Mackenzie Trough and Yukon Shelf are also described.

Geohazards on the continental slope include evidence for slope failures, such as the large Ikit Slump, a massive underwater landslide that may have occurred as recently as 1000 years ago. Seafloor offsets/faults also indicate regions of instability and may represent the locations of potential future landslides. A series of concentric ring faults with normal throws of 5 m to 10 m define part of the margin of the moat surrounding a large Fluid Escape Feature (see 2 frontispiece images). Buried tens of metres below the seafloor, sheet-like and ribbon-like mass transport deposits (MTDs) are evidence of previous landslide events of different scales and result from different failure processes. Still deeper and older slope failure events in the form of buried MTDs are visible on 2D and 3D seismic reflection profiles. Small-scale, non-tectonic normal faults occur within individual seismic slope units, and are most likely the expressions of previous regressive slope failure events. Other small-scale faults are the result of sediment compaction.

Evidence of fluids being expelled from the seafloor of the slope is seen in the form of large-scale conical to flat-topped Fluid Escape Features (FEFs). FEFs are formed by the eruption of fluids/sediments from deep below the seafloor. Some are associated with eruptive flows that can be imaged and mapped using sub-bottom profile data. Pockmarks, small-scale circular depressions related to fluid escape, are also present but largely restricted to a small region on the upper slope. A narrow belt of small-scale FEFs occurs along much of the shelf margin. These closely-spaced conical features form an FEF Zone that coincides with the outermost limit of subsea permafrost. Methane gas seeping from below the seafloor is imaged as water column anomalies in multibeam data along a portion of the shelf margin where the FEF Zone was probably removed during the Ikit Slump event. The anomalies are also coincident with the seaward limit of subsea permafrost at approximately 100 m water depth.

On the upper slope a shelf-parallel region of buried relict ice keel scour marks in the Paleo-Scour Zone may indicate modification of sediment physical properties (due to the relict scouring process) well below the modern seafloor. Beneath the Paleo-Scour Zone a region of older Mega-Scale Glacial Lineations (MSCLs) marks the position of a southwest-moving glacial ice melange that grounded on the seafloor. Other paleo-scour zones are located in the Mackenzie Trough, and in deep water on the Beaufort Shelf below 60 m. The modern saturated scour zone is in shallower water with modern scouring occurring to greater than 50 m water depth.

A linear region of eroded seafloor along the upper slope is marked by truncated sedimentary strata. Erosion may be the combined result of wave action during Holocene marine transgression and modern east-flowing seafloor ocean currents. A belt of deeply eroded sediments also occurs along the western flank of the Mackenzie Trough. Here sediments have been eroded to expose an old buried ice scoured surface. Strong currents have sculpted exposed sediments of the relict scour topography into comet marks.

Amplitude anomalies detected in 2D seismic reflection data occur on the slope between approximately 200 m and 500 m BSF. Trough-over-peak reflection pairings are consistent with free-phase gas. The anomalies have sharp lateral gradients, apparent frequency loss and may exhibit velocity pull-downs beneath them. The geophysical expression of gas hydrates in 2D seismic data is a Bottom-Simulating Reflector (BSR), which often corresponds with the base of the hydrate stability zone. Analysis of seismic data available for the present study did not display any potential BSRs beneath the continental slope. However, conditions are thought to be favourable for gas hydrate development.

The existence of shallow gas, FEF's, pockmarks, potential for hydrates and subsea permafrost-trapping fluids suggests the outer shelf and upper slope may be subject to overpressures that may be difficult to predict in terms of degree, geographic location and depth below seabed.

The presence of shallow gas, small-scale FEFs and pockmarks associated with the northern edge of permafrost along the shelf margin suggest that underlying sediments may be subject to overpressures. Similarly the presence of possible free gas and of gas hydrates, imply the potential for overpressured strata beneath the continental slope. In addition large scale FEFs on the continental slope imply long-lived seepage from depth of possible hydrocarbons

Shallow Water Flow (SWF) is a potential geohazard when drilling through overpressured strata and has been rarely encountered during drilling operations on the shelf. Beneath the slope SWF is possible where sedimentation rates have been high .

Section 3: Geotechnical Synthesis

A synthesis of the geotechnical legacy data has been completed in order to locate, catalogue, digitize, database and analyze geotechnical data acquired in the Canadian Beaufort Sea from 1965 through 2010. The analysis of the compiled geotechnical data has been used to characterize geotechnical properties of the surficial sediments for the assessment of seabed foundation conditions, slope stability and potential geohazards. Laboratory testing has been conducted on recent (2008 through 2010) Geological Survey of Canada Atlantic (GSCA) samples in order to provide additional geotechnical properties to enhance the engineering utility of the compiled data sets. Geotechnical data were reviewed and summarized in digital format for 17 industry and 183 government sample sites. There was a total of 104 boreholes and vibracores where analog data were digitized. The government data were mostly in a digital format and included 36 CPT sample sites in the Amauligak Area. The GSCA samples were limited to < 9 m below seafloor (mbsf). The sediments were characterized into 6 geotechnical units using mostly grain size, Atterberg Limits and bulk density data. The developed geotechnical characterization was correlated with

the geological/geophysical model for the outer shelf and upper slope. To a first approximation, geological/geophysical stratigraphic units could now be described in terms of their geotechnical properties.

The stress history using consolidation data indicates the near surface sediments (<10 mbsf) on the continental shelf and the upper 2 mbsf on the continental slope are over consolidated. The sediments below 10 mbsf on the shelf are either normally consolidated or under consolidated while the sediments below 2 mbsf on the upper slope are normally consolidated.

A preliminary slope stability assessment of near surface sediment on the continental slope was performed using a Total Stress Analysis (TSA) and Effective Stress Analysis (ESA). The only potential triggering event considered was rapid accumulation of sediment on the continental slope. Under static condition (i.e. no external triggers) the calculated Factor Of Safety (FOR) is greater than 7 for a sediment thickness of up to 50 m. However, if the seabed is loaded with a rapid sediment accumulation, the factor of safety will reduce to less than 1 under certain conditions.

For example, the thickness of the rapidly accumulated sediment required to reduce the FOS to 1 ranges from 7 m deposited on an underlying 40 m thick sediment unit to 15 m for a 1 m thick underlying sediment unit. The TSA analysis suggests that at existing slope profiles, the critical rapidly deposited sediment thickness is on the order of 15 to 20 m.

The scarcity of sample sites requires substantial extrapolation to develop a generic geotechnical model. The model described uses three cross sections. The variance in the 3 cross sections has minimal effects on slope stability. As such, a generic slope stability model has limited value. Site specific models resulting from concentrated geological and geotechnical sampling (I.e. CPT tests and geological/geotechnical boreholes) would be more beneficial in determining risk.

INTRODUCTION

This Environmental Studies Research Funds (ESRF) study was initiated because of the need to understand the impact of the environment on hydrocarbon exploration in deeper waters of the Canadian Beaufort Sea. Offshore exploration drilling between 1972 and 2006 (hiatus 1986 to 2005) was confined to the shelf in water depths less than 60 m. In 2009 exploration interest turned to deeper waters of the outer shelf and upper slope in 100 to 1500 m. Little was known about the occurrence and distribution of potential environmental geohazards that could adversely affect the integrity of drilling systems in these deeper waters. However, the seabed and sub-seabed geological, geophysical and geotechnical data collected in the first phase of drilling, coupled with the IOL, BP, ION/GXT and ArcticNet data acquired in 2009 to 2011, provided a significant contribution to a 'legacy' dataset to investigate the environmental factors of concern to deep water exploration drilling from both the industry and regulatory perspectives.

A joint industry, government and university project involving IOL, BP, Chevron, ConocoPhillips, Shell, ArcticNet, Arctic Institute of North America (University of Calgary), and the Geological Survey of Canada was implemented by ESRF. The Offshore Geotechnics Project of the Federal Program on Energy Research and Development (PERD) provided additional funding to supplement data interpretation. Natural Resources Canada, through the Geological Survey of Canada contributed scientific and technical expertise and laboratory facilities to support data analysis and interpretation. A Technical Advisory Group (TAG, see below) made up of industry, government and university representatives was established to guide the study. The project was divided into 3 components to allow for parallel research to be conducted from the start: (1) cataloguing of datasets and reports, (2) geological/geophysical synthesis and (3) geotechnical synthesis.

Through Public Works and Government Services Canada, work statements prepared by the TAG for the 3 components were put out to bid. The Arctic Institute of North America was selected to conduct the cataloguing, Fugro GeoSurveys Ltd. the geological/geophysical synthesis and Mitchelmore Engineering Consulting Limited the geotechnical synthesis. GSC scientists and technicians also participated in all 3 components of the study which were conducted in Calgary, St John's and Dartmouth respectively and coordinated out of Dartmouth.

The TAG identified the geographic area to be assessed by the study, a block along the outer shelf and upper slope which included the IOL, BP and Chevron lease blocks (see Section 1, Figure 8). A small block was added to include the site of the significant Amauligak oil discovery. This area was of key interest to the synthesis as the only deep geological/geotechnical/permafrost borehole in the Beaufort Sea was drilled to 500 m below seabed in the Amauligak lease block in 1988. The drilling results were included in the geological/geophysical component of the study.

Over the first 2 years of the study the Arctic Institute of North America (AINA) conducted a comprehensive search for relevant industry, government and university datasets and reports. These items, including reports, maps, data on rolled or folded chart paper (seismic, bathymetry and side-scan sonar), magnetic tapes, microfilm, etc., were described and catalogued in AINA's

Arctic Science and Technology Information System (ASTIS) and made publicly available in the

Hydrocarbon Impacts database. About 320 items were catalogued for the study area, and an additional 560 items outside the study area. Section 1 of this report describes how to access this information.

While AINA was locating and cataloguing data related to the outer shelf and upper slope, Fugro GeoSurveys Ltd., Mitchelmore Engineering and the GSC initiated the analysis of geological, geophysical and geotechnical data. As AINA identified new relevant data this information was added to the 2 syntheses.

The study includes the data catalogue, the assessment of identified seabed and sub-seabed geohazards, and an interpreted model of the stratigraphy, structure and geological framework in which geohazards have been identified.

The last step in the study was to link the geological/geophysical and geotechnical components. Two orthogonal schematics were generated for the outer central shelf region whereby the geological model developed in Section 2 was draped over the geotechnical model developed in Section 3 (see final chapter in Section 3). This is a key product of the study. It represents an initial attempt to integrate 3 datasets in the area of interest. It will be obvious to the reader that the 2 orthogonal schematics are the result of the extrapolation of limited data and represent a starting point for future research.

The dataset and report catalogue were mostly completed in 2013. The geological/geophysical and geotechnical syntheses were completed in 2015. Draft components were reviewed by TAG members, then went through the GSC science review process for open files.

From a scientific perspective the study covers legacy data to 2013 and represents the knowledge base as of 2014. Since then, ongoing analyses by researchers have continued and the reader is directed to also access the latest literature to have an updated understanding of seabed geohazard conditions in the outer shelf and upper slope of the Canadian Beaufort Sea.

ACKNOWLEDGEMENTS

The project leader would like to thank the members of the Technical Advisory Group for efforts made to provide data, guidance during project planning and execution, and in the report review. Thanks to Shannon Christoffersen Vossepoel for the review of Section 1 (cataloguing of datasets and reports), Ned King and Gordon Cameron for the scientific review of Section 2 (geological and geophysical component) and Jorn Landva for the scientific review of Section 3 (geotechnical component). Special thanks to ION/GXT for contributing 2D seismic reflection data in the study area.

The ArcticNet Network of Centre of Excellence and collaborations with IOL and BP 2009-201 onboard Canadian Coast Guard Ship *Amundsen* provided the key data sets that underpinned this study.

In addition, the study authors would like to thank members of the Hunters and Trappers Committees of Inuvik, Tuktoyaktuk, Aklavik, Sachs Harbour, Paulatuk and Ulukhaktok for

ongoing dialogues during community visits 2001-2009. These discussions were important in ensuring that environmental concerns raised by the communities (such as seabed ice scouring, subsea permafrost, slope stability) were dealt with in this study. In particular, insightful discussions over time with Billy Day, Vince Stein and Billy Archer helped focus the study.

Technical Advisory Group

Hugh Bain: Environmental Studies Research Funds

Genevieve Carr: Indian Affairs and Northern Development Canada

Ross Goodwin, Shannon Christoffersen Vossepoel: Arctic Institute of North America

Kevin Hewitt: Chevron Canada

Ben Seligman: Shell Canada

Karen Muggeridge: ConocoPhillips

Jim Thomson, Jeff Dingler: British Petroleum (BP)

George Reed, Jim Hawkins, Neil Darlow: Imperial Oil Limited (IOL)

Steve Blasco: Natural Resources Canada was project leader.

Regional Assessment of Seabed Geohazard Conditions Canadian Beaufort Outer Shelf and Upper Slope: Legacy Data Synthesis

Section 1

Cataloguing Datasets and Reports

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July 2016

Prepared in partial fulfillment of Public Works and Government Services Canada contract no. 23420-119230/001/HAL.

Abstract

The cataloguing component of this project was undertaken by the Arctic Science and Technology Information System (ASTIS) at the Arctic Institute of North America (AINA), University of Calgary. ASTIS completed three main tasks:

- ASTIS identified Canadian Beaufort Sea geological, geophysical and geotechnical publications already listed in the ASTIS database that contained information useful in identifying seabed geohazards. Most of these publications were from the AINA Collection in the University of Calgary Library, but publications from nine other government and university libraries were also included.
- ASTIS added to its database geohazard-relevant reports identified in the collections of the Geological Survey of Canada Atlantic (GSC Atlantic).
- ASTIS prepared a Microsoft Excel workbook describing more than a thousand datasets and reports in the O'Connor collection held by GSC Atlantic.

Geohazard-relevant publications and datasets were divided into two categories: those that were about the geographic “Area of Interest” of this project (Fig. 8), and those that were about the remainder of the Canadian Beaufort Sea. All of the resulting records were made available to the other project participants and to the public through ASTIS’s Hydrocarbon Impacts database. Detailed instructions for accessing this information are provided in this report.

As of July 2016 the database listed 194 geohazard-relevant publications about the “Area of Interest” and 168 publications about the remainder of the Canadian Beaufort Sea. The Excel workbook describing the O’Connor collection listed 48 geohazard-relevant reports and 125 datasets about the “Area of Interest” and 77 reports and 359 datasets about the remainder of the Canadian Beaufort Sea. ASTIS would welcome the opportunity to catalogue additional reports and datasets.

For more information about ASTIS and the catalogues prepared during this project please contact: Shannon Christoffersen Vossepoel, 403-220-4033, astis@ucalgary.ca.

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First and foremost, ASTIS would like to thank the project leader, Steve Blasco of the Geological Survey of Canada Atlantic, for his help. Steve was the driving force behind the project and was always available to provide advice and answer our questions.

ASTIS staff members attended meetings of the Technical Advisory Group (TAG) on June 23, 2010, Jan. 25, 2011, Dec. 7, 2011, and Oct. 11, 2012. We would like to thank all of the TAG members for their suggestions and support during these meetings.

ASTIS would also like to thank the following people for their assistance during Pamela Scowen's visit to GSC Atlantic in February 2011:

- Linda Ostrom (GSC Atlantic) created the original Excel workbook that Pam expanded by adding detailed information on the O'Connor collection.
- Kate Jarrett (GSC Atlantic) was extremely helpful getting Pam set up in the Marine Geoscience Collection Facility at GSC Atlantic and showing her where the O'Connor Beaufort Sea reports and data reside.
- Bob Harmes (now retired but formerly at GSC Atlantic) was instrumental in helping Pam identify and document the various types of geophysical data encountered.

Contents

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Introduction

The project "Regional Assessment of Seabed Geohazard Conditions Canadian Beaufort Outer Shelf and Upper Slope: Legacy Data Synthesis" is hereinafter referred to as "Beaufort Seabed Geohazard Legacy Data Synthesis".

The cataloguing component of the Beaufort Seabed Geohazard Legacy Data Synthesis (BSGLDS) project was undertaken by the Arctic Science and Technology Information System (ASTIS) at the Arctic Institute of North America, University of Calgary. ASTIS is Canada's national northern database, and contains 82,000 records describing publications and research projects about northern Canada and the adjacent marine regions. ASTIS is available for free from a bilingual website at www.aina.ucalgary.ca/astis. For more information about ASTIS please contact: Shannon Christoffersen Vossepoel, 403-220-4033, astis@ucalgary.ca.

ASTIS contains 7350 records describing northern petroleum industry reports, most of which have been donated to the Arctic Institute of North America (AINA) Collection in the University of Calgary Library. Of particular interest to the BSGLDS was the library of Canadian Marine Drilling Ltd. (CANMAR), which was donated to AINA in 1997 and was added to ASTIS using ESRF funding. This library contained reports from CANMAR and its parent, Dome Petroleum, as well as a large number of reports from other oil and gas companies working in the Beaufort Sea. ASTIS also describes Beaufort Sea geotechnical and granular resources reports supplied by Indigenous and Northern Affairs Canada's former Land and Water Management Directorate as part of ASTIS's work on the Northern Granular Resources Bibliographic Database.

Sixteen subsets of ASTIS, most of which have their own government, industry or university sponsors, are available online. Two of these, the Hydrocarbon Impacts database sponsored by Indigenous and Northern Affairs Canada and the Inuvialuit Settlement Region Database produced in cooperation with the Inuvialuit Joint Secretariat, now contain all of the ASTIS records identified or created for the BSGLDS. As described in more detail below, the Report Group menu of the Hydrocarbon Impacts database at www.aina.ucalgary.ca/hi was used to provide access to the results of the BSGLDS cataloguing component.

Most legacy data identified in this study predate the digital age and exist as hard copy reports, maps, track plots, acoustic profiles, core logs, etc. which had to be located, assessed, scanned catalogued and curated in the libraries discussed below. Scanned reports exist as hard copy, and maps and figures etc. are not georeferenced.

Identify Relevant Reports Already in ASTIS

The contract for the cataloguing component of the Beaufort Seabed Geohazard Legacy Data Synthesis was signed on Dec. 9, 2010. Work began immediately to identify Beaufort Sea geological, geophysical and geotechnical reports already in ASTIS that contained information useful in identifying seabed geohazards. These reports were divided into two categories: those that were about the geographic "Area of Interest" of this project, and those that were about the remainder of the Canadian Beaufort Sea.

The “Area of Interest” during the early months of this work was the large T-shaped region in Fig. 1. It included the outer shelf and upper slope of the Canadian Beaufort Sea in water depths of 50 to 1500 m, but also included a corridor to 25 m in the area of ConocoPhillips Canada’s Amauligak field and the Kugmallit Channel. When working to identify relevant reports ASTIS used a 1:250,000 map from Inukshuk Geomatics Inc. that contained detailed information about bathymetry, wellsites and leases.

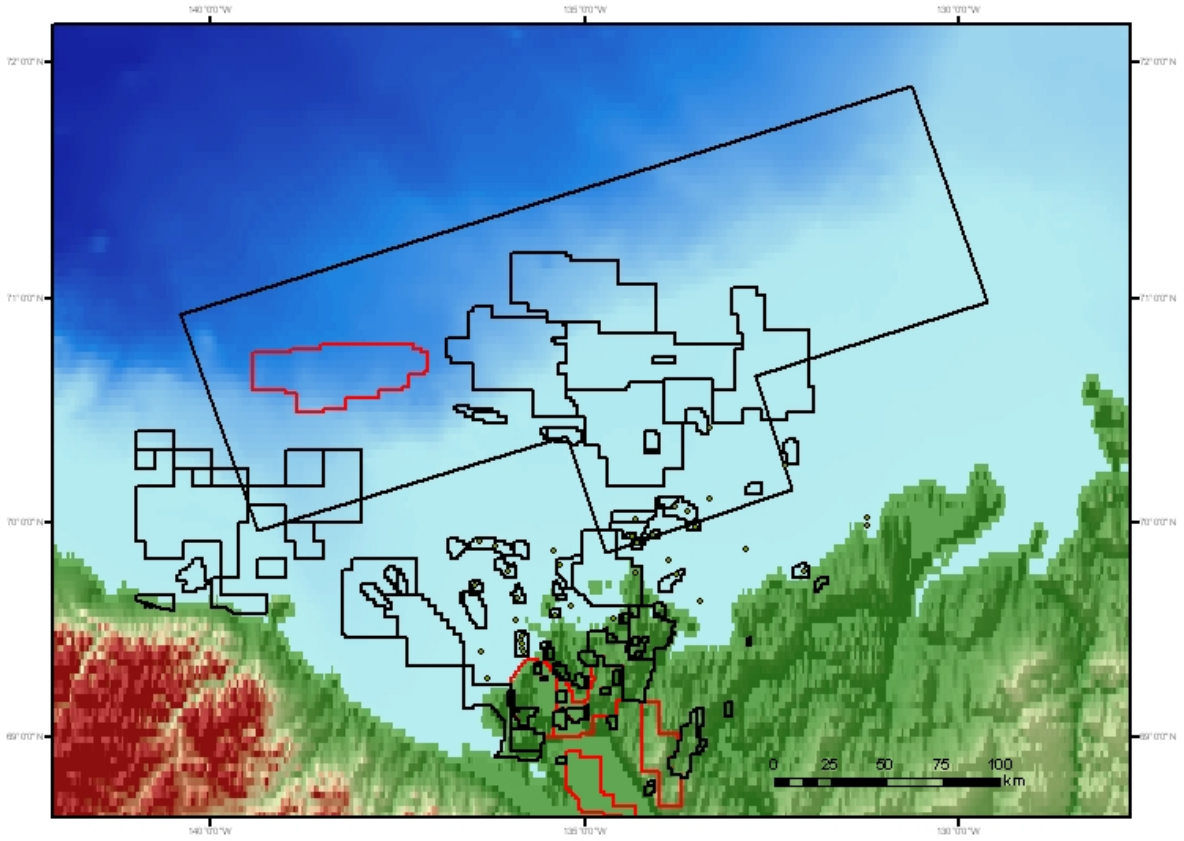


Fig. 1. December 2010 “Area of Interest”.

Reports that appeared, based on their ASTIS records, to contain information useful in identifying seabed geohazards and to fall within the geographic “Area of Interest” were examined in detail in the AINA Collection. Reports were considered to fall within the “Area of Interest” if any part of the area studied overlapped with any part of the “Area of Interest”. For a few of the reports that were selected, much of their information falls outside of the “Area of Interest”. When reports contained geohazard-relevant information about the “Area of Interest” their ASTIS records were tagged for retrieval and were upgraded to add additional information that would be useful to the other two BSGLDS contractors.

Reports that appeared, based on their ASTIS records, to contain information useful in identifying seabed geohazards but which fell outside the geographic “Area of Interest” were tagged for retrieval but were not examined in the AINA Collection.

By January 25, 2011, ASTIS had tagged the records of 127 reports about the geographic “Area of Interest” and 106 reports about the remainder of the Canadian Beaufort Sea. These records were made available from the Report Group menu of ASTIS’s Hydrocarbon Impacts database at www.aina.ucalgary.ca/hi. Most of the “Area of Interest” records were about the Amauligak/Kugmallit corridor, with only about 10% about the outer shelf and upper slope.

Catalogue Datasets and Reports at GSC Atlantic

From February 7 to 28, 2011, ASTIS Information Analyst Pamela Scowen visited the Geological Survey of Canada Atlantic, Dartmouth, Nova Scotia to catalogue datasets and reports. The following is a detailed report on Pam’s work during that trip.

On Feb 10, 2011, Steve Blasco and Pam discussed what Steve wanted accomplished during Pam’s time at GSC Atlantic. The priority was to go through the Beaufort Sea collection, a series of regional geological, geophysical and geotechnical Beaufort Shelf reports and data that Steve had prepared with M.J. O'Connor & Associates Ltd. as collaborative studies with industry under confidentiality agreements. These reports and data constitute the O’Connor collection for this ESRF cataloguing project.

The O'Connor collection is housed in the GSC Atlantic Marine Geoscience Collection Facility within a bank of filing cabinets in drawers numbered 1-52 (Fig. 2).

Fig. 2. Part of the GSC Atlantic Marine Geoscience Collection Facility. The upper 10 filing cabinets (drawers 1-40) and the lower, back 3 filing cabinets (drawers 41-52) contain the O'Connor collection.

Linda Ostrom (GSC Atlantic) had previously completed a first-pass cataloguing of the collection using Microsoft Excel. Each report, file folder or envelope was briefly described and assigned a sequential number. Loose rolls of data (seismic and bathymetry mainly) were grouped together in specially labelled drawers, but individual rolls were generally not given individual sequential numbers.

Pam started with Linda's original Excel workbook, renamed it “OConnorReportsData.xlsx”, and systematically worked through every item in the filing cabinet drawers. Each entry was expanded by adding a detailed description, and items that were within the BSGLDS “Area of Interest” or the remainder of the Canadian Beaufort Sea were tagged.

The O’Connor collection consists of: paper reports, seismic data (paper rolls), bathymetry data (paper rolls), side-scan sonar data (on “wet paper” which is generally folded but sometimes rolled), magnetic tapes, and many file folders or page-size envelopes of paper material (Figs. 3 to 7). There were numerous empty file folders, file folders with correspondence or handwritten notes, graphs, and calculations, transparent overlays, and also some folders with material that had no relevance to the Beaufort Sea.

Most of the reports are contained within the first 8 filing cabinet drawers: however, there are various reports scattered throughout the other 44 drawers. In addition to determining if the reports were within the BSGLDS “Area of Interest”, each report was searched in ASTIS. The ASTIS record number was added to the entries where applicable. Two hundred and eighty-six reports are tabulated in the “Reports” worksheet of the Excel workbook “OConnorReportsData.xlsx”.

Fig. 3. Typical drawer with reports. The BIO number 208 is visible on one of the reports.

Bob Harmes, an employee at GSC Atlantic until his retirement several years ago, helped Pam sort through and document the other 44 filing cabinet drawers which contain a diverse assortment of material. This information is recorded in the “Data” worksheet of

“OConnorReportsData.xlsx”. Where possible, it was determined if the material pertained to the BSGLDS “Area of Interest”.

Fig. 4. Map cases, file folders, envelopes, and small boxes with bathymetry data. The BIO numbers are written on the green stickers.

Pam and Bob documented and sorted 24 full drawers and 6 partially-full drawers of bathymetry/sonar/seismic data (Fig. 5).

Fig. 5. Drawer with seismic, sonar, and bathymetry data. The long seismic rolls are lying flat; the smaller, thicker bathymetry rolls are upright at the front of the drawer. Sonar records are on folded wet paper and generally stamped with time and location information.

Some rolls of seismic data were well-annotated with stamps or written notes identifying the date, year, ship name, line names, and line numbers (Fig. 6). Unfortunately, many of the rolls of seismic data were poorly annotated and Pam and Bob had to guess which cruise, year, lines, etc. the data belonged to by trying to match up the writing style or colour of ink of the notes on the roll. Pam and Bob did not have time to reroll each piece of data to the beginning of the line to see if more information was written on the other end of the roll.

Fig. 6. Rolls of seismic data from the Hudson 81 cruise (drawer 18). The rolls of seismic data are well marked for this cruise. Maps and log books belonging to the Hudson 81 cruise were put in this drawer.

Fig. 7. Side-scan sonar records on folded wet paper. These sonar records were well-marked with the stamps indicating where and when the data were collected.

Most of the side-scan sonar records had identifying stamps (Figs. 5 and 7). The location of the bathymetry data, however, was very difficult to determine as there was very little information written on the visible ends of the rolls.

Pam spoke to Steve Blasco for about half-an-hour on Sunday Feb 20, 2011, to discuss how the work was progressing. At that time Steve requested that Pam and Bob go to McGregor Geoscience Ltd. in Bedford, Nova Scotia, to recover Beaufort Sea reports that had been lent to McGregor numerous years previously. Pam and Bob were also asked to document the data that McGregor collected when the company was working in the Beaufort Sea and still had in storage.

With the help of Jane Hawken, the Geoscience Manager at McGregor Geoscience, Pam and Bob were able to quickly pull out the relevant 17 Beaufort Sea reports from McGregor's well-organized report storage room. Unfortunately, the boxes of Beaufort Sea data were not as easy to isolate. Approximately three years before, McGregor moved their office from Halifax to Bedford and their data storage room had not yet been reorganized. The boxes of Beaufort Sea data were not in one area but were scattered throughout the data storage room and interspersed with all their other archived data. Rather than start reorganizing McGregor's entire archives, Pam and Bob decided that their time would be best spent finishing their documentation of the Beaufort Sea filing cabinets at GSC Atlantic.

At the conclusion of this phase of the Beaufort Seabed Geohazard Legacy Data Synthesis cataloguing component all 52 drawers of O'Connor Beaufort Sea data had been documented in the Excel workbook OConnorReportsData.xlsx. The workbook was made available for download from the Report Group menu of ASTIS's Hydrocarbon Impacts database at www.aina.ucalgary.ca/hi for use by the BSGLDS geological/geophysical and geotechnical consultants.

The O'Connor collection contained approximately 35 "Area of Interest" reports that did not yet have ASTIS records. These reports were shipped to Calgary, ASTIS records were created for them, and the reports were shipped back to GSC Atlantic.

Other Work Prior to Contract Completion

Following Pamela Scowen's trip to GSC Atlantic in February 2011, work continued to identify relevant reports that were already in ASTIS. This work was guided by more detailed parameters provided by the Technical Advisory Group at their January 25, 2011, meeting. For example, it was made clear that only shallow offshore seismic surveys should be included, that reports about ice scour that included side-scan or multi-beam sonar data should be included, that publications about seismology and earthquake hazard risk should be included, and that reports about subsea permafrost that included borehole logs should be included.

In the spring of 2011 the BSGLDS geographic "Area of Interest" was revised to make the Amauligak/Kugmallit corridor narrower (Fig. 8). This necessitated the retagging of some of the ASTIS records that had been selected earlier, and revisions to the Excel workbook describing the O'Connor collection.

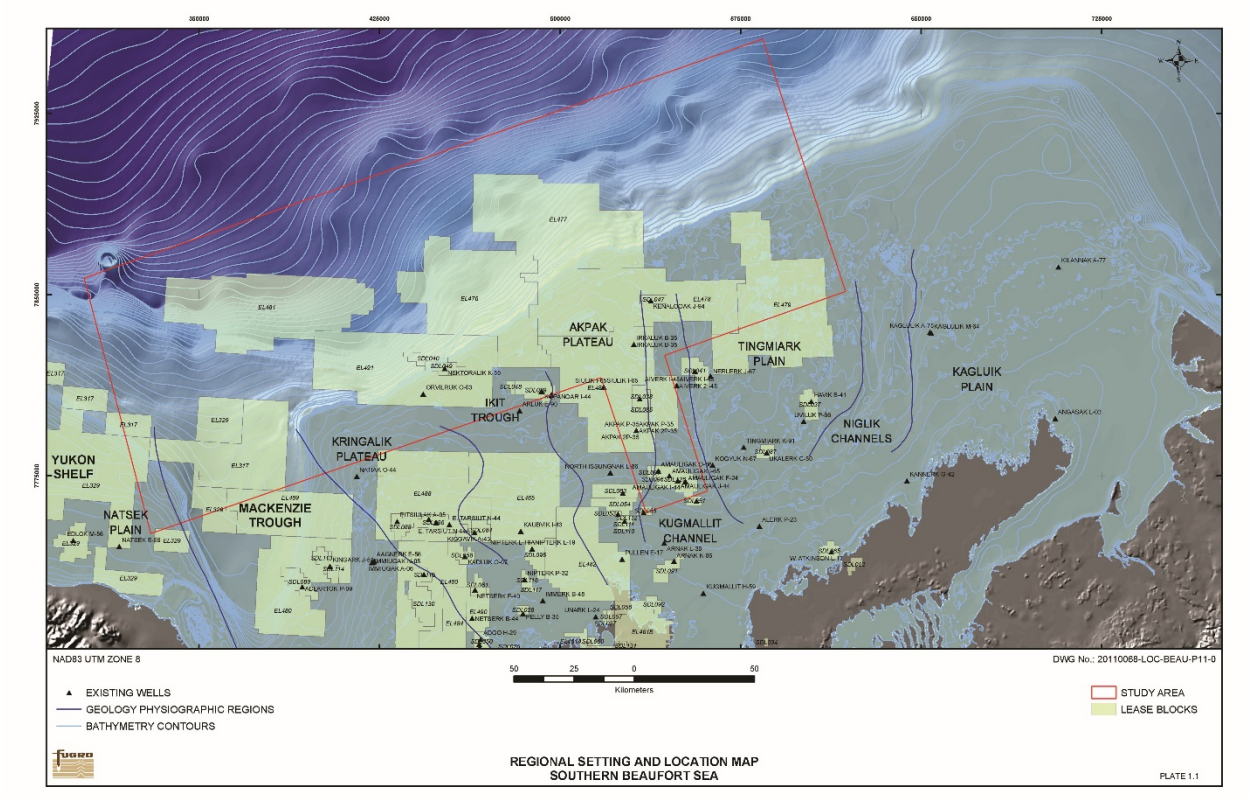


Fig. 8. Spring 2011 “Area of Interest”.

The contract for the cataloguing component of the BSGLDS ended on July 31, 2011. At that time there were 179 reports about the geographic “Area of Interest” in ASTIS, an increase of 52 reports since January. Although some reports had been removed from the “Area of Interest” because of the narrowing of the Amauligak/Kugmallit corridor, a much larger number of additional reports had been identified. These additional reports included many that already had records in ASTIS, as well as the approximately 35 reports from the O’Connor collection that were shipped to Calgary for record creation. The number of relevant Beaufort Sea reports outside the “Area of Interest” was 162, an increase of 56 since January. Many additional reports had been identified and some reports had been moved out of the “Area of Interest”.

As the contract ended, the Excel workbook describing the O’Connor collection (OConnorReportsData.xlsx) listed 1065 items: 286 reports and 779 datasets. The reports and data that were identified as being within the BSGLDS geographic “Area of Interest” were labelled with the ASTIS tag “BSG-S” (“S” for Shelf/Slope) and highlighted in red. The workbook contains 48 reports and 125 datasets that fall within the BSGLDS “Area of Interest”. Reports and data that may be of interest in the future (i.e., in the remainder of the Canadian Beaufort Sea outside the BSGLDS “Area of Interest”) are labelled with the ASTIS tag “BSG-R” (“R” for Remainder). There are 77 such reports and 332 datasets.

Creating Records for Reports Digitized by GSC Atlantic

In February, 2013, ASTIS received PDF files of 29 “Area of Interest” reports that had recently been digitized by GSC Atlantic. These were reports from the GSC Atlantic Marine Geoscience Collection Facility that were not part of the O’Connor collection and that therefore hadn’t been seen by Pamela Scowen. ASTIS records were created for the 18 of these reports that were not yet in ASTIS. The PDF files had not yet been publicly released by the companies that owned them, and were therefore saved to be made available online at project completion.

Other Work at Project Completion

In July, 2016, as the Beaufort Seabed Geohazard Legacy Data Synthesis project neared completion, ASTIS made the 29 PDF files discussed in the previous section publicly available on the AINA publications server and added links to their ASTIS records.

In early 2012 Parsons Corporation purchased O’Connor Associates Environmental Inc. and acquired some Beaufort Sea data that had belonged to Dr. Michael J. O’Connor. Parsons donated this data to the Arctic Institute of North America in the fall of that year. As part of its BSGLDS project completion work, in July 2016 ASTIS catalogued this data by adding it at the end of the Data worksheet of the OConnorReportsData.xlsx workbook. The data consisted of 27 items about the Canadian Beaufort Sea outside the “Area of Interest” and 22 items about the Alaskan Beaufort Sea. The data were shipped to GSC Atlantic to be added to the O’Connor collection.

ASTIS also created a record in the Polar Data Catalogue (PDC) for the BSGLDS catalogues. The PDC is a database of metadata and data that describes, indexes, and provides access to diverse datasets generated by Arctic and Antarctic researchers.

How to Access the Catalogues

To access the Beaufort Seabed Geohazard Legacy Data Synthesis catalogues go to ASTIS's Hydrocarbon Impacts database at www.aina.ucalgary.ca/hi. Choose the language that you wish to use, and click the "Enter = Entrez" button to go to the "Simple Search" page. On the "Report Group" menu the Beaufort Seabed Geohazard Legacy Data Synthesis section is about half way down (Fig. 9.). Select one of the three indented subheadings:

- "Outer Shelf, Upper Slope and Amauligak Corridor", to find reports about the "Area of Interest"
- "Remainder of the Canadian Beaufort Sea", to find reports outside the "Area of Interest"
- "O'Connor Catalogue", to download the catalogue of reports and datasets in the O'Connor collection.

(Selecting the main heading "Beaufort Seabed Geohazard Legacy Data Synthesis" will find the records in all three of the indented subheadings.) Click the "Search" button.

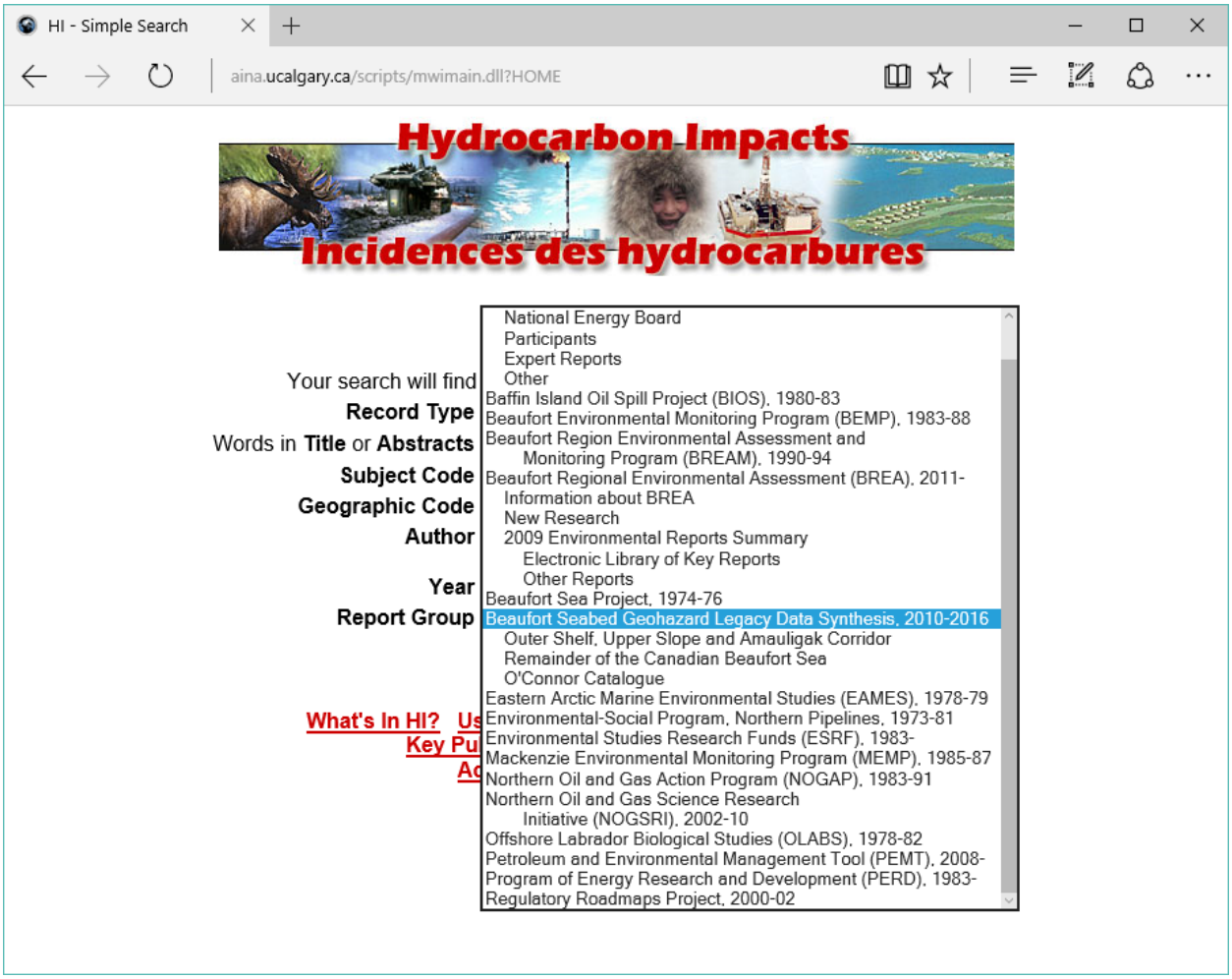


Fig. 9. The Hydrocarbon Impacts database Report Group menu.

If you select either of the first two subheadings you will be taken to a Hit List (Fig. 10) that shows the titles, authors and years of the records. If a Hit List entry ends with "*Web Link*", when you view the full record there will be a link to a full-text PDF file of the report. The Hit List is initially sorted by year, but you can click the link at the top of the page to sort by the first author of each record. Navigation links (Next, Last, etc.) allow you to move around in the Hit List. To see a full record, click on a title in the Hit List.

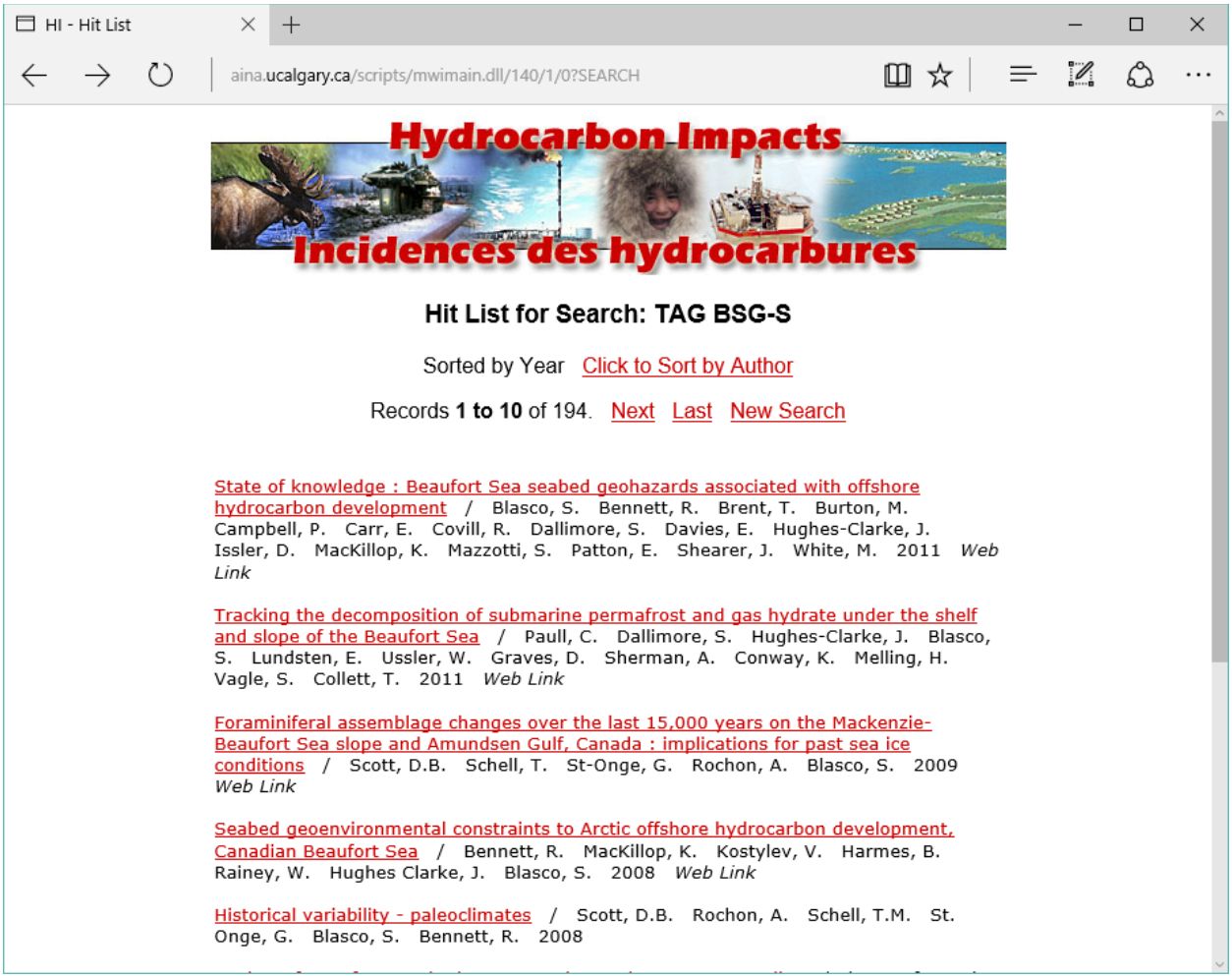


Fig. 10. Beginning of the Hit List of BSGLDS "Area of Interest" Reports.

When you click on a title in a Hit List, or when you choose “O’Connor Catalogue” in the Report Group menu, you are taken to a Full Record page (Fig. 11). Navigation links (Next, Last, etc.) allow you to move between Full Record pages. A Full Record includes a complete citation, an abstract, and subject and geographic broad codes and detailed terms. You can click on personal and corporate author names, subject codes, subject terms, geographic codes and geographic terms to search for other records that have the same name, code or term. Clicking on one of these links does a new search **of the full Hydrocarbon Impacts database** for the item that you clicked.

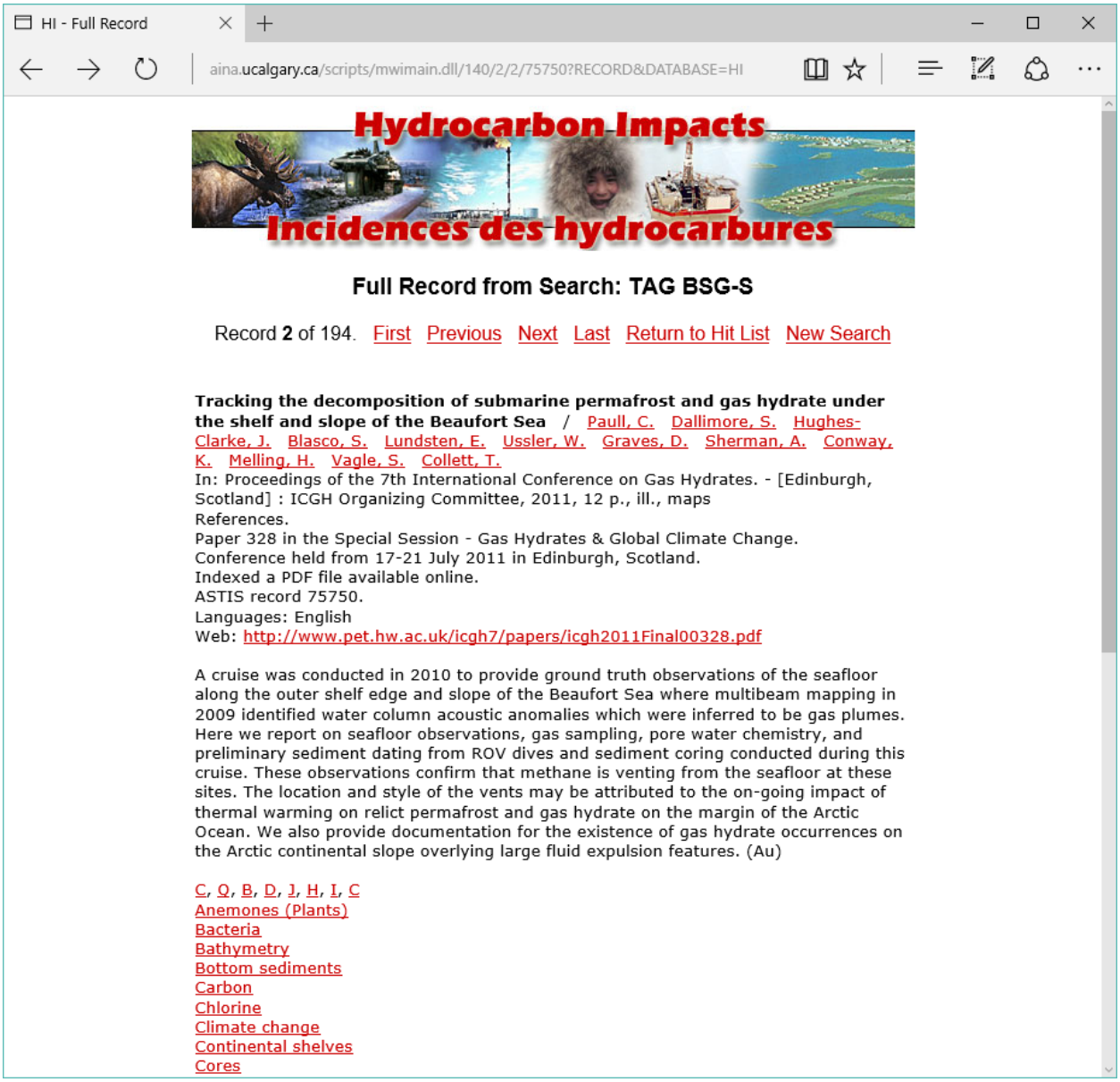


Fig. 11. Part of the Full Record that describes the second item in the Fig. 10 Hit List.

A Full Record also contains information on how to obtain a report. If the report is available online there will be a “Web:” field that links to it. If the report is available in a library the “Libraries:” field will contain interlibrary loan symbols indicating which libraries hold the report. The following interlibrary loan symbols are used in BSGLDS records:

- ACU - University of Calgary Library
- NFSM - Memorial University of Newfoundland Library
- NFSMO - Memorial University of Newfoundland, C-CORE Information Centre
- OOG - Natural Resources Canada, Ottawa Earth Sciences Library
- OONL - Library and Archives Canada, Ottawa
- OORD - Indigenous and Northern Affairs Canada, Departmental Library, Ottawa
- SSU - University of Saskatchewan Libraries, Saskatoon
- XNSDGSC - GSC Atlantic Marine Geoscience Collection Facility, Dartmouth
- XNWYL - Indigenous and Northern Affairs Canada, N.W.T. Lands Library, Yellowknife
- XQGLW - Indigenous and Northern Affairs Canada, Land and Water Management Directorate Storeroom, Ottawa

To download the Excel workbook catalogue of the O'Connor collection, on the Report Group menu choose "O'Connor Catalogue" to find the record in Fig. 12 and then click on the "Web:" link.

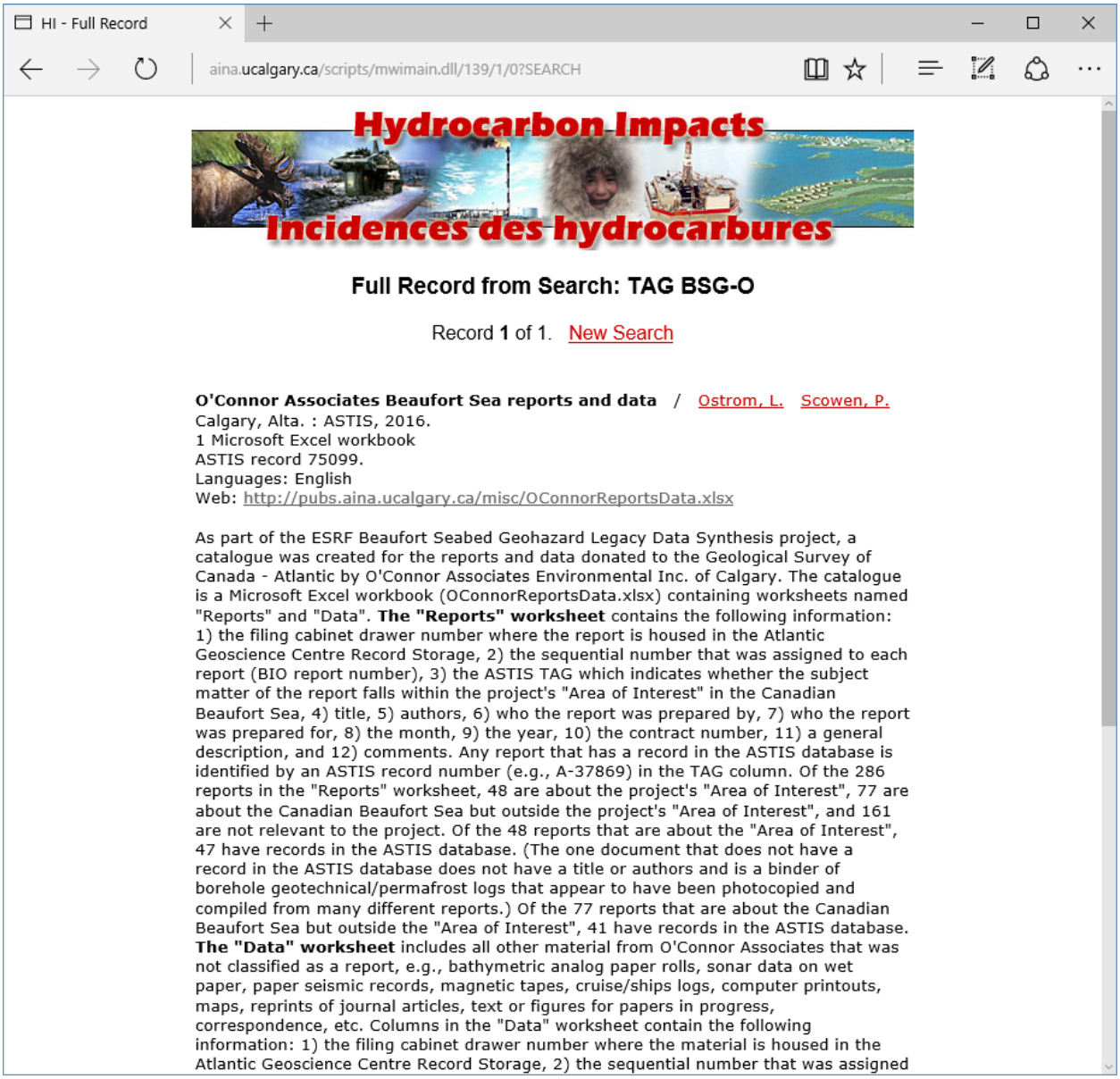
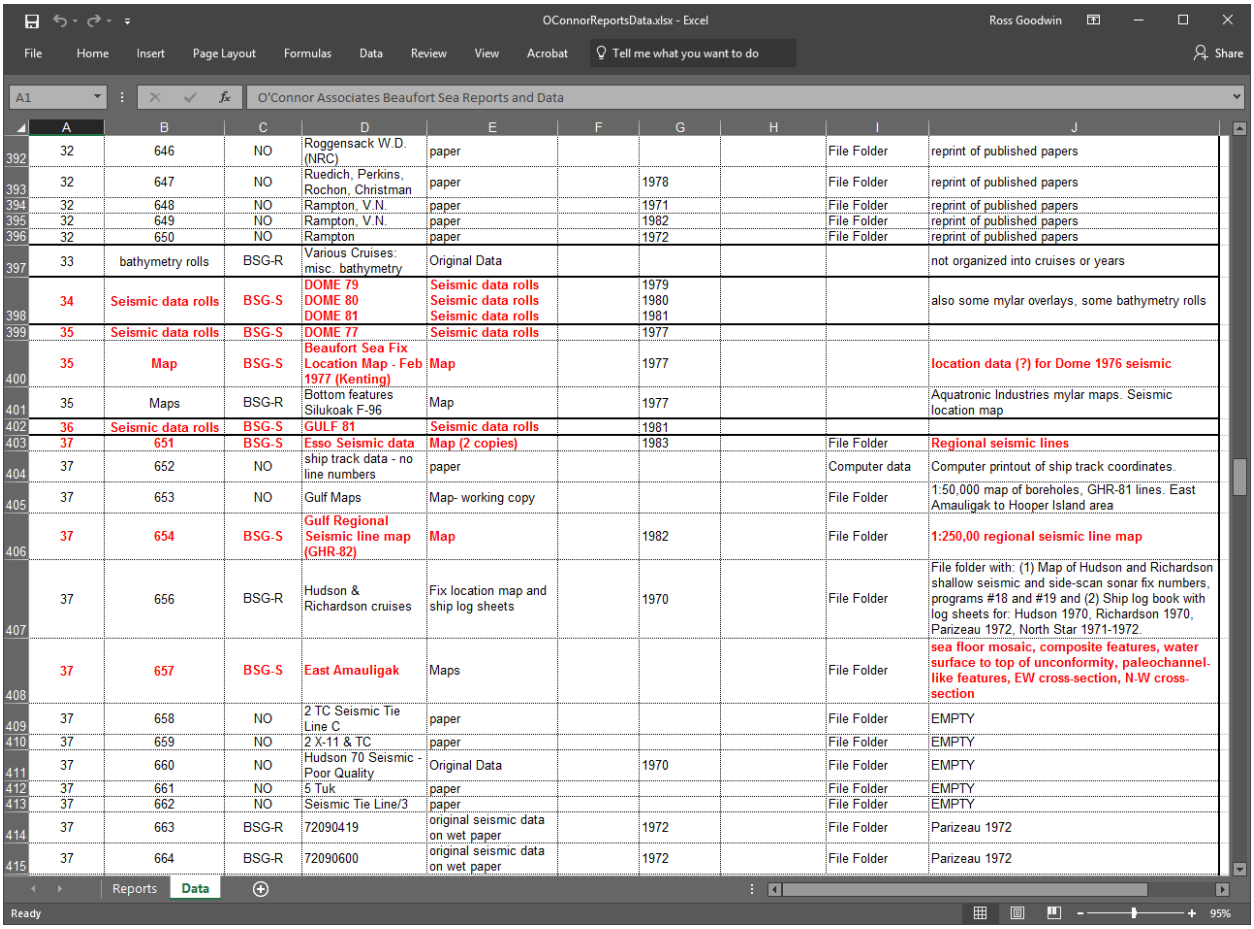


Fig. 12. Part of the Full Record that describes the Excel workbook catalogue of the O'Connor collection.

Fig. 13 shows a section of the Data worksheet of the Excel workbook catalogue. Each of the two worksheets in the workbook has a detailed explanation at the beginning of the worksheet. All of the O'Connor reports and data are, of course, available in the GSC Atlantic Marine Geoscience Collection Facility.



	A	B	C	D	E	F	G	H	I	J
392	32	646	NO	Roggensack W.D. (NRC)	paper				File Folder	reprint of published papers
393	32	647	NO	Ruedich, Perkins, Rochon, Christman	paper		1978		File Folder	reprint of published papers
394	32	648	NO	Rampton, V.N.	paper		1971		File Folder	reprint of published papers
395	32	649	NO	Rampton, V.N.	paper		1982		File Folder	reprint of published papers
396	32	650	NO	Rampton	paper		1972		File Folder	reprint of published papers
397	33	bathymetry rolls	BSG-R	Various Cruises: misc. bathymetry	Original Data					not organized into cruises or years
398	34	Seismic data rolls	BSG-S	DOME 79 DOME 80 DOME 81	Seismic data rolls Seismic data rolls Seismic data rolls		1979 1980 1981			also some mylar overlays, some bathymetry rolls
399	35	Seismic data rolls	BSG-S	DOME 77	Seismic data rolls		1977			
400	35	Map	BSG-S	Beaufort Sea Fix Location Map - Feb 1977 (Kenting)	Map		1977			location data (?) for Dome 1976 seismic
401	35	Maps	BSG-R	Bottom features Silukoak F-96	Map		1977			Aquatronic Industries mylar maps. Seismic location map
402	36	Seismic data rolls	BSG-S	GULF 81	Seismic data rolls		1981			
403	37	651	BSG-S	Esso Seismic data	Map (2 copies)		1983		File Folder	Regional seismic lines
404	37	652	NO	ship track data - no line numbers	paper				Computer data	Computer printout of ship track coordinates.
405	37	653	NO	Gulf Maps	Map- working copy				File Folder	1:50,000 map of boreholes, GHR-81 lines. East Amauligak to Hooper Island area
406	37	654	BSG-S	Gulf Regional Seismic line map (GHR-82)	Map		1982		File Folder	1:250,00 regional seismic line map
407	37	656	BSG-R	Hudson & Richardson cruises	Fix location map and ship log sheets		1970		File Folder	File folder with: (1) Map of Hudson and Richardson shallow seismic and side-scan sonar fix numbers, programs #18 and #19 and (2) Ship log book with log sheets for: Hudson 1970, Richardson 1970, Parizeau 1972, North Star 1971-1972.
408	37	657	BSG-S	East Amauligak	Maps				File Folder	sea floor mosaic, composite features, water surface to top of unconformity, paleochannel-like features, EW cross-section, N-W cross-section
409	37	658	NO	2 TC Seismic Tie Line C	paper				File Folder	EMPTY
410	37	659	NO	2 X-11 & TC	paper				File Folder	EMPTY
411	37	660	NO	Hudson 70 Seismic - Poor Quality	Original Data		1970		File Folder	EMPTY
412	37	661	NO	5 Tuk	paper				File Folder	EMPTY
413	37	662	NO	Seismic Tie Line/3	paper				File Folder	EMPTY
414	37	663	BSG-R	72090419	original seismic data on wet paper		1972		File Folder	Parizeau 1972
415	37	664	BSG-R	72090600	original seismic data on wet paper		1972		File Folder	Parizeau 1972

Fig. 13. Part of the Data worksheet of the OConnorReportsData.xlsx workbook.

Summary of Catalogue Contents

As of July 2016 the Report Group menu of the Hydrocarbon Impacts database finds records describing 194 reports about the “Area of Interest”. Sixty-one of those records have links to PDF files, and all but two of the remainder have interlibrary loan symbols. The two reports that we have no locations for were produced in 1980 by Geoterrex for Gulf Canada Resources. ASTIS has seen them, probably in someone’s personal collection.

The Report Group menu finds records describing 168 reports about the remainder of the Canadian Beaufort Sea. Forty-five of those records have links to PDF files, and all but one of the remainder have interlibrary loan symbols. The one report that we have no location for was produced in 1978 by Geomarine Associates for the GSC Terrain Sciences Division. ASTIS has never seen the actual report, but has seen it cited.

As of July 2016 the Excel workbook describing the O’Connor collection lists 1114 items: 286 reports and 828 datasets. The 48 reports and 125 datasets that were identified as being about the “Area of Interest” are labelled with the ASTIS tag “BSG-S” and highlighted in red. The 77 reports and 359 datasets that were identified as being about the remainder of the Canadian Beaufort Sea are labelled with the ASTIS tag “BSG-R”.

ASTIS would welcome the opportunity to catalogue additional reports and datasets for the Beaufort Seabed Geohazard Legacy Data Synthesis project.