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Exploration and exploitation of non-living natural resources on the continental shelf beyond 200 nautical miles: A status review

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Abstract: Activities by coastal States in relation to the exploration and exploitation of non-living natural resources (namely hydrocarbons and deep-sea minerals) on the continental shelf beyond 200 nautical miles (M) from their territorial sea baselines are reviewed. Geological conditions dictate such that hydrocarbons are likely to occur where there are thick accumulations of sediments (at least 2-3 km is needed for organic matter to generate significant amounts of hydrocarbons), whereas deep-sea minerals are found on or beneath the seabed of the deep oceans, which are generally "starved" of sediment. Thus, in general, sites for hydrocarbon exploration and for deep-sea mineral exploration are unlikely to overlap. On a 'normal' geological shelf with an average width of say ~60-100 km, hydrocarbon exploration is carried out generally within the 200 M limit of the Exclusive Economic Zone (EEZ) of the coastal State. Within the last decade, however, necessitated by depleting resources in the shallow waters of the shelf and slope, exploration has gradually moved from the geological shelf (water depth typically < 200 m) further out into deeper waters, and in some cases, beyond the 200 M limit. Thus far, only in a few places is oil and gas exploration being carried out on the continental shelf beyond 200 M. Examples include Australia, New Zealand, Norway, Argentina and Canada. Such activities mainly involve geological and geophysical investigations and assessment of the hydrocarbon potential, while some have resulted in commercial production. Besides the conventional hydrocarbons (oil and gas), continental margin sediments may also host significant accumulations of gas hydrates, which are regarded as a potentially important energy resource of the future. Along non-polar continental margins, gas hydrates are generally found beneath the continental slope and the continental rise, i.e. beyond the continental shelf proper, in water depths typically greater than 500 m but still mainly within 200 M of the territorial sea baselines. Where the continental margin is exceptionally wide, however, gas hydrates may occur in areas beyond the 200 M limit, on the extended continental shelf.

Keywords: Extended continental shelf, exploration and exploitation, natural resources, hydrocarbons, gas hydrates

INTRODUCTION

A fundamental role of the Commission on the Limits of the Continental Shelf[2] (CLCS) is to make recommendations on the outer limits of the continental shelf beyond 200 nautical miles (M) from which the breadth of the territorial sea is measured (i.e., the territorial sea baselines). These recommendations are based on the data and information provided by coastal States in their submissions to the CLCS in accordance with the provisions in Article 76 of the United Nations Convention on the Law of the Sea 1982 (UNCLOS) and Statement of Understanding contained in Annex II of The Final Act of the Third United Nations Conference on the Law of the Sea. The "legal" definition of the continental shelf, as per paragraph 1 of Article 76, is such that if the outer edge of the continental margin is at a distance greater than 200 M from the baselines from which the breadth of the territorial sea is measured, then the continental shelf may include those parts of the margin beyond the 200 M line. The term "extended continental shelf" here denotes that part of the continental shelf beyond the 200 M line to the outer limit line determined in accordance with Article 76.

The recommendations of the CLCS form the basis upon which coastal States may establish the outer limits of their continental shelf and, henceforth, exercise with certainty their sovereign rights over the extended continental shelf for the purposes of exploring and exploiting the natural resources of its seabed and subsoil, as provided for in Article 77 of UNCLOS. A coastal State wishing to extend its continental shelf beyond 200 M should submit the relevant scientific and technical data and information to the CLCS in accordance with the provisions of Article 76 and the Scientific and Technical Guidelines of the CLCS. The limits of the continental shelf established by a coastal State on the basis of the recommendations by the CLCS

[1] Disclaimer: The author is a member of the Commission on the Limits of the Continental Shelf, a UN body established under the UN Convention on the Law of the Sea 1982. The views expressed in this paper are solely of the author and do not necessarily reflect the views of the CLCS.

[2] CLCS website https://www.un.org/Depts/los/clcs_new/clcs_home.htm

shall be final and binding (as per paragraph 8, Article 76). As of June 2020, there are 85 submissions and 7 revised or partial revised submissions made by coastal States to the CLCS with regard to their extended continental shelf. To date (June 2020), only 35 of those submissions have been recommended upon by the CLCS and many more are awaiting consideration.

The submissions by coastal States represent vast areas of the oceans beyond 200 M from their territorial sea baselines (Figure 1). Beyond the outer limits of the continental shelf delineated in accordance with Article 76 of UNCLOS is the "Area", the seabed and subsoil of which come under the governance of the International Seabed Authority[3] (ISA), another independent body established under UNCLOS. This paper provides a brief review of ongoing activities related to the exploration and exploitation of non-living natural resources of the continental shelf beyond 200 M. Since industry data are seldom made public, this review is based on information made publically available on the websites of the relevant national authorities and agencies managing those activities as well as of the commercial entities engaged in those activities. All sources of information are referenced accordingly.

NON-LIVING NATURAL RESOURCES

"Natural resources" as defined under paragraph 4 of Article 77 of UNCLOS include "living organisms belonging to sedentary species", i.e., immobile organisms that are part of the seabed and subsoil at the time of exploitation. The present review, however, deals only with the non-living natural resources. Among the main types of non-living natural resources of the seabed and subsoil of the continental margin or shelf, are hydrocarbons (oil and natural gas), gas hydrates, and deep-sea minerals, which include mainly polymetallic sulphides, manganese nodules and cobalt crusts (Bollman *et al*., 2010). Hydrocarbons are more likely to occur in areas where there are thick accumulations of sediments, which geologists refer to as "sedimentary basins". Under average geothermal gradients of about 36 °C/km, at least 2 to 3 km of sediments are required so that sufficient temperature and pressure is attained for organic matter in the sediments to be converted into hydrocarbons. Sedimentary basins and, therefore, hydrocarbons tend to be found adjacent to the continents from which the sediments are derived, i.e. at continental margins (Figure 2). In contrast, seabed mineral deposits such as polymetallic sulphides, polymetallic nodules (mainly of manganese), and cobalt-rich ferromanganese crusts occur further away in the deep sea, which is typically underlain by oceanic crust and generally "starved" of terrestrial sediment supply. The most favourable sites for deep sea mineralisation are those associated with hydrothermal vents at mid-ocean ridges and along major oceanic fracture zones (Figure 3). Unless these sites happen to be within the limits of the extended continental shelf beyond 200 M, established in accordance with Article 76 of UNCLOS, they are part of the "Area" beyond national jurisdiction and subject to the governance of the ISA.

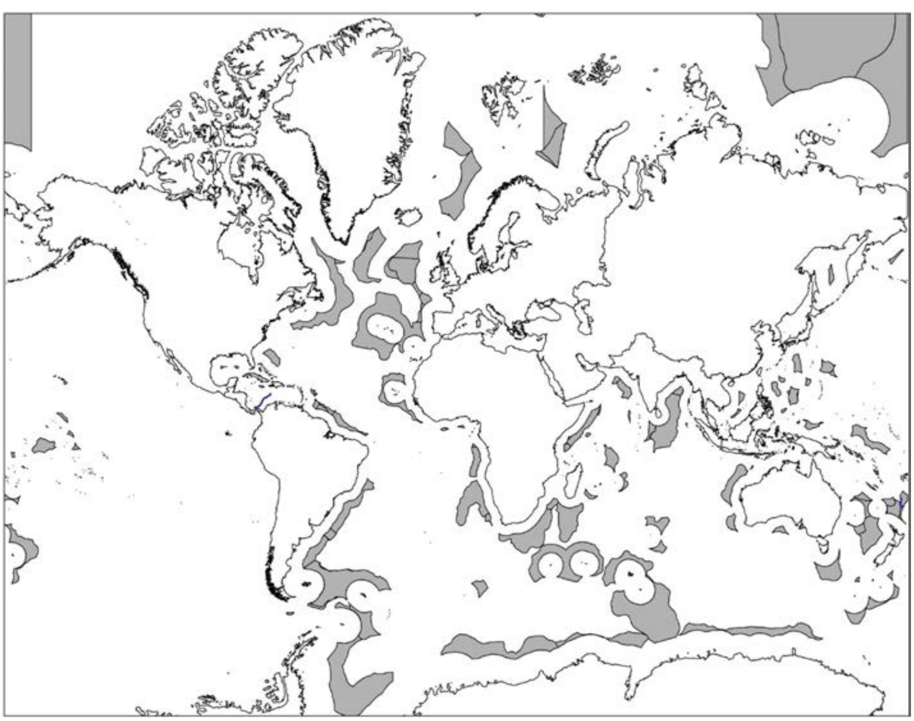

Figure 1: Global map showing marine areas (shaded grey) located beyond the 200 nautical mile from the baselines (coastlines) of coastal States. These areas, which are sometimes referred to as the "extended continental shelf" of the coastal State, are the subject of submissions by the respective coastal States to the Commission on the Limits of the Continental Shelf (CLCS) in accordance with article 76 of UNCLOS. Map information from UNEP website, www.continentalshelf.org.

[3] International Seabed Authority website https://www.isa.org.jm/

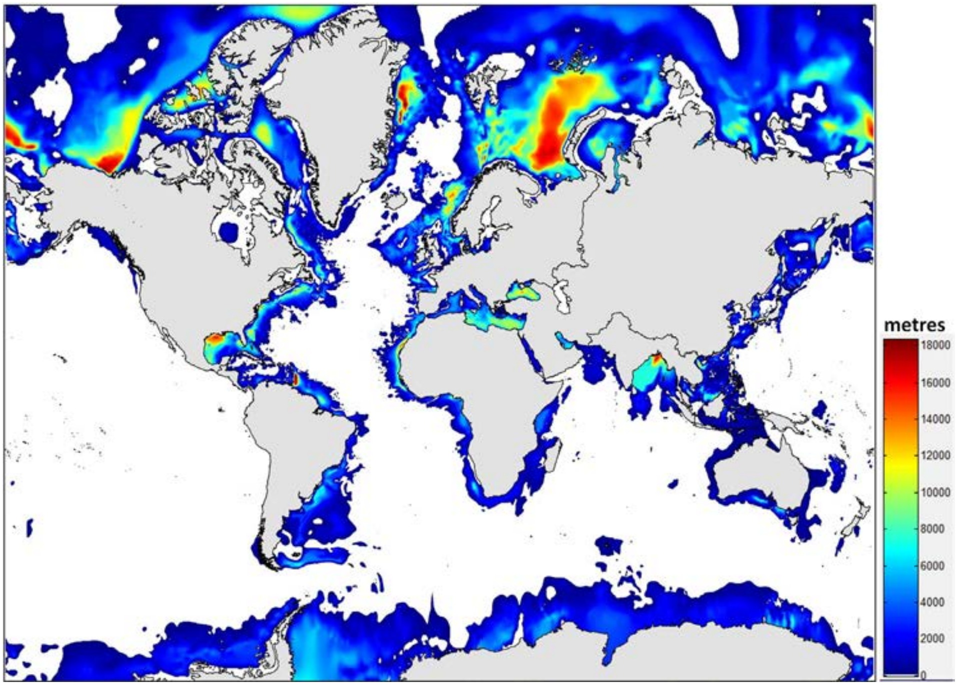

Figure 2: Map of sediment thickness in the oceans based on the 2019 global sediment thickness grid (Straume *et al.*, 2019). Only sediment thickness of 1000 m or greater is plotted. It shows that the main sites of sediment accumulation are at continental margins (colour-shaded areas) where hydrocarbons and gas hydrates are commonly found. Beyond the shaded areas (white areas covering much of the oceans) are where sediment thickness is unlikely to be conducive for conventional hydrocarbon generation, but instead they may host deep-sea mineral deposits.

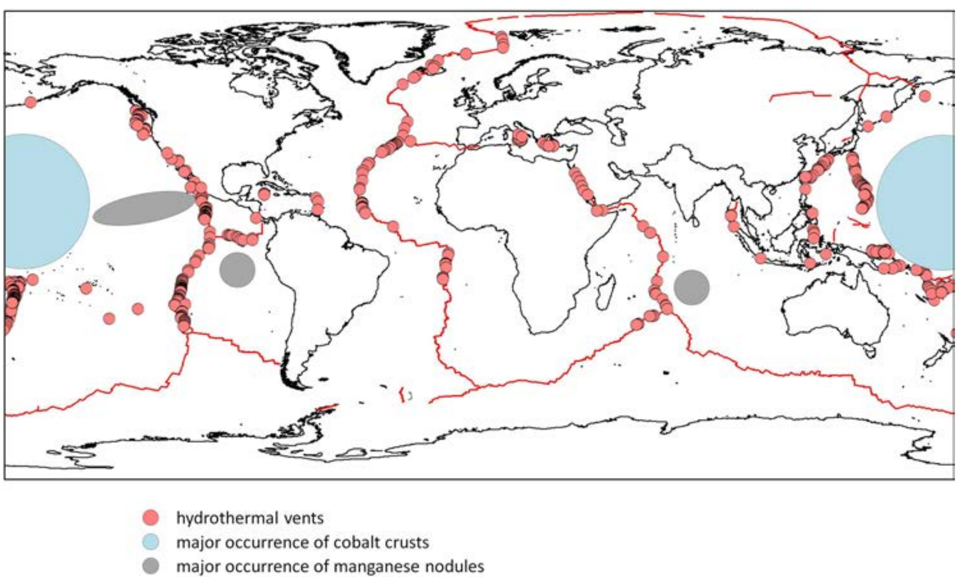

Figure 3: Economic concentrations of marine mineral deposits are found in the deep ocean basins, remote from continental margins and are mainly associated with hydrothermal vents at mid-ocean ridges and oceanic fracture zones. Three main types of deep-sea mineral deposits are shown. Map modified from Bollman *et al*. (2010), with addition of hydrothermal vents from Beaulieu *et al*. (2013).

In a typical “Atlantic-type” passive continental margin setting, shown schematically in Figure 4, the occurrences of the three main types of non-living resources – hydrocarbons, gas hydrates, and deep-sea minerals – appear to be almost mutually exclusive. As mentioned above, hydrocarbon generation and reservoir systems require a thick sediment accumulation that contains organic matter supplied from the land, whereas deep-sea minerals require proximity to hydrothermal activity such as oceanic spreading centres and negligible terrigenous sediment supply. The occurrence of gas hydrate is controlled mainly by water depth which, in turn, controls the pressure and temperature conditions required for hydrate formation. As a result, gas hydrates tend to accumulate within the continental slope and upper rise regions. Thus, while the hydrocarbon resource potential of the continental margin diminishes with distance from the coast due to decreasing thickness of sediment and increasing water depth, the potential for deep-sea mineral resources increases with increasing water depth towards the deep sea floor. In general, therefore, the sites for hydrocarbon exploration and those for deep-sea mineral exploration do not overlap in this type of continental margin setting.

Within this geological framework, it is expected that on a ‘normal’ geological shelf with an average width of ~60-100 km, hydrocarbon exploration would generally take place within the 200 M limit (EEZ) of the coastal State. Within the last few decades, however, exploration has gradually

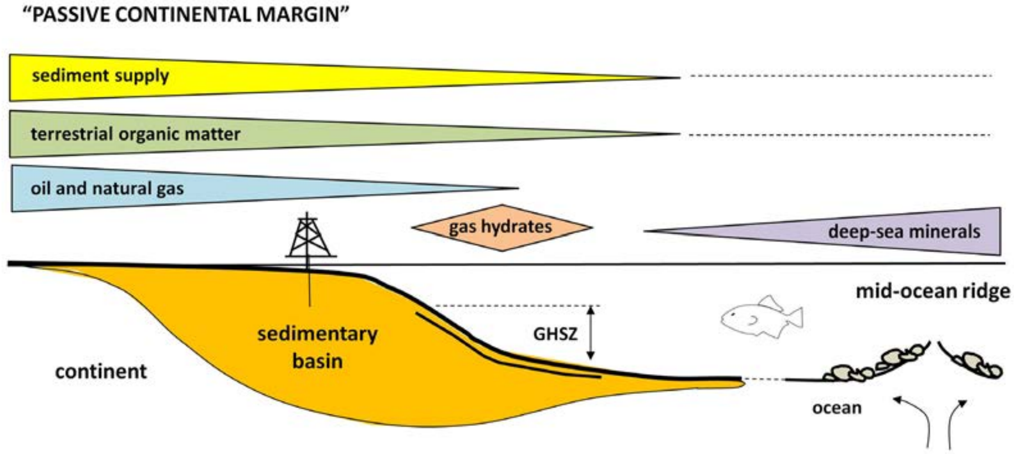

Figure 4: Schematic illustration of the general relationships between oil/gas (petroleum), gas hydrates and deep-sea minerals from continental margins to the deep sea. While the hydrocarbon resource potential diminishes with distance from the coast due to decreasing sediment thickness, the potential for seabed mineral resources increases with increasing water depth and distance from land. The principal reasons are (1) hydrocarbons systems require thick sediment supplied together with organic matter from the land, and (2) deposition of economic grade deep-sea minerals is more conducive when terrestrial sediment supply is negligible. Thus, sites for hydrocarbon exploration and those for seabed mineral exploration generally do not overlap in this type of continental margin setting. Gas hydrate formation is controlled by the gas hydrate stability zone (GHSZ).

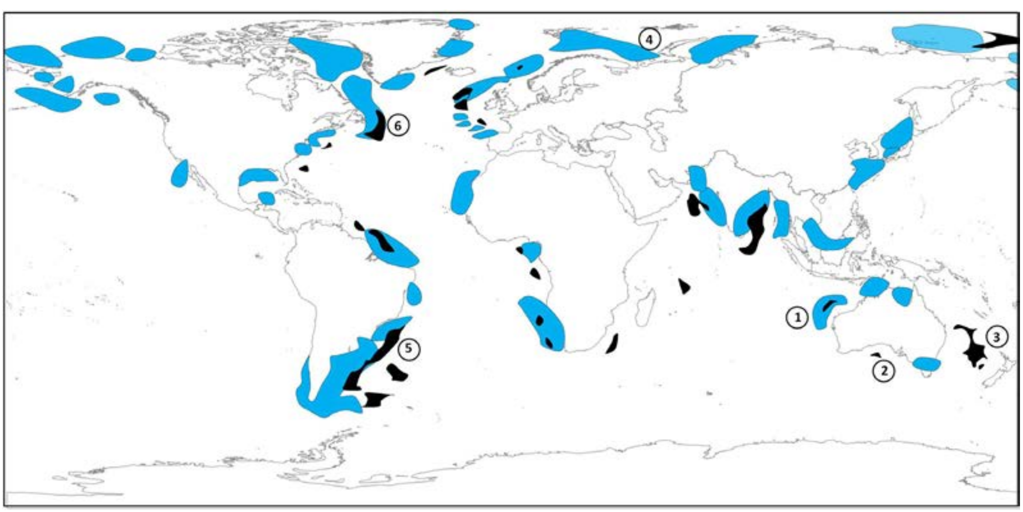

Figure 5: Major areas of continental margins where hydrocarbon exploration in deeper waters (>500 m) have taken place during the last few decades in the "deep-water basins" (blue shaded areas). Map is based on Stow & Mayall (2000). Only portions of these basins extend beyond 200 M from baselines, as indicated by the black-shaded areas numbered 1 to 6. They refer to areas described in this paper where exploration and exploitation of non-living resources beyond 200 M are taking place: 1 – Exmouth Plateau, Australia, 2 – Great Australian Bight, Australia, 3 – New Zealand, 4 – Norway (Barents Sea), 5 – Argentina, 6 – offshore Newfoundland.

moved from the shallow areas of the geological shelf into increasingly deeper waters. This effort has been motivated primarily by depleting resources in the shallow waters of the shelf and slope, the perceived greater chance of finding large hydrocarbon reservoirs in deeper waters, and the rapid improvements in exploration and exploitation technologies (Weimer, 2018). The petroleum industry refers to sedimentary basins that extend further out into the deep sea as "deep-water basins" (Figure 5), in reference to the technological challenges for explorationists that come with the increasing water depth. A distinction is sometimes made between "deep water" (water depths of 500-2000 m) and "ultra-deepwater" (>2000 m) basins (Stow & Mayall, 2000). Two decades ago, about 50 such basins were identified and considered to be "frontier" basins but now they have been proven to be rich in hydrocarbons (Weimer & Pettingill, 2007).

HYDROCARBON EXPLORATION AND EXPLOITATION ON THE CONTINENTAL SHELF BEYOND 200 M

When compared to the entire history of the oil and gas industry, exploration in deeper waters of the oceans is a relatively recent phenomenon. In the Sarawak and Sabah basins offshore Malaysia, for example, drilling for oil and gas in water depths of greater than 200 m began in the mid-1990s. It was only during the last decade or so, since the discovery of large deep-water oil and gas deposits, that drilling in the deep water areas increased rapidly. Globally, there are only a few places where oil and gas exploration is being carried out on the extended continental shelf beyond 200 M. Most of these activities involve geological and geophysical surveys to assess the hydrocarbon and mineral resource potential of the extended continental shelf areas. Some coastal States have offered offshore licenses for bidding application by commercial oil companies. In some cases, leases have been issued and exploration activities are now under way. In places where the outer limits of the continental shelf have been recommended on by the CLCS and the coastal States have deposited the coordinates of those outer limits with the Secretary-General of the United Nations, two examples stand out: Australia and New Zealand. There are also examples where coastal States have established their outer limits and made submissions to the CLCS but recommendations by the CLCS are still pending. As established by several legal scholars (e.g., Elferink, 2012; Mossop, 2016), the absence of an outer limit does not prevent a coastal State from exercising its inherent rights to explore and exploit its natural resources on the continental shelf, as stipulated in Article 77 of UNCLOS.

Australia

Australia established its outer limits of the continental shelf following the recommendations made by the CLCS on 9 April 2008. It deposited the coordinates of the outer limits on 2 November 2012, an obligation of the coastal State under Article 76 (paragraph 9). Out of the eight regions of "legal" continental shelf beyond 200 M identified by Australia and considered to have potential for petroleum exploration (Symonds & Wilcox, 1989), exploration activities to date have been limited to two of those regions (Figure 6): on Exmouth Plateau, NW Shelf region and in Ceduna Sub-basin, Great Australian Bight. Incidentally, these two areas were ranked qualitatively as having "fair" to "poor" potential for petroleum recovery (Symonds & Wilcox, 1989). Their true potential remains to be seen, in light of any drilling that may happen in the near future. On Exmouth Plateau, where several exploration blocks straddle the 200 M line, an exploration contract was awarded to Shell Australia Pty. Ltd. in 2013 (Shell, 2014) (Figure 6A). The license has a total area of 15,790 sq. km and the exploration program was expected to include seismic acquisition and drilling. In the Great Australian Bight, southern Australian margin, a few exploration blocks (permits) in the Ceduna sub-basin appear to include an area of the continental shelf beyond 200 M (Figure 6B). As of 2019, those blocks are being operated by Equinor (formerly Statoil). According to information on Equinor's website[4] those permits carry a work programme commitment that includes seismic data acquisition and drilling. There has been no drilling yet to date.

New Zealand

The outer limits of the continental shelf beyond 200 M of New Zealand were established following the recommendations of the CLCS on 22 August 2008. Information on New Zealand's continental shelf is made available publically on the Land Information New Zealand (LINZ) website[5]. The extended continental shelf area of New Zealand is about 1.7 million sq. km. New Zealand's land territory (comprising mainly the two main islands, North and South Islands) accounts for only 4% of the total land and maritime space (Figure 7). This vast area of the continental shelf is underlain by sedimentary basins with great thicknesses of sediments, but with unknown or unrealized potential for natural resources exploration and exploitation, especially hydrocarbons (Bland *et al.*, 2015).

Since the establishment of the outer limits of its continental shelf, New Zealand has undertaken a massive research effort towards understanding petroleum systems of its sedimentary basins in areas beyond 200 M. The activities include geological and geophysical (marine seismic, gravity and magnetic) investigations of petroleum prospectivity, mapping basin geometry, sediment thickness, and assessing hydrocarbon generation potential through geochemical basin modelling (Bland *et al*., 2015). In NW Province of New Zealand, to the northwest of North Island, major sedimentary basins have been identified for further investigations and exploration to assess the petroleum potential (Figure 7A). Maps of sediment thickness in that region show that the sediments may reach thicknesses of up to 11 km. It is interesting to note that the area of continental shelf of New Zealand that is most prospective for deep sea mineral exploration is mainly within the 200 M limit. For the time being, however, according to information given by the authorities on their website, the extended continental shelf of New Zealand is currently inactive with regards to mineral exploration.

Other examples of exploration in areas beyond 200 M

Besides Australia and New Zealand, a few other coastal States have also engaged in exploration activities on the continental shelf beyond 200 M. Norway made

[4] https://www.equinor.com/en/where-we-are/australia.html (last accessed 3 June 2019).

[5] https://www.linz.govt.nz/about-linz/what-were-doing/projects/new-zealand-continental-shelf-project/map-continental-shelf (last accessed 3 June 2019).

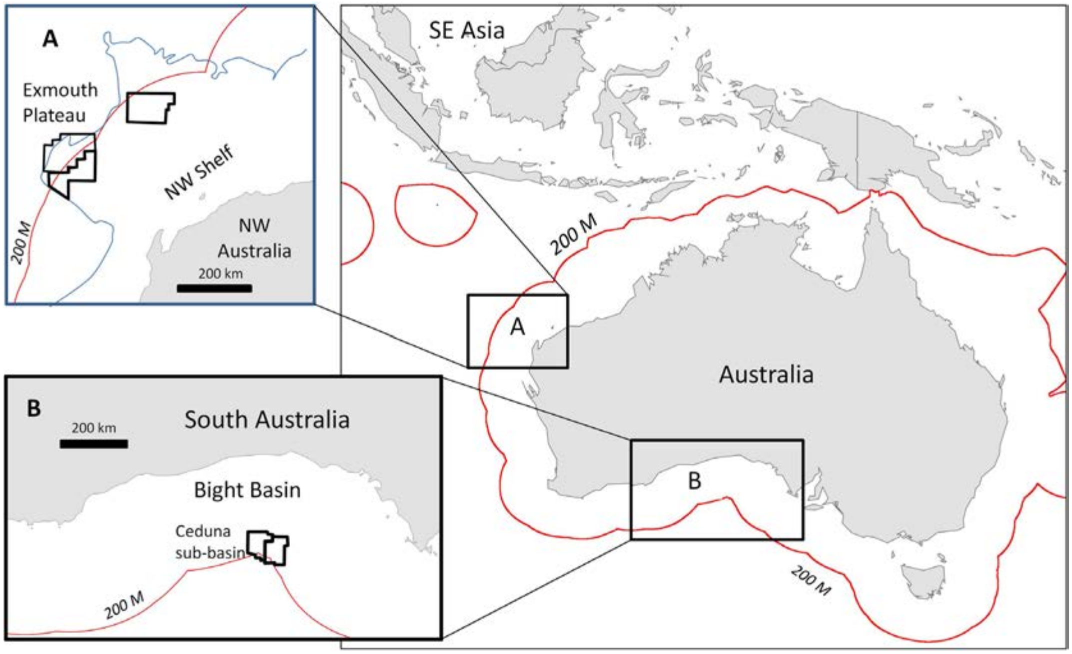

Figure 6: Australia continental shelf areas beyond 200 M that have ongoing hydrocarbon exploration activities. (A) NW Shelf, in the Exmouth Plateau region, where several block straddle the 200 M limit. (B) Ceduna sub-basin, South Australian Bight, where two exploration permits include areas beyond the 200 M. Geospatial information on continental shelf (200 M) from Australian Marine Spatial Information System (AMSIS). http://www.ga.gov.au/scientific-topics/marine/jurisdiction/amsis. Last accessed 3June 2019. Exploration permit outlines obtained from Shell and Equinor websites.

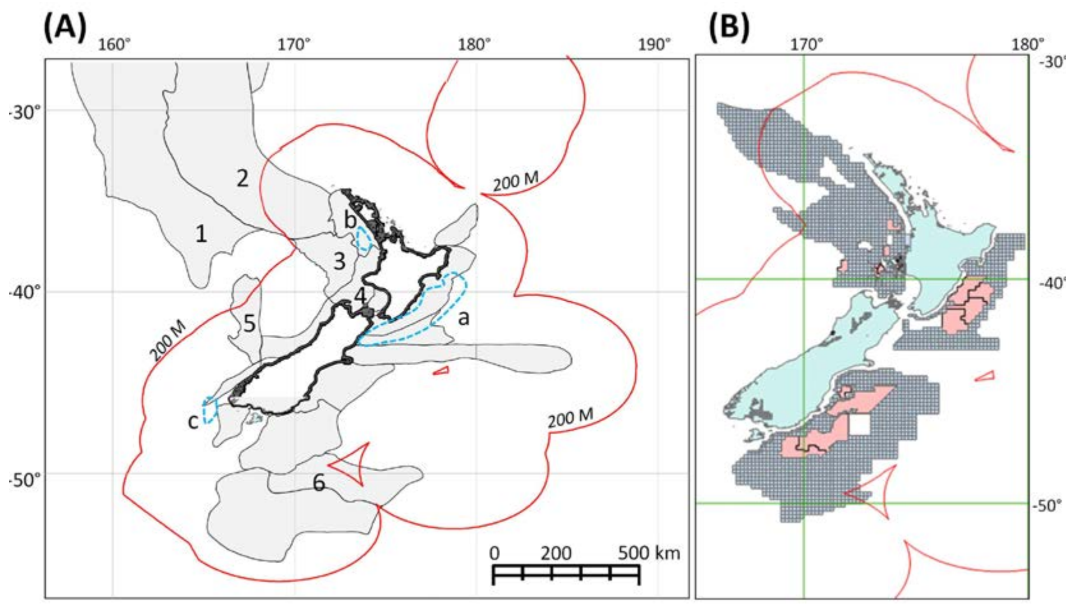

Figure 7: The continental shelf around the New Zealand landmass is underlain by sedimentary basins with great thicknesses of sediments and therefore of enormous hydrocarbon potential. (A) Outline of major sedimentary basins, shaded grey, most of which are within the 200 M limit (red lines). Numbers refer to individual basins: 1 – Lord Howe Rise, 2. New Caledonia, 3 – Deepwater Taranaki, 4 – Taranaki, 5 – Bellona, 6 – Pukaki. Only a few of these (2, 5, 6) extend beyond 200 M. Basin outlines are based on CGG Robertson's (2019) World Sedimentary Basin shapefiles. Blue dashed open polygons (a, b, and c) are three main areas of gas hydrate occurrences based on information on GNS Science website (accessed 2 June 2019): a – Northland-Taranaki basins, b – Hikurangi margin, c – Fjordland Puysegur margin. (B) Petroleum exploration permits (pink areas) on the continental shelf of New Zealand compared to exploration blocks potentially on offer but are closed as of 2019 (GIS shapefiles obtained from GNS Science website, accessed 2 June 2019). Note that some blocks are outside the 200 M limit in two regions: in the Northwest quadrant (Deepwater Taranaki and New Caledonia basins) and in the Southwest quadrant (Pukaki Basin).

the submission on its continental shelf in the North East Atlantic and the Arctic to the CLCS in 2006, and recommendations were issued by the CLCS in 2009. Petroleum exploration in offshore Norway started in the mid-1960s, initially in the North Sea and Norwegian Sea, and by early 1980s, in the Barents Sea. These activities were carried out within the 200 M limit until 2013, when exploration blocks located in the north-eastern corner of the Norwegian sector of the Barents Sea, which are located beyond 200 M, were opened. In 2017 a natural gas deposit was discovered in this area of Barents Sea by Statoil's discovery well 7435/12-1 (Korpfjell) drilled on a large structure called the Haapet Dome (NPD, 2018a) (Figure 8). Although the volume of hydrocarbons was found to be non-commercial – according the figures from NPD (2018a), 11.5 million standard cubic meters or 72 million barrels of oil equivalent – the discovery is a strong indicator of the potential for future hydrocarbon resource from the continental shelf beyond 200 M.

Another example is Argentina, whose submission on its outer limits was considered and recommendations were made by the CLCS in 2016 and 2017. The oil industry had acquired in 2017 extensive 2D seismic data, totalling 35,000 line km over the entire area, which is deemed a frontier basin as no well has been drilled yet in the 450,000 sq. km of continental shelf including large areas beyond the 200 M limit (Hodgson *et al*., 2017). In 2018 Argentina launched its first bid round in more than 20 years, offering offshore exploration blocks that partly include areas beyond 200 M in the northern sector of its continental shelf, with some blocks subsequently awarded to several major oil companies (Energy Industry Review, 2019) (Figure 9).

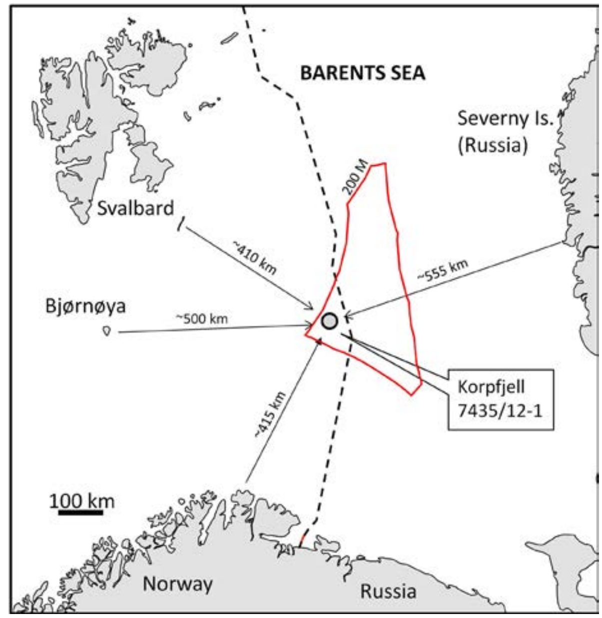

Figure 8: The Statoil Korpfjell gas discovery in 2017 on the Norwegian continental shelf in the Barents Sea is located more than 200 M (370 km) from the coastline, i.e. beyond the Exclusive Economic Zone. Red polygon represents 200 M line measured from respective coastlines. Map drawn based on information from Norwegian Petroleum Directorate (NPD, 2018a).

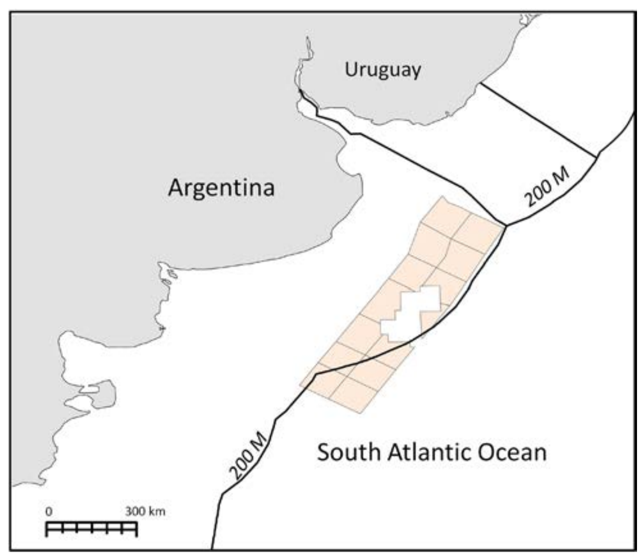

Figure 9: Oil exploration blocks offered in offshore Argentina in 2018, some straddling the 200 M limit line. Map drawn based on GIS shapefiles from Lynx Information Systems, http://data.lynxinfo.co.uk/LicensingRounds/ Accessed 2 June 2019.

Canada

Canada has made submissions to the CLCS with respect to the outer limits of its continental shelf beyond 200 M in two regions: the Atlantic Ocean in 2013 and Arctic Ocean in 2019. Both submissions are awaiting consideration and recommendations by the CLCS. Canada's Atlantic submission is an example, as mentioned above, where a coastal State has exercised its sovereign rights to explore and exploit the natural resources of its continental shelf beyond 200 M without the outer limits having been recommended upon by the CLCS. The Canadian Atlantic margin, particularly the Grand Banks and Labrador Sea areas off Newfoundland, has had a long history of hydrocarbon exploration on the continental shelf since the 1960s. There were major oil fields discovered mainly during the early 1980s – Hibernia (discovered in 1979), Hebron (1981), Terra Nova (1984) and White Rose (1984) – and these fields are currently in production (Figure 10). All these developments are, however, within 200 M from the Newfoundland coastline. In recent years, however, there has been exploration of the continental shelf beyond 200 M involving extensive seismic exploration and drilling. Information on these activities is reported on the website of the Canada-Newfoundland and Labrador Offshore Petroleum Board (CNLOPB), which shows the status of the licensing rounds in the Labrador Sea and offshore Newfoundland. Many blocks on offer are located outside the 200 M line, especially in the Grand Banks, Flemish

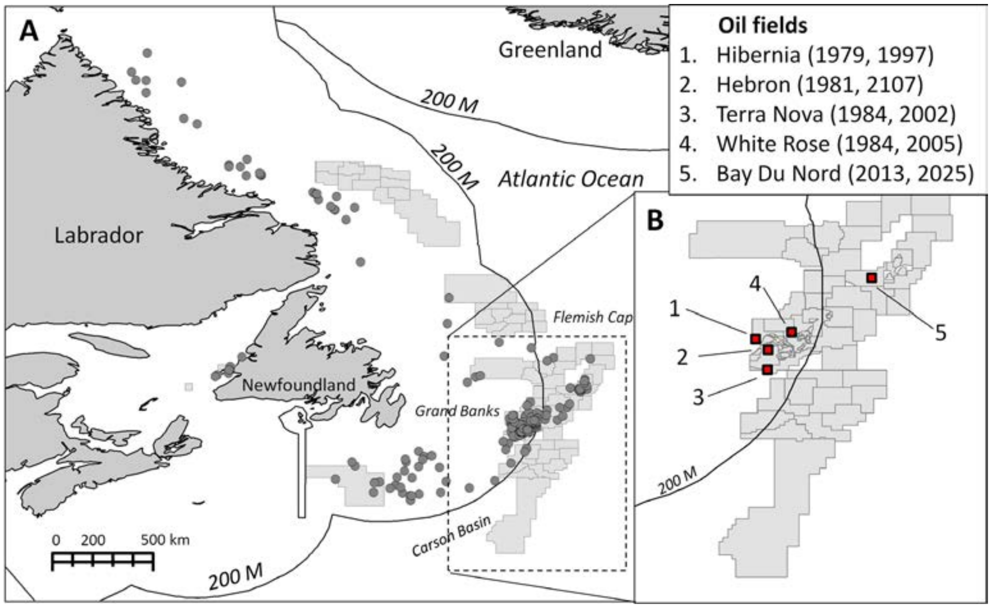

Figure 10: (A) Petroleum exploration licenses in the Grand Banks and Labrador Sea, offshore Newfoundland and Labrador, Canada, based on data published by the Canada-Newfoundland Labrador Offshore Petroleum Board (CNLOPB). Many blocks on offer for bidding, especially in the Flemish Cap area (marked by dashed rectangle, area zoomed in B) are located beyond 200 M. (B) Zoom-in of dashed rectangle in A, showing the location of four major producing oil fields in the Grand Banks area, discovered prior to 1985 and within the 200 M limit. Nos. 1 to 5 refer to oil fields (discovery year, production year). Outside the 200 M limit is the Bay Du Nord oil discovery of 2013 in the Flemish Cap area and is being developed and put on stream by 2025. Bay Du Nord would become the first oil production beyond 200 M.

Cap and Carson basins (Figure 10A). Seismic surveys and drilling in the Labrador Sea and offshore Newfoundland have been carried out by oil companies over the last several years and provided further information on the hydrocarbon potential.

There were also significant oil discoveries in recent years, some of which could lead to development and production in the near future. Oil production on the continental shelf beyond 200 M may actually happen soon, for on 26 July 2018, Newfoundland and Labrador had announced a development agreement for the Bay du Nord oil discovery in the Flemish Pass basin, located about 500 km (270 M) offshore (Figure 10B). Bay du Nord was discovered in 2013 by Equinor with estimated oil reserves of nearly 300 million barrels, and according to the government announcement (National Energy Board Canada, 2019), the oil production could start in 2025. With this oil development project, Canada is leading the way in oil and gas exploration and exploitation of natural resources on the continental shelf beyond 200 M. Besides Bay du Nord, there are several other oil discoveries made nearby, also beyond 200 M[6].

GAS HYDRATES

Besides "conventional" hydrocarbon deposits on the continental shelf ("conventional" in the sense that the oil or natural gas is exploitable by currently available technologies), a potentially important hydrocarbon resource is gas hydrate, which has been touted as an important energy resource of the future (Lu, 2015; Ruppel, 2018). Gas hydrate is a form of "unconventional" hydrocarbons in that they require a method of extraction not normally employed for conventional hydrocarbons (oil and gas). Many coastal States, including China, United States, Republic of Korea, Japan, Canada, India and Taiwan are actively pursuing research and development on gas hydrate exploitation on their respective continental margins. Thus far, however, there is no commercial exploitation of gas hydrates on the continental margin/shelf.

Gas hydrate is a natural gas, essentially methane, 'trapped' in the crystal lattice of ice or water molecules due to low temperature and high pressure conditions that can occur in two main environments: (1) beneath the seabed of the continental slope and continental rise due to the extreme water depths (e.g., in the mid-latitudes, water depths greater than 500 m), and (2) in permafrost regions of the continents. Due to its restricted stability field, 98% of gas hydrate occurrences are in marine areas, in water depths ranging from 300 m to 3000 m (i.e., in the outer continental shelf and slope, in the geological sense) while the remaining 2% are in permafrost regions (Birchwood *et al.,* 2010; Ruppel, 2018).

[6] Other discoveries by Equinor in the same area of Bay du Nord field: Mizzen, Harpoon, Baccalieu, Bay de Verde. Source: Equinor website: https://www.equinor.com/en/where-we-are/canada.html. Last accessed 7 June 2019.

The presence of gas hydrates in the seabed of the oceans is usually detected from marine seismic reflection surveys as “bottom-simulating reflectors” (BSR). An example of a BSR indication of gas hydrate is from the continental margin off Sabah, (NW Borneo), Malaysia (Figure 11). The absence of a BSR, however, does not necessarily indicate absence of gas hydrates. Nevertheless, where present, BSRs are used to identify and estimate the resource potential for gas hydrates. It is difficult to estimate the resource volume of gas hydrate precisely, as quantitative data and information on the occurrence and distribution of gas hydrates on the continental margins beyond 200 M are still scanty and therefore large uncertainties exist in the estimated volumes of this potential energy resource. Global estimates of total gas hydrate resource volumes vary by several orders of magnitudes, depending on the method used, and range from 20 to 1200 trillion cubic meters (Mosher, 2011; Lu, 2015; Kretschmer *et al*., 2015; Ruppel, 2014, 2018). Hydrate occurrences and resource volumes are sometimes predicted and estimated based on theoretical calculations of the gas hydrate stability zone. Several models of hydrate occurrence have been published by, among others, Klauda & Sandler (2005), Wallmann *et al*. (2012) and Kretschmer *et al*. (2015). These models require “ground-truthing” by surveying and drilling.

The United States Geological Survey (USGS) Gas Hydrates Project maintains a database of occurrences of gas hydrates, proven through indirect detection (BSR) or by drilling and sampling (Figure 12), which suggests that we are still a long way from knowing exactly how much gas hydrate resource is there globally. According to a factsheet released by the USGS in 2018, an international effort in sampling (by coring) and production testing are being undertaken, involving Japan, USA, Korea, India and China (Ruppel, 2018). So far, most of the marine scientific research and exploration activities are undertaken by national agencies and related academic/research institutions, and these activities have taken place mainly within the 200 M limit. Japan is one of the major contributors to gas hydrate research although gas hydrate occurrences in the continental shelf of Japan are mostly within its 200 M limit. Research activities are important for developing the exploitation technologies required worldwide for the future exploitation of gas hydrate resource. New Zealand is also actively engaged in research on gas hydrates on its continental shelf and has identified at least three major areas of hydrate potential, although these are also within the 200 M limit (see Figure 7A).

In 2017 Norway has also started evaluating gas hydrate and seabed mineral resource of its continental shelf, according to the Norwegian Petroleum Directorate report in 2018 (NPD, 2018b). In Barents Sea, where seabed temperatures can be 0°C or lower, the hydrate stability zone may reach up to 400 m depth. In addition, a number of sulphide deposits (both smokers and mounds) have also been identified along the volcanic Mohn Ridge in the Norwegian extended continental shelf (Chand *et al*., 2012).

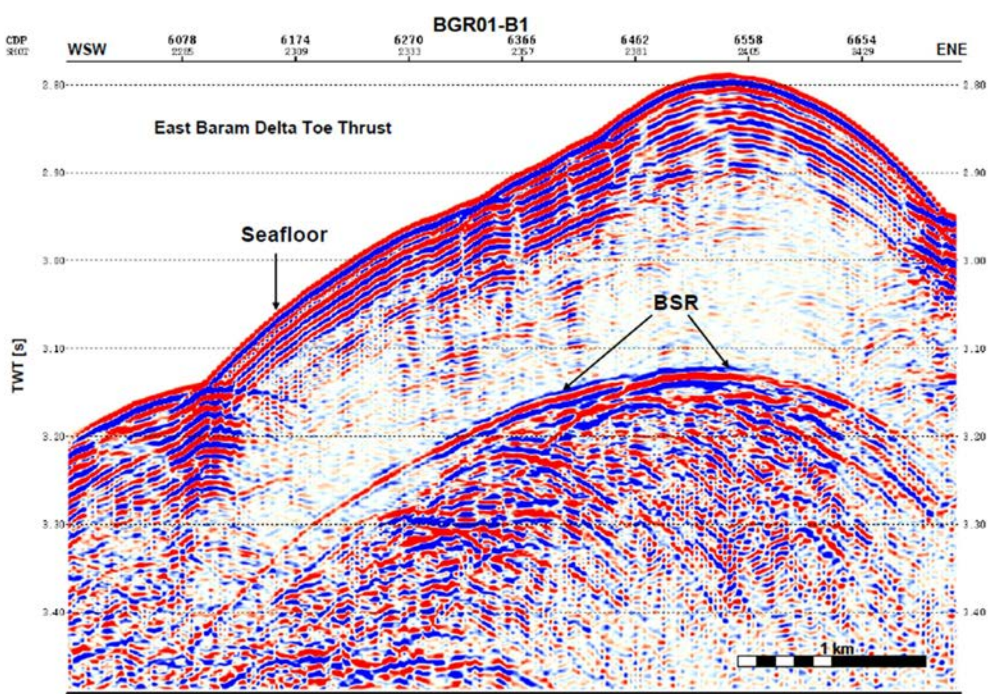

Figure 11: The presence of gas hydrate below the sea-bed results in a density contrast in the sediment above and below the top of gas hydrate accumulation, which is detected in the seismic records as a strong reflector that mimics the shape of the sea bottom. An example of a “bottom-simulating reflector” (BSR) is shown here on multi-channel seismic reflection data from offshore Sabah, Malaysia (from Goh *et al*., 2017).

Gas hydrate formation requires sediment as host and therefore tends to be in proximity to the continental shelf proper. Thus, most of the gas hydrate occurrences mentioned above are within the EEZ of the coastal States. Only in wide continental margins, significant gas hydrate accumulations are likely to occur in the seabed beyond the 200 M limit. An example of such geologic situation is in the Labrador Sea and Grand Banks region, offshore Canada, where gas hydrates have been identified from extensive geophysical surveys of the continental margin (Mosher, 2011). From that study, a map of gas hydrate stability zone indicates potential hydrate occurrences between 350 and 2875 m water depth along the continental slope and rise (Figure 13). Indeed, gas hydrates have been identified by the presence

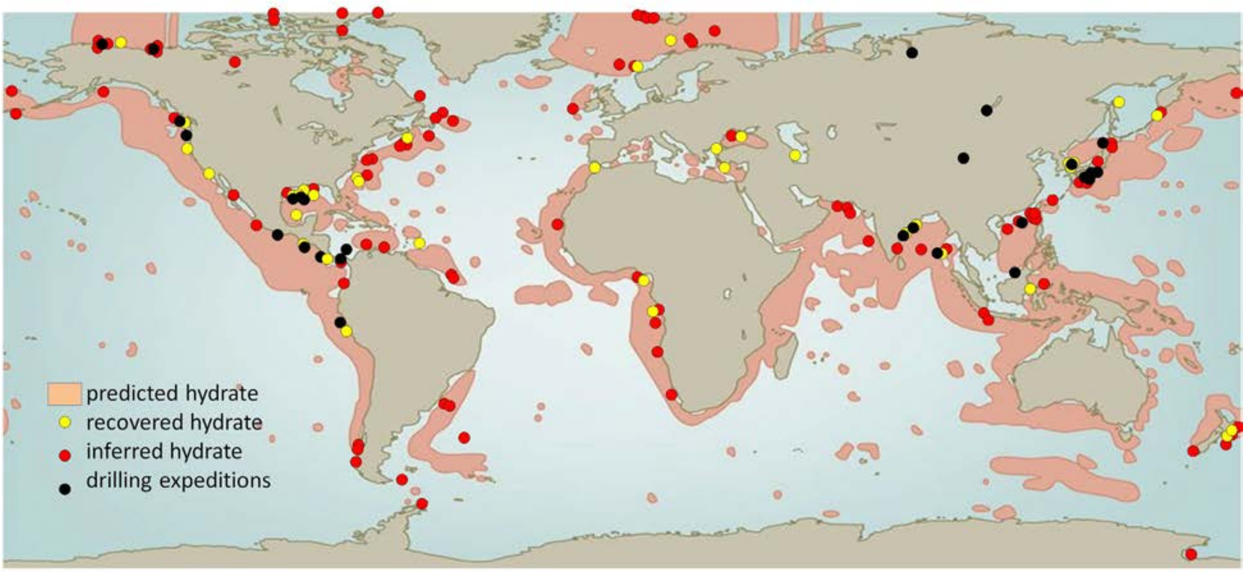

Figure 12: Predicted global distribution of gas hydrates based on theoretical calculations (Klauda & Sandler, 2005) shown by pink shaded areas mainly along the margins of continents. The predicted hydrate distribution map is from Bollman *et al*. (2010) used with permission from maribus gGmbH, www.maribus.com. Added to this map are coloured circles representing known occurrences of hydrates based on data compiled by USGS Gas Hydrate Project (Ruppel, 2018). Three categories of data points are shown: sites where gas hydrate has been recovered, sites where gas hydrate was inferred from seismic data, and sites where gas hydrate was investigated by drilling expeditions in continental permafrost or oceanic environments. Source: https://www.usgs.gov/news/modern-perspective-gas-hydrates.

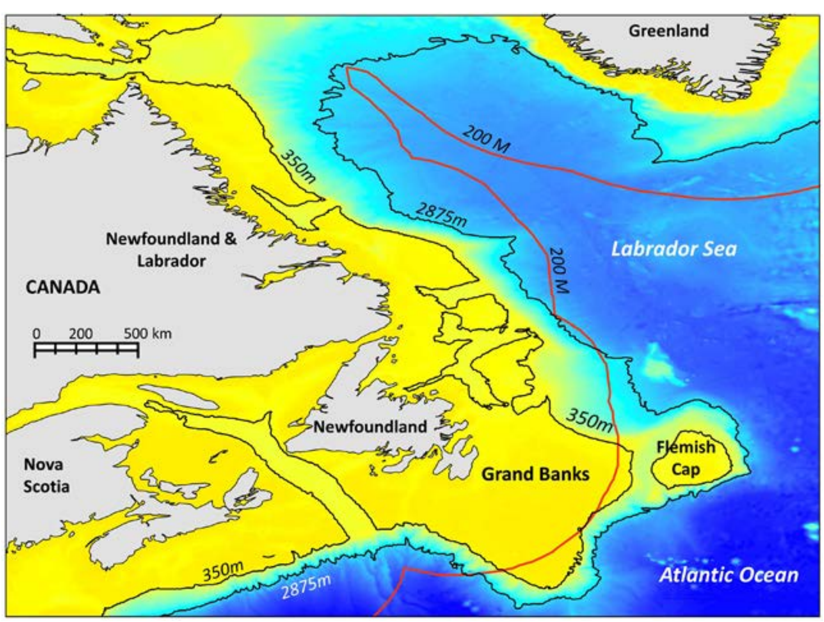

Figure 13: Gas hydrate stability zone offshore Newfoundland and Labrador Sea, offshore Canada, defined by water depth contours at 350 and 2875 m, as the predictor of hydrate occurrence (Mosher, 2011). Note that some parts of the margin with potential hydrate formation, i.e. in the Grand Banks and Flemish Cap areas, lie beyond 200 M limit (red line).

of BSRs on the Sackville Spur in the Flemish Pass, which lie beyond the 200 M line.

SUMMARY

- Exploration and exploitation of non-living resources on continental shelf areas beyond 200 M are being carried out by coastal States. Activities include marine scientific research, offshore oil and gas licensing, and exploratory drilling.
- Oil and gas (conventional hydrocarbons), gas hydrates and deep-sea minerals are the three main types of non-living resources being actively explored on the continental shelf beyond 200 M.
- Geology dictates where these different types are likely to occur along a continental margin. In a typical passive continental margin setting, oil and gas resources generally occur where sediments are sufficiently thick (at least 2-3 km) and contain sufficient organic matter for hydrocarbon generation. Hence, hydrocarbon resources are generally found relatively close to shore.
- Since gas hydrates in marine sediments have a narrow stability field, under normal geologic settings (where continental shelf width is ~60-100 km) they are mainly found on the continental shelf within the 200 M limit. In exceptional geologic situations where the continental margin is extremely broad (greater than 200 M or 370 km), gas hydrates as well as conventional hydrocarbons may occur beyond 200 M.
- Unlike hydrocarbons, deep-sea minerals require oceanic hydrothermal activity and a "sediment-starved" environment further out in the deep sea, remote from terrestrial sediment supply. Hence, deep-sea minerals are likely to be found in economic quantities in areas beyond 200 M.
- Due to diminishing oil and gas reserves in the shallow shelf areas, exploration and exploitation for conventional hydrocarbons have extended into deeper waters, reaching into areas beyond 200 M, even along "conventional" (geologic) margins.
- In areas of broad continental shelves, such as the Grand Banks of Newfoundland and Barents Sea shelf, the potential exists for hydrocarbon and gas hydrate resources occurring seaward of the coastal State's 200 M limit but within its extended continental shelf. In the Flemish Pass basin, in particular, the world's first exploitation of hydrocarbon resources beyond 200 M is expected to begin by 2025 when the Bay Du Nord field is put on stream.

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