ANALYSIS OF CLCS RECOMMENDATIONS IN LIGHT OF THEIR RELEVANCE TO THE DELINEATION OF A UNITED STATES EXTENDED CONTINENTAL SHELF (ECS) IN THE ARCTIC

BY

ONNI BOWEN IRISH
Bachelor of Science in Foreign Service (BSFS), Walsh School of Foreign Service,
Georgetown University, 2012

THESIS

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This thesis has been examined and approved in partial fulfillment of the requirements for the degree of Master of Science in Ocean Mapping by:

Thesis Director, Dr. Larry Mayer, Professor of Earth Sciences and Ocean Engineering, Director of School of Marine Sciences and Ocean Engineering, University of New Hampshire

Dr. Larry Mayer, Professor of Earth Sciences and Ocean Engineering, Director of School of Marine Sciences and Ocean Engineering, University of New Hampshire

Dr. David Mosher, Professor of Earth Sciences, Center for Coastal & Ocean Mapping, University of New Hampshire

Betsy Baker, Professor of the Vermont Law School

On May 16th, 2016

Original approval signatures are on file with the University of New Hampshire Graduate School.

DEDICATION

I would like to dedicate this work to my parents, Tere and Jim Irish.
Without their support and passion for loving one's work I would not be where I am today.
Thank you for being you.

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I would like to thank my thesis committee for challenging and supporting me throughout this research. In particular, I would like to thank Dr. Larry Mayer for taking a chance on a 'non-hard science' undergraduate.

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ABSTRACT

ANALYSIS OF CLCS RECOMMENDATIONS IN LIGHT OF THEIR RELEVANCE TO THE DELINEATION OF A UNITED STATES
EXTENDED CONTINENTAL SHELF (ECS) IN THE ARCTIC

by

Onni Irish

University of New Hampshire, September, 2016

Article 76 of the United Nations Convention on the Law of the Sea provides a mechanism by which a coastal State can extend sovereign rights over the seafloor and subsurface outside of its 200 nautical mile exclusive economic zone. In order for a coastal State to delineate this region, often referred to as the extended continental shelf (ECS), bathymetric, geophysical and geological data must be collected and analyzed to define the limit of the juridical continental shelf defined within Article 76. The coastal State must present its ECS delineation to the Commission on the Limits of the Continental Shelf (CLCS). The CLCS reviews coastal States' submissions and issues recommendations concerning the proposed ECS boundary and its accordance with Article 76. The United States has a potential ECS in the Chukchi Borderland region north of Alaska. This thesis examined two coastal States' CLCS recommendations in regions morphologically similar to the Chukchi Borderland, the Kerguelen Plateau (Australia) and Vøring margin (Norway), to assess the criteria that the CLCS utilized to classify these features in order to forecast the impact these recommendations may have on a potential submission of the United States in the Chukchi Borderland region. This thesis has found that the CLCS requires a coastal State with seafloor highs that are connected to its continental margin to show that these features are (or are not) morphologically and geologically continuous with the continental margin and landmass. If the coastal State can prove the seafloor high under question satisfies both of these criteria, it could potentially increase the coastal State's final ECS outer boundary. Application of these criteria to the Chukchi Borderland region found that available data could substantiate an argument that the Chukchi Borderland fulfills both criteria; however, further geological data may need to be collected from the northern extension of the Chukchi Borderland to support an Article 76 seafloor high classification.

I. Introduction, Background & Objective:

Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS) (Table 1) provides a mechanism by which a coastal State may extend sovereign rights over resources of the seafloor and subsurface outside of its 200 nautical mile (M) exclusive economic zone (EEZ). Certain morphological, geological, and geophysical criteria must be met in order for a coastal State to delineate this region referred to as the extended continental shelf (ECS). The establishment of an ECS involves the collection and analysis of bathymetric, geophysical and geological data to apply the criteria defined within Article 76. The coastal State must present its ECS delineation to the Commission on the Limits of the Continental Shelf (CLCS), composed of 21 scientists who are experts in the fields of hydrography, marine geology and geophysics. The CLCS reviews coastal States' submissions, including the relevant datasets, and makes recommendations as to whether they believe that the proposed ECS boundary is in accordance with Article 76 of UNCLOS. To date, 23 submissions have been reviewed by the CLCS and accompanying recommendations published. The United States has a potential ECS in many regions (see: http://ccom.unh.edu/theme/law-sea), one of which is in the area of the Chukchi Borderland north of Alaska. This thesis will examine other coastal States' CLCS recommendations, specifically assessing criteria the CLCS utilized to classify seafloor highs, to forecast the impact these recommendations (and criteria) may have on a potential submission of the United States in the Chukchi Borderland region under Article 76 of UNCLOS.

Approach:

In order to accomplish the above stated objective, the first part of the thesis will review Article 76 of UNCLOS as well as critical complexities of the article that are relevant for the Arctic Ocean, specifically seafloor highs as defined in Article 76, paragraph 3 and 6. To fully understand Article 76, this introductory section will also address the work of the CLCS and its Scientific & Technical Guidelines (S&TG), a document meant to provide technical guidance to coastal States as they collect relevant data and prepare their submissions to the CLCS.

After this introduction, the physiographic components of the Arctic Ocean, including features in both the Eurasia and Amerasia basins, will be presented. Tectonic models for the Amerasia Basin, where the Chukchi Borderland is located, will be discussed. Following the models, the Chukchi Borderland and its northern extension's geophysical and geological characteristics will be reviewed in connection to the contemporary tectonic models. Once the Chukchi Borderland review is complete, several morphologically analogous regions that have CLCS recommendations will be presented. Publicly available geophysical and geological studies will be integrated to give context to the CLCS' statements. For each set of recommendations, a comparison to the Chukchi Borderland and its northern extension will be completed to analyze the potential relevance the CLCS recommendations may have for the classification of these features. Lastly, the overall findings and conclusions for these analyses will be presented.

A series of appendices (Appendix I-VI) provide more detailed contextual information for each of this thesis' respective sections, including:

- **Appendix I:** Brief History of Article 76 of UNCLOS
- **Appendix II:** The Commission on the Limits of the Continental Shelf
- **Appendix III:** Arctic Exploration & Scientific History

- **Appendix IV:** Early Tectonic Models for the Amerasia Basin
- **Appendix V:** Geological Background for Kerguelen Plateau, Australia
- **Appendix VI:** Geological Background for Vøring Plateau & Vøring Spur, Norway

Article 76:
Definition of the continental shelf

1. The continental shelf of a coastal State comprises the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured where the outer edge of the continental margin does not extend up to that distance.
2. The continental shelf of a coastal State shall not extend beyond the limits provided for in paragraphs 4 to 6.
3. The continental margin comprises the submerged prolongation of the land mass of the coastal State, and consists of the seabed and subsoil of the shelf, the slope and the rise. It does not include the deep ocean floor with its oceanic ridges or the subsoil thereof.
4. (a) For the purposes of this Convention, the coastal State shall establish the outer edge of the continental margin wherever the margin extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by either:
   i. line delineated in accordance with paragraph 7 by reference to the outermost fixed points at each of which the thickness of sedimentary rocks is at least 1 per cent of the shortest distance from such point to the foot of the continental slope; or
   ii. a line delineated in accordance with paragraph 7 by reference to fixed points not more than 60 nautical miles from the foot of the continental slope.

   (b) In the absence of evidence to the contrary, the foot of the continental slope shall determined as the point of maximum change in the gradient at its base.
5. The fixed points comprising the line of the outer limits of the continental shelf on the seabed, drawn in accordance with paragraph 4(a)(i) and (ii), either shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured or shall not exceed 100 nautical miles from the 2,500 metre isobaths, which is a line connecting the depth of 2,500 metres.
6. Notwithstanding the provisions of paragraph 5, on submarine ridges, the outer limit of the continental shelf shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured. This paragraph does not apply to submarine elevations that are natural components of the continental margin, such as its plateaux, rises, caps, banks and spurs.
7. The coastal State shall delineate the outer limits of its continental shelf, where that shelf extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by straight lines not exceeding 60 nautical miles in length, connecting fixed points, defined by coordinates of latitude and longitude.
8. Information on the limits of the continental shelf beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured shall be submitted by the coastal State to the Commission on the Limits of the Continental Shelf set up under Annex II on the basis of equitable geographical representation. The Commission shall make recommendations to coastal States on matters related to the establishment of the outer limits of their continental shelf. The limits of the shelf established by a coastal State on the basis of these recommendations shall be final and binding.
9. The coastal State shall deposit with the Secretary-General of the United Nations charts and relevant information, including geodetic data, permanently describing the outer limits of its continental shelf. The Secretary-General shall give due publicity thereto.
10. The provisions of this article are without prejudice to the question of delimitation of the continental shelf between States with opposite or adjacent coasts.

Table 1

Article 76: Continental Shelf & Continental Margin:

Article 76 of UNCLOS (Table 1) derives from a complex series of events and documents that date back to the World War I era. Appendix I provides a brief historical overview of the derivation of Article 76 and the events that led to UNCLOS. For a more comprehensive historical review of Article 76, the *Travaux Préparatoires* provide an official documentation of the negotiations and drafting that produced UNCLOS (Nordquist et al., 1993).

From a scientific perspective, Article 76 transplanted (and redefined) a series of marine geological terms into the juridical realm. The two 'formula' lines, for example, presented in paragraph 4, define the extent of the *juridical* continental margin; whereas, the two 'constraint' lines, defined in paragraph 5, set the limit of the *juridical* continental shelf. Both of these terms, continental margin and continental shelf, are morphological components defined within the field of marine geology, yet are given juridical definitions in Article 76.

Note that in order to emphasize when the legal or marine geological continental shelf and continental margin are discussed, the type of feature is described in italics as either *juridical* or *geological.* This same approach is applied to seafloor highs to highlight the difference between submarine *elevations* and submarine *ridges.*

Continental Margin:

From the marine geological perspective, the geological continental margin consists of the extension of the submerged continental crust (landmass) into the ocean that encompasses the *geological* continental shelf, slope and rise until the transition to oceanic crust (Hedberg, 1979). The morphology of *geological* continental margins varies throughout the world depending on the type of tectonic setting among many factors; for example, at a subduction zone the continental rise may be absent, and therefore the *geological* continental margin may consist only of a continental shelf and truncated slope.

UNCLOS transplanted this scientific term, that is similar to the geologic definition, into the legal realm and defined a *juridical* continental margin in Article 76, paragraph 3, as the "submerged prolongation of the land mass of the coastal State" that comprises the seafloor and sub-seafloor of the *geological* continental shelf, slope and rise (Table 1). When a coastal State believes its *juridica*l continental shelf may extend beyond 200 M, it must determine the limit of its *juridical* continental margin by utilizing the two formula lines defined in Article 76, paragraph 4 (Table 1). The extent of the *juridical* continental margin could also lie within 200 M if the two formula lines do not exceed the 200 M boundary.

Continental Shelf:

Geologically, the continental shelf is defined as the region of the *geological* continental margin from the shoreline to the shelf-break, the latter of which demarcates a change from the *geological* continental shelf to the continental slope. The shelf-break is a significant change in gradient and is a consistent feature of all continental margins. The *geological* continental shelf is a generally flat region, with a gentle seaward slope of ~0.1 degrees, whereas the continental slope is usually characterized as having steeper seaward slope that is often greater than 1.0 degree (Kent, 1982). It is important to reiterate that not all *geological* continental margins are the same, and the geomorphological characteristics found in one margin may be very different from another due to its geological composition and tectonic and sedimentation history.

Article 76 defines the *juridical* continental shelf in two ways. The first definition is a distance-based definition (up to 200 M) from the coastal State's baselines. The second definition is based upon Article 76's constraint and formula lines (discussed later on in this section). Thus, the *geological* continental shelf is defined by the presence of two distinct morphological components, the shoreline and shelf-break, whereas the *juridical* continental shelf is defined either by a 200 M limit from the coastal State's baselines or by the criteria prescribed in Article 76, paragraph 5. Figure 1 compares the *geological* and *juridical* definitions.

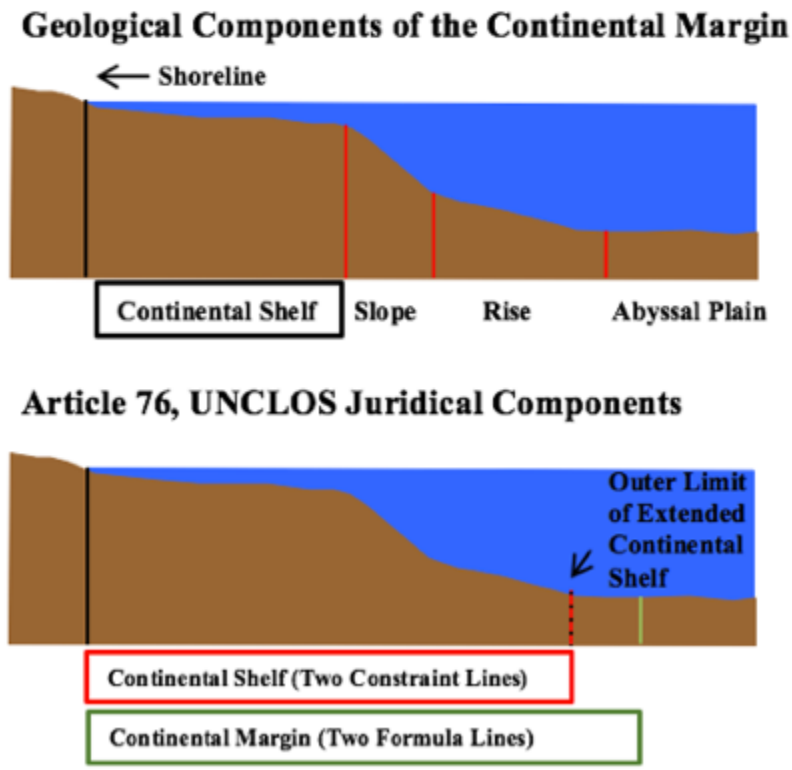


Figure 1: Cartoon diagrams depicting the difference between the *geological* components of the continental margin versus the *juridical* components based upon Article 76 of UNCLOS. Figure adapted and modified. Source: (MacNab, 2001)

Article 76 (paragraph 4(b), Foot of Slope (FOS)):

In order for a coastal State to establish its ECS, it first must determine its Foot of Continental Slope (FOS), which is defined "as the point of maximum change in the gradient at its base," unless "evidence to the contrary" is present (Table 1) (Article 76, paragraph 4(b)). The use of the word, "its," within paragraph 4(b) refers to the continental slope. Therefore, the FOS is the point of maximum change in gradient, where the angle of the slope of the seafloor changes most rapidly at the base of the slope region. Within an ideal passive margin, this maximum change in gradient is ideally located at the slope-rise transition or slope-deep basin floor intersection where no rise exists. Figure 2 is a simplified diagram depicting the location of the

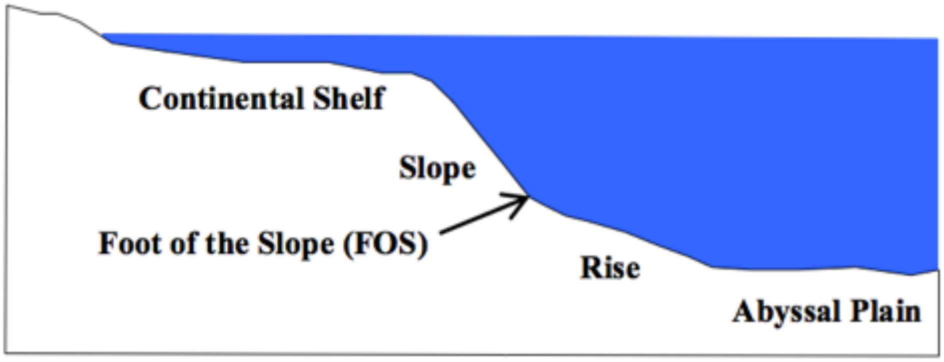


Figure 2: Cartoon diagram shows the general region where the FOS is located, between the slope and rise, where the maximum change in gradient occurs. Figure adapted. Source: (Mayer, 2013)

FOS in a stylized passive margin. Determining the location of the FOS in nature is not straight forward. Few *geological* continental margins have the characteristics of the ideal passive margin shown in Figure 2 and some margins are often complicated by not having a rise or having more than one localized maximum change in gradient.

The coastal State can take several approaches to defining the FOS, however, it must first define a base of slope (BOS) zone. The BOS zone must capture the regional change in gradient and the FOS is the maximum change in gradient in the BOS zone.

1) **Morphological Approach:**

If the maximum change in gradient is clearly located within the BOS zone at the intersection of the *geological* continental slope and rise, it can be mathematically determined and the coastal State may use this point as its FOS. This determination is based upon the morphology of the region and bathymetric data alone can be utilized to find the FOS.

2) **Geomorphological Approach:**

On geologically complex margins, a second methodology can be employed for determining the FOS. If the coastal State believes that the BOS zone, the region of the most seaward extent of continental slope processes, is not co-located with the morphological point of maximum change in gradient across the continental slope, it may present geologic arguments to support its choice of the BOS zone and then determine the point of maximum change in gradient within this BOS zone. A number of geological arguments can be utilized to identify the BOS zone. Evidence of down-slope sediment movement and/or other transport processes may be analyzed in relation to the upper and lower slopes to determine the specific dimensions and location of the BOS zone. Once the BOS zone is established based upon geological evidence, the maximum change in gradient within this zone is the FOS. Figure 3 depicts a BOS zone identified using supporting geological evidence from the CLCS Recommendations for the Irish Porcupine

Figure 3: The Base of Slope (BOS) Zone as depicted in the CLCS Recommendations (2007) for Ireland, Porcupine Abyssal Plain. Source: (CLCS/54, 2007, p. 14)

Abyssal Plain. Overall, with this method the placement of the FOS is the result of an analysis dependent on the geomorphology and geological processes of the region.

3) **Evidence to the Contrary:**

A third approach to identify the FOS is to invoke *evidence to the contrary* (Article 76, paragraph 4(b)). Within the S&TG, the CLCS stated that invoking *evidence to the contrary* does not disagree with the original morphological approach (maximum change in gradient at its base), but complements the general rule (CLCS, S&TG, 6.1.2). This provision reinforces that in addition to submitting bathymetric and geomorphological evidence, a coastal State has the right to also submit "all other necessary and sufficient geological and geophysical evidence" that supports its proposed location of the FOS (CLCS, S&TG, 6.1.3). The CLCS stated that it interprets this provision to signal that a coastal State can use the best available geophysical and geological evidence to identify the FOS when the bathymetric and geomorphological data does not, or cannot, identify the FOS (CLCS, S&TG, 6.3.1). The CLCS discussed, in the S&TG, a number of scenarios in which this may be the case, however, the underlying requirement the CLCS emphasized in determining the FOS' location is finding the transition point (or boundary) from continental to oceanic crust along the *geological* continental margin (CLCS, S&TG, 6.3.6-6.3.13).

A coastal State is not required to use one of these particular methods over another to determine its FOS points. In fact, some UNCLOS practitioners take the view that a morphological approach cannot be separated from a geomorphological one. This perspective states that the key language to define the FOS is "at its base" (Article 76, paragraph 4(b)), and the coastal State has the discretion to define the "base" on both morphological (bathymetric) and geological criteria.

Article 76 (paragraph 4(a)), Formula Lines:

Article 76, paragraph 4(a), prescribes two formula lines for a coastal State to establish the extent of its *juridical* continental margin. One of these formula lines is dependent on sediment thickness (Article 76, paragraph 4(a)(i)) and is often referred to as the Gardiner Formula. The second formula line is based up on distance (Article 76, paragraph 4(a)(ii)) and is known as the Hedberg Formula. The coastal State can use one or both formula lines in combination to determine the outer edge of its continental margin, whichever is more advantageous (i.e., whichever combination of formulas extends farthest seaward).

The sediment thickness formula requires an understanding of the seafloor geomorphology as well as sediment thickness. This formula states that a coastal State can place its outermost fixed points where the sediment thickness is at least 1% of the shortest distance from the FOS (Article 76, paragraph 4(a)(i)). If, for example, the sediment thickness 200 km from the FOS is 2 km and thinner everywhere beyond, then the coastal State can place a formula point at this location. If the sediment, however, is less than 2 km thick at this point, then the coastal State must move this formula point landward until the sediment thickness is at least 1% of the distance from the FOS (Fig. 4).

The Hedberg Formula is based only upon the morphology of the seafloor. The formula states that outermost fixed points can be placed 60 M from the FOS (Fig. 4). The coastal State draws a series of 60 M arcs from its FOS points to determine this formula line's outer extent.

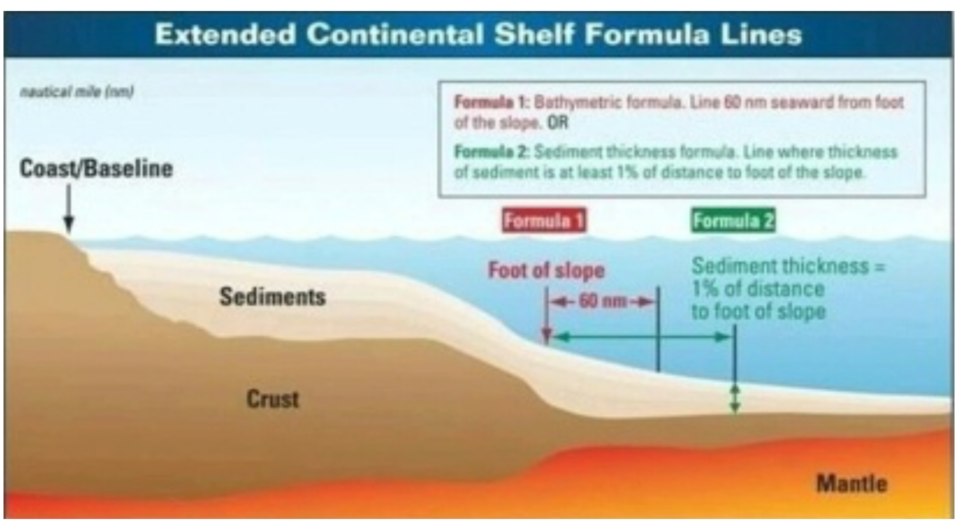


Figure 4: Diagram depicts the two formula lines and their general application in a cartoon scenario. Source: http://www.continentalshelf.gov/about/index.htm

Article 76 (paragraph 5), Constraint Lines:

After applying the formula lines, a coastal State must employ the constraint lines. The constraint lines were included to limit coastal States that potentially could extend their ECS beyond what was thought reasonable by the delegates of UNCLOS. The first constraint line is based upon distance, whereas the second is dependent on water depth and distance.

The first constraint line is a limit at 350 M from the coastal State's baselines (Fig. 5) (Article 76, paragraph 5). The baselines are defined in UNCLOS Articles 5 and 7 and can be either normal or straight lines connecting the relevant baseline points. The coastal State's baseline points are determined by the lower water line of its tidal datum and what it recognizes on large-scale official nautical charts (Article 6, paragraph 1). Note, that even though this constraint line depends on the location of the baselines, the CLCS has no oversight of where and how the coastal State determines its baseline points and baselines when it reviews a coastal State's submission.

The second constraint line is dependent on water depth and distance. This constraint line requires the coastal State to determine the 2,500 m isobaths contour and draw a series of 100 M arcs from points on the 2,500 m contour (Fig. 5) (Article 76, paragraph 5). The coastal State decides which points along the 2,500 m contour are most advantageous to build the 100 M arcs (i.e., most seaward). After selecting the chosen points on the 2,500 m contour and drawing 100 M arcs from these points, the second constraint line is defined as the most seaward extent of the

Figure 5: A coastal State may use either or both constraint lines to define its outer limits of the continental shelf, 350 M seaward of the baselines or 100 M seaward of the 2,500 m isobath contour. Source: http://www.continentalshelf.gov/about/index.htm

100 M arcs and their intersection points. The 2,500 m isobaths must be measured (bathymetry) and not generated from a grid, if at all possible.

The coastal State can invoke whichever constraint line is more advantageous (seaward), similar to its choice to use only one or a combination of the formula lines. The coastal State's ECS, however, can never exceed the outer limit formed by the constraint lines, even if the formula lines exceed this limit. Conversely, if the combined outer boundary of the formula lines does not exceed the constraint lines' outer boundary, then the constraint lines are not invoked and the outer limit of the *juridical* continental shelf is determined by the formula lines.

Article 76, Delineating the ECS Outer Limits:

After the coastal State applies the two formula lines and two constraint lines to its continental margin, the last step is to delineate the outer limit of its *juridical* continental shelf by straight lines connecting fixed points that do not exceed 60 M (Article 76, paragraph 7). If it is more advantageous for a coastal State to utilize outermost fixed points that are less than 60 M, then it has the right to do so.

Commission on the Limits of the Continental Shelf (CLCS):

The CLCS was established within Article 76 with the directive to "make recommendations to coastal States on matters related to the establishment of the outer limits of their continental shelf" (Article 76, paragraph 8). If the coastal State disagrees with the Commission's recommendations, it may negotiate with the Commission or make a revised or new submission to the Commission (UNCLOS, Annex II, Article 8). After the CLCS makes recommendations and the coastal State is in agreement with the recommendations, it will submit the final outer limits of its continental shelf to the UN Secretary-General and the Secretary-General will publish the limits on charts along with any other relevant information (Article 76, paragraph 9). The Secretary-General's published ECS limits are *final and binding.* It is noteworthy that the CLCS does not dictate the outer limits of the continental shelf for a coastal State; this is the explicit right and responsibility of the coastal State itself.

As mentioned previously, the CLCS is composed of twenty-one scientists who specialize in the fields of geology, geophysics, and/or hydrography (UNCLOS, Annex II, paragraph 1). The main outputs of the CLCS are the formal summaries of the recommendations that are published by the Division for Ocean Affairs and Law of the Sea (DOALOS). If the coastal State grants permission, DOALOS will make public the full recommendations. As of the writing of this thesis, the CLCS has produced 23 sets of summary recommendations (as of May 2016). For a more detailed review of the CLCS, its functions and guiding documents, see Appendix II.

Introduction to Ambiguities Associated with Article 76, paragraph 6:

The most challenging aspect of Article 76 is the lack of clarity for many of the terms presented in the article. This is particularly true for the concept of seafloor highs presented in Article 76, paragraph 6, which has great relevance to a potential United States submission for the

Arctic. Three types of seafloor highs are identified in Article 76: oceanic ridges, submarine *ridges*, and submarine *elevations*. In addition to these three types of features, Article 76 qualifies these features by discussing two other concepts: *natural prolongation* (Article 76, paragraph 3) and *natural component* (Article 76, paragraph 6). Article 76 does not provide any further insight into the meaning of any of these terms and UNCLOS practitioners have debated interpretations and real-world applications to seafloor highs around the globe. This section is meant to provide a glimpse into the multiple views that exist for each of these terms, integrating the S&TG's guidance as well as input from scientists and lawyers.

Paragraph 6 of Article 76 is important to this thesis' objectives because the area of concern in the Arctic is one composed of morphologically elevated features. Analogous features that were analyzed within the context of seafloor highs, in other CLCS recommendations, will prove useful to form arguments for these Arctic features. Within this discussion of seafloor highs, it is important to note that morphology refers to the shape of a feature, whereas geomorphology is the study of the origin and evolution of a feature in addition to its morphology (i.e., it explains the morphology). The following terms will be discussed in this section:

- Oceanic Ridges
- Submarine Ridges
- Submarine Elevations
- Natural Prolongation
- Natural Component
- Crustal Neutrality

Oceanic Ridges:

According to paragraph 3 of Article 76, the *juridical* continental margin includes the submerged prolongation of the land mass of the coastal State including the shelf, slope and rise; however, it does not include "the deep ocean floor with its oceanic ridges or the subsoil thereof" (Table 1). This clause does not provide a distinction between *a submerged prolongation of the* *land mass* and the *deep ocean floor with its oceanic ridges.* Without such clarity, it raises the question: can a distinction be made between oceanic ridges of the deep ocean floor and oceanic ridges *not* of the deep ocean floor?

Submarine Ridges, Submarine Elevations, and Natural Component:

This question is answered in part by UNCLOS definitions of submarine *ridges* and submarine *elevations* within paragraph 6 of Article 76 (Table 1).

> …on submarine ridges, the outer limit of the continental shelf shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured. This paragraph does not apply to submarine elevations that are natural components of the continental margin, such as its plateaux, rises, caps, banks and spurs. (Article 76, paragraph 6)

From this paragraph, it is clear that Article 76 distinguishes between a feature it categorizes as submarine *ridges* and submarine *elevations*. The first sentence of paragraph 6 specifies that the outer limit of the *juridical* continental shelf on a submarine *ridges* cannot exceed the 350 M (from baselines) constraint line. Conversely, it is inferred, given the phrase used "this paragraph does not apply," that both constraint lines (350 M and 2,500 m isobaths +100 M) can be applied to submarine *elevations* that are *natural components* of the *juridical* continental margin.

Given this definition of a submarine *elevation,* it is deduced that submarine *ridges* are not *natural components* of the *juridical* continental margin given their separate attention in the first sentence of paragraph 6. Paragraph 6, however, could also be read differently, namely that many types of submarine *elevations* exist, including submarine *ridges*; however, only those submarine *elevations* that are *natural components* of the *juridical* continental margin may apply the depth constraint line (2,500 m isobaths +100 M). Note that there is no explicit definition of *natural component.*

With either interpretation, a non-exhaustive list of examples of submarine *elevations* that are *natural components* of the *juridical* continental margin are presented within Article 76, paragraph 6. This array of examples is inferred to be non-exhaustive from the word choice "such as" to describe the five examples of "plateaux, rises, caps, banks and spurs."

It is clear that it is advantageous for a coastal State to classify a seafloor high as a submarine *elevation* because they can utilize either of the constraint lines, potentially increasing the seaward extent of a coastal State's ECS delineation. This makes the classification of seafloor highs an important aspect of Article 76. It is also a precarious topic due to the lack of clear definitions for each of these terms. Table 2**,** taken from Symonds and Brekke (2004a), summarizes which constraint lines apply to each classification of seafloor highs:

Type of Seafloor High	**Article 76 province that it relates to**	**Maximum extent of continental shelf**
Oceanic Ridge	Deep Ocean Floor	200 M from baselines
Submarine Ridge	Continental Margin	350 M from baselines
Submarine Elevation	Continental Margin	350 M from baselines or 2,500 m isobaths +100 M, whichever is greater

Table 2: Constraint Line application to seafloor highs, Article 76, paragraph 6.
Source: Symonds and Brekke (2004a)

There is a question that follows from Article 76, paragraphs 3 and 6, concerning criteria used to classify seafloor highs: Given that these *juridical* seafloor high terms derive from the marine *geological* realm, do the scientific definitions for these seafloor highs inform their *juridical* meaning? To help answer these questions, it is appropriate to explore writings of the CLCS and UNCLOS practitioners about this issue.

The Scientific & Technical Guidelines of the CLCS & Article 76, paragraph 6:

The CLCS emphasized within the S&TG that the classification of seafloor highs is not based upon geographical denominations or even the official names of such features, but rather a more rigorous investigation is required based upon scientific data (CLCS/11, 7.1.8). The array of evidence the CLCS aims to examine includes data that can elucidate the key characteristics of the features under question and their relationship with the *geological* continental margin, including geological composition, tectonic history, and geomorphology.

Above all else in this discussion, the primary criterion utilized by the CLCS to evaluate seafloor highs is morphology (CLCS/11, 7.2.10). The key characteristic to determine if a seafloor high is a *natural prolongation* is a morphological attachment between the seafloor feature and the adjacent continental margin. In order to prove *natural prolongation*, the coastal State must show that the seafloor high contributes to the FOS envelope of the continental margin. The FOS envelope consists of a line connecting FOS points. If the feature contributes to the FOS envelope then the morphological (i.e., *natural prolongation*) criterion is satisfied.

The 2012 International Tribunal on the Law of the Sea's (ITLOS) judgment for the case between Bangladesh and Myanmar addressed this specific issue. In the ITLOS judgment, the Tribunal concluded that *natural prolongation* and the *juridical* continental margin are "closely interrelated" and the two terms "refer to the same area" (ITLOS, Bangladesh Myanmar Case, 2012, p. 127 (434)). To define the *juridical* continental margin, a coastal State must apply paragraph 4, the formula lines, to define the outer edge of the continental margin. The driving component to defining the outer extent of the formula lines (and paragraph 4) is the FOS. Therefore, by defining the FOS points and connecting those points to establish the FOS envelope demonstrates the *juridical* continental margin's *natural prolongation*.

This connection between *natural prolongation* and the *juridical* continental margin is discussed within the S&TG as well. The CLCS defined the test of appurtenance as the process of applying paragraph 4 of the Article 76 to prove that "the *natural prolongation* of a coastal State's submerged land territory to the outer edge of its continental margin extends beyond 200 M" (CLCS, S&TG, 2.2.4).

If a ridge-like feature is morphologically unattached to the *geological* continental margin and does not contribute to the FOS envelope, then the feature would be considered an oceanic ridge. Thus, based upon this primary criterion of morphological connection, the classification of oceanic ridges is relatively straight-forward.

Questions do remain, however, regarding the classification of oceanic ridges. If the UNCLOS authors intended for the term oceanic ridge to refer to the *geological* mid-ocean ridges (MOR) of the ocean basins, then that would have significant implications for certain countries. Iceland, for example, was formed (and continues to grow) as an above sea-level manifestation of the Mid-Atlantic Ridge in the Atlantic Ocean as the Eurasia and North American plates pull apart. Therefore, Iceland is an island that is morphologically attached to the Mid-Atlantic Ridge, a ridge system that is a *geological* oceanic ridge. The morphological attachment between Iceland and the Mid-Atlantic Ridge may provide evidence to prove that the *geological* oceanic ridge is a *natural prolongation* and a *natural component* of Iceland. In its submission to the CLCS in April 2009, Iceland made this argument. The CLCS will decide when it reviews Iceland's submission.

The following analysis of the S&TG approach to seafloor highs focuses on CLCS statements about the classification of these features. In particular, this analysis concentrates on the definition of *natural component*, the driving distinction between submarine *ridges* and submarine *elevations.*

S&TG Discussion of Ridges:

The CLCS acknowledged the complexity of classifying real-world ridge features into one of the three Article 76 seafloor high classifications in the S&TG. The CLCS stated that it is difficult to identify and discuss each and every scenario for ridge-like seafloor features because the morphology and tectonic setting varies throughout the world and numerous types of processes can form such features (CLCS/11, 7.2.1). Transform ridges, for example, which may have originated from a continental crust environment may develop into an oceanic crustal environment, thus complicating the feature's classification along its entire length as an oceanic ridge or submarine *ridge* (CLCS/11, 7.2.3). The CLCS discussed an example where a ridge of oceanic origin, composed of basalt, through time accreted to a continental margin (morphological connection) (CLCS/11, 7.2.4). How would this ridge be classified: submarine *ridge* or perhaps as a submarine *elevation*? Accretion is a part of the natural growth of continents, but due to the differing geologic processes associated with a feature, is the feature a *natural component* of the margin? By raising examples such as these, the CLCS acknowledged within the S&TG the difficulty of classifying seafloor highs according to Article 76.

The CLCS presented a non-exhaustive table of possible tectonic settings for ridge formation (CLCS/11, 7.2.1). Some of the settings discussed include ridges formed by hot spots, interaction of oceanic crustal plates, uplift of oceanic crust, large mantle plumes, island arc systems and extension and thinning of continental crust (CLCS/11, 7.2.1). These differing tectonic settings demonstrate that the specific classification of a ridge is highly debatable due to the variety of tectonic settings that could form such a feature and the lack of clarity provided in paragraphs 3 and 6 of Article 76.

S&TG Crustal Neutrality & Ridges:

Article 76 makes no statement about the crustal type of the coastal State's landmass and "submerged prolongation of the landmass"; therefore, UNCLOS practitioners refer to this as crustal neutrality. The continental margin of a coastal State can be of oceanic or continental origin because the terms *land mass* and *land territory* are neutral terms and do not specify a specific crust type or geological composition. The S&TG refers to crustal neutrality with respect to classifying seafloor highs by stating that the crustal type of a feature cannot be the sole distinguishing factor when classifying ridge (CLCS/11, 7.2.9). The major criteria in classification are the morphology of the ridge and its relationship to the continental margin as discussed above (CLCS/11, 7.2.10). Thus, given Article 76 and the multitude of complex geological processes that could form or integrate a ridge into a *geological* continental margin, the CLCS stated that its analysis of seafloor ridges is based upon “a case-by-case basis” (CLCS/11, 7.2.10; 7.2.11).

S&TG, Submarine Elevations and Natural Component:

Within the context of UNCLOS, submarine *elevations* are submarine ridge-like features that are *natural components* of the continental margin; therefore, evaluating how the CLCS examines the *natural component* criterion is critical to the differentiation between submarine *ridges* and submarine *elevations*. The S&TG stated that the concept of *juridical natural prolongation* triggers a review of the *geological* processes of continental growth (CLCS/11, 7.3.1). The CLCS presented two broad types of continental growth scenarios in the S&TG; firstly, continental growth within active margins and secondly, continental growth within passive margins (CLCS/11, 7.3.1).

Within an active margin, continental growth occurs through the accretion of crustal material and sediments to a *geological* continental margin (CLCS/11, 7.3.1(a)). The accreted material can be of any origin or composition; oceanic, island arc, or continental (CLCS/11, 7.3.1(a)). Given this criterion, the CLCS stated, “any crustal fragment or sedimentary wedge that is accreted to the continental margin should be regarded as a natural component" (CLCS/11, 7.3.1(a)).

With respect to passive margins, continents fracture and fragment before seafloor spreading initiates (CLCS/11, 7.3.1(b)). Thus, continental growth in this setting includes "thinning, extension, and rifting of the continental crust and extensive intrusion of magma into and extensive extrusion of magma through that crust" (CLCS/11, 7.3.1(b)). The S&TG stated that seafloor highs created by these processes should be considered *natural components* of the *geological* continental margin (CLCS/11, 7.3.1(b)).

The CLCS' emphasis on highlighting the tectonic processes that dictate the growth (and destruction) of continents points to its focus on the geological evolution of not only the feature at hand, but also the larger tectonic context surrounding the feature and continental margin. The growth of continents, no matter the geological process, can join geologic material of disparate origins. Therefore, the specific geological composition of a feature may not necessarily be the only factor. Rather, its tectonic origin and evolution may prove critical when examining potential submarine *elevations*.

S&TG Conclusion:

Although the S&TG provide some basic understanding into the views of the CLCS at the time they were written (1999), the recommendations provide more recent insight into whether or not the stipulations set forth in the S&TG are actualized in the CLCS' evaluation of specific seafloor highs. The S&TG give insight into how the CLCS applies a hybrid interpretation of Article 76 seafloor highs that combines scientific knowledge of marine geology and legal aspects from the Convention resulting in an UNCLOS-specific categorization of a feature. At the same time, the S&TG raise some interesting considerations that place Article 76 at this juncture between law and science. For example, is the CLCS obligated to use the same scientific criteria to evaluate all seafloor highs and classify them into one of the broadly defined categories found in the S&TG? UNCLOS practitioners agree on the need for consistent practices; in particular, two past CLCS Members, Harald Brekke and Philip Symonds (2004a) articulated this concern. There is no legal mandate, however, that requires the CLCS to implement consistent practices.

Article 76 (paragraph 6), Seafloor Highs Interpreted by UNCLOS Practitioners:

Multiple interpretations in the literature exist regarding seafloor high classification. The following analysis is not meant to be exhaustive, but rather to provide insight into the spectrum of interpretations. The review of different UNCLOS practitioners' views to date will follow the evolving pattern of thought for each specific seafloor high classification.

Oceanic Ridges:

Brekke and Symonds (2004a) classified an oceanic ridge as a ridge of the deep ocean floor that shares no morphological attachment with the *geological* continental margin. Therefore, the feature does not contribute to the FOS envelope and has a shared tectonic and geologic origin with the deep ocean floor (Brekke and Symonds, 2004a;2004b). This interpretation is shared by many others (Symonds et al., 2000; Gudlaugsson, 2004; Suarez, 2008; Gao, 2009; Weiguo, 2011). Many of these authors note that even if a ridge shares geologic similarities with the *geological* continental margin, it still remains morphologically detached from the margin, and thus is still an oceanic ridge.

Submarine Ridges & Submarine Elevations:

Symonds et al. (2000) and Brekke and Symonds (2004b) pointed to the geologic context surrounding a feature to help discern a distinction between the two feature types. They cited two criteria with respect to the classification of a submarine *ridge* and submarine *elevation.* Firstly, and most importantly, the bathymetric high must demonstrate a morphological connection to the *geological* continental margin to distinguish it from an oceanic ridge. For some features, demonstrating this morphological connection is sufficient to classify the feature as a submarine *ridge* (Brekke and Symonds, 2004b).

Secondly, to show that the feature is a *natural component* of the continental margin and thus a submarine *elevation*, the feature's geologic and tectonic history must be evaluated (Brekke and Symonds, 2004b). Brekke and Symonds (2004b) generalized this second criterion as "geological continuity." If the submarine high's geologic and tectonic characteristics are similar to the coastal State's landmass then the feature can be classified as a submarine *elevation* because the feature has been proven to be a *natural component* of the *geological* continental margin by sharing "geologic continuity" with the landmass (Brekke and Symonds, 2004b). The authors stated that proving "geologic continuity" includes evaluating the feature's crustal characteristics, origin, formation, and tectonic setting. The authors conceded that in some cases demonstrating continuous, uniform "geologic continuity," between a *geological* continental margin and seafloor high may be impossible.

When "geologic continuity" cannot be proven between the feature and landmass, the feature can still be classified as a submarine *elevation.* Brekke and Symonds (2004b) stated that when a submarine high shows "transitional crust" between the continental margin and deep ocean floor, then the tectonic history of the feature must be reviewed to determine if its origin aligns more with the landmass or deep ocean floor. If the tectonic history can be proved to coincide with the landmass' tectonic origin, then the feature can be classified as a submarine *elevation*; however, if the evidence supports a tectonic history that is more similar to the deep ocean floor's tectonic origin, then the feature is classified as a submarine *ridge*.

Brekke and Symonds (2011) review of published recommendations discerned some key patterns of the CLCS' behavior with respect to their analysis of submarine *ridges* and submarine *elevations*. The authors concluded that the CLCS evaluates all seafloor highs, no matter the type of feature, for "geological continuity" with the landmass of a coastal State when the seafloor highs create an outer edge of the *juridical* continental margin outside of 350 M (Brekke and Symonds, 2011). They observed that the CLCS bases its classifications of submarine *elevations* on two criteria; firstly, a morphological connection and secondly, "geological continuity" with the landmass. With respect to the "geological continuity" analysis, the CLCS conducts a two-pronged analysis when assessing the geological and geophysical evidenced provided by the coastal State. Firstly, the CLCS compares the feature's geological characteristics with the landmass of the coastal State and then assesses the feature's similarities with the surrounding deep ocean floor (Brekke and Symonds, 2011). This type of analysis parallels the argument Brekke and Symonds put forth in 2004(b).

Suarez (2008) and Weiguo (2011) shared the same interpretation of submarine *ridges* and submarine *elevations* as Brekke and Symonds (2004a; 2004b). Suarez (2008) and Weiguo (2011) advocated for the analysis of the same two criteria, firstly, and most importantly, morphological connection and contribution to the FOS envelope. Following this analysis, the second criterion, "geological continuity," is assessed with the landmass. This interpretation implies, like Brekke and Symonds (2004a; 2004b), that Suarez (2008) and Weiguo (2011) equated *natural component* to "geological continuity." Weiguo (2011) noted, like Brekke and Symonds (2004a), that submarine *ridges* do not have to show a "geological continuity" with the *geological* continental margin, only submarine *elevations* that are *natural components* of the *geological* continental margin must demonstrate this "geological continuity" in the form of similar geologic origin, rock-type, crustal characteristics, and tectonic setting (Weiguo, 2011).

With respect to submarine *ridges* and *elevations*, Gudlaugsson (2004) argued the same morphological criterion as Brekke and Symonds (2004a; 2004b), Suarez (2008) and Weiguo (2011). The second criterion Gudlaugsson (2004) put forth, however, departs from these other authors' interpretations. He stated that the differentiation between submarine *ridges* and submarine *elevations* based upon geological and tectonic evidence violates the principles of crustal neutrality; therefore, evaluating features based upon their aspect ratio is more appropriate. The aspect ratio is the ratio between the length and width of the feature (Gudlaugsson, 2004). He stated that the aspect ratio approach would help distinguish submarine *ridges* and submarine *elevations* (Gudlaugsson, 2004).

Gao's (2009) analysis of submarine *ridges* and submarine *elevations* parallels the arguments of Brekke and Symonds (2004a; 2004b), Suarez (2008), and Weiguo (2011), namely differentiating a submarine *elevation* from a submarine *ridge* based upon geologic evidence. He based this argument on the fact that the delegates of UNCLOS included the two specific phrases, *natural component* and *natural prolongation*, within Article 76; therefore, the two phrases must have fundamentally different meanings (Gao, 2009). Gorski (2009) held the same semantic argument, advocating for distinct and separate meanings between *natural component* and *natural prolongation*.

Gorski (2009), like the previous authors, pointed to the geologic setting as the distinguishing factor between submarine *ridges* and submarine *elevations*. Unlike the arguments

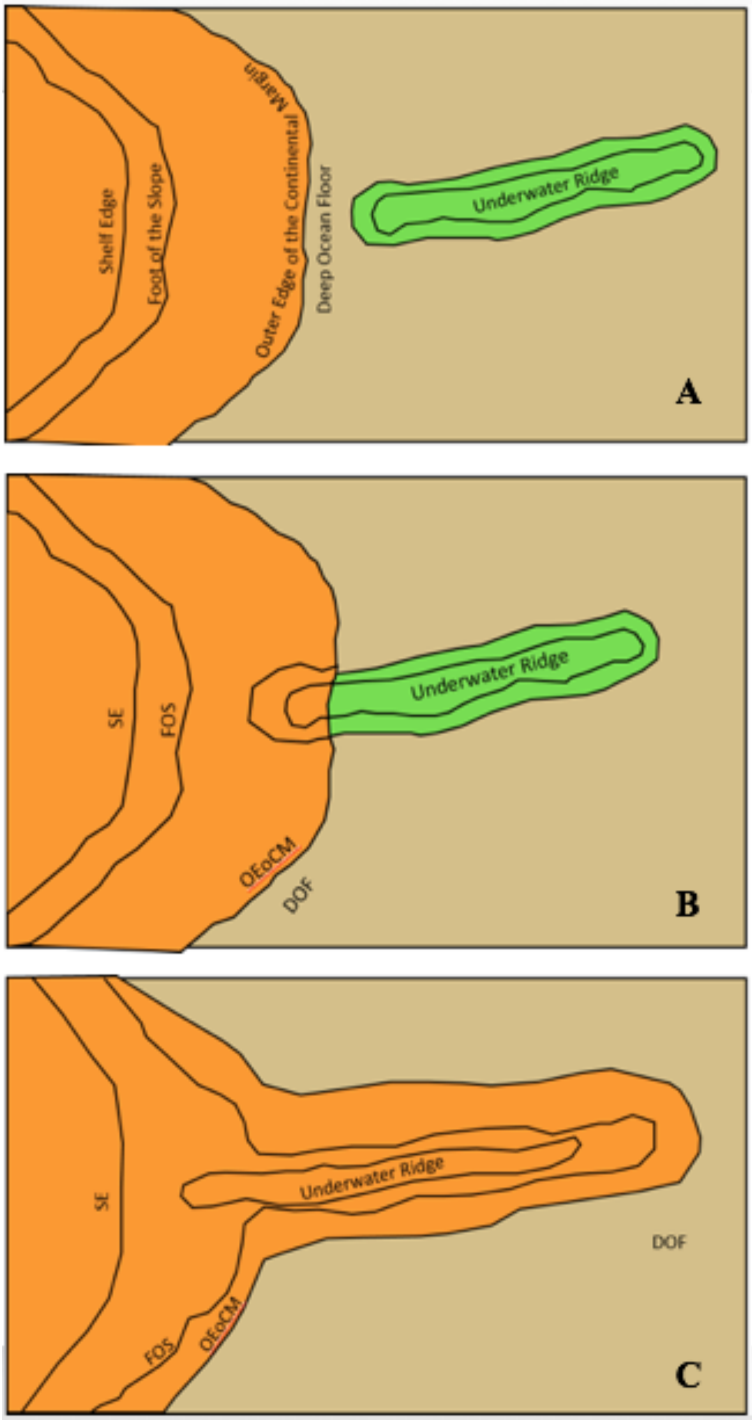


Figure 6: Depiction of different scenarios for oceanic ridges according to Article 76, paragraph 6. **A:** Oceanic ridge of the Deep Ocean Floor (DOF); **B:** Oceanic ridge of the DOF that does not contribute to the Foot of Slope (FOS); **C:** Underwater ridge that contributes to the FOS and Outer Edge of the Continental Margin (OEoCM); SE: Shelf Edge; Source: Diagrams recreated with permission from Brekke (2014).

put forth by previous authors, however, Gorski (2009) concluded that submarine *ridges* only exist in relation to island states and do not occur in relation to continents. He stated that any seafloor high that may affect the *geological* continental margin should be classified as either a submarine *elevation* or oceanic ridge (Gorski, 2009).

At the Summer Academy on the Continental Shelf (SACS) in June 2014, Brekke (2014) gave a presentation on the classification of seafloor highs and pointed to the S&TG to help distill the differences between the classifications. The interpretations he presented are consistent with those previously discussed. The additional value Brekke's (2014) presentation provided were visuals that depict scenarios for the classification of seafloor highs. These diagrams have been reproduced here with the author's permission.

In Figure 6A, Brekke (2014) provided an example of an oceanic ridge that is morphologically detached from the geological continental margin and thus resides outside of the FOS envelope beyond 200 M. Figure 6B shows that part of the ridge is within the outer edge of the geological continental margin, but it still does not contribute to the FOS envelope. Again, in this case, the feature would be considered an oceanic ridge because of the absence of a morphological attachment between the ridge and geological continental margin. Figure 6C shows a ridge that has been accreted to the *geological* continental margin and contributes to the FOS envelope. This feature would no longer be classified as an oceanic ridge but is a ridge that is part of the *geological* continental margin (i.e., submarine *ridge* or submarine *elevation*).

Brekke (2014) also provided diagrams (Fig. 7A and 7B) that depict his interpretation of the difference between a submarine *ridge* and submarine *elevation*. With respect to a submarine *ridge,* he suggested that this type of feature is morphologically connected to the *geological* continental margin (Brekke, 2014). A submarine *elevation*, however, in addition to the morphological connection, also shows "geological continuity" with the landmass. This implies that a submarine *elevation* is a submarine *ridge* that is a *natural component* of the *geological* continental margin by proof of "geological continuity." Figures 7A and 7B depict these two scenarios.

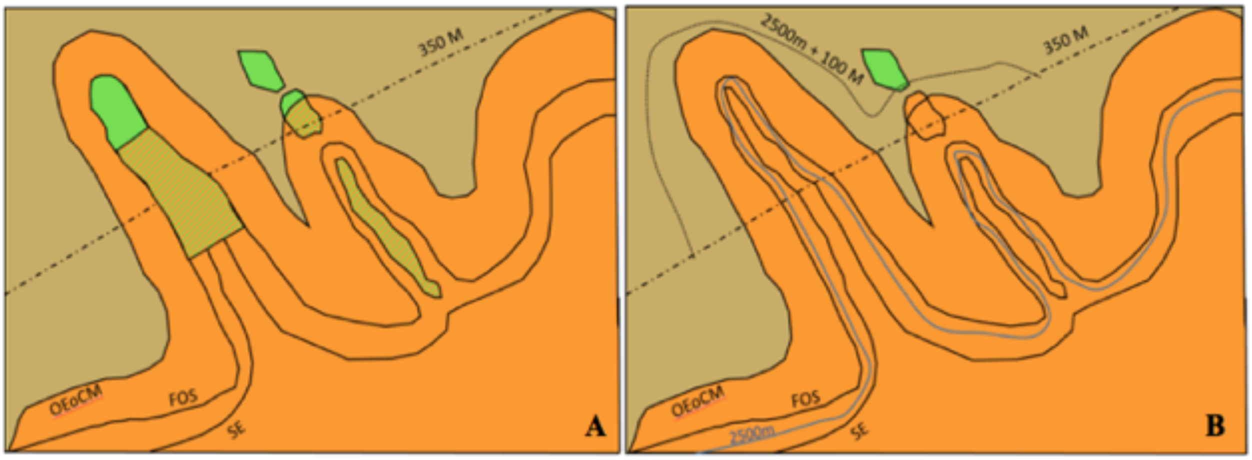


Figure 7: A: Submarine Ridges that are morphologically integral parts of the Outer edge of the Continental Margin (OEoCM) and contribute to the Foot of the Slope (FOS) envelope; however, the ridges have a composition (green-cross-hatching) that is different from the continental margin or transitional (oceanic to continental) in nature. **B:** Submarine elevations that are natural components of the continental margin not only contribute morphologically to the OEoCM, and thus FOS envelope, but also have the same or similar composition as the continental margin and landmass; SE: Shelf Edge; Source: Diagrams recreated with permission from Brekke (2014).

UNCLOS Practitioners' Views on Article 76, paragraph 6 Takeaways:

Brekke and Symonds (2004a) argued that the classification of seafloor highs should be based on clear criteria, which would allow the CLCS to maintain a level of transparency with coastal States and provide a consistent review process for seafloor highs. Clearly criteria and a transparent review process are critical to ensuring a fair and equitable ECS review process for all coastal States. Brekke and Symonds (2004a) also emphasized that the text of Article 76 reigns supreme over any interpretation or supporting documentation, including the S&TG, something that UNCLOS practitioners must keep in mind.

The table below (Table 3) summarizes the general criteria utilized to classify seafloor highs based upon the repeated arguments put forth by the UNCLOS practitioners reviewed here. Figure 8 shows a further breakdown of seafloor high classification analysis.

Seafloor High	**Basic Operationalized Definition for Application to Real-World Features**
Oceanic Ridges	• Morphologically disconnected from the continental margin • May or may not share geological continuity with continental margin (composition and/or tectonic history) • Often composed of oceanic basalt
Submarine Ridges	• Morphologically connected to the continental margin of the coastal State and contributes to the FOS envelope • In some cases, the feature shows transitional crust, signifying both continental and oceanic crust, but shares a tectonic origin with the deep ocean floor
Submarine Elevations	• Morphologically connected to the continental margin of the coastal State and contributes to the FOS envelope • Demonstrates, at the very least, some geological continuity with the continental margin (including "geological characteristics, origin, rock-types, crustal characteristics, development and tectonic setting") • Argument is strongest when geological continuity is found throughout the entire length of the feature • In some cases, the feature shows transitional crust and shares a tectonic origin with the landmass

Table 3: Summary of general criteria utilized to classify seafloor highs according to Article 76, paragraph 6.

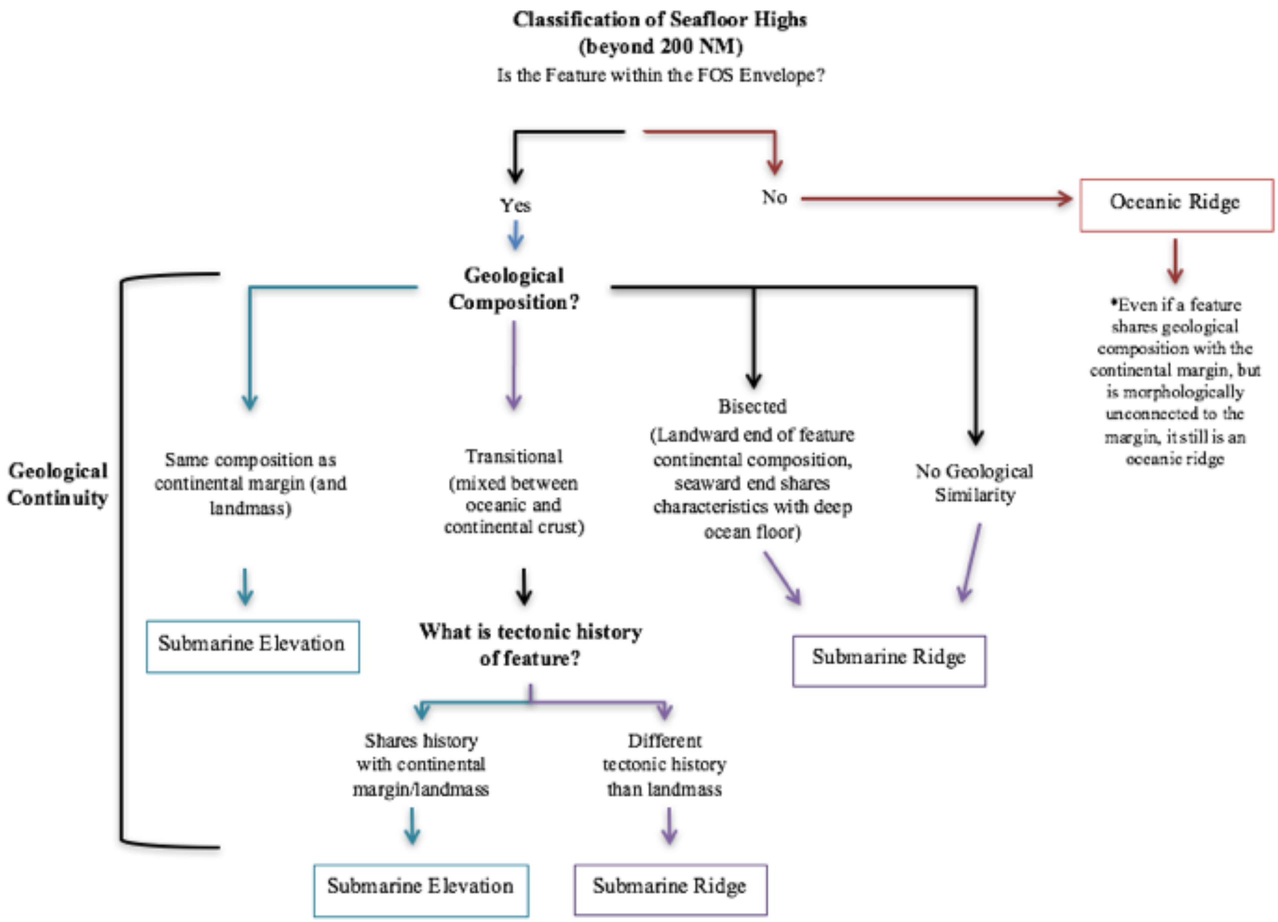


Figure 8: Breakdown of Article 76, paragraph 6 seafloor high classification based upon UNCLOS practitioners' arguments.

II. Arctic Ocean

Morphological Background:

In order to analyze how the United States' Arctic region may compare to other regions for which CLCS recommendations have been made, it is important to review the morphological inter-basinal highs in the Arctic Ocean as well as the tectonic context surrounding these features. The Arctic Ocean is divided into two major basins, the Eurasia and Amerasia basins (Fig. 9). The first has a distinct and well-understood geological history while the evolution of the latter is still debated. The focus of this section will be to discuss the modern theories that exist for the Amerasia Basin's tectonic evolution. This section will also review the role that the Chukchi Borderland and its northern extension plays in each of these tectonic models. Following these presentations, the converging evidence for the composition and origin of the Chukchi Borderland and its northern extension will be described. For a more comprehensive review of the physiographic components of Amerasia Basin, see Jakobsson et al. (2003; 2012).

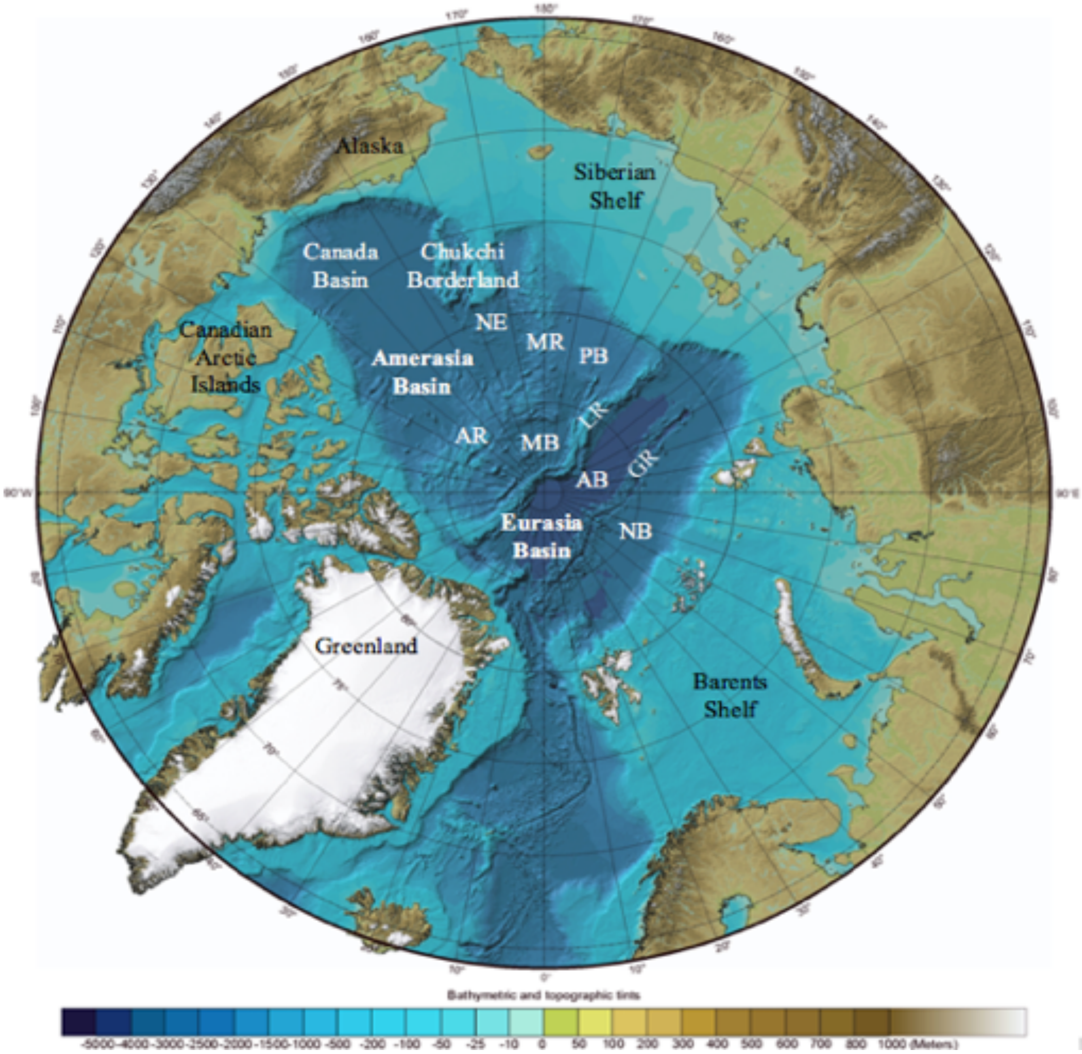


Figure 9: Physiographic components of the Eurasia and Amerasia basins; International Bathymetric Chart of the Arctic Ocean (IBCAO v. 3.0; Jakobsson et al., 2012); NE: northern extension of the Chukchi Borderland; MR: Mendeleev Ridge; PB: Podvodnikov Basin; AR: Alpha Ridge; MB: Makarov Basin; LR: Lomonosov Ridge; AB: Amundsen Basin; GR: Gakkel Ridge; NB: Nansen Basin

Lomonosov Ridge and Eurasia Basin:

The Lomonosov Ridge runs parallel to the Barents-Kara Shelf of Eurasia and extends from the Canadian margin to the Siberian margin, separating the Eurasia and Amerasia basins (Fig. 9) (Johnson et al., 1990). The feature is a sliver of continental crust that separated from the

Barents-Kara Shelf roughly 56 Ma during the Paleogene propagation of the Mid-Atlantic Ridge into the Arctic Ocean (Jokat et al., 1992; Cochran et al., 2006).

Within the Eurasia Basin, clear magnetic anomalies are located on either side of a central spreading ridge called Gakkel Ridge (Gaina et al., 2011; Saltus et al., 2011). A gravity low is present along the axis of the Gakkel Ridge, representing the central valley of this ultra-slow spreading center (Jokat et al., 1992; Dick et al., 2003).

Amerasia Basin:

The Alpha and Mendeleev ridges, often referred to as the Alpha-Mendeleev ridge complex, run roughly parallel to the Lomonosov Ridge on the Amerasia Basin side of the Arctic Ocean (Fig. 9) (Johnson et al., 1990). The Amerasia Basin has three sub-basins: The Makarov, Podvodnikov and Canada basins (Johnson et al., 1990). The Chukchi Borderland dominates the southern portion of the Amerasia Basin as a morphological high that rises as much as 3,000 m above abyssal depths of the adjacent Canada Basin. The Amerasia Basin's evolution is not well understood and multiple tectonic models have been published. All are in agreement, however, that the Amerasia Basin opened prior to the Eurasia Basin and has been tectonically dormant since the Mesozoic (Coakley et al., in press).

Canada Basin:

Canada Basin is the largest component of the Amerasia Basin and is bounded by continental margins and fragments on at least three sides. To the south, is the United States and Canadian Beaufort margin; to the east, is the Canadian Arctic Archipelago and to the west is Northwind Ridge (the eastern flank of the Chukchi Borderland) (Mosher et al., 2012b). To the north are the Alpha and Mendeleev ridges. Canada Basin consists of the Canada Abyssal Plain and Nautilus and Stefansson basins (Mosher et al., 2012b). It has a general depth of approximately 3,800 m and is relatively featureless and level (Mosher et al., 2012b). The basin's sediment cover is the thickest (12-13 km) offshore of the Mackenzie River and thins further north (Shimeld et al., 2016). The combination of thick sediment cover and weak and complex magnetic anomalies makes it difficult to discern the basin's basement and thus its nature and origin ((Mosher et al., 2012b; Gaina et al., 2014).

Makarov and Podvodnikov basins:

The Makarov Basin is a relatively small basin in comparison to the Canada Basin. It is ~300 km wide north to south and 400 km east to west (Evangelatos and Mosher, 2016). This basin is the northern boundary of the Amerasia Basin and it sits at a depth of 4,000 m, 200 m deeper than the average depth in Canada Basin (Evangelatos and Mosher, 2016). Makarov Basin is bordered by the Lomonosov Ridge to the north and the Alpha Ridge. To the west is the Podvodnikov Basin. The Podvodnikov Basin sits just north of the Siberian Shelf and adjoins Makarov Basin via a depression informally known as the Arlis Gap.

Alpha and Mendeleev ridges:

Grantz and Hart (2012) stated that the Alpha-Mendeleev ridge complex is a wide and prominent bathymetric high that ranges in depth from approximately 3,800 m to as shallow as 900 m below sea level. Johnson et al. (1990) described the Alpha and Mendeleev ridges as separate entities due to the presence of a depression, a depth of 2,700 m, between the two ridges informally known as Cooperation Gap. Despite differences in naming, both the ridges have irregular gravity and aeromagnetic fields, encompassing an area of 700,000 km^2 (Gaina et al., 2011; Saltus et al., 2011; Coakley et al., in press).

The Alpha and Mendeleev ridges have a complicated morphology with local highs that are 10-100 km in length and elevated 500 to 1,500 m above the ridges (Coakley et al., in press). The Mendeleev Ridge is narrower and blockier than the Alpha Ridge (Coakley et al., in press). Currently, two hypotheses exist for the origin of the Alpha and Mendeleev ridges:

1.) Alpha-Mendeleev ridge complex is a mafic-volcanic plateau that was created by hot spot volcanism (Forsyth et al., 1986; Lawver and Muller, 1994; Lawver et al., 2002; Jokat, 2003; Funck et al., 2011; Grantz et al., 2011).
2.) Alpha-Mendeleev ridge complex is highly attenuated continental crust that has been altered by a pulse(s) of volcanism in the Cretaceous (a Large Igneous Province (LIP), discussed further below) (Miller et al., 2006; Lebedeva-Ivanova et al., 2006; Bruvoll et al., 2012; Døssing et al., 2013; Brumley, 2014).

Coakley et al. (in press) reported that the key driving factor for the convergence to these two theories is that many seismic velocity profiles across the ridges display a layer beneath the lower crust that has a high velocity (7.5 km/s), which has been interpreted as either highly attenuated continental crust (Lebedeva-Ivanova et al., 2006) or Icelandic type crust (Forsyth et al., 1986; Funck et al., 2011).

Chukchi Borderland

Morphology:

The Chukchi Borderland is an approximately 800 km long and 400 km wide bathymetric high in the Amerasia Basin that accounts for 4% of the Arctic Ocean (Fig. 10) (Johnson et al., 1990; Jakobsson et al., 2003; 2012; Mayer and Armstrong, 2012). The Borderland protrudes out of the Chukchi Shelf between eastern Siberia and western Alaska into the Amerasia Basin

(Jakobsson et al., 2003). The region includes two topographic highs, including the Northwind Ridge and Chukchi Plateau, as well as three western plateaus (Arlis, Sargo, and T3) that are located on the Russian side of the U.S.-Russian 1990 maritime boundary agreement (Mayer and Armstrong, 2012). The Borderland exhibits plateau-like crests and in some locations rises 3,400 m above abyssal depth, to depths as shallow as 246 m. The Northwind, Chukchi and Mendeleev plains are located between the Borderland's ridges at depths ranging from 2,100 and 3,850 m.

The east side of the Chukchi Borderland is the Northwind Ridge. It drops to the Canada Basin with a steep escarpment with slopes between 5-20º and 3,000 m of relief (Mayer and Armstrong, 2012). The western boundary of the Chukchi Borderland is the Chukchi Plateau, which is adjacent to the Chukchi Plain and merges with the Siberian Shelf further to the west.

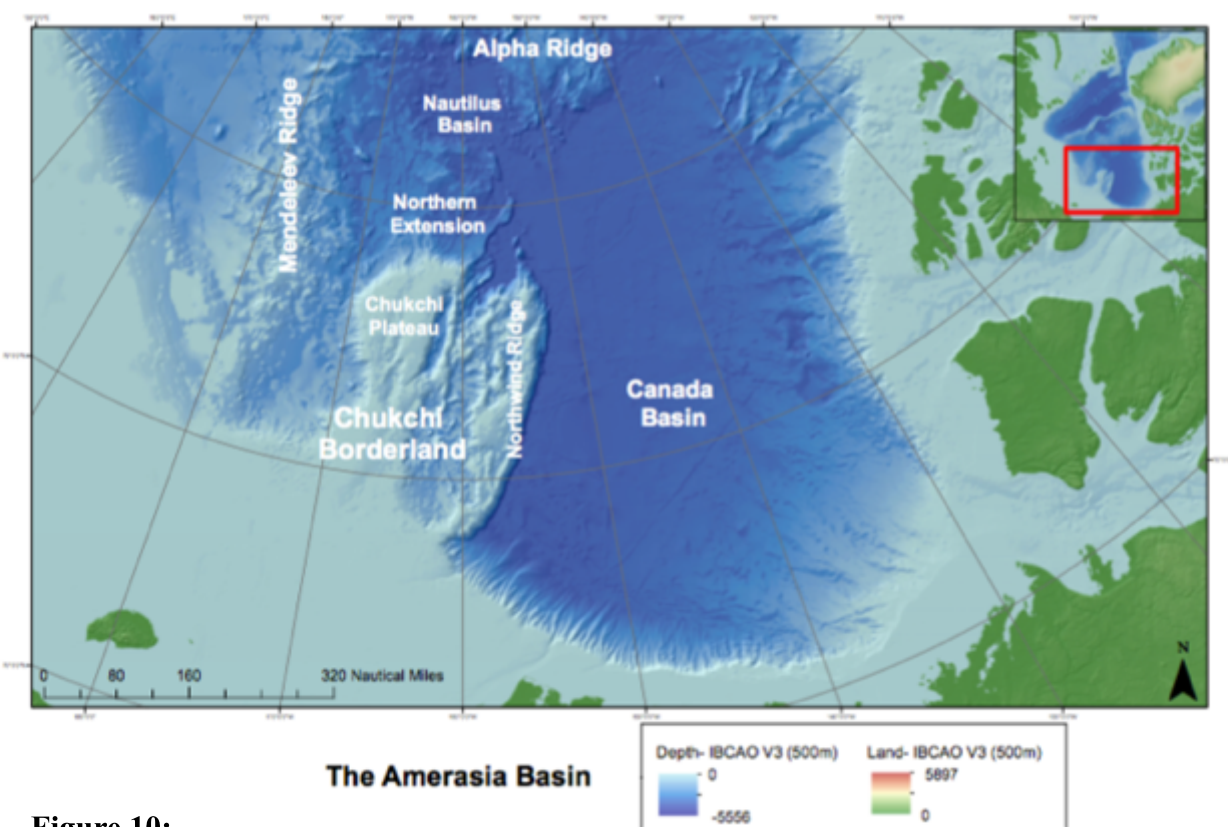


Figure 10:
Physiographic components of the Amerasia Basin

The northern extension of the Chukchi Borderland is a complex bathymetric feature that extends north from Chukchi Plateau into the Nautilus Basin.

Continental Fragment:

Scientists have suspected that the Chukchi Borderland was a continental fragment since the 1960's. The name given to the Chukchi Borderland derives from Shepard (1948) based on his understanding that the morphological highs associated with the Chukchi region were similar to a continental borderland (Dietz and Shumway, 1961). Heezen and Ewing (1961) and Shaver and Hunkins (1964) concluded that the Chukchi Cap was a semi-detached piece of continental crust that was accreted to the Alaskan continental margin. Evidence for morphological continuity between the Alaskan continental margin and Chukchi Borderland was established by the mid-20th Century (Dietz and Shumway, 1961; Heezen and Ewing, 1961; Shaver and Hunkins, 1964).

Recent History of Amerasia Basin Data Collection:

By the early 2000's, it was clear that existing Arctic bathymetric and geophysical data were insufficient to scientifically support a delineation for an extended continental shelf in the Arctic according to Article 76 of UNCLOS and the CLCS' S&TG (Appendix III describes early Arctic exploration and data collection). Little data existed in both basins due to perennial ice-cover. For example, by 2006, only ~3,000 line-km of seismic reflection data had been collected in the Canada Basin (Mosher et al., 2013). This paucity of high quality data signaled a need for multi-year data collection missions for all Arctic countries, including the United States, Russia, Denmark (Greenland), Canada and Norway. Given the criteria for defining the continental shelf in Article 76, these Arctic data collection missions focused specifically on bathymetry, sediment thickness, seafloor morphology, and geomorphology.

After an ECS desktop study in 2002 (Mayer et al., 2002), the United States embarked on Arctic mapping and data collection missions in 2003, 2004, and from 2007 to 2012, collecting dredge samples, multibeam bathymetry, and seismic data among other data sets (Mayer and Armstrong, 2012; Mosher et al., 2013). From 2007 to 2011, the United States and Canada conducted annual two-ship missions, using the United States Polar Class Coast Guard Cutter (USCGC) *Healy* and the Canadian Coast Guard (CCG) Ship *Louis S. St.-Laurent* (*LSSL*), an Arctic Class 4 icebreaker (Mayer and Armstrong, 2009; Mosher et al., 2013). During these joint missions, the USCGC *Healy* collected bathymetric and subbottom profiler data while the CCG *LSSL* collected seismic refraction and reflection data (Mosher et al., 2013). The USCGC *Healy* collected 420,000 km^2 of bathymetry data over the eight cruises and the two ships jointly collected over 15,000 line-km seismic reflection data as well as shipborne gravity and high-resolution subbottom reflection data during their joint operations (Mayer and Armstrong, 2003; 2004; 2007; 2008; 2009; 2011; 2012; Mosher et al., 2013). In addition, 17 dredge sites were occupied during the ECS scientific missions and 157 expendable sonobuoys were deployed to collect wide-angle reflection and refraction data (Fig. 11) (Brumley, 2014). These data will be referred to as ECS data. For further information on the USCGC *Healy* cruises, see Mayer and Armstrong (2003; 2004; 2007; 2008; 2009; 2011; 2012) and information on the CCG *LSSL* cruises see Jackson et al. (2008; 2009); Mosher et al. (2009; 2011; 2012a). Hutchinson et al. (2009) and Mosher et al. (2013) also provided an overview of the joint ship operations.

These data collection efforts in combination with the ECS projects of other Arctic nations have greatly augmented the Arctic geophysical database. Coakley et al. (in press) noted that these data have now allowed for an adequate understanding of the Amerasia Basin. It is important to note, however, that concurrent non-ECS data collection missions have also been conducted. Coakley et al. (2005), for example, collected bathymetry, seismic, subbottom, and gravity data in the Arctic Ocean in the summer of 2005 on the USCGC *Healy*. The R/V *Polarstern* also acquired seismic data over the Chukchi Borderland in the summer of 2008 (Hegewood and Jokat, 2013). A number of other authors (e.g., Grantz et al., 1998; Jokat, 2003; Jakobsson et al., 2012; Gaina et al., 2011) have collected non-ECS geophysical and geological data from the Amerasia Basin as well.

The compilation of all of these data, both ECS and non-ECS, into composite grid maps have empowered scientists to begin to ask more targeted questions about specific Amerasia Basin features' (Coakley et al., in press). The basin's full tectonic history, particularly the absolute timing of events, however, is still not resolved (Coakley et al., in press). Coakley et al. (in press) suggested, for example, that the Alpha and Mendeleev ridges will "float in geologic time" until ground truth samples (i.e., Ocean Drilling Project (ODP) Sites) can correlate the stratigraphy with geologic time. The only samples that exist are from dredge sites, piston cores, and a drill from a submersible (Jokat, 2003; Mayer and Armstrong, 2008; 2009; 2012; Morozov et al., 2013).

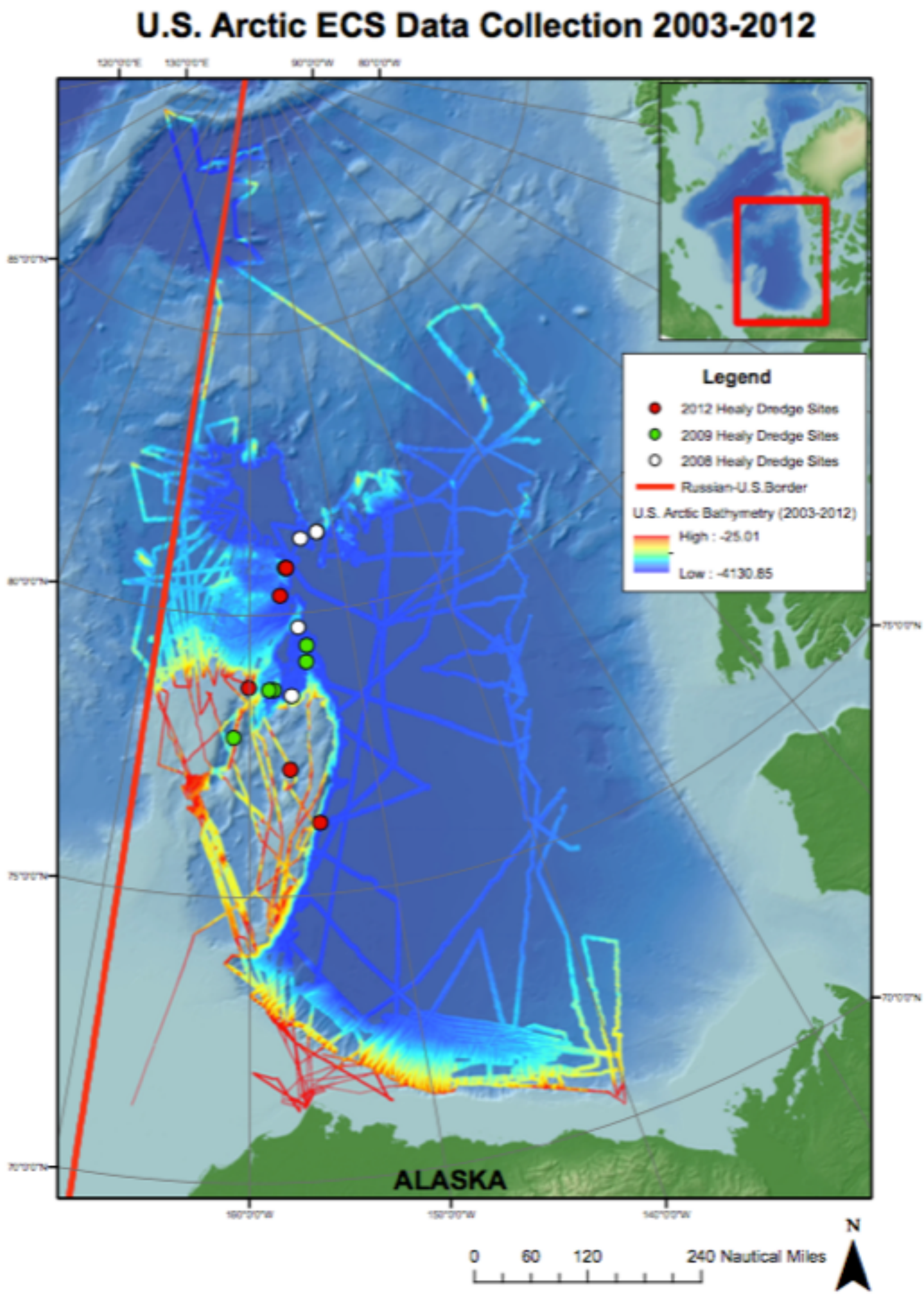


Figure 11: Bathymetric data collection and dredge sample locations for the Chukchi Borderland region north of Alaska. Data collection: 2003-2012 by Center for Coastal & Ocean Mapping/Joint Hydrographic Center (CCOM/JHC) on USCGC *Healy*

Historical Takeaways:

The first half of the twentieth century was both an exciting and critical time for scientific exploration in the Arctic (see Appendix III). It is noteworthy that the geologic understanding of the Arctic Basin kept pace with the technological advancements of the time. The scarcity of data in the Arctic and advent of UNCLOS in 1982 illuminated the need to collect extensive, high-resolution bathymetric and geophysical data in the Arctic Ocean. The maps presented below, taken from Dietz and Shumway (1961) and Jakobsson et al. (2012) demonstrate the evolution of morphologic knowledge of the Chukchi Borderland from 1961 to present (Fig. 12).

Scientific exploration in the Arctic Ocean is not complete and as Coakley et al. (in press) stated, new datasets are needed to ground truth the collected geophysical data, in particular more bathymetric, potential field, P-wave and S-wave velocities and samples that recover stratigraphic, rock type, and basement information.

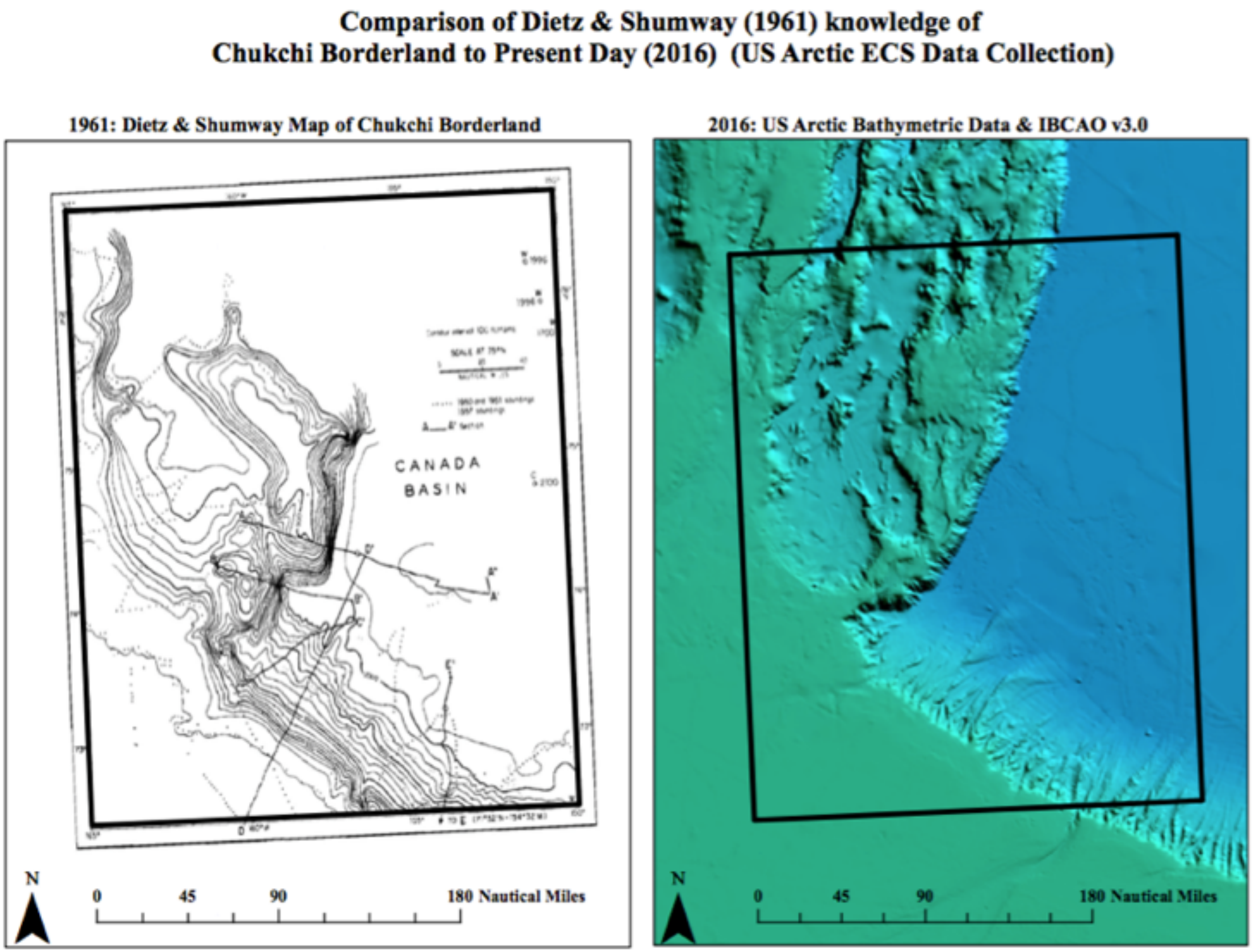


Figure 12: Knowledge of the Chukchi Borderland in 1961 (Dietz and Shumway, 1961) compared to our understanding of the region in 2016.

Contemporary Amerasia Basin Tectonic Models:

Despite the paucity of data collection in the Arctic Ocean during most of the 20th Century, tectonic models were presented as early as 1935 (Shatskiy, 1935) based on implications from adjacent onshore geology. Given the collection of modern data (both ECS and non-ECS), many of the earlier models are now discounted (Appendix III describes early Arctic exploration and data collection and Appendix IV discusses these previous models). Below is a summary of each of the contemporary models.

An Arctic Large Igneous Province (LIP):

Before discussing the contemporary Amerasia Basin tectonic models, it is necessary to introduce the concept of a large igneous province (LIP). A LIP is a geologic event during which large volumes of mafic extrusive and intrusive rock are emplaced onto Earth's crust by a mechanism that cannot be attributed to normal seafloor spreading (Bryan and Ernst, 2008). LIPs also can have complex plumbing systems such as dike swarms, sills, layered intrusions, and deep mafic underplating (Bryan and Ernst, 2008). LIP pulses have life spans of ~1-5 Myr and can have a significant impact on the geomorphology of the planet (Bryan and Ernst, 2008; Ernst, 2014). The composition of LIP basalts is distinctly different from MOR basalts, in that the former are alkaline, enriched in incompatible elements and contain high $^{3}He/^{4}He$ ratios, whereas the latter are tholeiitic (Fougler, 2007). The Cretaceous is particularly noted for LIPs. They are associated with continental flood basalts, volcanic rift margins, oceanic plateaus and ocean basin flood basalts (Bryan and Ernst, 2008). LIP events have also been connected to continental rifting and break up (Døssing et al., 2013). The number of worldwide LIP events associated with the Cretaceous imply that the Cretaceous was a time of abnormal global magmatism (Maher, 2001).

As scientific exploration has expanded in the Arctic, a growing body of evidence supports the conclusion that a LIP event(s) occurred in the Arctic during the Cretaceous (e.g., Lawver and Muller, 1994; Maher, 2001; Gottlieb et al., 2010; Corfu et al., 2013). Aeromagnetic data over the Alpha and Mendeleev ridges display dense and high amplitude (± 5,000 nT or greater) magnetic anomalies of long to medium wavelengths (Saltus et al., 2011). The chaotic magnetic domain extends from the Alpha and Mendeleev ridges into the northern region of the Canada Basin, northern extension of the Chukchi Borderland, as well as northern Canada and Greenland, covering an area of over one million km^2 (Saltus et al., 2011).

Tarduno (1998) and Maher (2001) first associated this massive Arctic magnetic domain with the term High Arctic Large Igneous Province (HALIP). Other authors have referred to the chaotic magnetic character as the "Alpha-Mendeleev LIP" (e.g., Grantz et al., 2009; 2011; Saltus et al., 2011) and more recently as the "High Arctic Magnetic High" (HAMH) (e.g., Saltus and Oakey, 2015). It is uncertain if the HALIP, Alpha-Mendeleev LIP, and HAMH represent one LIP event or a series of LIPs that affected the Alpha and Mendeleev ridge complex and other parts of the Arctic. All authors do agree, however, that a LIP(s) specifically affected the Alpha and Mendeleev ridges and this event(s) played a role in the Amerasia Basin's tectonic history (Coakley et al., in press).

One of the key issues of debate is the life span (~1-5 My) associated with LIPs and the rock samples taken from the Alpha-Mendeleev ridge complex that show a long time span (50 My) of igneous activity (130 to 80 Ma) (Coakley et al., in press). To reconcile this issue, some authors argued for multiple pulses of a LIP (or the HALIP) in the Arctic during the Cretaceous (e.g., Brumley, 2014; Mukasa et al., 2015). Overall, there seems to be a general consensus that the Alpha-Mendeleev ridge complex experienced two pulses, the first at 130-120 Ma and the second at about 90-80 Ma (Brumley, 2014; Saltus and Oakey, 2015). Some authors argue, however, that the Alpha-Mendeleev LIP is representative of one (e.g., Grantz et al., 2011) or even three (e.g., Mukasa et al., 2015) episodes of LIP activity in the Cretaceous.

Estrada et al. (in press) pointed out that few rock samples from the Alpha-Mendeleev ridge complex have been recovered, which makes it difficult to constrain Arctic LIP activity. The only rock samples are:

- Sixteen piston cores and twelve gravity cores recovered from the northern and southern crests of the Alpha Ridge and from a large graben on the Alpha Ridge during the 1983 Canadian Expedition to Study the Alpha Ridge (CESAR) (Mudie and Blasco, 1985; Van Wagoner et al., 1986). All of the cores except one contained late Cenozoic (0-66 Ma) muds (Mudie and Blasco, 1985). The last core's oldest stratigraphic section was laminated diatom ooze of Campanian-Maastrichtian age (83.6-66 Ma) (Mudie and Blasco, 1985).
- A basalt sample taken from a gravity core on the central part of the Alpha-Mendeleev ridge complex during the ARCTIC-98 expedition, which yielded an age of 82 ± 1 Ma ($^{40}Ar/^{39}Ar$ dating) (Jokat, 2003).
- A trachybasalt sample drilled from the northern Mendeleev Ridge during the Russian expedition, Arctic-2012, which was dated to 127 ± 3 Ma (U-Pb analysis) (Morozov et al., 2013).
- Basaltic samples recovered from the southern Alpha Ridge and Chukchi Borderland (by dredge) during the USCGC *Healy*'s 2008 and 2009 expeditions, which yielded ages of ca. 112 Ma, ca. 100, ca. 85-73 Ma ($^{40}Ar/^{39}Ar$ dating) (Brumley, 2014; Mukasa et al., 2015).

Brumley (2014) stated that the USCGC *Healy*'s 2008 basaltic rocks are geochemically similar to Cretaceous basalts recovered from Ellesmere Island and Franz Josef Land, which are believed to be the remnants of the HALIP. Other authors state (e.g., Grantz et al., 2011) that these samples only provide evidence for an Alpha-Mendeleev LIP event(s).

While there is convergence of thought about a Cretaceous LIP(s) in the Amerasia Basin, there is still disagreement about how the Alpha and Mendeleev ridges were formed. Therefore, the composition of the protolith beneath the volcanics on Alpha and Mendeleev ridge remains a question. Some believe the entire Alpha and Mendeleev ridge complex is an oceanic plateau (e.g., Jokat et al., 2013), whereas others believe it is composed of transitional crust (e.g., Funck et al., 2011) or stretched continental crust overprinted by LIP volcanism (e.g., Lebedeva-Ivanova et al., 2006; Døssing et al., 2013; Brumley, 2014). The LIP overprinting makes it difficult, if not impossible, to decipher the Alpha and Mendeleev ridges' underlying basement. Therefore, understanding the region's tectonic history prior to a LIP pulse(s) is near impossible (Saltus et al., 2011; Mosher et al., 2012b; Evangelatos and Mosher, 2016).

The models discussed below all involve the HALIP or Alpha-Mendeleev LIP event(s), but in subtly different ways, specifically whether or not the Alpha and Mendeleev ridges' protolith was oceanic or continental.

The Amerasia Basin's Rotational Model:

Carey (1955; 1958) first suggested a rotational model to explain the Chukchi Borderland's current position in the Amerasia Basin; however, his model was based on evidence from the surrounding land-geology and not data from the Amerasia Basin itself (Lawver and Scotese, 1990). Until 1970, all tectonic models for the Amerasia Basin relied on the same terrestrial geology data from around the basin (Lawver and Scotese, 1990).

The "rotational" or "windshield wiper" model is the most widely known scenario for the opening of the Amerasia Basin (Grantz et al., 2011). The basic components of this model require a ~60-90º counter-clockwise rotation of Arctic Alaska from Arctic Canada with a central pole of rotation centered near the Mackenzie Delta (Fig. 13) (Lawver and Scotese, 1990; Grantz et al., 1998; Grantz et al., 2011). With this model, a transform boundary must exist to the north of the rotation along the Lomonosov Ridge. This model states that seafloor spreading formed the Canada Basin as Arctic Alaska rotated away from Canada (Grantz et al., 2011). Different rotational models restore the Chukchi Borderland to different positions along Arctic Canada, usually to some location between the Mackenzie Delta and Prince Patrick Island (e.g., Carey, 1955; 1958; Vogt et al., 1982; Grantz et al., 1998; 2011). Coakley et al. (in press) noted that the most difficult aspect of the rotational model is that it is unprecedented in geologic history and therefore skepticism regarding the extent of such rotation exists (Coakley et al., in press).

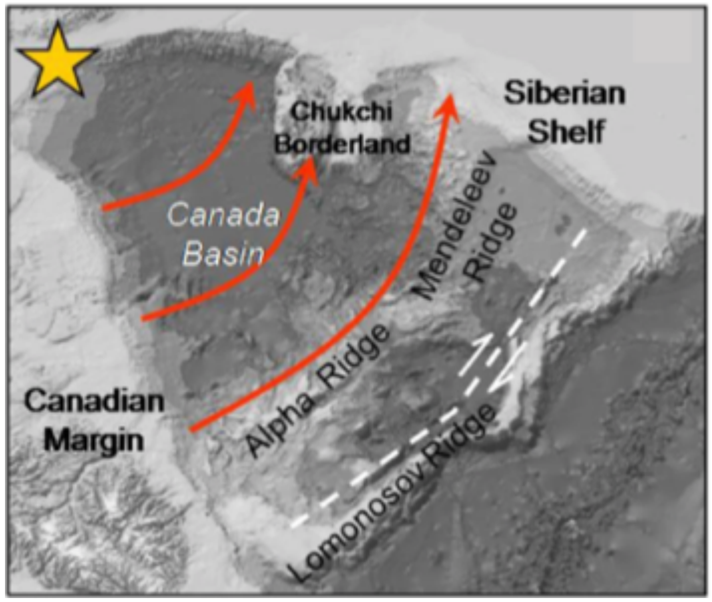


Figure 13: General Diagram depicting the Rotational Model for the opening of the Amerasia Basin. Source: Brumley (2009).

Different iterations of the rotational model put forth conflicting origins for the Alpha and Mendeleev ridges given the difference in opinion regarding the underlying crust (e.g., Grantz et al., 2011; Kazmin et al., 2015). The most recent presentations of the rotational model are Grantz et al. (2011), Scotese (2011), Kazmin et al. (2015), and Oakey and Saltus (2015), whereas

Brumley (2014) focused on the specific pre-rift position of the Chukchi Borderland without discussing a tectonic mechanism.

Seafloor Spreading in the Canada Basin:

Seafloor spreading in the Canada Basin was first proposed by Vogt et al. (1982) and Grantz et al. (1998) after Laxon and McAdoo's (1994) inference from gravity data of a fossil ridge axis, which is now called the Canada Basin Gravity Low (CBGL) (Fig. 14A). One pair of conjugate magnetic anomalies on either side of the CBGL have been inferred as additional evidence for Canada Basin seafloor spreading (Fig. 14B) (Taylor et al., 1981; Vogt et al., 1982; Grantz et al., 2011; Chian et al., 2016).

Mosher et al (2012b) and Chian et al. (2016) took a more detailed look at the tectonics and sedimentary composition of the Canada Basin by utilizing multichannel seismic (MCS) and potential field data. From these data, Chian et al. (2016) analyzed sonobuoys in the Canada Basin and classified them into oceanic, transitional, and continental crust based upon velocities. The authors cross-referenced their analysis with potential field data (gravity and magnetic) (Fig. 14A&B). Chian et al. (2016) concluded that the central part of the Canada Basin is the only region of oceanic crust. The identified central axis in the basin that is composed of oceanic crust is coincident with a blocky morphology zone, the CBGL, and a basement ridge structure (Mosher et al., 2012b; Chian et al., 2016).

Chian et al. (2016) also analyzed the thickness of the observed oceanic crust with predicted rates of spreading and found inconsistencies for spreading duration in certain models (e.g., Grantz et al., 2011). Shorter durations of spreading would require spreading rates that would not produce oceanic crust that is as thin as that interpreted (4-7 km thick); however, the

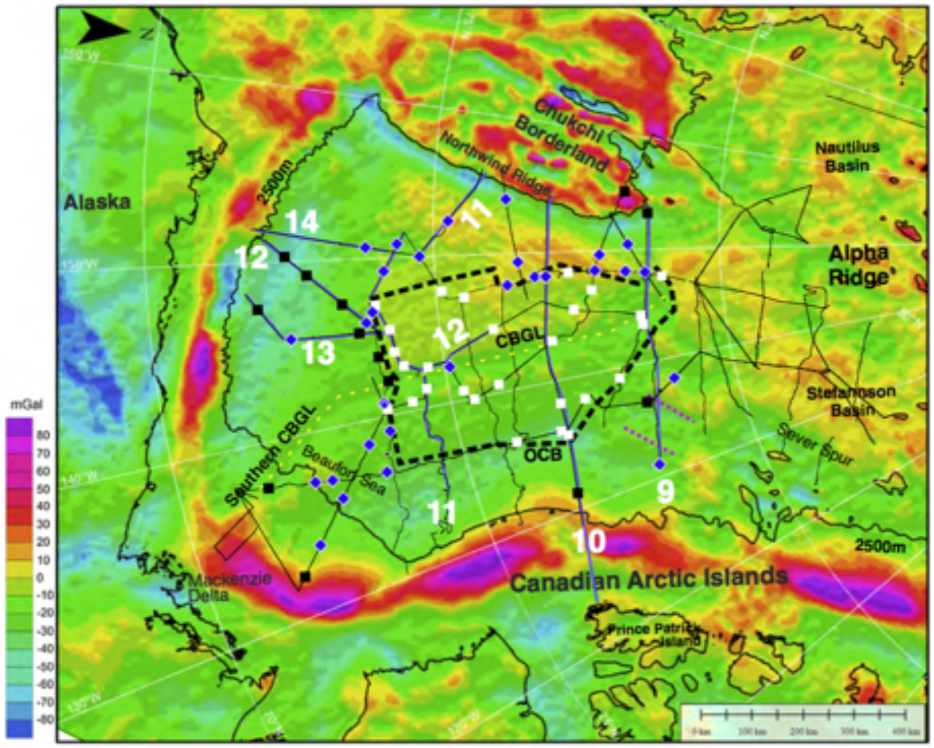


Figure 14A: Free Air gravity anomaly map of Canada Basin. Sonobuoy models classified as white squares, continental as black squares and transitional as blue diamonds. Dashed polygon indicates the ocean-continent boundary (OCB). The number of each solid blue line indicates the figure number of the seismic transects. Parallel red dots indicate a basement depression Source: Data: Anderson et al., 2010; Map: Chian et al., 2016

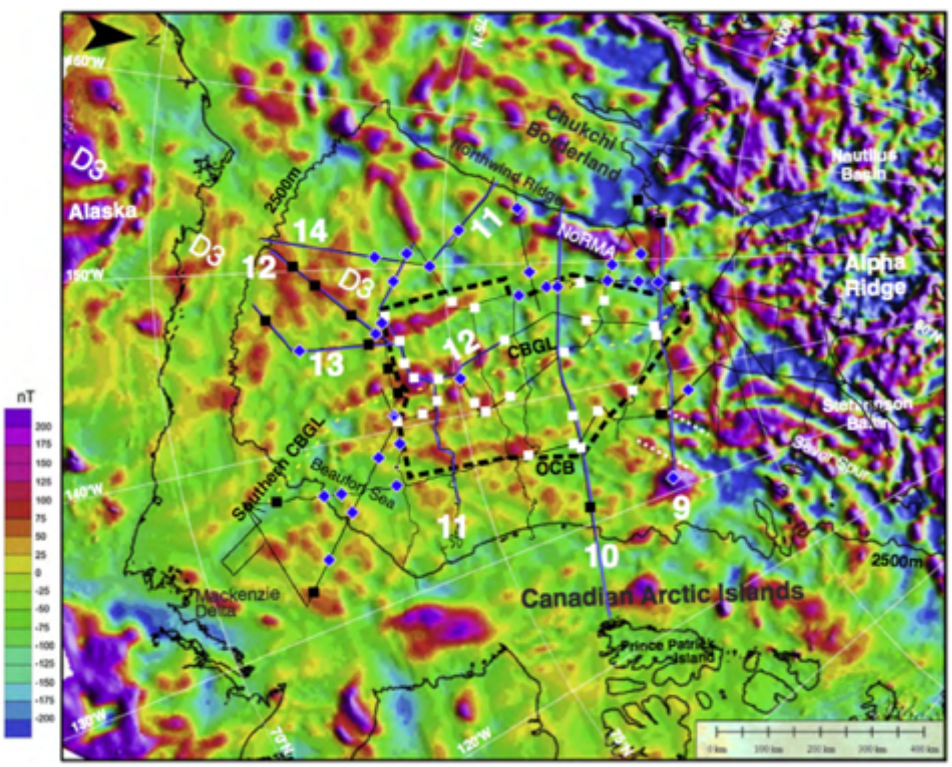


Figure 14B: Magnetic anomaly map of Canada Basin (after Gaina et al., 2011). Sonobuoy models classified as oceanic are shown as white squares, continental as black squares and transitional as blue diamonds. Dashed polygon indicates ocean-continent boundary (OCB). Each solid blue line and number indicates a seismic transect. D3 indicates a regional magnetic zone defined by Saltus et al. (2011). Parallel white dots indicate a basement depression. Source: Data: Gaina et al., 2011; Map: Chian et al., 2016 authors concluded that ultra-slow spreading (Dick et al., 2003) is the most likely type of regime that affected Canada Basin (Chian et al., 2016).

On either side of the Canada Basin's region of oceanic crust, transitional to thinned continental crustal velocities were detected and reflection data show a basement with smooth morphology (Fig. 14A&B) (Mosher et al., 2012b; Chian et al., 2016). Mosher et al. (2012b) described grabens and half-grabens in the northern section of the Canada Basin (north of 77-78ºN), which are indicative of continental extension. Shimeld et al. (2016) also found that the 5-7 km sediment isopachs beneath the Canada Basin identify a north-south trending graben that is 45 km wide, a feature that Mosher et al. (2012b) also discussed. This graben is coincident with the CBGL.

Saltus et al.'s (2011) analysis of Canada Basin's magnetic character provided further support to the conclusion that the basin is composed of highly extended continental crust or is of a transitional nature. Discerning a continuation of the spreading center further north is inhibited by volcanics of the Alpha Ridge which overprints most of the northern Canada Basin structure and to the south by the Mackenzie Delta's thick sedimentary record (Mosher et al., 2012b; Shimeld et al., 2016; Chian et al., 2016).

The literature has come to a variety of conclusions about Canada Basin seafloor spreading. Mosher et al (2012b) concluded that the evidence for seafloor spreading in the Canada Basin is consistent with a rotational model. Gaina et al. (2014) found that the rotational model can be "partially" supported by the pseudo-linear magnetic anomalies in the potential field data. Coakley et al. (in press) noted, however, that the observed offset from Canada Basin's extinct mid-ocean ridge is inadequate to explain more than just a small portion of the basin's opening. Chian et al. (2016) concluded that the geographic extent of oceanic velocities and magnetic data is consistent with a counterclockwise rotational model, however, pointed out that although the geographic extent of the oceanic crust is symmetrical about the CBGL, an asymmetrical distribution of the oceanic crust near the margins of the basin suggests a tectonic model more complicated than a simple rotation. The authors also stated that the sonobuoy velocity analysis cannot help determine if Canada Basin seafloor spreading occurred before, during or after a LIP(s) event in the Arctic (Chian et al., 2016).

Despite these different conclusions, a growing body of evidence including seismic, gravity and magnetic data, is converging to the conclusion that at least in the central area of the Canada Basin, seafloor spreading occurred in association with the opening of the Amerasia Basin. The extent and duration of such seafloor spreading is still unknown.

Transform Boundary:

Accompanying a rotational model, a transform boundary must exist to the north of Canada Basin, along or near Lomonosov Ridge. Some authors have found evidence for such a transform boundary; if their conclusions can be validated, then this would provide significant support for a rotational model in the Amerasia Basin.

Cochran et al. (2006) studied the Amerasia Basin flank of the Lomonosov Ridge and found evidence for a long shear margin. They concluded that the existence of a marginal ridge separating oceanic and continental crust bounded by a region of ridges and basins on the continental side are all characteristic of a shear margin. They examined Grantz et al.'s (1979) pole of rotation (69.1ºN, 130.5ºW), and determined that the sub-parallel ridges along the Lomonosov Ridge, namely Geophysicists, Oden, and Marvin spurs, are continental slivers that fragmented from Lomonosov Ridge along a shear margin (Cochran et al., 2006).

Miller and Verzhbitsky (2009) analyzed Arctic Russian land-based geology to see if the Siberian Shelf's stratigraphic record could provide constraints for Amerasia Basin plate tectonics. The authors found that the inception of rifting between the proto-Lomonosov Ridge and proto-Alpha and Mendeleev ridges, and thus the formation of the Makarov Basin, must have occurred between 136 and 117 Ma. They also noted that the complex normal faults related to the Makarov Basin and Alpha and Mendeleev ridges are parallel to the extensional regime on Arctic Russia, indicating the extent of the rift system. Lebedeva-Ivanova et al.'s (2006) analysis of seismic data from the Mendeleev Ridge found that the ridge was underlain by rifted continental crust, another piece of evidence that supports this theory.

Evangelatos and Mosher (2016) examined the Makarov Basin, adding to the body of evidence in support for a transform boundary along the Lomonosov Ridge. They discovered a deep-basin (5 km thick) within the Makarov Basin by examining a seismic line that crossed from the Lomonosov Ridge to the Alpha Ridge. This sub-basin has a rhomboidal shape and is immediately next to the Lomonosov Ridge with the same strike as the ridge itself (Evangelatos and Mosher, 2016). The authors concluded that the steep (4-8º) morphology of the Amerasia flank of the Lomonosov Ridge combined with the multiple sub-parallel ridges (including Geophysicists, Marvin, and Oden spurs) that they characterize as splay faults are indicative of a strike-slip tectonic regime. They contrast this flank of the ridge to the Eurasia flank which is block-faulted and stepped, key characteristics of rifted passive margins. No evidence for such passive margin rifting is present on the Amerasia flank. They also point to Jokat et al.'s (2013) discovery of "horst-like" structures in the basement of the nearby Podvodnikov Basin from a seismic reflection profile. Jokat et al. (2013) interpreted these structures to be fragments of continental basement originally from the Lomonosov Ridge and Evangelatos and Mosher (2016) suggested that the structures could be buried extensions of Geophysicists Spur.

Debate about whether or not a transform boundary existed on the Amerasia flank of the Lomonosov Ridge continues. The major differences with respect to the location of the boundary is between Miller and Verzhbitsky (2009), who take the position that an Atlantic-like rift system existed, and Cochran et al. (2006), who support a transform boundary along the Amerasia flank. Evangelatos and Mosher (2016) integrated these two theories, inferring that the boundary was originally a transform-transtensional boundary along the Amerasia flank of the Lomonosov Ridge. As rotation continued; however, the tectonic stress shifted, becoming extensional and orthogonal to the Lomonosov Ridge (Evangelatos and Mosher, 2016). They state that this type of boundary is consistent with Grantz et al.'s (2011) proposed rotational model.

Grantz et al. (2011) Rotational Model:

Grantz et al. (2011) provides the most recent iteration of the rotational model, which is two-phased (Fig. 15). The first phase occurred from 195-160 Ma and includes a counterclockwise rotation of the Chukchi micro-continent away from northwest Canada. This rotation created ocean-continental transitional (OCT) crust in the proto-Canada Basin. Extensive thinning of the continental crust on either side of the fault zone occurred (Grantz et al., 2011).

After this initial phase, a subsequent clockwise rotation of the Chukchi micro-continent away from the Eurasia continental margin occurred. The micro-continent rotated onto the OCT crust in the proto-basin between 145.5-140 Ma. The pole of rotation for this movement was in the Mackenzie Valley of northwest Canada, located at 72ºN, 165ºW. Grantz et al. (2011) proposed that this clockwise rotation occurred along a thrust fault beneath the Chukchi micro-continent that is buried by the Early to mid-Neocomian synrift sequence on the Northwind Ridge.

Grantz et al. (2011) stated that the second phase of the Canada Basin's opening occurred from 131-127.5 Ma, which enlarged the proto-basin when Mid-Ocean Ridge Basalt (MORB) intruded along its central axis. The MORB crust was created by a 10-15º counterclockwise rotation from a pole in the lower Mackenzie Valley. Grantz et al. (2011) stated that the OCT-MORB boundary is apparent south of 78ºN, however, after this second phase, an oceanic volcanic plateau formed to the north of the Canada Basin (127-75 Ma). This volcanic plateau, known as the Alpha-Mendeleev LIP, overprinted on the OCT-MORB boundary in northern

Canada Basin. The LIP event also formed the northern extension of the Chukchi Borderland (Grantz et al., 2011).

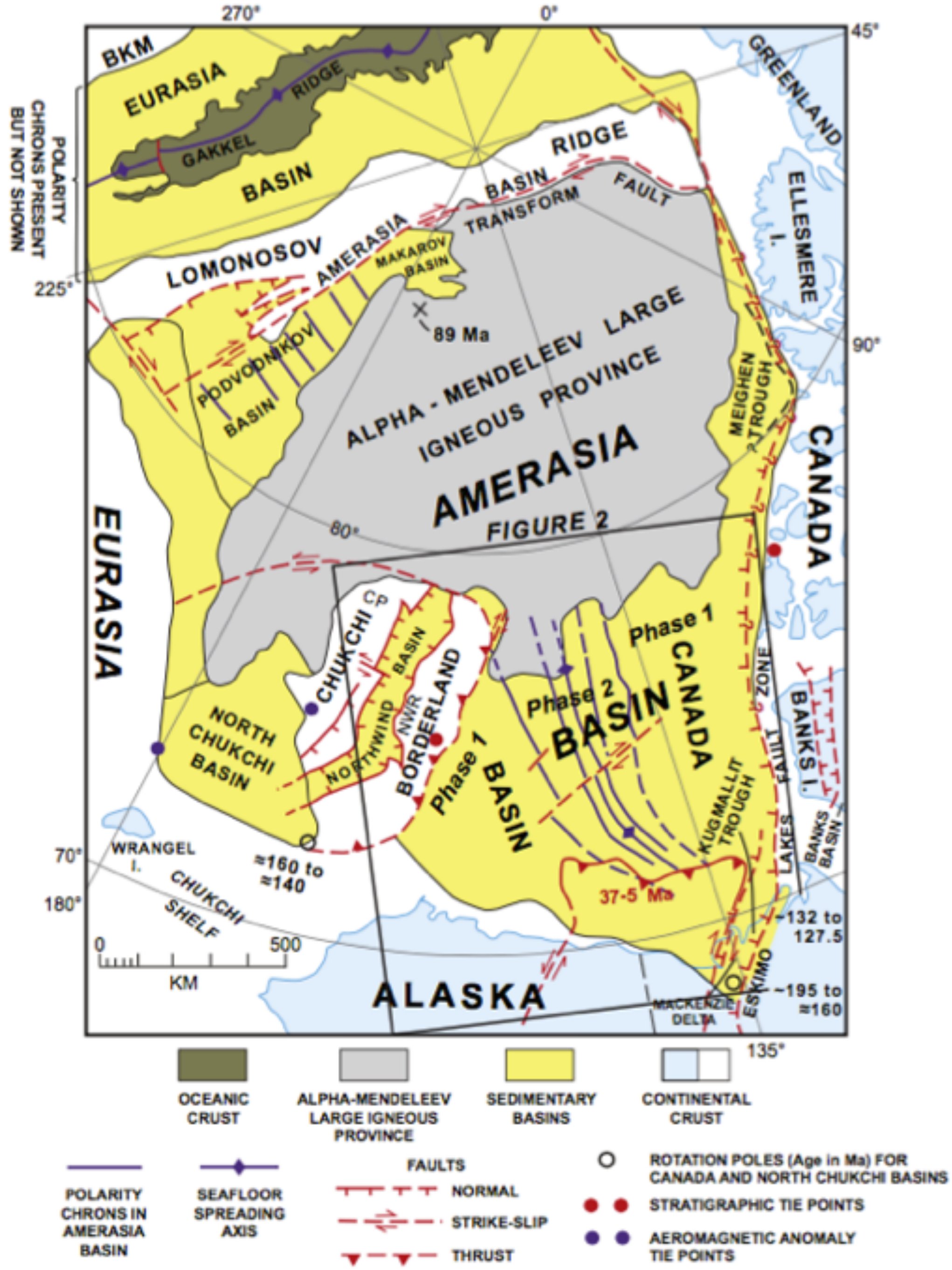


Figure 15: General diagram depicting the Grantz et al. (2011) rotational model for the opening of the Amerasia Basin. Source: Grantz and Hart, 2012 (p.127)

In order for this model to be feasible, Grantz et al. (2011) explained that a thrust fault must exist along the eastern side of the Northwind Ridge (Fig. 15&16). The authors stated that the thrust fault is concealed in the stratigraphy and is too deep for existing seismic data to detect. Grantz et al. (2011) inferred the thrust fault's location by physiography and first-order geologic features of the Chukchi Borderland (Fig. 16) (Grantz et al., 2011; Grantz and Hart, 2012). Brumley (2014) and Coakley et al. (in press) stated that no evidence for shortening related structures exist in the Amerasia Basin or on the Chukchi Plateau, which refutes Grantz et al. (2011) proposed thrust deformations. The seismic profiles crossing the Canada Basin and Northwind Ridge only show evidence for extension (Arrigoni et al., 2007; Arrigoni, 2008; Brumley, 2009; Hutchinson et al., 2010; 2012; Mosher et al., 2012b).

In this model, Grantz et al. (2011) treated the Chukchi Borderland as a micro-continent that experienced both counterclockwise and clockwise rotation and the northern extension of the Chukchi Borderland as a volcanic edifice that was built by the Alpha-Mendeleev LIP event.

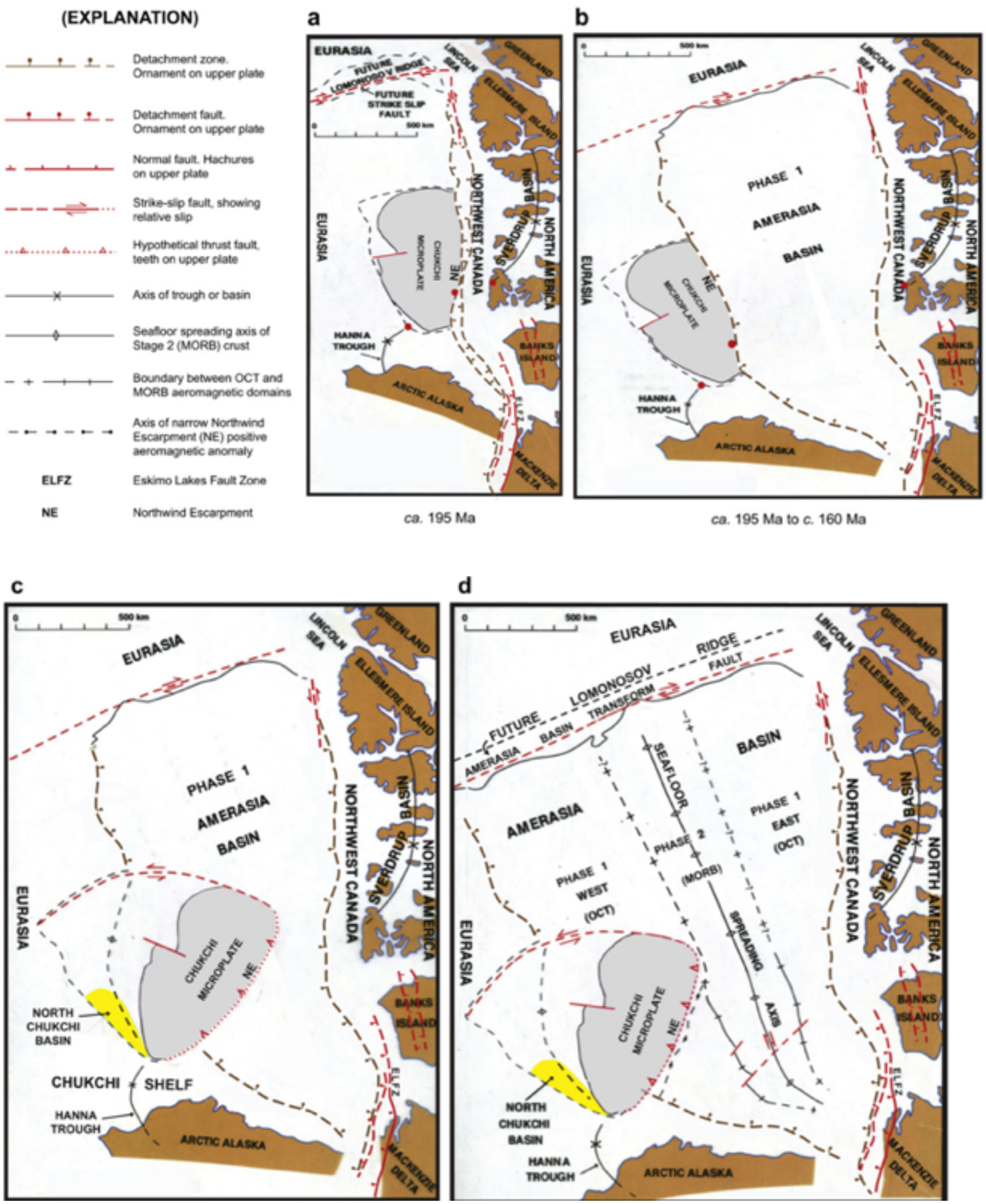


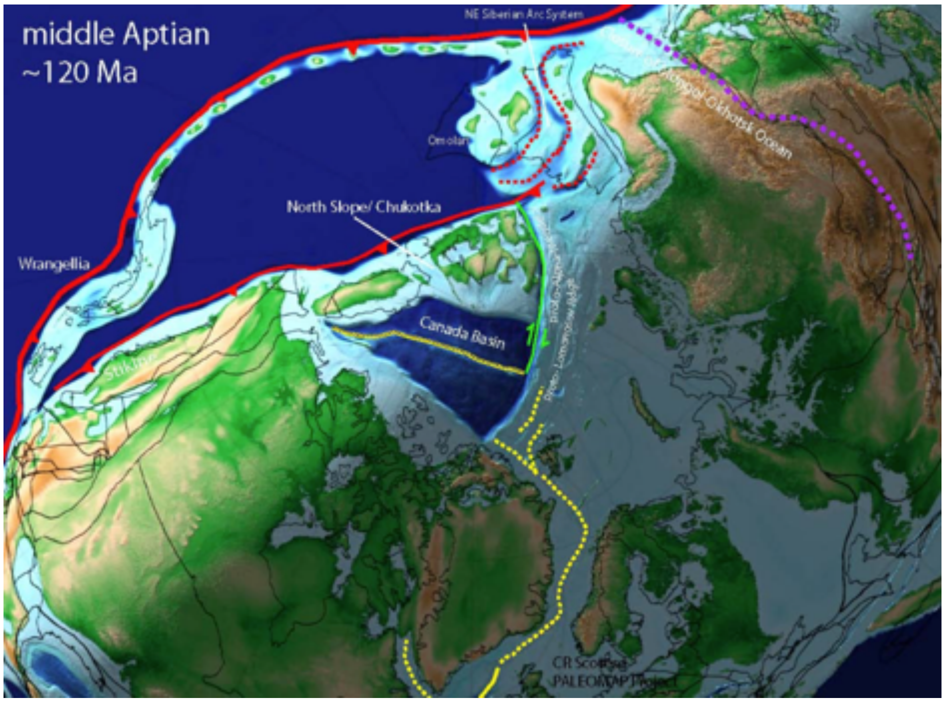
Figure 16: Grantz et al. (2011) rotational model phases for the opening of the Amerasia Basin. Source: Grantz and Hart, 2012 (p.133)

Russian Tectonic Model (2015):

The Russian Federation submitted to the CLCS a partial submission for its Arctic region on 3 August 2015 (Russian Arctic Executive Summary, 2015). The Russian Federation's submission presented not only its revised Arctic ECS outer limit but also a review of its interpretation of the geologic evolution of the Arctic Ocean. The Russian model for the Amerasia Basin's opening is presented in Kazmin et al. (2015). Other authors, such as Scotese (2011), present similar models.

The Russian model, like Grantz et al. (2011), presents a two-stage model for the Amerasia Basin's tectonic evolution. The first stage includes a counterclockwise rotational opening in the Canada Basin between the Late Jurassic and mid Cretaceous (155 to 120 Ma), which was preceded by substantial continental crust extension in the Canada Basin (Scotese, 2011; Kazmin et al., 2015). In this scenario, Canada Basin's opening was driven by northward moving subduction underneath the North Slope-Chukotka block (Fig. 17 and 18) (Scotese, 2011). The rotational movement of the North Slope-Chukotka block ended when it intercepted central Alaska, roughly 115 to 110 Ma, marking the termination of proto-Canada Basin formation (Scotese, 2011). A sinistral strike slip boundary existed on the northern boundary of the Canada Basin, but south of the Lomonosov Ridge (Fig. 17 and 18) (Kazmin et al., 2015).

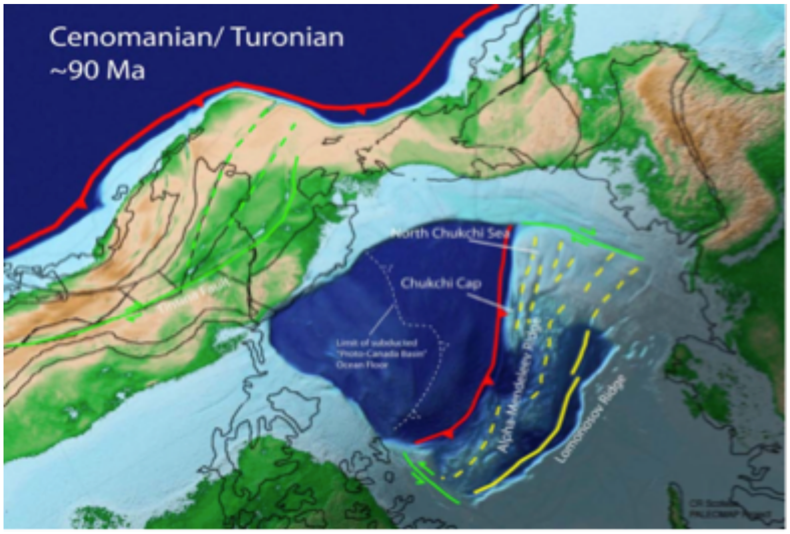
After the Canada Basin's initial opening during the mid-Late Cretaceous (~100 – 65 Ma), the second stage to Amerasia Basin formation included the Makarov and Chukchi basins' openings (Scotese, 2011). The proto-Alpha and Mendeleev ridges were apart of the continental shelf adjacent to the proto-Lomonosov Ridge prior to the basins' openings (Fig. 17, 18, 19) (Scotese, 2011). Scotese (2011) concluded that subduction occurred on the south side of the proto-Alpha-Mendeleev ridges, which resulted in roll-back extension on the ridges' other flank, allowing for the opening of Makarov Basin (Fig. 19 and 20).



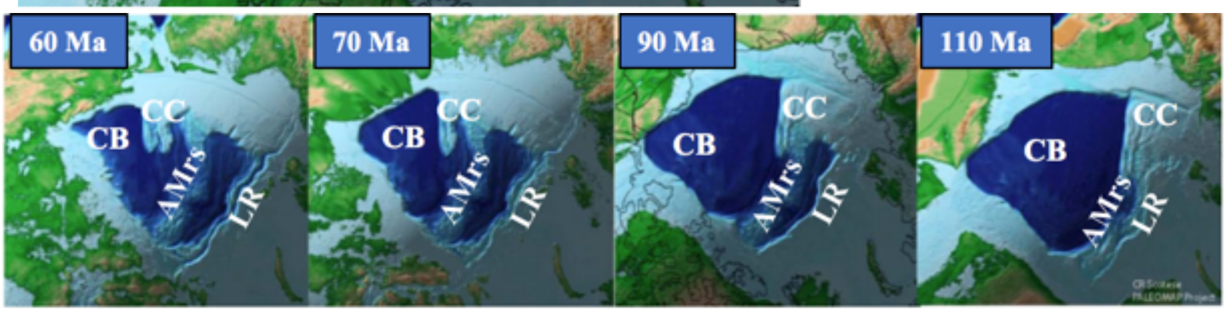
Figures 17: Overview of the first stage of Amerasia Basin Opening: Canada Basin. Yellow dotted line is Canada Basin seafloor spreading. Green line is transform boundary. Source: Scotese (2011), p.27

Figure 18: First stage of Amerasia Basin Opening broken up into three stages (100 Ma, 120 Ma, 150 Ma). Canada Basin. Yellow dotted line is Canada Basin seafloor spreading. Source: Scotese (2011), p.28

Roll-back subduction is in contrast to conveyor belt subduction, which is often associated with mid-ocean ridges (Scotese, 2011). Scotese (2011) stated that roll-back is passive subduction that is very slow (2-5 cm/yr) and occurs exclusively in landlocked conditions, causing extension on adjacent continents. This type of subduction is short lived (10's My), almost no volcanism occurs, and no ridge forms. This passive subduction is in contrast to the conveyor belt subduction, which is active, rapid (8-10 cm/yr) and long lived (10's to 100's My) (Scotese, 2011).



Figures 19: Second stage of Amerasia Basin Opening: Green line is transform boundary, Yellow line is seafoor spreading in proto-Eurasia Basin, Yellow dotted lines extension, Red line subduction. Source: Scotese (2011), p.27



Figures 20: Second stage of Amerasia Basin Opening through geological time (60 Ma; 70 Ma; 90 Ma; 110 Ma): Canada Basin (CB); LR: proto-Lomonosov Ridge; AMrs proto-Alpha and Mendeleev ridges; CC Chukchi Cap; CB Canada Basin. Source: Scotese (2011), p. 28

As roll-back subduction occurred along the Alpha and Mendeleev ridges, causing extension between the proto-Lomonosov Ridge and Alpha and Mendeleev ridges, the Makarov Basin formed between the bathymetric highs (Scotese, 2011; Kazmin et al., 2015). Scotese (2011) stated that as roll-back extension continued to occur in the mid Late Cretaceous, extension on the Alpha and Mendeleev ridges as well as the Chukchi Cap occurred. Roll-back subduction ceased when the Amerasia trench collided with northwest Alaska, ~65 Ma (Scotese, 2011).

This second stage of Amerasia Basin opening (120-60 Ma) is also associated with the first pulse of HALIP in the Early Cretaceous (130-120 Ma) (Kazmin et al., 2015). Scotese (2011) attributed the HALIP to roll-back extension, where the Alpha and Mendeleev ridges' continental crust was so thinned and extended, it allowed for massive volcanism. The rotation of the stress field in this second stage of opening became perpendicular to the first stage's original strike-slip direction, creating a dextral strike-slip boundary between the North Chukchi and East Siberia Sea (Fig. 19) (Scotese, 2011). Extension in this second phase occurred perpendicular to the continental shelf border to the north (the Lomonosov Ridge). This regime lasted until the Late Cretaceous (~100-80 Ma) when the second pulse of HALIP occurred, emplacing volcanics over the thinned and extended continental crust between the Lomonosov Ridge and Chukchi Borderland (Kazmin et al., 2015).

Kazmin et al. (2015) stated that this model is supported by block faulting on the Lomonosov Ridge's Amerasia flank, which is characteristic of extensional faulting and not of strike-slip motion, a conclusion that conflicts with Evangelatos and Mosher's (2016) findings. Within the Russian Federation's submission to the CLCS (2015), reference is made to a third stage of the Arctic Ocean's opening, namely the initiation of seafloor spreading in the Eurasia Basin along the Gakkel Ridge, ~56 Ma. Figure 21 provides a visual overview of the Russian tectonic model.

Morozov et al. (2013) provided support for this rotational model by examining geologic samples collected on the Mendeleev Ridge during the Russian Federation's High-Latitude Expedition, Arctic-2012. From August to October 2012, two icebreakers and two accompanying submarines collected geologic samples on the Mendeleev Ridge including nine dredge sites, six piston cores, six grab sample sites, and three drilling sites (Morozov et al., 2013). Scientists on the submarine chose sampling locations by examining video footage and then working with the icebreakers above to coordinate drilling and dredge operations. They were able to record the sampling process, documenting the exact sample location.

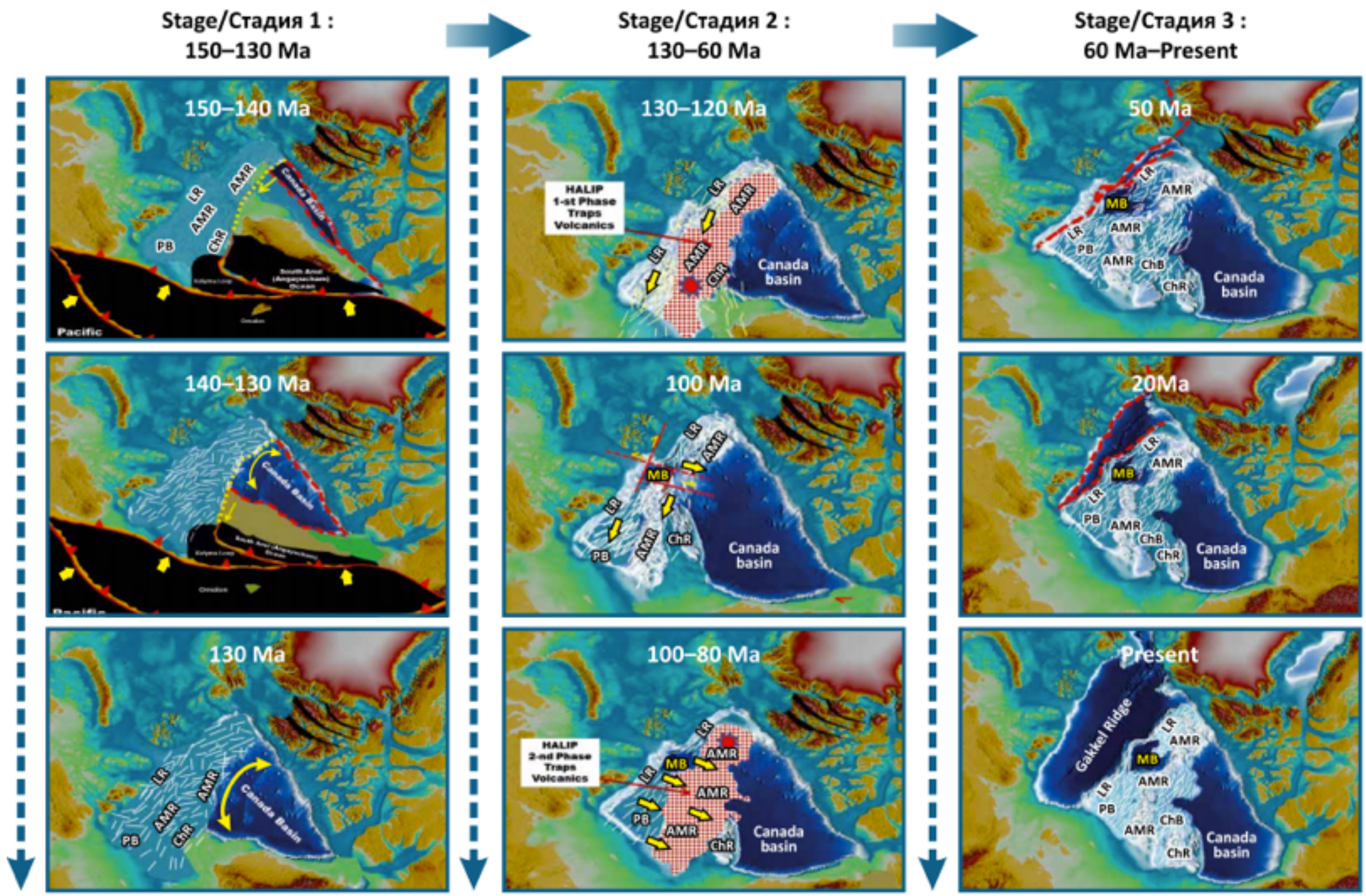


Figure 21: Russian Federation ECS Submission stage-by-stage proposed tectonic model for the Amerasia Basin opening. LR: Lomonosov Ridge; AMR: Alpha-Mendeleev Ridge; ChB: Chukchi Basin; ChR: Chukchi Rise; PB: Podvodnikov Basin; MB: Makarov Basin. Source: Russian Federation ECS Submission, 2015

Two drill core sites (one site in the north and south) on the Mendeleev Ridge recovered trachybasalts that were dated using U-Pb analysis. The southern core sample revealed an age of 260 Ma (Morozov et al., 2013). Coakley et al. (in press), however, cautioned that this age could be from contamination from sediments and not representative of the trachybasalts. The second trachybasalts have an age of 127 Ma, which Morozov et al. (2013) concluded were consistent with the HALIP.

Morozov et al. (2013) also found that the basalts from the northern extension of the Chukchi Borderland are alkaline subaerial basalts that are dissimilar to MORB and closer in character to continental plateau basalts. They cited CCOM/JHC's USCGC *Healy* data from 2008 and 2009 (Mayer and Armstrong, 2008; 2009), specifically dredge sites, DR-6,7 and DS-3,4 that recovered alkaline subaerial basalts. The authors concluded that these rock samples provide evidence for massive extension and thinning of continental crust along the northern extension of the Chukchi Borderland; implying areas contiguous to the Chukchi Borderland cannot be of oceanic origin (Morozov et al., 2013).

Similar to Grantz et al. (2011), Kazmin et al. (2015) and Scotese (2011) support a rotational model that treats the Chukchi Borderland as a continental fragment that underwent rotation and extensive thinning and stretching. The major difference between Grantz et al.'s (2011) model and the Russian model is that Scotese (2011), Morozov et al. (2013), and Kazmin et al. (2015) all treat the northern extension of the Chukchi Borderland as a continental fragment that is an extension of the Chukchi Plateau that experienced extension like the plateau itself. Scotese's (2011) model also requires subduction along the Chukchi Borderland and Alpha and Mendeleev ridges. Encompassed in this model, again, is seafloor spreading along a central axis in the Canada Basin followed by the emplacement of the HALIP, in this case two pulses rather than the one as proposed by Grantz et al. (2011).

Oakey and Saltus (2015): Chukchi Borderland and Sever Spur Conjugate Margins:

Oakey and Saltus (2015) proposed a new iteration of the rotational model, the only difference being that their pole of rotation is south of that proposed by Grantz et al.'s (2011) 72ºN, 165ºW. Their model is coincident with Mosher et al.'s (2012b) proposed axis for seafloor spreading in the Canada Basin. To accommodate this axis of spreading, they calculated a pole of rotation at 64.6ºN, 130.8ºW, with 13.2º of rotation (Oakey and Saltus, 2015). With Oakey and Saltus' (2015) pole-of-rotation, the Chukchi Borderland would be restored near Sever Spur, located off of the Canadian continental margin. The authors created 2-D gravity and magnetic models for the two features in order to compare their morphological and physical properties (Oakey and Saltus, 2015). They found that Sever Spur and the Chukchi Plateau have similar crustal structures and are likely conjugate margins; however, the type of rifting is asymmetric between the two features. The authors also noted that with this model, a transform boundary must exist to the north to accommodate such rotation. They are uncertain if this motion was a discrete transform structure or a broad zone of deformation (Oakey and Saltus, 2015). Oakey and Saltus' (2015) conclusion that the Chukchi Plateau and Sever Spur are conjugate margins focuses on the initial phase of the Amerasia Basin's tectonic evolution. It is clear that Oakey and Saltus (2015) treat the Chukchi Borderland as a continental fragment.

Brumley (2014) Pre-Rift Position of the Chukchi Borderland:

Brumley (2014) utilized U.S. ECS multibeam bathymetry, dredge rock samples, and a seismic line to examine the composition and origin of the Chukchi Borderland within the context of the Amerasia Basin's opening. She stated that these data collectively demonstrate that the Chukchi Borderland, its northern extension, and the Alpha Ridge were impacted as one unit during the opening of the Amerasia Basin. Within her analysis, she does not discuss the specific tectonic mechanism that separated the Chukchi Borderland from its proposed pre-refit position (e.g., seafloor spreading).

Brumley (2014) presented a reconstruction that restored the Chukchi Borderland to a pre-rift position near the Pearya Terrane, located off of northern Ellesmere Island and the Lomonosov Ridge. She argued that the Chukchi Borderland, Pearya, and southwest Svalbard share similar Ordovician and Silurian calc-alkaline magmatism. The Chukchi Borderland's intrusive and metamorphic history is similar to the basement rocks of the Pearya Terrane off of Ellesmere Island and the southwest Terranes of Svalbard (Fig. 22).

Pearya was a composite terrane that was adjacent to the Paleozoic Laurentian passive margin and connected to the margin by collision 481-460 ma (Brumley, 2014). She proposed that as the Chukchi Borderland rifted from the Laurentian arc terrane, two pulses of the HALIP occurred in the Cretaceous (~120 Ma, ~80 Ma), which emplaced volcaniclastic basalts over the stretched and thinned continental crust (Brumley, 2014).

Brumley's (2014) model, like those previously discussed, interprets the Chukchi Borderland as a continental fragment that has been rifted away from a continental margin prior to 120 Ma. She concluded, like Grantz et al. (2011) and Kazmin et al. (2015), that after the Chukchi Borderland moved away from its pre-rift position at least one episode of a LIP occurred in the Alpha Ridge area. She stated that this was the HALIP (Brumley, 2014). Lastly, like Kazmin et al. (2015), Brumley (2014) concluded that the northern extension of the Chukchi Borderland shares a common tectonic history with the Chukchi Plateau.

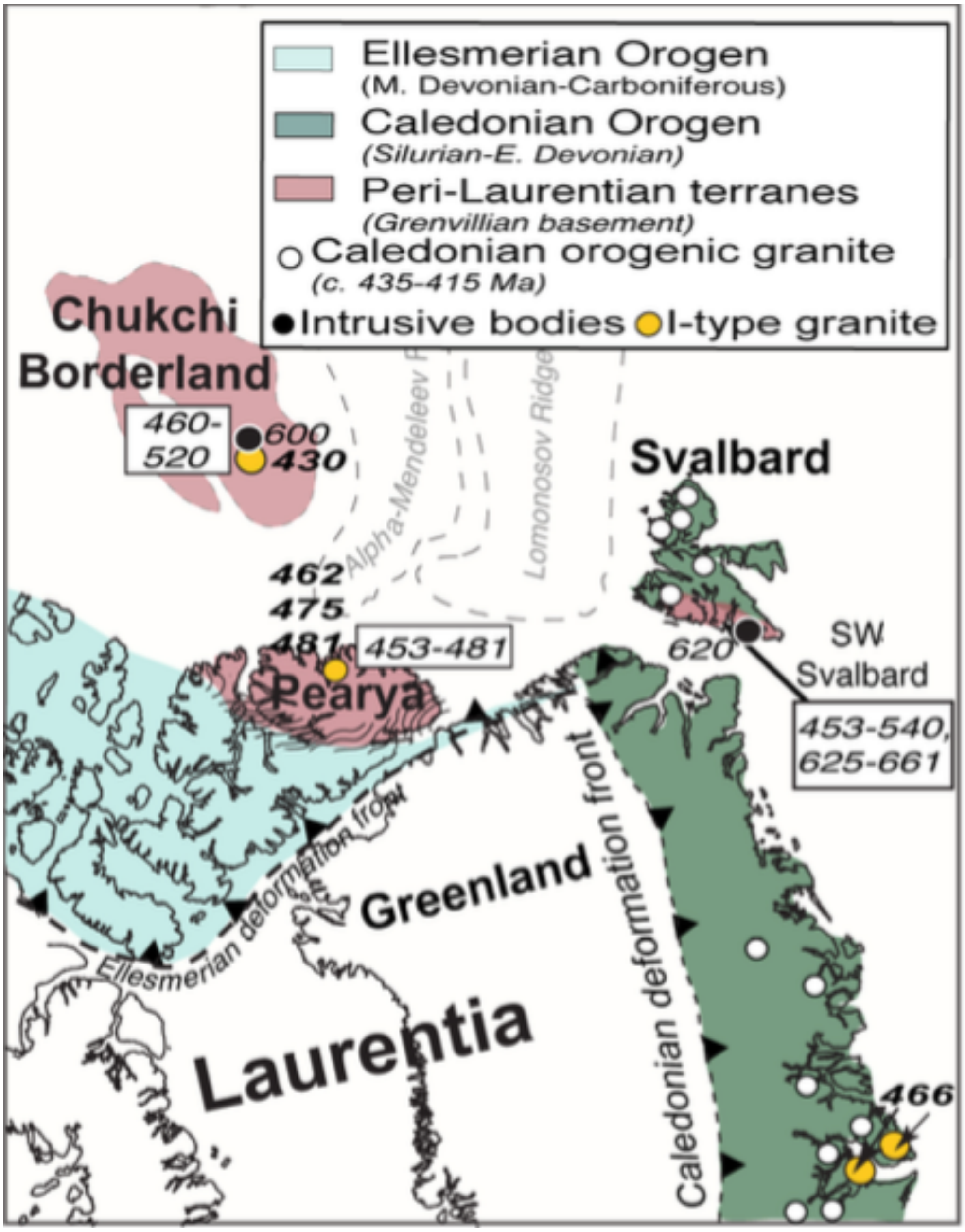


Figure 22: Schematic illustration of northern Laurentia terranes prior to opening of the Amerasia Basin. Yellow dots are locations of arc granites (I-type) with associated zircon U-Pb ages in bold type. Black dots represent rift related intrusive bodies with associated zircon U-Pb ages and white boxes show ages of Cambro-Ordovician metamorphic events. Source: Brumley, 2014 (p.82)

Chukchi Borderland

Geological & Geophysical Evidence for Continental Crust:

All of the tectonic models presented here treat the Chukchi Borderland as a continental fragment. This interpretation dates back to the 1960's as discussed previously. The Borderland's continental crust composition is derived through a combined analysis of the potential field data, bathymetry, and dredge samples (Hall, 1990; McAdoo et al., 1999; Alvey et al., 2008; Glebovsky et al., 2013; Brumley, 2014). McAdoo et al. (1999) concluded through their gravity-bathymetry analysis that the Chukchi Borderland was similar to the Alaskan margin in composition however, its continental crust has experienced stretching and thinning. McAdoo et al. (1999) also showed that the Chukchi Borderland is composed of continental crust with crustal velocities between 5.2 and 6.1 km/s, amounting to a thickness of 30 km (Hall, 1990; Alvey et al., 2008; Glebovsky et al., 2013; Hegewood and Jokat, 2013).

The continental affinity of the Borderland is supported by the presence of curvilinear sub-parallel fault blocks separated by deep basins, that indicate continental rifting (Hall, 1990; Brumley, 2009; Brumley, 2014). MCS profiles show normal faults and horst and graben structures, reflecting an east-west extensional regime (Arrigoni et al., 2007; Ilhan and Coakley, 2012; Hegewood and Jokat, 2013). The Borderland also exhibits irregular and low amplitude magnetic anomalies, indicative of a continental character (Taylor et al., 1981; Saltus et al., 2011). In particular, the southern portion of the Chukchi Borderland has magnetic anomalies that are similar to the magnetic signature on the Chukchi Shelf (Saltus et al., 2011).

Brumley's (2014) analysis of the dredge samples collected from the Chukchi Borderland confirm a continental origin due to recovered metamorphic crystalline basement rocks. Dredge site (HLY0905-DS5), from the central area of the Borderland, yielded rock samples interpreted to be similar in composition to terranes from northern Ellesmere Island and Svalbard (Brumley, 2014). These findings are complemented by Chian et al.'s (2016) sonobuoy analysis, which found that the two sonobuoys located along the northern end of the Northwind Ridge demonstrated continental crust. This finding is consistent with Brumley's (2014) geochemical analysis of samples taken from Northwind Ridge that showed continental lithologies.

Ilhan and Coakley (2015) stated that the Chukchi Borderland's fault blocks and depositional history indicate that it has been attached to the Chukchi Shelf since it experienced extension, and therefore the Borderland and Chukchi Shelf share a common geologic history. It is clear that the morphological continuity with the Alaskan continental margin along with the available geophysical and geological evidence support the conclusion that the Chukchi Borderland is composed of continental crust.

Northern Extension of the Chukchi Borderland

Morphology:

The northern extension of the Chukchi Borderland is a complex bathymetric feature that steps down to the Nautilus Basin. The northern extension was called the 'Mendeleev Abyssal Plain' (Jakobsson et al., 2003) until recently and thought to be of oceanic origin (e.g., Hegewood and Jokat, 2013) before new bathymetric and seismic data were collected (e.g., Mayer and Armstrong, 2012; Chian et al., 2010). Multibeam bathymetry data show parts of the northern extension are more than 1,000 m above abyssal depth and evidence for landslides and submarine channels, indicative of turbidite flow in this region (Mayer and Armstrong, 2003;2004; 2007;2008; 2009; 2010; 2011; 2012; Flinders et al., 2014). The geomorphology of the Healy Spur and Northwind Spur, both located on the northern extension, provide evidence for east-west extension like the extension found on the Chukchi Borderland. These two spurs match across rift

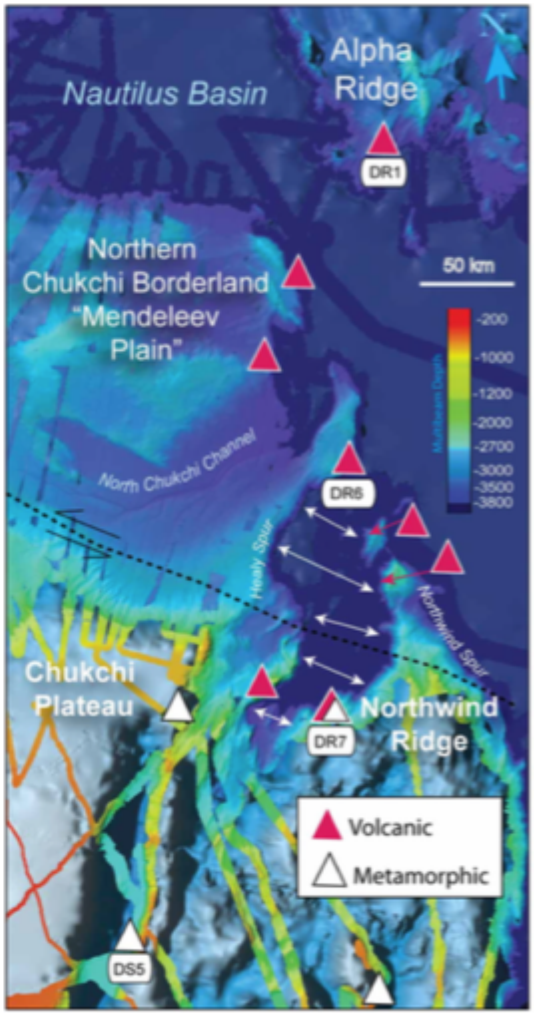


Figure 23: Healy Spur and Northwind Spur locations are labeled and white arrows indicate the direction for east-west extension. Image taken from Coakley et al. (in press)

grabens (Fig. 23) (Coakley et al., in press). It is clear from a bathymetric perspective that the northern extension of the Chukchi Borderland is connected to the Chukchi Plateau and is distinct from the Canada Basin and abyssal depths.

Geological & Geophysical Evidence:

Refraction data show that the northern extension of the Chukchi Borderland has a continental-type crustal structure, with a lower crust velocity less than 6.7 km/s (Chian et al., 2010; Hutchinson et al., 2012). This continental crust is highly stretched and thinned but shows local influences from the Northwind Ridge and Chukchi Borderland, specifically the extension that impacted the Canada Basin and Chukchi Borderland during initial formation (Hutchinson et al., 2012).

Brumley (2014) analyzed a U.S.-Canadian ECS seismic reflection line (*LSSL*11) which began on the Chukchi Plateau, crossed the northern extension and the Alpha Ridge and ended in the southern portion of the Makarov Basin (Fig. 24A&B). This seismic line, in conjunction with the bathymetry data, show closely spaced normal faults, which Brumley (2014) concluded are consistent with extension. Rift basins, half-graben structures, block rotations, and growth faults are all evident in the seismic line as well, which Brumley (2014) states is evidence for continental-rifting.

The northern extension is considered a continuation of the Chukchi Borderland and composed of the same continental crust (Brumley, 2014; Coakley et al., in press). It experienced extensive rifting, normal faulting, and rifting basin development as well as rift-related basaltic volcanism (Brumley, 2014).

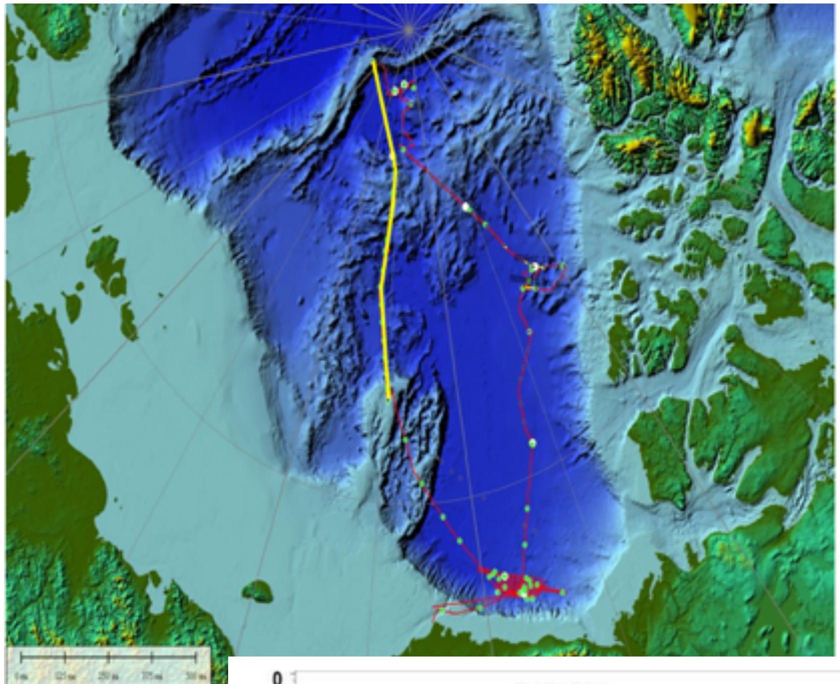
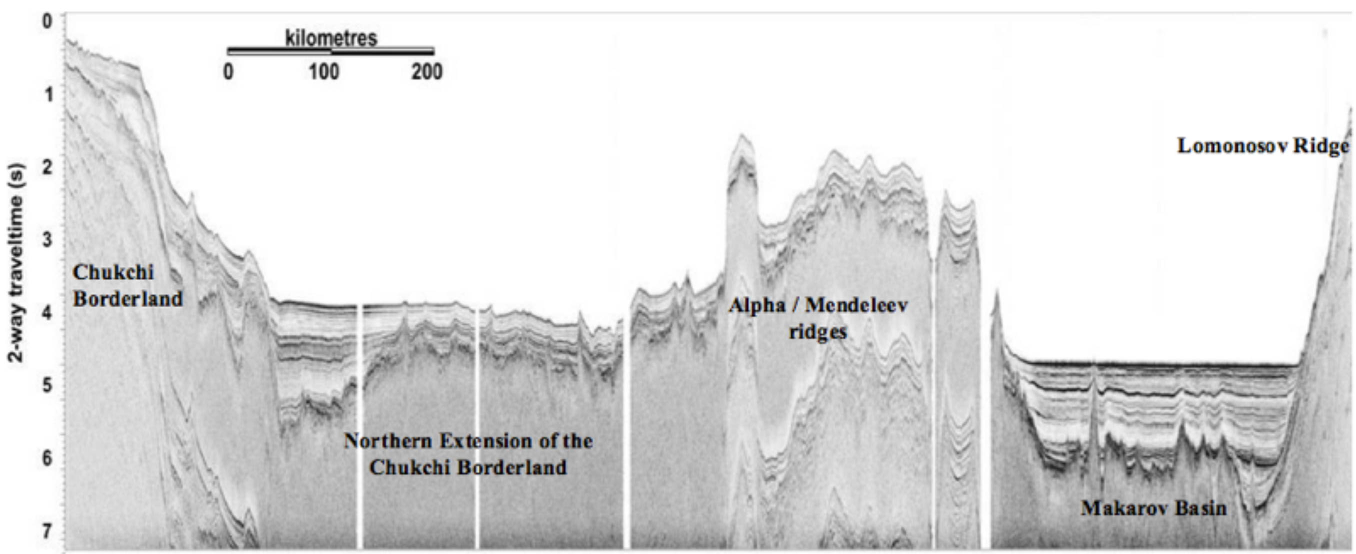


Figure 24: A: Yellow line is location of the seismic reflection line Brumley (2015) analyzed (LSSL11, 01-03). **B:** Figure shows the transect itself across the Chukchi Borderland, to the northern extension of the Chukchi Borderland and Alpha / Mendeleev ridges and across the Makarov Basin to the Lomonosov Ridge.
Source: Mosher et al., 2016.



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Synopsis:

Tectonic models for formation of the Amerasia Basin demonstrates a range of pre-rift positions for the Chukchi Borderland and its northern extension. Despite the differences among these models, there is a general consensus about specific characteristics of features and events that occurred during opening of the Amerasia Basin, including:

1.) **Seafloor Spreading:**

Some level of seafloor spreading in the Canada Basin contributed to the Amerasia Basin's opening and likely separated the Chukchi Borderland from a continental margin (no matter its pre-rift position along the Canadian margin) (Laxon and McAdoo, 1994; Grantz et al., 1998; Chian et al., 2010; Saltus et al., 2011; Hutchinson et al., 2012; Mosher et al., 2012b; Gaina et al., 2014; Chian et al., 2016).

2.) **Transform Boundary:**

A transform boundary existed in the northern Canada Basin just south of or adjacent to the Lomonosov Ridge (Cochran et al., 2006; Miller and Verzhbitsky, 2009; Evangelatos and Mosher, 2016).

3.) **An Arctic LIP:**

At least one LIP event occurred in the Amerasia Basin. This emplacement of volcanics overprinted on the Alpha and Mendeleev ridges as well as the northern extension of the Chukchi Borderland and northern region of the Canada Basin. The volcanic rocks mask the underlying crust, making it difficult to use seismics to understand the protolith beneath and thus the tectonic regime prior to the LIP(s). It is inconclusive if this LIP represents one event or multiple events (Maher, 2001; Jokat, 2003; Funck et al., 2011; Grantz et al., 2011; Saltus et al., 2011; Bruvoll et al., 2012; Corfu et al., 2013; Dossing et al., 2013; Jokat et al., 2013;

Morozov et al., 2013; Brumley, 2014; Kazmin et al., 2015; Mukasa et al., 2015; Saltus and Oakey, 2015; Coakley et al., in press).

4.) **Continental Fragment:**

Morphological, geological, and geophysical evidence support the conclusion that the Chukchi Borderland is a continental fragment associated with the Alaskan-Siberian margin (Shepard, 1948; Dietz and Shumway, 1961; Heezen and Ewing, 1961; Shaver and Hunkins, 1964; Taylor et al., 1981; Hall, 1990; Grantz et al., 1998; McAdoo et al., 1999; Grantz et al., 2004; Hopper et al., 2005; Arrigoni et al., 2007; Alvey et al., 2008; Brumley, 2009; Saltus et al., 2011; Houseknecht and Bird, 2011; Glebovsky et al., 2013; Hegewood and Jokat, 2013; Brumley, 2014; Chian et al., 2016; Ilhan and Coakley, 2015).

With the exception of Grantz et al. (2011), all modern tectonic models have treated the northern extension of the Chukchi Borderland as a thinned continental fragment that is the morphological continuation of the Borderland and shares a common geological history with the Borderland (Scotese, 2011; Brumley, 2014; Kazmin et al., 2015). The northern extension is differentiated from the Chukchi Plateau by the degree of extension and overprinting by a LIP event(s) (Chian et al., 2016; Hutchinson et al., 2012; Dossing et al., 2013; Flinders et al., 2014; Brumley, 2014).

III. Morphological CLCS Analogs:

Two regions of the 23 published CLCS summaries of the recommendations appear morphologically similar to the Chukchi Borderland and its northern extension and may provide insight into how the CLCS may respond to a submission in the Chukchi Borderland region. These regions are the Kerguelen Plateau located in the Southern Ocean and the Vøring margin located in the North Atlantic Ocean. Below are images of these regions and profiles as well as profiles of the Chukchi Borderland (Figs. 25, 26, 27).

From previous analyses of available CLCS recommendations, the Kerguelen Plateau (Fig. 26) is most similar morphologically to the Chukchi Borderland region. The Kerguelen Plateau's complex geologic origin and LIP overprint masks much of the underlying basement, which is similar to the situation in the Amerasia Basin. The plateau's complex geologic signature and uncertain tectonic past parallels the Borderland's complicated tectonic history, making a comparative analysis of the two regions appropriate within the context of Article 76.

Vøring Plateau and Vøring Spur (Fig. 27) were also chosen due to the similar morphological characteristics and their complex geology. The existence of two bathymetrically elevated features (Vøring Plateau and Spur) is similar to the Chukchi Borderland and its northern extension.

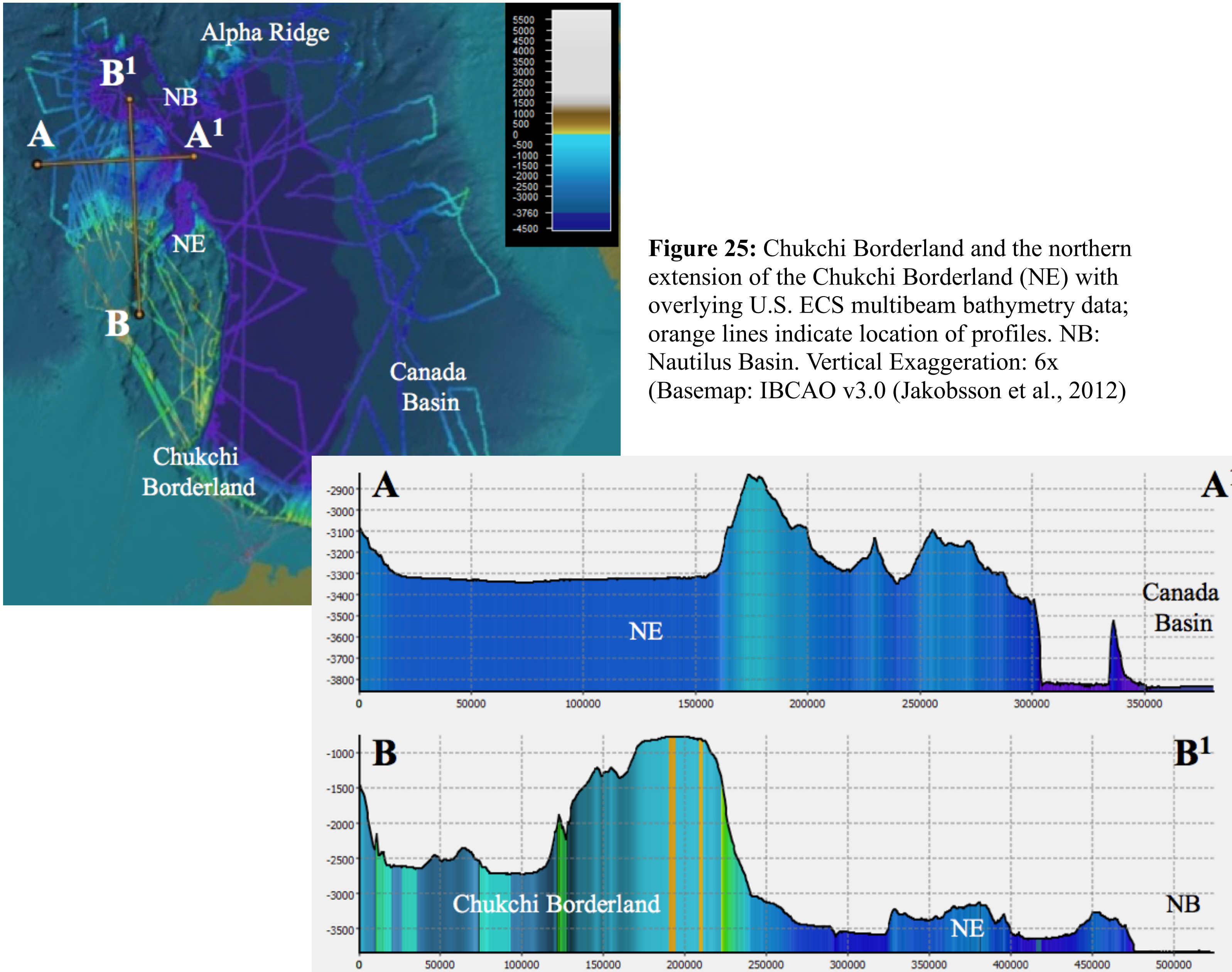

Figure 25: Chukchi Borderland and the northern extension of the Chukchi Borderland (NE) with overlying U.S. ECS multibeam bathymetry data; orange lines indicate location of profiles. NB: Nautilus Basin. Vertical Exaggeration: 6x (Basemap: IBCAO v3.0 (Jakobsson et al., 2012)

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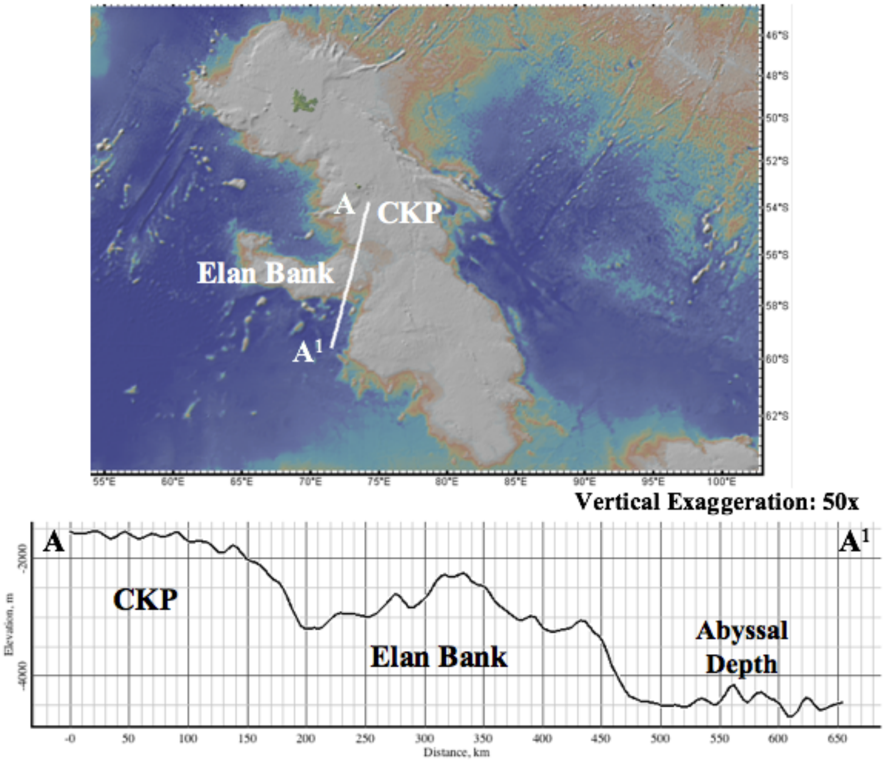

Figure 26: Kerguelen Plateau, located in the Southern Ocean. CKP is the Central Kerguelen Plateau and is the central feature that allowed Australia to justify its natural prolongation and prove certain features were natural components, including the Elan Bank. The white line is the location of the profile (GeoMappApp 3.6.0, GMRT 3.1 Grid).

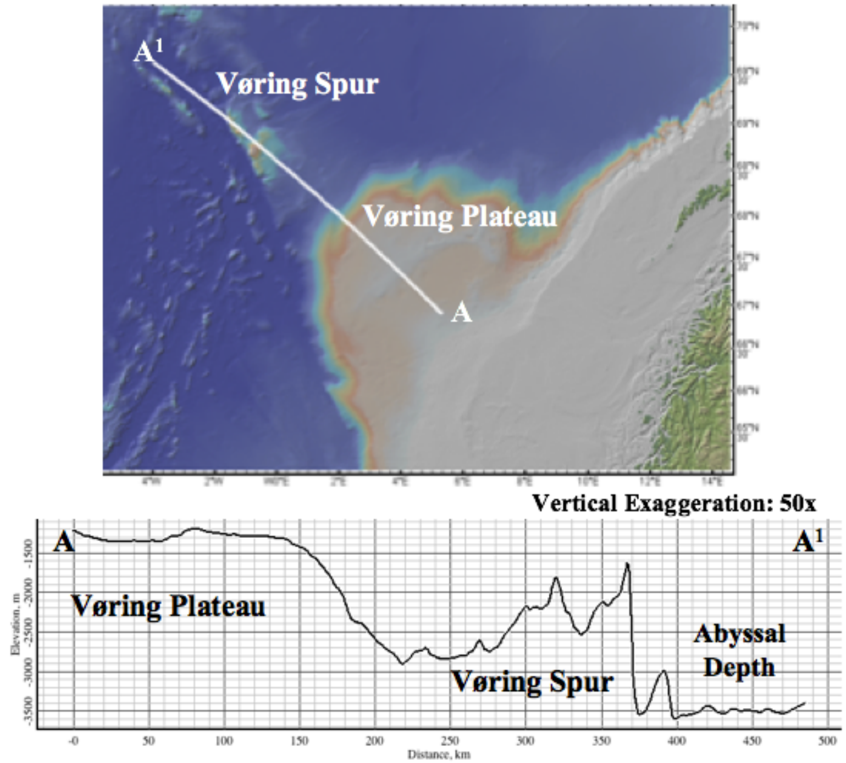

Figure 27: Vøring Plateau and Spur, located off the coast of Norway. The Vøring Plateau's morphological connection to Norway's continental margin allowed for its argument to classify the plateau as a submarine elevation. Norway argued that the Vøring Spur was a submarine elevation that is a natural component of the margin, however, the CLCS determined that it was a submarine ridge according to Article 76, paragraph 6. The white line is the location of the profile

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Analog 1: Kerguelen Plateau Geological Evolution & CLCS Recommendations Analysis

Kerguelen Plateau & Provinces:

The Kerguelen Plateau is a continuous southeast-trending bathymetric high located in the northern part of the Southern Ocean, between 65ºS and 45ºS. The plateau sits on the Antarctic Plate and lies at a water depth between 1000-4000m, rising 2000-4000 m above the surrounding ocean basins. It is over 2500 km long and 200 to 600 km wide and covers an area of 1.5 million km^2 (Fig. 28) (Borissova et al., 2002). The adjacent ocean basins include the Australian-

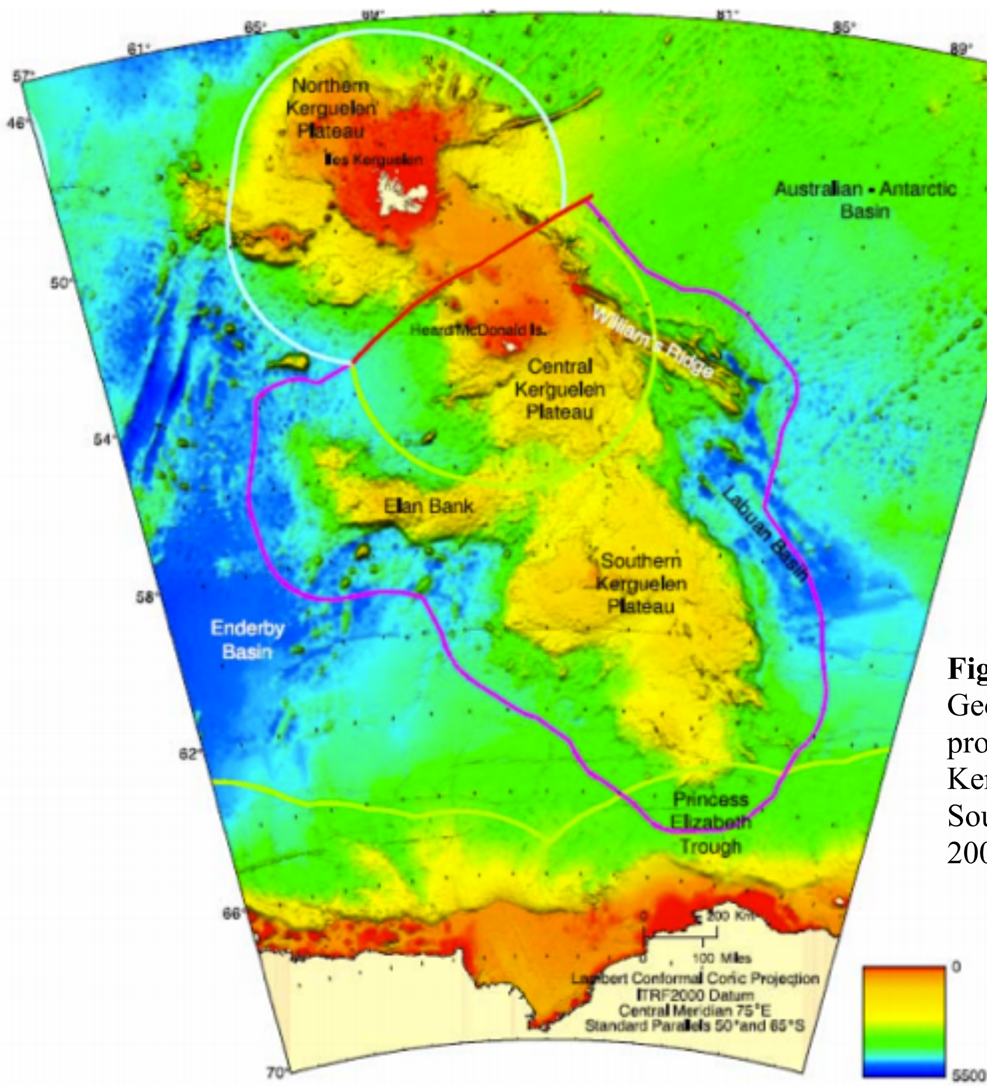


Figure 28: Geomorphological provinces of the Kerguelen Plateau. Source: CLCS/58, 2008, p. 23.

Antarctic Basin to the northeast, the Prince Elizabeth Trough to the south and Enderby Basin to the west.

It has become widely accepted that the Kerguelen Plateau is a LIP that formed in the Early Cretaceous (100-131 Ma) over the Kerguelen hotspot, which was adjacent to, near, or on the axis of breakup of the Indian plate from the Australia-Antarctica plate (Borissova et al., 2002). The plateau was affected by multiple episodes of volcanism, major rifting in the Late Cretaceous, and differential vertical movements through the Tertiary (Frey et al., 1991; Munschy et al., 1992; Borissova et al., 2002).

Although a general consensus exists regarding a LIP origin, the details of its tectonic history were still disputed in 2004 when the Australian Government made its submission to the CLCS (Borissova et al., 2002). The provinces of the Kerguelen Plateau all show distinct geologic characteristics that do not necessarily correlate with other provinces of the plateau, making it difficult to piece together the tectonic puzzle. The Kerguelen Plateau was a frontier for marine geology in 2004, very much like the Amerasia Basin is today.

The plateau is divided into distinct provinces based upon morphology, structure and tectonic history. The following breakdown summarizes the provinces of the Kerguelen Plateau and Figure 28 shows their specific locations (Borissova et al., 2002).

- Southern Kerguelen Plateau (SKP)
- Central Kerguelen Plateau (CKP)
- Northern Kerguelen Plateau (NKP)
- Elan Bank
- Williams Ridge
- Labuan Basin

All provinces, except for the NKP, lie within the Commonwealth of Australia's jurisdiction. The NKP is under the jurisdiction of the French Republic and no CLCS recommendations are published for this province, therefore it will not be discussed further. The Labuan Basin is a distinct province of the plateau that is important to tectonic models and understanding the plateau's evolution; it is discussed in more detail in Appendix V.

Overview of the Australian ECS Project & Interaction with the CLCS:

On 15 November 2004, the Commonwealth of Australia made a formal submission through the Secretary-General to the CLCS regarding Australia's proposed outer limits of the continental shelf beyond 200 M. Australia's submission (CLCS/44) was a complete submission in the sense that it included every region of its coastline. Four years later, on 9 April 2008, the Commission reported its recommendations for the Australian submission (CLCS/58).

In preparation for its submission, Australia conducted a preliminary study of its potential ECS (Symonds and Wilcox, 1989). After this initial analysis, Geoscience Australia (AGSO) collected bathymetry, seismic, gravity, magnetic, dredge and other datasets to determine Australia's outer limits of the continental shelf, and submitted its arguments to the CLCS. In the Kerguelen Plateau region alone, AGSO collected over 5,500 km^2 of seismic data, including the first seismic data to be collected over Elan Bank and in Labuan Basin (Borissova et al., 2002).

The AGSO noted, "in areas of complex morphology and ambiguous crustal structure, a detailed understanding of the continental margin geology is essential to optimize the extent of the legal continental shelf" (Borissova et al., 2002, p.1). Therefore, prior to Australia's submission in 2004, the country's scientific team synthesized and interpreted all of the new and legacy data into an overarching public report for each respective Australian region, including the Kerguelen Plateau. The reports' main purpose was to present the physiographic, geologic, and tectonic context of each region to support Australia's proposed outer limits of the continental shelf (Borissova et al., 2002). Borissova et al. (2002) presented the stratigraphy, structure, and tectonic history for the Kerguelen Plateau region.

The following analysis of the Kerguelen Plateau's provinces will provide a general morphological and geological overview. The CLCS recommendations for each specific province of the Kerguelen Plateau will be discussed as well, emphasizing critical geological and/or geophysical evidence. Other relevant geological and geophysical information about the provinces can be found in Appendix V.

Before discussing these provinces, it is important to acknowledge that the CLCS reiterated Australia's statement that the Kerguelen Plateau "forms a continuous, elongated morphological feature that constitutes a submarine prolongation of the landmass" (CLCS/58, p. 23). In this case, the 'landmass' includes the Heard and McDonald Islands. The CLCS' test of appurtenance, where the outer edge of the *juridical* continental margin is proven to exceed 200 M, is satisfied; therefore, Australia is entitled to establish its *juridical* continental shelf beyond 200 M (CLCS/58, p. 24).

Central Kerguelen Plateau (CKP)

Province Overview:

The CKP is located between 50ºS and 55ºS (Fig. 29). It has average depths ranging from 500-1,000 m and includes a sedimentary basin in its northern region called Kerguelen-Heard Basin, which is a 'sag' basin that covers >40,000 km^2. Heard and McDonald Islands are located on the CKP. It is important to note that GeoMapApp 3.6.0, GMRT 3.1 Grid does not include Australia bathymetric data for the Kerguelen Plateau, only American data and satellite altimetry were available.

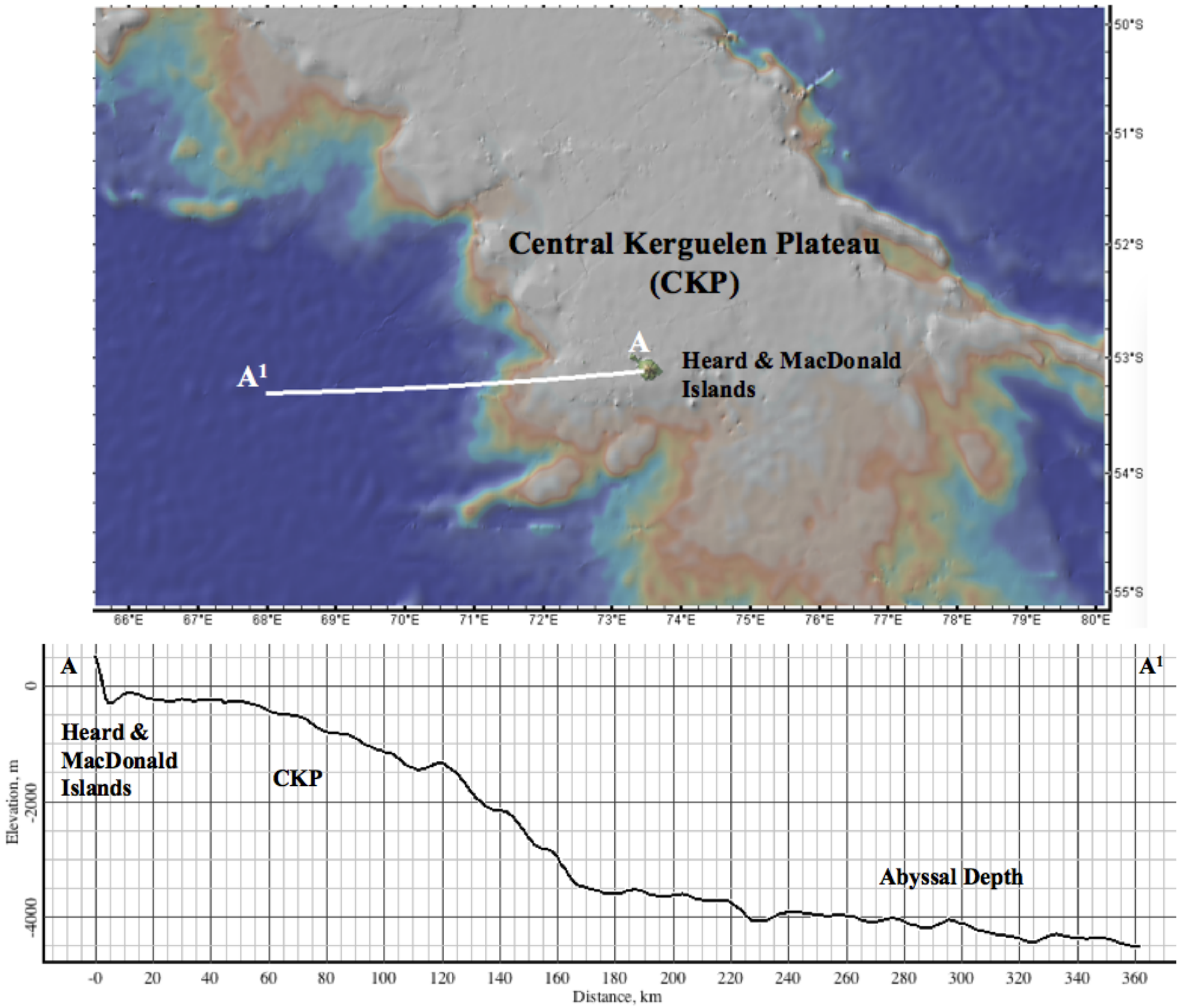


Figure 29: GeoMapApp map and accompanying profile of CKP (GeoMapApp 3.6.0 GMRT 3.1 Grid)

CLCS Recommendations' Consideration and Classification of Submarine Highs:

The CLCS stated that "based on the literature and the evidence in the Submission" Australia's islands, Heard and McDonald Islands, were built by magmatism penetrating through and adding to the older parts of the CKP's crust (CLCS/58, p. 28). Since Heard and McDonald Islands are situated *on* the CKP, Australia proved *natural prolongation* by morphological continuity between the islands and CKP.

The CKP's crust is 25 km thick and two ODP Sites 747 and 1138 located on the southern portion of the CKP sampled Cretaceous basement (basalt dated to the Cenomanian (85-88 Ma)) (Munschy et al., 1992). The CLCS noted that the Australian Government provided evidence that magmatic rocks sampled from the CKP "show chemical evidence of contamination by the continental crust" and that these same magmatic rocks are present beneath the Kerguelen-Heard Basin and Heard Island as well (CLCS/58, p.28). The key information is that the magmatic rocks that were found to have geological evidence of continental crustal contamination on the CKP are the same rock type found underneath Heard Island. This evidence supports the geological continuity argument. Given the morphological and geological continuity between Australia's landmass (Heard Island) and the CKP, the CLCS classified the CKP as a submarine *elevation* that is a *natural component* of the continental margin.

Southern Kerguelen Plateau (SKP)

Province Overview:

The SKP is the southernmost component of the Kerguelen Plateau and is defined as the area of the plateau south of 55ºS. It lies at water depths of 1,500 to 2,500 m (Fig. 30) and has a complex tectonic history. Little was known about this province until the mid-1980's when two cruises (Marion Dufresne 48 Cruise and AGSO Survey 47) collected 12,500 km of seismic reflection data and samples from the province providing a more detailed look at its stratigraphic and structural character (Munschy and Schlich, 1987; Fröhlich and Wicquart, 1989; Ramsay et al., 1986; Borissova et al., 2002). These data provided evidence for multiple stages of normal faulting, extensional structures, complex north-south trending grabens, strike-slip faulting, and large northwest trending basement ridges (Houtz et al., 1977; Coffin et al., 1986; Fritsch et al.,

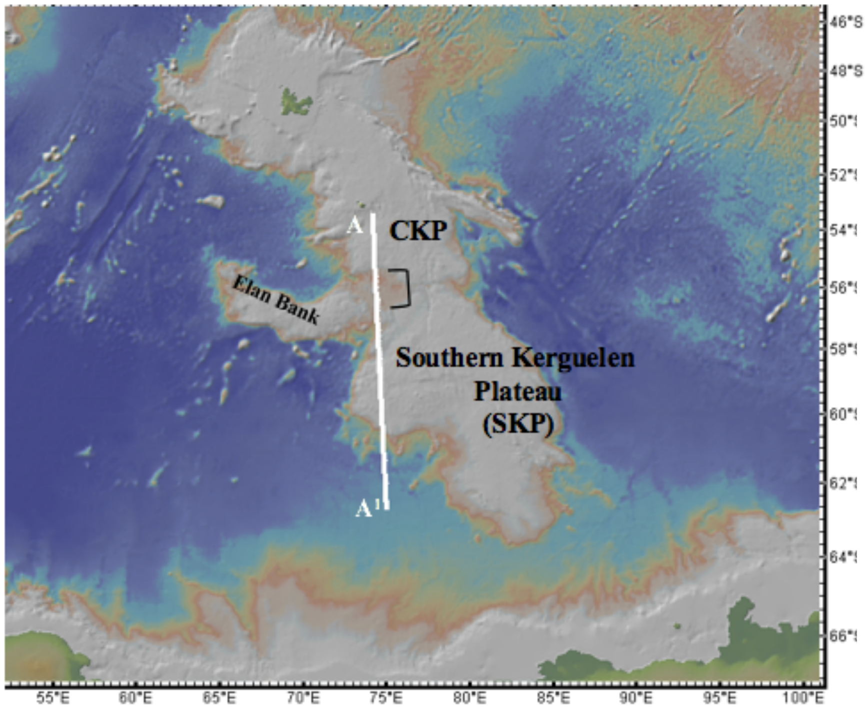
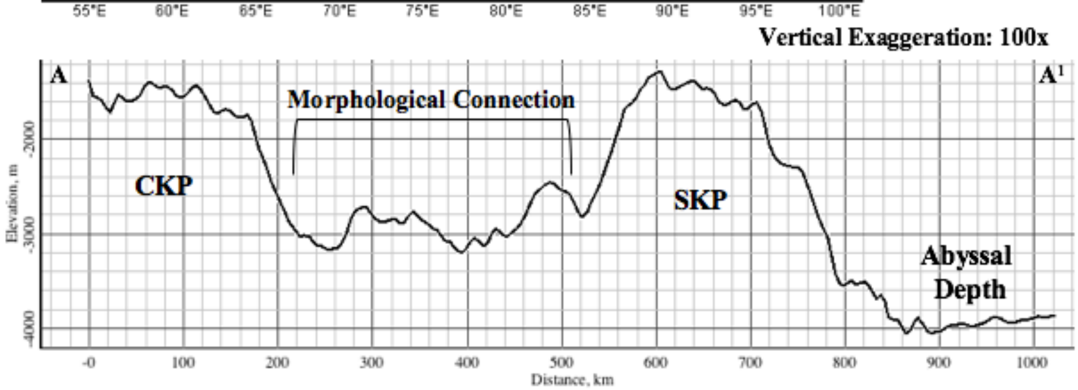


Figure 30: GeoMapApp map and accompanying profile (white line) show CKP to SKP morphological connection (saddle). Change in elevation from the CKP (~1300 m) to deepest point of saddle (~2800m) to SKP (~1550 m). (GeoMapApp 3.6.0 GMRT 3.1 Grid)



1992; Rotstein et al., 1992; Royer and Coffin, 1992; Angoulvant-Coulon and Schlich, 1994; Könnecke et al., 1998; Gladczenko and Coffin, 2001).

This province has a relatively large sedimentary basin, called Raggatt Basin, located in the northern part of the SKP. The basin has 2,500 m of sediment dated Albian to Miocene (113-5.3 Ma) (Colwell et al., 1988; Coffin et al., 1990). Other important features of the SKP are its major rift zones, including the 77 Degree Graben, 59 Degree Graben, and SKP Rift Zone (Munschy et al., 1993; Angoulvant-Coulon and Schlich, 1994). Each of these rift zones intersects the plateau from a different direction and were formed between 72-60 Ma during a major extensional phase. Tikku and Cande (2000) argued that these complex rift systems might have been the plate boundary between the Australian and Antarctic plates at 75-63 Ma.

CLCS Recommendations' Consideration and Classification of Submarine Highs:

The CLCS explicitly referenced the evidence that the Australian Government provided that shows the morphological connection between the CKP and the SKP by stating that the "CKP is connected morphologically to the large underwater feature known as the SKP" (CLCS/58, p. 28). This morphological attachment is shown in Figure 30, where it dips from 1300 m to 2800 m and returns to a depth of 1550 m on the SKP. It is significant to note that Australia showed that the surrounding abyssal depth is 4000 m or deeper, so a 1,500 m drop in elevation is well above the deep ocean floor.

The presence of a saddle connecting the CKP and SKP is critical evidence for fulfilling the morphological criterion in the classification of seafloor highs. For the SKP to be considered a seafloor high according to Article 76, it must demonstrate a morphological connection to the landmass, in this case the CKP, which is where Heard and McDonald Islands are embedded. Therefore, the critical morphological link between the CKP and SKP is a saddle connecting the provinces.

After satisfying this morphological criterion, it is clear that the Australian Government successfully convinced the CLCS that the CKP and SKP have a similar geological composition. The CLCS stated in the recommendations that "…the major parts of the SKP are also made up of Late Cretaceous magmatic rocks, ca. 100 Ma old (90-118 Ma), similar to the crust of the CKP" (CLCS/58, p. 28). This statement demonstrated that CLCS agreed with the Australian Government's argument that a morphologic and geologic connection exists from Heard Island to the CKP, and then to the SKP.

Geochemical analysis of SKP basement basalts revealed, like the CKP, silica-saturated transitional tholeittes that were contaminated by continental lithosphere (Borissova et al., 2002). This result indicates that the SKP is possibly underlain by continental crust (Borissova et al., 2002). Another suggestion is that the mantle plume responsible for creating the Kerguelen Plateau contained continental isotopic and chemical elements (Mahoney et al., 1995). Others argue, however, that the geochemical evidence may mean that original rifting between Antarctica and Australia left continental fragments which formed the basis for the SKP (Coffin and Eldholm, 1994). Borissova et al. (2002) stated that SKP's complex extensional structures and heterogeneity may be explained by the presence of underlying continental fragments, which were overlain by Cretaceous basalts, thickening and changing the geochemical signature of the crust.

It is also significant to note that the velocity-depth structure of the Raggatt Basin is distinctly different from other hotspot oceanic plateaus. Its structure is more reflective of a thinned continental crust overlain by basalt (Operto and Charvis, 1995). Yet some authors disagree with this conclusion, arguing that the low velocity crustal structure under the SKP is due to reheating of the oceanic plateau's basalt (Gladczenko and Coffin, 2001).

Within the context of Article 76 classification of seafloor highs, the SKP's *natural prolongation* was demonstrated through morphological connection with the CKP as well as its contribution to the FOS envelope. It was shown to be a *natural component* through its *natural prolongation* (morphological connection) and its "geological crustal type continuity" with the CKP and its two islands. The most important takeaway from the SKP classification is that by 2004, when Australia submitted to the CLCS, the scientific community did not have definitive agreement about the SKP's tectonic origin. Yet despite disagreement about how and why the SKP's basalt is contaminated with continental crust, Australia presented a convincing argument to the CLCS that proved geological continuity from Heard Island to the SKP. From the evidence Australia used to substantiate its argument, the CLCS felt it could classify the SKP as a submarine *elevation* that is a *natural component* of the continental margin.

Elan Bank

Province Overview:

The Elan Bank is a submarine high that extends west from the CKP. The province's shallowest water depth in the west is 500 m and 1000 m in the east (Fig. 31). Australia acquired bathymetry, gravity, and seismic data on the bank, all of which indicate that the province has two basement highs that are displaced in a northwest-southeast trend along its central region (Borissova et al., 2002). The bank has a crustal thickness of 15 km and exhibits east-west structural trends that are 600 km long and 100-200 km wide, a characteristic that is distinctly

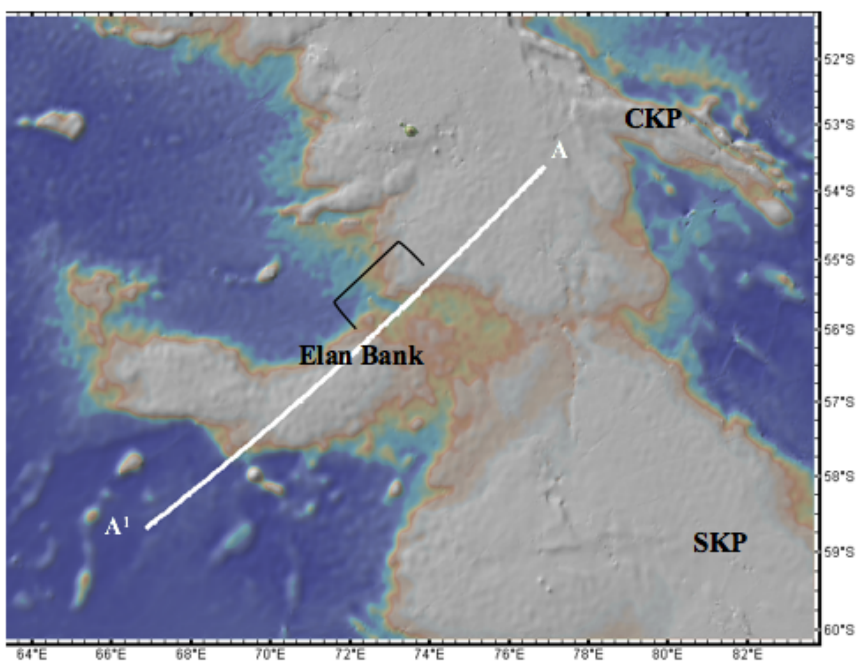
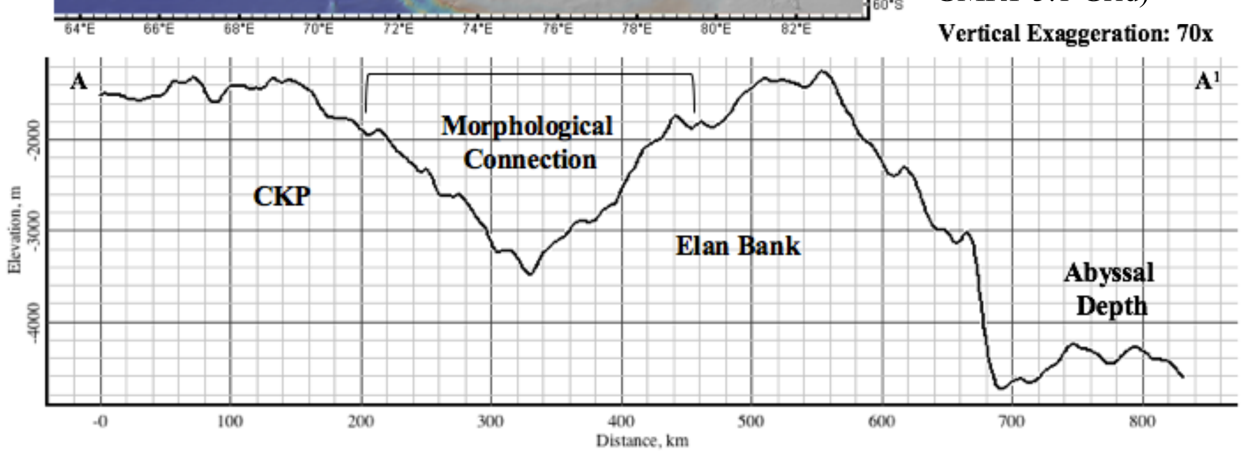


Figure 31: GeoMapApp map and accompanying profile (white line) show CKP to Elan Bank morphological connection (saddle). Change in elevation from the CKP (~1300 m) to deepest point of saddle (~3200m) to Elan Bank (~1200 m). Surrounding Abyssal Depth: >4000 m (GeoMapApp 3.6.0 GMRT 3.1 Grid)



different from the CKP and SKP (Könnecke et al., 1997). Angoulvant and Schlich (1994) stated that this structural unit may be a remnant from the separation of the Broken Ridge and Kerguelen Plateau during the Late Cretaceous to early Tertiary.

CLCS Recommendations' Consideration and Classification of Submarine Highs:

The Elan Bank presents a unique seafloor high case study that is distinctly different from the CKP and SKP. The CLCS did not explicitly mention the morphological connection that exists between the CKP and Elan Bank in the Australian recommendations. This morphological connection is obvious when reviewing available data as well as Australia's maps published in its submission and the CLCS recommendations. The CLCS only acknowledged this morphological connection in the recommendations when it agreed with Australia's classification of the Elan Bank as a province of the "composite seafloor high" known as the Kerguelen Plateau (CLCS/58, p.23). Given the lack of explicit discussion of a morphological connection, it seems Australia presented a convincing morphological argument to the CLCS that satisfied this first criterion. The CLCS also could have felt that because the morphological connection was clearly present, it was unnecessary to discuss it in their recommendations.

With respect to satisfying the geological continuity criteria, Australia presented to the CLCS an important ODP Site from the Elan Bank. ODP Site 1137 was located on a central high of the bank and recovered samples that definitively showed that at least part of the bank has a continental origin (Coffin et al., 2000; Frey et al., 2000; Nicolaysen et al., 2000; 2001; Weis et al., 2001). Site 1137's samples were the only undisputable continental basement rock recovered from the Kerguelen Plateau prior to 2004 (Borissova et al., 2002). The Elan Bank's low crustal velocity is consistent with the continental basement rock samples from Site 1137 (Charvis et al., 1997). With these data, it seems Australia successfully convinced the CLCS that the Elan Bank is composed of continental crust and has been intruded with and overlain by volcanics (Borissova et al., 2002).

Another component to proving geological continuity is understanding a province's tectonic origin. Borissova et al. (2002) stated that the specific time when the Elan Bank was formed was debated as of 2002. The theories that existed included: the Elan Bank formed during the Valanginian (134-139 Ma) during the separation of India/Elan Bank and Antarctica; or the Elan Bank formed in the Albian (100-113 Ma) during the breakup of India and Elan Bank (Borissova et al., 2002). In either tectonic scenario, the bank was moved from the Indian to the Antarctic plate through a ridge jump. For this to occur, extensive Albian volcanism must have happened, overprinting and modifying the bank's original continental composition (Borissova et al., 2002). Similar to the SKP, it is clear that the scientific community had not reached a universally accepted conclusion for the tectonic origin of the Elan Bank when Australia made its submission to the CLCS in 2004.

Despite the ambiguity regarding Elan Bank's tectonic origin, Australia presented a cohesive argument that convinced the CLCS that the province was a submarine *elevation* that is a *natural component* of the continental margin. It is likely that Australia's presentation of ODP Site 1137 heavily influenced Elan Bank's classification due to the CLCS' statement in the recommendations that points to this evidence. The CLCS stated that Australia's discovery of continental crust contamination on the CKP and SKP "shows the involvement of crust similar to that of the Elan Bank" (CLCS/58, p. 28). Therefore, Australia's argument to the CLCS seems to be:

1.) Heard and McDonald Islands are "embedded" in the CKP's Late Cretaceous magmatic crust. Heard Island's basalt shows evidence for continental crust contamination.

2.) The SKP and Elan Bank are composed of similar crustal types, and possess similar continental crustal contamination as the CKP, which means they share a similar crustal type with Heard Island.

3.) Therefore, the "CKP, SKP and Elan Bank are all *natural components* of the continental margin of the Heard and McDonald Islands" (CLCS/58, p.28).

4.) All three of these features are therefore submarine *elevations*.

Another important conclusion, is that no universally agreed upon tectonic history was present in 2004 regarding the Elan Bank's (and SKP's) tectonic history. The CLCS accepted this level of uncertainty and was comfortable classifying the province as a submarine *elevation* without knowing its exact tectonic history.

Williams Ridge

Province Overview:

On the eastern side of the CKP, Williams Ridge extends out in a north northwest-south southeast direction as a continuation of a high standing basement ridge (Fig. 32). The ridge's shallowest region is 500 m below sea level. Williams Ridge's crust is 12-15 km thick, which is more akin to the Kerguelen Plateau structurally than to the adjacent Labuan Basin (Gladczenko

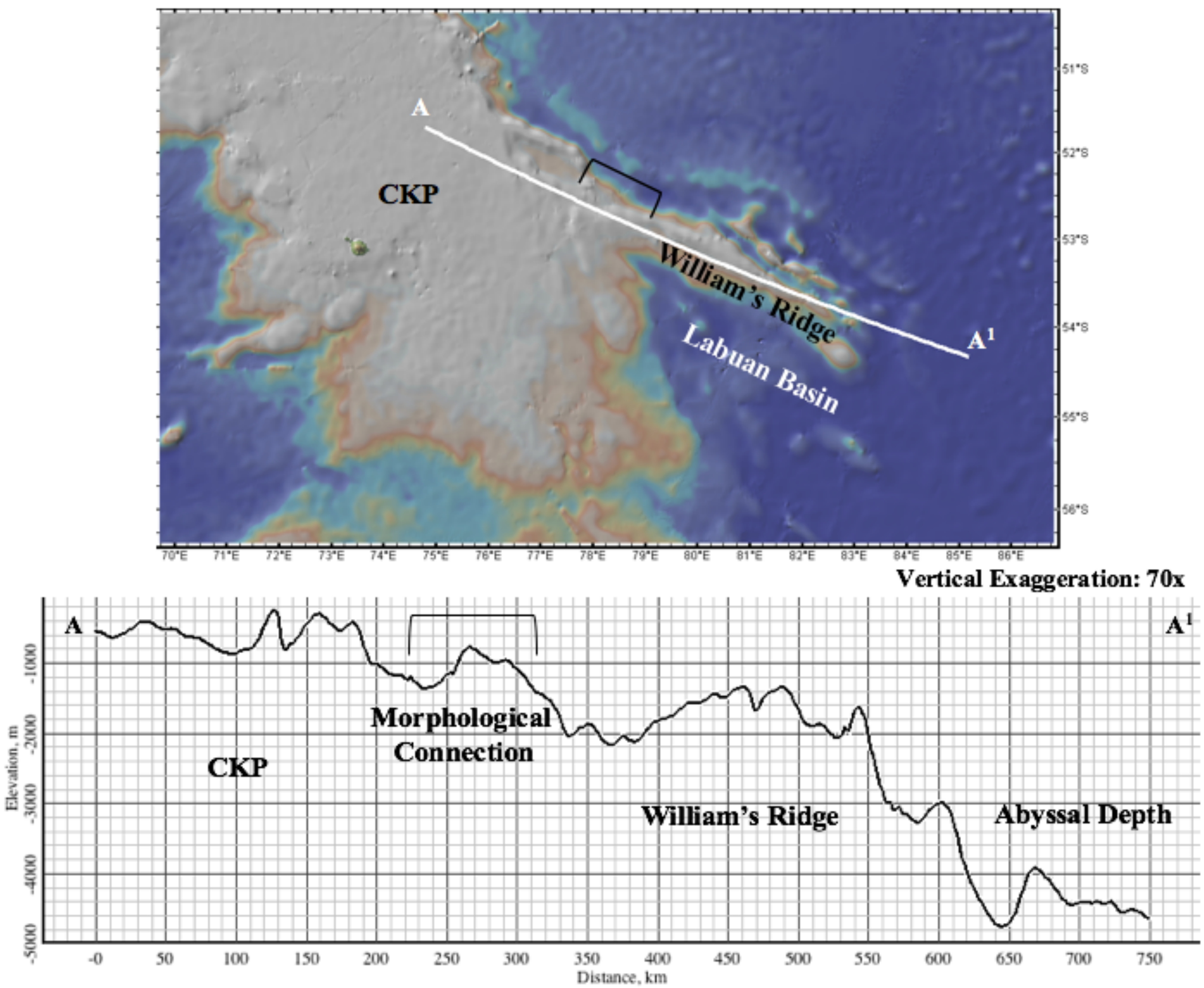


Figure 32: GeoMapApp map and accompanying profile (white line) show CKP to William's Ridge morphological connection (saddle). Change in elevation from the CKP (~1000m) to deepest point of saddle (~1400m) to Elan Bank (~1400 m). Surrounding Abyssal Depth: >4000 m (GeoMapApp 3.6.0 GMRT 3.1 Grid)

and Coffin, 2001). It is composed of two blocks separated by a narrow fault-bounded valley (Borissova et al., 2002).

CLCS Recommendations' Consideration and Classification of Submarine Highs:

In the Australian submission to the CLCS, Australia treated Williams Ridge as a submarine *elevation*; however, the CLCS concluded differently. The CLCS' stated that the data presented in the submission with respect to Williams Ridge gave "only indirect evidence of its nature and origin" and the "Commission is of the opinion that the geological origin of the Williams Ridge still remains unresolved" (CLCS/58, p. 28).

The CLCS' statement regarding indirect evidence is most likely in reference to the fact that no geological data, such as ODP sites, were drilled on the province to provide evidence for its origin. The only geophysical and geological data collected from the ridge prior to 2004 was one seismic line, one dredge sample and one core sample. The dredge sample recovered Miocene basalt and the core sample yielded Late Cretaceous sediments (Borissova et al., 2002). These data are insufficient to understand the geological composition and tectonic origin of the ridge. Borissova et al. (2002) stated that knowledge about Williams Ridge's basement derived from Broken Ridge, a conjugate feature north of the Kerguelen Plateau. Therefore, it seems evident that with such little data, the CLCS felt it had an incomplete picture of the ridge's geologic composition. Borissova et al. (2002) even stated that Williams Ridge is not well understood geologically and tectonically.

The recommendations also stated that the CLCS' questioned the applicability of provision 7.3.1.b of the S&TG to Williams Ridge. This provision of the S&TG discusses the characteristics of submarine *elevations* within passive margin settings. The provision specifically discusses the growth of continents by "thinning, extension and rifting of continental crust and extensive intrusion of magma into and extensive extrusion of magma through that crust" (S&TG, 7.3.1.b). Since Williams Ridge's basement was not sampled and therefore could not provide evidence of tholeitte basalts that exhibited continental crust contamination, Williams Ridge was not classified as a submarine *elevation* that is a *natural prolongation* of the continental margin.

Lastly, and most interestingly, the CLCS refrained from classifying Williams Ridge as a submarine *ridge* even though it acknowledged that the Australian Government showed a morphological connection between the ridge and plateau by referring to Williams Ridge as an "element" of the "composite sea-floor high" known as the Kerguelen Plateau (CLCS/58, p. 23). By examining the Global Multi-Resolution Topography (GMRT) Grid in GeoMapApp (Fig. 32) Williams Ridge is clearly morphologically connected to the CKP. This morphological continuity fulfills the primary criterion for the classification of submarine *ridges* and submarine *elevations*. Even with this criterion filled, the CLCS did not classify Williams Ridge as any type of seafloor high according to Article 76, paragraph 6. Yet, in the CLCS recommendations' map (CLCS/58, Figures C.1 & C.2, p.17, 19), FOS points circle the ridge and the 60 M arc formula line is applied to these FOS points. The 350 M constraint line is also applied to Williams Ridge. From these maps, it seems the CLCS considered Williams Ridge to be a submarine *ridge* until Australia could provide definitive geological evidence to prove it was a *natural component* of the margin.

Takeaways from the CLCS' Analysis of the Kerguelen Plateau's Provinces:

Given that the Kerguelen Plateau's tectonic history was poorly constrained as of 2004, an important conclusion from this analog analysis is the CLCS' emphasis on "geological crustal type continuity" rather than "geological tectonic history continuity." The CKP, SKP, and Elan Bank's tectonic histories' were narrowed down to a few hypotheses, but no definitive conclusion regarding the specific tectonic events or mechanisms associated with the provinces' evolution were known when Australia made its submission to the CLCS.

This conclusion is reinforced by the fact that Borissova et al. (2002) conceded that the Australian scientific team did not know how much continental crust existed beneath the plateau at the time of Australia's submission. Borissova et al. (2002) also stated that it was unknown what processes at the triple junction of the Indian, Australian, and Antarctica allowed for continental fragments to be left behind and overprinted by a LIP. It is clear that even with these tectonic 'unknowns' the CLCS felt that Australia presented a convincing argument, backed by a robust spectrum of geological and geophysical data, to decide if the plateau's provinces were *natural components* of the continental margin.

Implications for the Chukchi Borderland and its Northern Extension:

The 2008 CLCS recommendations for the Kerguelen Plateau and the accompanying 2002 AGSO report provide important information that is applicable to a potential United States ECS delineation in the Amerasia Basin of the Arctic Ocean. Although the Chukchi Borderland and Kerguelen Plateau are not analogous in terms of geologic composition and tectonic history, key parallels with respect to Article 76 exist.

Firstly, it is clear that the Australian scientific team had an incomplete picture of the specific tectonic histories for each province of the Kerguelen Plateau when Australia made its submission. The CLCS accepted this level of uncertainty yet still felt comfortable to classify seafloor highs with the available data according to Article 76, paragraph 6. The CLCS seemed to focus on two pieces of evidence in its review of Australia's argument for each individual province of the plateau: 1) bathymetry (to determine morphological continuity) and; 2) ODP and other geological sample records, seismic reflection and refraction data, combined with potential field data (magnetic and gravity) to determine “geological continuity.” The CLCS also seemed to emphasize “crustal type continuity” over “tectonic history continuity” when examining the Kerguelen provinces. Williams Ridge is an example of this criteria because Australia did not present any (or any convincing) geological data that showed that the ridge’s crustal type was similar to Heard and McDonald Islands, the CKP, SKP, and/or Elan Bank.

If the same logic that the CLCS employed to assess the Kerguelen Plateau’s provinces is applied to the Chukchi Borderland and its northern extension, the disagreement about the specific tectonic origin and the Borderland’s conjugate margin becomes less important. The key evidence the CLCS would focus on are the multiple datasets that indicate that the Chukchi Borderland is composed of continental crust and reveal that the northern extension is likely composed of continental crust, but highly extended and overprinted by volcanics. The northern extension may be an example of the submarine *elevation* the CLCS describes in 7.3.1b in the S&TG.

The CLCS would likely point out that a major difference between the Kerguelen Plateau and Chukchi Borderland is the available geological data. The Australian scientific team presented to the CLCS the results from 19 ODP Sites (Legs 119, 120, 183), 22 sonobuoy stations, 18 dredge sites, and ten core samples (Appendix V, Fig. 48). The Amerasia Basin, however, has no ODP Sites, 70 high quality sonobuoy stations, 17 dredge sites, some piston cores, and a drill sample from a submarine (Mayer and Armstrong, 2003; 2004; 2007; 2008; 2009; 2010; 2011; 2012; Morozov et al., 2013; Brumley, 2014; Chian et al., 2016). The only scientific borehole in the Arctic Ocean is on the Lomonosov Ridge. Given how the CLCS treated Williams Ridge on the basis of a lack of data, it may take a similar perspective with respect to the northern extension without more robust geophysical and geological data.

Analog 2: Vøring margin Geological Evolution & CLCS Recommendations Analysis

Vøring Margin & Provinces:

The Vøring margin is a passive rifted margin and is a product of the continental breakup in the Norwegian-Greenland Sea. The regional high that protrudes from the Vøring margin is often referred to in the literature as the "Vøring Marginal High" (Blystad et al., 1995; Brekke, 2000; Mjelde et al., 2007; Wangen and Faleide, 2008). The Vøring margin, including the Vøring Marginal High, lie off the coast of the Kingdom of Norway. In Norway's submission to the CLCS, it divided the Vøring Marginal High into two distinct features, the Vøring Plateau and Vøring Spur.

The Vøring Plateau is located to the northwest of the Vøring Escarpment and is situated between the Jan Mayen and Bivorst lineaments (Fig. 33) (Brekke, 2000). The Jan Mayen

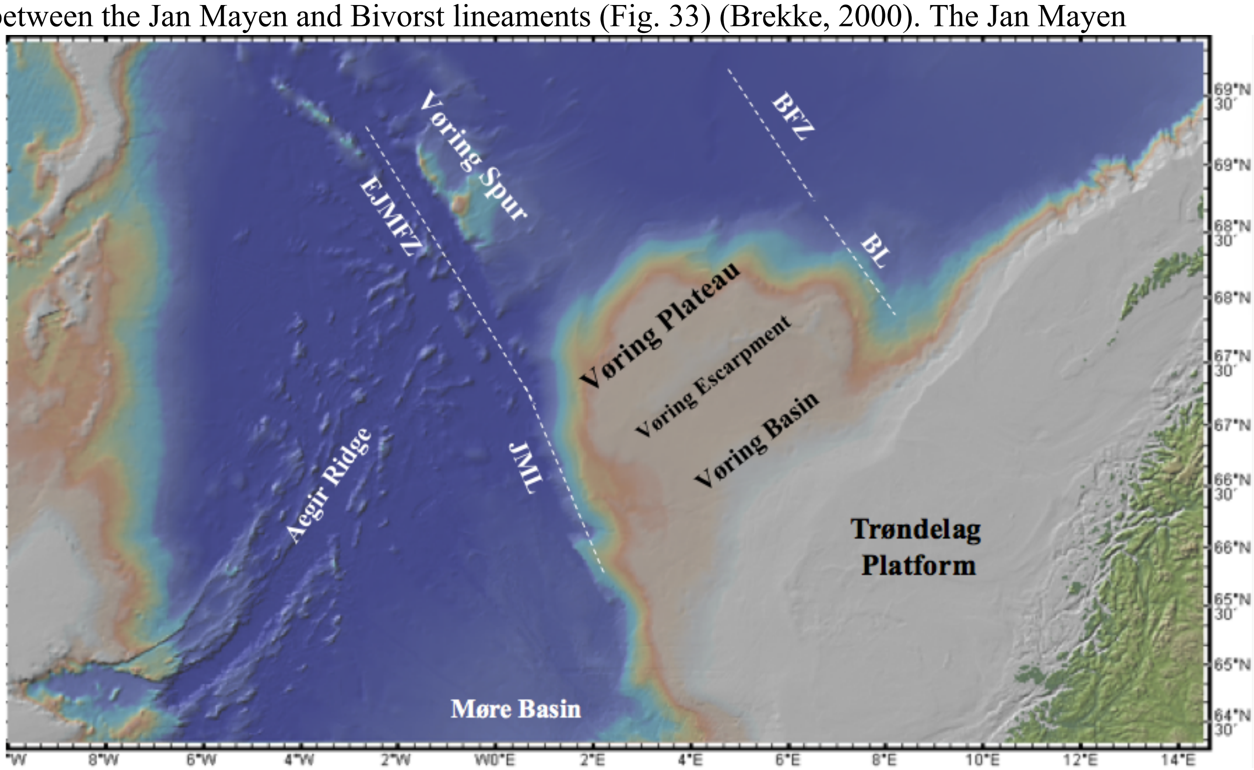


Figure 33: Overview figure of the Vøring Marginal High, including the Vøring Plateau and Vøring Spur. BL: Bivrost Lineament; BFZ: Bivrost Fracture Zone; EJMFZ: East Jan Mayen Fracture Zone; JML: Jan Mayen Lineament (GeoMapApp, 3.6.0, GMRT 3.1 Grid)

Lineament is an extension of the fracture zone that separates the Vøring Margin from the Møre Basin to the south (Wangen and Faleide, 2008). To the southeast of the Vøring Escarpment is the Vøring Basin and further landward of the basin is the Trøndelag Platform (Mjelde et al., 2007). More detailed information about the Vøring Plateau and Spur are provided in Appendix VI.

Overview of Norwegian ECS Project & Interaction with the CLCS:

The first seismic data were collected in the Norwegian-Greenland Sea in 1969 (Brekke, 2000). As the petroleum industry expanded in Norway during the second half of the 20th Century, the Norwegian Petroleum Directorate (NPD) collected additional seismic, gravimetric, and magnetic data in the region (Brekke, 2000). At the same time, Deep Sea Drilling Project (DSDP) missions and other academic research projects pursued geological sampling to better understand the area's geologic history and plate tectonic regime (Johnson and Heezen, 1967; Avery et al., 1968; Meyer et al., 1972; Talwani and Eldholm, 1972; 1977; Brekke, 2000). In particular, in 1987, ODP Leg 104 collected cores from Sites 642E on the outer portion of the Vøring Plateau (Eldholm et al., 1989). With the increase in data collection in the Norwegian-Greenland Sea, scientists developed a better understanding of the region's tectonic past.

Although seismic data acquisition began in the Norwegian-Greenland Sea in 1969, the NDP did not collect seismic data from the Vøring Margin until 1985 (lasting to 1992) (Brekke, 2000). In 1992, surveys were conducted in the Vøring Basin using ocean bottom seismometers (OBS), which proved to be a useful method to determine sediment velocities, depth to basement, and intrabasement and upper mantle structure (Mjelde et al., 1997; 2001). It became quickly apparent that the Vøring margin's conjugate margin was East Greenland. Scientists expanded the repository of available data to study the Vøring Marginal High by analyzing data collected off of Greenland, in particular ODP sites in eastern and southern Greenland (Brekke, 2000).

In 1996, the NDP was tasked by the Norwegian Ministry of Foreign Affairs to collect data and map the Norwegian and Barents seas to determine the extent of Norwegian ECS in these regions. The same year, an OBS survey was conducted, acquiring data across the continent-ocean transition (COT) zone of the Vøring Marginal High (Mjelde et al., 2001). Other datasets were collected for this ECS project, including bathymetry, potential field (magnetic and gravity) and seismic data (Olesen et al., 2007).

After analyzing new ECS and legacy data, Norway submitted through the Secretary-General to the CLCS its proposed ECS limits for the Northeast Atlantic and Arctic regions on 27 November 2006. Norway's submission included the Vøring Plateau and Vøring Spur.

The morphological and geological overviews of these provinces presented here are based upon the literature published before Norway made its submission in 2006. The literature that was published during the CLCS' review of the Norwegian submission is also assessed (literature published between 2006 and 2009). Evaluation of this literature is important because Norway submitted additional information (NOR-PRE-007-31-01-2008) with respect to the Vøring Spur to the CLCS in 2008. Unlike the Australian Government, Norway has not published any official public geological reports on the Vøring Plateau and Spur.

The CLCS published its recommendations on 27 March 2009 and classified the Vøring Plateau as a submarine *elevation* that is a *natural component* of the continental margin and the Vøring Spur as a submarine *ridge* according to Article 76, paragraph 6.

Vøring Plateau

Province Overview:

The Vøring Plateau is a prominent bathymetric high that is the central component of the Vøring Marginal High. The Vøring Plateau is connected to the Norwegian continental margin via the Vøring Basin, which is a ~120-160 km wide saddle feature between the Trøndelag Platform and the Vøring Plateau (Fig. 34). The Trøndelag Platform is at depths of ~400 m and the Vøring

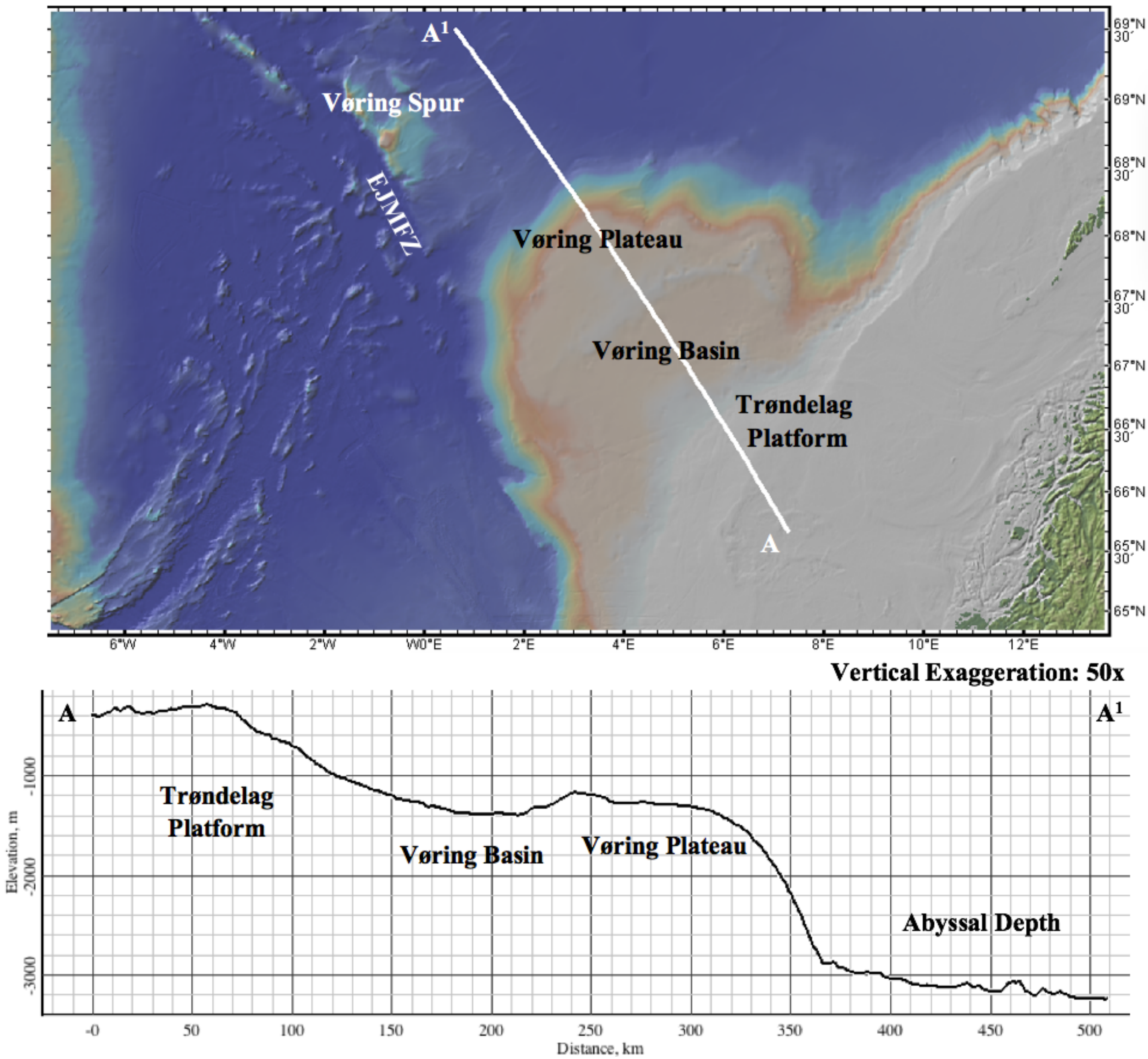


Figure 34: Vøring Plateau Overview and Profile. EJMFZ: East Jan Mayen Fracture Zone. Source: GeoMapApp 3.6.0, GMRT 3.1 Grid

Basin drops to a depth of 1400 m before rising to the plateau at depths of 1200-1300 m. The surrounding abyssal depth is at ~3000 m or greater.

The Vøring Plateau rises 1500-1800 m above abyssal depth and is roughly 150 km long (northeast to southwest direction) and 400 km wide (southeast to northwest direction) (Fig. 34). It is important to note that GeoMapApp 3.6.0, GMRT 3.1 Grid does not include Norwegian bathymetric data for this region, only American data and satellite altimetry were available.

The Vøring Plateau has a layer of Tertiary sediments overlying thick lower Eocene flood basalts (Brekke, 2000). Underneath the flood basalts, there is evidence for continental crust underplated by mafic intrusions that thins progressively seaward (Skogseid et al., 1992; Mjelde et al., 2001; 2007; Meyer et al., 2009). The outer extent of the Vøring Plateau is composed of thick units of seaward dipping reflectors that represent oceanic crust (Ewing and Houtz, 1979; Spudich and Orcutt, 1980; Mjelde et al., 2001; Mosar et al., 2002; Olesen et al., 2007; Meyer et al., 2009).

The magnetic anomalies on the northern part of the Vøring margin and into the Lofoten margin are evidence for typical seafloor spreading, whereas the diffuse anomalies on the southern Vøring Plateau "climb up" onto the plateau. These magnetic anomalies may represent intruded oceanic and continental crust from an event that occurred after seafloor spreading in the north (Fig. 35) (Olesen et al., 2007).

Mjelde et al. (2001) analyzed seismic profiles from the Vøring Plateau. They found that the outer portion of the plateau is composed of oceanic crust that is dissimilar to normal seafloor

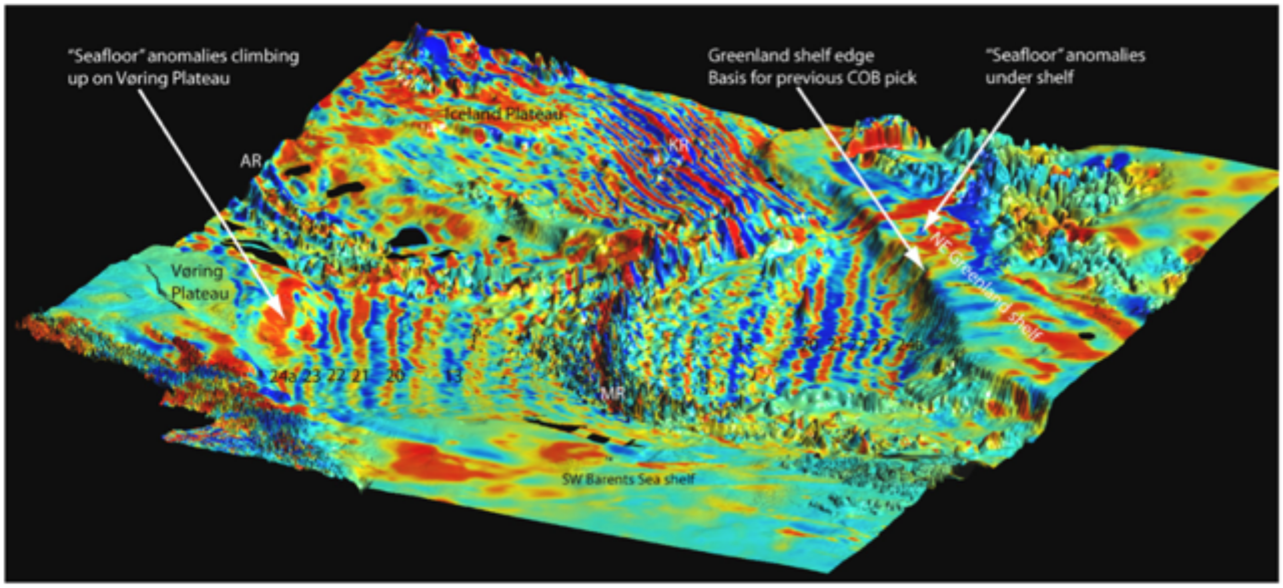


Figure 35: Perspective view from the north of the aeromagnetic dataset draped on bathymetry/ topography. Note that the oldest magnetic anomalies along the Mohns Ridges on the Norwegian side climb up on the slope of the Vøring Plateau. AR: Aeir Ridge; MR: Mohns Ridge; KR: Kolbeisney Ridge. Numbers refer to magnetic chrons. Source: Olesen et al., 2007, p. 58.

spreading crust, whereas the landward side of the plateau showed evidence for continental crust overprinted by flood basalts and underplated by magmatic intrusions. The authors also found a COT zone of 30-50 km on the plateau. On the landward side of the COT, a zone of extended continental crust adjacent to the Vøring Escarpment and Vøring Basin is present (Mjelde et al., 1997; 2001). This seismic structure analysis complements Olesen et al.'s (2007) magnetic anomaly study of the Vøring Plateau.

Adding to the repository of Vøring data, is ODP Site 642E on the plateau. The plateau's conjugate margin, East Greenland, also includes ODP sites, Sites 988-990 (from ODP Leg 163). Southern Greenland was drilled during ODP Leg 152, providing additional ODP sites (Sites 914-919) that give contextual information about the tectonic setting of the region. Site 642E's lowest layer shows evidence for interaction between the mantle and crustal material and/or crustal melt underplating (Meyer et al., 2009).

Meyer et al. (2009) pointed out that mantle-crustal interactions within volcanic rifted margins usually includes mantle traversing through continental lithosphere. ODP Legs 152 and 163 sampled magmas that erupted right before the final opening of the northeast Atlantic Ocean. These samples contain evidence for mantle-continental crust interaction (Meyer et al., 2009). The authors stated that complex types and magnitudes of crustal-mantle interactions occurred during this breakup, however, it is certain that the mantle material traveled through continental crust (Meyer et al., 2009). Comparing the Greenland ODP sites to Site 642E on the Vøring Plateau, shows that the cores' upper crustal samples are isotopically similar, however, their lower crustal samples are completely different. Meyer et al. (2009) stated that this difference between the conjugate margins could be attributed to either a difference in pre-breakup crustal composition or to a different type of mantle-continental crust interaction between the two margins.

The major takeaway from these reports is that the Vøring margin and its conjugate on East Greenland show evidence for continental crust influenced and altered by magmatic formation. The Vøring Plateau, in particular, experienced crustal thinning and extension followed by magmatic intrusions and extrusions during Eocene breakup (Wangen and Faleide, 2008; Meyer et al., 2009). Together, the magnetic anomaly data, seismic velocity structure, and geological samples provide a robust spectrum of evidence in support of the conclusion that the Vøring Plateau has a continental crust composition and origin.

CLCS Recommendations' Consideration and Classification of Submarine Highs:

Like the CLCS' approach with the Kerguelen Plateau, the CLCS appeared to examine Norway's submission for the Vøring Plateau to see if it established two criteria: 1) a morphological connection to the continental margin, discerned through bathymetry; and 2), geological continuity with the continental margin, proven through an array of geological and geophysical data.

Norway seems to have presented a successful argument to fulfill the first criterion (morphological continuity). The CLCS stated that the Vøring Plateau (and Vøring Spur) ‘dominate’ the Northeast Atlantic Norwegian continental margin (CLCS/62, 2009, p.22). The Vøring Plateau is later described as a “large, 1,300-1,500 m deep feature within the margin” (CLCS/62, 2009, p.22).

After the CLCS confirmed that the morphological continuity was satisfied, the second criterion, “geological continuity” was addressed. Norway presented arguments, and the CLCS agreed, that the Vøring Plateau is “underlain by extended continental crust that merges with anomalously thick, breakup-related magmatic crust beneath its outer part” (CLCS/62, 2009, p. 26). This interpretation is substantiated by later geological studies (see Appendix VI for further detail).

The Norwegian Government presented a successful morphological and geological argument that convinced the CLCS that the Vøring Plateau was a submarine *elevation* that is a *natural component* of the continental margin. The CLCS’ agreement to classify the Vøring Plateau as a submarine *elevation* is an example of a submarine *elevation* that has ‘transitional crust,’ in the sense that part of the feature is composed of continental crust and other part is composed of oceanic crust, as discussed in Figure 8 in this thesis’ introduction.

Vøring Spur

Province Overview:

The Vøring Spur is a roughly triangular bathymetric high that is located to the northeast of the Vøring Plateau (Fig. 36). The feature shows a rugged topography and is connected to the Vøring Plateau by a saddle that ranges from 600 to 900 m above abyssal depth. The spur is roughly 200 km long (northeast to southwest direction) and 200 km wide in the south, narrowing to a width of 150 km in the north. The Vøring Spur has a shallowest depth of approximately 1400 m. Its morphology is complex and it rises above abyssal depth between 500-2300 m, depending on location.

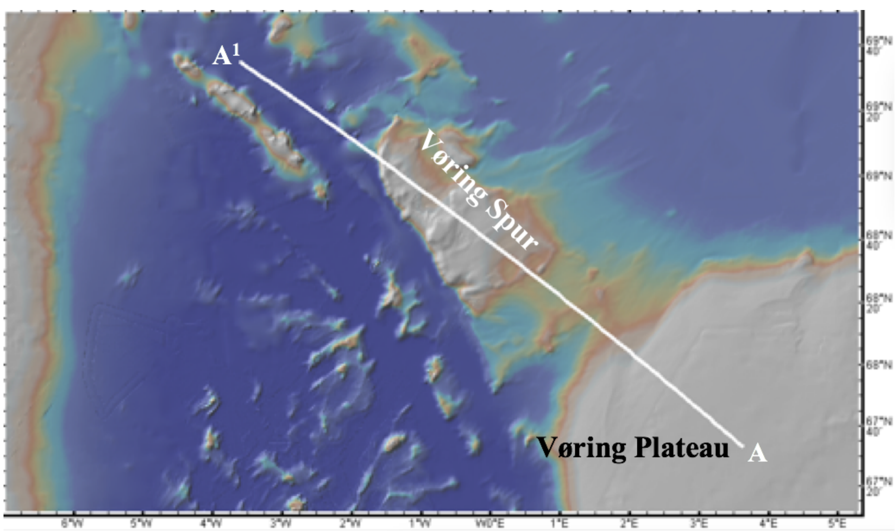
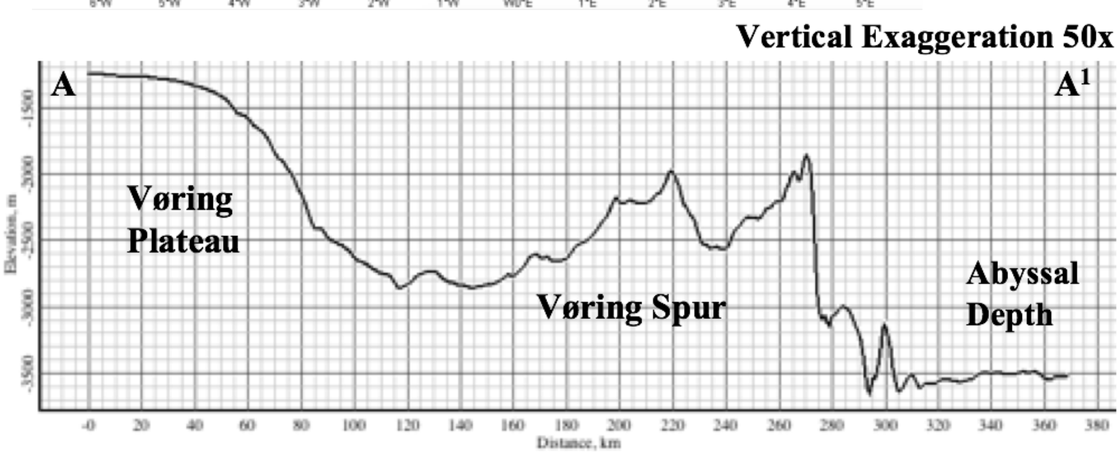


Figure 36: Vøring Spur Overview and Profile. EJMFZ: East Jan Mayen Fracture Zone. Source: GeoMapApp 3.6.0, GMRT 3.1 Grid



The spur is located to the north of the East Jan Mayen Fracture Zone (EJMFZ) and along the trend of the Aegir Ridge (Breivik et al., 2008). The spur's border with the EJMFZ is a steep scarp and contrasts with the rest of the spur's morphology, which gradually merges with the seafloor (Breivik et al., 2008).

Initially, the Vøring Spur was thought to be either a continental fragment or a remnant of breakup magmatism (Christensen and Mooney, 1995; Breivik et al., 2014). Further analysis of the spur found that both of these hypotheses were incorrect. Breivik et al. (2008) produced a velocity model that crossed from the Vøring Plateau to the Vøring Spur. The profile showed the difference in basement structure between the two provinces (Fig. 37 and 38). The authors concluded from their seismic analysis of both wide-angle and conventional reflection data that the Vøring Spur was created by secondary magmatic growth of oceanic crust during the Late Miocene. This secondary magmatism underplated older oceanic crust and uplifted the spur to its

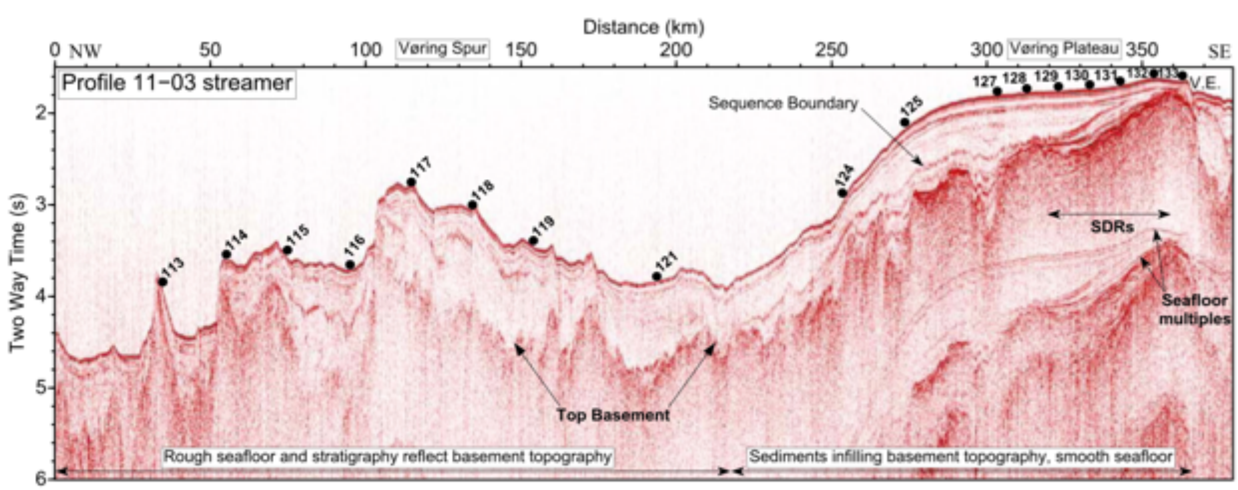


Figure 37: Single-channel streamer reflection seismic data of Profile 11-03. OBS/H locations are shown with filled black circles, with the instrument number above. SDRs: Seaward Dipping Reflectors; VE: Vøring Escarpment; Source: Breivik et al., 2014, p.6736

present position (Breivik et al., 2008). Breivik et al. (2008) also found that the velocity structure of the spur is similar to the Vøring Plateau's outer crust, seaward of the COT zone (Fig. 38).

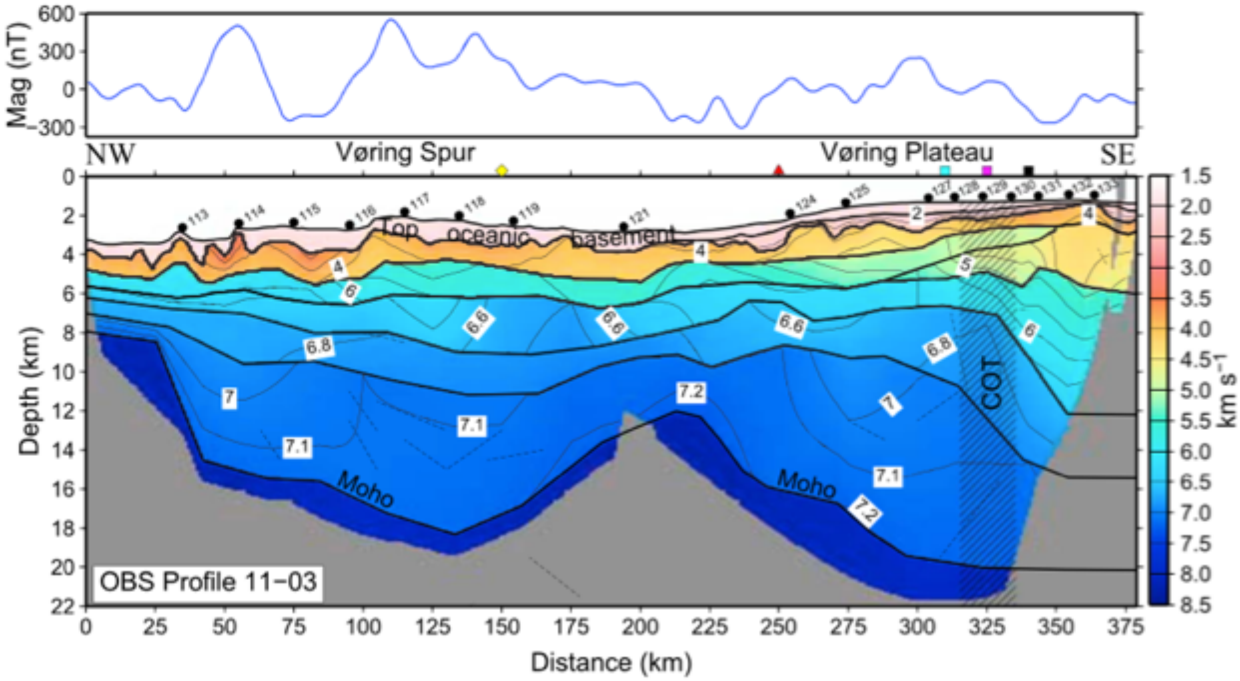


Figure 38: Gridded crustal velocity model of Profile 11-03. The parts of the model not covered by rays are masked; floating reflectors (dashed lines) do not constraint velocity and are not included in the ray coverage. The OBS/H locations are numbered on the seafloor. Hachures indicate the continent-ocean transition (COT). Velocity contour interval is 0.2 km/s, except for the lowermost crustal layer where it is 0.1 km/s. Positions of 1-D velocity profiles shown as color symbols. The magnetic track collected along profile is shown above. Source: Breivik et al., 2014, p.6742

The spur's magnetic pattern is chaotic and does not align with the regular seafloor spreading anomalies distinguishable to the north (Fig. 39) (Breivik et al., 2008). Breivik et al. (2008) also found that the positive magnetic anomalies on the spur are associated with the uplifted zones of the spur. Based upon this information, Breivik et al. (2008) concluded that on the southern side of the spur uplift activated the EJMFZ, and on the northern side uplift occurred by reactivating normal faults that border older half grabens.

It is likely that Breivik et al.'s (2008) arguments regarding the origin of the Vøring Spur are the same or similar to those within the Norwegian submission to the CLCS in 2008 to

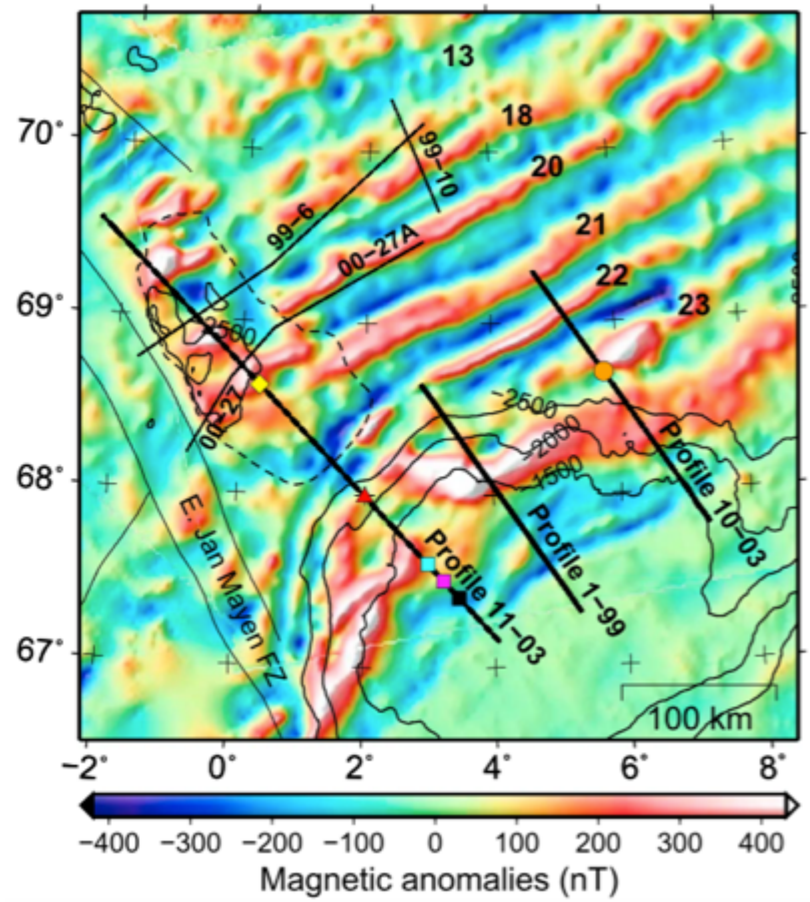


Figure 39: Magnetic map over the Voring Spur area with OBS survey navigation, illuminated from the NW. The central part of the map is covered by the newer surveys RAS-03 and JAS-05 (Olesen et al., 2007; Gernigon et al., 2009), and marginal parts by the compilation of Verhoef et al. (1996). Some bathymetric contours and the extent of thick oceanic crust (dashed line) under the Vøring Spur (Breivik et al., 2008) are shown, and seafloor spreading anomalies are annotated. (Approximate ages: A23: 51.4 Ma, Ass: 49.4 Ma, A21: 47.1 Ma, A20: 43.2 Ma, A18: 39.3 Ma, and A13: 33.3Ma (Cande and Kent, 1995) The positions of the MCS lines are shown by thin black lines. Positions of 1-D velocity profiles are indicated by color symbols.
Source: Breivik et al., 2014, p. 6746

supplement their 2006 submission (NOR-PRE-007-31-01-2008). Note that no geologic samples were recovered from the Vøring Spur as of Norway's supplementary submission (2008).

CLCS Recommendations' Consideration and Classification of Submarine Highs:

The CLCS acknowledged in the recommendations that Norway presented a sufficient argument that the Vøring Spur met the morphological criterion with respect to seafloor high classifications. Specifically, the CLCS stated that it "recognizes that by way of the FOS envelope and morphology, the Vøring Spur is part of the submerged prolongation of the landmass of Mainland Norway" (CLCS/62, 2009, p.26). In the recommendations, the CLCS provided a detailed description of the Vøring Spur's morphology and connection to the Vøring Plateau, in particular its contribution to the FOS envelope of the continental margin:

> The Vøring Spur is a bathymetric high that extends to the northwest from the Vøring Plateau… along the rugged northern margin of the Vøring Spur the gradients are relatively low, but the base of the continental slope is generally readily identifiable on a morphological basis with respect to the smooth, flat seafloor of the Lofoten Basin. (CLCS/62, 2009, p.26).

With respect to the second criterion, the CLCS said that the evidence provided for the spur's geological origin and composition indicates that the feature "remains poorly understood" (CLCS/62, 2009, p.26). The CLCS acknowledged that the information Norway presented in its submission, combined with supplementary information submitted in 2008 (NOR-PRE-007-31-01-2008), "indicate that the Vøring Spur is underlain by thick magmatic crust and has a different evolution and geologic character to the adjacent Vøring Plateau" (CLCS/62, 2009, p.26).

Given this information, the CLCS stated that based upon the evidence, the spur could not be classified as a submarine *elevation*. Instead, it is a submarine *ridge*. The CLCS' statement regarding the Vøring Spur's geologic composition and distinctly different geologic origin from the Vøring Plateau is critical to analyzing the criteria the CLCS emphasized as well as its logic in classifying seafloor highs within Norway's submission.

Takeaways from the CLCS' Analysis of the Vøring margin's provinces:

The Norwegian CLCS recommendations agreed with the chosen FOS points around the Vøring Spur. In particular, to the south and west, the CLCS stated that Norway presented a convincing argument that the morphology of both the plateau and spur are controlled by the EJMFZ. The features exhibit steep morphology adjacent to the EJMFZ and the CLCS stated that "the base of the continental slope can be readily identified on a morphological basis by the change to the flat, smooth deep ocean floor of the Norway Basin" (CLCS/62, 2009, p.22). A similar morphological comparison was conducted to the north and the CLCS stated that the

Vøring Spur's base of the slope was distinct from the "smooth, flat seafloor of the Lofoten Basin" (CLCS/62, 2009, p.22).

This relative comparison is an important discussion point because it seems the Norwegian Government presented a two-fold morphological argument to the CLCS. Firstly, it seems Norway presented to the CLCS that the Vøring Plateau and Spur were morphologically connected to Norway's mainland and showed that the FOS envelope around these features was a continuation of the FOS envelope along Norway's continental margin. Secondly, it seems Norway showed the CLCS how these features contrasted with the adjacent deep ocean floor. This second comparison is apparent by the CLCS' statement in the recommendations that the Vøring Spur's base of the slope can be identified on a morphological basis and contrasts with the adjacent Norway and Lofoten basins.

The most important takeaway from the CLCS review of the Vøring Spur, in conjunction with the Vøring Plateau, is the relative comparison of not only their geologic composition but also their geologic origin. The Vøring Spur, as the CLCS noted in its review, "has a different evolution and geologic character to the adjacent Vøring Plateau (CLCS/62, 2009, p.26). As Breivik et al. (2008) confirmed, this different geologic evolution is late Miocene secondary magmatic growth of oceanic crust which underplated older oceanic crust and uplifted the spur to its present position. In contrast, the Vøring Plateau is a continental fragment that is a remnant from Eocene continental breakup with East Greenland. The plateau has been affected by both seafloor spreading magmatism as well as magmatic intrusions. The key point here is that the Vøring Plateau shares a tectonic origin with the Norwegian mainland, whereas the Vøring Spur does not. Therefore, the Vøring Plateau was deemed by the CLCS to be a submarine *elevation* that is a *natural component* of the continental margin, whereas the Vøring Spur was determined to be a submarine *ridge*.

Implications for the Chukchi Borderland and its Northern Extension:

The 2009 CLCS recommendations for the Vøring Plateau and Vøring Spur, accompanied by the scientific literature, offer valuable information that may forecast a potential United States ECS delineation in the Chukchi Borderland region. Like the Kerguelen Plateau analog, the Chukchi Borderland is not analogous in terms of geologic composition and tectonic history to the Vøring margin, however, despite this difference key parallels with respect to Article 76 exist.

The Vøring Plateau is an example that may be analogous to the northern extension of the Chukchi Borderland. Firstly, both features are morphologically connected to the continental margin and have relief that is at least 1,000 m above abyssal depth. Thus, the northern extension of the Chukchi Borderland would most likely satisfy the morphological criterion. The second criterion, "geological continuity," is a more interesting comparison. The Vøring Plateau's geological composition is multifaceted, including continental, transitional, and oceanic crust. The feature's stretched continental crust is also underplated by magmatic intrusions and overlain by flood basalts. The northern extension of the Chukchi Borderland is similar in the sense that the feature is treated as highly stretched continental crust that has been overlain by a LIP signature in most Amerasia Basin tectonic models (Scotese, 2011; Brumley, 2014; Kazmin et al., 2015). Within this context, both the Vøring Plateau and northern extension seem analogous to the submarine *elevation* example the CLCS described in S&TG 7.3.1b. If this hypothesis can be verified by further geological data samples, then the northern extension of the Chukchi Borderland's seafloor high classification may follow the same logic as that of the Vøring

Plateau. This would mean the northern extension of the Chukchi Borderland would be considered a submarine *elevation* that is a *natural component* of the continental margin.

Similarly, the Vøring Spur may also serve as a analog to the northern extension of the Chukchi Borderland. The Vøring Spur, as proven by Breivik et al.'s (2008) analysis, is a product of late Miocene second generation magmatism that is unrelated to the original seafloor spreading magmatism in the North Atlantic. The CLCS seemed to focus specifically on two pieces of geological evidence in its review of the Vøring Spur. Firstly, the Vøring Spur is composed of oceanic crust and secondly, its tectonic origin and evolution is distinctly different from the Vøring Plateau and mainland Norway's origin. At least one author hypothesizes that the northern extension of the Chukchi Borderland is composed of oceanic crust and was built by the Arctic LIP event(s) in the Cretaceous during Amerasia Basin formation (e.g., Grantz et al., 2011). However, given recently acquired MCS data that crosses the Chukchi Borderland, the northern extension of the Chukchi Borderland, Alpha Ridge, and Makarov Basin (Fig. 24; Mosher et al., 2016), this hypothesis may be discounted. The same conclusion that arose from the northern extension of the Chukchi Borderland's comparison to the Vøring Plateau is applicable here. Further geological data needs to be collected to definitively prove that the northern extension of the Chukchi Borderland is composed of oceanic or continental material. If the former, the CLCS would likely classify it as a submarine ridge, similar to its conclusion for the Vøring Spur. If the northern extension, however, can be proven to be composed of continental crust overprinted by a LIP, the CLCS may follow the classification logic applied to the Vøring Plateau.

IV. Conclusions:

> *[U.S.] support for the proposal on the continental shelf contained in the report of the Chairman of the Second Committee rested on the understanding that it was recognized—and to the best of his knowledge, there was no contrary interpretation—that features such as the Chukchi plateau situated to the north of Alaska and its component elevations could not be considered a ridge and were covered by the last sentence of the proposed paragraph 5 bis of article 76*
> U.S. Representative to UNCLOS III Negotiations, 128th meeting, paragraph 156, at 43, April 3, 1980; Nordquist et al., 1993, p. 870

Article 76 of UNCLOS provides a mechanism by which a coastal State can extend sovereign rights over resources of the seafloor and subsurface outside of its 200 nautical mile exclusive economic zone. Certain geological and geophysical criteria must be met in order for a coastal State to delineate this region often referred to as the Extended Continental Shelf (ECS). The establishment of an ECS involves the collection and analysis of bathymetric, geophysical and geological data to apply the criteria defined within Article 76, one of which is the classification of seafloor highs that are *natural prolongations* of a coastal State's landmass as either submarine *elevations* or submarine *ridges.* The coastal State must present its ECS delineation to the Commission on the Limits of the Continental Shelf (CLCS). The CLCS reviews coastal States' submissions and produces recommendations concerning the proposed ECS boundary and its accordance with Article 76 of UNCLOS. Summaries of these recommendations are published with the permission of the coastal State.

The United States has a potential ECS in many regions, one of which is the Chukchi Borderland area north of Alaska. This thesis examined two coastal States' CLCS recommendations, specifically assessing criteria that the CLCS used to classify seafloor highs and, to forecast the impact these recommendations (and criteria) may have on a potential submission of the United States for the Chukchi Borderland. This analysis is important for three reasons: 1) It provides insight into the type of evidence and amount of data the coastal States offered to substantiate their seafloor high classification. 2) It gives perspective on how the CLCS interpreted concepts of Article 76, such as *natural prolongation* and *natural component* in real-world settings. 3) It reveals that the CLCS used consistent criteria to classify seafloor highs in different submissions, which means these same criteria may be applicable to the Chukchi Borderland region.

The region north of Alaska includes two seafloor highs, namely the Chukchi Borderland and the northern extension of the Chukchi Borderland (Fig. 40). The Chukchi Borderland is a seafloor high that is connected to the Alaskan-Siberian continental margin and protrudes into the Amerasia Basin of the Arctic Ocean. Multibeam bathymetry data show that the Borderland rises up to 3,400 m above the adjacent flat abyssal plains of the Canada Basin (Mayer and Armstrong, 2012). It was hypothesized as early as the 1960's that the Chukchi Borderland was a continental fragment (e.g., Dietz and Shumway, 1961) and this conclusion has been proven through numerous geological and geophysical studies since (Taylor et al., 1981; Hall, 1990; Grantz et al., 1998; McAdoo et al., 1999; Grantz et al., 2004; Hopper et al., 2005; Arrigoni et al., 2007; Alvey et al., 2008; Saltus et al., 2011; Houseknecht and Bird, 2011; Glebovsky et al., 2013; Hegewood and Jokat, 2013; Brumley, 2014; Chian et al., 2016; Ilhan and Coakley, 2015).

The northern extension of the Chukchi Borderland is a complex bathymetric feature that is morphologically connected to the Chukchi Borderland to the south and steps down to the Nautilus Basin to the north (Fig. 40). It was called the 'Mendeleev Abyssal Plain' (e.g., Jakobsson et al., 2003) until recently and thought to be of oceanic origin (e.g., Hegewood and Jokat, 2013) before new bathymetric and seismic data were collected which revealed a continental-type crustal structure (Fig. 41) (Chian et al., 2010; Mayer and Armstrong, 2012). New multibeam bathymetry data show parts of the northern extension are more than 1,000 m above abyssal depth and evidence for landslides and submarine channels, indicative of turbidite flow, are present in this region (Mayer and Armstrong, 2012; Flinders et al., 2014).

Most authors treat the northern extension as a morphological and geological continuation of the Chukchi Borderland, the only difference is that the northern extension has experienced volcanic emplacement from a Large Igneous Province (LIP) (e.g., Chian et al., 2010; Hutchinson et al., 2012; Scotese, 2011; Brumley, 2014; Kazmin et al., 2015; Coakley et al., in press). A LIP is a geologic event during which large volumes of mafic extrusive and intrusive rock are emplaced onto Earth's crust by a mechanism that cannot be attributed to normal seafloor spreading (Bryan and Ernst, 2008). Grantz et al. (2011), however, disagrees with the above hypothesis and argues that the northern extension is composed of oceanic crust that derived from (or is associated with) the Arctic LIP event(s).

Numerous tectonic models exist for the Amerasia Basin because the emplacement of LIP volcanics have made it difficult to image the underlying crust. Another factor is the unusual position of the Chukchi Borderland within the basin because it has no obvious conjugate margin. Due to these uncertainties, varying Amerasia Basin tectonic reconstructions have been presented (e.g., Grantz et al., 2011; Scotese, 2011; Brumley, 2014; Kazmin et al., 2015; Oakey and Saltus, 2015). Since the scientific community is in universal agreement that the Chukchi Borderland is a continental fragment, all tectonic reconstructions treat it as such in the models.

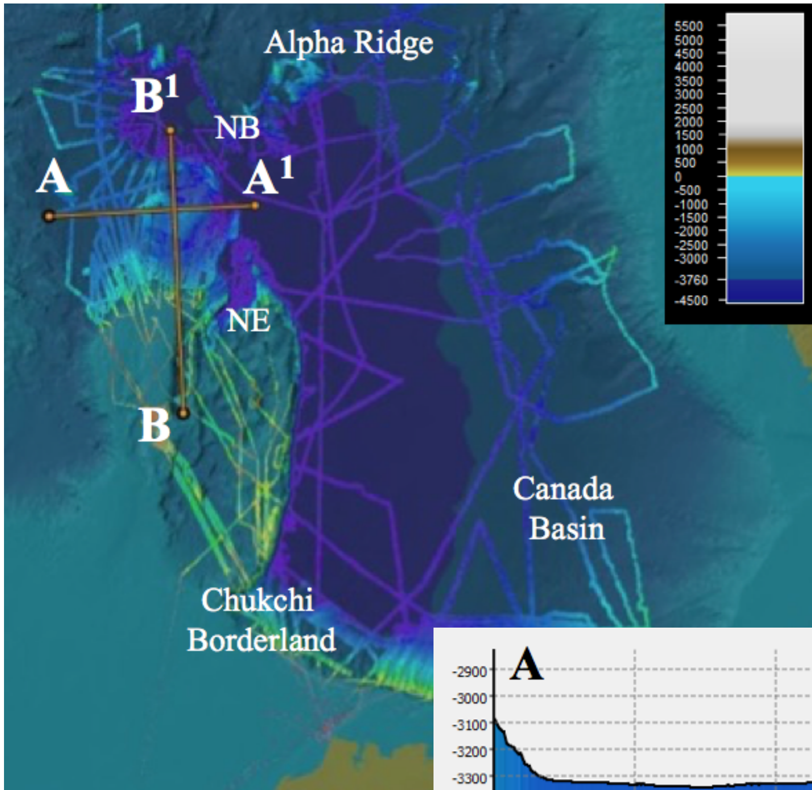
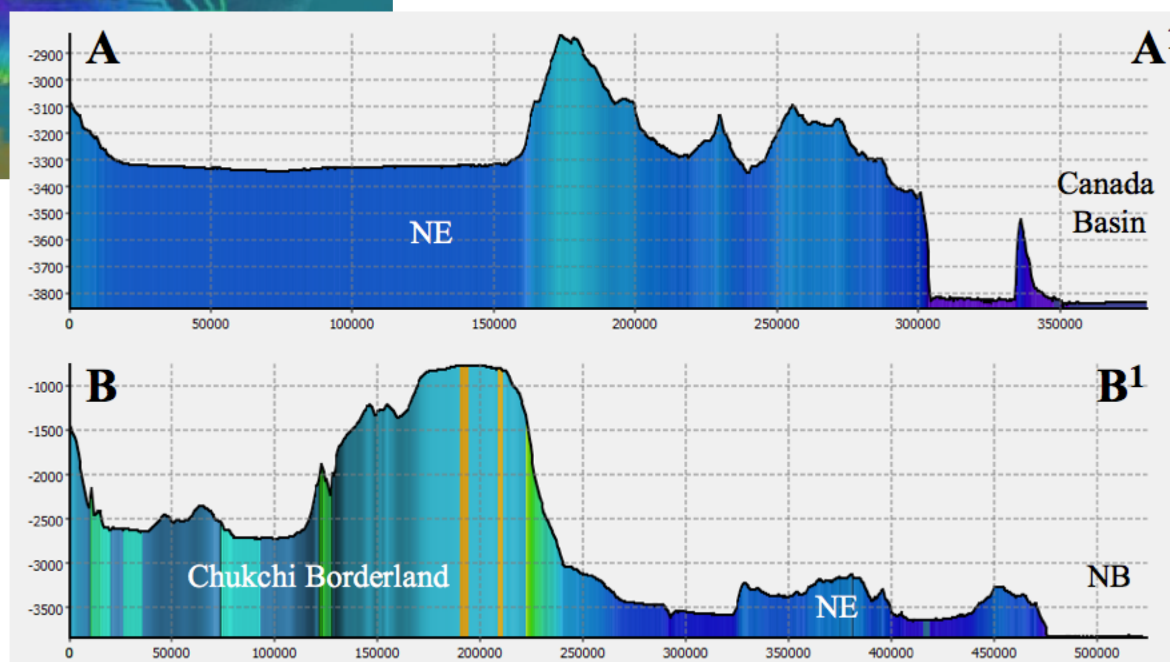
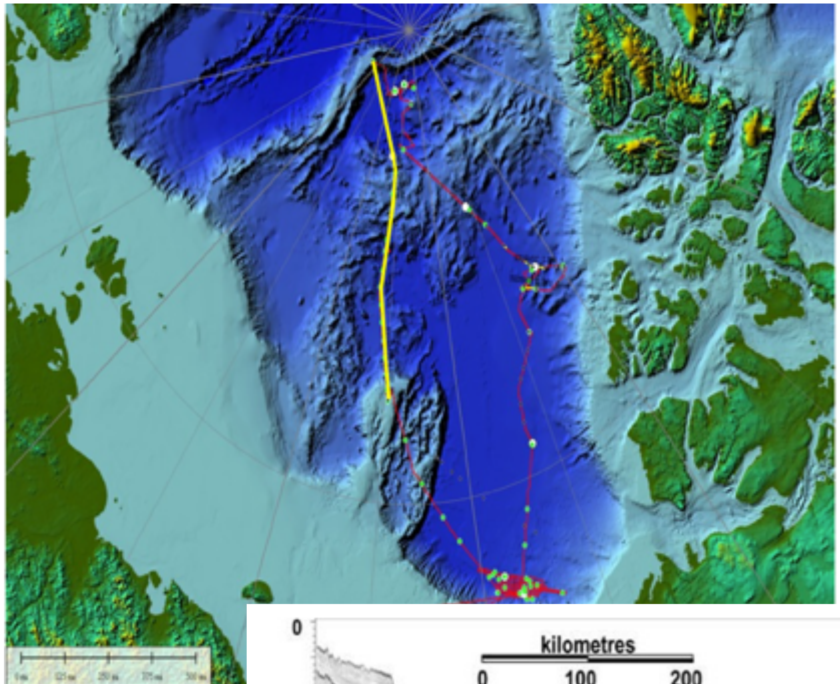


Figure 40: Chukchi Borderland and the northern extension of the Chukchi Borderland (NE) with overlying U.S. ECS multibeam bathymetry data; orange lines indicate location of profiles. NB: Nautilus Basin. Vertical Exaggeration: 6x (Basemap: IBCAO v3.0 (Jakobsson et al., 2012)





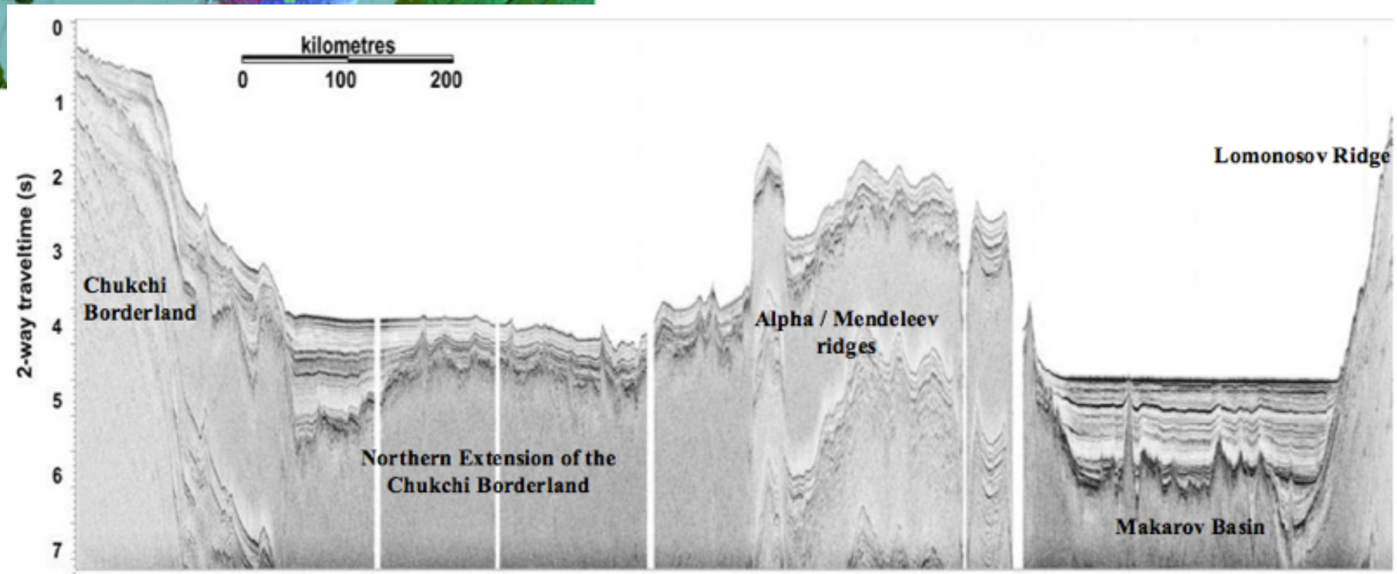


Figure 41: A: Yellow line is location of the seismic reflection shown as a profile below. **B:** Figure shows the transect itself across the Chukchi Borderland, to the northern extension of the Chukchi Borderland and Alpha / Mendeleev ridges and across the Makarov Basin to the Lomonosov Ridge.
Source: Mosher et al., 2016.

As of May 2016, the CLCS has published 23 recommendation summaries for coastal States' outer limits of their ECS. The two chosen for this thesis were the submission of Australia for the Kerguelen Plateau in the Southern Ocean and the submission of Norway for the Vøring margin in the north Atlantic Ocean. These regions are morphologically similar to the Chukchi Borderland region. Although these regions and the Chukchi Borderland are not neccesarily analogous in terms of geologic composition and tectonic history, key parallels with respect to Article 76 exist. For context, Australia made its submission to the CLCS in 2004 and the CLCS made recommendations in 2008, whereas Norway made its submission in 2006 and the CLCS made its recommendations in 2009.

The Kerguelen Plateau (Fig. 42) is similar morphologically to the Chukchi Borderland region. Its complex geologic signature and uncertain tectonic past parallels the Borderland's complicated tectonic history, making a comparative analysis of the two regions appropriate within the context of Article 76. Geoscience Australia (AGSO) collected data to determine Australia's outer limits of the continental shelf for its submission to the CLCS. AGSO published its findings from these data collection efforts in public reports. Borissova et al. (2002) provided a report for the Kerguelen Plateau, and present the plateau's stratigraphy, structure, and tectonic history. The plateau is divided into four distinct seafloor high provinces: Central Kerguelen Plateau (CKP), Southern Kerguelen Plateau (SKP), Elan Bank, and Williams Ridge.

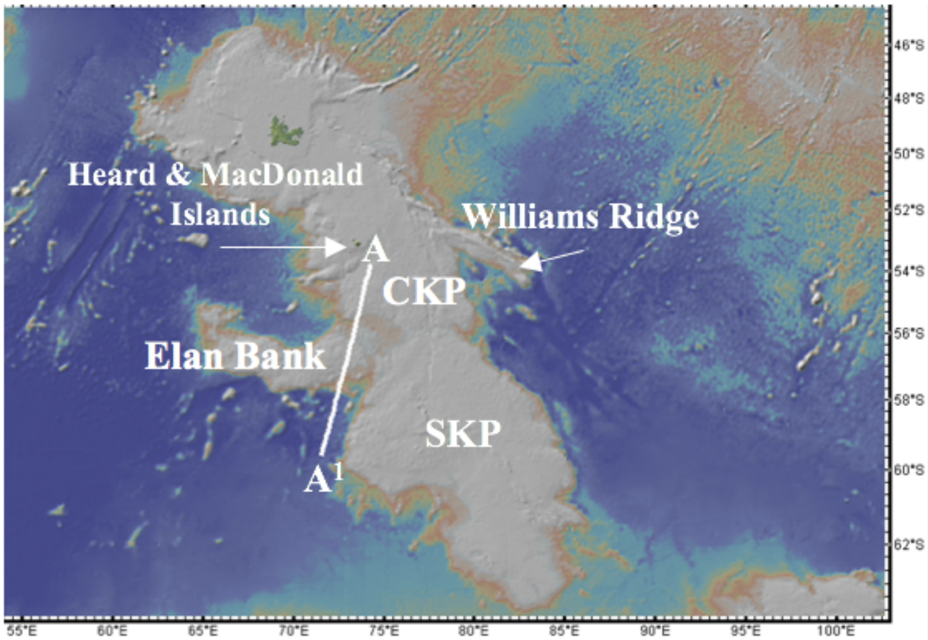
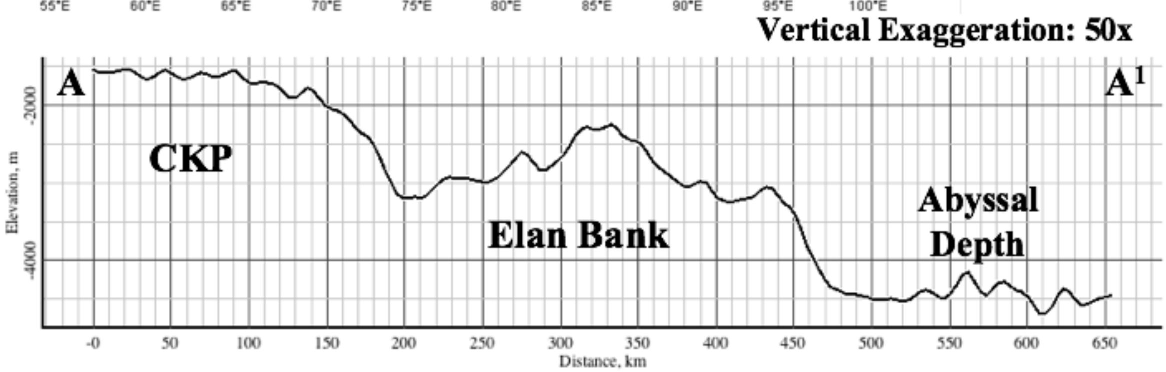


Figure 42: Kerguelen Plateau, located in the Southern Ocean. CKP is the Central Kerguelen Plateau and is the central feature that allowed Australia to justify its natural prolongation and prove certain features were natural components, including the Elan Bank and the Southern Kerguelen Plateau (SKP). Williams Ridge was not classified as anything. The white line is the location of the profile Source: GeoMappApp 3.6.0, GMRT 3.1 Grid.



The Vøring margin off the coast of Norway has two bathymetrically elevated features (Vøring Plateau and Spur) that are also similar morphologically to the Chukchi Borderland and its northern extension (Fig. 43). Unlike Australia, Norway did not publish scientific reports for the Vøring Plateau and Spur and therefore this thesis' analysis of the region is based upon the literature available prior to 2009.

From the assessment of these two CLCS recommendations, it appears that the CLCS utilized specific criteria when reviewing seafloor highs and classifying them according to paragraph 6 of Article 76. The first criterion is morphological continuity with the landmass and the second criterion is geological continuity with the continental margin. Fulfillment of the first

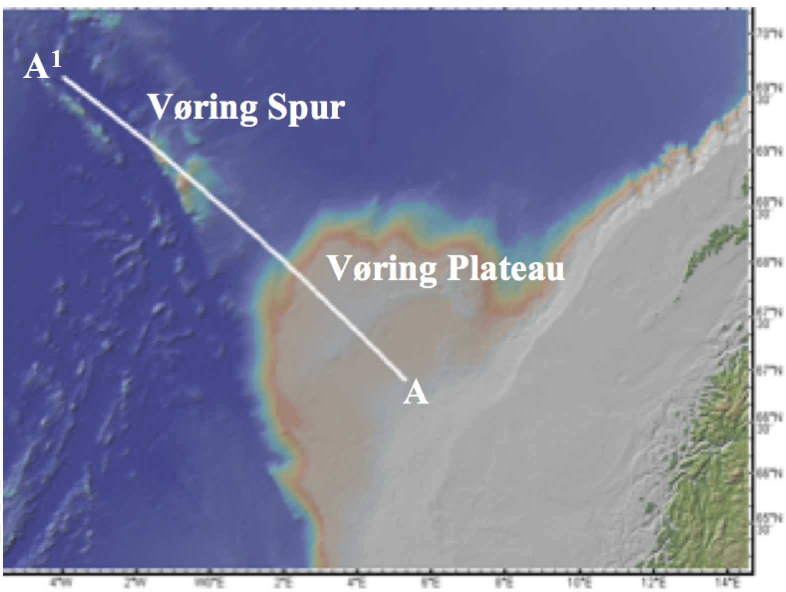
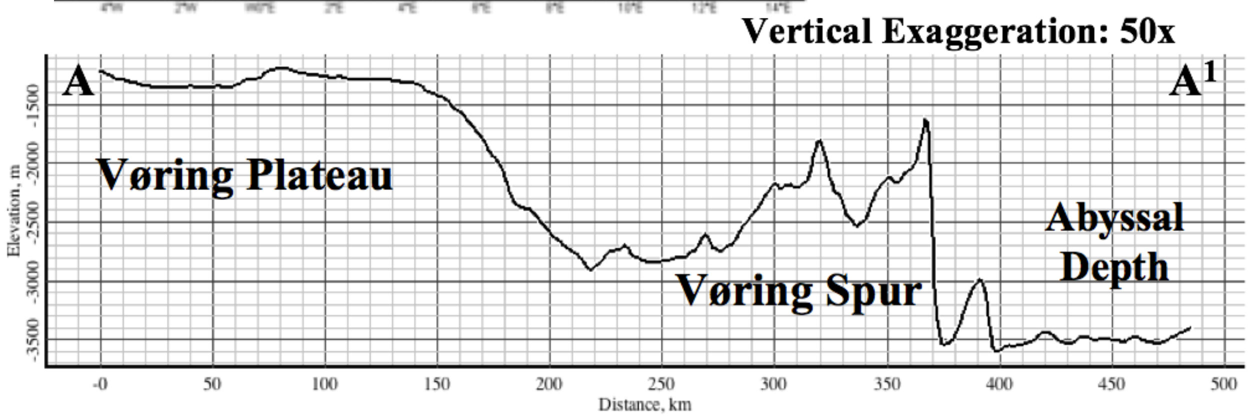


Figure 43: Vøring Plateau and Spur, located off the coast of Norway. The Vøring Plateau's morphological connection to Norway's continental margin allowed for its argument to classify the plateau as a submarine elevation. Norway argued that the Vøring Spur was a submarine elevation that is a natural component of the margin, however, the CLCS determined that it was a submarine ridge according to Article 76, paragraph 6. The white line is the location of the profile. Source; GeoMappApp 3.6.0, GMRT 3.1 Grid.



criterion seems to be equated to proving the seafloor high is a *natural prolongation* of the landmass (Article 76, paragraph 1). If the first criterion is satisfied, the second criterion is considered. Fulfillment of the second criterion, geological continuity, seems to prove the seafloor high is also a *natural component* of the continental margin and thus a submarine *elevation* (Article 76, paragraph 6). Failure to meet this second criterion signals that the feature is not a *natural component* of the margin, and thus is considered a submarine *ridge*.

With respect to the primary criterion of morphological continuity, the CLCS assessed the seafloor high's morphological attachment to the continental margin and thus the coastal State's landmass, no matter if the landmass was an island or continent. If the seafloor high was morphologically continuous with the continental margin and thus contributed to its Foot of Slope (FOS) envelope, then the feature fulfilled this primary criterion. For the seafloor highs examined in this thesis (CKP, SKP, Elan Bank, Williams Ridge Vøring Plateau, and Vøring Spur), all of them satisfied this criterion. Fulfillment of this morphological continuity criterion meant that each of these seafloor highs were *natural prolongations* of the landmass (Article 76, paragraph 1).

If the coastal State convinced the CLCS its seafloor high(s) fulfilled this first criterion, the CLCS then turned to the coastal State's arguments for the seafloor high's geological continuity.

Borissova et al. (2002), and references therein, report that the Kerguelen Plateau formed at the triple junction of the Australian, Antarctic, and Indian plates. During separation of these plates, a continental fragment(s) (or remnant crust) was left behind and was overprinted by a LIP, forming the Kerguelen Plateau. This tectonic history is a general overview and, as of 2004 when Australia made its submission, the individual provinces' tectonic histories were not well understood. Despite this, the CLCS felt that Australia presented a convincing argument to classify three of the four provinces (CKP, SKP, Elan Bank) as submarine *elevations.* These provinces showed "chemical evidence of contamination by the continental crust" and were the same magmatic rocks present beneath Heard Island (CLCS/58, p.28). For the Kerguelen Plateau case study, it appears that "crustal type continuity" was the dominant factor that dictated these provinces' seafloor high classifications. In the view of the CLCS, Australia did not have sufficient geologic data to support the argument that Williams Ridge was geologically continuous with the continental margin and landmass. Therefore, due to insufficient data the CLCS refrained from classifying Williams Ridge.

The Norwegian case study complements the Australian example with respect to “crustal type continuity”, however, adds a complexity to the geological continuity analysis in terms of evaluating seafloor highs based upon tectonic origin. With respect the Vøring Plateau and Spur, it appears that Norway successfully demonstrated to the CLCS that the Vøring Plateau is composed of continental crust underplated and overprinted by magmatism. Norway also presented information that convinced the CLCS that the Vøring Plateau is a product of continental breakup between Norway and East Greenland. Thus, the plateau shares a common tectonic history with the Norwegian landmass. From this information, the CLCS felt that the Vøring Plateau fulfilled both the “crustal type continuity” and “tectonic origin continuity” requirements of the geological continuity argument.

The Vøring Spur provides a more interesting case study. In 2008, Norway submitted additional information during the subcommission’s review of its submission because the CLCS felt that the feature was “poorly understood” (CLCS/62, p.27). These data were focused on the tectonic origin of the Vøring Spur and most likely was the data reported in Breivik et al.’s (2008) publication that concluded that the Vøring Spur was a product of secondary magmatism. This meant that the spur’s tectonic origin was distinctly separate from mainland Norway’s tectonic origin. The CLCS concluded from Norway’s 2008 supplementary information that the Vøring Spur “has a different evolution and geological character to the adjacent Vøring Plateau” (CLCS/62, p.27). Therefore, the spur could not be classified as a submarine *elevation* that is a *natural component* of the margin, but rather a submarine *ridge*. In this situation, it appears that the driving factor that prevented the Vøring Spur from being considered a *natural component* of the margin was its distinctly different composition and tectonic origin from the continental margin.

Figure 44 summarizes the general thought process for seafloor high classification presented in this thesis' introduction coupled with the real-world examples reviewed in the CLCS' recommendations for Australia and Norway.

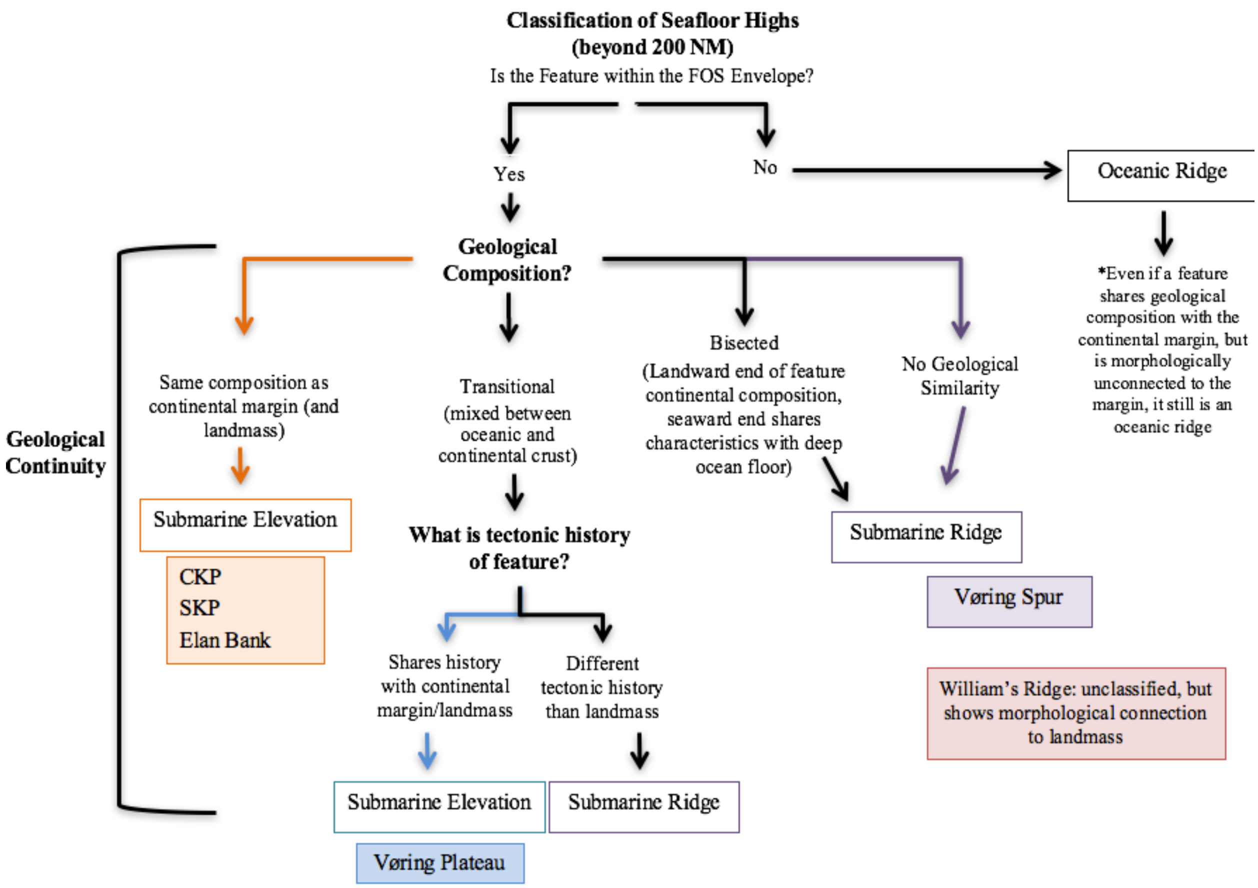


Figure 44: Summary of seafloor high classification given Article 76, paragraph and real-world examples reviewed in this thesis.

One of the key points of conclusion from these analyses is that proving a seafloor high is *only* a *natural prolongation* of the landmass is insufficient to classify it as a submarine *elevation* or *ridge* according to the CLCS' interpretation of Article 76. The Vøring Spur presents a clear case where a morphological attachment to the 'landmass' exists and contributes to Norway's FOS envelope. The CLCS, however, would not classify the spur until Norway provided evidence that showed its composition and origin, which the Commission felt proved that it is distinctly different from the Vøring Plateau and continental margin of Norway. The Williams Ridge case study also supports this conclusion. The CLCS refrained from classifying Williams Ridge as any type of seafloor high due to insufficient geological data, even though the morphological connection to the CKP is apparent. It seems the CLCS wanted Australia to present clear evidence of Williams Ridge's composition and origin as Norway did for Vøring Spur. This means that the CLCS must be convinced that the seafloor high under question is *not* a *natural component* of the margin for it to classify a feature as a submarine *ridge*. If the CLCS has any doubts about the coastal State's geological arguments for composition and/or tectonic origin, or feels there is insufficient evidence, it will refrain from classifying the seafloor high under question.

Given these real world examples of Article 76 seafloor highs, it is appropriate to compare the criteria the CLCS utilized to assess these features to the Chukchi Borderland and its northern extension.

The primary criterion for seafloor high classification is proving morphological continuity with the landmass. The Chukchi Borderland fulfills this criterion as it rises up to 3400 m above abyssal depth. The northern extension is a morphological continuation of the Chukchi Borderland that rises up to 1000 m above abyssal depth and appears to be one morphological entity. Therefore, both features may be a *natural prolongation* of the landmass and fulfill this primary criterion the CLCS utilizes for seafloor high classification.

The second step is to apply the "geological continuity" criterion to the Chukchi Borderland and its northern extension. With respect to the Chukchi Borderland, geological and geophysical data point to a continental crustal composition (see above) (e.g., Taylor et al., 1981; Hall, 1990; McAdoo et al., 1999; Arrigoni et al., 2007; Saltus et al., 2011; Brumley, 2014; Ilhan and Coakley, 2015). However, its tectonic origin is still under review (e.g. Grantz et al., 2011; Brumley, 2014, Kazmin et al., 2015; Oakey and Saltus, 2015).

The Kerguelen Plateau case study presents an interesting comparison to the Chukchi Borderland with respect to tectonic origin. The Kerguelen Plateau provinces' individual tectonic histories were not well established at the time of Australia's submission, and two to three hypotheses existed for each province. Despite this fact, the CLCS felt Australia presented robust arguments, supported by enough geological samples and other datasets, to classify the CKP, SKP, and Elan Bank as submarine *elevations*. This is the same situation with the Chukchi Borderland. Geological samples, seismic, and potential field (magnetic and gravity) data all indicate that the Borderland is composed of continental crust. Therefore, if the same logic the CLCS employed with the Kerguelen Plateau's provinces is applied to the Chukchi Borderland, then it would also be classified as a submarine *elevation*. Overall, this signals that in situations where seafloor highs' crustal characteristics are similar or the same as the continental margin and landmass, understanding the feature's tectonic origin is less important to the CLCS' classification of seafloor highs according to Article 76.

The northern extension of the Chukchi Borderland provides a more challenging situation. An expendable sonobuoy study found that the northern extension of the Chukchi Borderland has a possible continental-type crustal structure (Chian et al., 2010). Seismic reflection and refraction data showed that the northern extension of the Chukchi Borderland is composed highly stretched continental and transitional crust that has been locally influenced by the Chukchi Borderland and the Alpha Ridge (Hutchinson et al., 2012). The extension that impacted Canada Basin and Chukchi Borderland during initial formation also impacted the northern extension (Hutchinson et al., 2012; Brumley, 2014). Coakley et al. (in press) stated that two spurs of the northern extension appear to have experienced the same type of extension as the Borderland itself. The northern extension has also been affected by an Arctic LIP(s) event which has emplaced volcanics on the continental crust (Hutchinson et al., 2012; Dossing et al., 2013; Brumley, 2014; Coakley et al., in press). All tectonic models, except for one (Grantz et al., 2011), treat the northern extension of the Chukchi Borderland as an extension of the Borderland itself (e.g., Scotese, 2011; Brumely, 2014; Kazmin et al., 2015). With these recent data collection and analysis efforts, it seems that the hypothesis that the northern extension is composed of oceanic crust is being disproven. Instead, these data are converging to the conclusion that the northern extension is composed of continental crust that has been more extensively thinned and overprinted by a LIP event(s). If this hypothesis can be definitively proven, this would mean that the northern extension is an example of a submarine *elevation* according to the CLCS' S&TG 7.3.1b.

The Vøring Plateau and Vøring Spur provide analogs to the northern extension of the Chukchi Borderland. The Vøring Plateau is composed of both continental and oceanic crust with a continental-oceanic transition (COT) zone in the middle of the plateau. In particular, the continental crust on the Vøring Plateau was underplated *and* overprinted by magmatism. It also shares a tectonic history with the continental margin and mainland Norway. If the above conclusion that the northern extension is composed of continental crust that has been overprinted by a LIP(s) and shares a tectonic origin with the Chukchi Borderland is definitively proven, then the CLCS may classify the northern extension in the same manner it did for the Vøring Plateau.

The Vøring Spur may present a case study for the northern extension of the Chukchi Borderland if further geological data are collected and disprove the continental origin. The Vøring Spur was classified by the CLCS as a submarine *ridge*. After the Vøring Spur satisfied the morphological continuity criterion, it failed to fulfill the two "geological continuity" criteria: (1) shared geological composition with the continental margin; and (2) shared tectonic origin with the continental margin and landmass. Breivik et al. (2008) showed that the Vøring Spur is composed of oceanic crust and has a distinctly separate tectonic origin. If further data from the northern extension shows that it is not composed of continental crust, but rather oceanic crust, then the CLCS would likely classify the northern extension of the Chukchi Borderland as a submarine *ridge*.

One of the driving factors for why the northern extension of the Chukchi Borderland's composition and origin remain uncertain is the number of geological samples available from the feature and the Amerasia Basin in general. Indeed, this is the major differences between the case studies reviewed above and the northern extension of the Chukchi Borderland. Since the Norwegian Government did not produce a report as did Australia (Borissova et al., 2002), it is unclear how many geological samples it had collected prior to its submission and used to substantiate its arguments to the CLCS. One ODP Site, however, from the Vøring Plateau was drilled prior to Norway's submission and most likely evidence from it was presented to the CLCS. ODP sites from the plateau's conjugate margin (Greenland) were also available prior to Norway's submission.

The Australian Government had a significant number of geological samples, including multiple ODP Sites from the Kerguelen Plateau to use as evidence in its submission to the CLCS. One ODP site (Site 1137) in particular proved critical to the classification of the Elan Bank as a submarine *elevation* because it showed indisputable evidence of continental crust that was overprinted and modified by a LIP. Conversely, the CLCS felt Australia presented insufficient evidence from Williams Ridge to classify it because Australia provided "only indirect evidence of its nature and origin" (CLCS/58, p. 28).

It is important to compare this array of information to data presently available in the Amerasia Basin. Few dredge samples were recovered and no scientific boreholes are located in the basin. This paucity of samples is mostly due to difficulty in accessing the Arctic Ocean because of perennial sea ice conditions, harsh weather, minimal daylight, and high costs associated with Arctic exploration. However, drilling in the high Arctic has been successful (ODP Leg 302 drilled the Lomonosov Ridge in 2004) with great logistical detail (Moran et al., 2006).

A main conclusion from this CLCS analog analysis is that future geological data collection missions on the northern extension of the Chukchi Borderland will dictate its seafloor high classification according to Article 76. It is important to note that more geological samples and geophysical data are available for the northern extension of the Chukchi Borderland than Williams Ridge. However, there is no definitive proof of either features' composition or origin. Until such data are collected, such as a scientific borehole, to provide conclusive evidence for the northern extension's composition, the CLCS may choose to not classify it, similar to its approach for Williams Ridge.

In conclusion, this thesis presented morphological analogs to the Chukchi Borderland region that have accompanying CLCS recommendations to distill the criteria the CLCS utilized to classify seafloor highs according to Article 76. The two analogs, the Kerguelen Plateau and Vøring margin, show that the CLCS implemented consistent criteria to evaluate seafloor highs across different submissions. Application of these criteria to the Chukchi Borderland region reveal that with available data, the Chukchi Borderland would be considered a submarine *elevation* according to Article 76 of UNCLOS. With respect to the northern extension of the Chukchi Borderland, available data suggests that the feature is morphologically continuous with the Borderland and thus a *natural prolongation* of the landmass. However, with the currently available geological and geophysical data from the northern extension, it is uncertain whether the CLCS would consider the feature to be geologically continuous with the Borderland and Alaskan margin. This shortcoming could be addressed with the collection of further geological and geophysical data. As demonstrated on Kerguelen Plateau, geological samples are a necessary way to elucidate the feature as a *natural component* of the continental margin. This information may ultimately determine if the northern extension is classified as a submarine *elevation* or submarine *ridge*.

While growing evidence points to the fact that the northern extension of the Chukchi Borderland shares a common geologic origin with the Chukchi Borderland (though more highly extended and overprinted by LIP magmatism), it is uncertain whether the CLCS will find the feature to be a *natural component* of the Chukchi Borderland and Alaskan Margin.

Appendix I:

Brief History of Article 76 UNCLOS:

Article 76 of UNCLOS derives from a complex series of events and documents that date back to the World War I (WWI) era. Sir Cecil Hurst, in 1923, articulated in his book, *Whose is the bed of the Sea?,* an occupation based theory that posited that the seabed was inherently un-owned by any individual or State; however, if a State wanted to assert ownership of the seabed, simple occupation sufficed (Hurst, 1924). Hurst's occupational theory prompted The Assembly of the League of Nations to have its Council attempt to codify international law pertaining to the exploitability of the seabed beyond the territorial sea, raising questions like who owned which parts (living and non-living resources) of the seabed and what constituted property rights (Jensen, 2014). Note that the existence of a territorial sea evolved as a distinct maritime zone that dates back to the 1700's. Major maritime and fishing countries in the 18th century, like Iceland, the United Kingdom, and Norway, claimed territorial seas, all ranging from two to four nautical miles (M) from their coastlines. This distance was chosen because it was the maximum distance a shot cannon ball could travel (Kurlansky, 1997).

Despite Hurst's theory and the League of Nations' discussions of the seabed, it was not until after World War II that coastal States began to declare their rights to the seabed and its resources. These declarations began with the United States. On September 28th, 1945, President Harry Truman set forth two proclamations regarding United States' governance in the high seas. The first pertained to the United States' rights to fisheries beyond its territorial sea, whereas the second dealt with natural resources on and below the seafloor of the continental shelf adjacent to the U.S. coastline (Procl. 2667-2668, 1945). The latter proclamation declared that the United States was conscious of the global demand for fossil fuels and other minerals and supported exploration and exploitation efforts to find new sources (Procl. 2667, 1945). In particular, the proclamation stated:

> the Government of the United States regards the natural resources of the subsoil and seabed of the continental shelf beneath the high seas but contiguous to the coasts of the United States as appertaining to the United States, subject to its jurisdiction and control… The character as high seas of the waters above the continental shelf and the right to their free and unimpeded navigation are in no way thus affected (Procl. 2667, 1945).

This proclamation, which became known as the Truman Proclamation, did not claim jurisdiction over the continental shelf itself, rather it stated that the United States claims *jurisdiction and control* over the natural resources of the subsoil and seabed *on or below* the continental shelf. After the Truman Proclamation, many other coastal States followed suit, declaring similar rights to the natural resources of the subsoil and seabed of their continental shelves. In 1953, the United States turned the proclamation into law by creating the Outer Continental Shelf Lands Act, legislation meant to control the exploration and exploitation of the continental shelf off of the United States' coastlines (Sohn et al., 2010).

The Truman Proclamation was the first time that the phrase "continental shelf" was used within a legal setting. The proclamation itself did not define the term; however, a press release published with the proclamation declared the continental shelf to comprise the subsoil and seabed of the submarine areas contiguous to the coastline of the United States and covered by no more than 100 fathoms (182.9 m) of water. At the time, this depth is what scientists communicated as the general depth of the *geological* continental shelf. In 1969, the International Court of Justice (ICJ), in adjudicating the *North Sea Continental Shelf case*, officially acknowledged that the Truman Proclamation was the origin for the *juridical* continental shelf (ICJ, 1969).

In 1947, the United Nations General Assembly (UNGA) established the International Law Commission (ILC) to conduct research and studies for the explicit purpose of encouraging the advancement of international law (Charter of the United Nations, Article 13(1)). The ILC was tasked with identifying and researching the most important topics of international law (ILC, Doc. A/RES/174(II), 1947). In 1949, the ILC produced a list of 14 topics, one of which was governance of the high seas (ILC, Doc. A/CN.4/13, 1950). Busch (2015) provides a detailed discussion of the ILC's role in the formation of the definition for the *juridical* continental shelf and how its work provided the basis for the First United Nations Conference on the Law of the Sea (UNCLOS I) in 1958.

When the ILC made the highs seas a top priority of research in 1949, it also ranked it as one of the top three topics of high priority out of the 14 chosen subjects (ILC, Doc. A/CN.4/13, 1949). As such, the ILC conducted extensive research on how the *juridical* continental shelf should be defined and what type(s) of jurisdiction a coastal State should have over it. Much of the ILC's discussion revolved around predicted advancements in technology that would improve coastal States' abilities to exploit the continental shelf (ILC, Doc. A/CN.4/13, 1950). The ILC stated that the *juridical* continental shelf could not be defined in the *geological* sense and drafted a series of articles that based a coastal State's *juridical* continental shelf limit upon firstly, an exploitability criterion and then secondly, a fixed limit based upon a water depth of 200 m (Sohn et al., 2010; ILC, Doc. A/CN/.4/48, 1951). After much deliberation and input from the UNGA, the ILC revised its final draft article in 1956 to include both formulas, empowering a coastal State to establish the outer limits of its *juridical* continental shelf based upon whichever formula was more advantageous to its coastline. The specific language of the ILC was:

> …to a depth of 200 metres, or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas (ILC, Doc. A/3159, p. 296).

The ILC's work regarding the *juridical* definition of the continental shelf essentially became Article 1 of the 1958 Continental Shelf Convention (CSC), which was drafted during UNCLOS I (Sohn, et al., 2010). Article 1 of this convention stated:

> The term 'continental shelf' is used as referring (a) to the seabed and subsoil of the submarine areas adjacent to the coast [including the coast of islands] but outside the area of the territorial sea, to a depth of 200 meters or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas (Article 1(a) of the CSC).

The depth component to this article was incorporated because the authors believed that in order to ensure fairness in application for any coastal State, a basic depth that characterizes the *juridical* continental shelf should be included, an argument that the ILC had originally posited (Sohn et al., 2010). The second component to this clause followed the ILC's work also by repeating the exploitability criterion, allowing coastal States to extract natural resources on the *juridical* continental shelf beyond the 200 m depth as far as its technological capabilities permitted. After the CSC was ratified, a second conference, UNCLOS II, was convened in Geneva, Switzerland in 1960; however, no new agreements or modifications to the 1958 Convention came out of those deliberations (Sohn et al., 2010).

By the 1960's, technological advancements had matured to a point where the exploitability of natural resources was possible in depths greater than 200 m. In 1967, at the twenty-second session of the UNGA, Maltese Ambassador Arvid Pardo delivered a speech that highlighted the technological progress for deep sea drilling and mining operations in the open ocean. He emphasized the need to protect the oceans from such exploitation for future generations. Ambassador Pardo's speech led to the idea that the ocean floor and water column outside of national jurisdiction should be preserved for the common heritage of mankind.

Ambassador Pardo's speech, combined with an awareness of rapid developments in ocean exploration and exploitation prompted a third conference (UNCLOS III) in 1973, where delegates debated major revisions to the 1958 CSC. Ambassador Pardo's argument became an integral part of UNCLOS, Part XI: Sections 1-4; the region that falls outside of national jurisdiction of coastal States is the 'common heritage of mankind' and referred to within UNCLOS as 'The Area.'

The UNCLOS III negotiation process was polarized as States divided into allied groups depending on the morphology of their *geological* continental margins, namely into the "broad-margin States," "narrow margin States," and the landlocked and developing States (Sohn et al., 2010; Nordquist et al., 1993). One of the main objectives of the new set of negotiations was to eliminate the exploitability criterion from the CSC and replace it with a more tangible benchmark (Nordquist et al., 1993). The term *natural prolongation* became a popular topic during the negotiation process, a term taken from the 1969 ICJ *North Sea Continental Shelf cases*. The ICJ used the phrase in the following context:

> …what the Court entertains no doubt is the most fundamental of all Rules of law relating to the continental shelf, enshrined in Article 2 of the 1958 Geneva Convention, though quite independent of it—namely that the rights of a coastal State in respect to the area of continental shelf that constitutes a natural prolongation of its land territory into and under the sea exist *ipso facto* and *ab initio*, by virtue of its sovereignty over the land (ICJ, 1969).

The delegates of UNCLOS III produced a new definition of the *juridical* continental shelf, aligning it with the 1969 ICJ phrase *natural prolongation of the land territory*. This amendment to the definition of the *juridical* continental shelf was incorporated into Article 76, paragraph 1 (Sohn et al., 2010).

The above discussion is a brief review of the history of Article 76 of UNCLOS that focuses on the origin of the *juridical* continental shelf. Beyond this juridical definition, Article 76 goes on to define limits to the *juridical* continental shelf through the description of two formula lines and two constraint lines. The application of the formula lines and constraint lines as presented in Article 76 will be explored in more detail in the following section. A history of the origin of the formula and constraint lines is outside the scope of this thesis. For a more comprehensive historical review of Article 76, however, the *Travaux Préparatoires* provide an official documentation of the negotiations, drafting and discussions that occurred during UNCLOS III that produced the final Convention (Nordquist et al., 1993).

Appendix II:

The Commission on the Limits of the Continental Shelf

Composition and Functions of the Commission:

The CLCS is composed of twenty-one scientists who specialize in the fields of geology, geophysics and/or hydrography (UNCLOS, Annex II, paragraph 1). The CLCS' functions within Annex II, Article 3(1) of UNCLOS. The CLCS has two main functions. The first of which is to evaluate a coastal State's submitted ECS data and related material and provide recommendations to the coastal State regarding its proposed outer limit of its continental shelf (UNCLOS, Annex II, Article 3(1a)). The CLCS's second function is to offer scientific and technical advice to coastal States during their preparation of ECS submissions, if such help is requested by the coastal State (UNCLOS, Annex II, Article 3(1b)).

Sub-Commissions:

With twenty-one members, the Commission analyzes coastal States' submissions by sub-commissions, each of which is composed of seven members (UNCLOS, Annex II, Article 5). The sub-commissions are charged with investigating the submitted datasets and ECS outer limits of a coastal State's submission. These sub-commissions are selected based upon Commissioners' expertise and geographical representation to ensure a balanced and fair review (UNCLOS, Annex II, Article 5). If a Commissioner has provided a coastal State with technical advice with its submission and/or is a national of the particular coastal State whose submission is being reviewed, these Commissioners cannot serve on the sub-commission (UNCLOS, Annex II, Article 5). Those Commissioners that are blocked from participating on the sub-commission are still allowed to vote on the final recommendations for that coastal State (UNCLOS, Annex II, Article 6). Due to an influx of submissions in May 2009, the Commission now reviews nine submissions concurrently, and sometimes more, where each Commissioner serves on three sub-commissions (CLCS/50, 2006, p. 3).

When the sub-commission finishes its review of a submission, it submits its proposed recommendations to the plenary Commission for review (UNCLOS, Annex II, Article 6(1)). Once the plenary Commission has discussed the sub-commission's work, the Commission votes on the proposed recommendations. The recommendations must be approved by a two-thirds majority of Commissioners that are present (UNCLOS, Annex II, Article 6(3)).

Core Documents of the Commission:

The CLCS retains a set of core documents that serve as its governing instruments. These instruments include the Rules of Procedure (RoP), Modus Operandi, the S&TG, and Statements by the CLCS Chairman. Below is a brief summary describing each of these documents.

- **RoP (CLCS/40/Rev. 1):** The purpose of the RoP is to elucidate the procedures of the CLCS in relation to the submitting coastal State and rules for internal CLCS procedures. The RoP's three annexes are in regards to submissions in case of a dispute between States (Annex I), confidentiality (Annex II), and the Modus Operandi (Annex III) (CLCS/40/Rev.1).
- **Modus Operandi (CLCS/40/Rev. 1, Annex III)**: The Modus Operandi was incorporated as an Annex III of the RoP in 2001 and details the internal functions and procedures of the CLCS as it examines a submission (CLCS/40/Rev.1, Annex III, IV). The Modus Operandi was integrated into the RoP after the Commission's twelfth session when it realized while reviewing its first submission, Russian Federation (2001), that it need to synchronize its internal guiding documents (Suarez, 2008). Included in the Modus

Operandi is a requirement that the submitting coastal State include an executive summary of its submission.

- **Scientific and Technical Guidelines (S&TG) (CLCS/11)**: The S&TG were published in 1999 and its purpose is to support coastal States in preparing their submissions (CLCS/11, p.6). The S&TG also provide guidance on the scope and depth of admissible scientific and technical evidence the CLCS expects when it reviews submissions (CLCS/11, 1.2). Lastly, the S&TG are meant to provide a baseline in which the CLCS can provide scientific advice to coastal States if requested during the preparation of a submissions (CLCS/11, p.6). The discussion above regarding how the CLCS interprets the phrase *evidence to the contrary* with respect to establishing the FOS is one example of what kind of technical information is included in the S&TG.
- **Statements by the CLCS Chairman (CLCS/1 – CLCS/88):** The Statements by the Chairman provide updates and information on the progress of the CLCS' work at each of its sessions. Sometimes, the Statements by the Chair offer insight into the internal proceedings, thought process, and justification for the CLCS' published recommendations, information that cannot be found in the executive summaries of published recommendations. Thirty-nine Statements by the Chairman have been published thus far.

All of these instruments of the CLCS are important to understanding the internal architecture of the CLCS, the thought processes of the Commissioners, and the workflow of sub-commissions.

Appendix III:

Arctic Exploration & Scientific History:

Fridjotf Nansen initiated Arctic exploration in the late 1890's during the *Fram*'s ice drift (1893-1896) (Nansen, 1898). In 1907, Nansen created the first bathymetric map of the Arctic Ocean by utilizing the seven soundings he collected during his ice drift (Nansen, 1907). More robust Arctic exploration, however, was pioneered by the Soviet Union in the early 20th Century. Between 1935 and 1939, the Soviet icebreakers, *G. Sedv* and *Sadko*, collected 55 soundings off the Siberian Arctic continental margin (Dietz and Shumway, 1961). During the same timeframe, the Soviet Union launched an ice-based mission called the Soviet Ice Drifting Expedition, where Soviet scientists landed on the pack ice near the North Pole to collect data, including 16 deep soundings (Dietz and Shumway, 1961). As technology matured in the early 20th Century, mostly due to the two world wars, the scientific community's capabilities to use available technological advancements for Arctic exploration expanded.

The Soviet Union's dominate Arctic exploration role continued throughout and after the world wars. The Soviets first discovered the Lomonosov Ridge in 1948, during their High Latitude Air Expedition, and named the feature after an eighteenth century Russian physicist (Dietz and Shumway, 1961; Weber and Sweeney, 1990; Jokat et al., 1992). Interestingly, since 1904 scientists had hypothesized that a bathymetric barrier, like the Lomonosov Ridge, existed in the Arctic Ocean based upon tidal analyses (Jokat et al., 1992). The Soviets also discovered the Alpha Ridge, but only explored small areas of the feature (Weber and Sweeney, 1990). The Russians kept their Arctic discoveries and soundings data secret until 1954 before making it publicly available on their 1954 Soviet *Bathymetric Chart of the Arctic Ocean* (Weber and Sweeney, 1990; Jokat et al., 1992).

Exploration of the Arctic by the U.S. military began during the WWII era. Starting in 1946, the U.S. began flying B-29 reconnaissance flights over the Arctic (WHOI, 2015). By 1951, these reconnaissance missions were daily endeavors and three ice islands (T-1, T-2, T-3) identified (WHOI, 2015). In 1952, the U.S. Alaska Air Command established Project ICICLE in order to better understand these ice islands (WHOI, 2015). They chose T-3 for their planned weather and geophysical research (WHOI, 2015). T-3 was located over the southern flank of the Lomonosov Ridge; however, the U.S. team had little knowledge of this feature's presence (Weber and Sweeney, 1990). From 1952-1954, scientists conducted a number of studies on the T-3 ice island, including collecting hydrographic, seismic and weather data (WHOI, 2015).

The International Geophysical Year (IGY) occurred from 1957 and 1958 and is marked with a number of Arctic-based missions. The U.S. military installed two drifting stations that year under Project ICESKATE, including one station called ALPHA and another called BRAVO, the latter of which was located on the previous T-3 ice island (WHOI, 2015). That same year, the U.S. *SSN Nautilus* was the world's first nuclear-powered submarine and the first vessel to obtain an almost continuous echogram, which provided the first continuous bathymetric profile across the Arctic Ocean (Dietz and Shumway, 1961). The *SSN Nautilus* traveled from Point Barrow, AL to the North Pole in the summer of 1958, traveling a distance of 3,700 km (Dietz and Shumway, 1961; Weber and Sweeney, 1990). The U.S. *SSN Skate* also lead missions in the Arctic, one in August 1958 and a second in March 1959 collecting sounding data using a Precision Depth Recorder (Dietz and Shumway, 1961; Weber and Sweeney, 1990). Because the Soviets were keeping their Arctic data secret, the *SSN Nautilus* and *SSN Skate's* soundings offered the first glimpse into the morphology of the Arctic seafloor to the international scientific community (Dietz and Shumway, 1961). Indeed, the ALPHA drifting station "discovered" the

Alpha Ridge during the IGY mission, after the Russians had initially found the ridge but had not reported it (Heezen and Ewing, 1961; Weber and Sweeney, 1990).

Following the IGY year, the U.S. Navy continued to increase its presence in the Arctic for data collection. The Arctic Research Laboratory Ice Station, ARLIS, project was established in 1960 with ARLIS I (WHOI, 2015). This first project's success was limited due to resupplying issues, however the following ARLIS II endeavor was more successful, and provided drifting data for over 30 years (Weber and Sweeney, 1990; WHOI, 2015).

As joint U.S. military and scientific missions increased in the Arctic in the 1960's, Columbia University's researchers, Bruce Heezen, Marie Tharp, and Maurice Ewing were expanding their research into the Arctic. Heezen and Ewing (1961) discovered that the mid-ocean ridge spreading center in the Atlantic Ocean extended into the Arctic Ocean by analyzing seismic records. Heezen and Ewing (1961) also described the Alpha Ridge as a broad plateau feature with a minimum depth of 2,000 m that forms the transition to the Arctic continental margins. It is important to note that the theory of Plate Tectonics was in a nascent stage by the 1960's and Heezen and Tharp's work studying the Arctic Ocean was contributing to their understanding of Earth's plate tectonic boundaries.

As more hydrographic data were collected in the Arctic Ocean, the collection of Arctic marine geologic samples was growing as well. Between 1957 and 1973, over 600 sediment cores were collected in the Amerasia Basin among the many different international projects, including the ice stations ALPHA, CHARLIE, ARLIS II, and T-3. All of these samples, except for two were of the Pliocene and Pleistocene age (Weber and Sweeney, 1990). The two exceptions included two cores taken from the T-3 ice station over the Alpha Ridge that recovered a late

Campanian-Maastrichtian silicoflagellate assemblage and a second core that included Paleocene to Eocene material (Weber and Sweeney, 1990).

During the same time frame, the U.S. Navy conducted aeromagnetic surveys over the northern Canada Basin and Alpha Ridge (Weber and Sweeney, 1990). These data led Kovacs & Vogt (1982) to conclude that the Alpha Ridge was a regional magnetic high and Taylor (1983) to state that the Alpha Ridge is likely of continental nature because such extreme magnetic anomalies are associated with continental features (Taylor, 1983; Weber and Sweeney, 1990).

All of these data collection efforts have led to multiple compilations into common grids for the scientific community. Nansen's first bathymetric map of the Arctic Ocean has evolved into the International Bathymetric Chart of the Arctic Ocean (IBCAO), which has been continuously updated since 2000 (Jakobsson et al., 2000; 2008; 2012). In addition, the Arctic Gravity Project amassed all the available gravity anomaly data, including shipboard, submarine, satellite, air-based, and land and sea ice based surveys into one common grid. The first iteration of this map was published in 2002, followed by an update in 2008 (Kenyon et al., 2008)

Only 600 sediment cores had been collected by the early 1970's in the Amerasia Basin and all were of limited use to understanding the tectonic origin of the basin, given that 598 of those samples were less than 5.3 Ma. Technological advancements by the 1970's allowed for *in situ* data collection, which helped strengthen the scientific community's understanding of the Amerasia Basin. The first MCS reflection and paleomagnetic data were collected in the mid 1970's in the Beaufort and Chukchi Seas (Grantz et al., 1979; Grantz and May, 1982; Lawver and Scotese, 1990).

In 1979, the Canadians embarked on a scientific mission called the Lomonosov Ridge Experiment (LOREX), which supported the conclusion that the Lomonosov Ridge was of continental origin and was separated from the Barents-Kara Shelf by seafloor spreading (Johnson et al., 1990). Four years later, Canada conducted the Canadian Expedition to Study the Alpha Ridge (CESAR) Expedition, which collected the first dredge samples from the Alpha Ridge as well as 1,300 spot soundings from the coast of Ellesmere Island to the Alpha Ridge (Mudie and Blasco, 1985; Van Wagoner et al., 1986; Johnson et al., 1990; Weber and Sweeney, 1990). The CESAR team collected bathymetry, gravity, high resolution shallow seismic reflection, intermediate depth reflection, crustal refraction measurements, geothermal measurements, magnetotelluric measurements, coring and dredging samples, bottom photography and surface and bottom current measurements (Weber and Sweeney, 1990). They also collected 16 piston cores and twelve gravity cores from the Alpha Ridge (Mudie and Blasco, 1985; Weber and Sweeney, 1990). These data were the first of their kind, an interdisciplinary effort to systematically study the composition and origin of the Alpha Ridge (Weber and Sweeney, 1990).

The CESAR Project's geologic samples were determined to be highly altered fragmental basalt of late Cretaceous age (Forsythe et al., 1986; Weber and Sweeney, 1990). These samples led to the interpretation that the Alpha Ridge was an oceanic plateau because such volcanic rocks are associated with a shallow water environment (Sweeney and Weber, 1986; Weber and Sweeney, 1990). Van Wagoner (1986) concluded that the CESAR rock samples derived from a phreatomagmatic eruption in shallow water, ranging from 200 to 800 m. She suggested that the Alpha Ridge was an aseismic ridge that formed by a hotspot that occurred during seafloor spreading in the Canada Basin in the Cretaceous (Van Wagoner, 1986). Lawver and Scotese (1990) challenged this conclusion stating that the CESAR data remained inconclusive regarding the origin of the Alpha Ridge.

Historically, in the absence of much data, a number of hypotheses have been put forth for the origin of the Alpha and Mendeleev ridges (Table 4).

Number	Hypothesis	Authors
1.	Subsided and stretched fragment of continental or transitional crust	Eardley, 1948, Saks et al., 1955; King et al., 1966; Karasik et al., 1984; Crane, 1987
2.	Rafted continental fragment	Coles et al. 1978; Sweeney et al. 1982
3.	Extinct spreading center	Johnson and Heezen, 1967; Beal, 1968; Vogt and Ostenso, 1970; Ostenso and Wold, 1971; Hall, 1970, 1973
4.	Extinct island arc/subduction zone	Herron et al., 1974
5.	Trace of a hot spot	Vogt et al., 1979; Irving and Sweeney 1982; Van Wagoner and Robinson 1985
6.	Aseismic oceanic ridge or plateau	Vogt et al. 1979; Jackson et al., 1986
7.	Leaky Transform	Embry, 1985

Table 4: Table summarizing different theories for the origin of the Alpha and Mendeleev Ridges as of 1990 (Taken from Weber and Sweeney, 1990; Lawver and Scotese, 1990)

With the acquisition of new data, several of these hypotheses have been discounted. For example, Vogt et al. (1982) cited morphological evidence and a lack of linear anomalies to dismiss the potential that the Alpha Ridge is a part of a mid-ocean ridge. Lawver and Scotese (1990) supported this conclusion by demonstrating that the current depth of the Alpha Ridge and its estimated age (~70 Ma) does not correlate with the age-depth relation for a mid-ocean ridge based upon Parisons and Scalter (1977)'s model.

As scientific missions explored the Alpha Ridge, concurrent missions were exploring other major bathymetric highs of both the Amerasia and Eurasia Basins. Grantz et al. (1998) collected piston core samples from the Northwind Ridge. In 1991, the RV *Polarstern* collected the first multichannel seismic (MCS) data on the Lomonosov Ridge*,* data that confirmed the continental origin of the Lomonosov Ridge (Jokat et al., 1992). The SCICEX program also collected bathymetric data from the Arctic Ocean between 1993 and 1999, from U.S. Navy Sturgeon-class fast attack submarines (Edwards and Coakley, 2003). In 2004, the first deep-water Arctic drilling project was conducted on the Lomonosov Ridge (Project IODP/ACEX), recovering a >400 m composite core (Moran et al., 2006).

The first half of the twentieth century was both an exciting and critical time for scientific exploration in the Arctic. It is noteworthy that the geologic understanding of the Arctic Basin kept pace with the technological advancements of the time. It is clear from this brief historical review that in recent history many of the theories presented for specific features in the Amerasia Basin, such as the Alpha Ridge, began to converge to a sub-set of the original theories as more data were collected. The scarcity of data in the Arctic and advent of UNCLOS in 1982 illuminated the need to collect extensive, high-resolution bathymetric and geophysical data in the Arctic Ocean.

Appendix IV:

Early Tectonic Models for the Amerasia Basin:

The earliest models for the tectonic evolution of the Amerasia Basin utilized data collected from the surrounding continents and created a large-scale model, fitting specific features into the proposed model (Lawver and Scotese, 1990).

One of the first proposed models assumed that the Canada Basin derived from the oceanization of continental crust (Shatskiy, 1935). In this model, Shatskiy (1935) stated that the Canada Basin was originally a cratonic high that deposited debris and sediment on Arctic Canada and the North Slope of Alaska (Lawver and Scotese, 1990). The cratonic high subsided and was 'oceanized' due to mantle convection, which destroyed the cratonic high's root (Shatskiy, 1935).

Churkin (1970) argued that the Canada Basin was formed due to the entrapment of oceanic crust (Churkin, 1970). The Kula plate, composed of early Mesozoic oceanic lithosphere, traveled north into the Arctic Basin in the mid-Cretaceous (Churkin, 1970). Simultaneously, the Kolyma terrane and Eurasia plate "sutured" together cutting the Kula plate off from the Pacific (Churkin, 1970).

Three other major models for the Amerasia Basin's formation were put forth between the 1960's and 1980's, including the Arctic Island Strike-Slip model, Arctic Alaska Strike-Slip model and the Rotational model (Lawver and Scotese, 1990). All of these models assume *in situ* formation of oceanic crust by seafloor spreading (Lawver and Scotese, 1990).

The Arctic Island Strike-Slip model (Fig. 45A) was first put forth by Johnson and Heezen (1967) and states the North Slope of Alaska rifted either from the Lomonosov Ridge or the Alpha and Mendeleev Ridges, which created a sinistral transform fault along the Canadian Arctic

Islands (Johnson and Heezen, 1967). This model assumes that the Alpha and Mendeleev Ridges were an active spreading center, or were formed parallel to a linear spreading center (Johnson and Heezen, 1967).

The Arctic Alaska Strike-Slip Model (Fig. 45B) of Herron et al. (1974) stated that either northeastern Siberia or the Chukchi Plateau rifted from the Canadian Arctic Islands along a transform fault (Herron et al., 1974). The transform fault paralleled the Arctic Alaska margin. This model requires that the Arctic Alaska block requires little to no motion of the Arctic Alaskan block in relation to the cratonic North America (Herron et al., 1974).

Lastly, the Rotational Model assumes that Alaska, and the Chukchi Borderland, were sutured onto Arctic Canada and Alaska rotated away from

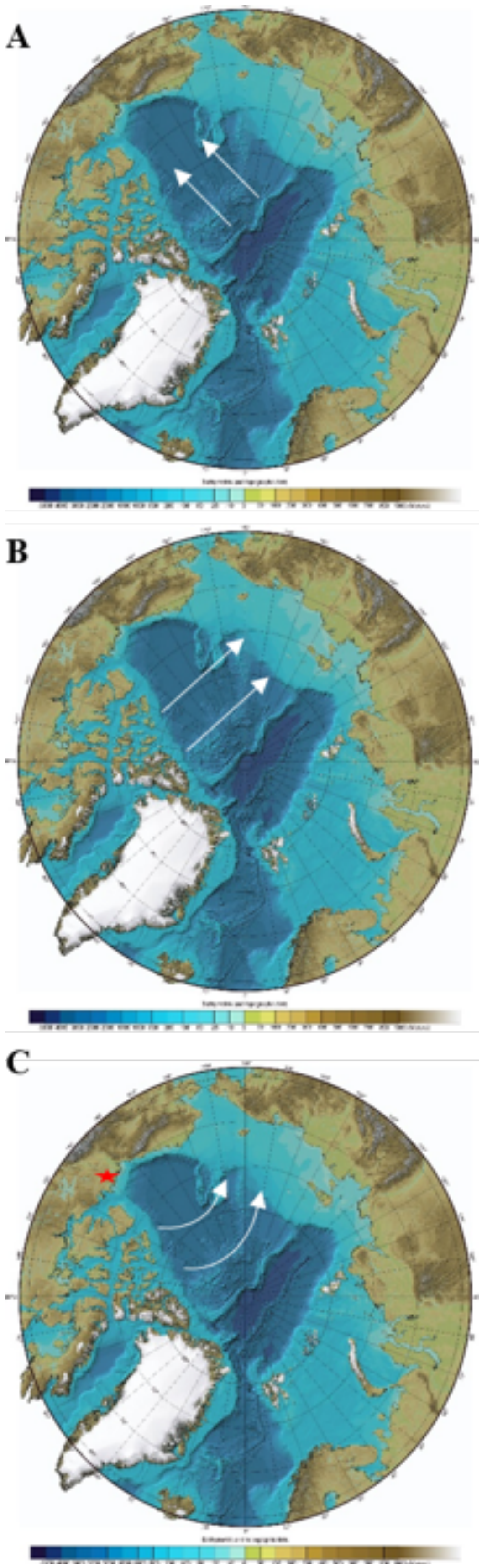


Figure 45: A: Schematic of the Arctic Island Strike-Slip Model. In this model, Alaska rifted from the Lomonosov Ridge; **B:** Schematic of the Arctic Alaska Strike-Slip Model. In this model, eastern Siberia rifted off of the Arctic Margin of Canada. The northern margin of Alaska and the Lomonosov Ridge are both shear margins. **C:** Schematic of the Rotational Model. This model is discussed in the thesis in detail, but in summary, Alaska rotates away from Arctic Canada about a pole of rotation located in the Mackenzie delta. Source: Figure adapted from Cochran et al., 2006, p. 19.

Canada by seafloor spreading in the Canada Basin. The pole of rotation for such movement is in the Mackenzie River Delta region (Fig. 45C). This model also assumes a transform boundary along or just south of the Lomonosov Ridge. The Rotational Model is discussed in more detail in the thesis as it is still considered a plausible explanation for the opening of the Amerasia Basin.

A summary of these early tectonic models is given below (Fig. 46). All of these models have been discounted, except for the Rotational Model, given modern data collection.

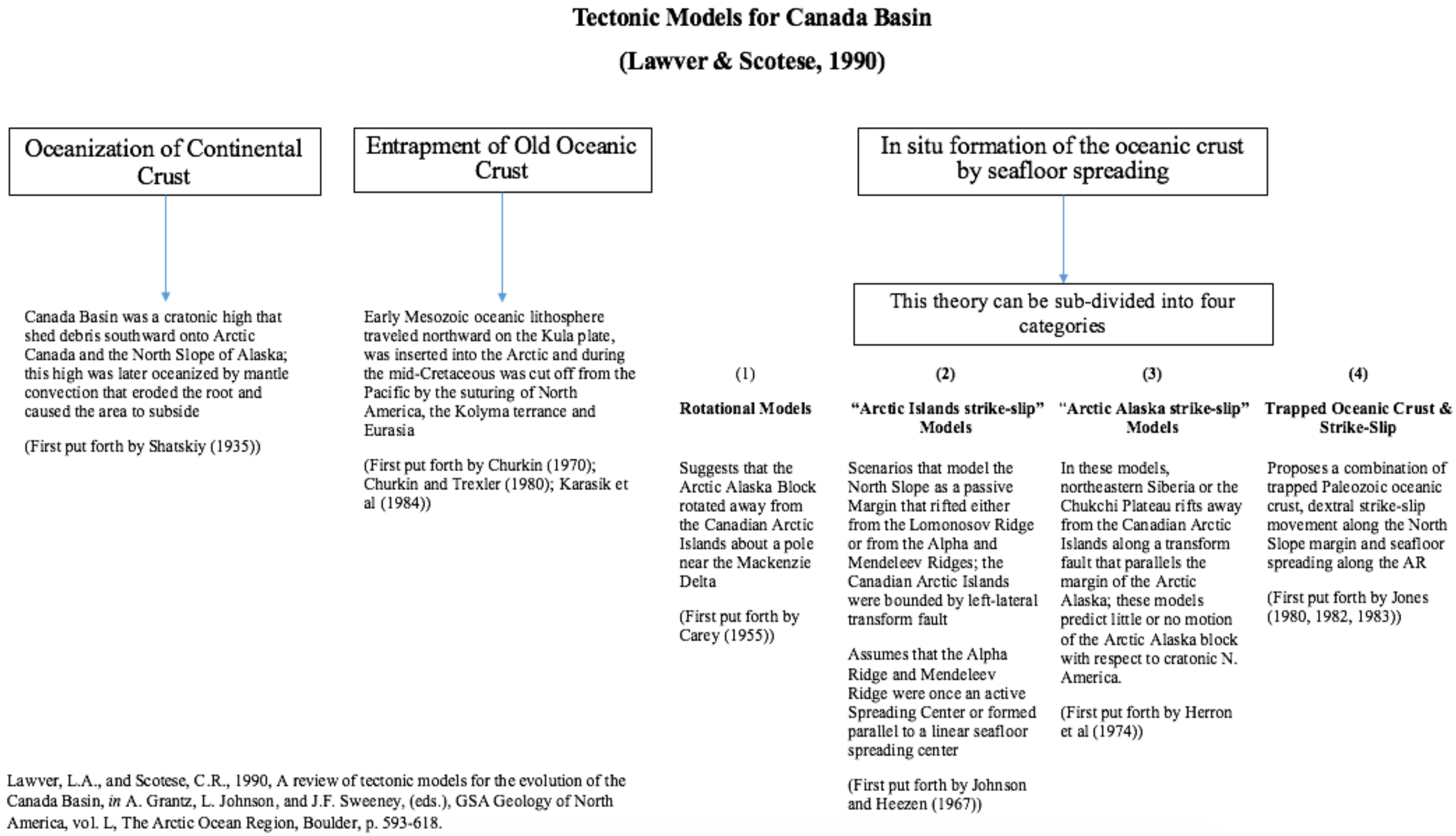


Figure 46: Early Tectonic Models (1935-1983) Source: Lawver and Scotese, 1990

Appendix V:

Geological Background for Kerguelen Plateau, Australia

Kerguelen Plateau, French and Australian Jurisdiction:

Kerguelen Plateau is divided between two countries' jurisdiction: The Commonwealth of Australia and French Republic. Australia controls the Heard and McDonald Islands on the central part of the plateau, while France owns the Kerguelen Islands to the north. The existence of these inhabitable islands is what invokes the countries' rights to delineate an EEZ and ECS around their respective islands. In 1983, a delimited boundary came into force between the two countries EEZs in the central part of the plateau (CKP) (Australian Department of Foreign Affairs and Trade, 1983) (Fig. 47). The ECS boundary between France and Australia has only been negotiated in the east, the western region has not been delimited as of 2016.

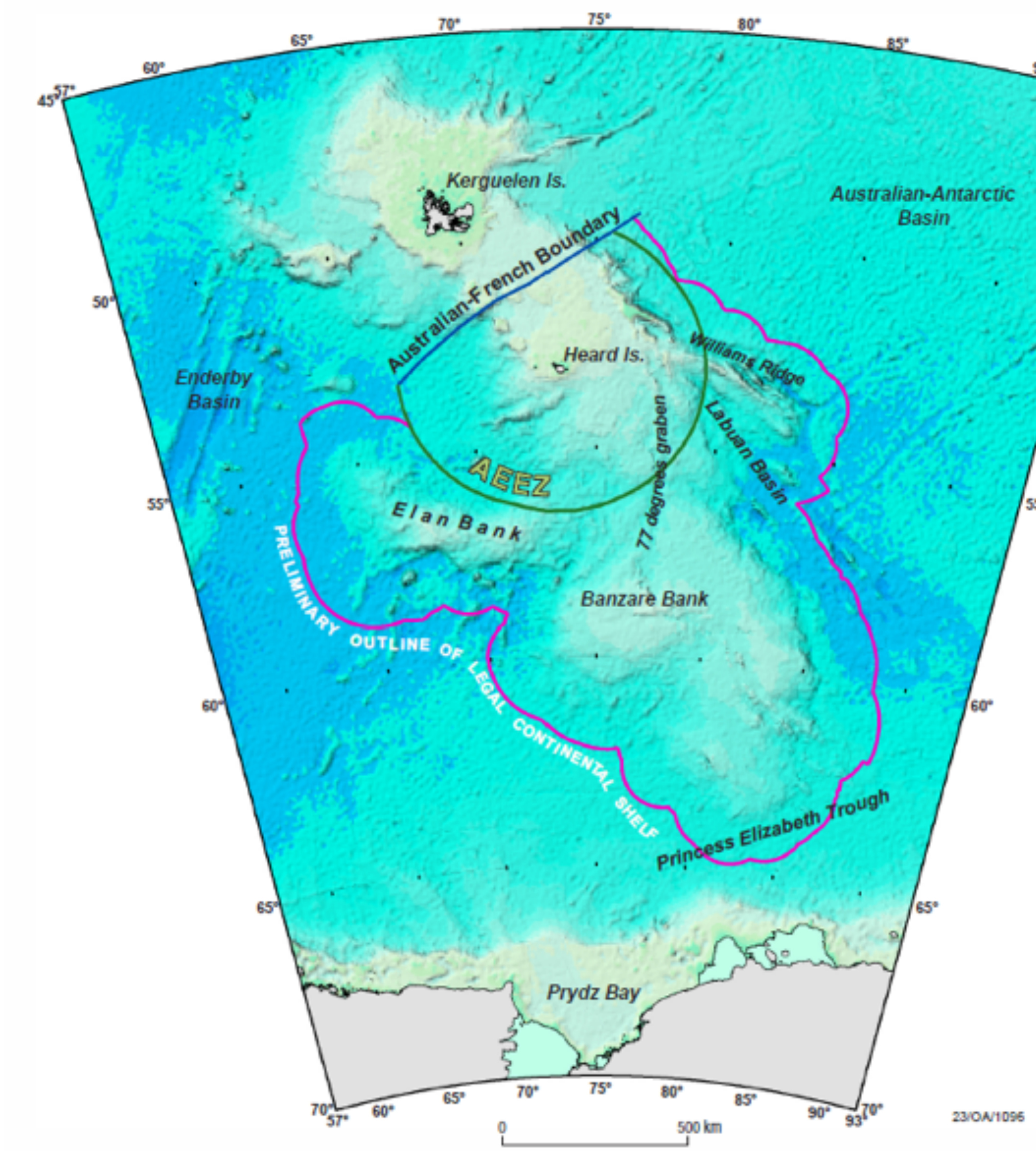


Figure 47: Bathymetric image for the Kerguelen Plateau with preliminary UNCLOS boundaries. Green Line is the EEZ boundary around Heard and McDonald Islands, blue line is the negotiated boundary between France and Australia, and magenta line is the preliminary boundary of the extended Continental Shelf on the southern part of the Kerguelen Plateau. It is not necessarily indicative or representative of the final outer of the Continental Shelf that might be used by Australia in any submission it makes to the CLCS. Source: AGSO Report; Borissova et al., 2002.

Central Kerguelen Plateau:

Seismic Refraction:

Seismic refraction data demonstrate that the CKP's igneous crust is 19-21 km thick and consists of three layers: the upper layer has velocities between 3.8 to 4.9 km/s (1.2-2.3 km thick); the middle layer shows velocities between 4.7 to 6.7 km/s (2.3 to 3.3 km thick); and the lower layer has velocities greater than 6.6 km/s and is ~17 km thick (Charvis et al., 1995). Borissova et al. (2002) concluded that due to the scarcity of seismic lines over the CKP, the underlying basement under the Kerguelen-Heard Basin could not be identified. Between 2,000-2,900 m of Cenozoic sediments fill the Kerguelen-Heard Basin and are highly reflective, making it difficult to understand the basement structure beneath (Fröhlich and Wiquart, 1989; Charvis et al., 1993).

Stratigraphy:

ODP missions 119, 120, and 183 (Sites 736, 737, 747, and 1138) and Marion Dufresne cruises (Sites 35, 38, 48, 109, and Eltanian 54) recovered key geological data from the CKP (Fröhlich, 1983; Wicquart and Fröhlich, 1986, Munschy and Schlich, 1987; Schlich et al., 1989; Wise et al., 1992; Coffin et al., 2000). The oldest sediment sampled on the CKP is from ODP Site 1138 and dated to Albian (113 -100 Ma). Volcanics dated to the Late Cretaceous (100- 66 Ma) and Oligocene-Miocene (34 - 5.3 Ma) have also been collected (Borissova et al., 2002).

Two ODP Sites 747 and 1138 located on the southern portion of the CKP sampled Cretaceous basement (basalts dated to the Cenomanian (85 – 88 Ma)) (Munschy et al., 1992). ODP Site 1138 is located 150 km to the southeast of Heard Island and recovered Cenomanian to Turonian (99 -89 Ma) glauconitic sandstones and claystones (Coffin et al., 2000). Beneath this layer were basalt flows and volcanoclastics. Site 1138 also recovered wood, leaves, and fern frond debris (Coffin et al., 2000). This evidence indicates that the CKP experienced a shallow neritic environment by the Cenomanian/Turonian (99-89 Ma) (Coffin et al., 2000). A black organic rich claystone layer above the late Cretaceous sediments represents the transition from the shallow water to pelagic environment (Coffin et al., 2000). The basement itself exhibited a felsic composition, which was interpreted to be reflective of the highly evolved magmas from the final stages of plateau construction (Borrisova et al., 2002).

Basement Characteristics:

Only three seismic lines were collected over the CKP (Borissova et al., 2002). The CKP and SKP's basement is composed of silica-saturated transitional theolite that erupted either subaerially or right below the sea surface during the early to late Cretaceous (Coffin et al., 2000). Coffin et al. (2002) concluded that the SKP and CKP were created 120-100 Ma at a rate of 0.9 m^3/year. ODP drilling Site 747, on the CKP, recovered basement basalts that show geochemical evidence for continental lithosphere (Coffin et al., 2000). The CKP's basement is slightly different from the SKP's basement in that it is not as faulted and it has volcanic intrusions that rise above the basement, forming bathymetric highs (Borissova et al., 2002). Overall agreement exists that the CKP formed in the early Cretaceous a few million years after the SKP formed (Borissova et al., 2002).

Volcanic activity on the CKP ended during the Cenomanian, but it remained a subaerial and/or a shallow water environment until the Turonian when thermal subsidence initiated (Munschy et al., 1992; Coffin et al., 2000). Some argue that the CKP remained a neritic environment until the Eocene due the presence of pelagic chalks (Fröhlich and Wicquart, 1989). By Middle Eocene, the Kerguelen-Heard platform was created (Leclaire et al., 1987). The CKP had subsided by the Miocene and volcanic activity is now only present on the Heard and McDonald Islands (Fröhlich, 1983).

Southern Kerguelen Plateau:

Seismic Refraction:

Seismic velocity analyses of the SKP show that the province is 22 km thick and composed of three layers: the upper layer with velocities between 3.8 to 6.5 km/s (~5.3 km thick); a lower layer with velocities between 6.6 and 6.9 km/s (~11 km thick); and a seismically reflective transition zone with velocities between 6.7 km/s and 6.9 km/s (4 to 6 km thick) at the base of the crust (Operto and Charvis, 1995; 1996). This reflective transition zone located at the SKP's crust-mantle boundary has not been imaged on the CKP or NKP. Operto and Charvis (1995; 1996) hypothesized that the basaltic flows on the SKP may overlay extended continental crust fragments. Furthermore, Borissova et al. (2002) stated that Raggatt Basin's crustal structure is similar to a volcanic passive margin, which may support Operto and Charvis' (1995) conclusion.

Stratigraphy:

Sedimentary records from ODP Sites 748 and 750 located on the western and eastern sides of the Raggatt Basin demonstrate different depositional timeframes for each side of the SKP (Fritsch et al., 1992). On the western side, at Site 748, Cretaceous glauconites were recovered, which is evidence for a neritic environment until 66 Ma (Schlich et al., 1989; Coffin et al., 1990; Fritsch et al., 1992). Site 750, in the eastern SKP, provides evidence that the region remained a neritic to pelagic environment until the Coniacian (86 Ma). Samples recovered from Site 750 are Albian (113 -100 Ma) clay with charcoal and siderite and Turonian to Santonian (94-84 Ma) chalk that include clay layers with pyritized wood pieces (Schlich et al., 1989). The upper sedimentary layer is Santonian to Maastrichtian (84-66 Ma) chalk and limestone that exhibit a high organic content (7%), implying that this part of the SKP was a tropical, swampy onshore environment that experienced high rainfall (Schlich et al., 1989). After the Santonian, the eastern portion of the SKP subsided rapidly until the end of the Cretaceous. These events were followed by thermal subsidence for the entire SKP until the late Eocene (40 Ma) (Borissova et al., 2002).

Basement Characteristics:

The SKP's basement has been sampled at multiple ODP Sites (Sites 738, 747, 748, 749, 750 and 1136) (Fig. 48) and dredge samples located on the 77 Degree Graben (Leclaire et al., 1987). Like the CKP, the SKP's basement is composed of silica-saturated transitional theolite that erupted either subaerially or right below the sea surface during the early to late Cretaceous (Borissova et al., 2002). The SKP's basement, however, is morphologically elevated above the CKP's. Coffin et al. (2002) stated that the SKP's lava flows formed as inflated pahoehoe flow and due to the lack of pillows and quenched glassy margins that accompany submarine volcanism, this implies that a subaerial eruption is likely. This finding is also reinforced by evidence from emplaced felsic pyroclastics, through inflated pahoehoe and subaerial sediments that are in contact with the top layers of the basement basalt (Coffin et al., 2000).

The basement of the SKP is composed of dipping reflector sequences and is significantly faulted, especially within the 59°S and 77°E grabens (Borissova et al., 2002). Seismic lines to the east of Raggatt Basin exhibit evidence for an intra-basement horizon hidden under volcanic flows. ODP Site 1136 on the SKP has the oldest basalt sampled on the entire plateau, dated to 117 ± 0.8 Ma (Barron et al., 1989; Schlich et al., 1989; Schlich et al., 1992; Coffin et al., 2000). Other samples from the SKP indicate younger ages between 112-114 Ma, including the Raggatt Basin's basement which formed 112-110 Ma through subaerial eruption (Borissova et al., 2002; Coffin et al., 2002).

Elan Bank:

Seismic Refraction:

AGSO Survey 179 collected five lines on the western and southern parts of the bank. Borissova et al. (2000) discovered that the bank has seaward dipping reflectors which are indicative of a mafic igneous upper crust. Charvis et al. (1997) interpreted the velocity (~6.8 km/s) of the lower crust to be indicative of continental crust.

Stratigraphy:

Until ODP Leg 183, which recovered continental rocks from the Elan Bank, the province was thought be an outcrop of the Kerguelen LIP (Weis et al., 2001; Royer and Coffin, 1992). ODP Leg 183, Site 1137, which was located on a central high of the bank, recovered fluvial clast deposits of garnet-biotite gneiss interbedded with basalts, which signifies that at least a portion of the Elan Bank has a continental origin (Coffin et al., 2000; Frey et al., 2000; Nicolaysen et al., 2000; Nicolaysen et al., 2001; Weis et al., 2001). The recovered conglomerate of continental origin was sourced in a local subaerial environment and deposited in a braided river environment (Nicolaysen, et al., 2000). As of 2004, when Australia made its submission, this fluvial conglomerate is the only undisputable continental basement rock recovered from the Kerguelen Plateau (Borissova et al., 2002).

Site 1137's brecciated and massive basalts were dated to 109.3 Ma (Coffin et al., 2002). The low velocity (~6.8 km/s) of the lower crust of the Elan Bank reported by Charvis et al. (1997) is consistent with the continental basement rock samples. Seaward dipping reflectors in the upper crust of the Elan Bank consists of mafic igneous material (Borissova et al., 2000).

Site 1137 also included zircons and monazites in the clasts, which were dated between 675 and 938 Ma (Nicolaysen et al., 2001). The biotite grains were dated to the Cambrian (~550

Ma) (Nicolaysen et al., 2001). Borissova et al. (2002) stated that these Cambrian (541- 485 Ma) age clasts from Site 1137, combined with the low velocity structure of the bank's base of crust, provide strong evidence that continental crust is mixed in with the mafic rocks of the plateau.

Basement Characteristics:

Elan Bank's basement exhibits high internal reflectivity in relation to other parts of the plateau and terrace-like blocks that "step down" to Enderby Basin (Borissova et al., 2002). Evidence for a faulted basin overlain by volcanic lava flows is exhibited in one seismic line. Dipping reflector sequences are similar to those on the Kerguelen Plateau and Borissova et al. (2002) stated that this evidence is indicative of lava flows formed through subaerial eruptions that occurred during the separation of the micro-continent from the major continental plates (Antarctica and Indian plates).

The non-reflective buildups and faulted intrabasement reflector sequences are similar evidence to what is found on volcanic passive margins, particularly on marginal plateaus like Wallaby and Exmouth Plateaus off of Western Australia (Symonds et al., 1998; Planke et al., 2000). To the south of the bank is a very strong reflection (7.5 sec TWT) which covers well-layered crust. Borissova et al. (2002) stated this reflector could be COT crust. The authors also concluded that beneath this COT layer there might be highly extended continental crust that has sedimentary sequences covered by basalt. Further seaward, towards Enderby Basin, the transitional crust thickens and merges with oceanic crust, which Borissova et al. (2002) pointed out is consistent with the typical structure of volcanic rifted continental margins.

Williams Ridge:
Seismic Refraction:

One seismic line was collected on the western side of the ridge, which displays a dipping reflector sequence. This sequence does not have an accompanying magnetic signature, a common characteristic for basaltic lava flows (Borissova et al., 2002). Therefore, this sequence is unlikely to be a basalt flow and Borissova et al. (2002) hypothesized that the sequence may be representative of sediment interbedded with volcanics or a non-volcanic sedimentary source.

Stratigraphy:

As of 2004, Williams Ridge had not been drilled and its stratigraphic sequence and basement had not been sampled (Borissova et al., 2002). Dredge and core samples taken from a basement high that is a part of the northern part of the ridge recovered Miocene basalt and Late Cretaceous sediments (Borissova et al., 2002). These sediments contain volcanic ash and glass, which correspond to similar sediments found on the NKP near the Kerguelen and Heard Islands as well as a large basement high on the SKP (Borissova et al., 2002).

Basement Characteristics:

As of 2002, when Australia was preparing its submission, it seems Williams Ridge's basement character was deduced through an analysis of its conjugate margin, Broken Ridge. The Kerguelen-Broken Ridge Platform was created (or joined) in the Cenomanian (100-94 Ma) and experienced a neritic to bathyl environment until the Santonian (86-83) (Driscoll et al., 1991). During the Eocene, the platform experienced uplift and then separated by 40 Ma (Borissova et al., 2002).

Borissova et al. (2002) suggested that Williams Ridge's basement has a similar age and structure as Broken Ridge. Broken Ridge's basement was sampled during ODP Leg 183, and recovered alkaline basalts estimated to be 94 Ma that erupted as subaerial lava flows (Duncan and Pringle, 2000). If Broken Ridge's basement structure is similar to Williams Ridge's, this would mean that Williams Ridge is relatively young in comparison to the Elan Bank, CKP and SKP. It would also suggest that Williams Ridge is not underlain by continental crust even though morphological continuity between the plateau and ridge exists (Borissova et al., 2002).

Labuan Basin:

The Labuan Basin is located on the western flank of the Kerguelen Plateau, situated between Williams Ridge to the north, CKP to the northeast, and SKP to the east. It is considered a morphologically and structurally distinct province of the plateau and contains 2.4 to 4 km of sediment above basement (Borissova et al., 2002). The basin's tectonic history is intricately tied to the plateau and the two features are thought to have formed originally during the separation of India and Australia from Antarctica (Borissova et al., 2002). The specific age and origin for the basin, however, is still suspect due to a scarcity of data. The Labuan Basin is thought to be older than the plateau and the result of massive amagmatic extension between Australia and Antarctica (Rotstein et al., 1991).

The basin is subdivided into three distinct provinces (eastern, western, and southern sections) based upon differences in structure and total magnetic intensity (TMI) (Borissova et al., 2002). The basin's basement in the east has rounded topography trending in a NNW direction and is not faulted, whereas the basin's basement in the west is blocky and faulted (Borissova et al., 2002). The southern province does not have a distinct boundary fault with the SKP and is generally not faulted. The presence of dipping reflectors in the south indicate that volcanism affected this portion of the basin during formation (Borissova et al., 2002). The TMI signature in the west corresponds to bathymetric highs, whereas in the east the TMI expression is weak or nonexistent over basement highs (Borissova et al., 2002).

One of the most important findings Borissova et al. (2002) found was that Labuan Basin's basement is unlike surrounding basement. Enderby and Australian-Antarctica basins' basements have typical characteristics for oceanic crust. Labuan Basin's basement, however, is more characteristic of magmatic or continental basement (Borissova et al., 2002).

Borissova et al. (2002) concluded that it is possible that different crustal types underlie Labuan Basin, including extended continental crust, magmatic crust, and/or early Cretaceous oceanic crust. The basin's connection to and role in the Kerguelen Plateau's provinces' tectonic histories is important to regional tectonic models. Australia put all of its FOS points along the margin of the CKP, SKP and Williams Ridge and none that extended into Labuan Basin. Therefore, the basin is less relevant from an Article 76 perspective.

Kerguelen Plateau Region's Tectonic History:

Although some specific details regarding the Kerguelen Plateau are not well understood. A general overview of the tectonic history of the Kerguelen Plateau and its region was presented in Borissova et al. (2002). It is probable that this tectonic model is similar or a replica of that presented to the CLCS in the Australian submission.

During the Oxfordian-Valanginian (160-131 Ma), Gondawana began to separate, creating an emergent plate boundary between India and Australia-Antarctica. As the Indian plate separated from the combined Antarctica-Australia plate, continental fragments may have been left over from this breakup. Borissova et al. (2002) stated that this separation between India and Australia-Antarctica created the initial Labuan Basin and Diamantina zone within an extensional terrane between the two continents. This theory suggests that a mixture of oceanic and continental crust underlies the Labuan Basin.

An extensional rift system likely grew between Australia and Antarctica between the Hauterivian to Albian (134 – 97 Ma), which served as epicenter of future breakup between the two continents. The Elan Bank broke off from the Indian plate in the Albian when a mid-ocean ridge formed between the two plates, transferring the bank to the Antarctic plate (Frey et al., 2000). The feature was incorporated into the Kerguelen Plateau due to its proximity to the Kerguelen hotspot. Australia-Antarctica and India continued to move apart by seafloor spreading until 85 Ma.

Concurrently, starting 130 Ma, the Kerguelen hotspot formed the Kerguelen LIP through magmatic eruptions that were near or above sea level. LIP formation primarily occurred between the Barremian to Albian (131 – 97 Ma). The SKP was affected first by the volcanic eruptions, followed by the Elan Bank and CKP. Geological evidence is inconclusive if the SKP and CKP's volcanism formed at a spreading ridge (like Iceland) or a hotspot (like Hawaii) (Coffin and Gahagan, 1995). Evidence for subaerial eruptions is clearly found on the SKP and Elan Bank. Subsidence of the plateau began shortly after its formation beginning with the SKP in the Aptian. As the SKP eroded and subsided, Elan Bank and CKP continued to be subaerial.

During the mid-Cretaceous, the Cenomanian to Santonian (97 – 83 Ma), extension occurred between Australia and Antarctica. By the Santonian, India began to move north. Broken Ridge was formed by the Kerguelen hotspot by the Cenomanian (95 Ma) and was sutured to the Kerguelen Plateau. At the same time, most of the plateau was transitioning from neritic to bathyl marine conditions as it subsided. The Labuan Basin and Diamantina Zone both experienced extensional faulting and peridotite intrusions formed in the region, followed by quick subsidence of the Labuan Basin.

By Late Cretaceous (Campanian), the southern margin of Australia separated from Antarctica. On the Kerguelen Plateau, between 75 – 69 Ma, the major rift system that dominates the SKP was formed (77 E Degree, 59 S Degree, and SKP rift). The SKP's Raggatt Basin underwent normal faulting and was uplifted as subsidence for the entire plateau continued.

Between the Middle Eocene to Oligocene (45 – 34 Ma), hotspot magmatism became isolated to the Antarctica plate when the South East Indian Ridge (SEIR) met the Kerguelen Plume. By 43 Ma, the NKP separated from Broken Ridge and Labuan Basin broke from the Diamantina Zone. Concurrently, the eastern flank of the plateau was uplifted to or above sea level and experienced erosion. After 34 Ma, the Kerguelen Plateau continued to subside and sedimentation rates changed as different ocean currents began to interact with the plateau's morphology, including the Antarctic Circumpolar Current.

Evidence for Continental Crust within the Kerguelen Plateau:

The geochemical evidence for continental crust contamination in the Elan Bank's basement combined with the CKP and SKP's uncommon crustal structure have led to the propagation of many theories regarding the origin of the Kerguelen Plateau's crust (Operto and Charvis, 1995; 1996; y et al., 1992; Albiert, 1991; Mahoney et al., 1995; Borissova et al., 2002).

The three main theories proposed to explain the existence of continental crust in relation to the plateau's origin are as follows:

1.) A continental sliver exists in the core of the Kerguelen Plateau and is a left over fragment from the separation of India and Antarctica (Houtz et al., 1977);

2.) The plateau was formed from massive on or off-axis hotspot oceanic volcanism (although this theory does not explain the continental crust contamination) (Coffin and Edholm, 1994); The first two ODP missions on the plateau, which recovered volcaniclastic rocks and altered basalts from the plateau's basement, support this theory.

3.) The plateau is a combination of crustal blocks, including continental and oceanic crusts (Coffin et al., 1986). This theory does not provide a mechanism to explain why the plateau is a combination of continental and oceanic crust as well.

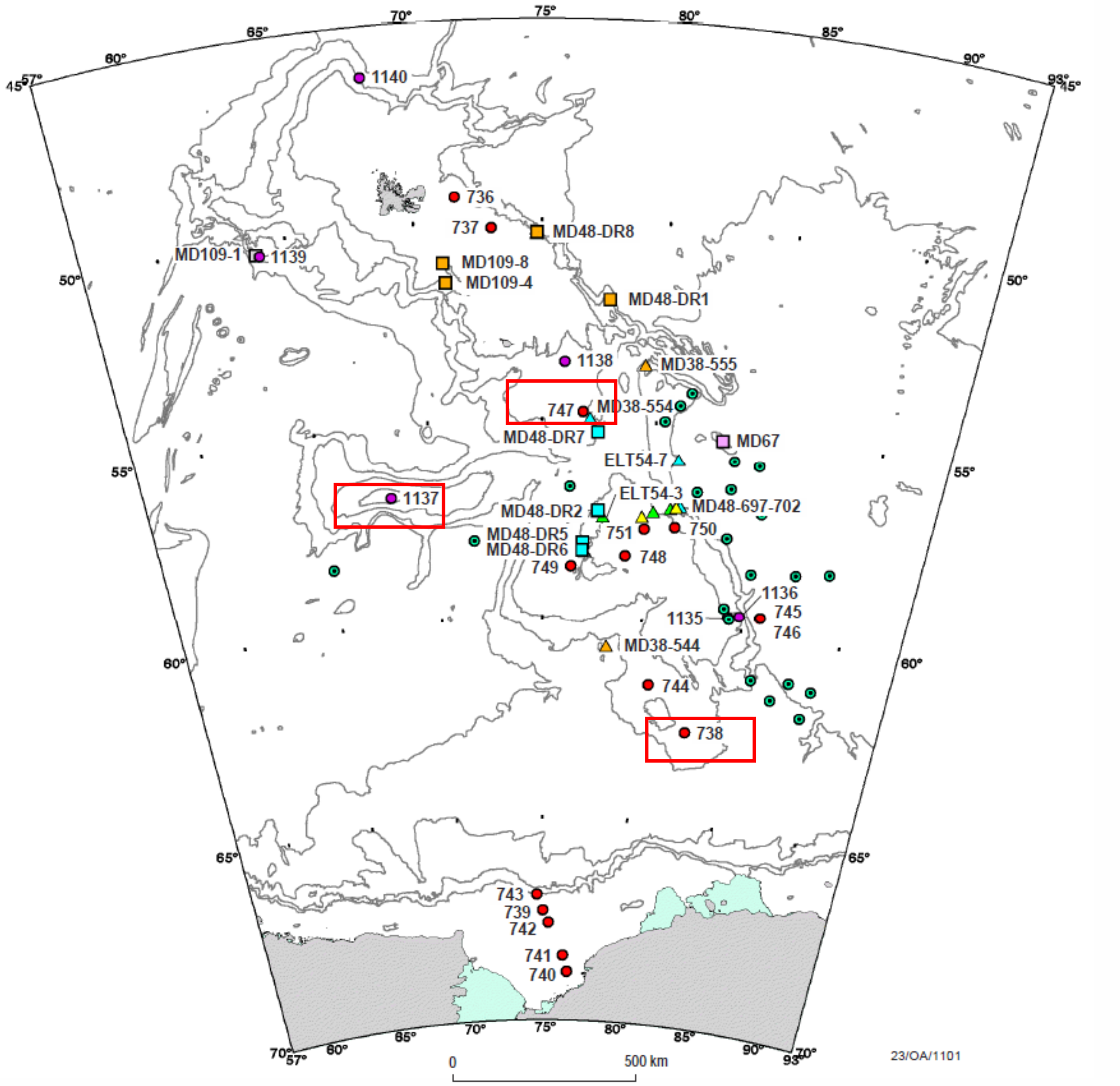
With the advent of Australian ECS and non-ECS data collection missions on and around the Kerguelen Plateau, the theory that at least part of the plateau has a continental origin gained traction (Borissova et al., 2002). The evidence presented above in each of the provinces' sections has converged to the conclusion that at least part of the plateau has a continental origin. Hassler and Shimizu (1998) sampled peridotite xenoliths on the Kerguelen Archipelago (located on the NKP) which provided evidence for a continental origin. This information further bolsters the continental origin argument.

Kerguelen Plateau Unknowns (as of 2004):

One of the most important concessions that the AGSO report makes is with respect to the unknown aspects of the tectonic history of the plateau region. Borissova et al. (2002) stated:

> One of the least understood questions is the extent of the continental crust beneath the Kerguelen Plateau and possibly the Labuan Basin. Size and location of continental fragments prior to the start of extensive volcanism in the Early Cretaceous are unknown and therefore plate tectonic reconstructions are incomplete and may be erroneous. There is a lack of understanding of plate geometries at the Australia/India/Antarctica triple junction (Borissova et al., 2002, p. 68).

This quote is extremely important within the context of Article 76, paragraph 6. Borissova et al. (2002) conceded that the sequence of tectonic events on and around the Kerguelen Plateau remain poorly constrained due to a scarcity of data and the disparate structural characteristics for each province (Borissova et al., 2002). Previously proposed tectonic models may now be obsolete with the analysis of Australia's ECS data and ODP Leg 183. Such new information has introduced new complexities to the tectonic model(s) for the Kerguelen Plateau region. This dynamic that was present in 2002-2004 as Australia prepared and made its submission to the CLCS is very similar to the situation in the Amerasia Basin today.



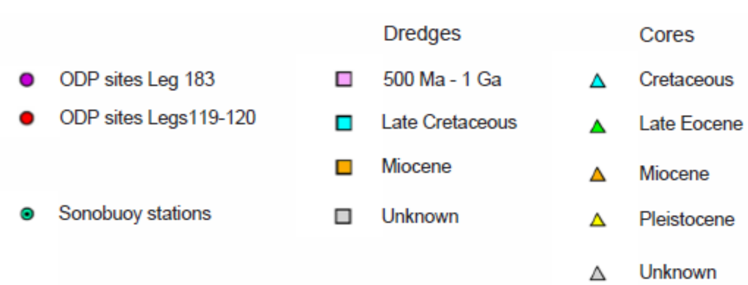


Figure 48: Locations of geological sampling sites, ODP wells, and sonobuoy stations used in this study. Source: AGSO Report; Borissova et al., 2002

Appendix VI: Geological Background for Vøring Plateau and Spur, Norway

Vøring Plateau:

Magnetic Signature:

Olesen et al. (2007) examined the magnetic anomalies on the Vøring Plateau region. The authors found that the Vøring Plateau has younger anomalies that are wide, diffuse, and chaotic that "climb up" on the plateau (Fig. 35), whereas the anomalies to the north of the plateau (on the northern part of the Vøring Margin and Lofoten Margin) are distinct and simple, characteristic of typical seafloor magnetic anomalies.

The relatively young magnetic anomalies Olesen et al. (2007) was referring to are 24A and 24B, which are located on the seaward extent of the Vøring Plateau and do not correspond with typical seafloor spreading (Skogseid and Eldholm 1987; Olesen et al. 1997; Brekke, 2000; Olesen et al., 2007). Anomalies 24A and 24B correspond with Chron 24n1n (52.51 Ma) and 24n3n (53.13 Ma), respectively (Fig. 49) (Cande and Kent, 1995). These anomalies can be traced without offsets. 24B, however, is impacted by the presence of the seaward dipping reflectors on the seaward extent of the plateau (Olesen et al., 2007). Olesen et al. (2007) reported that these two anomalies make a gentle convex shape that bend to the west. Since 24A and 24B are distinctly different from the older, seafloor spreading anomalies to the north, this suggests different origins for the two sets of anomalies (Olesen et al., 2007).

Ocean Bottom Seismographs (OBS) Data:

This magnetic anomaly analysis is complemented by the Norwegian 1996 OBS survey, which collected multiple profiles from the plateau. OBS Profile Three was a 119.4 km strike profile that crossed from the outer extent of the Vøring Plateau and ended seaward of the magnetic anomaly 24A (Fig. 49) (Mjelde et al., 2001). Mjelde et al. (2001) found that the

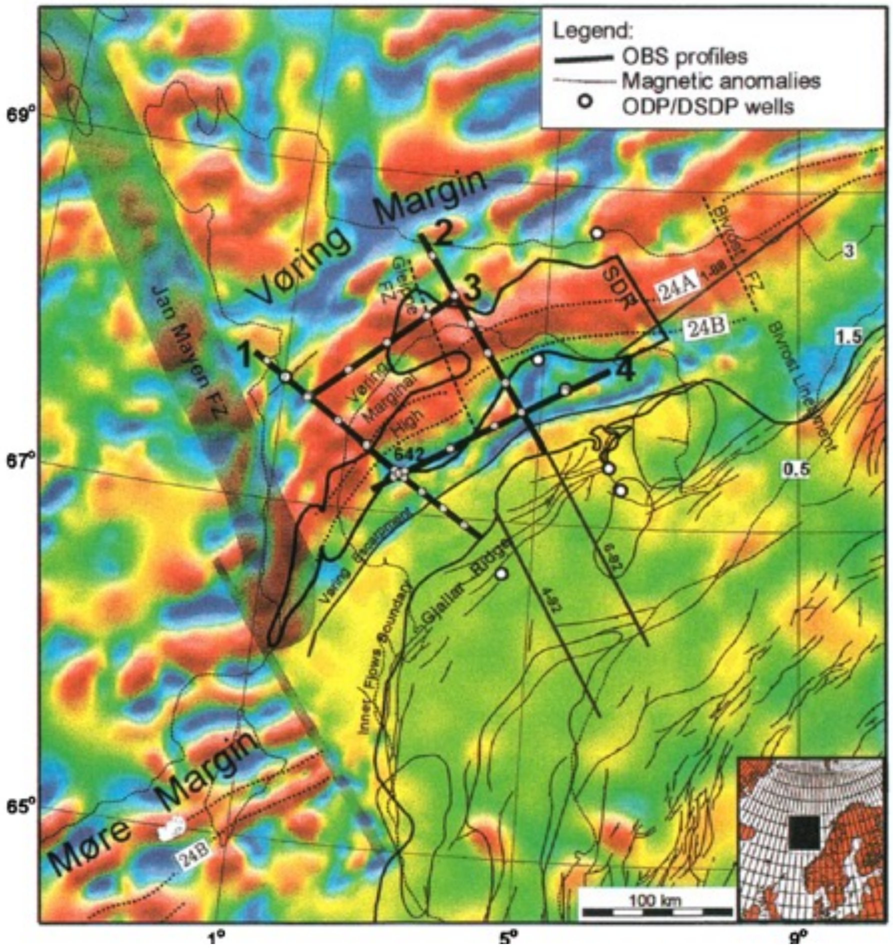


Figure 49: Map of magnetic anomalies. Magnetic anomalies 24A and 24 B are from Blystad et al. (1995) and the areal extent of the seaward dipping reflectors is from Planke et al. (1999). The four solid lines are the presented OBS profiles. Solid lines landward of the inner flows represent Tertiary domes. Projection is European Datum 1950. (Source: Mjelde et al., 2001)

velocity structure of this profile suggested an oceanic crust consistent with magnetic anomaly 24A that cannot be classified as normal oceanic crust (Ewing and Houtz, 1979; White et al., 1992; Mjelde et al., 2001).

A second profile taken from the Vøring Plateau (OBS Profile Four) was a 175 km long strike profile acquired close to the Vøring Escarpment that is also landward of the magnetic anomaly 24B and crosses ODP Site 642E (Fig. 49) (Mjelde et al., 2001). The velocity structure shows an upper crystalline crust layer that increases from 6.1-6.4 km/s at the top to 6.7-7.0 km/s at its base (Mjelde et al., 2001). Mjelde et al. (2001) stated that these velocities are consistent with the velocity structure found on the landward side of the Vøring Escarpment, which implies that the crystalline crust from Profile Four is of continental origin (Mjelde et al., 1997; 2001). Mjelde et al. (2001) also found that this part of the Vøring Plateau has experienced magmatic underplating. The velocity structure in the lower crust showed velocities increasing from 7.0-7.4 km/s at the top of the layer to 7.2-7.8 km/s at the base (Mjelde et al., 2001). These high velocities were interpreted to be intrusions and similar magmatic underplating velocity structures were found landward of the Vøring Escarpment (Mjelde et al., 2001).

From these two OBS profiles, Profile Three demonstrated that the outer portion of the Vøring Plateau is comprised of oceanic crust that is dissimilar to normal seafloor spreading crust, whereas OBS Profile Four showed evidence for continental crust that has been overprinted by flood basalts and underplated by magmatic intrusions. Mjelde et al. (2001) also analyzed each OBS velocity structure and detected a pattern for the transition from continental to oceanic crust

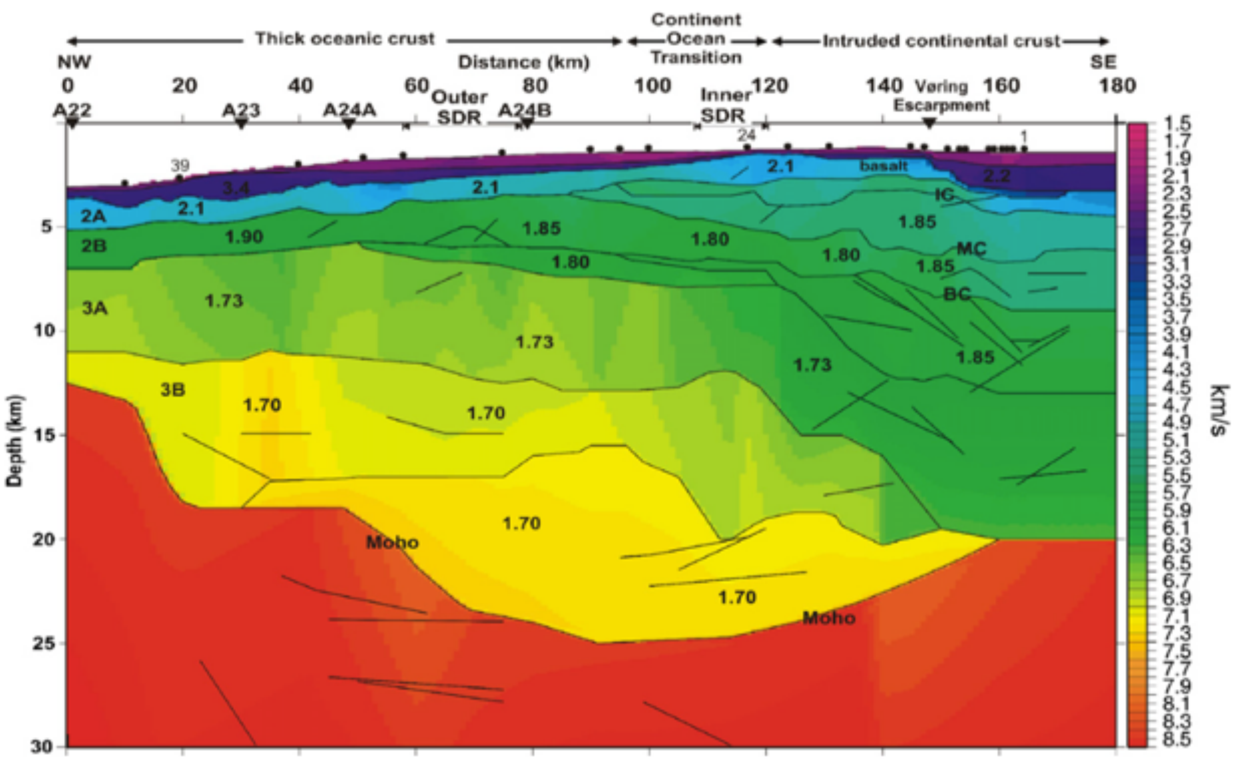


Figure 50: Final velocity model. P-Wave velocities (km/s) are given as color shading, and the numbers represent Vp/Vs-ratios. 24A, 24B, 23, 22: magnetic anomalies; VE: Vøring Escarpment; 2A, 2B, 3A, 3B: oceanic crustal layers; IC: intra Campanian; MC: mid-Cenomanian; BC: Base Cretaceous. Line segments within layers represent floating reflectors. OBS positions are shown on the seafloor. Source: Mjelde et al., 2007

(Fig. 50). The authors were able to discern zones of oceanic, transitional, and continental crust based upon the OBS stations, which were located 30 km a part on the seafloor along the Vøring Marginal High (Mjelde et al., 2001). Mjelde et al. (2001) confirmed through this analysis that the seaward extent of the Vøring Plateau is oceanic crust and moving landward, a COT zone of 30-50 km existed, followed by a zone of extended continental crust adjacent to the Vøring Escarpment and Vøring Basin (Mjelde et al., 1997; 2001). This seismic structure analysis complements Olesen et al.'s (2007) regarding the magnetic anomaly signature of the Vøring Plateau.

ODP Leg 104:

Adding to the repository of Vøring data, the plateau was drilled during ODP Leg 104 (Site 642E) and its conjugate margin, East Greenland, was drilled during ODP Leg 163 (Sites 988-990) (Eldholm et al., 1987; Allan et al., 1998). In addition, Southern Greenland was drilled during ODP Leg 152 (Sites 914-919), which also provided contextual information about the tectonic setting of the region. Site 642E, located on the seaward end of the Vøring Plateau, recovered a 320 m thick layer of marine sedimentary rocks, a 770 m thick magmatic transitional-type "enriched" MOR tholeiitic basalts layer and a 170 m thick layer of rhyolitic ignimbrite, tholeiitic basaltic dykes, basaltic andesites and dacites (Eldholm et al., 1989; Meyer et al., 2009). Site 642E's volcanic rock successions are associated with the initial breakup stages between the Vøring Margin and Greenland. Meyer et al. (2009) also reported that an analysis of the Cesium (Cs) within Site 642E's core showed an influence of continental crust in magma formation. Site 642E did not penetrate any deeper into the plateau beyond the last 170 m layer and therefore was unable to sample the basement (Eldholm et al., 1989; Meyer et al., 2009).

Voring Spur:

After the CLCS recommendations for the Vøring margin were published Breivik et al. (2014) analyzed the velocity structure of the spur in order to understand the formation and breakup magmatism in the region. Within this analysis, Breivik et al. (2014) compared the Vøring Spur to the Jan Mayen micro-continent to examine how a continental fragment would look like if it were present in the spur. The authors extracted two 1-D transects from the Jan Mayen Ridge and after comparing them to the Vøring Spur, found that the spur's velocities show significantly lower velocities throughout the crust, indicating that no continental material is present in the spur (Breivik et al., 2014).

Identifying the impact of magmatism on the Vøring Plateau and COT Zone:

During the continental breakup between Eurasia (Norway) and Greenland, the initial two stages were primarily a regime of extension with little magmatic activity (Brekke, 2000; Meyer et al., 2009). In the latter stages of breakup, however, extensive magmatic events coupled with the Iceland mantle plume, impacted the Northeast Atlantic region. This magmatism is referred to in the literature as the North Atlantic Igneous Province (NAIP) (Brekke, 2000; Meyer et al., 2009). The NAIP signature includes not only Iceland but magmatic activity outside the immediate vicinity of Iceland, such as seaward dipping reflector sequences and magmatic underplating throughout the region (Brekke, 2000; Mjelde et al., 2001; 2007; Meyer et al., 2009).

The Vøring rifted passive margin falls within the NAIP domain and the Vøring Marginal High and Vøring Basin were strongly affected by NAIP (Eldholdm et al., 1989; Skogseid et al., 1992; Mjelde et al., 1997; 2001; 2007). The magmatic rocks that affected the Vøring Margin include both intrusive and extrusive rocks, the latter of which are thick layers of seaward dipping reflectors as seen on the Vøring Plateau (Mosar et al., 2002). Mjelde et al. (2001) found from their analysis of OBS profiles on the Vøring Plateau that Early Tertiary continental breakup between Norway and Greenland experienced massive emplacement of magmatic rocks. On the Vøring margin, these magmatic rocks were partially extruded as flood basalts and partially intruded as sills in the sedimentary rocks of the Vøring Basin (Mjelde et al., 2001). Mjelde et al. (2001) also suggested that these magmatic rocks intruded into continental crust. The authors stated that the magmatic rock contamination affected the continental crust further seaward, to the point where the continental crust intersects with the inner region of the seaward dipping reflectors (discerned in the MCS data) (Dickin, 1988; Skogseid and Eldhold, 1989; Zehnder et al., 1990; Planke and Eldholm, 1994; Planke, 1994; Mjelde et al., 2001).

In part, the challenge to understanding the rifting regime and timing associated with continental breakup in the Norwegian-Greenland Sea was identifying the COT zone in the Northeast Atlantic because the region has been masked by magmatic rocks associated with the original breakup and the NAIP (Skogseid et al., 1992; Saunders et al., 1997; Eldholm et al., 2000; Berndt et al., 2001; Mosar et al., 2002). In 2007, a year after Norway made its submission to the CLCS, Mjelde et al. (2007) reported that the COT zone on the Vøring Marginal High could be constrained to a 25 km wide zone, with clearly defined stretched continental crust on the landward side and oceanic crustal velocities and densities on the seaward side (Fig. 50). Mjelde et al. (2007) stated that the COT zone is related to the detachment fault that exists in this region that originated from passive rifting during the last phase of continental breakup.

Tectonic Regime for the Vøring Margin:

Numerous authors have discussed Northeast Atlantic continental breakup between Greenland and Eurasia (Norway) (e.g., Lundin and Doré 1997; Doré et al., 1999; Brekke 2000;

Nøttvedt, 2000; Skogseid et al., 2000; Olesen et al., 2007). The Northeast Atlantic region was tectonically active from the Carboniferous to late Pliocene, with three main tectonic phases: (1) Carboniferous to Permian; (2) late Mid-Jurassic-early Cretaceous; (3) late Cretaceous-early Eocene (Bukovics et al., 1984; Brekke and Riis, 1987; Blystad et al., 1995; Doré and Lundin, 1996; Brekke, 2000; Mjelde et al., 2007; Wangen and Faleide, 2008). The Northeast Atlantic continental breakup and seafloor spreading is described in greater detail in by Doré et al. (1999); Roberts et al. (1999); and Lundin (2002).

Mosar et al. (2002) presented a geodynamic model for the separation between East Greenland and Norway where the Vøring Marginal High is treated as a seaward protrusion of the Norwegian continental margin and is composed of continental crust. The authors stated that the two conjugate margins fit tightly in the Late Permian and experienced continuous separation leading into the Eocene (Mosar et al., 2002). The crustal-scale cross sections from both margins show asymmetrical crustal extension. Mosar et al. (2002) stated that this asymmetry can be explained by a shift in the orientation of rifting. From the late Permian to Late Cretaceous, rifting occurred in a WSW-ENE to W-E oriented extension regime. During this period, Norway's continental crust was stretched and extended multiple times as numerous basins were formed (Mosar et al., 2002).

Following this tectonic regime, the rifting orientation shifted to be NNW-SSE from the Late Cretaceous to Early Tertiary (Mosar et al., 2002). By the Tertiary, the proto-North Atlantic Ocean had opened. In total, Mosar et al. (2002) calculated that the continental crust along Norway's margin experienced a total extension on the order of 200%, meaning that the margin doubled its width from the Permo-Carboniferous to present. This means that the Vøring Plateau's core composition is continental crust that has been stretched and thinned, as well as underlain and overprinted by magmatic rocks from the continental breakup between East Greenland and Norway.

Miocene reactivation in the Northeast Atlantic created the Vøring Spur, which uplifted the oceanic crust to its present position (Breivik et al., 2008). This tectonic history is discussed in greater detail in the thesis and is the key reason why the Vøring Plateau and Vøring Spur were classified as different seafloor highs according to Article 76, paragraph 6.

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