A SYSTEMATIC APPROACH TO THE IDENTIFICATION OF THE FOOT OF THE CONTINENTAL SLOPE – ARTICLE 76, UNCLOS

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Abstract

Australia, with its large, geologically diverse and generally sediment-starved continental margins, has developed an approach for foot of continental slope (FoS) identification that reconciles the legal and the geological aspects of the United Nations Convention on the Law of the Sea (UNCLOS), the Scientific and Technical Guidelines of the Commission on the Limits of the Continental Shelf (CLCS) and the physical characteristics of its margins. Fundamental to the development of the approach was that it be legally and scientifically sound, and that it could be applied to all of Australia's margins without recourse to ad hoc solutions.

Using UNCLOS and the guidelines of the CLCS, a strategy was developed that incorporated three types of FoS pick:

- morphological picks in cases where the base of the continental slope – the boundary between the slope and the rise, or the slope and the deep ocean floor – is readily defined using only morphological and bathymetric evidence (the so-called 'general rule' of the CLCS);
- geologically-supported picks where geological and geophysical data are used to support, confirm or supplement the morphologically determined location of the base of the slope; and
- 'evidence to the contrary' picks (the so-called 'exception to the general rule' as referred to by the CLCS) where morphological and bathymetric evidence are unable to locate the FoS through the normal approach involving the maximum change in gradient at its base.

In the first two types of pick, the FoS is located at the mathematically determined point of maximum change in the gradient at its base. However in the third type, the FoS is located at a proxy point defined on the basis of geological and geophysical information rather than on bathymetric data. As such proxy points represent evidence to the contrary for the FoS, they must be located within the morphological margin.

Introduction

Determining the foot of the continental slope (FoS) as the base point from which the outer edge of the continental margin is established under article 76 of UNCLOS (United Nations, 1983) is arguably the most important technical step that a State must undertake to delineate the outer limit of its continental shelf beyond 200 nautical miles (M). Unlike many other more routine tasks involved in the delineation of the

continental shelf, the task of identifying the FoS involves geological interpretation in a legal context on a case-by-case basis for every FoS point.

Although the CLCS has provided broad guidance within its guidelines (United Nations, 1999) as to how it expects States to identify the FoS, and some indication of the evidentiary burden that it may place on a State to support its interpretation, it remains the responsibility of the State to muster the technical and legal arguments necessary to make a valid and successful submission. Australia has large, geologically diverse and generally sediment-starved continental margins that formed in a variety of tectonic settings. It therefore needed to develop a systematic strategy for FoS identification that reconciled the legal and the geological aspects of UNCLOS and the CLCS guidelines with the physical characteristics of its margins.

The development of an approach to the identification of the FoS has been guided by three principles as follows:

1. UNCLOS is a legal document but it uses scientific concepts and methods to achieve its ends; that is, the science is subservient to the law and scientific terms must be read in the context of the Convention.
2. The approach must be entirely consistent with the words and intent of UNCLOS and, where possible, aligned with the guidelines of the CLCS.
3. Any approach developed should be capable of application on all of Australia's margins without recourse to ad hoc solutions in one part of the extended continental shelf that could compromise the submission in other parts of Australia's jurisdiction.

What is the FoS

Article 76 of UNCLOS provides a clear definition of the outer limit of the continental shelf that accommodates the geomorphologically different circumstances of coastal States around the world. It defines the continental shelf[1] as comprising:

> "*... the sea-bed and subsoil of the submarine areas that extend ... throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles ... where the outer edge of the continental margin does not extend up to that distance*" (Article 76(1)).

Further it defines the term continental margin as comprising:

> " *... the submerged prolongation of the land mass of the coastal State, and consists of the sea-bed and subsoil of the shelf, the slope and the rise. It does not include the deep ocean floor with its oceanic ridges ...*" (Article 76(3)).

Article 76 provides two methods for establishing the outer edge of the continental margin wherever the margin extends more than 200 M from the territorial sea

[1] Distinction needs to be made here between the legal continental margin and the legal continental shelf as used in UNCLOS. The legal continental margin is the area defined by the application of Article 76, para. 4; it is the 'legal' submerged prolongation of the State's land mass. The legal continental shelf is the jurisdictional area that a State obtains after the application of the constraints of Article 76, para. 5 to the continental margin.

baselines (TSB); both of these are based on measurements from foot-of-continental-slope (FoS) reference points. The means of determining the location of the FoS is contained in Article 76 paragraph 4(b):

> *"In the absence of evidence to the contrary, the foot of the continental slope shall be determined as the point of maximum change in the gradient at its base."*

This paragraph defines one apparently simple method for determining the location of the FoS - "*the point of maximum change in the gradient at its base"* - but it also provides the opportunity for a State to utilise an alternative approach if it believes that this methodology does not accurately reflect its rights. UNCLOS does not explicitly state the grounds on which a State may prepare a case using evidence to the contrary.

Possibly, for convenience, the CLCS refers to the process of defining a FoS by "*the point of maximum change in the gradient at its base*" as the "general rule". The process of determining an FoS point by the use of evidence to the contrary has been called "the exception to the general rule". It can be argued that the wording of paragraph 4(b) supports an opposing view and that it is evidence to the contrary that is the general rule; however, for the sake of simplicity, and in order to avoid confusion, we use the CLCS terminology here.

In Section 6 of its guidelines, the CLCS has made an effort to resolve the uncertainty concerning the exception. The CLCS approach has been to accept that the intent of article 76 is to define the outer limit of the continental shelf using the submerged prolongation of the continent – its continental margin. It has also accepted that on some occasions the simple shelf, slope, rise model envisaged by the "general rule" may not accurately reflect the rights conferred by Articles 76(1) and 76(3), especially in light of the improved understanding of the geomorphology and geology of continental margins since UNCLOS was negotiated. The approach that the CLCS has taken to deal with this uncertainty is to propose that the critical issue for the identification of the FoS is the definition of the term "base". Its most important recommendation in this regard is contained in paragraph 6.2.3 of the CLCS guidelines.

> "*The shelf and continental slope have characteristics typical of continental crust, often including thick layers of sediments. The foot and the base of the continental slope are inseparable, and commonly lie close to the outer edge of the continent, that is, near the place where the crust changes from continental to oceanic."*

The practical result of the CLCS's guidelines is that a nation has three approaches by which it can locate the FoS. The simplest is to use a morphological approach. This only requires the analysis of bathymetric information and is the least expensive option available, giving a satisfactory result for many, if not most margins. The second and third approaches, which are appropriate where the margin is geologically or morphologically more complex than the simple model envisaged by UNCLOS, is for a State to collect sufficient geological and geophysical information to make a case for the location of the "base" founded either on a geologically-supported morphological pick, or on a geological interpretation of the "outer edge of the continent". These

approaches necessitate the collection of a significant amount of geological and geophysical data and consequently involve greater cost; however, they may provide a State with the opportunity to significantly increase the size of its continental shelf that extends beyond 200 M – its extended continental shelf (ECS). Australia chose to collect sufficient data over all of its margins where an ECS is likely to exist in order to place itself in a position to be able to use geological evidence to support the location of the FoS if necessary.

Two points need to be made at this stage. Firstly, Article 76 makes no mention of crustal type (continental or oceanic). In fact, the history of the development of the concept of the continental shelf clearly shows that the scientific emphasis was on morphology. Although Article 76 alludes to continental and oceanic regimes, the use of crustal type was specifically rejected during the negotiation of the convention. The approach adopted to determine the submerged prolongation of the land mass of the State is based on morphology. Where morphological prolongation exists, there is no requirement to support the prolongation argument with geological data, although a State may choose to do so. States can use geological/geophysical data to clarify or support a case where morphological arguments are equivocal or incomplete. The second point, is that the FoS must lie within the morphological margin. In particular, where evidence to the contrary is utilised, the proxy pick is for the location of the FoS - a morphological feature that lies within the continental margin that consists of the shelf, slope and rise. It is not a proxy for the limit of natural prolongation of the continent. This is determined by the application of paragraph 4(a) to the proxy FoS location to give the outer edge of the continental margin.

Determination of the Location of the Foot of Slope (FoS)

In order to use a consistent approach across all of its margins, Australia adopted a protocol consisting of two stages. Firstly, each profile is assessed on the basis of morphology alone. The second stage, which is only relevant for a minority of profiles that generate FoS locations, uses geological evidence to locate the FoS. This second stage can lead to two further outcomes - a FoS defined using geological evidence to support the morphological location of the base of the slope; or a FoS defined on the basis of geological evidence alone (a proxy FoS). This last, and least common, type relies on the concept of evidence to the contrary and is located by proxy without any direct reference to morphology, and will often lie at a point where there is no change in the gradient of the seafloor.

Stage 1. The identification of possible morphological FoS locations

The CLCS has indicated that identification of the FoS requires that the location of the base of the slope first be identified and then the point of maximum change in gradient in this basal zone be determined. The identification of the base is an interpretive process, while the identification of the point of maximum change in gradient in this zone is a mathematical process. This means that scientific expertise is required for the identification of the base. This is true for the location of both a FoS point using morphology alone and for a FoS using geological supporting data. This raises the question: what is the base of the slope? Paragraph 6.2.2 of the CLCS guidelines advise:

"6.2.2. From a geomorphological perspective, the shelf in ideal cases is the part of the seabed adjacent to the continent, which forms a large submerged terrace that dips gently seaward. The breadth of the shelf depends on the geological evolution of the adjacent continent. The continental shelf extends seaward to the continental slope, which is characterized by a marked increase in gradient. The base of the slope is a zone where the lower part of the slope merges into the top of the continental rise or into the top of the deep ocean floor, in the case where no rise exists". (see Fig. 1)

On many margins this zone can be identified by morphology alone using standard morphological criteria. As a rule of thumb, we consider that the base must lie on the lower part of the morphological margin and would normally occur between the point where the general gradient of the margin became less than 1° (the lower end of the range of slope gradients) and above 0.5° (the generally quoted upper limit of rise gradients). The exact FoS location within the generally narrow, interpreted base of slope zone is then chosen as the point having the maximum change in gradient. It is recognised here that gradients are not the only characteristic to be used in distinguishing between slopes and rises, and that geological characteristics and evolution are also important. However, such factors cannot be readily assessed using bathymetric data alone, and indicate the need for other geological/geophysical data in places where the gradient alone may not be definitive.

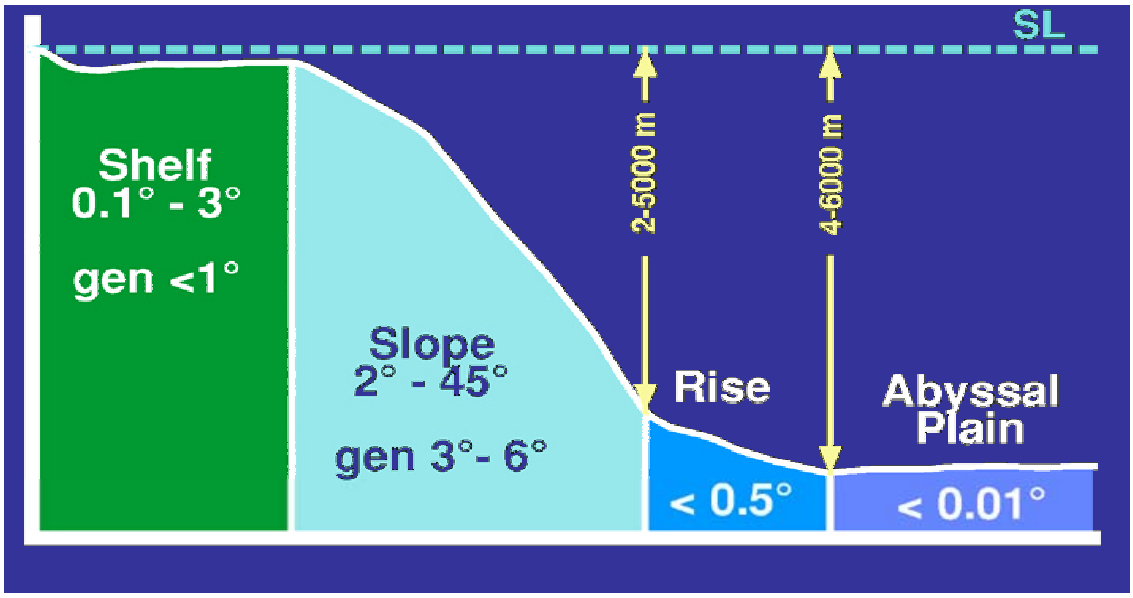

Figure 1. Shows a generalised profile illustrating the main morphological provinces of a simple continental margin. In this case, the abyssal plain is synonymous with the deep ocean floor of Article 76. Modified from Symonds et al. (2000).

The morphological FoS picking stage involves examination of bathymetric profiles along selected ship's tracks across a margin to determine possible FoS locations. The first location selected is the outer limit of the morphological margin. This point determines the outermost location for a potential FoS and therefore reduces the search area. Next, all other locations are identified on the profile where a case for the

location of the base of slope can be made. This often resulted in picks being made from the outer edge of the morphological margin back to the mid-slope. A location is then usually identified from amongst these possible base of slope locations as the preferred location for the FoS according to Article 76 criteria.

Two processes are applied to review the FoS locations. Firstly, profiles oriented in approximately the same direction are displayed as vertically stacked profiles aligned on the preferred FoS. The FoS points on these profiles are then compared in order to assess the consistency of picking. Secondly, the picks were plotted in plan view over a detailed bathymetric grid to ensure that they are all located in a similar part of the morphological margin. Anomalous picks are then examined a second time and re-picked if necessary.

Stage 2. FoS identification using geological/geophysical data.

Subsequent to the morphological picking, a second stage of analysis is undertaken on margins where it is believed that geological information could be used to support the location of a preferred FoS pick. The preferred FoS can be either a geologically supported morphological pick or an evidence to the contrary pick.

To make the case for a geologically supported FoS, it is necessary for a State to prove that the "*submerged prolongation of its land mass*" extends beyond the most-pronounced morphological FoS. Such situations are commonly identified during the morphological stage of picking, although this is not always the case.

To make the case for an evidence to the contrary pick it is necessary to demonstrate that there is no credible morphological pick and then to identify a geological proxy for the FoS.

Our approach to the use of geological data is guided by the following:

- The FoS must lie within the physical continental margin
- A State has the right to justify its case on the basis of the best understanding of the nature of continental margins at the time of submission.
- The reason for using geological data is to assist in the location of the base of slope zone.

The CLCS guidance on the location of the base was mentioned in the discussion on the identification of the morphological FoS. This guidance is also relevant to the identification of geologically supported FoS picks.

The issue that most often has to be resolved on the Australian continental margin is the nature of the features forming the deep margin, and in particular does a rise exist between the slope and the deep ocean floor? For the purposes of the convention, the CLCS has defined the rise as being (Paragraph 6.2.1)

> *"……The rise is normally a **wedge-shaped sedimentary body** having a smaller gradient than the continental slope. The rise developed predominantly*

in a rifted margin realm with sufficient supply of sediments from the continent ***after***[2] *breakup and commencement of sea-floor spreading*

This paragraph is important to geologically-supported FoS picks. Morphologicalally, a rise may be a feature near the base of the margin where the gradient lies below 1^{o}; however, this paragraph constrains a rise both in geological nature and mode of formation.

Evidence to the Contrary – "the exception to the general rule"

The CLCS has defined the use of evidence to the contrary in a restrictive sense; that is it is only to be used where a morphological or geologically supported morphological pick cannot reliably identify the location of the FoS. There are a number of situations where this may occur. The most obvious is the situation where there is no morphological feature on the continental margin that can reasonably be used to identify the FoS. Another situation is where the most obvious morphological feature that could be used as a FoS location lies in relatively shallow water far inboard of the base of the margin. An example of this situation was noted by Hedberg (1981) with regard to the east coast of the United States of America. As a result of a large sediment input from the continent, the rise, as it is commonly described in the literature covering this margin, has built up to such an extent that the FoS is traditionally defined at about 2000-2500 m water depth. Hedberg (1981) proposed that the most suitable location of the FoS for international boundary purposes was at about 4000-4500 m water depth, at the base of what has traditionally been referred to as the "upper rise", rather than "lower slope". This example highlights difficulties in determining what is the base of the slope and the top of the rise, and points to differences in thinking between the definition of geomorphological provinces in traditional scientific studies versus their use in UNCLOS to delineate marine jurisdictional boundaries.

In the application of evidence to the contrary to the Australian margin, we have used the following principals adapted from the CLCS guidelines.

- evidence to the contrary is only applied where the geomorphological evidence does not or cannot reliably locate the FoS
- evidence to the contrary is an opportunity for a State to use the best geological and geophysical evidence available to locate a proxy FoS; and
- the FoS shall be located inside the geomorphological continental margin

The CLCS has suggested that the most suitable place to locate the outer edge of the continent is within the continent ocean transition (COT) zone [3]. The CLCS has stated that it may consider the inner edge of the COT (iCOT) as equivalent to the FoS. There is currently no precise definition or consensus in the international literature on the exact extent and nature of COTs. They may extend over several tens of kilometres (paragraph 6.3.10 of the CLCS guidelines) up to about one hundred kilometres or so

[2] Our emphasis

[3] Scientific and Technical Guidelines of the CLCS Para 6.3.10. "the Commission may consider the landward limit of the transitional zone as an equivalent of the foot of the continental slope in the context of paragraph 4, provided that the submitted geophysical and geological data conclusively demonstrate that the submerged land mass of the coastal State extends to this point"

(Sayers et al., 2001). It is our opinion that the use of the iCOT as a proxy for the FoS is almost always impractical. This is because there is no agreed definition as to the location and characteristics of the iCOT, and it is therefore difficult to locate it with any consistency. An iCOT can reflect different geological processes on different types of margin, and even along the same margin. It may represent, amongst other things, a change in the characteristics (style, amount and timing) of extension of continental lithosphere, or the volume and nature of magmatism, as rifting proceeds towards continental breakup and the initiation of seafloor spreading. It is our experience that the iCOT is generally much more difficult to define than the outer edge of the continent ocean transition (oCOT/COB). This is because the oCOT/COB represents a fundamental change from continental to oceanic lithosphere, whereas the iCOT represents a change in the style of modification of continental lithosphere and is therefore a gradational boundary. It is our view that as the oCOT/COB is often more readily recognised on seismic and potential field data than the iCOT, it is a more logical location for a proxy FoS as long as it lies within the geomorphic margin. We define the oCOT/COB as the point, moving landward from the ocean, where the last unequivocal oceanic crust is present as determined using a variety of geophysical/geological information. If this point lies within the geomorphic margin, it can be considered as a proxy for the FoS, where no credible morphological FoS exists. Further support for this view is provided by paragraph 6.2.3 of the CLCS guidelines, as mentioned previously:

> "*... The foot and the base of the continental slope are inseparable, and commonly lie close to the outer edge of the continent, that is, near the place where the crust changes from continental to oceanic."*

The oCOT/COB is the place where the crust changes from continental (albeit modified by extension and magmatism) to oceanic (formed by seafloor spreading). As long as it lies within the geomorphic margin (i.e. landward of the deep ocean floor) it should be a valid proxy for the FoS.

Applying the reasoning above to define the 'legal' FoS using evidence to the contrary, the State must first show that there is no credible FoS based on morphology. It must then supply evidence on the location of the COT and its inner (iCOT) and/or outer (oCOT/COB) edges. If the edges of the COT can be reliably determined, and they lie within the morphological margin, then either edge could potentially be used to locate the proxy FoS using evidence to the contrary. In some cases, the COT may extend beneath the deep ocean floor, and the oCOT/COB will lie beyond the geomorphic margin and therefore cannot provide evidence to the contrary for the FoS. In such situations, where it can be demonstrated that the submerged prolongation of the crustal characteristics of the land mass of the coastal State extend beyond the morphological margin to the oCOT/COB, it is possible to argue that a proxy FoS could be located at the boundary between the deep ocean floor and the morphological continental margin. As the Commission's approach to evidence to the contrary assumes that no morphological basis exists for the identification of the FoS, there is no need to identify the point of maximum change in gradient when defining a proxy FoS. The oCOT/COB or perhaps iCOT, can simply be projected up to the seabed of the morphological margin to locate the proxy FoS.

Examples

Real data from the Australian margin can be used to illustrate the approach outlined above. In particular the geology and geomorphology of the Great Australian Bight illustrate many of the principles.

The Great Australian Bight is part of the southern Australian continental margin. It developed by the passive amagmatic breakup of Australia and Antarctica and includes in places a wide continent-ocean transition zone (Sayers et al 2001). Potentially up to three options exist for locating the FoS on profiles in this area.

The first stage of FoS identification is the analysis of a bathymetry profile to define possible FoS locations based only on morphology. Figure 2 shows the bathymetric profile along a seismic line collected across the Great Australian Bight margin, extending from mid-slope to the deep ocean floor. Consistent with our approach to first identify the edge of the morphological continental margin we have identified point B as marking this location. Point B lies at the boundary between a distinct morphological province with gradients between 0.7 and 1.4 degrees and above a province with a gradient of less than 0.1°, which we identify as the deep ocean floor.

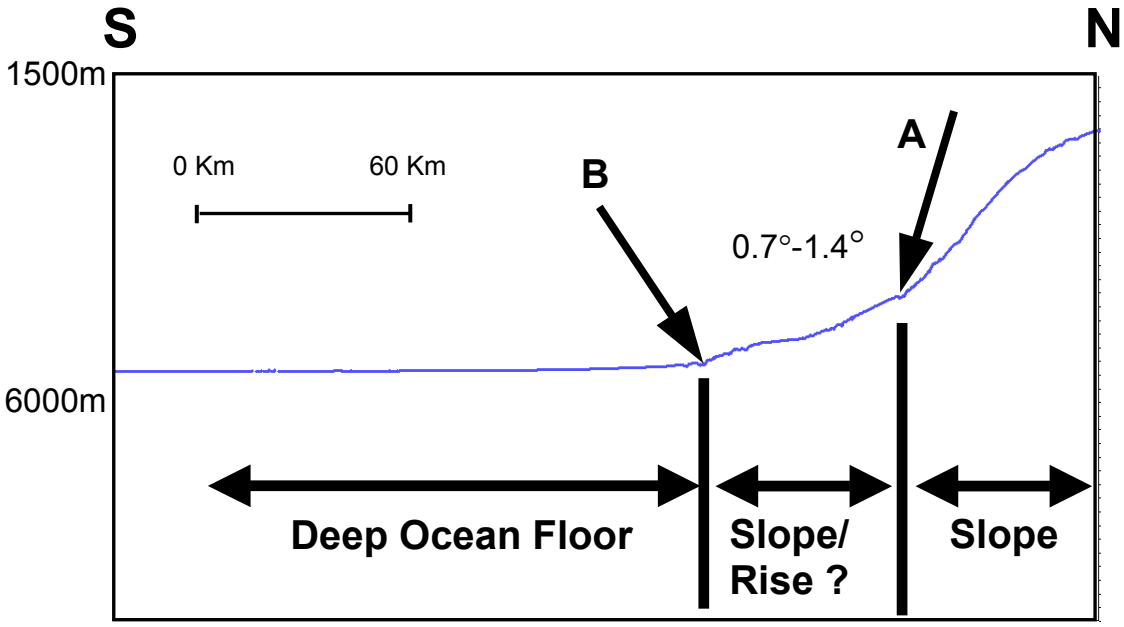

Figure 2. Bathymetric profile along a seismic line in the Great Australian Bight (blue). The two large arrows indicate possible locations of the FoS based on morphology. The left arrow (B) also represents the outer edge of the morphological continental margin

Next we identify other possible locations for the FoS on morphological grounds. To do this we attempt to divide the continental margin into shelf, slope and rise provinces. There are two obvious morphological provinces in the continental margin part of this profile - a deep lying province that lies between points B and A as marked on the profile. This province is relatively smooth and has gradients intermediate to those typically assigned to rises and slopes. Therefore, this province is identified

provisionally either as rise or lower slope. The steeper province above point A, has gradients more typical of a slope, and it is identified as a slope. Therefore we have two possible FoS locations based on morphology. On morphological evidence alone, we would most likely identify point A as the FoS.

We now include the use of other geological/geophysical data. Figure 3 shows the seismic profile recorded at the same time as the bathymetric profile. Two things are immediately obvious from this data. Firstly, the continent ocean boundary (point C; defined on the basis of seismic and potential field data; Sayers et al., 2001) lies beneath the deep ocean floor; secondly, the sediments that underlie the province that lies between points A and B predate the basin fill sediments. Closer investigation of the sediments indicates that they were deposited during the latest stages of breakup, with the most recent sediments in the package being deposited during an early slow spreading stage of oceanic crust formation. This observation has important implications for the identification of the location of the base of slope as it indicates that the province between points A and B is not a geological rise according to the CLCS definition as contained within paragraph 6.2.1 of its guidelines. Since this province lies within the margin domain, and is not part of the rise or shelf, it must be part of the slope under Article 76. Therefore, using geological supporting evidence, the FoS is located at point B.

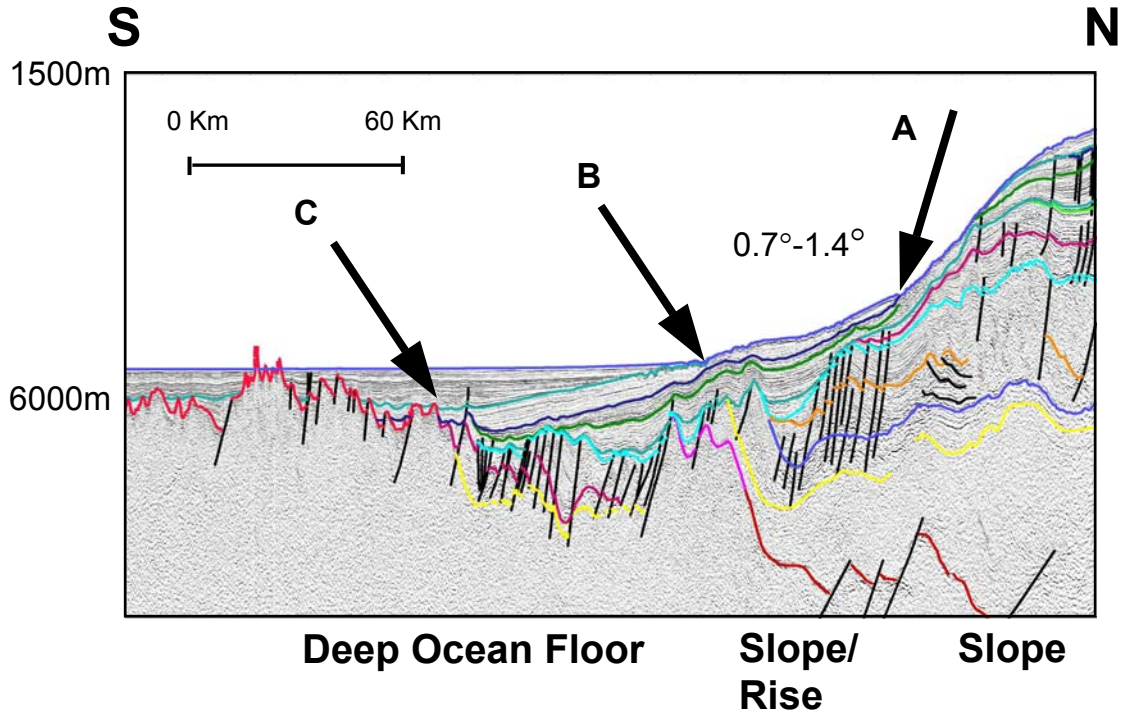

Figure 3. The interpreted seismic profile associated with the bathymetric profile in Figure 2. B is the onlap point of the basin sediments of the Australia-Antarctic Basin onto the older (Eocene and older) slope sediments of the Australian continental margin. C is the continent-ocean boundary, or outer edge of the continent-ocean transition, as defined by seismic and potential field data.

One final point can be made with regard to this profile that is relevant to the identification of FoSs using evidence to the contrary. If we were to ignore the fact that this profile has several locations on which the FoS can be identified using

morphology, or morphology with geological supporting data, we can consider the implications of the location of the oCOT/COB to the identification of a proxy FoS using evidence to the contrary.

As mentioned previously, on a margin where no FoS can be located using morphology, one alternative is to use the oCOT/COB to locate a proxy to the FoS. On this profile we are able to identify a clear COB at point C. It is our view, based on paragraphs 3 and 4(b) of Article 76, that any FoS, including a proxy FoS, must lie within the morphological margin. In Figure 3, the oCOT/COB (point C) lies beneath the deep ocean floor, and cannot therefore be used as a proxy for the FoS. In this situation and if it had not been possible to define any morphological FoS, we would have to seek an alternative solution to a proxy FoS. In this case, because the submerged prolongation of the modified continental crust of the land mass extends beneath the deep ocean floor, the most obvious solution is to locate the proxy FoS at the edge of the morphological margin (point B on Figure 3). This is, the same location as for the geologically supported morphological FoS. This high quality seismic section shows no obvious iCOT, and highlights the nebulous character of the iCOT and the difficulty in using it as a proxy FoS point.

One final sample profile is included here (Figure 4) to illustrate a situation where no morphological FoS can be located; this profile is an obvious candidate for the use of evidence to the contrary. The profile crosses a margin overwhelmed with sediment which has obscured the boundaries between the slope, the rise and the deep ocean floor. The start of the deep ocean floor (DOF) has been somewhat arbitrarily chosen and marked by the dotted line in Figure 4. Between the shelf edge and the deep ocean floor, a broad, relatively featureless province exists that incorporates the part of the margin that would normally contain the slope and rise. Using the evidence to the contrary approach outlined above, if the oCOT/COB and/or iCOT were readily identifiable and lay anywhere beneath this province, either could potentially be used as a proxy to the FoS. The proxy would be located by projecting its location upward onto the sea bed.

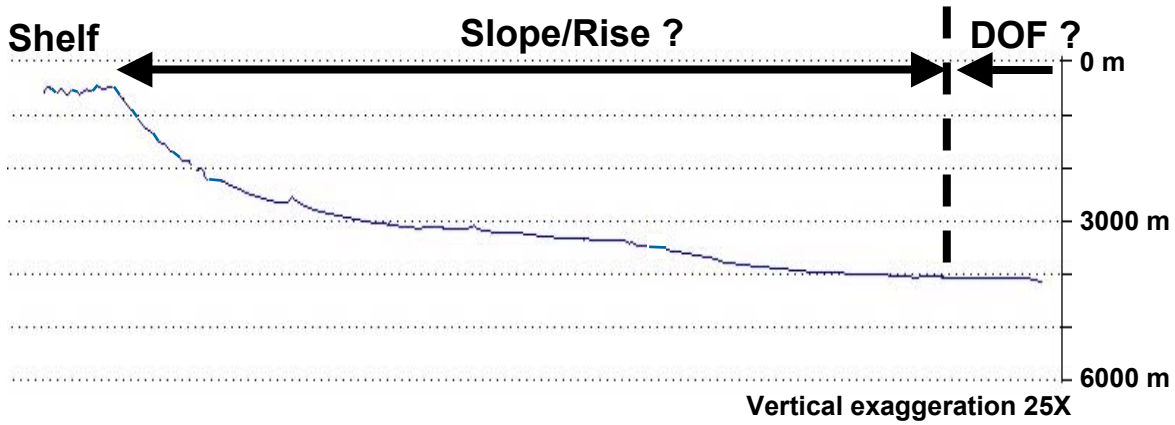

Figure 4. Bathymetric profile showing a complete margin transect from the shelf to the deep ocean floor over a margin overwhelmed by sediment input. No morphological FoS (geologically supported or otherwise) based on maximum change in gradient at its base can be readily defined on this profile and therefore it is a candidate for application of the evidence to the contrary approach.

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