FOOT OF THE CONTINENTAL SLOPE IN ARTICLE 76

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Abstract
Prolongation of the landmass is the fundamental principle of Article 76 of the United Nations Convention on the Law of the Sea, and reference to this principle has been useful where the outer edge of New Zealand's continental margin is geologically and morphologically complex.

The seafloor around New Zealand is characterised by ridges and plateaus that reflect the complex tectonic history of the region. Rifting and subduction processes have resulted in continental fragmentation, and in continental growth by the accretion of terranes, basin formation, and volcanic activity. Application of article 76 and of the Commission on the Limits of the Continental Shelf Guidelines to these features requires a thorough understanding of their morphology, geology and tectonic history.

This paper focuses on one technical aspect of article 76 — determining the location of the foot of the continental slope by *maximum change in sea floor gradient* and by *evidence to the contrary*. Examples from the New Zealand continental margin illustrate the sort of data that might be used as evidence to the contrary, and show situations where use of this evidence is more appropriate than a foot of the continental slope position based on maximum change in gradient at its base.

Introduction
Article 76 gives formulae for identifying the outer limit of the continental shelf that, in the absence of evidence to the contrary, are based on the morphology of the sea floor and thickness of sediments. The multifaceted nature of many continental margins means that the limit of natural prolongation can be hard to define from morphology alone. In some areas it is important to examine geophysical and geological evidence to find the boundary between the seabed and subsoil that are related to the land mass and the seabed and subsoil that are related to the deep ocean floor. The New Zealand continental margin is an example where an understanding of the geology and tectonic history is useful for identifying the limit of the continental shelf.

Along morphologically complex margins, geophysical and geological information can identify the region of the base of the slope where the maximum change in the sea floor gradient rule is applied. These data can also be used to determine the extent of the continental margin where foot of the continental slope positions, based on the maximum change in the gradient at its base, do not accurately reflect the extent of the natural prolongation of the landmass.

Foot of the continental slope

Article 76 provides the means to identify the limit of natural prolongation of the land mass of a coastal State. That limit is at the boundary between the seabed and subsoil that are related to the land mass and the seabed and subsoil that are related to the deep ocean floor.

Article 76 (1) states that:

> *"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,"*

and (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."*

These paragraphs state that, if the morphological boundary between the rise and the deep ocean floor, or the geological boundary between the submarine prolongation of the land mass and the deep ocean floor can be identified directly then they would define the extent of the continental margin. In practice, however, both of these boundaries are usually difficult to identify. It is often not possible to determine directly the boundary between the rise and the deep ocean floor because it is usually transitional or very subtle, and in some cases there is no rise present along the margin (Figures 1 and 2). Similarly, the geological boundary between continental rocks and rocks of the deep ocean floor can be transitional or masked by sedimentary and volcanic rocks (Figures 3 and 4).

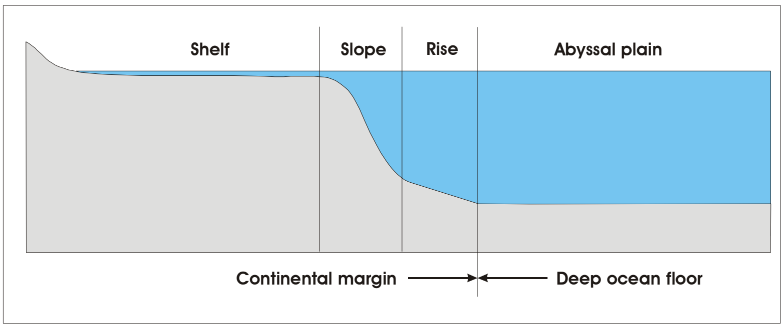

Figure 1: A schematic diagram of a margin with clear boundary between rise and deep ocean floor.

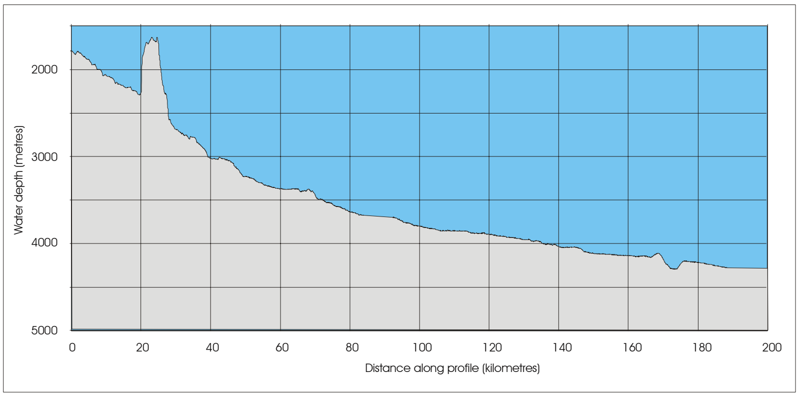

Figure 2: Example of a continental margin north of New Zealand with transitional boundary between slope, rise, and deep ocean floor.

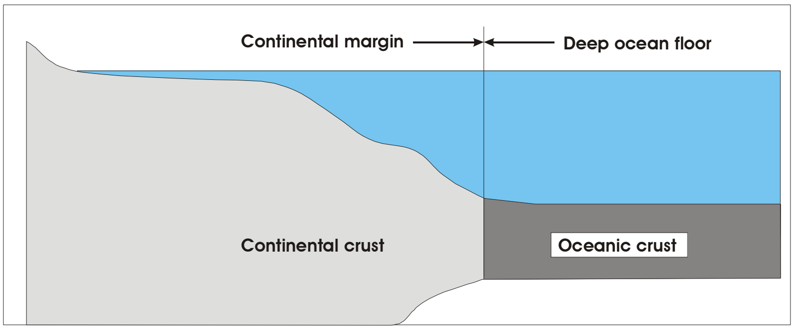

Figure 3: A schematic diagram of a margin showing geological boundary between the prolongation of the land mass and the deep ocean.

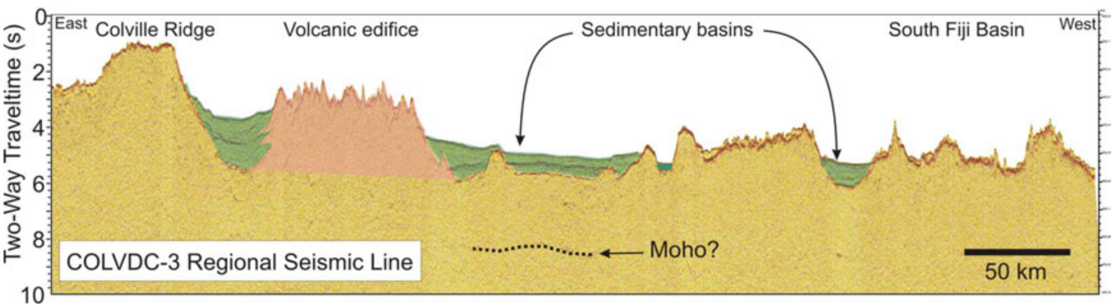

Figure 4: The continental margin at the Colville Ridge, north of New Zealand showing sedimentary basins and volcanoes along the margin make it difficult to identify the geological boundary between the prolongation of the continental rocks of the Colville Ridge to the deep ocean floor in the South Fiji Basin.

The difficulty of directly determining the extent of the continental shelf is recognised, and article 76 provides two formulae to be used as proxies to establish its extent.

According to article 76 (4) (a)

> *"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) a line delineated in accordance with paragraph 7 by reference to the outermost fixed points at 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.*"

In practice, establishing the outer edge of the continental margin requires location of the foot of the continental slope, and article 76 (4) (b) defines two methods for determining its location:

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

The Commission on the Limits of the Continental Shelf Guidelines (1999) (5.1.3) declare a preference for identifying the foot of the continental slope as the point of maximum change in sea floor gradient as the general rule, with reliance on evidence to the contrary as an exception to the rule. On many margins the morphological boundary between the slope and the rise is easily interpreted, and a formula that uses the point of maximum change in gradient to establish the foot of the continental slope can be readily applied.

Maximum change in the gradient at the base of the continental slope

The key requirements for identifying the point of maximum change in the gradient at the base of the continental slope are:

- Identification of the region defined as the base of the continental slope, and
- Determination of the location of the point of maximum change in gradient within this region.

In some areas the morphology of the continental margin can be clearly subdivided into shelf, slope, rise and abyssal plain. In these areas it is relatively straightforward to identify the region where the lower continental slope meets the rise, or where it meets the abyssal plain in cases where a rise is absent.

Along many margins around the world, however, there is substantial geographic variation in the morphology of the continental slope. The continental slope typically has a gradient of a few degrees, but can vary locally from steep escarpments to horizontal surfaces across terraces and ponded mid-slope basins. The morphology of the seabed where the continental slope merges with the deep ocean floor may be an abrupt boundary where the smooth and near-horizontal surface of the abyssal plain borders the continental slope, or it may be a complex transition where local relief on the ocean floor meets an irregular lower slope.

This variation reflects the diverse range of tectonic, sedimentary, and volcanic processes that are presently active, or have been active during the geological evolution of the margin. In these areas a careful regional analysis is often required to determine the region containing the base of the continental slope.

Having established the region of the base of the slope, the point of maximum change in gradient is determined by calculating the second derivative of the bathymetry values to locate the point of maximum change in gradient (Figure 5).

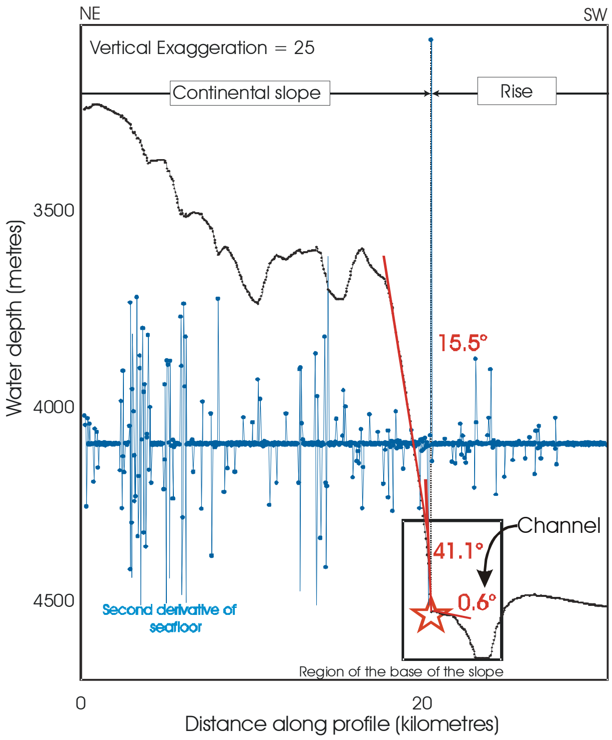

Figure 5: Determination of the foot of the continental slope (shown as a star) using the method of maximum change in gradient at its base. Digital bathymetry is shown as a black line, the second derivative of the bathymetry values, determined with GIS software, is the blue line and the red lines are seafloor gradients with the slope given in degrees.

Along morphologically complex margins it is often useful to consider the crustal structure and sediment depositional patterns to identify the region of the base of the continental slope before determining the change in sea floor gradient. Indeed, analysis of geophysical and geological data may, in some areas, show that the edge of the continental margin determined by the maximum change of sea floor gradient at the base of the continental slope is not a good approximation of the extent of natural prolongation of the land mass. It is in these areas where "*evidence to the contrary*" can be used to locate the foot of the continental slope.

Evidence to the contrary

The Commission Guidelines (1999) (6.1.10) state that in some situations

> *"the geomorphological evidence given by the maximum change in the gradient as a general rule does not or can not locate reliably the foot of the continental slope."*

These include situations where margin profiles have no single point with maximum change in gradient, or where irregular seafloor topography results in a point with maximum change in gradient at its base that does not accurately reflect the edge of the continental margin. In these cases establishing the true extent of natural prolongation requires consideration not just of the bathymetry, but also consideration of the crustal structure, sediment apron geometry, plate tectonic history, and other aspects of the growth of the continental margin and formation of the boundary between rocks that are part of the continent and those that are part of the deep ocean floor.

The Commission Guidelines (6.3) discuss potential examples of evidence to the contrary that might be used in relation to different types of continental margins. All of these examples use geological and geophysical data to identify features that serve as alternatives to foot of the continental slope positions based on the maximum change in gradient.

For rifted margins the Commission Guidelines (1999) (6.3.10) state that

> *"If the foot of the continental slope is very difficult to define on the basis of bathymetric data, the Commission might consider the continental-oceanic transitional (COT) ... as the place to determine the outer edge of the continental margin. Since the transitional zone can extend over several tens of kilometres, 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."*

The Commission recognises that transitional zones between the seabed and subsoil that are related to the land mass and the seabed and subsoil that are related to the deep ocean floor can be quite broad. These transitional zones may be several tens of kilometres wide, and are often characterised by faulted blocks of continental crust and areas of intruded and extruded volcanic rocks. The Commission considers that the outer edge of the continental margin may be defined using the formulae of article 76 (4) (a) and foot of the continental slope positions located at the inner edge of the continent-ocean transition zone (Figure 6).

Across an active convergent plate boundary, the Commission Guidelines (6.3) (a) identify either the "*seaward edge of the accretionary wedge*" or "*the foot of the upper plate and ... the foot of the inner trench wall*" as the seaward extent of the continental margin. The use of these locations is applicable where deep ocean seafloor is being subducted, but is not relevant in instances where the convergent plate boundary lies between continental blocks. In these areas, such as the South Island of New Zealand, the continent landmass occurs on both sides of the plate boundary and it does not disrupt continental prolongation. The outer edge of the continental margin therefore lies at the outboard edge of the continental blocks.

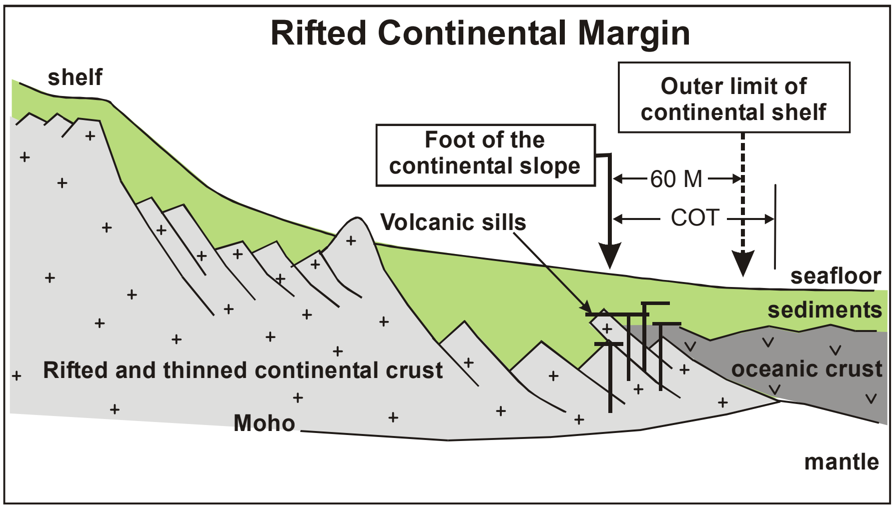

Figure 6: A schematic diagram showing a rifted continental margin where geological and geophysical evidence delimits the continent-ocean transition (COT). The landward limit of the transition zone is identified as the foot of the continental slope from witch the outer limit of the continental shelf can be determined (modified from Commission Guidelines 1999, fig 6.1D).

New Zealand examples of evidence to the contrary

Two areas of the New Zealand region where it has been helpful to use geological and geophysical data to identify the extent of natural prolongation are the Lau Terrace and the Hikurangi Plateau (Figure 7). In these areas seismic reflection data are used to interpret geological structure and locate the continent-ocean transition. This information is used as supporting evidence for the identification of the region of the base of the slope, or is used to demonstrate that the foot of the continental slope positions based on the maximum change in gradient are not appropriate because they do not accurately reflect the extent of continental prolongation.

The Lau Terrace and Western Lau Terrace

The northern New Zealand margin is characterised by shallow, northerly trending ridges and relatively wide, deep basins. They reflect a tectonic history dating from the early Cenozoic, and possibly even the Late Cretaceous, to the present. Ridges that extend northwards from the northern margin of New Zealand include an active volcanic arc (Kermadec Ridge) with the island volcanoes of the Kermadec islands, and the inactive Colville Ridge volcanic arc (Figure 8). The arcs extend onto the New Zealand landmass and are an integral part of New Zealand's geology and topography. The Lau Terrace and Western Lau Terrace are located along the western margin of the Colville Ridge adjacent to the oceanic South Fiji Basin.

The Lau Terrace is characterised on bathymetry maps as a ~350 km long ridge semi-parallel to the Colville Ridge (Figure 8). The terrace is enclosed by the continuous 2,500 m isobath that encompasses the Colville Ridge and the New Zealand landmass, and morphologically the Lau Terrace is a natural component of the New Zealand margin. A 40–60 km-wide lower slope terrace, referred to as the Western Lau Terrace, is located along the western flank of the Lau Terrace. Its regular morphology is interrupted by several small pinnacles and spurs that extend westward into the South Fiji Basin.

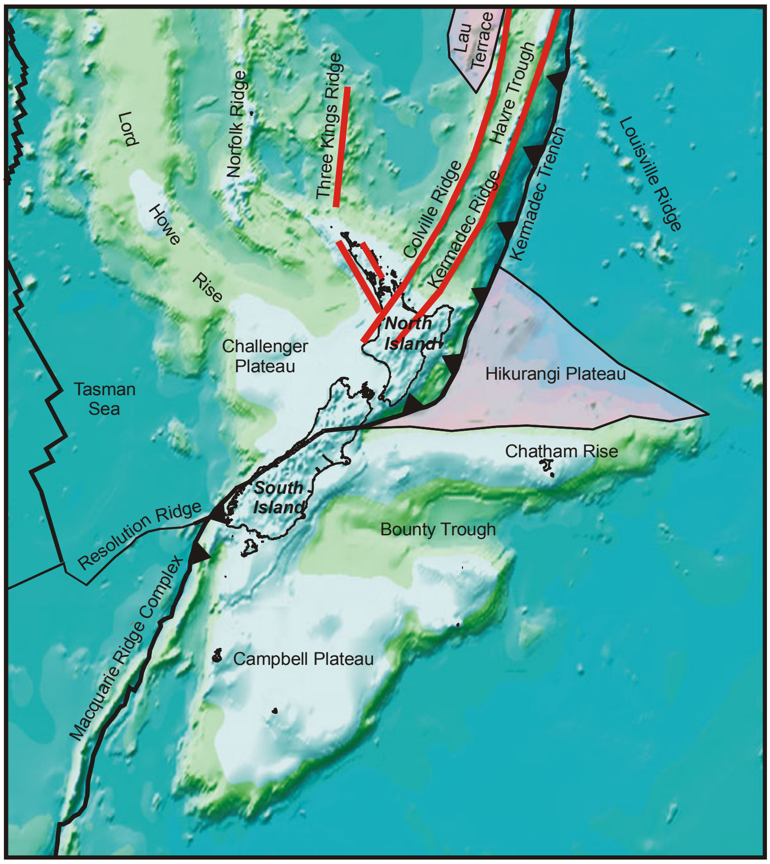

Figure 7. A map showing the tectonic features of New Zealand. The thick black lines are the present-day active plate boundary through New Zealand (triangles indicating subduction direction) and the former spreading centre in the Tasman Sea. Thick red lines show the location of active and fossil volcanic arcs associated with subduction. The shaded areas show the location of the Hikurangi Plateau and Lau Terrace.

Seismic reflection data show that basement for both the Lau Terrace and the Western Lau Terrace is comprised of tilted fault blocks (Figure 8). These west-facing fault blocks are interpreted to have formed as a result of rifting about an axis further west. In addition, gravity modelling indicates that the Western Lau Terrace crust is 1–2 km thicker than the 7–8 km thick oceanic crust further west in the South Fiji Basin. In contrast, the crustal thickness at the Lau Terrace to the east is 14–17 km. The interpretation of the gravity and seismic reflection data indicate that the Western Lau Terrace is thinned volcanic arc crust and is a natural prolongation of the New Zealand landmass.

On the lines shown in Figure 8 there are several possible locations where a foot of continental slope position can be identified with the “maximum change in gradient” formula. In order to determine which of these is the most appropriate, the region of the base of the slope must first be delimited. Identification of the continent-ocean transition zone is one way to locate this region which is thus interpreted to be at the western edge of the Western Lau Terrace. Foot of the continental slope positions can be determined from either the maximum change in sea floor gradient at its base or by using the point identified as the landward limit of the continent-ocean transition zone. In the example shown in Figure 8 these occur at the same location.

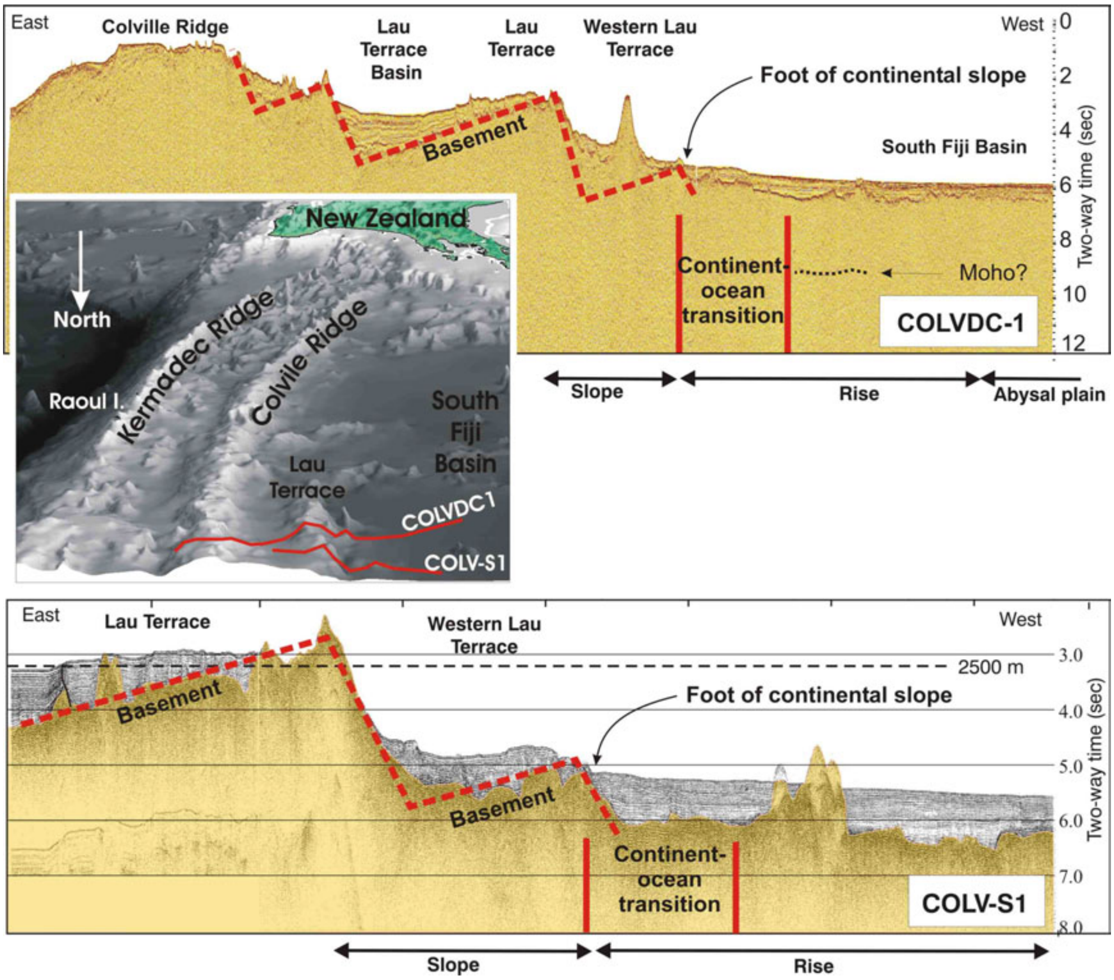

Figure 8: Seismic sections and a location map (looking south) of the Lau Terrace and Western Lau Terrace. This part of the New Zealand continental margin is characterised by terraces that are tilted basement fault blocks (red dashed line). The foot of the continental slope lies at the western edge of the Western Lau Terrace.

The Hikurangi Plateau

The Hikurangi Plateau (Figure 7) is a large igneous province lying east of the North Island and north of the Chatham Rise (Wood and Davy, 1994; Mortimer and Parkinson, 1996). It has an area of about 350,000 km^2 and lies at an average water depth of about 3,000 m. The plateau has a complex structure with typically 500 metres of sediments overlying a sequence of volcanic rocks. Gravity modelling indicates that its crust is 10–15 km thick, compared to 6–8 km for the oceanic crust to the northeast (Davy and Wood, 1994). The plateau is currently being subducted beneath the East Coast of the North Island of New Zealand.

The Hikurangi Plateau is the focus of a great deal of current research. It is thought to have formed before about 140 Ma and collided with the Chatham Rise portion of the Gondwana margin about 90 Ma (Davy, pers. com.). On seismic sections the surface of the Hikurangi Plateau can be traced beneath the northern margin of the Chatham Rise, possibly marking the location of a fossil subduction zone.

Although the Hikurangi Plateau is currently being subducted beneath the North Island, it is now sutured onto the Chatham Rise and is a natural prolongation of the New Zealand landmass. Much of the Chtaham Rise rests on the underlying Hikurangi Plateau, reinforcing the continuous connection between the elevated and thickened rocks of the Hikurangi Plateau and those of the Chatham Rise and onshore New Zealand.

Seismic lines recorded across the northern margin of the Chatham Rise and the Hikurangi Plateau (Figure 9) show that there is a break in slope along the base of the Chatham Rise. The Hikurangi Plateau is not composed of rocks 'of the deep ocean floor' so the continental margin occurs up to 700 kilometres further to the north at the edge of the Hikurangi Plateau. The northern edge of the plateau changes along strike from a one kilometre high escarpment on the seafloor in the west (profile A) to a buried escarpment in the east (profiles B and C).

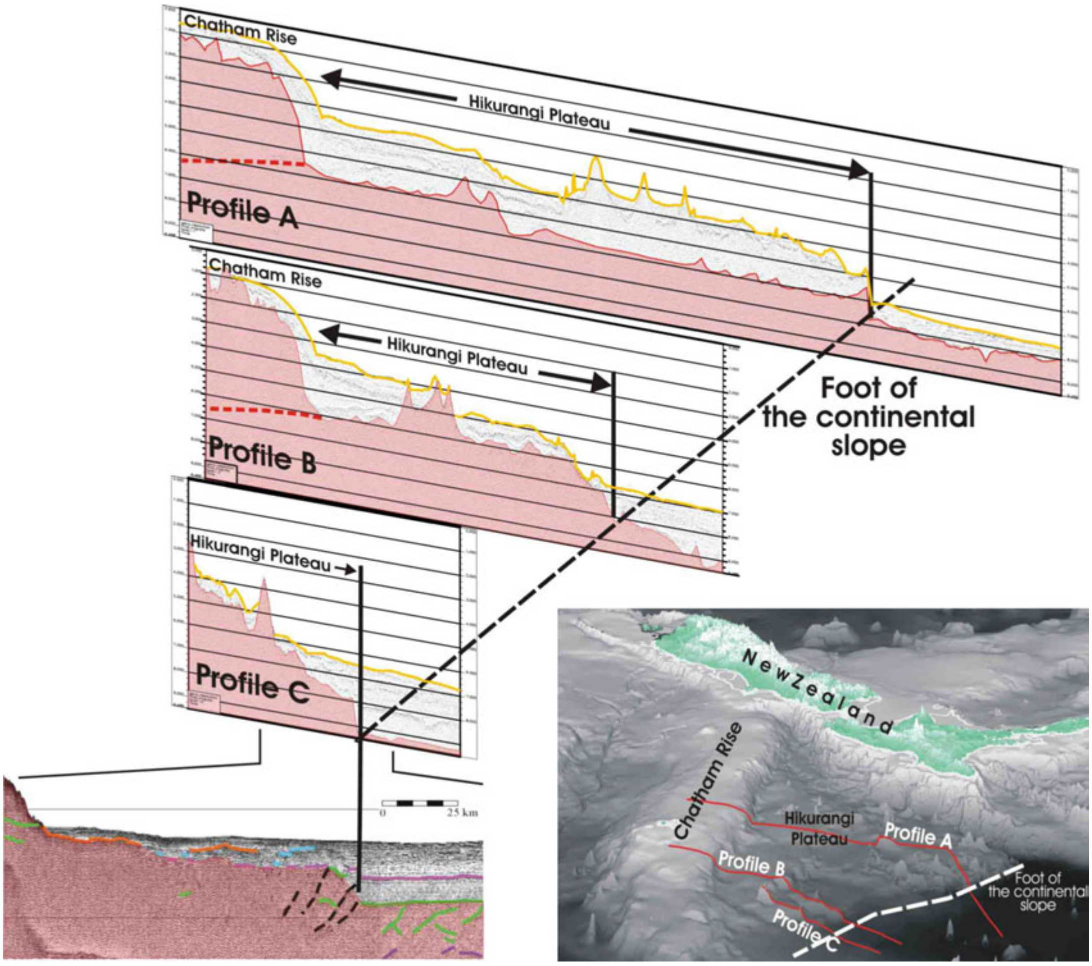

Figure 9: Seismic sections and location diagram (looking to the southwest) over the Chatham Rise and Hikurangi Plateau. The seismic profiles show the interpreted basement (pink) and paleo-suture (red dashed line) marking the location of a possible fossil subduction zone. The bottom seismic profile shows an interpretation of the northern edge of the plateau on Profile C. The foot of the continental slope is located at the point of the maximum change in seafloor gradient on profile A, but not on profiles B and C.

The foot of the continental slope is located at the point of the maximum change in seafloor gradient on profile A. On profiles B and C the foot of the continental slope is located at the inner edge of the continent-ocean transition zone between the Hikurangi Plateau and ocean crust further north. This boundary is about 100 km beyond the point of maximum change in seafloor gradient on profile C.

Conclusions

There are two steps to finding the base of the continental slope. The first step is to identify the region of the base of the continental slope, and the second step is determination of the location of the foot of the continental slope within that region. In areas where the morphology of the continental margin can be clearly subdivided into slope, rise and abyssal plain, it is relatively straightforward to identify the region of the base of the continental slope and to locate the point of maximum change in gradient within this region.

In areas where the natural prolongation of the landmass is hard to define from morphology alone, geophysical and geological data can be used to interpret the crustal structure of a continental margin and locate the continent-ocean transition. Determination of the location of the foot of the continental slope within that region can be by application of the maximum change in sea floor gradient formula, or where this in inappropriate, by locating the inner edge of the continent-ocean transition.

Acknowledgements

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References

CLCS/11, 1999. Scientific and Technical Guidelines of the commission on the Limits of the Continental Shelf. Commission on the Limits of the Continental Shelf.

Wood, R., Stagpoole, V., Wright, I., Davy, B., Barnes, P. 2003. New Zealand's Continental Shelf and UNCLOS Article 76. 56 p. Wellington, New Zealand: Institute of Geological & Nuclear Sciences Ltd and National Institute of Water and Atmospheric Research.

Davy, B and Wood, R 1994. Gravity and magnetic modelling of the Hikurangi Plateau. Marine geology. 118: 139-151.

Mortimer, N., Parkinson, D. 1996. Hikurangi Plateau: a Cretaceous large igneous provice in the southwest Pacific Ocean. Journal of geophysical research, 101: 687-696.

Wood, R, and Davy, B 1994. The Hikurangi Plateau. *Marine geology*. 118: 153-173.