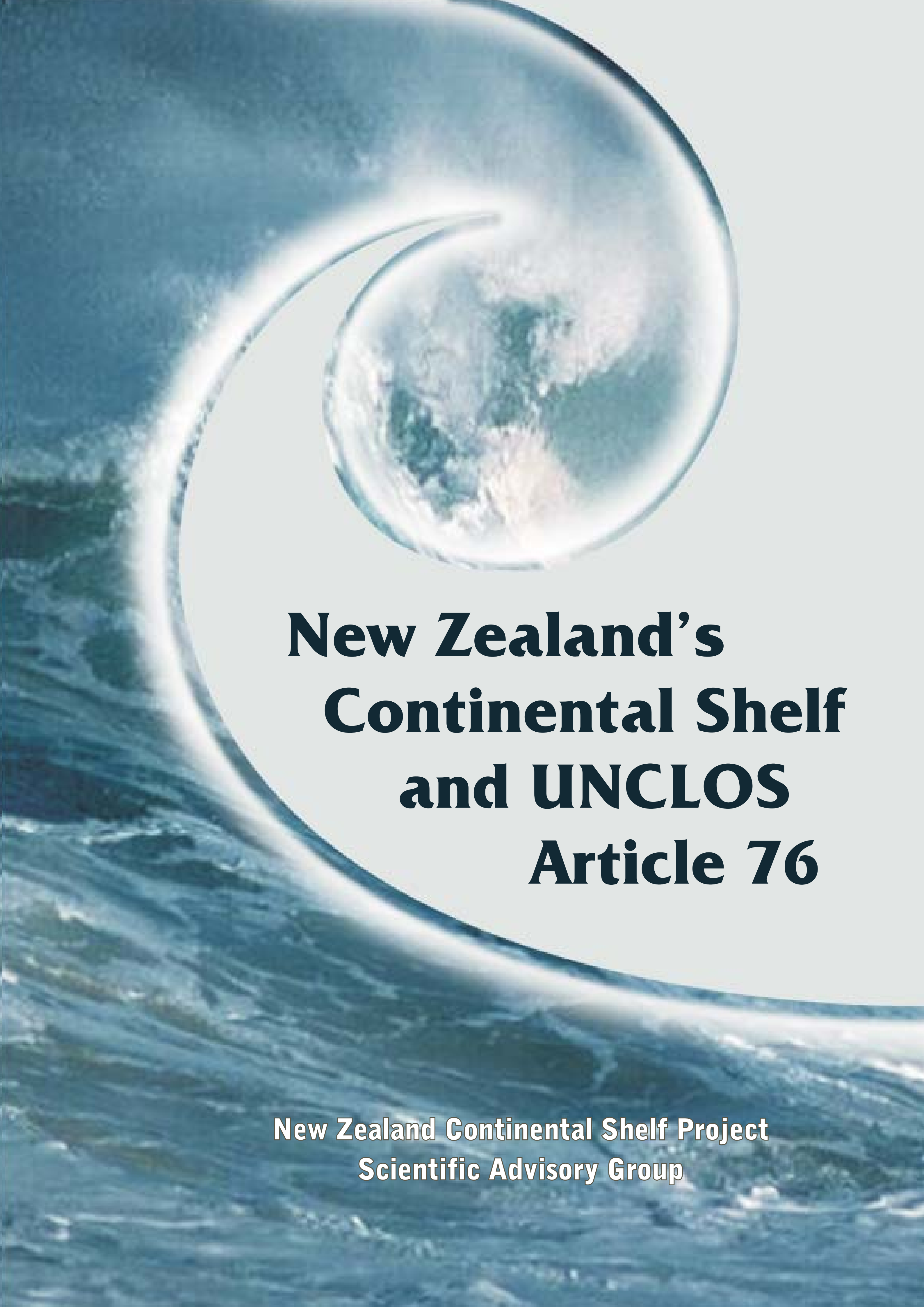

New Zealand's Continental Shelf and UNCLOS Article 76

New Zealand Continental Shelf Project
Scientific Advisory Group

"The more or less continuous landmass that appears above the waves is the upthrust welt that marks the seam between two lithospheric plates. Our country is not merely a sea-girt realm, it is a veritable kingdom of the deep."

Dr Ian Reilly, November 1994

The link between New Zealand and the surrounding oceans is profound. The islands of New Zealand are the emergent highlands of a vast sunken sub-continent shaped by global tectonic forces. New Zealand's land and surrounding sea floor share a common geological history that is reflected in their form and in the nature of the rocks beneath the surface.

Following the great Polynesian explorers of the South Pacific, the Dutch mariner Abel Tasman surveyed the west coast of New Zealand in 1642. His observations were the basis for the first published chart showing New Zealand. Captain James Cook made the first systematic measurements of the shape of the seafloor in the region during his voyage in 1769. The New Zealand Continental Shelf Project continues this tradition of scientific exploration. Its goal is to establish and document the extent of the submarine prolongation of New Zealand.

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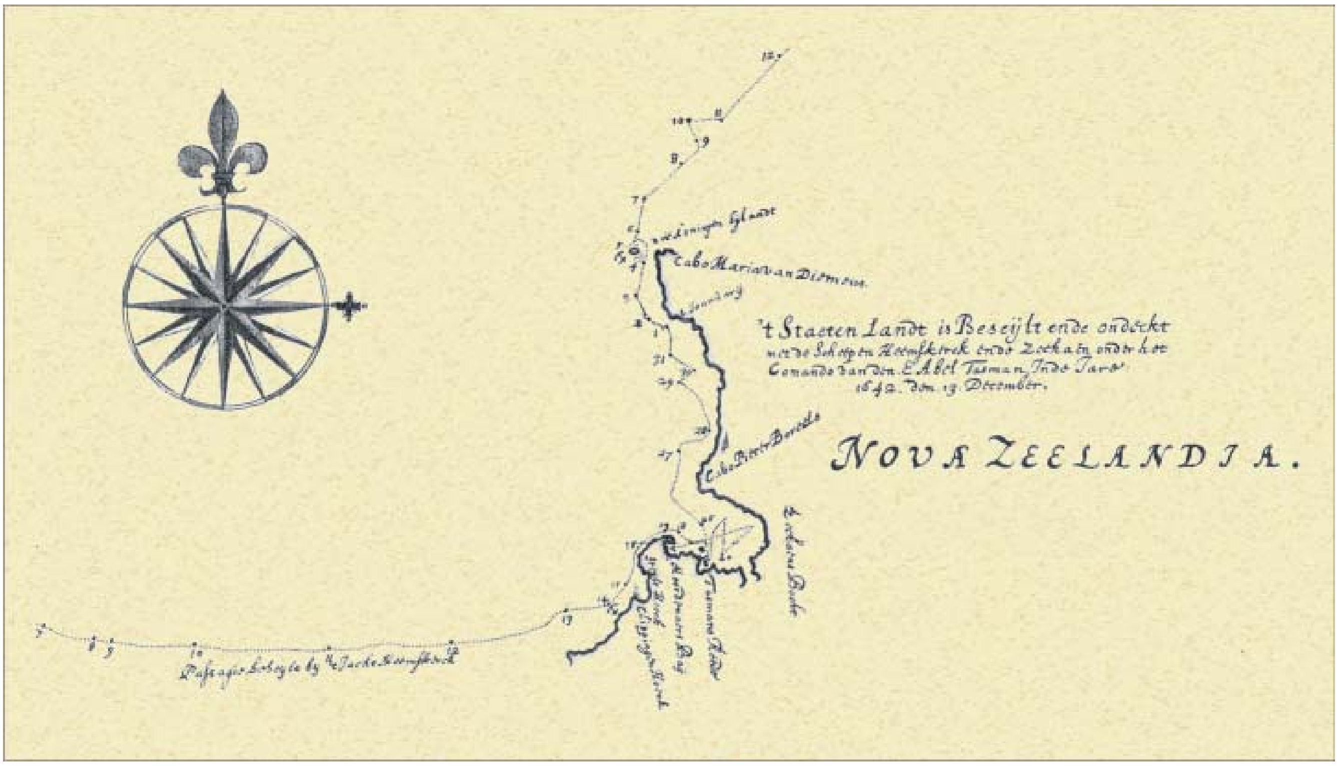
NIWA
Taihoro Nukurangi

New Zealand's Continental Shelf and UNCLOS Article 76



Ray Wood, Vaughan Stagpoole, Ian Wright,
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New Zealand Continental Shelf Project Scientific Advisory Group

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Title Page

This map of sections of the western coast of New Zealand's North Island and South Island is part of Visscher's chart of Abel Tasman's voyages in 1642-43 and 1644, and was drawn about 1666. A copy of this and other early charts of New Zealand can be found in *Historic Charts and Maps of New Zealand 1642-1875* by P.B. Maling.

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The NIWA research vessel Tangaroa undertook many surveys for the New Zealand Continental Shelf Project between 1998 and 2002. Bathymetry, seismic, gravity and magnetic data as well as dredged rock samples were acquired during these voyages.

The New Zealand Continental Shelf Project

Prompted by the desire to settle, in a spirit of mutual understanding and co-operation, all issues relating to the law of the sea, the international community has adopted the United Nations Convention on the Law of the Sea (UNCLOS). The Convention establishes the concept of the exclusive economic zone (EEZ), an area which extends up to 200 nautical miles from the territorial sea baselines of a coastal State. Within this zone, all coastal States have sovereign rights for the purpose of exploring, exploiting, conserving, and managing the natural resources of the waters, sea-bed and subsoil. In some circumstances, however, coastal States also have sovereign rights for the purpose of exploring and exploiting natural resources on and below the sea-bed and subsoil beyond 200 nautical miles from their territorial sea baselines. The area beyond 200 nautical miles is referred to as the extended continental shelf in this publication, and the conditions under which areas of the sea floor can be included in the extended continental shelf are set out in article 76 of the Convention.

Article 76 defines the means by which coastal States establish the extent of their extended continental shelf. The fundamental principle is that the continental shelf is the submarine prolongation of the land mass of the coastal State, as distinct from the deep ocean floor. The terms and formulae in the article describe procedures for determining the limits of the natural prolongation of the land territory and are based on the morphology and geology of the sea floor. The article describes how these attributes are used to define the extent of the continental shelf.

New Zealand ratified the United Nations Convention on the Law of the Sea in 1996. In order to define the extent of its continental shelf as described in article 76 of that convention, New Zealand has undertaken the Continental Shelf Project, a multi-phase, multi-disciplinary project to identify submarine areas that are the prolongation of the New Zealand land mass.

This document discusses technical and legal issues related to the application of article 76 that have arisen during the course of the Continental Shelf Project, and some of the practical aspects of managing the project. These are likely to be of interest to countries that are preparing a submission to define the outer limits of their extended continental shelf.

Part 1 of the document discusses the aspects of article 76 that are most relevant for determining the extent of New Zealand's extended continental shelf. They include understanding the meaning of continental prolongation; finding the foot of the continental slope; establishing the location of the 2,500 metre isobath; differentiating among submarine ridges, oceanic ridges, and natural components of the margin; establishing sediment continuity; dealing with enclaves; and using straight lines to connect fixed points to define the outer limit of the continental shelf.

Part 2 describes the data used by the New Zealand Continental Shelf Project, including the types of data, data processing and analysis techniques, and uncertainties.

Part 3 outlines the organisation of the final report of the New Zealand Continental Shelf Project. This report will form the basis for New Zealand's submission to the Commission on the Limits of the Continental Shelf.

Application of the principles of article 76 to the varied continental margins of the world requires understanding of the terms and formulae in the article. The efforts by the Commission on the Limits of the Continental Shelf (CLCS) to provide guidance are particularly useful, but even the Scientific and Technical Guidelines[1] issued by these experts acknowledge the complexity of the continental margins.

The New Zealand Continental Shelf Project team has referred to the publications of the CLCS[1,2] and to other published commentaries on article 76[3] in all phases of the project. Members of the project team have also contributed to the discussion of the application of article 76 by participating in international workshops and conferences.

This publication presents the New Zealand Continental Shelf Project team's current understanding of the nature of the New Zealand continental margin in terms of the principles and interpretation of article 76. The opinions are solely those of the authors and do not represent the official policy of the New Zealand government.

A submission defining the extent of New Zealand's continental shelf beyond 200 nautical miles from the baselines of the territorial sea will be submitted to the Commission on the Limits of the Continental Shelf. Figure 1 shows an estimate of the area of extended continental shelf beyond 200 nautical miles in the New Zealand region. In some areas the extent of the extended continental shelf is subject to negotiation with other coastal States.

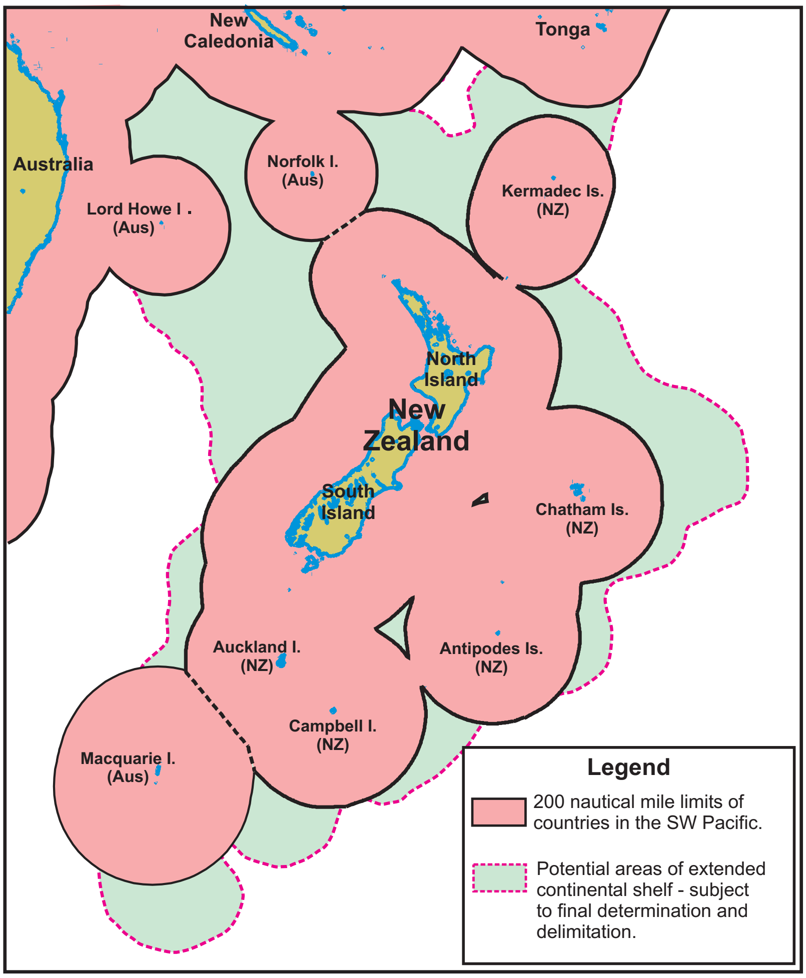


Figure 1 *Map showing the 200 nautical mile limits in the New Zealand region and an estimate of the area of extended continental shelf generated by the coastal States of the region. Some of these areas are subject to negotiation between the coastal States concerned.*

FOOTNOTE:
The international nautical mile (M) is equal to 1,852 metres (1.852 kilometres).

Part 1 – Article 76 and New Zealand's continental shelf

Introduction

Where the continental shelf extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, article 76 provides two formulae that are used to determine the outer edge of the continental margin. The outer edge of the continental margin is defined by fixed points located either 60 nautical miles from the foot of the continental slope, or where the sediment thickness is at least 1% of the shortest distance to the nearest foot of the continental slope position. There are also two constraints on the outer limits of the continental shelf: either 350 nautical miles from the baselines of the territorial sea, or 100 nautical miles from the 2,500 metre isobath (Figure 2).

The terms and formulae in article 76 have geomorphological, geological and legal contexts and can be applied in several ways[1,3]. Issues related to the application of article 76 that have arisen during the course of the New Zealand Continental Shelf Project and that are discussed in this publication are:

- Continental prolongation
- The foot of the continental slope determined from maximum change in gradient at its base and "evidence to the contrary"
- Sediment continuity
- The 2,500 metre isobath
- Submarine ridges, oceanic ridges and natural components of the margin
- Straight bridging lines

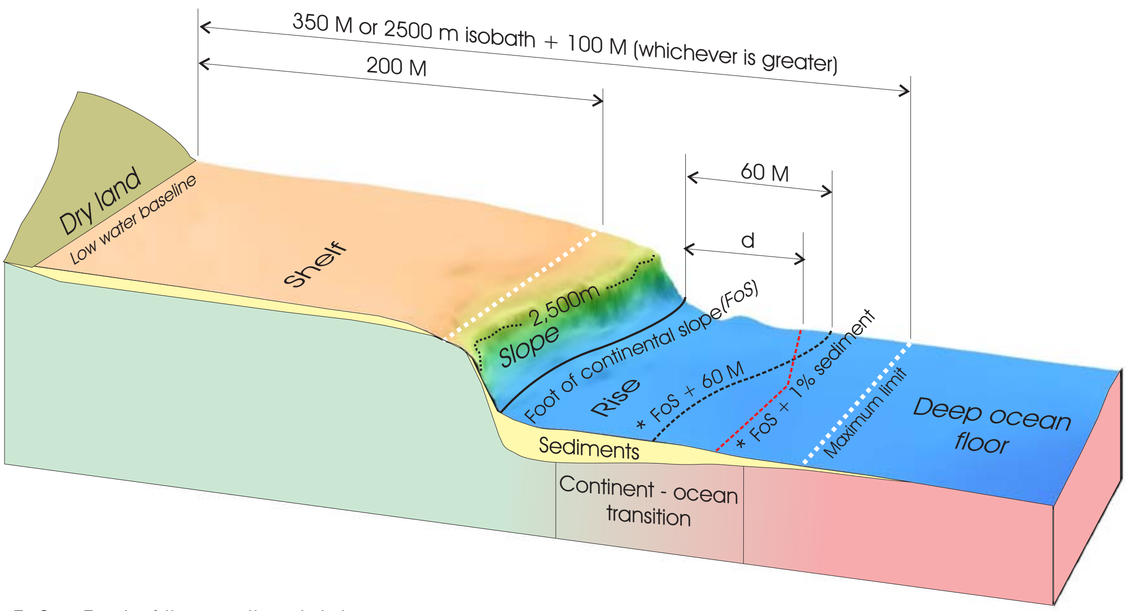


***Figure 2** Diagram summarising the formulae and constraints on the outer limits of the continental shelf from UNCLOS article 76 (modified from Kapoor and Kerr [4]).*

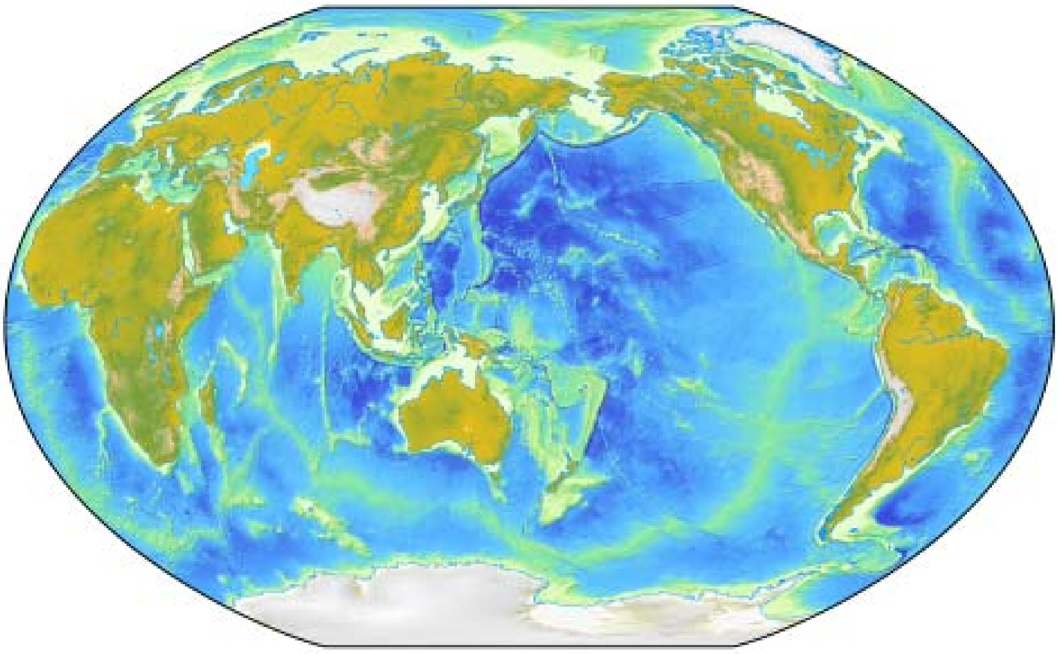


Figure 3 *Physiography of the Earth's continents and oceans (data from Etopo2 bathymetry released by the United States National Geophysical Data Center).*

Continental prolongation

Continents, oceans and plate tectonics

Even a casual glance at a map of the Earth's surface shows the variety and complexity of continental margins (Figure 3). Their morphology and geology reflect the tectonic processes that have formed them, including the rifting and collision of continents, plate subduction, transcurrent faulting, and volcanism. As a result of these processes, some margins have a relatively simple transition from continental rocks exposed above sea level to oceanic rocks beneath the deep ocean floor. On other margins, however, the transition can involve a rugged topography of ridges, seamounts, and canyons, including accreted and displaced terranes, and broad zones of transitional crust.

Article 76 (3) of the Convention states:

> "*The continental margin comprises 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 or the subsoil thereof.*"

The article distinguishes between those parts of the ocean floor that are related to the land, and those that are not. The continental margin "*consists of the sea-bed and subsoil of the shelf, the slope and the rise*", implying that these features are distinct, in both their geomorphology and geology, from areas that are a part of the deep ocean floor.

The chemical composition or tectonic origin of the rocks is not by itself sufficient information to distinguish continents from the deep ocean floor. Rocks of oceanic origin can be found anywhere, from mid-ocean ridges to the tops of mountain ranges. Continental rocks can be surrounded by oceanic crust and preserved as fragments isolated from the main continents.

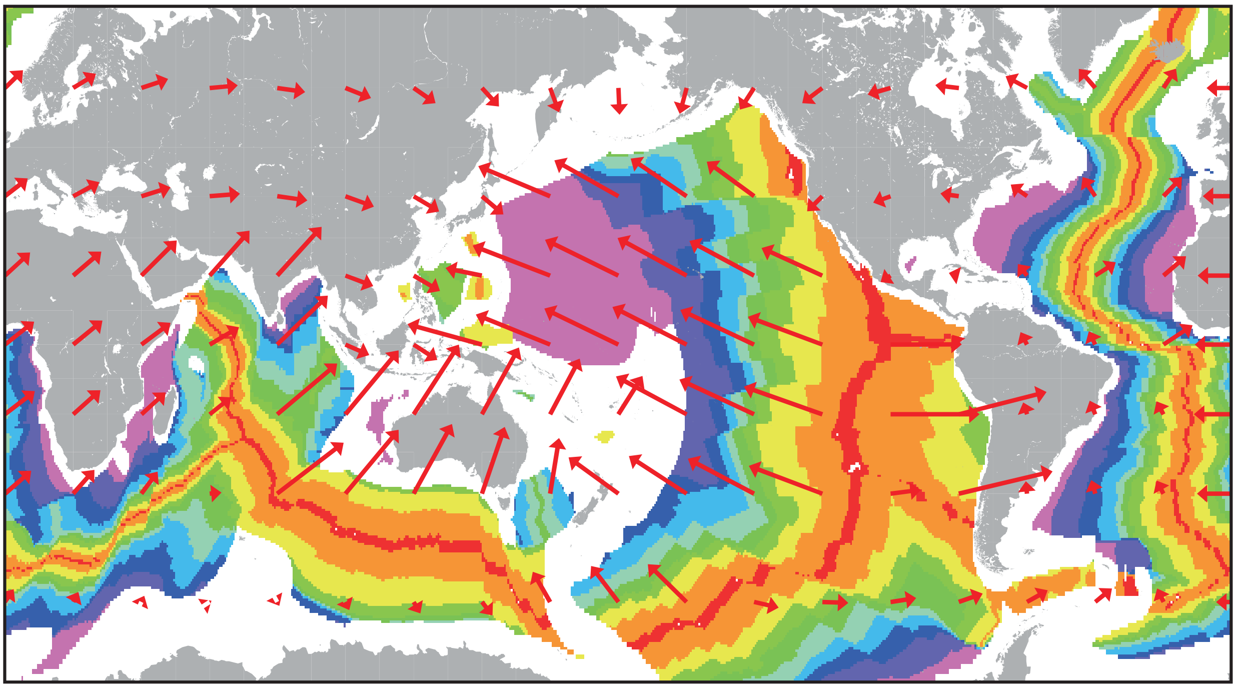
Continental rocks are the product of sedimentary, metamorphic and magmatic processes—they are commonly high in silica, but are quite varied in composition. On the other hand, the formation of oceanic crust is a relatively uniform process and, although the rocks of the deep ocean floor vary somewhat in chemical composition, they are generally basaltic. Basaltic rocks, however, are also common parts of continental land masses and can be voluminous. These basaltic rocks may have erupted in place or they may have been added to the continent by plate tectonic processes.

The distinction between those parts of the ocean that are a natural prolongation of the land territory and those that are part of the deep ocean floor lies in the tectonic context of the rocks, which is understood by studying their morphological and geological evolution. This complexity is why article 76 makes no mention of the chemical composition of the continental shelf or its origin, but rather defines the limits in terms of morphological and geological connections with the land mass.

When considering the extent of the submerged prolongation of the land mass it is necessary to understand what distinguishes continental land masses from the deep ocean floor. To do this it is useful to consider why some parts of the Earth are above sea level and other parts lie at great depths beneath the oceans.

The average elevation of the land masses is about 1,000 metres, and the average depth of the oceans is about 4,000 metres. The total range of elevation, however, is much greater—from highest mountain to deepest ocean trench is about 20,000 metres. These large topographic differences are due to variations in the composition and density of rocks in the Earth's crust, and to active tectonic forces that are continuously driving changes in the shape of the Earth's surface. The fundamental distinction between the land masses and the deep oceans is geological in origin, and the geological variation is manifest in the Earth's morphology. Why this is so can be most easily explained by considering how continents and oceans form.

Figure 4 *Map showing global plate motions[5] and age of the ocean basins interpreted from sea-floor spreading magnetic anomalies[6]. The youngest ocean crust is at the mid-ocean spreading centres (red) and the oldest crust (purple) is often adjacent to the continental margins. The white areas have no identified sea-floor spreading magnetic anomalies.*



Continents and deep ocean basins are a product of the global plate tectonic convection system (Figures 4, 5). At the outer skin of the global convection system, oceanic crust is generated at mid-ocean ridges and moves away from the ridges as younger crust is formed. As a result, the age of rocks of the ocean floor gets older with increasing distance from the spreading ridges (Figure 4). Continents are amalgamations of generally more buoyant rocks that are moved about on the plate tectonic conveyor system. The outer surface of the globe is thus divided into large plates that move relative to each other, and may include both ocean floor and continental rocks.

Deep ocean sea floor

Deep ocean sea floor forms by the cooling of basaltic magma rising from the mantle at mid-ocean spreading ridges. Because the Earth is not expanding, creation of new crust at mid-ocean ridges results in compression along other sections of the plate boundary. Along these margins older crust is recycled by subduction back into the Earth's mantle (Figure 5).

When new ocean floor is formed, some minerals within the rock become aligned with the orientation of Earth's magnetic field at the time that the molten magma solidifies. The orientation of the Earth's magnetic field, however, reverses periodically over geologic time. Strips of ocean crust of different age thus have different magnetic signatures. As a result, the deep ocean floor commonly shows a characteristic pattern of magnetic anomalies, usually in the form of stripes parallel to the mid-ocean ridges and symmetrical about them (Figure 4). The discovery of these magnetic anomalies led to the formulation of the theory of plate tectonics. Their analysis has contributed to our understanding of the present-day global tectonic forces, and how these forces have changed over time

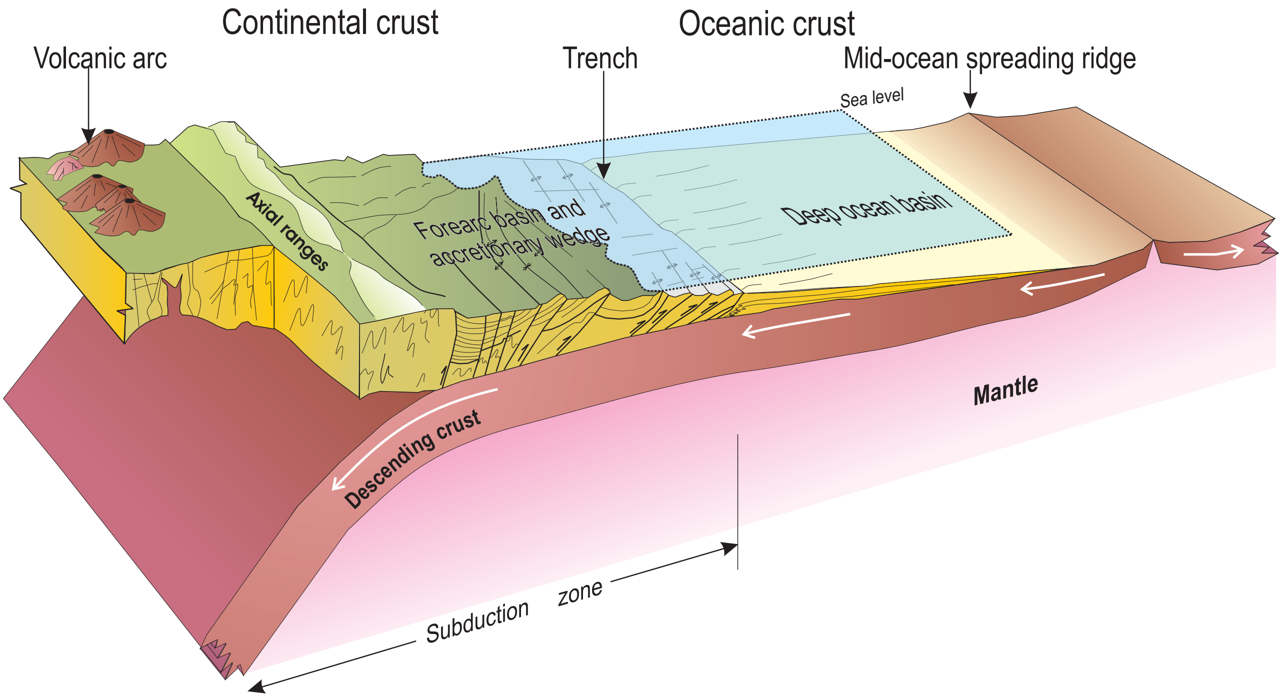


Figure 5 *Schematic cross-section showing the generation of ocean crust at mid-ocean ridges and subduction of crust beneath continents.*

Continental land masses

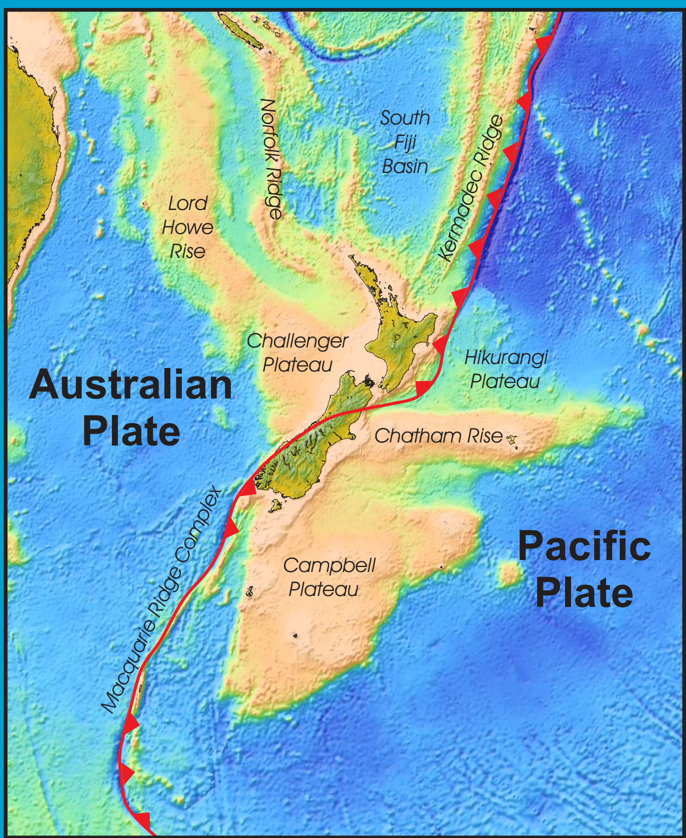
Land masses are not characterised by size or rock type, but are the result of igneous, metamorphic, sedimentary and tectonic processes that form geological crust distinctly different from crust of the deep ocean floor. The extent and composition of land masses can change with time. The following sections discuss the way in which continents grow and break apart, and the nature of the boundary between continents and the deep ocean floor.

Growth of continents

Most continents are an amalgamation of a wide variety of rock types. Continents grow by accretion and suturing—the addition of material along the boundary where plates move together. They also grow by the deposition of large volumes of sedimentary rocks in basins near the continental margin, and by volcanic activity.

New Zealand region

The New Zealand land mass is a composite. Some rocks were originally part of the Australian and Antarctic regions of Gondwana. Other rocks have been accreted to, intruded into, or deposited on the Gondwana rocks in the course of the tectonic evolution of the region. The same suites of rocks can be found both on land and in the submarine plateaus and ridges around New Zealand. This map shows the present-day tectonics of the New Zealand region. East of the North Island, the Pacific Plate is being subducted beneath the Australian Plate, and in the southwest corner of the South Island the Australian Plate is being subducted beneath the Pacific Plate (triangles show the subduction direction). The two subduction zones are linked through the South Island by the Alpine Fault, a predominantly strike-slip fault.



Growth at subduction zones

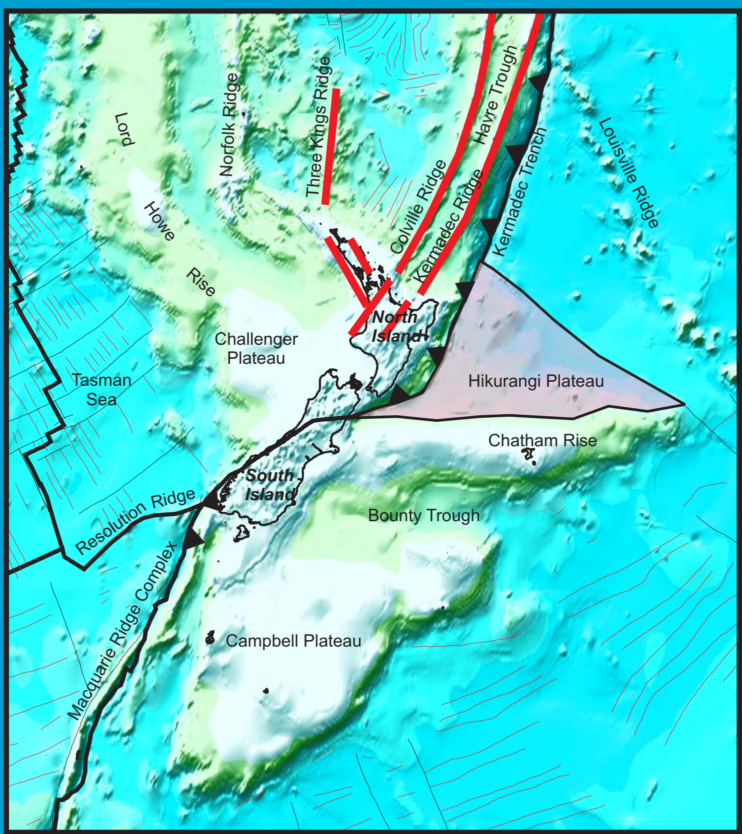
Where continental rocks and oceanic rocks collide, the oceanic crust is generally subducted beneath the continent (Figure 5). Occasionally, because of the geometry of the plate margin or the nature and buoyancy of the rocks on the subducting plate, pieces of the subducting plate—sometimes including oceanic crust—are scraped off onto the continent. These terranes—blocks of crust accreted at the plate margin—can be small or very large, depending on the nature, density and thickness of rocks arriving at the subduction zone, and the subduction dynamics.

The margins of many continents, including the basement terranes of New Zealand, are examples of this growth process. The basement of New Zealand consists of suites of rocks that were accreted to the Gondwana continent along a subduction margin[7].

Growth of the New Zealand continent

New Zealand has had a dynamic geologic history, strongly affected by plate tectonic events for at least the last 230 million years. The geology and bathymetry of the wider New Zealand continental region are thus complex, characterised by plateaus, ridges, troughs, seamounts, volcanic arcs, fracture zones and fossil oceanic spreading centres. The continent and land mass are a complex amalgamation of rifted crustal plateaus, accreted terranes and volcanic arcs.

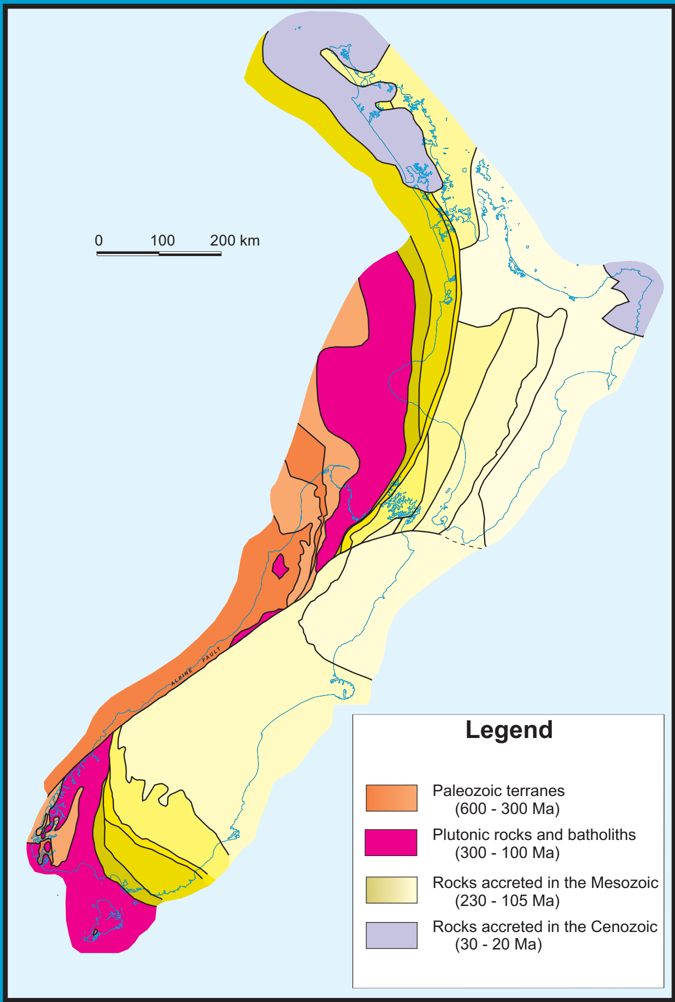
This map shows tectonic features in the New Zealand region. The thick black lines show the present plate boundary through New Zealand (with triangles indicating the subduction direction) and the former spreading centre in the Tasman Sea[8]. Grey lines are magnetic anomalies associated with seafloor spreading[8]. Thick red lines show the location of active and fossil volcanic arcs associated with subduction. The shaded area shows the location of the Hikurangi Plateau, a large igneous province accreted to New Zealand.



Accreted terranes of the New Zealand continent

The basement rocks of New Zealand[10] consist of Paleozoic rocks of Gondwana (550–250 million year old, orange colours), intrusive igneous rocks (red) and rocks that have been accreted to the margin in the last 230 million years (yellow colours and purple). Three phases of plate convergence have affected the New Zealand region since 230 million years ago.

1. ***A major period of continental growth took place along the Gondwana margin from the Triassic to the Early Cretaceous (230–105 million years ago). These rocks (yellow colours) were amalgamated onto the New Zealand land mass and are now a major component of the basement rocks of New Zealand.***
2. ***The Northland and East Coast Allochthons (purple), of the order of 100,000 km^3, were accreted to the New Zealand landmass about 25 million years ago[11] (Figure 9).***
3. ***Oblique convergence from about 30 million years ago to the present day has resulted in thickening of the crust and accretion of sediments along the modern plate boundary through New Zealand.***



Where two continents collide, the continental rocks generally resist being subducted, as neither plate can easily slide back into the mantle beneath the other. This causes a thickening of the crust and the uplift of the Earth's surface. Mountain ranges, such as the Himalayas or New Zealand's Southern Alps, usually form as a result. The colliding blocks can become welded together, enlarging the area of land mass and continental margin. The collision of continental masses can interfere with subduction, causing a local re-orientation of the plate boundary or the initiation of a new plate boundary elsewhere.

How accretion affects the extent of the continental margin is addressed in the CLCS Guidelines (7.3.1):

> "*In active margins, a natural process by which a continent grows is the accretion of sediments and crustal material of oceanic, island arc or continental origin onto the continental margin. Therefore, any crustal fragment or sedimentary wedge that is accreted to the continental margin should be regarded as a natural component of that continental margin.*"

In the Cretaceous, the Hikurangi Plateau, a large igneous province that is similar in composition to oceanic crust, but thicker and more buoyant, arrived at the subduction zone along the New Zealand portion of the Gondwana margin. Accretion of the plateau to the New Zealand continental mass[9] resulted in a re-organisation of the plate boundaries.

Growth by sedimentary basin formation

Erosion of continental land masses leads to the deposition of sediments in adjacent ocean basins (Figure 6). The amount of sediment can be very large, and tens of kilometres of sediment have been deposited in some basins. Parts of these basins may be underlain by oceanic rocks, but the affinity of the basins to the land mass is recognised by article 76 (4)(a), which uses sediment thickness as one of the criteria determining the extent of the extended continental shelf.

Sedimentary basins are the primary source of hydrocarbons, and their inclusion in the extended continental shelf reflects the focus on exploration for natural resources that has accompanied the evolution of the rights of coastal States to the continental shelf.

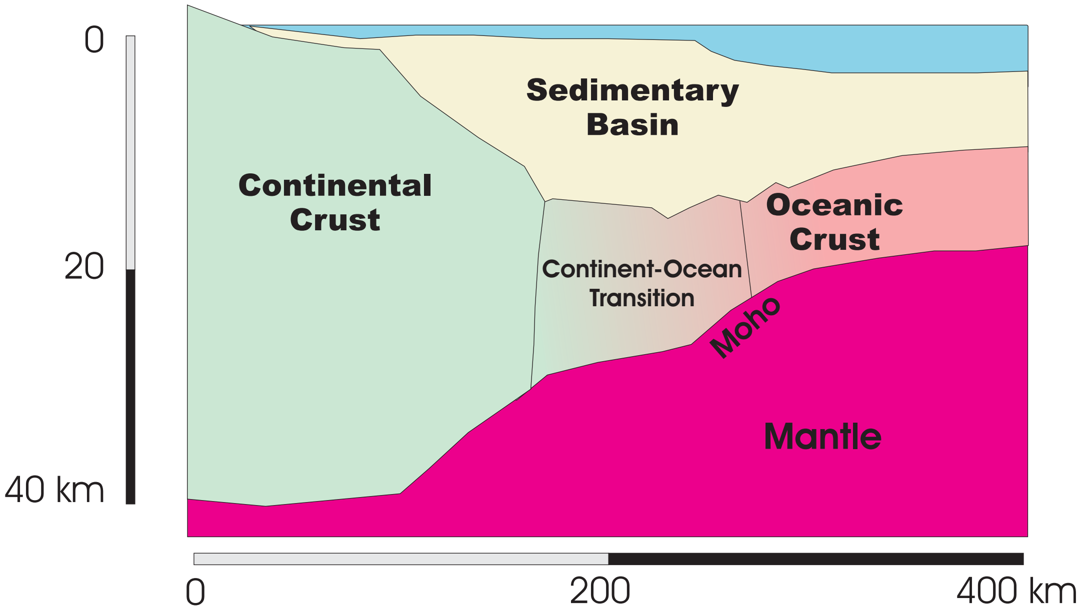


Figure 6 *Schematic diagram of a sedimentary basin at a passive continental margin.*

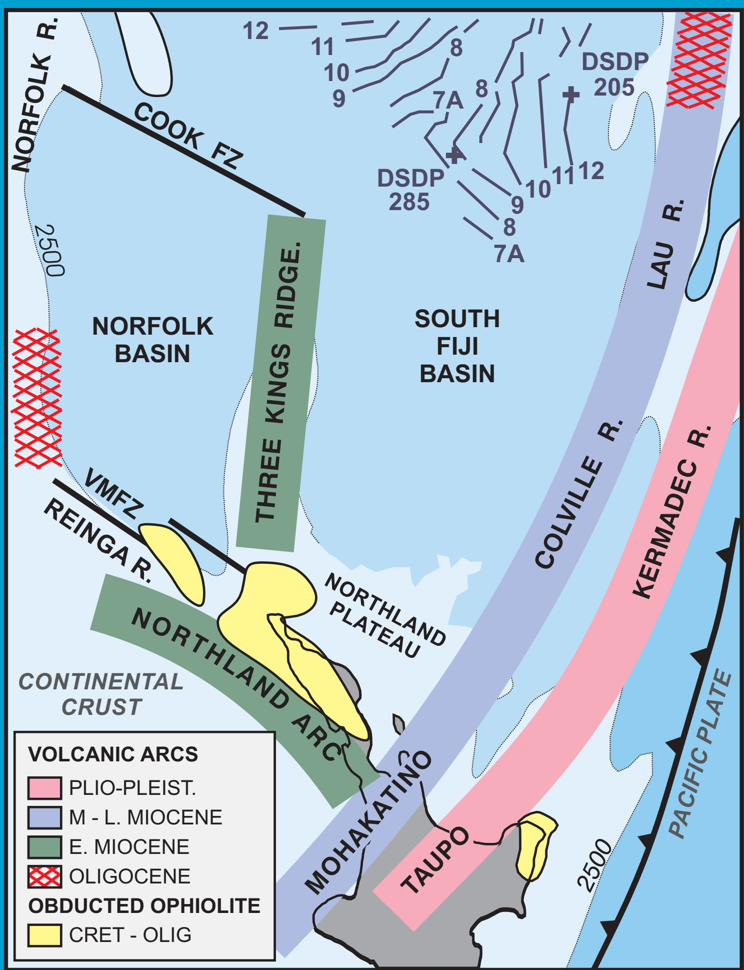
Growth by volcanism

The other geologic process leading to continental growth is volcanism. Volcanism can vary in scale from formation of isolated volcanoes within plates to massive eruptions of flood basalts. In terms of extension of the land mass, probably the most important volcanic activity is the formation of island arcs as part of the plate subduction process.

As rocks are subducted they are subjected to increasing heat and pressure. In normal circumstances water and other volatiles are expelled from the subducting plate and rise into the overlying mantle and crust. This causes the mantle and crust rocks to melt, and these molten rocks in turn rise to form volcanic island arcs (Figure 5).

Arc volcanism can produce acidic/silicic and more buoyant rocks that are the products of this refining and recycling of subducted plates. Lines of volcanoes, such as the Three Kings, Kermadec, Tonga and Colville Ridges north of New Zealand, are common above active and fossil subduction zones around the Pacific. Volcanic arcs often extend into large continental blocks (Figure 7), and the rocks associated with them form the core of many continents.

Figure 7 Mt Ruapehu and Mt Ngauruhoe (in the distance) are subduction-related volcanoes in the central North Island of New Zealand.



Growth of the New Zealand continent – volcanism

Over the last 20 million years, the subduction system north of New Zealand has migrated east, forming a series of volcanic arcs that extend northward from the North Island[12]. These arcs are tied to the geology of the North Island, and are manifest in onshore features such as the Miocene volcanics of Northland. The Taupo Volcanic Zone in the central North Island is an extension of the currently active volcanism along the Kermadec Ridge.

The Northland and East Coast regions contain significant ophiolite complexes (yellow areas)—rocks that formed as oceanic crust and have been tectonically added to the landmass (see Figure 9).

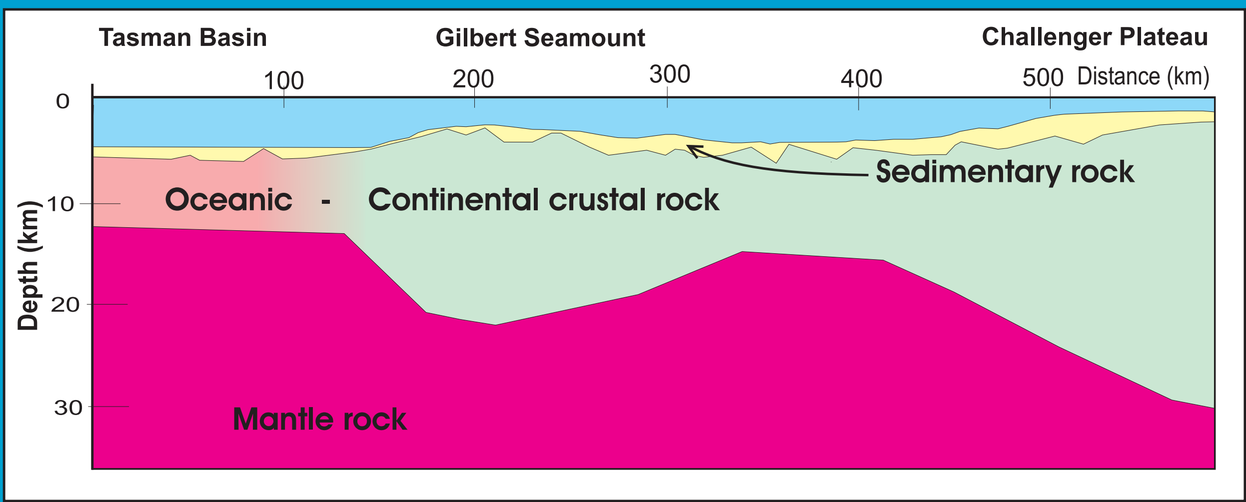
Expansion by fragmentation

Continents are also broken apart by plate tectonic processes. The same tensional forces that lead to sea-floor spreading can cause rifting and the fragmentation of continental crust. The fragments can be very large and separated by thousands of kilometres of oceanic crust, such as Australia and Antarctica, or South America and Africa. Some fragments are small blocks that lie relatively close to, or remain part of, the continental margin. During fragmentation of the continental margin, the continental crust can thin and subside below sea level. Volcanism within the extended and thinned continental crust often occurs during fragmentation. Continental crust is breaking up today in the East African rift, the Red and Dead Sea rift, and the Central Volcanic Region of New Zealand.

New Zealand continental fragmentation

The New Zealand continental block has been fragmented by at least two major phases of rifting over the last 120 million years. Fragmentation of Gondwana began more than 80 million years ago. Later, about 40 million years ago, the modern plate boundary began to develop through New Zealand.

Gilbert Seamount is a block of continental crust, originally part of Gondwana. The 4,000 metre deep saddle between it and New Zealand formed during fragmentation of Gondwana and the separation of New Zealand from Australia and Antarctica. This profile is a composite derived from the interpretation of seismic and gravity data along line NZ–C. The continuous rifted basement structure, thickness of the crust, and lack of seafloor spreading anomalies are evidence of prolongation of the New Zealand land mass to Gilbert Seamount.



The CLCS Guidelines (7.3.1) state

> "*In passive margins, the natural process by which a continent breaks up prior to the separation by sea-floor spreading involves thinning, extension and rifting of the continental crust and extensive intrusion of magma through that crust. This process adds to the growth of continents. Therefore, sea-floor highs that are formed by this breakup process should be regarded as natural components of the continental margin where such highs constitute an integral part of the prolongation of the land mass.*"

This means that natural prolongations of the land mass include rocks that can trace a continuous morphological or geological link to the land mass, even though that connection may have been modified by tectonic activity.

Assessment of prolongation relies on morphological and geological evidence of ties to the land mass—the continuity of the connection determines whether a feature is inherently related to a land mass (e.g., formed by the same processes, or accreted to it) or is a feature of the deep ocean.

A wide range of geophysical and geological data can be used to assess the nature of the rocks on and beneath the sea floor and their relationship with those of the land mass. Analysis of geological samples can provide powerful evidence for the origin of the rocks, but rock type by itself is not sufficient to demonstrate prolongation of the land mass. Geophysical data provide the most convincing evidence for a continuous connection with the land mass on the basis of morphology and/or geology. The tectonic history of the region can provide evidence for processes such as accretion and fragmentation, and therefore can be a basis for assessing prolongation.

Continent-ocean and plate boundaries

The boundary between the prolongation of the land mass and the deep ocean floor can be abrupt or gradual, depending on the tectonic dynamics of the formation of the margin. The boundary can often be difficult to identify, using even the most advanced geological and geophysical data.

There are a number of processes associated with continental breakup that can make the continent-ocean transition hard to locate. These processes can blur the contrast in rock types, making the transition harder to detect geologically, or bury the transition, making it harder to detect geophysically. During the initial stages of continental rifting, volcanic dikes and sills may intrude into extensive regions of the continental crust. The eruption of sub-aerial or submarine lava flows may bury the rift features, resulting in the formation of a broad continent-ocean transition zone that is difficult to resolve. In addition, the locus of rifting may shift during the early phase of continental break-up, resulting in a complex transition zone. The formation of thick sedimentary basins along the continental margin can further mask the location and nature of the continent-ocean boundary.

Where a continent-ocean boundary or continent-ocean transition exists, CLCS Guidelines (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.*"

This means 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.

Across an active convergent plate boundary, the CLCS 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. These locations are applicable where deep ocean sea floor is being subducted, but they are not relevant in instances where the convergent plate boundary lies between continental blocks.

In the latter case, the plate boundary does not disrupt continental prolongation because the continent is on both sides of the boundary. The outer edge of the continental margin therefore lies at the outboard edge of the continental blocks. The plate boundary through the land mass of New Zealand is an example of such a boundary.

Present day growth of the New Zealand continent

The Southern Alps, seen here from the space shuttle (photograph courtesy of NASA), are a modern example of the result of collision between continental rocks on the Pacific and Australian plates. The Southern Alps stretch for over 500 kilometres and at their highest point, Aoraki/Mt Cook, are over 3,000 metres above sea level. They are being uplifted at up to 10 millimetres per year along the Alpine Fault[13].

The foot of the continental slope

According to article 76 (1) and (3):

> "*The continental shelf of a coastal state comprises the sea-bed 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

> "*The continental margin comprises 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 or the subsoil thereof.*"

Therefore, if the geological boundary between the prolongation of the land mass and the deep ocean floor, or the boundary between the rise and the deep ocean floor can be identified directly, then it will define the extent of the extended continental margin. In practice, however, both of these boundaries are often difficult to identify[1,14]. The geological boundary between continental rocks and rocks of the deep ocean floor can be transitional and may be masked by sedimentary and volcanic rocks. Similarly, the boundary between the rise and the deep ocean floor is commonly transitional or very subtle, and in some cases there is no rise present along the margin. Even if the location of these boundaries can be directly established, not all coastal States will have sufficient resources to acquire the necessary scientific data to do so.

Article 76 recognises the difficulties associated with the direct determination of the extent of the extended continental shelf, and describes two formulae to be used to establish its extent. According to article 76 (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) 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.*"

Article 76 (4)(b) defines two methods for determining the location of the foot of the continental slope:

> "*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.*"

In practice, establishing the outer edge of the continental margin in most cases requires locating the foot of the continental slope. Determining the foot of the continental slope positions is therefore a critical component of the Continental Shelf Project.

The CLCS Guidelines (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, and provide for 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 the point of maximum change in gradient is a useful criterion. However, along some margins, the maximum change in gradient at the base of the continental slope is not easy to determine, and the extent of the continental shelf may be derived more accurately from other information.

Interpretation of what constitutes "evidence to the contrary" and when such evidence should be used have been the subject of considerable discussion[1,14].

The CLCS Guidelines (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.*"

The CLCS Guidelines suggest situations in which such evidence might be used. In some areas margin profiles have no single point with a maximum change in gradient. In other areas the sea-floor topography may be irregular, and the point with a maximum change in gradient may not accurately reflect the true geometry of the continental margin. The CLCS Guidelines (6.3) discuss options for the types of "evidence to the contrary" that might be used in relation to different types of continental margins. All the options 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.

Although the preference expressed in the CLCS Guidelines for the use of the maximum change in gradient is not free from doubt, the New Zealand Continental Shelf Project has followed the Guidelines, and in the majority of cases has identified the foot of the continental slope as the point of maximum change in gradient at its base. In a minority of cases, the maximum change in gradient does not provide a valid indication of the extent of continental prolongation from New Zealand. In these cases, "evidence to the contrary" has been used to substantiate the position of the foot of the continental slope in its geological context.

Maximum change in gradient at its base

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.

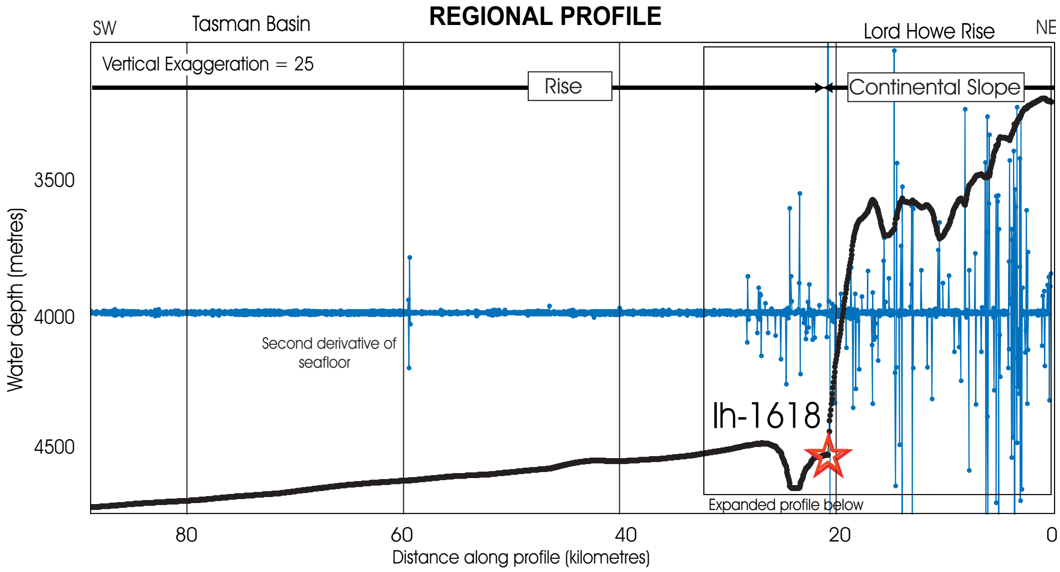
Along the New Zealand continental margin, as along many margins around the world, there is substantial geographic variation in the morphology of the continental slope. This variation reflects the diverse tectonic, sedimentary, and volcanic processes that are presently active, or have been active during the geological evolution of the margin. The continental slope typically has a gradient of a few degrees, but can vary locally from steep escarpments dipping at greater than 30° to horizontal surfaces across terraces and ponded mid-slope basins.

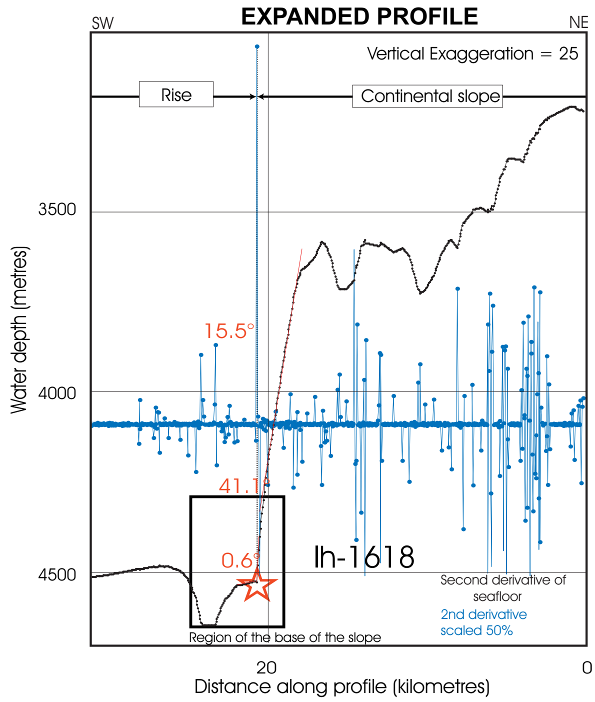
Beyond the slope, the deep ocean floor surrounding New Zealand typically lies at 4,500 to 5,000 metres depth, and is commonly, but not everywhere, an abyssal plain. The morphology of the sea-bed where the continental margin merges with the deep ocean floor is highly variable. In some places it is an abrupt boundary where the smooth and near-horizontal depositional surface of the abyssal plain abuts a well-defined lower slope. In other places it is a morphologically complex transition where local relief on the ocean floor meets an irregular lower slope.

Following the CLCS Guidelines (5.2.1, 5.4.4, 5.4.5, 6.1.2), the New Zealand Continental Shelf Project uses both continental margin morphology and crustal structure to identify the region of the base of the continental slope. The morphology is derived from analysis of single- and multi-beam swath bathymetry data. Crustal structure is determined by analysis of seismic reflection and refraction data, gravity and magnetic modelling, magnetic anomaly characteristics, and analysis of geological samples. The outer edge of the region of the base of the slope is determined from the direction of the abyssal plain, and its inner edge is determined from the direction of the land[1].

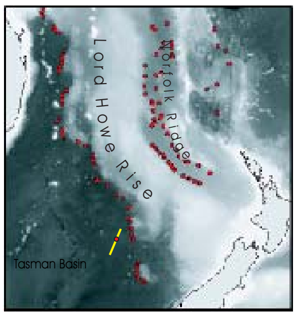
Maximum change in gradient at the foot of the continental slope

These diagrams illustrate the determination of the foot of the continental slope using the method of maximum change in gradient at its base. The upper diagram shows a profile across the continental margin and the second derivative of the bathymetry values. The lower diagram is an expanded view of the region of the foot of the continental slope. The second derivative of the bathymetry values is used to locate the point of maximum change in the gradient, and hence the foot of the continental slope.





Foot of continental slope and profile location



Western Lord Howe Rise
Foot of continental slope: lh-1618
Survey: TAN0006 - day 168-170

The rise is defined by the CLCS Guidelines (5.4.4) as the "*wedge shaped sedimentary body having a smaller gradient than the continental slope*". In the context of global plate tectonics, continental rises are generally confined to passive continental margins, where sediment preservation occurs. They are generally absent from convergent margins, where they have been either subducted or deformed by the subduction process. Rises are typically characterised by the following attributes[15]:

- Width of 100–1,000 kilometres;
- Very gentle sea-floor gradients of 0.1° to 0.6°, dipping oceanward to merge into the flat abyssal plain;
- Low local relief (less than 40 metres);
- Smooth depositional surfaces, occasionally eroded or with large bed-forms indicative of strong abyssal currents;
- Sediment accumulations up to several kilometres thick, with strata generally on-lapping the slope sediments and thinning ocean-wards towards the abyssal plain.

The New Zealand Continental Shelf Project uses GIS computer software to evaluate the gradient of the sea-bed in the region where the lower continental slope meets the rise, or where it meets the abyssal plain in areas where a rise is absent. Digital single-beam echo-soundings on profiles oriented nearly perpendicular to the margin, and in some cases multi-beam swath bathymetry data, are used for this analysis.

Average gradients are calculated over selected sections of the digital profiles using a best-fit mathematical regression. These gradients and best-fit regression lines are indicated on expanded sections of each profile, and are used to determine the location of the foot of the continental slope. As a starting point for this analysis, regional gradients less than 1° are considered to be representative of the continental rise and abyssal plain, and regional gradients greater than 2° to be representative of the New Zealand continental slope.

The width of the base of the continental slope is typically about 4–10 kilometres, but can vary according to the complexity of the margin from as little as 2 kilometres to greater than 20 kilometres.

Having established the region of the base of the slope, the point of maximum change in gradient is determined from the digital echo-sounding profiles. A computer algorithm is used to compute the second derivative of the bathymetry values and to locate the point of maximum change in gradient within the region of the base of the continental slope.

Evidence to the contrary

Article 76 defines the outer limit of the continental shelf in terms of both geology and geomorphology. Its natural components are the sea-bed and subsoil of the shelf, slope, and rise. Establishing the true extent of natural prolongation therefore requires consideration not just of the bathymetry, but also of the crustal structure, sedimentology, plate tectonic history, and other aspects of the growth of the continental margin and formation of the boundary between rocks of the continent and those of the deep ocean floor.

Along rifted and sheared continental margins, the outer edge of the continental margin is located at the continent-ocean transition zone, according to the CLCS Guidelines (6.3.10). The Commission recognises that transitional zones can be quite broad, and that faulted blocks of continental crust, and intruded and extruded volcanic rocks, can form across the continental margin for several tens of kilometres. It considers that the landward limit of the transition zone may be identified as the foot of the continental slope in the context of article 76 (4), provided that geophysical and geological data demonstrate conclusively that the submerged land mass of the coastal State extends to this point (Figure 8).

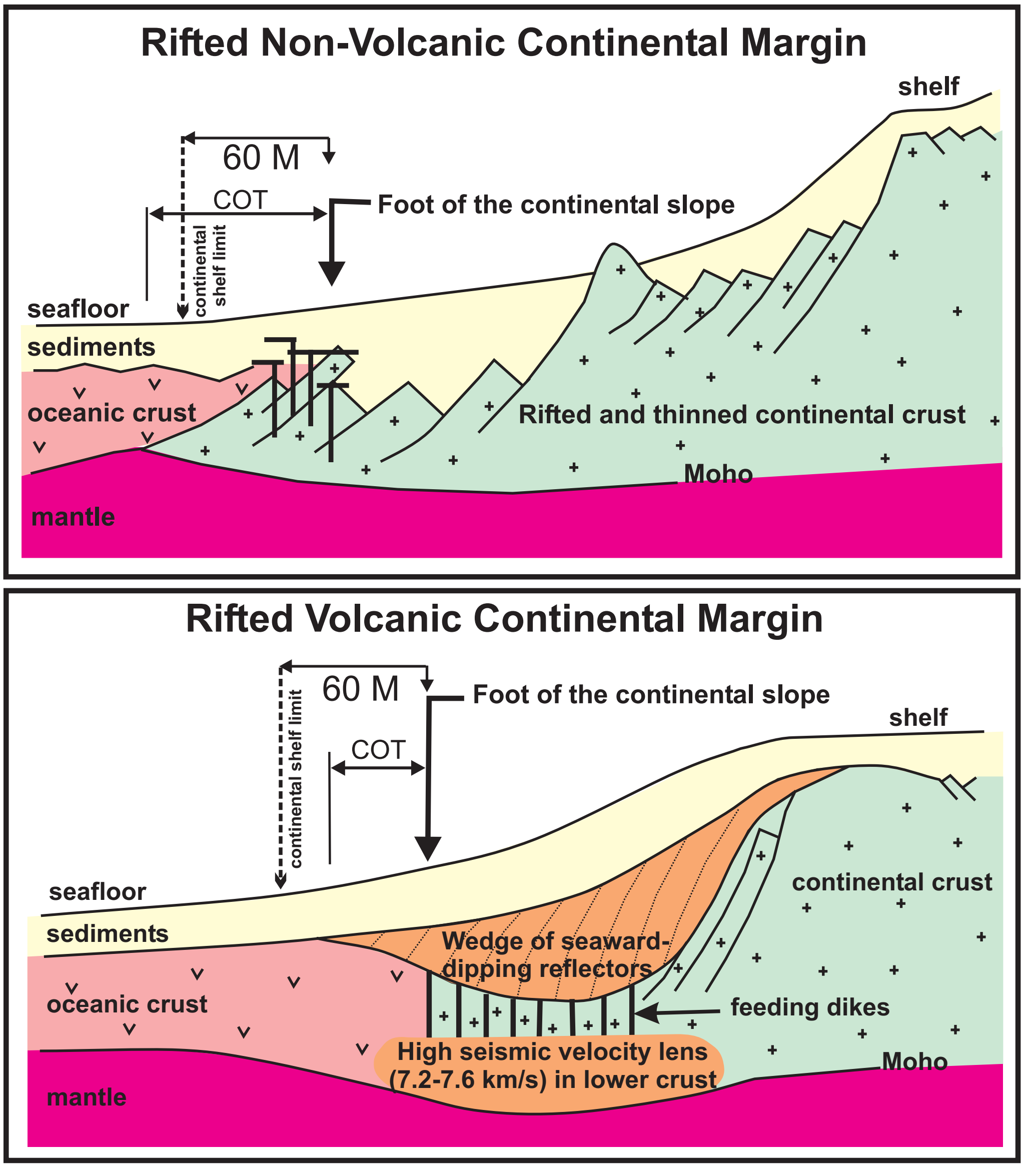


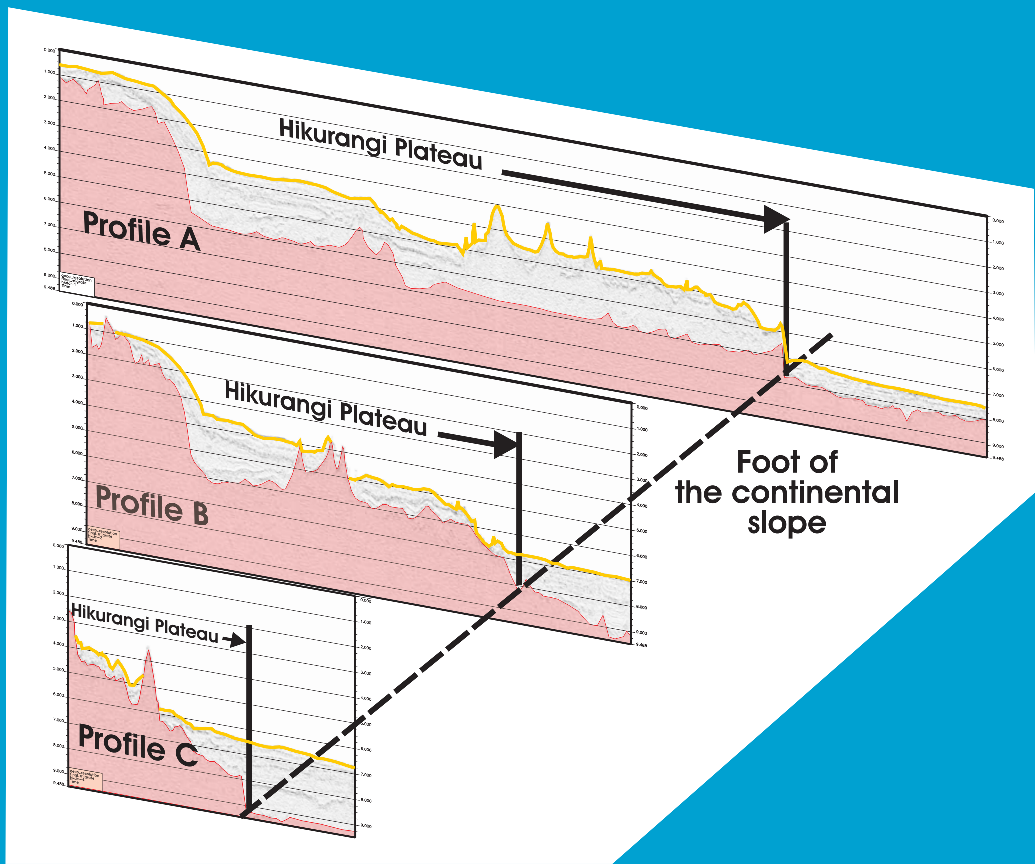
Figure 8 *Locations picked as foot of the continental slope, relative to the Continent-Ocean Transition (COT) zone, for volcanic and non-volcanic rifted margins (modified from Commission Guidelines fig 6.1D and 6.1E).*

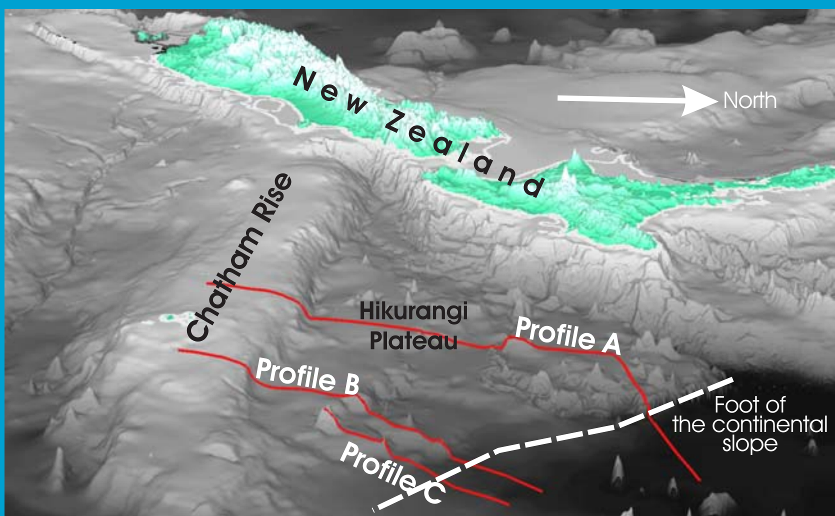
Where there is evidence that a continent-ocean transition zone should be used to determine the foot of the continental slope position, the New Zealand Continental Shelf Project identifies the inner (landward) edge of the continent-ocean transition zone as the foot of the continental slope to be used in the context of article 76 (4).

Geological and geophysical data used to identify the location of the continent-ocean transition zone, and therefore the foot of the continental slope position, include seismic reflection data, gravity and magnetic anomalies, and rock samples. These data are analysed to determine subsurface structure (particularly basement structure), crustal thickness, evidence of sea-floor spreading, and geological composition of the margin.

Using "evidence to the contrary" to identify the foot of the continental slope

The margin of the Hikurangi Plateau changes from a one-kilometre-high fault scarp on the seafloor in the west (Profile A) to a buried fault scarp in the east (Profiles B and C). The location diagram is looking to the southwest across the Hikurangi Plateau towards the New Zealand land mass. The foot of the continental slope is located at the point of the maximum change in sea-floor gradient on Profile A, and at the inner margin of the continent-ocean transition on Profiles B and C.





Sediment continuity

Article 76 (4) identifies formulae for determining the outer edge of the continental margin wherever the margin extends beyond 200 nautical miles from the baselines from which the territorial sea is measured.

Article 76 (4)(a) states:

> "*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:*
>
> *(i) a 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.*"

Article 76 specifies no requirements in respect of the continuity or thickness of the sedimentary layers between the observation point and the foot of the continental slope position used for the 1% calculation.

The CLCS Guidelines, however, extend the wording of article 76 to include a requirement for continuity of the sedimentary layers between the fixed points and the foot of the continental slope positions. The CLCS Guidelines (8.2.21, 8.5.3) state:

> "*In principle, the survey must be designed to prove the continuity of the sediments from each selected fixed point to the foot of the slope.*"

and the Commission invokes a principle of continuity in the implementation of the sediment thickness provision to state that:

> "*(a) To establish fixed points a coastal State may choose the outermost location where the 1 per cent or greater sediment thickness occurs within and below the same continuous sedimentary apron; and that*
>
> *(b) For each of the fixed points chosen the Commission expects documentation of the continuity between the sediments at those points and the sediments at the foot of the continental slope.*"

These guidelines introduce the concept of a "continuous sedimentary apron", but leave open questions about the depositional processes that formed the apron, and the requisite thickness of the sedimentary layers in order to constitute a continuous apron.

The sedimentary apron at the foot of the continental slope often consists of turbidites, sediments deposited by turbidity currents that transfer material from the shelf to the deep ocean floor. However, the sediment deposition can be the result of other processes, such as contour currents, volcanic activity, prograding sediment wedges, or deposition of pelagic oozes. Sediments between a fixed point based on sediment thickness and the foot of the continental slope may have been deposited by several of these processes, and therefore not form a simple apron.

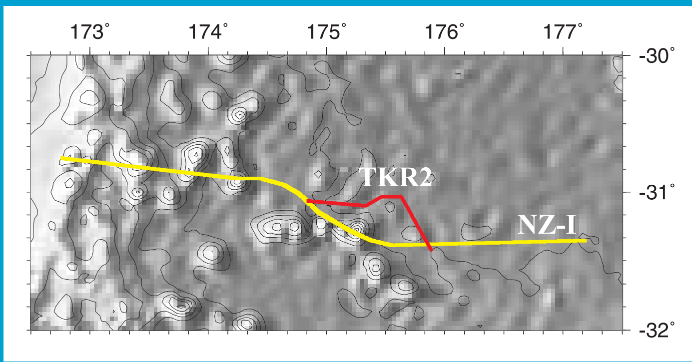
Similarly, the relief of seamounts and other basement structures can influence sediment deposition. In most cases these basement structures are relatively small and do not significantly disrupt the regional continuity of the sediment body. In some instances, however, they can be very large and could form barriers to sediment deposition between the fixed point and the foot of the continental slope position.

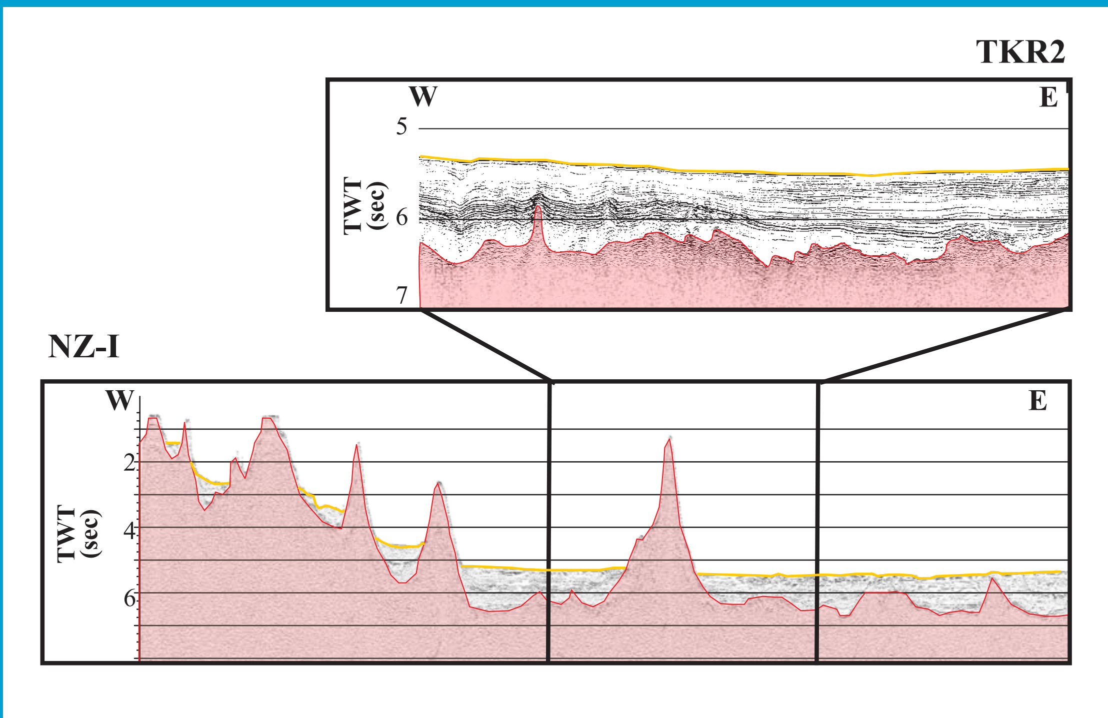
The New Zealand Continental Shelf Project addresses the continuity requirements at each fixed point based on the 1% sediment thickness criteria by describing the stratigraphy of the layers in the sedimentary apron and the connection of these sequences to the relevant foot of the continental slope position. The stratigraphy is based on analysis of the seismic character and velocities observed on seismic reflection and refraction data. The continuity of the connection of the sediments to the foot of the continental slope positions is assessed using seismic data, supported by other geological and geophysical data.

Where sea-floor morphology or other complexities in the geometry of the continental margin disrupt the continuity of the sedimentary apron along a profile between the fixed point and the nearest foot of the continental slope position, a well-supported interpretation of the distribution of sediments along the margin can demonstrate the regional continuity of the sedimentary apron. The regional interpretation of sediment distribution can be based on analysis of adjacent seismic profiles, regional bathymetry determined by marine surveys, or analysis of marine and satellite gravity data.

New Zealand example of sediment continuity

Interpreted seismic data from parallel lines (less than 10 kilometres apart) show that the sediment continuity is interrupted by a local basement high on seismic line NZ-I, but is continuous on the adjacent line TKR2. Other seismic lines in the region also indicate that a continuous sedimentary apron extends eastward from the continental margin to the end of line NZ-I.





The 2,500 metre isobath

The 2,500 metre isobath + 100 nautical mile constraint formula is used to determine the outer limit of the continental shelf along part of New Zealand's continental margin. Article 76 (5) states that

> "*The fixed points comprising the line of the outer limits of the continental shelf on the sea-bed, 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 isobath, which is a line connecting the depth of 2,500 metres.*"

According to article 76 (6), the 2,500 metre isobath + 100 nautical mile constraint formula may not be used in the special case of submarine ridges, but may be applied to submarine elevations that are natural components of the continental margin.

A four-stage procedure is used to determine sea-floor locations with depths of 2,500 metres.

1. Regions of the continental margin where this constraint formula might be applied are identified on existing bathymetry maps.
2. All ship-track crossings (using both digital and analog data) of the 2,500 metre isobath are analysed to select and/or interpolate 2,500 metre positions.
3. New high-quality bathymetry data are acquired in areas of poor data coverage.
4. Data from profiles which cross the 2,500 metre isobath and have a data measurement within the depth range of 2,500 ± 25 metres (i.e., 2,500 metres ± 1% uncertainty) are used to derive the 2,500 metre isobath + 100 nautical mile constraint line.

Article 76 (5) refers to "*the*" 2,500 metre isobath. Although this formulation appears to contemplate a single 2,500 metre isobath around a land mass, the Commission has recognised that faulting, folding and volcanism along continental margins can lead to complex or repeated occurrences of the 2,500 metre isobath. In these cases the CLCS Guidelines (4.4.2) state that

> "*Unless there is evidence to the contrary, the Commission may recommend the use of the first 2,500 m isobath from the baselines from which the breadth of the territorial sea is measured that conforms to the general configuration of the continental margin.*"

It is therefore possible to use the most seaward 2,500 metre isobath, as long as it conforms to the general configuration of the margin, i.e., is situated on a submarine feature that is a natural component of the continental margin.

As a result of geological and tectonic processes associated with growth of the New Zealand continental margin, some areas of the margin are characterised by multiple closures of the 2,500 metre isobath. The New Zealand Continental Shelf Project uses isolated closures of the 2,500 metre isobath to construct the 2,500 metre isobath + 100 nautical mile constraint line, provided that the isobaths lie within the natural prolongation of the land mass to the outer edge of the continental margin. Where these 2,500 metre positions are used to determine the outer limit of the continental shelf, geological and geophysical evidence is presented to demonstrate that the submarine features are natural components of the New Zealand continental margin.

Oceanic ridges, submarine ridges, and natural components of the margin

Article 76 (3) and (6) distinguish among three types of sea-floor highs:

- oceanic ridges of the deep ocean floor,
- submarine elevations that are natural components of the margin, and
- submarine ridges.

It is important to distinguish among these types of sea-floor highs because they directly influence the area of the extended continental shelf. The continental shelf of coastal States can extend to only 200 nautical miles on oceanic ridges, to 350 nautical miles on submarine ridges, and up to either 350 nautical miles or 100 nautical miles beyond the 2,500 metre isobath on submarine elevations.

There has been considerable discussion about the ridges and elevations referred to in article 76[16,17]. These references present numerous examples of complex margins around the world, and discuss possibilities for how sea-floor highs can be distinguished and the terms of article 76 applied.

At a fundamental level, the CLCS Guidelines (7.1.8) state that:

> "*The distinction between the "submarine elevations" and "submarine ridges" or "oceanic ridges" shall not be based on their geographical denominations and names used so far in the preparation of the published maps and charts and other relevant literature. Such a distinction for the purpose of article 76 shall be made on the basis of scientific evidence taking into account the appropriate provisions of these Guidelines.*"

The scientific evidence referred to here must demonstrate the natural prolongation of the land mass—the morphological and geological continuity of the sea-floor highs with the continental margin.

Also at a fundamental level, the term "ridge" universally has the concept of an elevated, narrow, and elongated body with steep sides. Some of the technical terms of article 76 may have somewhat different meanings when used in legal, geomorphological or geological contexts, but there appears to be universal agreement on this point.

Oceanic ridges

Oceanic ridges are part of the deep ocean floor and therefore are not part of the continental shelf. They include ridges formed by sea-floor spreading and associated processes that have not been tectonically accreted to the continental margin or are in any way an integral part of the land mass.

Two examples of oceanic ridges are mid-ocean spreading ridges, and ridges formed along transform faults perpendicular to sea-floor spreading ridges. Transform ridges can impinge on the continental margin. Spreading ridges do not usually impinge on the continental margin, but can do so in some tectonic settings.

Submarine elevations that are natural components of the margin

Article 76 (6) includes plateaus, rises, banks, caps and spurs among submarine elevations that are natural components of the margin. The CLCS Guidelines (7.3.1) recognise at least two origins of submarine elevations that are natural components of the margin:

> "*(a) In active margins, continents grow by the accretion of sediments and crustal material of oceanic, island arc or continental origin onto the continental margin. Therefore, any crustal fragment or sedimentary wedge that is accreted to the continental margin should be regarded as a natural component of that continental margin.*"

Figure 9 *These ophiolite rocks in northern New Zealand are old ocean crust that was amalgamated to the landmass about 25 million years ago.*

> "*(b) In passive margins, continental break up involves thinning, extension and rifting of the continental crust and extensive intrusion of magma into and extensive extrusion of magma through that crust. This process adds to the growth of the continents. Therefore, seafloor highs that are formed by this breakup process should be regarded as natural components of the continental margin where such highs constitute an integral part of the prolongation of the land mass.*"

Sea-floor highs that are "*an integral part of the prolongation of the land mass*" are by implication features that have a continuous morphological and geological connection with the land mass. Based on the CLCS Guidelines, a volcanic seamount or rocks of a mid-ocean spreading ridge are natural components of the margin if they have been accreted to a continent by tectonic activity (Figure 9). The formation of island arcs contributes significantly to continental growth by accretion, particularly in the Pacific region (Figure 10). Continental fragments that share their geologic origin and history with the land mass, but whose connection with it has been altered (but not severed) by rifting or other tectonic activity, are also natural components of the margin.

Figure 10 *White Island is an active volcano located in the Bay of Plenty, about 50 kilometres north of the North Island. It is part of the Kermadec Ridge system, a volcanic island arc associated with the subduction of the Pacific Plate beneath the Australian Plate.*

Article 76 is neutral with regards to the oceanic or continental affinity of the rocks of the continental shelf. A submarine elevation that is a natural component of the margin can be either oceanic or continental in origin, providing natural prolongation (continuity of morphology, geologic origin and history) can be established to the rocks of the coastal State's land mass.

Submarine ridges

Submarine ridges are part of the continental shelf, but they are not submarine elevations that are natural components of the continental margin. The distinction between submarine ridges and submarine elevations in terms of article 76 is not clearly established in the CLCS Guidelines, but may be based on assessing how integrally related the features are to the land mass.

Submarine elevations that are natural components of the continental margin share crustal characteristics, geologic origin, and tectonic evolution with the adjoining land mass. In contrast, a submarine ridge may be a feature that is morphologically connected to the land mass, but is not an integral part of the prolongation of the land mass because it has a different geologic origin and history. The geology of a submarine ridge can vary along its length, and may share its geologic origin and history with the associated land mass along some, or none, of its length.

The degree of similarity of geologic origin and history required to demonstrate that a submarine feature is "*a natural component of the continental margin*" may depend upon what type of crust the land mass has. Continental crust is formed as a result of multiple tectonic and refractive processes and can be variable in composition. Assessment of the geologic continuity between the land mass and a submarine high, and therefore classification of the high as a submarine ridge or as a submarine elevation that is natural component of the continental margin, would have to consider the inherent variability in the composition of continental crust.

An example of a submarine ridge might be a transform ridge extending between the continental margin where it initiated and the deep ocean floor. With increasing distance from the continental margin, the affinity of the rocks along the transform ridge could change from continental to oceanic. The location of the transition zone could be difficult to identify, but because its geologic nature changes along its length the feature would be classified as a submarine ridge. The extent of the extended continental shelf would be limited to 350 nautical miles along such a ridge. If a location could be established where the ridge was entirely oceanic and was no longer a geologic prolongation of the land mass, then seaward of that position the ridge would be a "*ridge of the deep ocean floor*" and no longer eligible to generate foot of slope positions.

The Macquarie Ridge Complex consists of a series of ridges that extend south from New Zealand for 1,600 kilometres (Figure 11). The majority of the rocks in the Macquarie Ridge Complex are oceanic in origin, although they are not part of a modern sea-floor spreading system. They are thought to have originated as an oceanic fracture zone, uplifted as a result of changes in relative motion between the Australian and Pacific plates[18,19]. However, at the northern end of the ridge system the rocks are continental, related to the land mass of New Zealand. The nature and exact location of the boundary between rocks of continental and oceanic affinity along the ridge complex are unknown. Further analysis will help determine the nature of this submarine feature.

New Zealand ridges

The New Zealand Continental Shelf Project differentiates among sea-floor highs using the following criteria.

- If the feature is continental in origin and there is a continuous morphological and geological connection with the land mass, then it is a submarine elevation that is a natural component of the margin.
- Regardless of its origin, if the feature has been accreted to the continental margin and is morphologically continuous with it, then it is a submarine elevation that is a natural component of the margin.
- Formation of an island arc is part of the continent building process, and if the arc is morphologically and geologically connected to the land mass then it is a submarine elevation that is a natural component of the margin.
- If the feature is of oceanic origin (i.e., either a spreading ridge or a transform ridge) then unless it has been accreted to the margin by tectonic activity, or is otherwise connected to the land mass, then it is part of the deep ocean floor and is an oceanic ridge.
- Regardless of its origin, if the feature is morphologically continuous with the margin, and is not an oceanic ridge, then it is either a submarine ridge or a submarine elevation that is a natural component of the margin, depending on the degree of geological continuity between the land mass and the ridge.

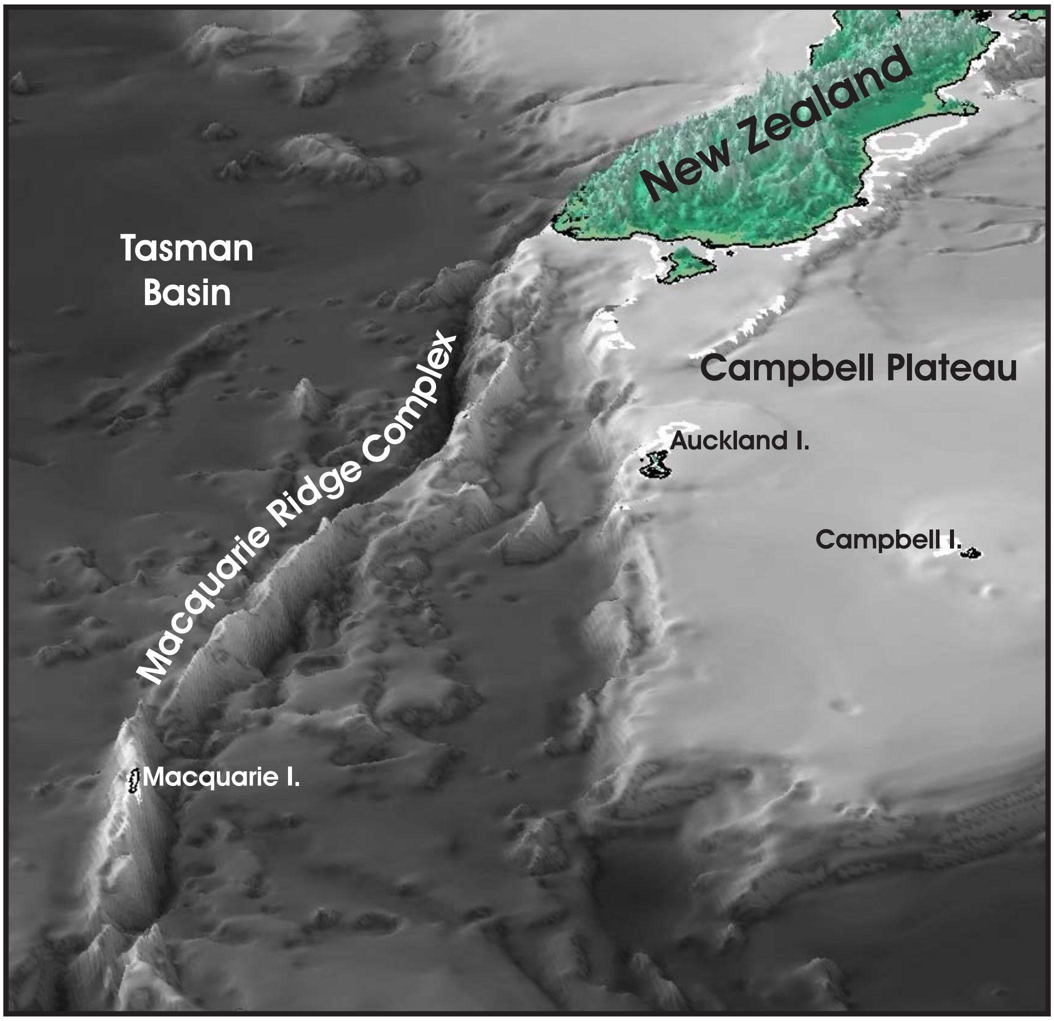


Figure 11 *The Macquarie Ridge Complex is a major submarine feature extending south from the New Zealand land mass. It includes rocks of both continental and oceanic origin.*

Straight bridging lines

There are regions which, by virtue of the shape of the continental margin, are encompassed by straight bridging lines that connect fixed points on either side of concave portions of the continental margin. Examples of these are shown as areas "A" and "B" in Figure 12. The enclosed areas lie beyond the extent of the continental shelf as defined by article 76 (4)(a) but within the constraints defined by article 76 (5) and (6).

The straight bridging lines are formed according to article 76 (7) by:

> "*straight lines not exceeding 60 nautical miles in length, connecting fixed points, defined by coordinates of latitude and longitude.*"

The CLCS Guidelines (2.3.8) state that

> "*These straight lines can connect fixed points located on one of, or any combination formed by, the four outer limits produced by each of the two formulae and the two constraints contained in article 76.*"

and that the straight lines should enclose (2.3.9, 2.3.10)

> "*only the portion of the sea-bed that meets all the provisions of article 76.*"

The 200 nautical mile EEZ is the outer limit of the continental shelf and it should be possible to use it as an endpoint for the straight lines. For points other than those based on sediment thickness, there is no other restriction on their use to construct straight bridging lines.

In the case of fixed points based on sediment thickness, the CLCS Guidelines (2.3.9) state that

> "*These straight lines should not be used to connect fixed points located on opposite and separate continental margins.*"

The meaning of "*separate continental margins*" is unclear. Article 76 (1) states that continental margins derive from the prolongation of the land territory. The concept of "*separate continental margins*" therefore implies prolongation from separate land masses. Fixed points that are located on prolongations of the same land mass are therefore part of the same continental margin, and can be used to form straight line segments.

If the 60 nautical mile straight lines are constructed as in Figure 12, then the only difference between areas "A" and "B" is one of scale. Both areas conform to the terms of article 76 (7), and cover sea floor that is beyond the limits of the continental shelf as defined in article 76 (4).

In most cases the use of straight line segments only has the effect of smoothing the outer limit line. Within the terms of article 76 there is no limit to the size of the enclosed area.

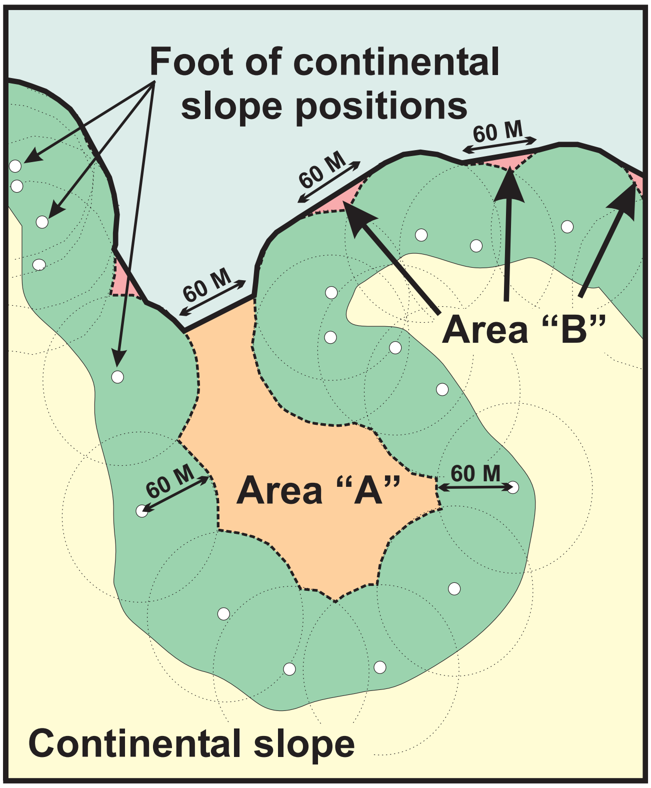


Figure 12 *Schematic map of straight bridging lines within the extended continental shelf.*

Part 2 – Data used to delimit the continental shelf

Introduction

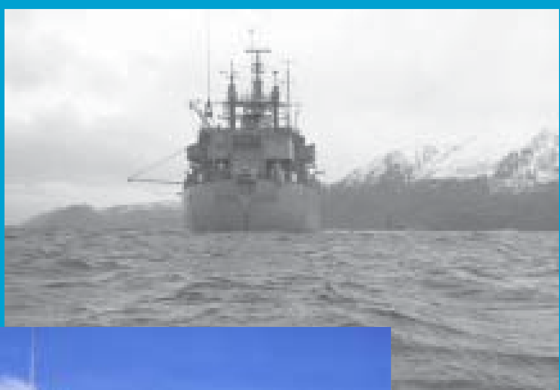
Article 76 specifies that the extent of the continental shelf is determined by establishing fixed points that define its outer margin. To do this it is necessary to know the shape of the sea floor and the nature of the rocks beneath the sea floor.

The shape of the sea floor is determined from analysis of bathymetry data. The nature of the rocks beneath the sea floor is determined directly from analysis of samples recovered by dredges or drill-holes, and indirectly by analysis of geophysical data. Geophysical data can be analysed to provide information about the physical properties of the rocks and their spatial distribution.

This section summarises how the data used by the New Zealand Continental Shelf Project Team were obtained and processed, and the uncertainties associated with the data.

The major components of the New Zealand Continental Shelf Project survey programme are:

- single-beam and multi-beam swath bathymetry mapping of sea-floor features to establish morphological continuity;



Survey vessels

The* Eltanin *(top), the* Fred H. Moore *(middle) and the* Geco Resolution *(bottom) are three vessels that made important contributions to New Zealand marine science. The USNS* Eltanin *was a United States research vessel that collected some of the first regional seismic data in the Southwest Pacific and the Ross Sea in the 1960s and 70s. The RV* Fred H. Moore *conducted the first high-quality, systematic regional seismic survey in the New Zealand region as part of a global reconnaissance project for Mobil Oil Company in 1972. The MV* Geco Resolution *collected high-quality seismic data for the New Zealand Continental Shelf Project in 2000–2001.

- low-fold multi-channel seismic reflection data to establish foot of the continental slope positions and to determine sediment thickness beyond 60 nautical miles from the foot of the continental slope;
- high-fold multi-channel seismic reflection data to establish foot of the continental slope positions, including those based on "evidence to the contrary" and to determine sediment thickness beyond 60 nautical miles from the foot of the continental slope;
- gravity and magnetic anomaly data to determine, in conjunction with multi-channel seismic reflection data, crustal thickness and origin, and
- sea-floor dredging samples to determine the geochemical affinity of volcanic and basement rocks, and test their connection with the land mass using isotopic analysis and radiometric dating techniques.

The New Zealand Continental Shelf Project team has merged historical geological and geophysical data (seismic reflection, seismic refraction, bathymetry, gravity and magnetic data, and rock sample analyses) with similar data collected by surveys undertaken for this project. The integrated data-set is used to make a comprehensive interpretation of the structure and extent of the New Zealand continental margin. Scientifically significant aspects of this interpretation have been published in scientific journals and presented at scientific and UNCLOS-related conferences[20,21,22,23].

All available scientific information is used for the New Zealand Continental Shelf Project, and the information is interpreted consistently and in accord with accepted international scientific opinion and the CLCS Guidelines. All the data used by the project are available to the Commission for inspection.

Data sources, processing and analysis

Bathymetry data

Much of the bathymetric data for the New Zealand margin measured from surface vessels is from reconnaissance surveys or from single profiles recorded during vessel transits. Before 1986, vessels determined their position using Transit satellite and/or celestial navigation. Global Positioning System (GPS) navigation has been available since 1986 (Figure 13).

Some areas in the New Zealand region have been surveyed during the last decade using multi-beam swath bathymetry, or interferometric side-scan sonar. Other multi-beam data available to the New Zealand Continental Shelf Project include single-track ship transits by foreign vessels (Figure 14).

Available global compilations of echo-soundings data have included the "General Bathymetric Charting of the Oceans" (GEBCO) series, with the fourth and fifth editions released in 1972 and 1982. Digital contours in the GEBCO Digital Atlas were completed in 1982 and updated in 1997 and 2003[24].

Global grids of bathymetry released by the United States National Geophysical Data Center (NGDC) include the ETOPO5 (5-minute grid resolution) and ETOPO2 data (2-minute grid resolution).

Compilations of echo-sounding bathymetry for the New Zealand region[25, 26] have also improved with time as more echo-sounding data, with more accurate navigation, have become available. The most recent regional compilation[27] includes both analogue and digital data, with at least threefold more data density than available via the National Geophysical Data Centre.

For the Continental Shelf Project, historical data have been extracted from New Zealand and international databases and are analysed for gross errors in navigation or bathymetry echo-soundings.

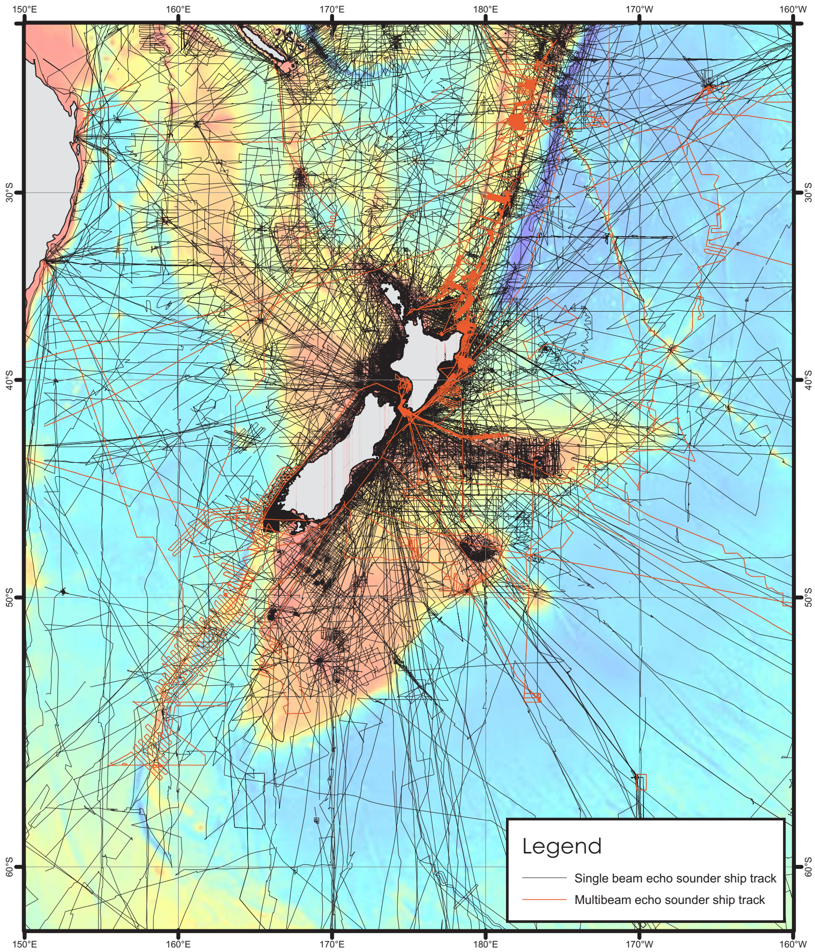


***Figure 13** Digital single-beam echo sounder and multi-beam swath bathymetry ship tracks.*

All historical bathymetry data, if not previously corrected for differences in seawater velocity, are corrected using standard echo-sounding correction tables[28]. Where sufficient information is available, standard Deep-Sea Sounding International Hydrographic Organisation (IHO) codes for navigational positioning, soundings, bathymetry fidelity, and data reduction[29] are established for both foot of the continental slope and 2,500 metre isobath positions.

Modern single-beam bathymetry data for the Continental Shelf Project have been acquired using best practice hydrographic surveying and processing, including correction for navigation spikes, editing and removal of "bad" points by comparing the data with hard-copy echograms, and corrections for heave, draught, and variations in seawater velocity. The acquisition and processing of bathymetry data for the Continental Shelf Project have been overseen by certified IHO Category A hydrographers.

Where multi-beam swath bathymetry data are used to establish foot of the continental slope positions or 2,500 metre isobath crossings, synthetic profiles perpendicular to the margin are constructed from the gridded multi-beam swath data. The resolution of the profile depends on the grid resolution of the processed data and is typically a few tens of metres.

In analysing single-beam and multi-beam swath bathymetry data, it is important to recognise artefacts arising from steep sea-floor topography and incorrect velocity models. Steep sea-floor topography is identified by hyperbolic reflections, often crossing other sea-floor reflections. The use of incorrect velocity models in processing swath bathymetry can usually be identified by consistent upward- or downward-curling of the bathymetry on the outer beams. The errors are usually identified and corrected using data from areas where multi-beam swath bathymetry data collected on different survey legs overlap.

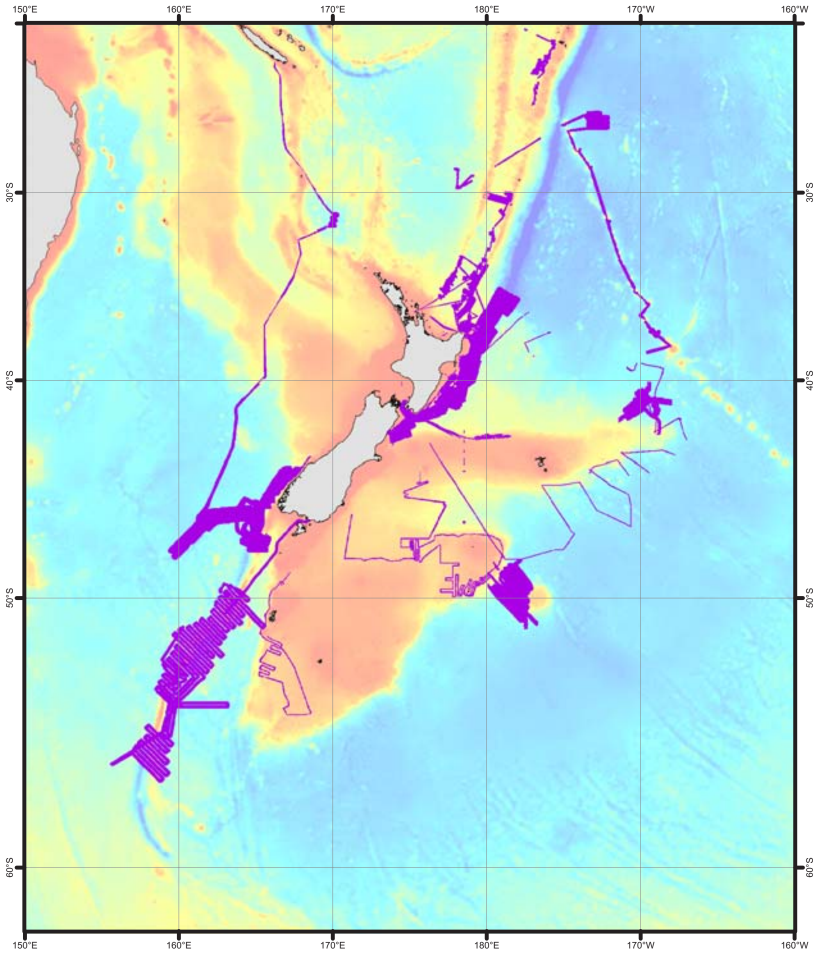


***Figure 14** Data coverage – multi-beam swath bathymetry.*

Seismic reflection data

Before the 1980s, reconnaissance seismic reflection data were largely collected on widely spaced cruise tracks by vessels using transit-satellite navigation, although the earliest cruises used celestial navigation. Seismic sources include a variety of airgun and sparker systems, with some single-channel and early multi-channel recording systems.

During more recent surveys, New Zealand research institutes have collected a mixture of single-channel and sparse multi-channel seismic reflection data, with navigation by transit satellite and GPS. Recent seismic data acquired by both New Zealand and overseas vessels are based entirely on GPS or Differential GPS navigation, and use modern multi-channel seismic reflection seismic systems. Figure 15 shows the tracks of seismic survey vessels.

Seismic reflection data are processed to enhance the quality of the signal by removing the effects of factors that affect the propagation of sound through the earth, including attenuation, dispersion, reflection, refraction, and scattering. Processing also removes effects arising from the geometry of the layers in the subsurface and from sources of acoustic noise in the environment.

Common processing steps include:

- applying a gain function based on estimates of the attenuation of the seismic signal to recover better estimates of the true impedance contrasts in the subsurface;
- analysing the frequency content of the data to estimate the effects of multiples and scattering, and using deconvolution techniques to remove these effects;

- analysing the frequency content of the data to estimate the effects of noise, and filtering to remove these effects;
- gathering traces into groups that contain reflections from the same subsurface positions and analysing the time-distance relationship of echoes from horizons to determine the subsurface velocities;
- adding the traces containing reflections from the same subsurface positions to improve the signal-to-noise ratio; and
- removing the effects of three-dimensional subsurface structure by migration.

To analyse and interpret seismic reflection data, the reflection characteristics (e.g., amplitude, frequency, continuity, spatial geometry) are used to infer the nature of the geological interface. Important seismic horizons include the ***sea floor*** (the boundary between the water and sediment), the ***top of basement*** (the boundary between sediment and the metamorphic/igneous crystalline basement), and the ***Moho*** (the crust-mantle boundary).

Analysis of geologic features that characterise the complex continental margin of New Zealand necessarily involves the interpretation of many features in the seismic data, and synthesis of data from other sources where available (e.g., well logs, rock samples, gravity and magnetic data, seismic refraction data). The interpretation is based on the understanding of the geologic processes that formed and shaped the rocks and is never done in isolation.

Seismic refraction data

Data from sonobuoys have been recorded by reconnaissance scientific surveys throughout the New Zealand region, and by the New Zealand Continental Shelf Project surveys (Figure 16).

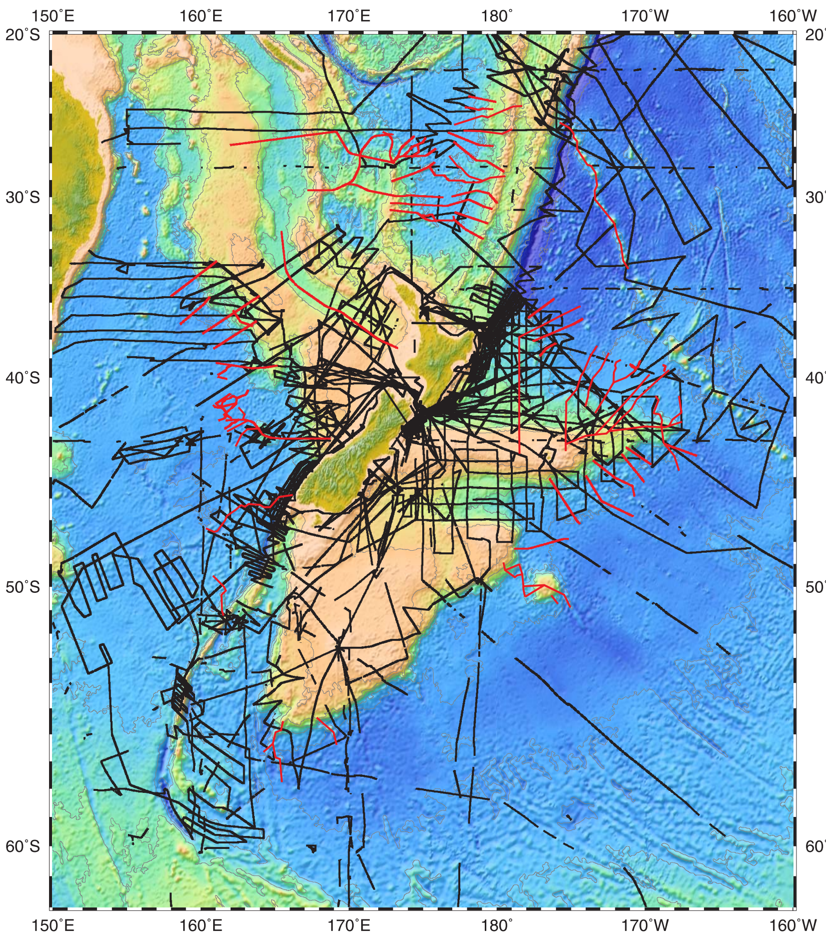


Figure 15 *Seismic reflection data coverage. Red lines indicate surveys undertaken for the New Zealand Continental Shelf Project; black lines are regional single-channel and multi-channel seismic reflection surveys.*

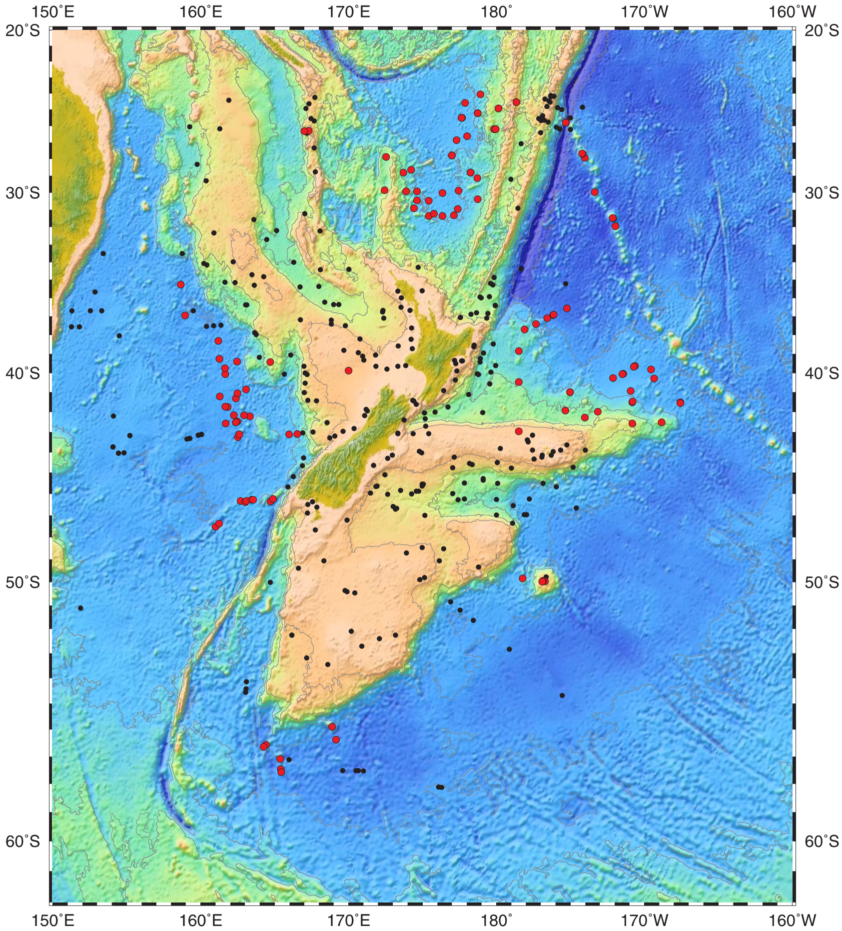


***Figure 16** Sonobuoy data coverage. Red dots indicate the location of sonobuoy data collected for the New Zealand Continental Shelf Project. Black dots indicate other sonobuoy data in the region.*

Sonobuoys provide information about sediment velocities for depth conversion, and substantiate regional interpretations of basement structure and crustal type. Although sediment unit velocities can be derived from multi-channel seismic reflection surveys, in deeper water (greater than about 4 kilometres) the velocities cannot be accurately resolved. For these water depths, sonobuoy-derived velocities are less variable and more reliable. The sonobuoys available for the Project generally have relatively short offsets (less than 20 kilometres) and therefore do not provide information about deeper crustal structure.

Very little processing is required for seismic refraction data, as it is important to preserve the waveforms for analysis. The geographic location is put in the headers, and basic filtering can be used to remove coherent or large-amplitude noise. Analysis of seismic refraction data requires picking the time of the first arrivals on the records. These times are used as input for forward modelling of the subsurface two-dimensional velocity and interface structure. An initial model is usually derived from other data sources such as seismic reflection data.

Satellite gravity data

Compilations of modern ERS-1 and GEOSAT satellite altimetry provide a consistent dataset of the marine gravity field[30] (Figure 17). These data are useful for identifying sea-floor features associated with continental rifting (e.g., rift blocks), ocean floor fabric and crustal structure. The satellite data are usually interpreted in conjunction with ship-acquired bathymetry, gravity, magnetic and seismic data.

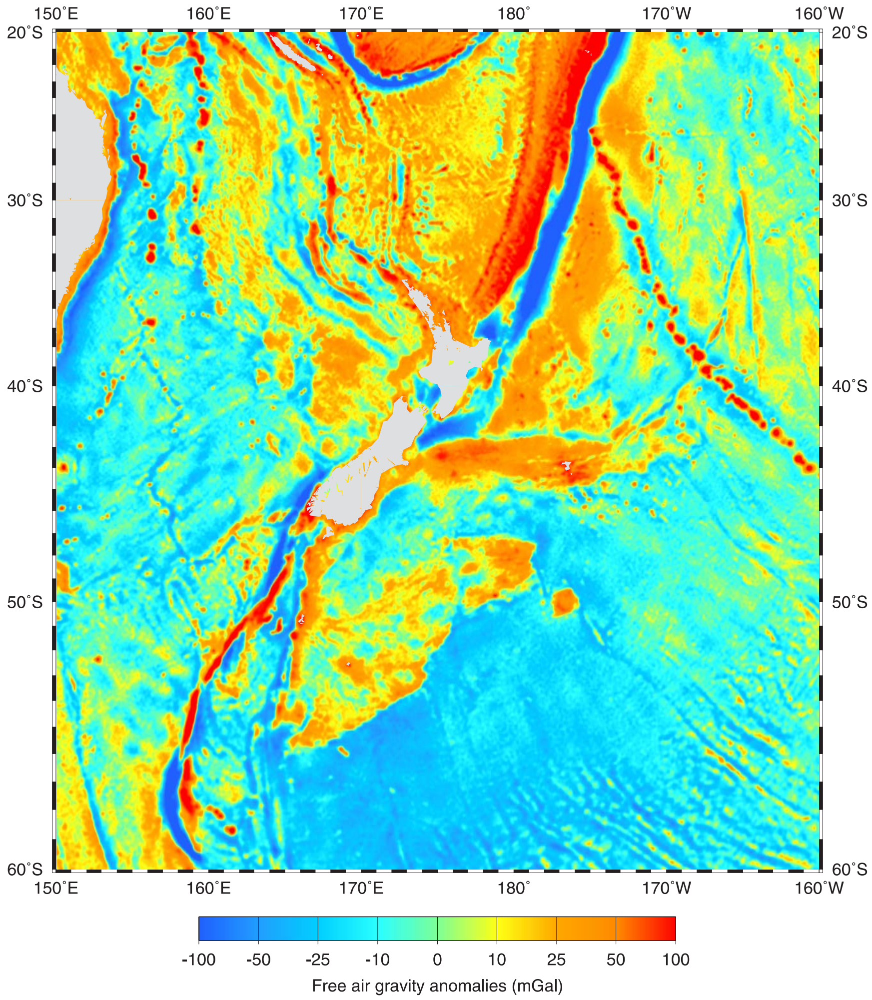


Figure 17 *Satellite-derived gravity data in the New Zealand region.*

Satellite altimetry data provide complete coverage of most of the oceans and have been processed to derive global gravity anomalies[30]. The most common data processing technique derives gravity values from the geoid by applying Fourier transforms to gradients computed in two orthogonal directions[31].

Satellite gravity anomalies are used to predict sea-floor topography using various inversion techniques[27,31]. These techniques generally make assumptions about the wavelength of crustal structure and rely on echo-soundings and marine gravity control points measured by surface vessels to constrain the topographic inversion modelling. The predicted sea-floor topography has been used to estimate the extent and depth of sedimentary basins. In some areas the three-dimensional structure of the bathymetry, basement and Moho has been modelled using these data[32].

Surface vessel gravity and magnetic data

The surface vessel gravity coverage is sparse beyond the New Zealand EEZ, with tracks spaced typically 100–150 kilometres apart (Figure 18). This is somewhat compensated for by satellite gravity data, which provide more complete coverage but do not have the same resolution as data from surface vessels. In some areas the gravity data have been interpreted to determine crustal structure[32,33], reflecting the continental or oceanic nature of the sea floor.

Surface vessel magnetic data coverage (Figure 19) is similar to the gravity coverage. These data were recorded by many of the same surveys discussed in the bathymetry and seismic sections, and have the same limitations in terms of navigational accuracy.

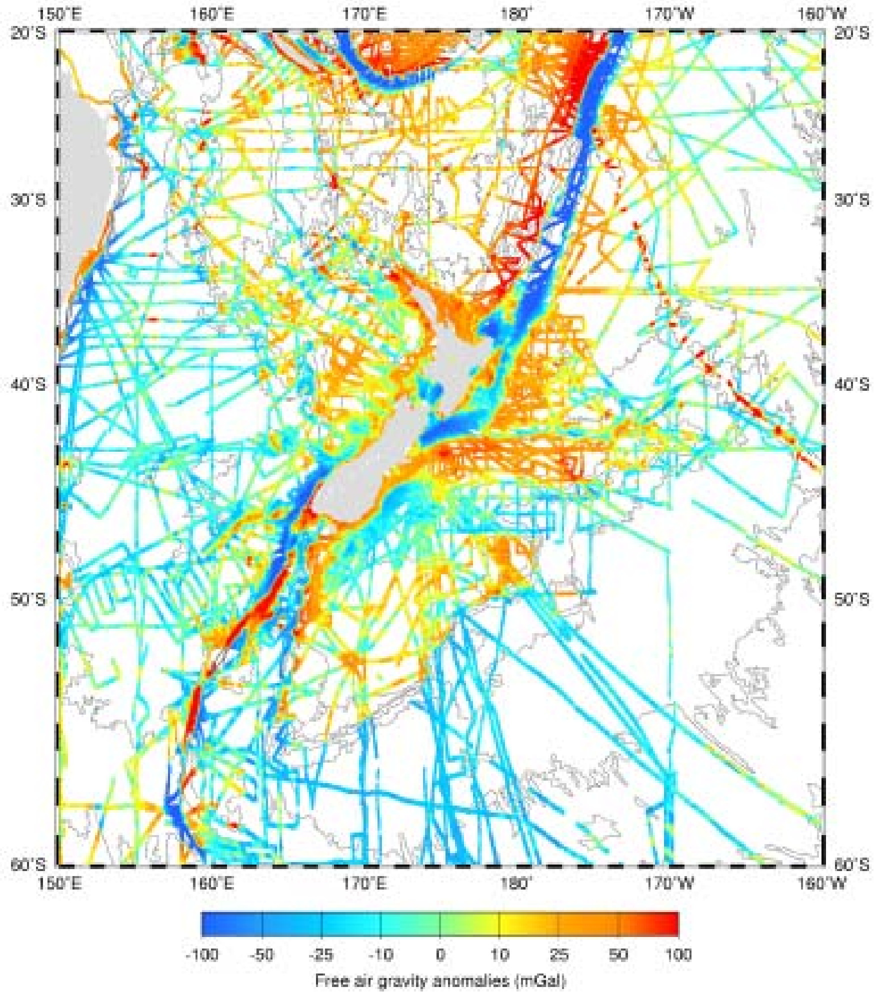
The magnetic data have been interpreted to identify sea-floor spreading anomalies[8], and to extend interpretations of New Zealand's onshore basement rocks into offshore areas[33,34,35,36,37].

Marine gravity measurements are tied to the New Zealand Potsdam system (1959), with latitude corrections derived from the International Gravity formula (1930). Eötvos accelerations due to ship motion have been removed from the data. Cross-correlation analysis with accelerometer measurements on the gravity sensor is used to remove the effects of variations in ship motion and sea conditions. Filtering over periods of 5–60 minutes (1–15 kilometres) is also used to remove obvious effects of sea motion.

The Earth's total magnetic field is measured by a magnetometer towed behind the ship. Marine magnetic anomalies are calculated with respect to the appropriate International Geophysical Reference Field[38]. Any data collected during periods of magnetic storms (as recorded by onshore geomagnetic observatories) are deleted from the database.

Gravity and magnetic data are most commonly analysed by forward modelling. An initial model is derived from other data. Estimates of rock properties may be obtained from rock samples from wells, and of subsurface structure from seismic reflection data. The subsurface structure and rock properties are varied until the calculated anomalies closely match the measured anomalies. Forward modelling can be done in either two or three dimensions.

Figure 18 Gravity data coverage - surface vessels.



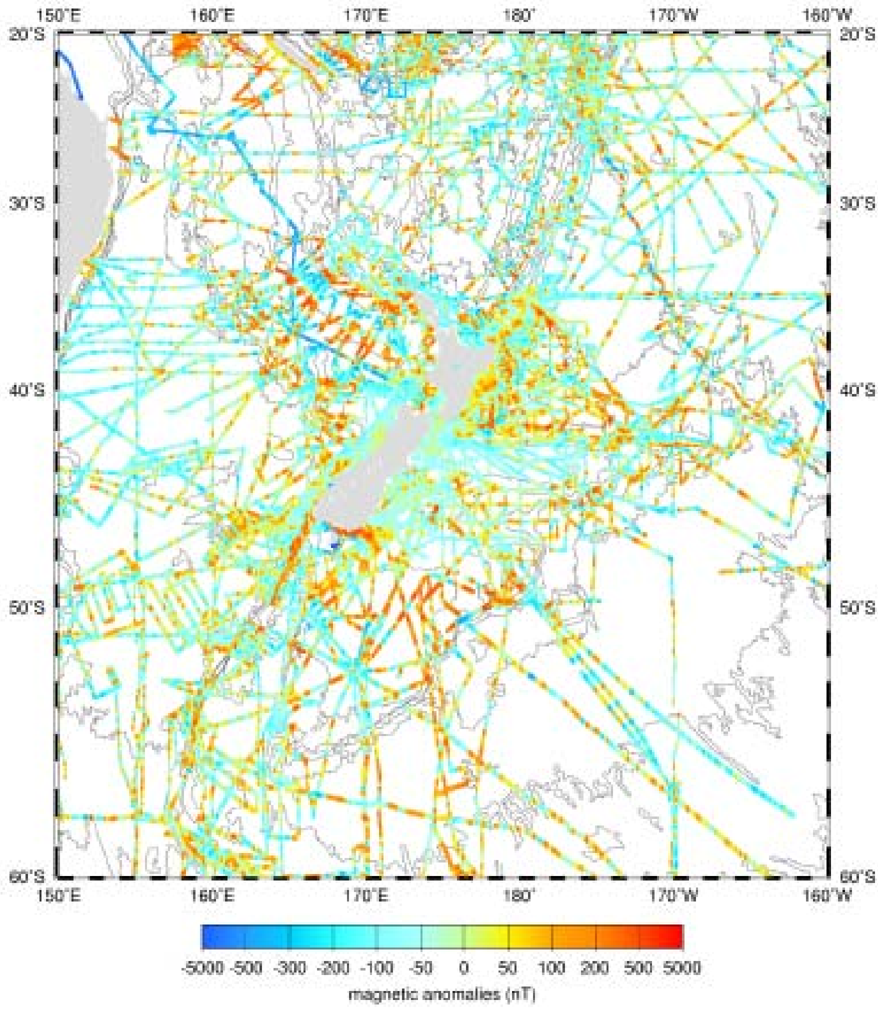


***Figure 19** Magnetic data coverage – surface vessels.*

Drill-hole data and rock samples

Data from drill-holes in the New Zealand region have been collected by international scientific projects—the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP)—and by oil exploration companies (Figure 20). Petroleum exploration wells are usually located in relatively shallow water near the coastline. DSDP and ODP wells are usually located in more remote locations, and can be particularly valuable because they provide information about the rocks near the limits of the extended continental shelf.

Drill-hole data include geological samples from cores and cuttings, and geophysical data from logs or other geophysical studies such as check-shot surveys.

Geophysical logs give information on the physical, chemical, and structural properties of the rocks penetrated by a drill-hole. A variety of geophysical techniques are available to make continuous, *in situ* measurements of these properties as they vary with depth. These data provide geologic information about the nature of the rocks and their regional correlations, and acoustic velocities that can be tied to regional seismic reflection profiles and used to calculate sediment thicknesses.

Where core material is available, measurements of the physical and chemical properties of the rocks are used to calibrate the geophysical signature of the rocks on the geophysical logs.

Rock samples have been collected by research surveys (Figure 20) and occasionally by fishermen. There are relatively few samples of solid rock (other than young, unconsolidated sediments) available from the New Zealand region.

Rock samples recovered from drill-holes are processed to obtain subsets that can be analysed to determine the chemical composition and age of the rocks. The processing procedures vary, depending on the nature of the rocks and the purpose for which they were collected. Processing typically involves crushing the samples to obtain powders. These powders are chemically treated or physically processed to remove unwanted components.

Rock samples recovered from dredges are analysed to determine their chemical composition and age. Analytical techniques include inspection of hand specimens and thin sections, X-ray fluorescence, mass spectroscopy, and radiometric and paleontological dating. These rock samples are processed in a manner similar to those recovered from drill-holes. Dredge samples, however, are likely to be weathered and it is important to select the best-preserved components of the samples.

Processing of down-hole geophysical data primarily involves specific corrections for the instruments and logs. These corrections include removing the effects of the drill-hole (size, unevenness, temperature, tool standoff) and of the drilling fluids that may partially mask or disrupt the log response of the formation. Acoustic logs are processed to remove noise and cycle-skips.

Analysis of well logs provides information about the nature of the rocks and their physical properties (i.e., density, porosity, permeability, acoustic velocity). Geophysical studies such as check-shot surveys provide information about the vertical and lateral distribution of these properties, especially the acoustic velocity of the rocks penetrated by the drill-hole.

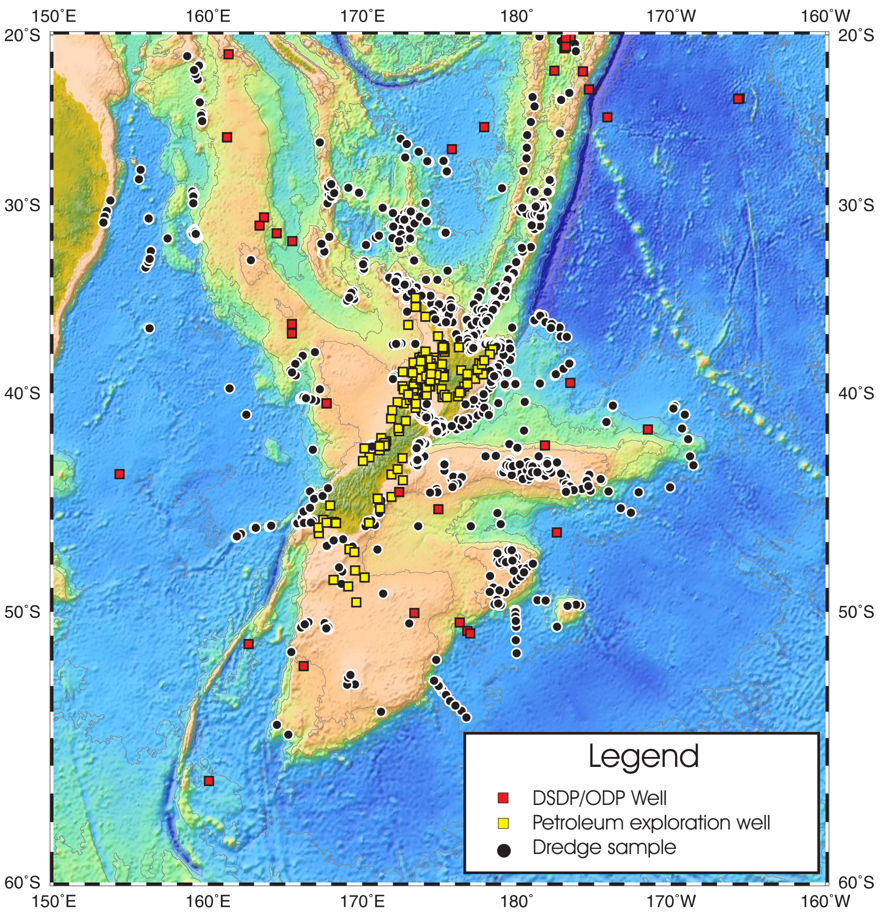


***Figure 20** Locations of drill-holes and dredge samples.*

Datums and projections

All co-ordinates used in the calculation of the outer limits of the extended continental shelf are expressed on the World Geodetic System 1984 (WGS84) datum. This is a realisation of an International Terrestrial Reference System (ITRS) that is equivalent to the International Terrestrial Reference Frame 1994 (ITRF94).

Geodetic calculations are all performed using the MarZone (MARitime ZONE boundary) software[39] with co-ordinates on the WGS84 datum. MarZone software computes the jurisdictional boundaries that are described in article 76 from the location of territorial sea baselines, the 2,500 metre isobath and fixed points. MarZone calculates the outer limit using the method of envelopes of arcs on the surface of the WGS84 geodetic ellipsoid.

Data uncertainties

The data used by the New Zealand Continental Shelf Project have been acquired using a wide range of instruments over a long period of time. The uncertainties in these data vary depending on their vintage and the instrumentation. Errors in navigation and positioning are a significant component of the uncertainty for each measurement. In addition, there are instrumental, signal processing, and interpretive uncertainties associated with each geophysical technique used for the project. Table 1 lists estimates of the uncertainties associated with the parameters used to delimit the continental shelf.

Table 1 *Uncertainty estimates used for the New Zealand Continental Shelf Project (adapted from Macnab 2000[40])*

Parameter	Techniques	Source of uncertainty	Uncertainty estimate
Foot of continental slope	Acoustic soundings, navigation and data interpretation	Measurement and interpretation accuracy	Up to 4 nautical miles (7.5 kilometres)
2,500 metre isobath	Acoustic soundings, navigation and data interpretation	Measurement and interpretation accuracy	Up to 4 nautical miles (7.5 kilometres)
1 % sediment thickness	Acoustic soundings, navigation and data interpretation	Measurement and interpretation accuracy	Up to 4 nautical miles (7.5 kilometres)
Land base point	Survey observations, navigation and charts	Measurement, interpretation accuracy and tolerance	Up to 300 metres
Foot of continental slope + 60 nautical miles distance	Geodetic calculations	Computation accuracy and tolerance	1 metre (+ foot of continental slope uncertainty)
2,500 metre isobath + 100 nautical miles distance	Geodetic calculations	Computation accuracy and tolerance	1 metre (+ 2,500 metre isobath uncertainty)
200 nautical mile limit	Geodetic calculations	Computation accuracy and tolerance	1 metre (+ land base point uncertainty
350 nautical mile limit	Geodetic calculations	Computation accuracy and tolerance	1 metre (+ land base point uncertainty)

Navigation and positioning accuracy

The New Zealand Continental Shelf Project uses data that have been collected over the last 40 years. The navigation methods used for these voyages, the relevant IHO codes, and the estimated uncertainties are shown in Table 2. Although the vintage of the data is a good indicator of the type of navigation systems used, the technologies overlapped as organisations adopted new systems at different times. These navigational uncertainties do not include the effects of human errors.

Table 2 Navigation uncertainty for data used by the New Zealand Continental Shelf Project

Vintage	Navigation	IHO Code	Uncertainty
Up to 1967	Celestial and dead reckoning	1G & 1H	3–4 nautical miles
1967–1990	Transit satellite and dead reckoning	1F & 1G	0.25–0.5 nautical miles
1988–2002	GPS	1D/E	30–100 metres
1996–2002	Differential GPS	1D	1–10 metres
All	Not specified	1G & 1H	3–4 nautical miles

Celestial navigation

Until relatively recent times (about the 1960s) sailors have guided their ships by celestial navigation—determining their position by observing the sun, moon, stars and planets.

Celestial navigation is a 100% observer-based method and its accuracy depends on the skills of the observer and the quality of the instruments used. At best it has an accuracy of 3–4 nautical miles. The repeatability has a similar accuracy range.

Dead reckoning

Dead reckoning is an estimate of the ship's position based on careful records of its movement. The initial point for dead reckoning is usually the last fix obtained from the sight of land at the start of a voyage. From this point, true courses steered and distances travelled (as recorded by ship's log) are plotted on a chart. Dead reckoning re-starts each time that new bearings, celestial observations, or electronic aids can provide an accurate fix.

This method is most often used in conjunction with several of the other navigation techniques and gives an estimate of position at times when the other methods are not available. The positions obtained are approximate because the method usually does not allow for the effect of leeway (wind), current, speed errors, helmsman error, or gyro error.

The accuracy is a function of the time between fixes and the number of course alterations. Errors can be large (several nautical miles) and hard to quantify. Positions are normally back-calculated between fixes once a new fix has been obtained.

TRANSIT satellite

TRANSIT was the first operational satellite positioning system established by the United States Navy. Positions were obtained by measuring the Doppler shift of the satellite signals. It became available for civilian use in 1967, but in some areas of the globe the system was not available 24 hours a day. The TRANSIT system operated until 1996, by which time it had been superseded by the GPS system.

With TRANSIT navigation the predicted positioning accuracy was 500 metres for a single-frequency receiver and 25 metres for a dual-frequency receiver. However, the achievable accuracy was not close to the theoretical optimum and depended heavily on the accuracy to which vessel course, speed, and time were known. A one-knot error in velocity input could cause a fix error of up to 0.2 nautical miles.

The TRANSIT satellites were not in evenly spaced orbits, and the time between fixes was often more than 6 hours (especially in areas south of New Zealand). The achievable accuracy of the system was about 0.25–0.5 nautical miles.

Global Positioning Satellite system (GPS)

The Navigation Satellite for Time and Ranging/Global Positioning Satellite System (Navstar/GPS) is a satellite-based radio-navigation system permitting land, sea, and airborne users to determine their three-dimensional position, velocity, and time 24 hours a day, in all weather, anywhere on the globe.

The program was created by the United States Department of Defense in 1973. The first GPS satellite was launched in February 1978 and the system was declared fully operational on 17 July 1995.

GPS is more user-friendly and an order-of-magnitude more accurate than earlier systems. Initially the civilian frequency had an uncertainty of 100 metres (at 95% confidence level). With time, the receiver quality improved and stand-alone GPS uncertainty decreased to about 30 metres (at 95% confidence level).

In March of 1990 the United States Department of Defense introduced a planned inaccuracy, *Selective Availability,* into the GPS signal. The satellites were instructed to "dither" their times and locations, rounding them off into less accurate steps. This degraded the positional accuracy of the GPS signal back to about 100 metres. From May 2000 *Selective Availability* was reset to zero, allowing the stand-alone receivers to once again operate with an accuracy of about 30 metres.

Differential Global Positioning Satellite system (DGPS)

Differential GPS enhances GPS with differential corrections to the basic satellite measurements. Differential GPS is based on accurate knowledge of the geographic location of at least one reference station, which is used to compute corrections to GPS parameters, error sources, and/or the resultant positions. These differential corrections are transmitted to GPS users, who apply the corrections to their received GPS signals or computed position.

Differential corrections can decrease the navigational uncertainty for a civilian user of GPS from 100 metres to less than 1 metre.

Early Differential GPS systems had a limited range because they relied on transmission of differential corrections from earth-bound stations. Since the mid 1990s, however, the differential corrections have been transmitted via communications satellites, giving an uncertainty of less than 10 metres.

Echo-sounding

Echo-sounding techniques have changed with time, but for the purposes of the New Zealand Continental Shelf Project most of these advances are of only moderate importance. The majority of the bathymetry data used for the Continental Shelf Project are from single-beam sounders along single ship tracks.

The New Zealand Continental Shelf Project has determined the sounding accuracy using the International Hydrographic Organisation standards for sounding in modern surveys[29].

Single beam

Over the last 30 to 40 years the main advances in single beam echo sounding have been the improvement of algorithms for bottom detection, the change from paper records to digital logging, and the use of narrow-beam sounders.

Multi-beam

The use of multi-beam swath bathymetry systems has increased over the last decade. These systems can improve the delineation of the 2,500 metre contour by accurately identifying its position, as well as the slope of the local sea floor. They can provide a more complete image of the margin, allowing more confident identification of foot of the continental slope positions based on maximum change of gradient at its base.

Sounding accuracy

All depth measurements inherently have fixed and variable errors. Fixed errors are those that remain the same, regardless of depth. Variable errors are affected by the water depth and usually increase with depth[41]. In water depths of most interest to the Continental Shelf Project (i.e., 2,500 metres or greater), the variable errors are larger than the fixed errors.

Fixed errors are generally small and have little effect on the uncertainty of the 2,500 metre contour position. They include the effects of vessel parameters such as draught and squat, instrument inaccuracies associated with heave and bottom detection, and tidal effects.

Vessel parameters can be measured before the start of a survey and the uncertainties estimated. Estimates of the instrument inaccuracies are based on the manufacturer's specifications. The tidal effects are based on real-time measurements, modelled values based on observed data, or a fixed value applied in the processing.

Variations in the speed of sound in water introduce variable errors that have a significant impact on depth measurement. For most single beam surveys the sounder is set to a fixed velocity of sound through the water (usually 1,500 metres/second or 1,463 metres/second) and the initial depths are corrected using Echo-Sounding Correction Tables[28] during post-survey processing. These global correction tables are compiled from data with a varied spatial distribution, and their expected uncertainty varies from ± 5 metres to ± 20 metres. In 2,500 metres of water, an error in velocity of 1 metre/second results in a depth error of about 2 metres, and an error of 10 metres/second results in a depth error of about 17 metres. Modern surveys are improving the accuracy of depth measurements by making real-time velocity measurements in the water column. Profilers accurately measure the velocity *in situ* or calculate velocity by measuring the variation of salinity, temperature and pressure with depth.

The area of the echo-sounder "footprint" also contributes to the variable error. The beam width for single-beam sounders is typically 20° to 30°. This means the echo-sounder has a "footprint" of about 1,000 metres in 2,500 metres of water. The interaction of the sounder beam with sea-floor topography (side swipe, hyperbolic returns), based on the wavelength of the sound pulse and the depth over this area, smooths large features and obscures small features. It can horizontally displace the 2,500 metre contour on a sloping sea floor.

The uncertainty in the horizontal position of the 2,500 metre contour is due to the cumulative effect of inaccuracies in depth measurement, and variations in water velocity, beam width and sea-bed slope. For example, a sounder with a 24° beam width and a 10 metre/second velocity error will have a depth error of 57 metres. This translates to a potential contour displacement of up to 3,250 metres on a 1° slope.

In summary, the uncertainty of bathymetry measurements associated with sounding inaccuracies varies as a function of water depth and sea-floor topography. It is typically of the order of 1% of the water depth. In depths over 1,000 metres, the uncertainty of depth measurements is usually several tens of metres.

Seismic reflection data

Uncertainties in the interpretation of seismic reflection data arise from navigational errors, from the use of simplistic or incorrect velocity/depth and density/depth functions, and from errors in interpretation due to factors such as shallow volcanics and lateral changes in lithology.

The vertical resolution is a function of the frequency content of the signal, the acoustic velocity of the rocks, and the complexity of the geology. The maximum vertical resolution is generally considered to be ¼ of the signal wavelength at the dominant frequency. For example, if the dominant frequency of the signal is 50 Hz and the acoustic velocity is 2,500 metres/second, then the wavelength is 50 metres and the vertical resolution is about 10–15 metres in horizontal strata.

The resolution is also a function of the size of the Fresnel zone, the area of the reflection interface that contributes to the reflection. This area is a function of both the depth and dominant frequency. For the example above, with a wavelength of 50 metres, the diameter of the area contributing to a reflection at a depth of 1,000 metres would be about 300 metres. At a depth of 5,000 metres it would be about 700 metres.

The geology can be a significant source of uncertainty. If the nature of the rocks is not known, or if the geology is complicated by factors such as faulting or volcanic intrusion, then the interpretation can be very inaccurate. Wells and dredge samples are the best sources of information about the nature and physical properties of the rocks in the subsurface.

In well-surveyed sedimentary basins, with adequate well control and relatively simple stratigraphy, the vertical uncertainty is probably of the order of a few tens of metres. In reconnaissance areas beyond the continental shelf, where the velocities and stratigraphy are poorly known, the uncertainties in interpreted depth for the basement and Moho and are probably of the order of a few hundred metres and a few kilometres, respectively.

Seismic refraction data

Uncertainties in sonobuoy interpretations arise from sonobuoy drift, and from interpretive constraints such as seismic reflector/refractor horizon identification, lateral variability in the acoustic velocity, and the availability of other data such as seismic reflection data to guide the solutions. Large-volume seismic sources generally reduce the measurement errors because the recorded signal strength is stronger, and the source-receiver offset can be longer.

For the New Zealand Continental Shelf Project, velocities were calculated for the main sediment units observed in the deep ocean basins. The uncertainty in the velocities derived from sonobuoy models is about ± 10%.

Satellite gravity data

Satellite gravity anomalies include the effects of changes in bathymetry, sediment thickness, crustal structure, and ocean circulation. The uncertainty in satellite gravity values can be of the order of 4–7 mGal[30], increasing near the coast. The spacing of the orbits and the elevation of the satellites result in a spatial resolution of about 15 kilometres.

Surface vessel gravity and magnetic data

Uncertainties in marine gravity anomalies arise primarily from base level variations among surveys, and noise arising from the gravity meter response to variations in the state of the sea. The uncertainty of regional gravity compilations is typically about ±5 mGal.

Uncertainties in the analysis and modelling of these data arise from the irregular distribution of the data, the lack of knowledge of the three-dimensional subsurface structure and distribution of rock properties, and the non-uniqueness of the solutions. The spatial resolution of the data is a function of water depth, and is typically about 5 kilometres.

Uncertainties in marine magnetic anomalies arise primarily from diurnal and magnetic storm effects. The uncertainty of regional magnetic compilations is typically about ±100 nT. The spatial resolution of the data is a function of water depth, and is typically about 1–2 kilometres.

Drill-hole data and rock samples

Uncertainties in drill-hole data arise primarily from down-hole sample contamination. These are reduced by application of good drilling practice, casing strategy and well log correlation. All uncertainties in dating samples and elemental analyses of rock samples are determined from laboratory treatment of the samples and stated when the data are presented.

Uncertainties in analyses of sea-bed rock samples include locating where the sample came from on the sea floor. This error varies with water depth and is typically between 50 and 500 metres.

Scientist loading a sonobuoy into a compressed air launcher

Dredging bottom samples from the continental shelf

Part 3 – Data organisation – submission to the Commission on the Limits of the Continental Shelf

The New Zealand Continental Shelf Project has involved over 10 years of data acquisition, compilation, and analysis, and covers the entire New Zealand region in the Southwest Pacific. Both the area covered and the volume of data are large, and data organisation has been an essential aspect of the project.

The documents prepared by the Continental Shelf Project will form the basis for New Zealand's submission to the Commission on the Limits of the Continental Shelf.

The final report of the Continental Shelf Project will have four main parts and five appendices (Figure 21). The Introduction describes the project and summarises the data used to define the outer limits of the continental shelf. It describes the morphological and geological setting of New Zealand, and highlights the links of offshore areas to the New Zealand landmass. The Introduction describes how article 76 is applied to the morphological and geological features that make up the New Zealand continental margin. The extent of the extended continental shelf is presented, including a discussion of the relevant boundaries of other coastal States.

The second part of the final report is organised geographically to make it easier to deal with the large volume of data. The project region is divided into six areas. This part presents an overview of the morphology and geology of each area, and places them in the context of the prolongation of the land mass. Examples of analyses of geological and geophysical data are included to illustrate the major aspects of prolongation in each area.

The second part includes detailed descriptions of the straight line segments defining the outer limits of the continental shelf for each of the six areas. The latitude and longitude coordinates for the fixed points defining the straight line segments are listed: sediment thickness positions, foot of the continental slope + 60 nautical mile positions, 2,500 metre depth + 100 nautical mile positions, and 200 and 350 nautical miles from territorial sea baseline positions. For each point, reference is made to the fixed points (foot of the continental slope positions, 2,500 metre depth positions, baselines of the territorial sea) that determine their position. In areas where the margin is morphologically and/or geologically complex, the data analysis is discussed in detail and presented in the context of the tectonic evolution of the area.

The third part contains general information supporting the analyses in part 2. It includes descriptions of all the data used by the project, including information about data collection and processing, procedures for data analysis, estimates of uncertainties, factual data about the surveys, and references.

The fourth part of the report contains charts and other large figures that graphically present the data used to define the fixed point locations.

Five appendices accompany the report. These contain the locations of the fixed points used for calculating the limits of the continental shelf for each area. The supporting evidence for each fixed point is described and analysed. The nature of the supporting data varies depending on whether the point is a foot of the continental slope position, a sediment thickness position, a 2,500 metre depth position, or a 200 nautical mile or 350 nautical mile position. The results of the data analysis are discussed and illustrated. The descriptions of the analytical procedures are included in the third part of the report.

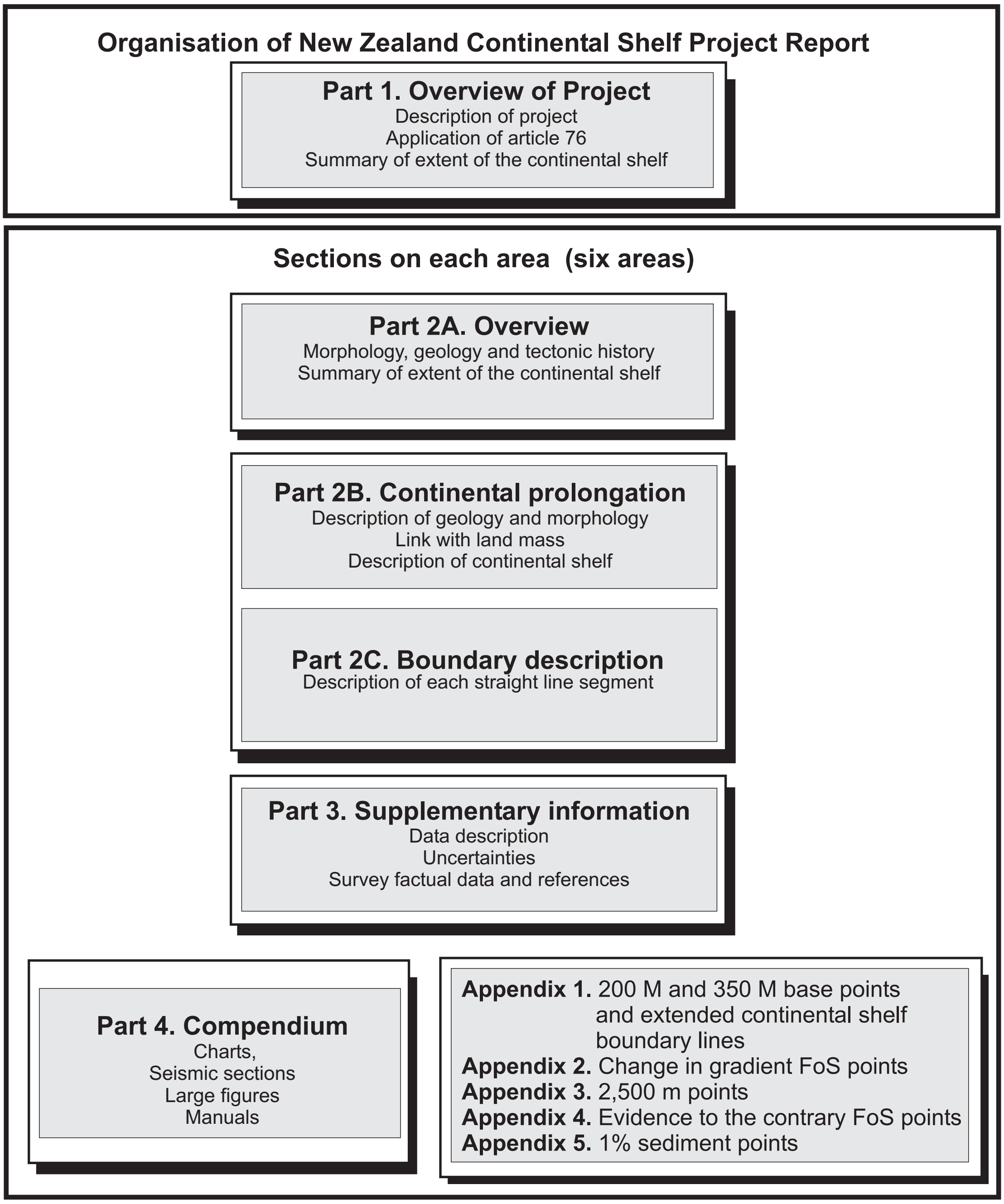


Figure 21 Organisation of the project report on New Zealand's continental shelf; FoS = foot of the continental slope.

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Glossary

Basaltic - Dark, fine-grained igneous rocks usually rich in iron and magnesium and relatively low in silica

Dikes - Sheet-like igneous intrusions that cut across other strata

Gondwana - A supercontinent that included Africa, India, Australia, Antarctica, South America, Madagascar, Sri Lanka and New Zealand. It formed about 2,000 million years ago and began to break apart about 180 million years ago.

Graben - Tensional feature, formed when a block of rock is downthrown between two faults

Moho - The Mohorovicic discontinuity, the geophysical boundary between the crust and mantle, characterised by an increase in acoustic velocity

Pelagic sediment - Sediment deposited in the deep ocean, derived from oceanic organisms or chemically derived from the seawater

Sills - Sheet-like igneous intrusions that are emplaced parallel with other strata

Silicic - Rocks with a relatively high percentage of silica (quartz), e.g., granite, rhyolite

Terrane - A region of crust with well defined margins that has a different tectonic history from that of adjacent regions

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Appendix

United Nations Convention on the Law of the Sea (UNCLOS)

PART VI. CONTINENTAL SHELF

Article 76. Definition of the continental shelf

1. The continental shelf of a coastal State comprises the sea-bed 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 sea-bed 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) a 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 l 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 be 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 sea-bed, 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 isobath, which is a line connecting the depth of 2,500 metres.

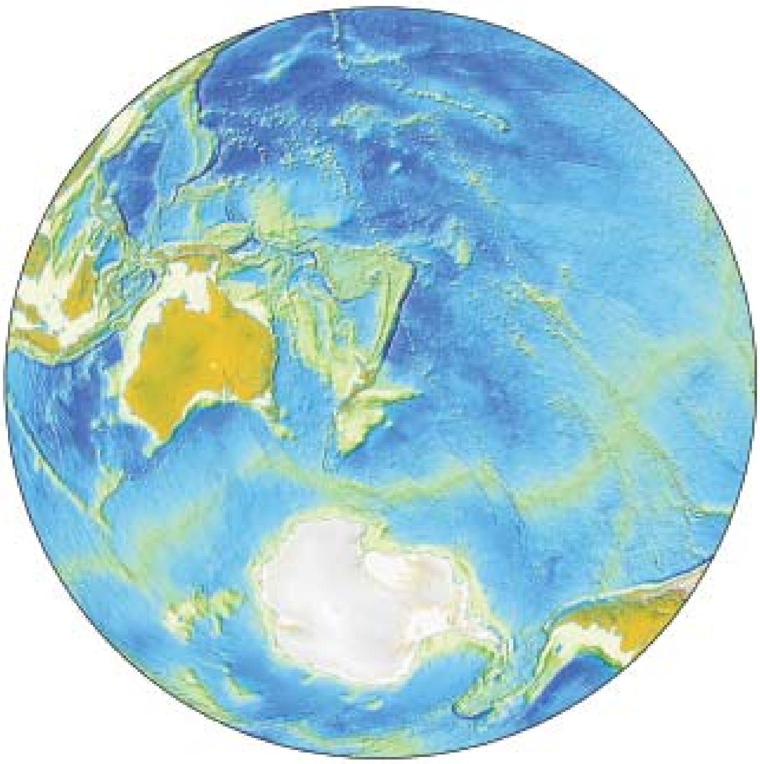
6. Notwithstanding the provisions of paragraph 5, on submarine ridges, the outer limit of the continental shelf shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured. This paragraph does not apply to submarine elevations that are natural components 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 co-ordinates 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.



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This document, written by members of the New Zealand Continental Shelf Project Team, discusses various aspects of the terms and formulae of article 76 of the United Nations Convention on the Law of the Sea, and the challenges that have arisen in applying them to the real-world submarine morphology and geology of the Southwest Pacific. It is likely to be of interest to other countries that are preparing a submission to define the outer limits of their continental shelf. The document includes a discussion of the data used by the project, and the organisation of the final report that will be used as the basis for New Zealand's submission to the Commission on the Limits of the Continental Shelf.

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