(Mortimer, N. et al., 2017)

Zealandia: Earth's Hidden Continent

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ABSTRACT

A 4.9 Mkm^2 region of the southwest Pacific Ocean is made up of continental crust. The region has elevated bathymetry relative to surrounding oceanic crust, diverse and silica-rich rocks, and relatively thick and low-velocity crustal structure. Its isolation from Australia and large area support its definition as a continent—Zealandia. Zealandia was formerly part of Gondwana. Today it is 94% submerged, mainly as a result of widespread Late Cretaceous crustal thinning preceding supercontinent breakup and consequent isostatic balance. The identification of Zealandia as a geological continent, rather than a collection of continental islands, fragments, and slices, more correctly represents the geology of this part of Earth. Zealandia provides a fresh context in which to investigate processes of continental rifting, thinning, and breakup.

INTRODUCTION

Earth's surface is divided into two types of crust, continental and oceanic, and into 14 major tectonic plates (Fig. 1; Holmes, 1965; Bird, 2003). In combination, these divisions provide a powerful descriptive framework in which to understand and investigate Earth's history and processes. In the past 50 years there has been great emphasis and progress in measuring and modeling aspects of plate tectonics at various scales (e.g., Kearey et al., 2009). Simultaneously, there have been advances in our understanding of continental rifting, continent-ocean boundaries (COBs), and the discovery of a number of micro-continental fragments that were stranded in the ocean basins during supercontinent breakups (e.g., Buck, 1991; Lister et al., 1991; Gaina et al., 2003; Franke, 2013; Eagles et al., 2015). But what about the major continents (Fig. 1)? Continents are Earth's largest surficial solid objects, and it seems unlikely that a new one could ever be proposed.

The *Glossary of Geology* defines a continent as "one of the Earth's major land masses, including both dry land and continental shelves" (Neuendorf et al., 2005). It is generally agreed that continents have all the following attributes: (1) high elevation relative to regions floored by oceanic crust; (2) a broad range of siliceous igneous, metamorphic, and sedimentary rocks; (3) thicker crust and lower seismic velocity

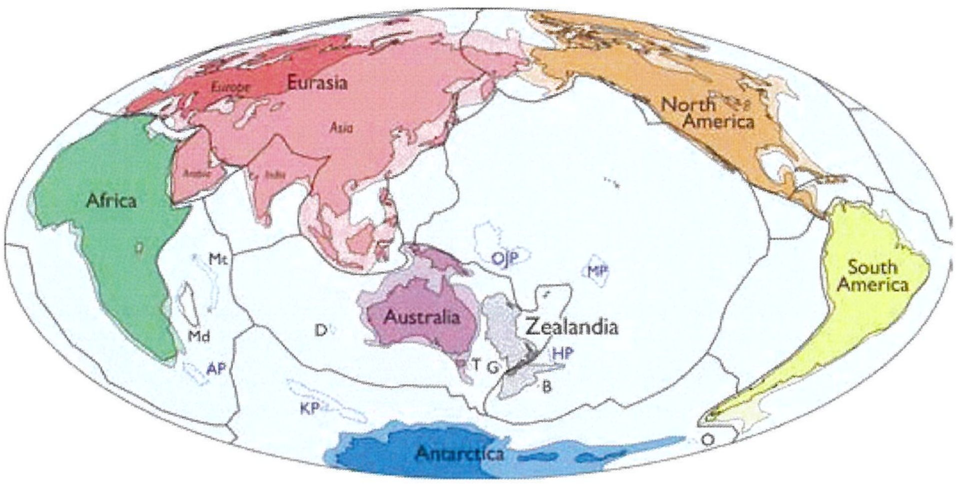

Figure 1. Simplified map of Earth's tectonic plates and continents, including Zealandia. Continental shelf areas shown in pale colors. Large igneous province (LIP) submarine plateaus shown by blue dashed lines: AP—Agulhas Plateau; KP—Kerguelen Plateau; OJP—Ontong Java Plateau; MP—Manihiki Plateau; HP—Hikurangi Plateau. Selected microcontinents and continental fragments shown by black dotted lines: Md—Madagascar; Mt—Mauritia; D—Gulden Draak; T—East Tasman; G—Gilbert; B—Bollons; O—South Orkney. Hammer equal area projection.

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structure than oceanic crustal regions; and (4) well-defined limits around a large enough area to be considered a continent rather than a microcontinent or continental fragment. The first three points are defining elements of continental crust and are explained in many geoscience textbooks and reviews (e.g., Holmes, 1965; Christensen and Mooney, 1995; Levander et al., 2005; Kearey et al., 2009; Condie, 2015). To our knowledge, the last point—how "major" a piece of continental crust has to be to be called a continent—is almost never discussed, Cogley (1984) being an exception. Perhaps this is because it is assumed that the names of the six geological continents—Eurasia, Africa, North America, South America, Antarctica, and Australia—suffice to describe all major regions of continental crust.

The progressive accumulation of bathymetric, geological, and geophysical data since the nineteenth century has led many authors to apply the adjective *continental* to New Zealand and some of its nearby submarine plateaus and rises (e.g., Hector, 1895; Hayes, 1935; Thomson and Evison, 1962; Shor et al., 1971; Suggate et al., 1978). "New Zealand" was listed as a continent by Cogley (1984), but he noted that its continental limits were very sparsely mapped. The name Zealandia was first proposed by Luyendyk (1995) as a collective name for New Zealand, the Chatham Rise, Campbell Plateau, and Lord Howe Rise (Fig. 2). Implicit in Luyendyk's paper was that this was a large region of continental crust, although this was only mentioned in passing and he did not characterize and define Zealandia as we do here.

In this paper we summarize and reassess a variety of geoscience data sets and show that a substantial part of the southwest Pacific Ocean consists of a continuous expanse of continental crust. Furthermore, the 4.9 Mkm^2 area of continental crust is large and separate enough to be considered not just as a continental fragment or a microcontinent, but as an actual continent—Zealandia. This is not a sudden discovery but a gradual realization; as recently as 10 years ago we would not have had the accumulated data or confidence in interpretation to write this paper. Since it was first proposed by Luyendyk (1995), the use of the name Zealandia for a southwest Pacific continent has had moderate uptake (e.g., Mortimer et al., 2006; Grobys et al., 2008; Segev et al., 2012; Mortimer and Campbell, 2014; Graham, 2015). However, it is still not well known to the broad international science community. A correct accounting of Earth's continents is important for multiple fields of natural science; the purpose of this paper is to formally put forth the scientific case for the continent of Zealandia (Figs. 1 and 2) and explain why its identification is important.

Figure 2. Spatial limits of Zealandia. Base map from Stagpoole (2002) based on data from Smith and Sandwell (1997). Continental basement samples from Suggate et al. (1978), Beggs et al. (1990), Tulloch et al. (1991, 2009), Gamble et al. (1993), McDougall et al. (1994), and Mortimer et al. (1997, 1998, 2006, 2008a, 2008b, 2015). NC—New Caledonia; WTP—West Torres Plateau; CT—Cato Trough; Cf—Chesterfield Islands; L—Lord Howe Island; N—Norfolk Island; K—Kermadec Islands; Ch—Chatham Islands; B—Bounty Islands; An—Antipodes Islands; Au—Auckland Islands; Ca—Campbell Island. Mercator projection.

ZEALANDIA AS A CONTINENT

New Zealand and New Caledonia are large, isolated islands in the southwest Pacific Ocean. They have never been regarded as part of the Australian continent, although the geographic term Australasia often is used for the collective land and islands of the southwest Pacific region. In the following sections, we summarize the four key attributes of continents and assess how Zealandia meets these criteria.

Elevation

Continents and their continental shelves vary in height but are always elevated relative to oceanic crust (Cogley, 1984). The elevation is a function of many features, fundamentally lithosphere density and thickness, as well as plate tectonics (e.g., Kearey et al., 2009). The existence of positive bathymetric features north and south of New Zealand has been known for more than a century (Farquhar, 1906). The accuracy and precision of seafloor mapping have improved greatly over the past decades (Brodie, 1964; Smith and Sandwell, 1997; Stagpoole, 2002) and a deliberately chosen color ramp on a satellite gravity-derived bathymetry map provides an excellent visualization of the extent of continental crust (Fig. 2). The approximate edge of Zealandia can be placed where the oceanic abyssal plains meet the base of the continental slope, at water depths between 2500 and 4000 m below sea level. The precise position of the foot of the continental slope around Zealandia was established during numerous surveys in support of New Zealand's Law of the Sea submission (Wood et al., 2003; UNCLOS, 2008).

Zealandia is everywhere substantially elevated above the surrounding oceanic crust. The main difference with other continents is that it has much wider and deeper continental shelves than is usually the case (Fig. 1). Zealandia has a modal elevation of ~–1100 m (Cogley, 1984) and is ~94% submerged below current sea level. The highest point of Zealandia is Aoraki–Mount Cook at 3724 m.

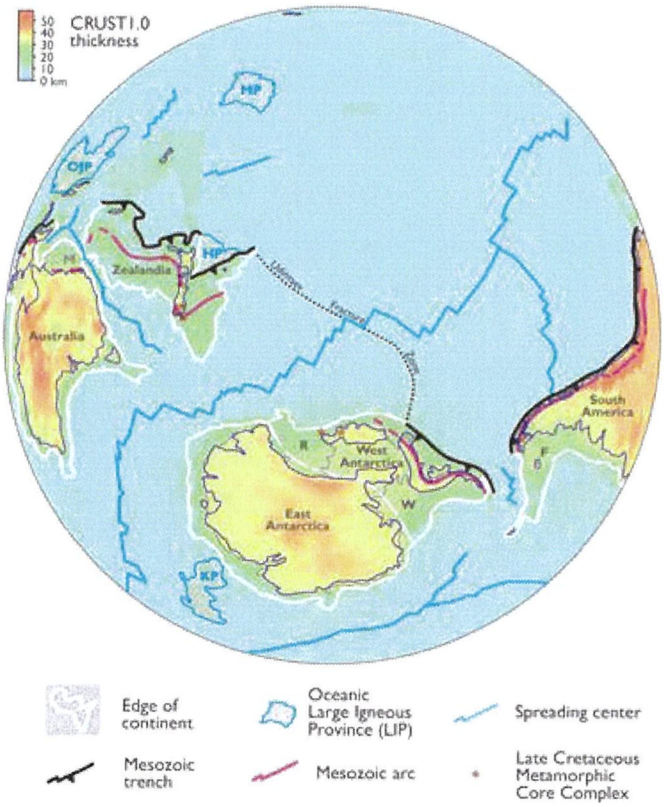

Figure 3. Present day map of CRUST1.0 crustal thickness (Laske et al., 2013) showing the dispersed Gondwana continents of Australia, Zealandia, East and West Antarctica, and South America. Note thin continental crust in vicinity of Mesozoic arc. M—Marion Plateau; R—Ross Sea; W—Weddell Sea; F—Falkland-Malvinas Plateau. LIP abbreviations: KP—Kerguelen Plateau; OJP—Ontong Java Plateau; MP—Manihiki Plateau; HP—Hikurangi Plateau. Thick coastlines in Antarctica are isostatically corrected ice-free coastlines (Jamieson et al., 2014). Orthographic projection.

Geology

By itself, relatively high elevation is not enough to establish that a piece of crust is continental. Oceanic large igneous provinces such as the Ontong Java Plateau (Fig. 1; Coffin and Eldholm, 1994) are elevated but not continental. Rocks of the modern oceanic crust typically comprise basalt and gabbro of Jurassic to Holocene age. In contrast, continents have diverse assemblages of Archean to Holocene igneous, metamorphic, and sedimentary rocks, such as granite, rhyolite, limestone, quartzite, greywacke, schist, and gneiss, arranged in orogenic belts and sedimentary basins.

Essential geological ground truth for Zealandia is provided by the many island outcrop, drill core, xenolith, and seabed dredge samples of Paleozoic and Mesozoic greywacke, schist, granite, and other siliceous continental rocks that have been found within its limits (Fig. 2). Many of these have been obtained from expeditions in the past 20 years (see Fig. 2, caption). Orogenic belts, of which the Median Batholith and Haast Schist are parts, can be tracked through onland New Zealand and across Zealandia (Fig. 2). Thus, there is a predictable regional coherency and continuity to the offshore basement geology.

Traditionally, continents have been subdivided into cratons, platforms, Phanerozoic orogenic belts, narrow rifts, and broad extensional provinces (Levander et al., 2005). Eurasia, Africa, North America, South America, Antarctica, and Australia all contain Precambrian cratons. The oldest known rocks in Zealandia are Middle Cambrian limestones of the Takaka Terrane and 490–505 Ma granites of the Jacquiery Suite (Mortimer et al., 2014). Precambrian cratonic rocks have not yet been discovered within Zealandia, but their existence has been postulated on the basis of Rodinian to Gondwanan age detrital zircon ratios (Adams and Griffin, 2012). Furthermore, some Zealandia mantle xenoliths give Re-Os ages as old as 2.7 Ga (Liu et al., 2015). Geologically, Zealandia comprises multiple Phanerozoic orogenic belts on which a broad extensional province and several narrow rift zones have been superimposed (Mortimer and Campbell, 2014).

Atop its geological basement rocks, Zealandia has a drape of at least two dozen spatially separate Late Cretaceous to Holocene sedimentary basins. These typically contain 2–10-km-thick sequences of terrigenous and calcareous strata (Zealandia Megasequence of Mortimer et al., 2014) and include a widespread continental breakup unconformity of ca. 84 Ma age (Bache et al., 2014). The Zealandia Megasequence provides a Zealandia-wide stratigraphic record of continental rifting, and marine transgression events, similar to that seen in formerly conjugate east Australian basins (Blewett, 2012).

Crustal Structure

Continental crust varies considerably in thickness and physical properties. Christensen and Mooney (1995) give an average P wave velocity of 6.5 km^{-1} and