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Playing jigsaw with Large Igneous Provinces—A plate tectonic reconstruction of Ontong Java Nui, West Pacific

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Key Points:

- New plate kinematic reconstruction of the western Pacific during the Cretaceous
- Detailed breakup scenario of the "Super"-Large Igneous Province Ontong Java Nui
- Ontong Java Nui "Super"-Large Igneous Province as result of plume-ridge interaction

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Abstract The three largest Large Igneous Provinces (LIP) of the western Pacific—Ontong Java, Manihiki, and Hikurangi Plateaus—were emplaced during the Cretaceous Normal Superchron and show strong similarities in their geochemistry and petrology. The plate tectonic relationship between those LIPs, herein referred to as Ontong Java Nui, is uncertain, but a joined emplacement was proposed by Taylor (2006). Since this hypothesis is still highly debated and struggles to explain features such as the strong differences in crustal thickness between the different plateaus, we revisited the joined emplacement of Ontong Java Nui in light of new data from the Manihiki Plateau. By evaluating seismic refraction/wide-angle reflection data along with seismic reflection records of the margins of the proposed "Super"-LIP, a detailed scenario for the emplacement and the initial phase of breakup has been developed. The LIP is a result of an interaction of the arriving plume head with the Phoenix-Pacific spreading ridge in the Early Cretaceous. The breakup of the LIP shows a complicated interplay between multiple microplates and tectonic forces such as rifting, shearing, and rotation. Our plate kinematic model of the western Pacific incorporates new evidence from the breakup margins of the LIPs, the tectonic fabric of the seafloor, as well as previously published tectonic concepts such as the rotation of the LIPs. The updated rotation poles of the western Pacific allow a detailed plate tectonic reconstruction of the region during the Cretaceous Normal Superchron and highlight the important role of LIPs in the plate tectonic framework.

1. Introduction

The plate tectonic setup of the central and western Pacific since the Cretaceous is a mosaic of multiple small and short-lived oceanic plates and continental fragments. Plate kinematic reconstructions [e.g., *Davy et al.*, 2008; *Chandler et al.*, 2012; *Seton et al.*, 2012] struggle to explain all the features of the difficult interplay between Large Igneous Provinces (LIP), relict spreading centers, subduction, and hot spot volcanism overprinting the area. As the generation of most of the oceanic crust of the western Pacific takes place during the Cretaceous Normal Superchron (CNS), no magnetic seafloor-spreading anomalies constrain the plate tectonic reconstructions (Figure 1). The remnants of the proposed "Super"-LIP (Ontong Java Nui) emplacement during the Early Cretaceous [*Taylor*, 2006; *Chandler et al.*, 2012, 2013] play an important role in this setup, since two former components of this Super-"LIP"—the Ontong Java Plateau and the Hikurangi Plateau—interact with subduction trenches bordering the Australian Plate (Figure 1) and were possibly individual oceanic plates during the Cretaceous. We suggest that the termination of the subduction at the eastern Gondwana margin is caused by the arrival of the Hikurangi Plateau at the subduction zone [*Davy and Wood*, 1994; *Luyendyk*, 1995; *Billen and Stock*, 2000; *Davy et al.*, 2008, 2012; *Matthews et al.*, 2012; *Reyners*, 2013; *Davy*, 2014; *Timm et al.*, 2014]. This process initiated a global plate reorganization event [*Matthews et al.*, 2012]. The third major LIP component, the Manihiki Plateau, has currently no direct interaction with active plate boundaries, but tectonic deformation at its margins, due to the possible breakup of Ontong Java Nui and internal fragmentation must have occurred during the Cretaceous [*Winterer et al.*, 1974]. The internal fragmentation and partitioning of the Manihiki Plateau into three subprovinces has previously been ignored by all published plate tectonic reconstructions. Recent findings reveal distinct differences in the tectonic and magmatic evolution between the main two subprovinces the Western Plateaus and the High Plateau [*Pietsch and Uenzelmann-Neben*, 2015; K. Hochmuth et al., Multiphase magmatic and tectonic evolution of a large igneous province—Evidence from the crustal structure of the Manihiki Plateau, western Pacific, submitted to *Geophysical Journal International*, 2015].

In this paper, we analyze the role of the Ontong Java Nui LIPs in the plate tectonic framework of the western Pacific Ocean and revisit the hypothesis of the coupled emplacement of the major LIPs of the western Pacific as proposed by *Taylor* [2006] and *Chandler et al.* [2012]. By reexamining available seismic refraction/

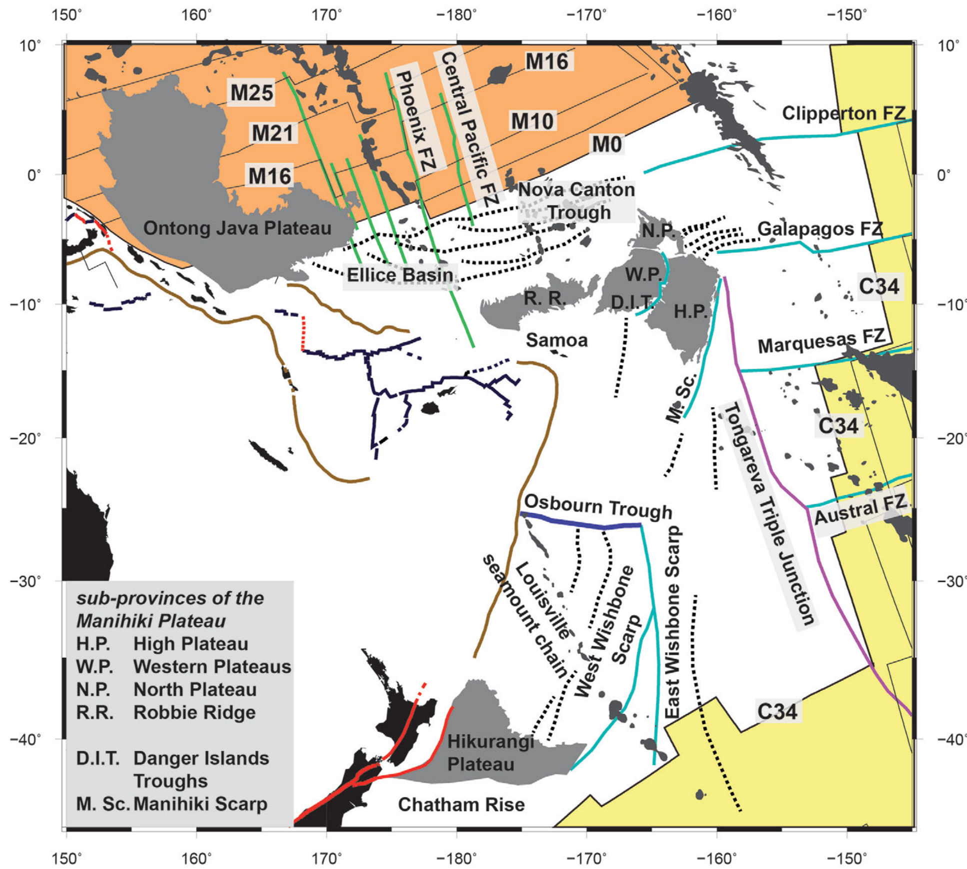

Figure 1. Current plate tectonic setup of the western Pacific Ocean; active subduction zones are shown in brown, transform faults in red and mid-ocean ridges in black. Black dashed lines are tectonic lineations tracked from magnetic anomaly maps [*Maus et al*., 2009] and gravity anomaly maps [*Sandwell et al*., 2014]. Green and turquois lines indicate fault zones within Jurassic seafloor [*Nakanishi et al*., 1992] and Cretaceous seafloor, respectively. The former spreading center at the Osbourn Trough is marked in blue and the Tongareva Triple Junction Trace is marked in magenta. Isochrons (thin black lines) are taken from *Seton et al*. [2012] and are shaded in orange for the M-Series and in yellow for the C-Series on the Pacific Plate. Pacific seafloor emplaced during the CNS is shown in white.

wide-angle reflection data along with seismic reflection records and global gravity and bathymetry grids, we present a more detailed reconstruction of the emplacement of the western Pacific's LIPs, possible breakup scenarios, and the role of internal fragmentation of the Manihiki Plateau.

2. Geological Setting

2.1. The Large Igneous Provinces of the Western Pacific

The crustal structure and geodynamic development of LIPs differ greatly from those of normal oceanic crust. Although the igneous material (basalt in the upper crust, gabbros in the lower crust) is the same, the crust of LIPs is 3 times thicker on average than that of normal oceanic crust [*Coffin and Eldholm*, 1994; *Ridley and Richards*, 2010]. The Ontong Java Plateau has a crustal thickness of >30 km [*Furumoto et al*., 1976; *Miura et al*., 2004]. Crustal thickness of the High Plateau of Manihiki Plateau is about 20 km (Hochmuth et al., submitted manuscript, 2015). The Western Plateaus of the Manihiki Plateau show a crust that thins from a maximum crustal thickness of 17 km in the east to 9 km in the west (Hochmuth et al., submitted manuscript, 2015). The crustal thickness of the Hikurangi Plateau is inferred to be approximately between 17 and 23 km from gravity modeling [*Davy et al*., 2008]. All these LIPs experienced phases of secondary magmatic and volcanic activity, which partly overprinted tectonic sutures [*Davy et al*., 2008; *Inoue et al*., 2008; *Hoernle et al*., 2010; *Pietsch and Uenzelmann-Neben*, 2015].

An important key feature of LIPs is the High-Velocity Zone (HVZ) with *P* wave velocities between 7.3 and 7.7 km/s within its lower crust. The HVZ is believed to consist of olivine and pyroxene crystal fractionation,

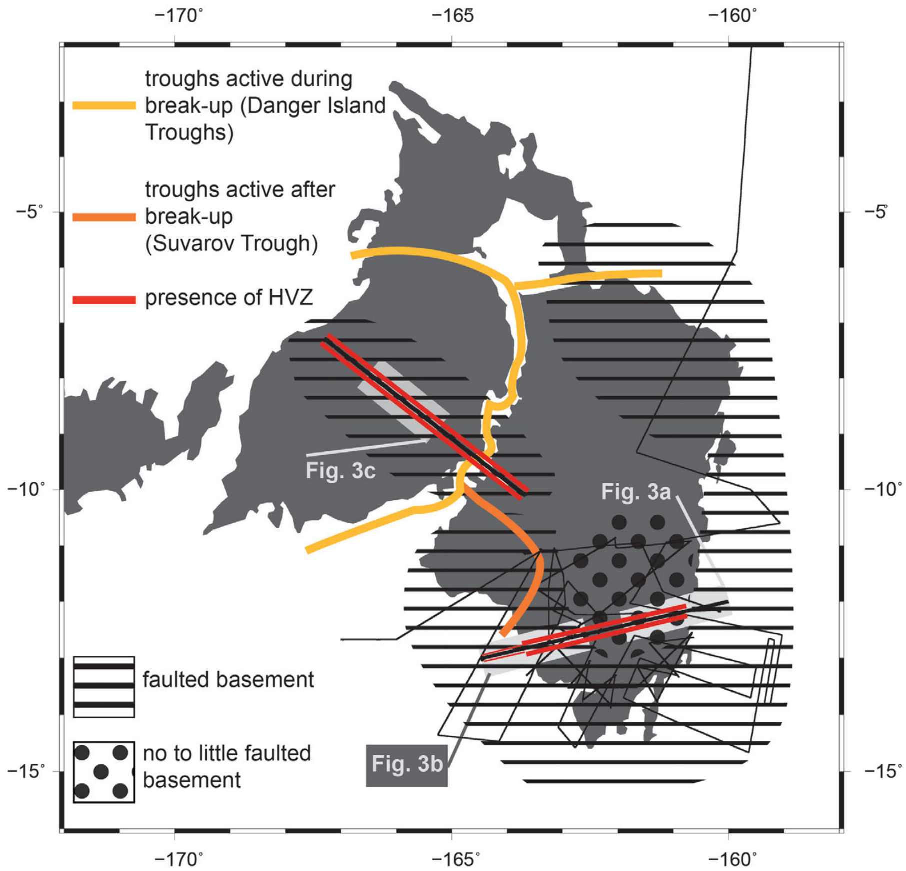

Figure 2. Relicts of tectonic alteration on the Manihiki Plateau as seen in seismic reflection lines from SO-224 and KIWI-12 (thin black lines) and seismic refraction lines (thick black lines) from SO-224. Dashed areas indicate faulted basement. The dotted areas show little to no faulting within the basement. The yellow line indicates a series of troughs (e.g., Danger Islands Troughs) active during the supposed breakup of Ontong Java Nui. The orange line marks the Suvarov Trough, which was active after the initial breakup. The red lines on the seismic refraction profiles indicate the presence and thickness of the High-Velocity Zone (HVZ), within the *P* wave velocity models. The position of the seismic refraction profiles shown in Figure 3 is indicated by the light grey boxes.

which is trapped above the crust-mantle boundary (Moho) [*Ridley and Richards*, 2010; *Karlstrom and Richards*, 2011]. The presence of the HVZ indicates the influence of hot mantle upwelling, e.g., due to the presence of a hot spot or a mantle plume. The configuration of the HVZ along LIP margins allows an insight into tectonic alteration as well as LIP formation processes (Figure 2). HVZs have been derived from seismic refraction/wide-angle reflection experiments, which have been carried out on the Ontong Java Plateau [*Furumoto et al*., 1976; *Miura et al*., 2004] and on the Manihiki Plateau (Figures 2 and 3) [*Winterer et al*., 1974; Hochmuth et al., submitted manuscript, 2015]. In addition to the LIPs of the western Pacific, numerous active and former hot spot tracks, such as the Louisville seamount chain and the Samoa hot spot, characterize the area (Figure 1).

The omnipresence of volcanically altered oceanic crust has an important impact on the plate tectonic mechanisms of the western Pacific. For example, buoyancy calculations by *Cloos* [1993] predict that oceanic plateaus as thick as 17 km can be subducted. Orogenesis by subducting oceanic plateaus requires a broad volcanic feature ($>$100 km long and 50 km wide) with a crustal thickness of 30 km [*Cloos*, 1993]. These calculations indicate that LIPs can play a significant role in the plate tectonic framework, especially in the Pacific Ocean, since it is surrounded by subduction zones. LIPs influence the behavior of oceanic plates by volcanic arc polarity reversal [e.g., *Musgrave*, 1990; *Mann and Taira*, 2004] or altering subduction patterns [e.g., *Gutscher et al*., 1999; *Liu et al*., 2010].

2.2. The Plate Tectonic Framework of the Pacific During the Cretaceous

The plate kinematics of the Cretaceous Pacific area include countless microplates and past subducted plates [e.g., *Seton et al*., 2012]. During the Jurassic, the so-called Pacific Triangle developed, which is the birthplace

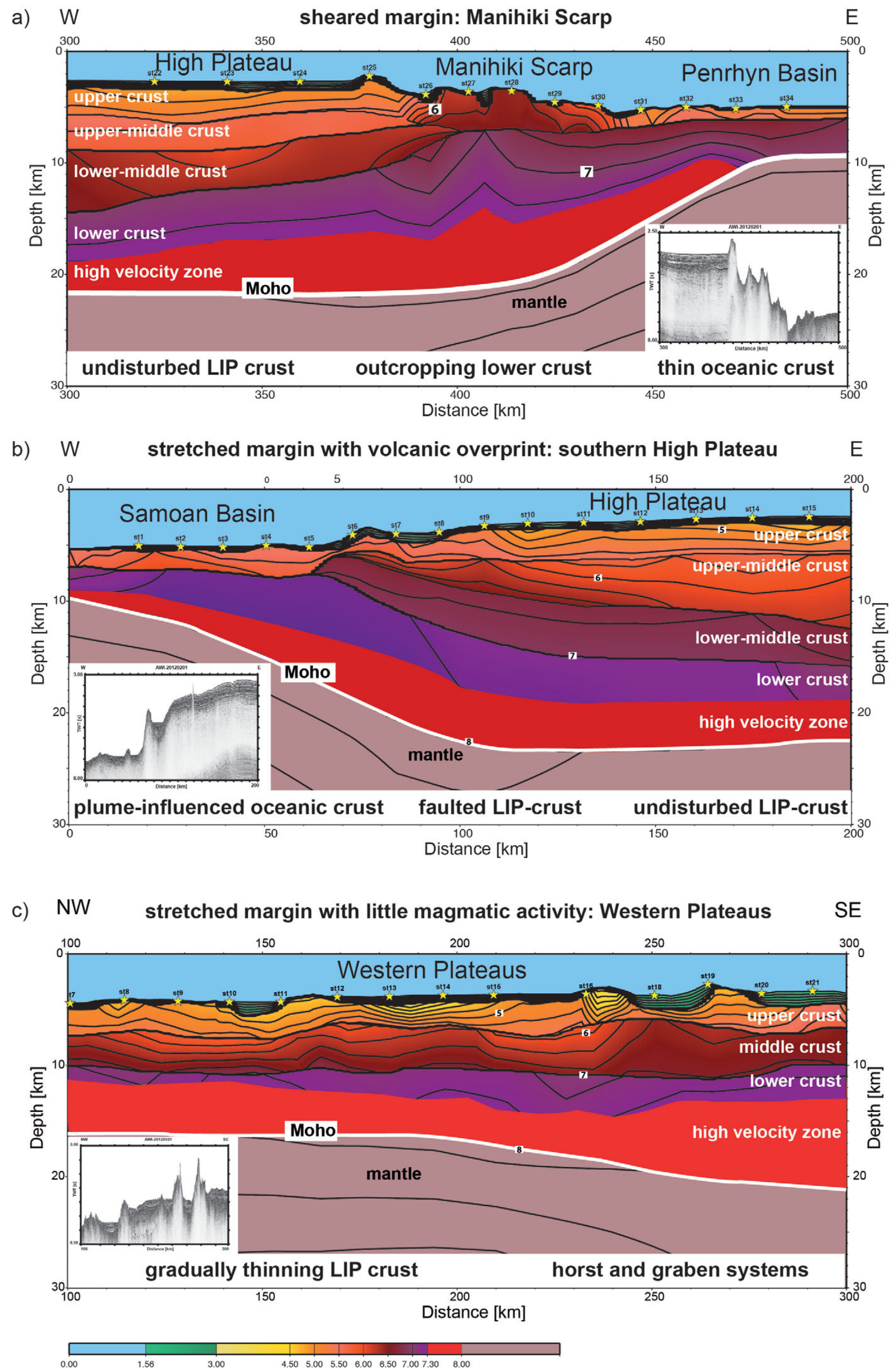

Figure 3. Examples for *P* wave velocity models crossing the different margins of the Manihiki Plateau. The position of the different profiles is indicated in Figure 2. (a) The Manihiki Scarp—a sheared margin, (b) the southern High Plateau—a stretched margin with volcanic overprint, and (c) a part of the Western Plateaus—a stretched margin with little magmatic activity; the small insets depict the corresponding reflection seismic data of the shown profile. For more information on the experimental setup and a view of whole profiles, see Hochmuth et al. (submitted manuscript, 2015) and *Uenzelmann-Neben* [2012].

of today's Pacific Plate. The Pacific Triangle was formed by the Izanagi Plate in the northwest, the Farallon Plate in the northeast, and the Phoenix Plate in the south, which were connected by triple junctions. Magnetic seafloor spreading anomalies can be identified from M27 (155 Ma) to M0 (120 Ma) within the Phoenix lineation northeast of the Ontong Java Plateau [*Nakanishi et al.*, 1992] (Figure 1). After the CNS, magnetic seafloor spreading anomalies can be traced from C34n (83 Ma) to C1 (0.8 Ma) to the east of the Manihiki

Plateau (Figure 1). The whole tectonic reorganization of the Ontong Java Nui LIPs occurred during a time of a relatively stable magnetic field, which does not allow to trace the motion of individual plates by polarity reversals of the magnetic field. In this case, the plate motion can be traced either by fracture zones [*Matthews et al*., 2012], which act as motion paths, or by the variations of the strength of the magnetic field [*Granot et al*., 2012].

We introduce two competing models deciphering this time period presented in the literature, and will reexamine these models in the light of newly acquired data from the Manihiki Plateau: the "Super"-LIP Ontong Java Nui and the separated formation of the Ontong Java Plateau with a coupled emplacement of Manihiki and Hikurangi.

2.2.1. The Ontong Java Nui Hypothesis

Taylor [2006] hypothesized that the three major LIPs of the western Pacific Plate were emplaced as a single "Super"-Large Igneous Province. This "Super"-LIP Ontong Java Nui was formed in the vicinity of the Farallon-Phoenix-Pacific triple junction approximately at 125 Ma [*Timm et al*., 2011]. The trace of this triple junction is imprinted on today's Pacific Plate by a gravity anomaly called the Tongareva Triple Junction Trace, which is trackable from the Manihiki Plateau to the Pacific-Antarctic Ridge striking NW-SE [*Larson et al*., 2002; *Viso et al*., 2005] (Figure 1). The breakup of Ontong Java Nui was initiated at all margins of the Manihiki Plateau between 120 and 118 Ma. To the south, the Osbourn Trough developed as a spreading center, separating the Hikurangi Plateau from Manihiki [*Billen and Stock*, 2000; *Worthington et al*., 2006; *Davy et al*., 2008]. The Ontong Java Plateau drifted away to the west by spreading at the Nova Canton Trough [*Taylor*, 2006; *Chandler et al*., 2012]. The northeastern fragment of the Manihiki Plateau rifted northeastward on the Farallon Plate and the eastern part of the Manihiki Plateau was integrated into the Phoenix Plate in a southward direction [*Larson et al*., 2002; *Viso et al*., 2005]. The motion between the Hikurangi Plateau and the Manihiki Plateau stopped at 100 Ma with the Hikurangi Plateau jamming into the subduction zone at the Chatham Rise followed by cessation of spreading at the Osbourn Trough [*Davy et al*., 2008; *Davy*, 2014]. Other authors [e.g., *Billen and Stock*, 2000; *Sutherland and Hollis*, 2001; *Worthington et al*., 2006] argue for a longer lifespan of the Osbourn Trough, but all agree that the cessation of spreading occurred within the CNS (120–83 Ma). At around 80 Ma, spreading in the Nova Canton Trough between the Ontong Java Plateau and the Manihiki Plateau terminated [*Taylor*, 2006], although the Ontong Java Plateau was not subducting at the Solomon Trench at that time. The opening at the Nova Canton Trough included a rotational component [*Chandler et al*., 2013] between 37° and 52° obtained from paleomagnetic reconstructions. This rotation requires either a decoupling of the Ontong Java Plateau from the Pacific Plate or a yet unrecognized large-scale rotation of the Pacific Plate between 125 and 83 Ma.

The main objections toward this coupled emplacement of the three LIPs include the different crustal thicknesses between the Ontong Java Plateau (>30 km of crust) [*Furumoto et al*., 1976; *Gladczenko et al*., 1997; *Richardson et al*., 2000; *Klosko et al*., 2001; *Miura et al*., 2004] and the conjugate margin at the Manihiki Plateau, the Western Plateaus, which present a gradual decrease of crustal thickness from 17 to 9 km toward the Nova Canton Trough (Hochmuth et al., submitted manuscript, 2015). If the emplacement was coupled, the Western Plateaus should have a similar crustal thickness as its conjugate plateau. Additionally, the tectonic fit between the two plateaus cannot be achieved easily since secondary volcanism and tectonic activity altered the plateaus margins [*Pietsch and Uenzelmann-Neben*, 2015]. A further complication of the plate kinematic reconstruction is that the Nova Canton Trough does not show a clear spreading axis, but seems to consist of multiple small ridges and fracture zones, which point to a scissor-like opening of the basin [*Taylor*, 2006; *Chandler et al*., 2012].

2.2.2. Individual Emplacement of Ontong Java and Manihiki-Hikurangi

Whereas the coupled emplacement of the Hikurangi Plateau and the Manihiki Plateau seems to be a well-established factor in the plate kinematics of the western Pacific, the fit between the Ontong Java Plateau and the Manihiki Plateau is still under debate for the reasons mentioned above. Therefore, we give an overview of published scenarios, which do not include a coupled emplacement between the Ontong Java Plateau and the Manihiki and Hikurangi Plateaus. *Larson and Chase* [1972] and *Winterer et al*. [1974] propose a plate tectonic setup, where the oceanic plateaus of Ontong Java Nui are situated on the spreading axis between the Pacific and the Antarctic Plate. The different subprovinces of the Manihiki Plateau are created by a spreading segment jump [*Winterer et al*., 1974] or the presence of the Farallon-Antarctic spreading on the High Plateau [*Larson and Chase*, 1972]. *Larson* [1997] propose that individual plumes created the Manihiki Plateau and the Ontong Java Plateau. The Pacific-Phoenix spreading ridge separated these plumes. The

Table 1. Additional Dated Locations and Paleolatitude Data Used as Constraints for the Plate Kinematic Reconstruction

	Latitude	Longitude	Age	Paleolatitude	Reference
ODP Leg 130–807	3.6000	156.620	122.3	−17.9 ± 3.3	*Mahoney et al.* [1993]
ODP Leg 192–183	−1.177	157.015	121	−27.9 ± 7.2	*Riisager et al.* [2003]
ODP Leg 192–1184	−5.011	164.223	123.5	−34.4 ± 5	*Chambers et al.* [2004]
ODP Leg 192–1185	−0.358	161.668	121	−23.3 ± 2.2	*Riisager et al.* [2003]
ODP Leg 192–1186	−0.680	159.844	121	−25.2 ± 3.5	*Riisager et al.* [2003]
ODP Leg 192–1187	0.943	161.451	121	−22.2 ± 2.3	*Riisager et al.* [2003]
DSDP Leg 33–317	−11.0015	−165.263	116.8 ± 3.7	−47.5	*Cockerham and Jarrard* [1976]
So168 DR55	−40.7508	−160.916	115		*Mortimer et al.* [2006]
Malaita	−8.772	160.916	160		*Ishikawa et al.* [2005]

present Nova Canton Trough was created after the primary magmatism by reheating and extension of the young lithosphere. This concept highlights the importance of a possible ridge-plume interaction creating the LIPs of the western Pacific.

3. Overview on Published and Additional Data

Before we reevaluate emplacement mechanisms and tectonic activity, a condensed overview on the relevant data, which is currently available in the western Pacific region, is presented. The main phase of tectonic evolution within this region occurs during the CNS. Small variations within the magnetic field strength during this time period have been detected in the Atlantic Ocean offshore North Africa [*Granot et al*., 2012], but unfortunately these variations cannot be recognized within the western Pacific. The Nova Canton Trough shows no clear spreading axis, and the Osbourn Trough is magmatically overprinted by the Louisville hot spot in the south and the smaller Austral-Cook and MacDonald hot spots in the north [*Billen and Stock*, 2000]. Therefore, the intensity variations cannot help to reconstruct the plate reorganization, magnetic data can only be used to frame the crust, which was emplaced during the CNS.

Chandler et al. [2013] compiled all available paleolatitude data from Deep Sea Drilling Project (DSDP), Ocean Drilling Project (ODP), and International Ocean Drilling Project (IODP) cores on the Ontong Java Plateau (Table 1). Their findings point to an emplacement latitude of the Ontong Java Plateau between 17°S and 33°S with a clock-wise rotation of the plateau of between 37° and 52°. This rotation is currently not integrated in any plate kinematic reconstructions and may indicate a large-scale rotation of the Pacific Plate or an individual motion of the Ontong Java Plateau during the Cretaceous.

Drilled cores reaching the crystalline basement are sparse in the area, and only a very small number have published basement ages. But along with dredges, e.g., from the Wishbone Scarp [*Mortimer et al*., 2006] or the Danger Islands Troughs [*Ingle et al*., 2007], and rocks outcropping on islands, e.g., Malaita [*Ishikawa et al*., 2005, 2007; *Musgrave*, 2013], they can be used as a valuable references for the timing of local tectonic events (Table 1).

Further constraints to be considered include tectonic lineations trackable in satellite gravity anomaly maps and bathymetric maps. Large-scale anomalies such as the Tongareva Triple Junction trace [*Larson et al*., 2002], the East and West Wishbone Scarps [*Mortimer et al*., 2006], and the Manihiki Scarp [*Viso et al*., 2005] are relicts of former plate boundaries (Figure 1). Additional information of the plate motion can be extracted from intraplate fracture zones. *Taylor* [2006] and *Chandler et al*. [2012] examined the fracture zones within the Ellice Basin (Nova Canton Trough), which strike in an East-West direction. North-south striking fracture zones can be observed north and south of the Osbourn Trough (Figure 1). Fracture zones dissect the Ellice Basin and the Phoenix lineations [*Nakanishi et al*., 1992]. The large Pacific Fracture zones, e.g., Galapagos Fracture Zone or the Clipperton Fracture Zone, further constrain the evolution of the Pacific Plate and the Pacific-Farallon spreading center.

The LIP itself provides important constraints for the plate reconstruction of the Cretaceous western Pacific. The current state of these magmatic bodies has been altered by tectonic deformation and volcanism of later magmatic stages and does not necessarily resemble the LIP at its emplacement. In our reconstruction, we account for crustal extension due to crustal stretching or massive emplacement of magmatic material as well as for "lost" fragments to the east and north of the Manihiki Plateau [*Larson et al*., 2002; *Viso et al*., 2005; *Pietsch and Uenzelmann-Neben*, 2015].

4. Possible Breakup Mechanisms on the Manihiki Plateau

The Manihiki Plateau plays an important role in the plate tectonic setup of the Pacific during the Cretaceous, since it potentially exposes breakup margins toward the other LIPs of the region and the seafloor emplaced during the CNS. A close examination of the crustal structure along with the magmatic and tectonic activity displayed in high-resolution seismic reflection data [*Pietsch and Uenzelmann-Neben*, 2015] and seismic refraction/wide-angle reflection data (Hochmuth et al., submitted manuscript, 2015) acquired in 2012 [*Uenzelmann-Neben*, 2012] allows us to identify possible breakup mechanisms on the Manihiki Plateau. Additionally, it is important for further reconstructions to incorporate the amount of crustal growth created by later magmatic stages and tectonic strain (Figure 2).

The Manihiki Plateau was created by a first phase of extrusive volcanism with an approximated minimum age of 125 Ma [*Timm et al*., 2011]. Later magmatic stages (<65 Ma) differ between low-volume secondary magmatism on the Western Plateaus and high-volume emplacement at the High Plateau [*Pietsch and Uenzelmann-Neben*, 2015; Hochmuth et al., submitted manuscript, 2015].

A more important factor for assessing the extension of the crust after the initial emplacement of the LIP is the tectonic alteration (Figure 2), which is visible by countless faults (e.g., High Plateau) and the decrease of crustal thickness (e.g., Western Plateaus) [*Ai et al*., 2008; *Pietsch and Uenzelmann-Neben*, 2015; Hochmuth et al., submitted manuscript, 2015]. The potential overlap (o) between the two plateaus can be calculated by the stretching coefficient (β) and the width of the stretched crust (w) with the following formula: $o = w^*(\beta - 1)/\beta$. Additional information on the extent of the LIP influenced crust can be derived from the presence of a HVZ with *P* wave velocities above 7.3 km/s in the lower crust of the plateaus (Hochmuth et al., submitted manuscript, 2015) (Figure 3).

We identify four different areas of tectonic characteristics on the Manihiki Plateau. On the central High Plateau, tectonic activity is low and mainly induced by magmatism [*Pietsch and Uenzelmann-Neben*, 2015] (Figure 2). The eastern flank of the High Plateau, the Manihiki Scarp, exhibits a north-south trending sheared margin [*Larson et al*., 2002; *Viso et al*., 2005; *Pietsch and Uenzelmann-Neben*, 2015; Hochmuth et al., submitted manuscript, 2015] with up to eight basement ridges exposing lower crust (Figure 3a). The HVZ terminates below the basement ridges, and crustal thickness decreases from 15 to 4.5 km within 60 km lateral distance (Figure 3a). Additional crustal material seems to be emplaced by the exposure of lower crustal material and not by stretching processes.

The southern High Plateau shows multiple normal fault systems, which can be related to rifting activity during the Cretaceous and later tectonic stress (40–1.8 Ma) [*Pietsch and Uenzelmann-Neben*, 2015] (Figure 2). This area has also been influenced by secondary magmatic stages (>65 Ma) and even younger magmatic activity (23–10 Ma). The HVZ in the lower crust of the Manihiki Plateau stretches into the Samoan Basin (Figure 3b). Crustal stretching (β) is evident but relatively small ($\beta = 1.26$).

The western High Plateau and the Western Plateaus show low-volume secondary magmatism [*Pietsch and Uenzelmann-Neben*, 2015; Hochmuth et al., submitted manuscript, 2015]. In seismic refraction/wide-angle reflection data from the Western Plateaus, we observe a constant presence of the HVZ and a decrease in crustal thickness from 18 km in the East to 9 km in the West ($\beta = 2$) over 400 km distance (Figure 3c). This indicates a potential overlap with a conjugate margin of 200 km. Small and large offset faults are present throughout the subprovince (Figures 2 and 3).

Other significant features of the Manihiki Plateau are its internal troughs, the N-S trending Danger Islands Troughs and the NE-SW trending Suvarov Trough (Figure 2). Seismic reflection data indicate that the Suvarov Trough is younger than 65 Ma and can therefore not be a result of the initial tectonic activity within the CNS (R. Pietsch and G. Uenzelmann-Neben, manuscript in preparation, 2015a). Seismic refraction/wide-angle reflection data reveal the lack of typical upper crustal material within the Danger Island Troughs, but a relatively undisturbed lower and middle crust (Hochmuth et al., submitted manuscript, 2015). The Danger Islands Troughs mark, as a series of pull-apart basins a significant border between the two magmatic and tectonic regimes of the High Plateau and the Western Plateaus. By tracing the exposed fault systems in

Table 2. Overview on the Different Margins of Ontong Java Nui and Their Individual Features

Margin	Characteristica	Regional Example	Reference	Interfered From
Tectonically inactive margin	Slow decrease in depth, basalt flows into the oceanic basin, dip angle $< 0.1^\circ$	Northern Ontong Java Plateau	*Mochizuki et al.* [2005]	Seismic reflection, bathymetry, and gravity anomaly
Subducting margin	subduction of LIP crust	Ontong Java Plateau—Solomon Trench Hikurangi—Chatham Rise	*Miura et al.* [2004], *Davy et al.* [2008], and *Davy* [2014]	Seismic refraction, reflection seismic, bathymetry, and gravity anomaly
Sheared margin	Rough topography with multiple ridges exposing lower crustal layers, sudden termination of HVZ	Manihiki Scarp	*Larson et al.* [2002], *Viso et al.* [2005], *Ai et al.* [2008], *Pietsch and Uenzelmann-Neben* [2015], and Hochmuth et al. (submitted manuscript, 2015)	Seismic reflection, refractions seismic, bathymetry, and gravity anomaly
Stretched margin with little magmatic activity	Countless large and small offset faults, low-volume secondary magmatism, constant HVZ, massive crustal stretching	Western Plateaus (Manihiki Plateau), Rekohu Embayment (Hikurangi Plateau)	*Davy et al.* [2008] and Hochmuth et al. (submitted manuscript, 2015)	Refraction seismic, reflection seismic, bathymetry, and gravity anomaly
Stretched margin with magmatic overprint	Multiple fault systems, massive magmatic activity during later magmatic stages, small amount of crustal stretching	Southern Manihiki Plateau, Southeast High Plateau (Hikurangi Plateau)	*Davy et al.* [2008], *Pietsch and Uenzelmann-Neben* [2015], and Hochmuth et al. (submitted manuscript, 2015)	Refraction seismic, seismic reflection data, gravity anomaly, and bathymetry
Rifted margin	Short LIP—ocean basin transition area, sharp boundary, sudden depth decrease dip angle $> 5^\circ$	Rapuhia Scarp (Hikurangi Plateau)	*Davy and Collot* [2000] and *Davy et al.* [2008]	Seismic reflection, bathymetry, and gravity anomaly

bathymetry [*Weatherall et al.*, 2015] and global satellite gravity anomaly maps [*Sandwell et al.*, 2014], a rotational component from NNE-SSW striking features in the North to NNW-SSE striking features in the South can be observed [*Nakanishi et al.*, 2015]. This supports the hypothesis that the Western Plateaus and the High Plateau acted as individual tectonic plates during part of the Cretaceous.

Similar margin features as described above can be seen on the Ontong Java Plateau and the Hikurangi Plateau (Table 2 and Figure 4). We extrapolated our classification of the breakup margins across these plateaus by including published seismic reflection and refraction data along with gravity models, gravity anomaly maps, and bathymetric measurements. In addition to the margins encountered on the Manihiki Plateau, a tectonically inactive margin and subducting margins are present on the Ontong Java Plateau and the Hikurangi Plateau (Figure 4). The Rapuhia Scarp of the western Hikurangi Plateau shows a very narrow transition zone between LIP crust and normal oceanic crust [*Davy and Collot*, 2000] and introduces a fourth mode of rifting within the system.

5. Plate Tectonic Reconstruction of the Cretaceous Western Pacific

The regional plate kinematic reconstruction presented here uses the global plate tectonic GPlates model of *Seton et al*. [2012] as its basis. We additionally use the hot spot reference frame W&K08-D by *Wessel and Kroenke* [2008] and *Chandler et al*. [2012]. The model comprises the time frame from 125 to 80 Ma and translates directly into the model by *Seton et al*. [2012] for the development after the CNS. An overview on the modeled tectonic events is provided in Table 3.

5.1. The Emplacement of Ontong Java Nui—Plume-Ridge Interaction and Single "Super"-Plume Head

The published data indicate that at least two main eruptive centers were present, on the High Plateau of the Manihiki Plateau and on the High Plateau of the Ontong Java Plateau, during the initial emplacement of the LIP [*Furumoto et al*., 1976; *Miura et al*., 2004; Hochmuth et al., submitted manuscript, 2015]. The presence of the thinner Western Plateaus (Figure 3c) and possible eastern Ontong Java Plateau makes the scenario of a single "Super"-plume [*Taylor*, 2006] surfacing in the area unlikely, since this should create a crust of comparable crustal thickness. *Larson* [1997] proposed that the oceanic LIPs of the region originated by two individual plume heads rising at both sides of the Pacific-Phoenix spreading center. Individual plumes would explain the significant differences in crustal thickness. The Nova Canton Trough, which separates the Ontong Java Plateau and the Manihiki Plateau, shows a reorientation of the spreading orientation in comparison to its predecessor the Pacific-Phoenix Ridge from E-W to NE-SW (Figure 5). Even though a clear spreading axis is not detectable

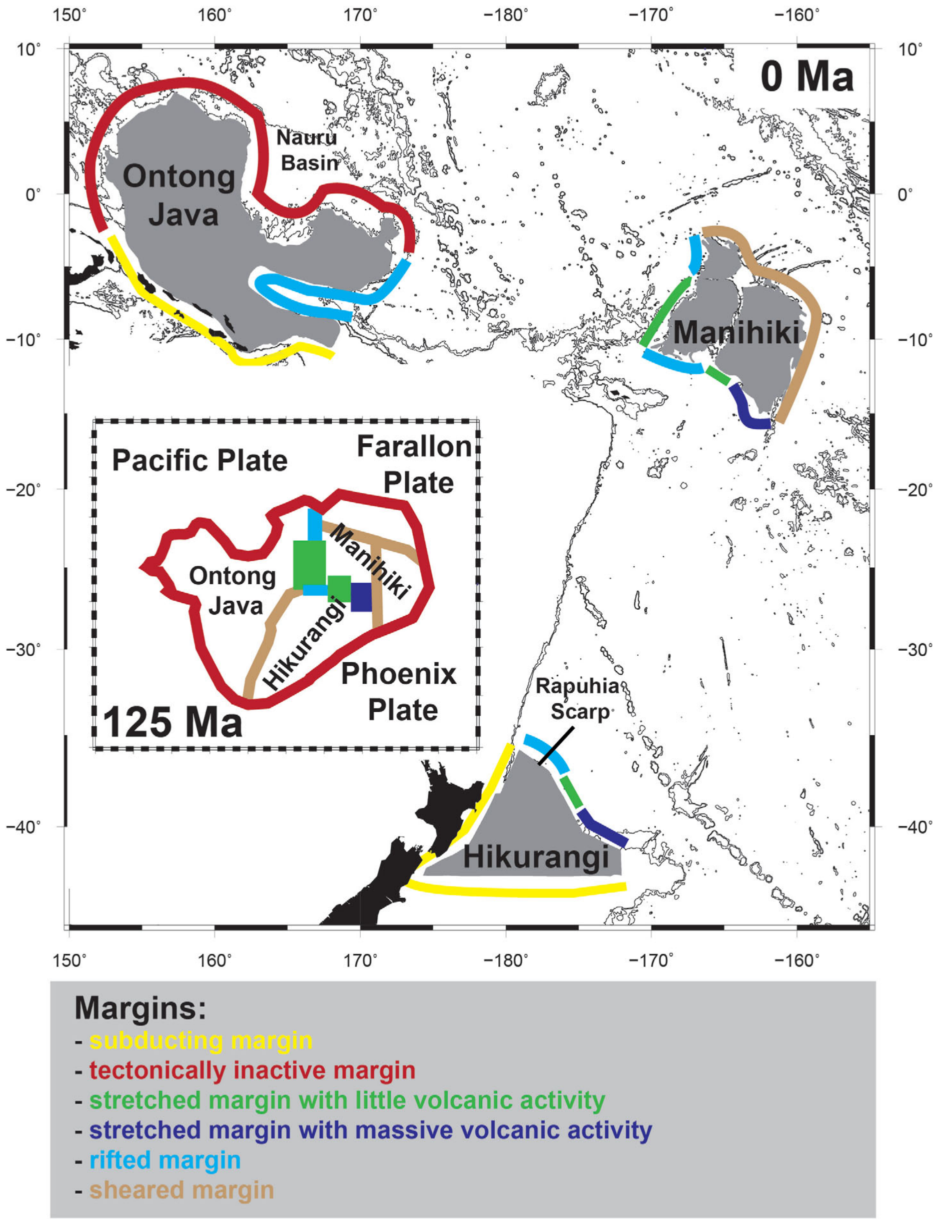

Figure 4. Classification of the margins of Ontong Java Nui in their current setting (main figure) and during their emplacement (inlet figure).

[*Taylor*, 2006; *Chandler et al.*, 2012], it can be inferred that the oblique spreading in the Nova Canton Trough cross cuts the magnetic spreading anomaly M-Series at M10 in the vicinity of the Ontong Java Plateau and leaves the M1 spreading center visible northeast of the Manihiki Plateau (Figure 5) [*Nakanishi et al.*, 1992]. Therefore, the spreading in the Nova Canton Trough is distinct from the earlier spreading in the area and is not caused by an overprinting of a former spreading center during the CNS as suggested by *Larson* [1997]. In addition, the possible presence of three areas of mantle upwelling within such a confined area—an Ontong Java Plume, a Manihiki/Hikurangi Plume and the Pacific-Phoenix ridge—seems geodynamically unrealistic. However, the concept of the interaction between plumes and the Pacific-Phoenix spreading center appears to be an important factor in the emplacement of Ontong Java Nui.

A ridge-centered hot spot can currently be observed, for example, on Iceland [e.g., *Ito et al.*, 1996; *Darbyshire et al.*, 1998] and the interaction between a hot spot and a spreading ridge is present, for example, at the Galapagos hot spot [e.g., *Sinton et al.*, 2003; *Kokfelt et al.*, 2005]. Modeling of these interactions reveals that

Table 3. Overview on the Tectonic Events in the Western Pacific From >125 to 83 Ma

	Manihiki Plateau	Ontong Java Nui	Pacific
Prior to 125 Ma	Subaerial emplacement as a single crustal unit by massive volcanic outpourings	Emplacement by massive volcanic out pourings with multiple main centers of activity Result of plume-ridge interaction	Formation of the Pacific Triangle (180 Ma) Seafloor spreading at multiple triple junctions
120 Ma	High magmatic activity on the High Plateau Limited magmatic activity on the Western Plateaus	Initial motion between Manihiki and Hikurangi rotation and crustal stretching	
118 Ma	Initiation of the fragmentation of the Manihiki Plateau Creation of the Manihiki Scarp, spreading north of the High Plateau Creation of the Danger Islands Troughs Initiation of crustal stretching at the Western Plateaus	Development of the Osbourn spreading center between Manihiki and Hikurangi Rotation of the Ontong Java Plateau along with the Western Plateaus	Triple Juction jump (PAC-FAR-PHO) (Tongareva Triple Junction) Reorganization of plate tectonic framework Possible initiation of the rotation of the Pacific Plate Southward migration of Farallon Phoenix spreading along Tongareva Triple Junction trace
115 Ma	Incorporation of NE—Manihiki into Farallon Plate Incorporation or E-Manihiki into Phoenix Plate	Initiation of spreading at Nova Canton Trough	Initiation of ocean—ocean subduction at West Wishbone Scarp
110 Ma		First interaction between Hikurangi Plateau and Chatham Rise Rotation of Osbourn Trough Soft—docking of Hikurangi Plateau with Chatham Rise	
100 Ma	Final development of the Danger Islands Troughs	Establishment of oblique spreading at Nova Canton Trough	
95–83 Ma		Cessation of southward subduction of Hikurangi Plateau Cessation of spreading at Nova Canton Trough Incorporation into Pacific Plate	Full establishment of spreading within the Bellingshausen Sea Cessation of subduction at West Wishbone Scarp

the plume-ridge interaction is mainly influenced by the spreading rate at the ridge and the plume flux [*Albers and Christensen*, 2001]. Therefore, multiple pulses and the spreading at the ridge between the pulses can create areas of variable crustal thickness. The nature of the plume-ridge interaction—whether centered or off axis—also influences the emplacement process. Off-axis plumes have to penetrate a thicker and older lithosphere and have an up-slope flow toward the ridge [*Ribe et al*., 1995; *Ito et al*., 1996; *Ribe*, 1996; *Ribe and Delattre*, 1998; *Ito et al*., 2003]. To explore the result of a possible interaction of an arriving plume head at the Pacific-Phoenix ridge, models of hot spot-ridge interactions [e.g., *Dyment et al*., 2007] and models of plume-ridge interactions [e.g., *Whittaker et al*., 2015] can be used. These scenarios differ mostly in the volume of the emplaced igneous material, which is far larger for a plume scenario. It has also been proposed that plume-ridge interaction causes asymmetric seafloor spreading [*Müller et al*., 1998]. When a spreading system approaches a hot spot, the magmatic flow is channeled toward the ridge resulting in an additional production of seamounts. An increased steady magma supply would possibly generate an oceanic plateau (Figure 6). The main emplacement of the LIP would occur during a phase of a ridge-centered plume with massive volcanic outpourings and intrusions within the lower crust. As soon as the ridge passes the area of the plume, the emplacement of igneous material decreases, but channeling toward the ridge is still present, possibly resulting in an area of thinner, but still overthickened oceanic crust. The former main emplacement area with its large crustal thickness is rifting away from the ridge (Figure 6). The interplay between ridge dynamics and a plume might help to understand the observation of the large differences in crustal thickness across the LIP. On the Manihiki Plateau, a strong seismic intrabasement reflection is traceable [*Pietsch and Uenzelmann-Neben*, 2015], which can be interpreted to represent an initial formation stage of the plateau. Strong intracrustal seismic wide-angle reflections (Hochmuth et al., submitted manuscript, 2015) can also be attributed to this layer. The strong reflections within the crust in both data sets might be the result of the overprinting between an early arrival of the plume and the main emplacement phase during the time of a ridge-centered plume. A similar setup of pulsating volcanic activity has been reported for the

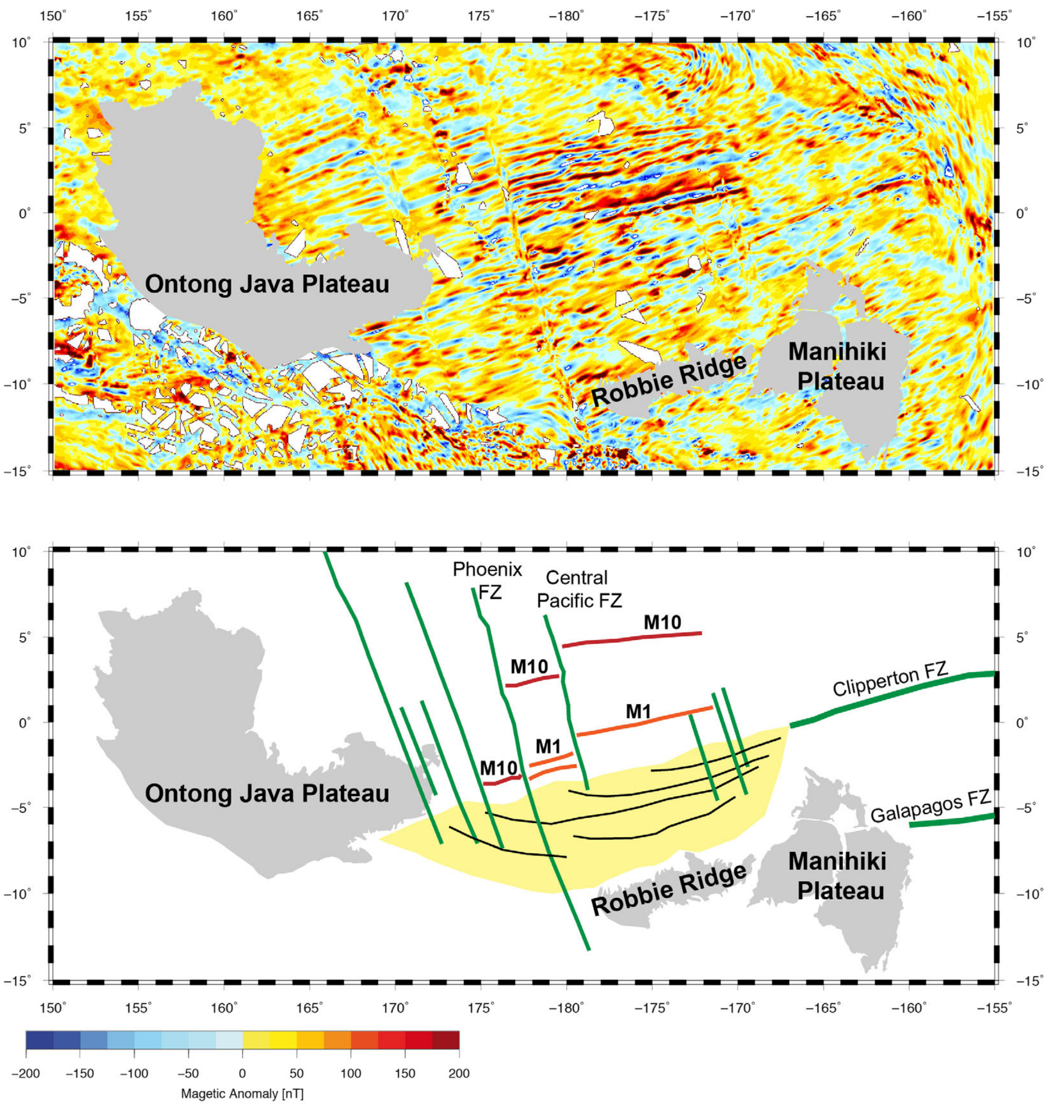

Figure 5. (a) Magnetic anomaly map of the Nova Canton Trough after *Maus et al*. [2009], grey areas indicate the oceanic LIPs (b) tectonic interpretation with major fracture zones in green from *Nakanishi et al*. [1992] for the Phoenix lineations and additional smaller fracture zones at the convergence between the Nova Canton Trough and the Clipperton FZ, fracture zones within the Nova Canton Trough (yellow area) after *Taylor* [2006] in black and the magnetic isochrones of M10 (red) and M1 (orange) within the Phoenix lineations [*Nakanishi et al*., 1992].

Southeast African LIP, where the Transkai Rise separates, analog the Western Plateaus of the Manihiki Plateau, two areas of thicker LIP crust, the Agulhas Plateau and the Mozambique Ridge [*Gohl et al*., 2011].

Since the data indicate a tectonic connection, within the crust of the Western Plateaus between the Ontong Java Plateau and the Manihiki Plateau and the presented emplacement mechanism does not oppose such a scenario, we attempt our reconstruction with the reassemblage of Ontong Java Nui, by accounting for rotational components [*Chandler et al*., 2013; *Davy*, 2014], the growth of the LIP after breakup by either crustal stretching or secondary magmatism and incorporating for the characteristics of the breakup margins. Subducted fragments are added. Here we use the traceable slab of the Hikurangi Plateau below New Zealand [*Reyners*, 2013] and the estimated extension of the Ontong Java Plateau by *Musgrave* [2013]. Since the northeastern and the eastern fragment of the Manihiki Plateau were subducted, we estimated the extent of these fragments under the assumption that the emplacement mechanism is similar to that of the northern Ontong Java Plateau, where basalt flows limit the extent of the Nauru Basin [*Mochizuki et al*., 2005] (Figure 4). These assumptions result in an initial size of Ontong Java Nui to be 1.1% of the Earth's surface, which is larger than previously anticipated.

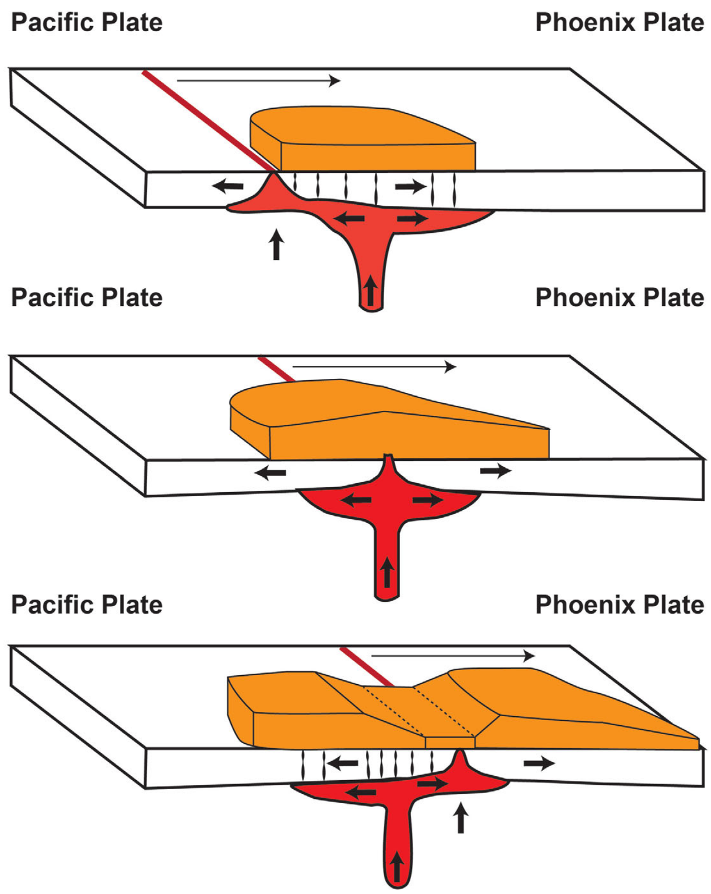

Figure 6. Sketch of possible plume-ridge interaction at the Pacific-Phoenix ridge, (top) surfacing of a plume head in vicinity of the Phoenix-Pacific spreading ridge; (middle) plume head at the ridge creating a thicker plateau; (bottom) spreading center moved away from the plume creating rifting of the thick plateau and emplaces a thinner oceanic plateau between the previously emplaced parts.

By comparing the reassembled LIP with recent global plate tectonic models [e.g., *Seton et al*., 2012] and magnetic lineations [*Nakanishi et al*., 1992], the paleolatitudes calculated for the Ontong Java Plateau are approximately 400 km farther north than the reconstructed position of the Ontong Java Plateau (Figure 7). Even though only a few paleolatitude calculations exist, implying a large error margin, we investigate further possible factors for this significant offset. The mismatch between the reconstructed and the magnetic lineations is partly due to the complicated spreading at the Pacific-Phoenix-Farallon Triple Junction, where the presence of multiple microplates and jumping spreading centers is proposed [*Seton et al*., 2012]. The Phoenix lineations show multiple fracture zones (FZ) within their sequence [*Nakanishi et al*., 1992], including the Phoenix FZ and the central Pacific FZ (Figures 5 and 7). These induce a considerable offset between the magnetic lineations in the vicinity of the Ontong Java Plateau and are, along with other smaller FZ, traceable within the eastern Nova Canton Trough [*Maus et al*., 2009; *Sandwell et al*., 2014] (Figure 5). The crust of the Nova Canton Trough was emplaced after the oceanic LIPs, which allows an emplacement of the LIP farther north with later, postemplacement movement toward the south. From asynchronous bends in the seamount chains of the Gilbert Ridge and the Tokelau seamounts, *Koppers and Staudigel* [2005] inferred two short extensional phases within the Nova Canton Trough (67 and 57 Ma), which might be related to a reactivation of the trough or to the activity of fracture zones. If these fracture zones were active after the Cretaceous spreading in the Nova Canton Trough, they can at least partly account for the offset between reconstructed and calculated paleolatitudes (Figure 7). We, therefore, infer an emplacement of Ontong Java Nui between 18°S and 40°S (Figure 8a).

The absolute plate motion of the Pacific Plate during the Cretaceous is vaguely constrained by direct measurements from basaltic flows, but a hook-like shape of the absolute polar wander path is proposed [*Sager*, 2006; *Wessel and Kroenke*, 2008]. Unfortunately, the data from the Ontong Java Plateau do not fit this path. *Sager* [2006] suggests a decoupling of the northern and southern Pacific Plate—including the Ontong Java Plateau—during the Cretaceous. Paleo-plate boundaries are not observed within the Jurassic Pacific Plate, which makes this uncoupling rather unlikely. If the Pacific Plate and the Ontong Java Plateau were coupled during the Early Cretaceous, we can infer that the rotation of the Ontong Java Plateau was at least partly also performed by the Pacific Plate. It is also important to account for the possible Neogene intraplate motion, which occurred at the Nova Canton Trough [*Koppers and Staudigel*, 2005]. Unfortunately, the data needed to distinguish between these scenarios are not available. In addition, the Southern Hemisphere Pacific is underrepresented in the calculations of the rotation poles [*Sager*, 2006], which might be a cause for an underestimate of possible rotations. To be able to constrain the motion of the Pacific Plate before its

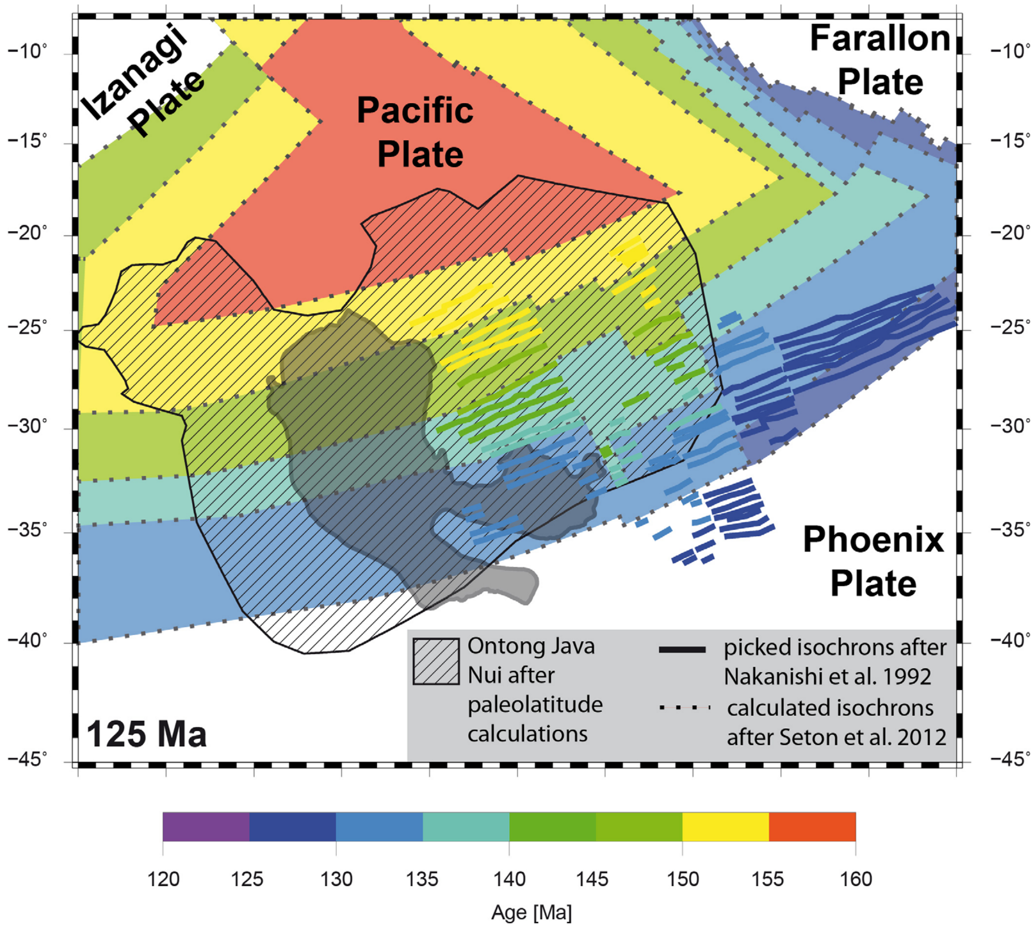

Figure 7. Comparison of paleolatitude data (hatched area of possible emplacement of Ontong Java Nui), calculated isochrons (dashed lines) [*Seton et al.*, 2012], and magnetic anomaly lineations (continuous lines) [*Nakanishi et al.*, 1992]. The grey area indicates the Ontong Java Plateau in relation to the magnetic anomaly lineations.

connection to the global plate tectonic circuit, it is necessary to obtain a better insight in the internal plate motion of the Pacific Plate and a closer grid of basement samples from both hemispheres. In our reconstruction, we assume a rotation of the Pacific Plate along with the Ontong Java Plateau based on *Chandler et al*. [2013].

5.2. The Initial Breakup of Ontong Java Nui—Evaluation of the Breakup Mechanisms on Oceanic LIPs (120–116 Ma)

The development of breakup margins can be traced along all margins of the Manihiki Plateau. The initial breakup of the "Super"-LIP was rather complex and included multiple tectonic deformations such as shearing and crustal stretching before the establishment of clear spreading centers (Figure 8b). The relicts of these first movements between the oceanic LIPs and within the Manihiki Plateau are imprinted in the nature of the different margins (Figure 3). The magmatic activity was still strong on the plateaus [*Inoue et al*., 2008; *Hoernle et al*., 2010; *Pietsch and Uenzelmann-Neben*, 2015], leading to alteration and magmatic overprinting of the tectonic sutures.

We present the tectonic mechanisms initiating the breakup of Ontong Java Nui and the fragmentation of the Manihiki Plateau in an anticlockwise fashion beginning in the south, where the Osbourn Trough is located (Figure 1) [*Billen and Stock*, 2000; *Worthington et al*., 2006; *Downey et al*., 2007]. The first motion between the Hikurangi Plateau and the Manihiki Plateau occurred at the southern Western Plateaus and the conjugate Rapuhia Scarp, where a rifted margin was identified (Figure 4). This rapid separation was followed by a phase of crustal stretching at the southern High Plateau and the eastern Hikurangi Plateau, possibly including an anticlockwise motion (Figure 8b). Normal faults are identified in seismic reflection data

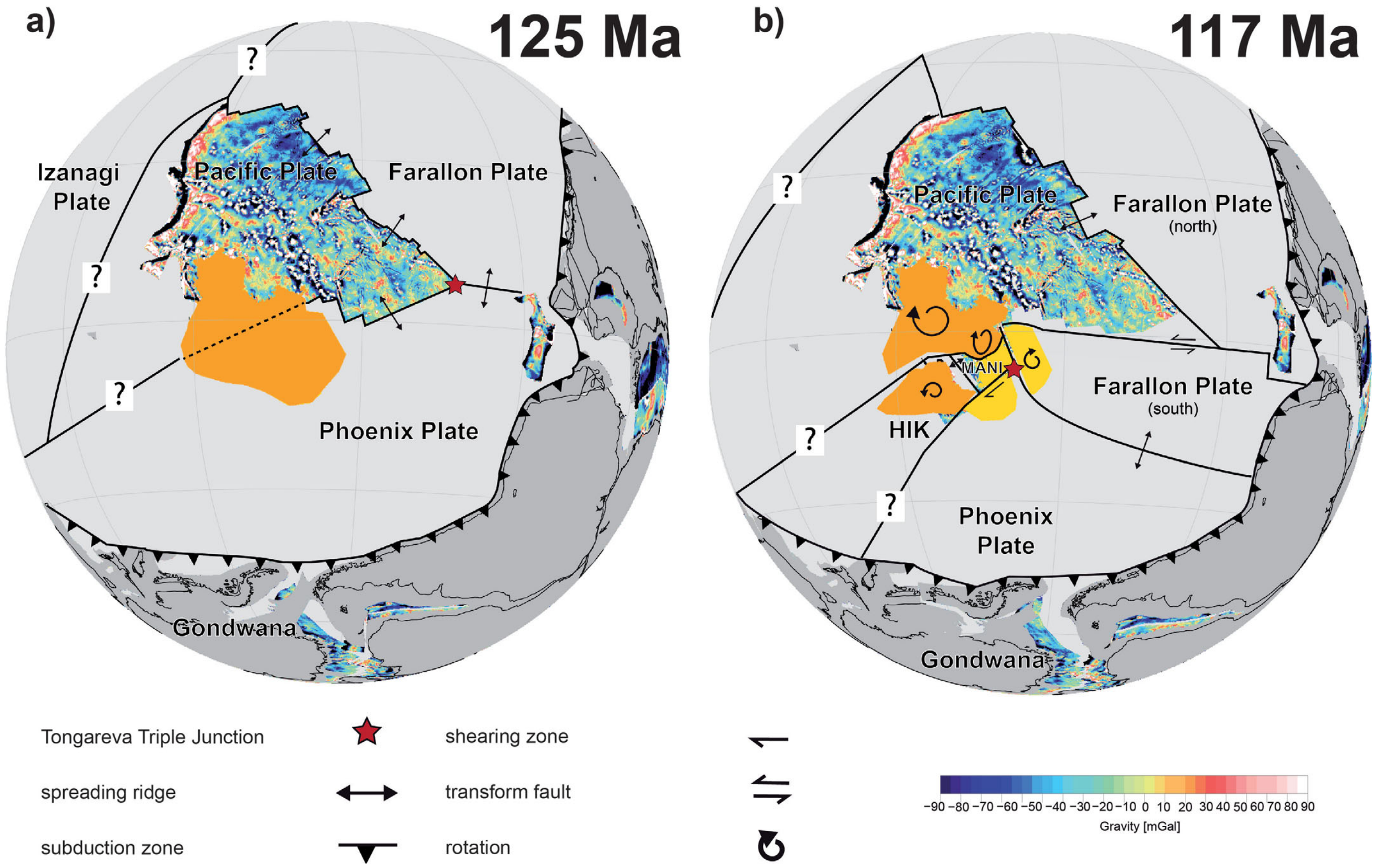

Figure 8. Tectonic evolution of the western Pacific during the CNS. The model shows the plate kinematic model of *Seton et al*. [2012] with updated rotation poles for the western Pacific region obtained in this study. The fixed plate is the Pacific Plate; gravity anomaly map taken from *Sandwell et al*. [2014]; plate boundaries (relevant for the reconstruction) are marked in black, continental fragments are shown in grey with today's coast lines in black for better orientation; light grey areas shows seafloor, which has been subducted; Ontong Java Nui related LIPs are marked in orange and yellow for the Manihiki Plateau; the red star indicates the position of the Tongareva Triple Junction; MANI = Manihiki Plate, HIK = Hikurangi Plate (a) 125 Ma and (b) 117 Ma.

[*Pietsch and Uenzelmann-Neben*, 2015]. The presence of a HVZ within the Samoa Basin can be attributed to the later overprint of the presence of the Tahiti-Society Islands hot spot at the Manihiki Plateau (R. Pietsch and G. Uenzelmann-Neben, manuscript in preparation, 2015b) (Figure 3b) and is not a relict of the "Super"-LIP breakup. To the east, the Osbourn Trough intersects with the Manihiki Scarp. This shearing zone (Figure 3a) can be traced along the eastern High Plateau and established itself as the eastern plate boundary of the Manihiki Plateau (Figure 1). As *Larson et al*. [2002] proposed, the triple junction between the Pacific, Farallon, and Phoenix Plates jumped to the northeastern corner of the Manihiki Plateau, the northern end of the Tongareva Triple Junction Trace (Figures 1 and 8). This gravity anomaly trace is the relict of the southward motion of the triple junction.

Seton et al. [2012] in their model divided the Farallon Plate in a northern Farallon Plate north of the Clipperton FZ and a southern Farallon Plate called the Chasca Plate. The Phoenix Plate is called Catequil Plate in their reconstruction. To allow a better comparison between those reconstructions, we also separate between a northern and a southern Farallon Plate (Figures 8b and 9a–9c). The eastern fragment of the Manihiki Plateau is incorporated into the Phoenix Plate along the Manihiki Scarp and moves southward (Figures 8b and 9a–9c). The northeastern fragment of the Manihiki Plateau becomes part of the southern Farallon Plate (Chasca Plate). The northern margin of the Manihiki Plateau is mostly unsurveyed, but bathymetry [*Nakanishi et al*., 2015] and gravity data [*Sandwell et al*., 2014] indicate the presence of massive tectonic activity, possibly related to shearing processes. We propose a fast clock-wise rotation of the northeastern fragment of the Manihiki Plateau, resulting in multiple ridges (Figure 1) and the possible extension of the crust on the northern High Plateau (Figure 2).

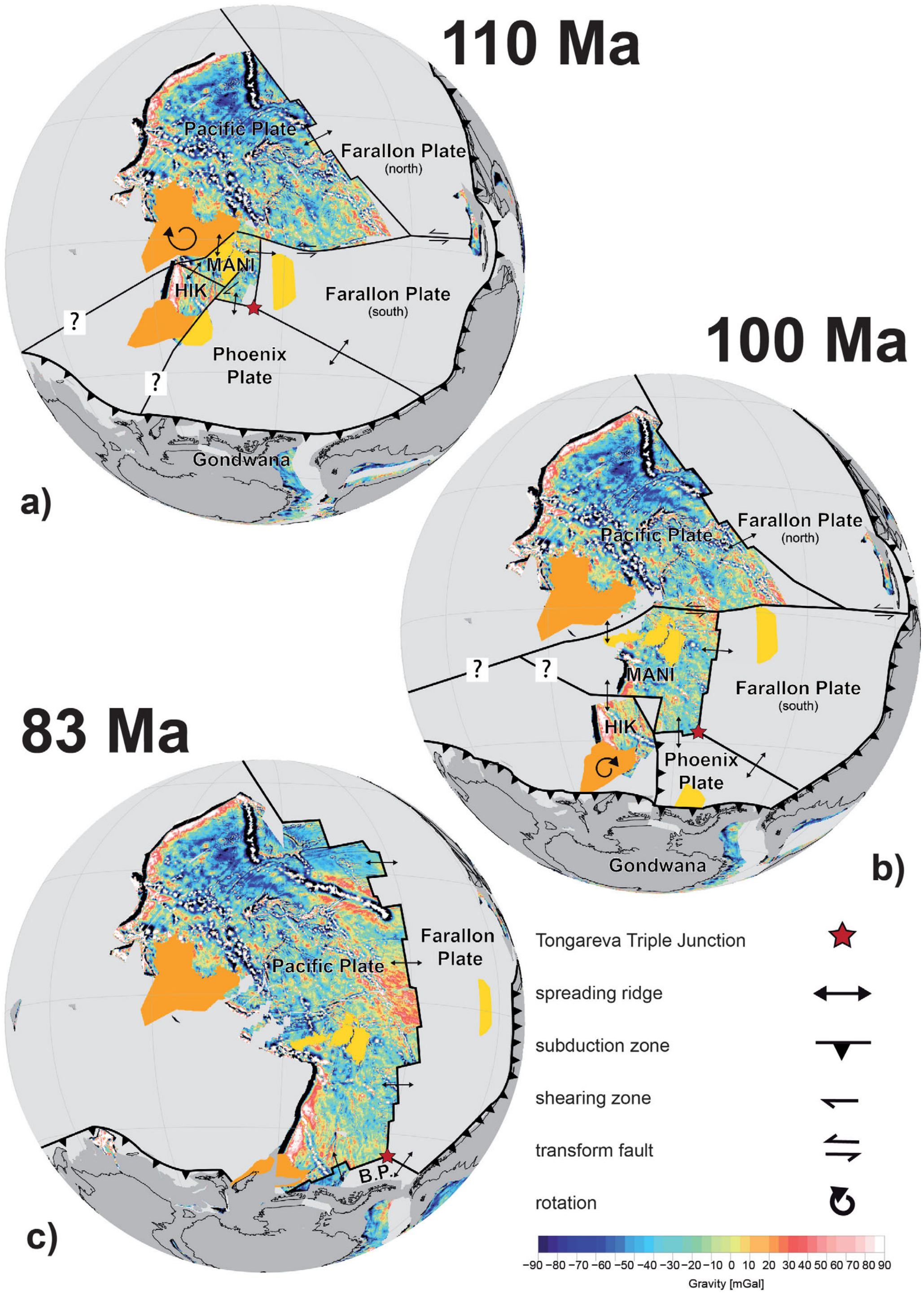

Figure 9. Tectonic evolution of the western Pacific during the CNS. The model shows the plate kinematic model of *Seton et al*. [2012] with updated rotation poles for the western Pacific region obtained in this study. The fixed plate is the Pacific Plate; gravity anomaly map taken from *Sandwell et al*. [2014]; plate boundaries (relevant for the reconstruction) are marked in black, continental fragments are shown in grey with today's coast lines in black for better orientation; light grey areas shows seafloor, which has been subducted; Ontong Java Nui-related LIPs are marked in orange and yellow for the Manihiki Plateau; the red star indicates the position of the Tongareva Triple Junction; MANI = Manihiki Plate, HIK = Hikurangi Plate, B.P. = Bellingshausen Plate (a) 110 Ma, (b) 100 Ma, and (c) 83 Ma.

Additional to these major breakup scenarios, the Manihiki Plateau is fragmented into its subprovinces. At the Danger Islands Troughs, the division into the Western Plateaus and the High Plateau is manifested by a series of pull-apart basins (Hochmuth et al., submitted manuscript, 2015), which show a similar rotation as proposed for the Ontong Java Plateau. The Western Plateaus seem to have moved with the Ontong Java Plateau during the initial phase of breakup (Figure 8b), leading to faulting and stretching of the crust. Therefore, the thinner crust of the Western Plateaus (Figure 3c) can result from a combination of the emplacement mechanism and tectonic stress during the breakup of Ontong Java Nui (Figures 6 and 8b). The Hikurangi Plateau and Ontong Java Plateau are separated by the former spreading center between the Pacific and Phoenix Plate, which possibly developed a transform motion (Figures 8b and 9a). The reconstruction in this area is very difficult and can only be achieved by crude assumptions of the subducted seafloor. *Musgrave* [2013] proposed an additional triple junction in this area to account for the so-called Malaita Terranes. In his study, *Musgrave* [2013] omits the rotation of the Ontong Java Plateau [*Chandler et al*., 2013]. This rotation enables to reconstruct the Malaita terranes, which lay on 160 Ma old crust [*Tejada et al*., 2002; *Ishikawa et al*., 2005, 2007] without additional plateboundaries.

5.3. Dispersal of Ontong Java Nui Over the Pacific Ocean

After the initial breakup, which involved a tremendous (up to 200 km at the Western Plateaus) amount of crustal stretching, short-lived spreading centers and rotational forces, the plate boundaries stabilized (Figure 9a). The timing of the stabilization correlates with the fading of massive volcanic activity on the Manihiki Plateau [*Pietsch and Uenzelmann-Neben*, 2015]. Therefore, the influence of the plume ceased and secondary phases of magmatic stages show a clearly weaker and more localized volcanic emplacement. The Osbourn Trough developed a spreading half-rate of 10 cm/a (116–100 Ma) and significantly slows down the production of new crust after the soft-docking of the Hikurangi Plateau at the Chatham Rise [*Davy et al*., 2008; *Davy*, 2014] (Figure 9b). The interaction with the Chatham Rise also introduces a rotation of the Hikurangi Plate, which can also be observed in the change in orientation of the Osbourn Trough (Figure 9b) [*Davy*, 2014]. The morphology of the Osbourn Trough resembles a slow spreading ridge [*Billen and Stock*, 2000; *Downey et al*., 2007]. Therefore, we propose a change in orientation from NW-SE to W-E after the soft-docking of the LIP crust at the continental Chatham Rise and a slowing of the spreading rate to 3 cm/a, which is consistent with previous publications calculating spreading rates [*Billen and Stock*, 2000; *Downey et al*., 2007]. The Hikurangi Plate partly subducted beneath the Gondwana Margin at the location of the Chatham Rise (Figure 9a). This docking event has a great impact on the whole western Pacific and led *Matthews et al*. [2012] to propose that kinks within fracture zones can be correlated and dated to this event. In our reconstruction, we also link reorientations of fracture zones observed on the Hikurangi Plate and Manihiki Plate to this time frame (Figure 1).

To the East, the Wishbone Scarp, a short-lived interoceanic subduction zone, develops [*Mortimer et al*., 2006], representing the plate boundary between the Phoenix (Catequil) Plate and the Hikurangi Plate (Figure 9b). The Hikurangi Plate subducts below the Phoenix Plate at this location. The shape of the Wishbone Scarp gives further indication of a clockwise rotation of the Hikurangi Plate after the initial collision with the Chatham Rise (Figure 1).

The Manihiki Plateau was decoupled from the Pacific Plate by the Clipperton Fracture Zone and moved eastward (Figure 9a). The motion at the Danger Islands Troughs stopped at around 110 Ma due to the establishment of an oblique spreading within the Nova Canton Trough (Figures 9a and 9b). This indicates, that the different subprovinces of the Manihiki Plateau acted as individual plates for a short time, but still inherited significant differences within their crustal structure during the initial breakup of Ontong Java Nui. For the Nova Canton Trough, a scissor-like opening was proposed by *Taylor* [2006] and *Chandler et al*. [2012], separating the Ontong Java Plateau from the Manihiki Plateau with an additional rotational component (Figures 9a and 9b).

After the hard docking of the Hikurangi Plateau with the Chatham Rise, subduction at the Gondwana margin ceased, leading to one of the largest reorganizations within the plate tectonic framework of the Pacific [e.g., *Luyendyk*, 1995]. Seafloor spreading ceased around the Manihiki Plateau and between the different fragments of Ontong Java Nui (Figure 9c). With the establishment of the spreading in the Bellingshausen Sea [e.g., *Eagles et al*., 2004; *Wobbe et al*., 2012], the different plateaus are firmly integrated into the Pacific Plate. Younger tectonic activity can mainly be related to hot spot volcanism. *Koppers and Staudigel* [2005] identified tectonic activity within the area of the Nova Canton Trough at 67 and 57 Ma leading to the reorientation of the Gilbert Ridge and the Tokelau seamount chain, respectively. Multiple fracture zones are identified at the junction between the Nova Canton Trough and the Clipperton FZ as well as at the central

Table 4. Relative Stage Rotations of the Ontong Java Nui Related LIPs to the Ontong Java Plateau (Fixed to Pacific Plate), While Acting as Individual Plates

	t_1	t_2	Latitude	Longitude	ω
High Plateau	118	100	−33.72	−4.34	35.28°
	100	90	−45.48	−32.98	16.99°
Western Plateaus	110	100	−47.78	−7.77	28.91°
	100	95	−45.48	−32.98	16.99°
Northeastern fragment	118	110	−70.61	−18.19	129.52°
Eastern Fragment	118	105	−18.07	−24.77	49.50°
Hikurangi Plateau	120	118	−24.97	52.50	32.53°
	118	100	−77.54	100.71	33.83°
	100	95	−25.38	−65.41	10.96°

Nova Canton Trough (Figure 5). This motion may have been responsible for the southward motion of the Ontong Java Plateau and the reactivation of the Nova Canton Trough as well as the creation of the Suvarov Trough on the Manihiki Plateau (Pietsch and Uenzelmann-Neben, manuscript in preparation, 2015b).

In summary, we updated rotation poles (Table 4) for the different plates of the western Pacific by considering and incorporating concepts such as the rotation of the Ontong Java Plateau and the Hikurangi Plateau and the presence of a subduction zone at the Wishbone Scarp, which have previously not been modeled in a plate kinematic context. Our reconstruction is based on the presence of the LIPs in the western Pacific and gives a detailed history of the early stages of breakup as visible at the plateaus margins. We additionally present evidence for post-Cretaceous tectonic activity in the area of the Nova Canton Trough, which possibly allows the reconciliation between the reconstructed latitudes and paleolatitudes obtained from rock samples.

6. Conclusions

The Large Igneous Provinces of the western Pacific play an important role within the plate tectonic framework of the region. By evaluating possible emplacement scenarios of a joined emplacement of the Ontong Java Nui related LIPs, an interaction between an arriving plume head and the Pacific-Phoenix ridge can explain the individual crustal structure of the oceanic plateaus. Seismic refraction and reflection data, along with bathymetry and gravity measurements shed light on the multifaced breakup mechanisms of the "Super"-LIP. The initial breakup includes short-lived spreading centers to the north and east of the Manihiki Plateau, crustal stretching at the Western Plateaus, and the southern High Plateau and shearing forces along the Manihiki Scarp. The subprovinces of the Manihiki Plateau acted as individual plates. Whereas the Western Plateaus rotated along with the Ontong Java Plateau resulting in the pull-apart basins of the Danger Islands Troughs, the High Plateau shows clear breakup margins to all parts of Ontong Java Nui. The updated version of rotational parameters for the western Pacific includes the individual plates of the Manihiki Plateau as well as the rotation of the Ontong Java Plateau and the Hikurangi Plateau, which have so far been excluded from plate kinematic reconstructions. Late Cretaceous and early Paleocene tectonic activity within the Nova Canton Trough allows the reconciliation between the paleolatitudes from rock samples and the modeled latitudes.

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References

Ai, H.-A., J. M. Stock, R. Clayton, and B. Luyendyk (2008), Vertical tectonics of the High Plateau region, Manihiki Plateau, Western Pacific, from seismic stratigraphy, *Mar. Geophys. Res.*, *29*(1), 13–26, doi:10.1007/s11001-008-9042-0.

Albers, M., and U. R. Christensen (2001), Channeling of plume flow beneath mid-ocean ridges, *Earth Planet. Sci. Lett.*, *187*(1-2), 207–220, doi:10.1016/S0012-821X(01)00276-X.

Billen, M. I., and J. Stock (2000), Morphology and origin of the Osbourn Trough, *J. Geophys. Res.*, *105*(B6), 13,481–13,489, doi:10.1029/2000JB900035.

Chambers, L. M., M. S. Pringle, and J. G. Fitton (2004), Phreatomagmatic eruptions on the Ontong Java Plateau: An Aptian 40Ar/39Ar age for volcaniclastic rocks at ODP Site 1184, *Geol. Soc.*, *229*, 325–331, doi:10.1144/GSL.SP.2004.229.01.18.

Chandler, M. T., P. Wessel, B. Taylor, M. Seton, S.-S. Kim, and K. Hyeong (2012), Reconstructing Ontong Java Nui: Implications for Pacific absolute plate motion, hotspot drift and true polar wander, *Earth Planet. Sci. Lett.*, *331-332*, 140–151, doi:10.1016/j.epsl.2012.03.017.

Chandler, M. T., P. Wessel, and W. W. Sager (2013), Analysis of Ontong Java Plateau palaeolatitudes: Evidence for large-scale rotation since 123 Ma?, *Geophys. J. Int.*, *194*(1), 18–29, doi:10.1093/gji/ggt075.

Cloos, M. (1993), Lithospheric buoyancy and collisional orogenesis: Subduction of oceanic plateaus, continental margins, island arcs, spreading ridges, and seamounts, *Geol. Soc. Am. Bull.*, *105*(6), 715–737, doi:10.1130/0016-7606(1993)105 < 0715:LBACOS > 2.3.CO;2.

Cockerham, R. S., and R. D. Jarrard (1976), Paleomagmatism of some leg 33 sediments and basalts, *Inital Rep. Deep Sea Drill. Proj.*, *33*, 631–647, doi:10.2973/dsdp.proc.33.1976.

Coffin, M. F., and O. Eldholm (1994), Large igneous provinces: Crustal structure, dimensions, and external consequences, *Rev. Geophys.*, *32*(1), 1–36, doi:10.1029/93RG02508.

Darbyshire, F. A., I. T. Bjarnason, R. S. White, and Ó. G. Flóvenz (1998), Crustal structure above the Iceland mantle plume imaged by the ICE-MELT refraction profile, *Geophys. J. Int.*, *135*(3), 1131–1149, doi:10.1046/j.1365-246X.1998.00701.x.

Davy, B. (2014), Rotation and offset of the Gondwana convergent margin in the New Zealand region following Cretaceous jamming of Hikurangi Plateau large igneous province subduction, *Tectonics*, *33*, 1577–1595, doi:10.1002/2014TC003629.

Davy, B., and J. Y. Collot (2000), The Rapuhia Scarp (northern Hikurangi Plateau)—Its nature and subduction effects on the Kermadec Trench, *Tectonophysics*, *328*(3-4), 269–295, doi:10.1016/S0040-1951(00)00211-0.

Davy, B., and R. Wood (1994), Gravity and magnetic modelling of the Hikurangi Plateau, *Mar. Geol.*, *118*(1-2), 139–151, doi:10.1016/0025-3227(94)90117-1.

Davy, B., K. Hoernle, and R. Werner (2008), Hikurangi Plateau: Crustal structure, rifted formation, and Gondwana subduction history, *Geochem. Geophys. Geosyst.*, *9*, Q07004, doi:10.1029/2007GC001855.

Davy, B., V. Stagpoole, D. Barker, and J. Yu (2012), Subsurface structure of the Canterbury region interpreted from gravity and aeromagnetic data, *N. Z. J. Geol. Geophys.*, *55*, 185–191, doi:10.1080/00288306.2012.690765.

Downey, N. J., J. M. Stock, R. W. Clayton, and S. C. Cande (2007), History of the Cretaceous Osbourn spreading center, *J. Geophys. Res.*, *112*, B04102, doi:10.1029/2006JB004550.

Dyment, J., J. Lin, and E. T. Baker (2007), Ridge-hotspot interactions: What mid-ocean ridges tell us about deep Earth processes, *Oceanography*, *322*, 137–144, doi:10.1038/322137a0.

Eagles, G., K. Gohl, and R. D. Larter (2004), High-resolution animated tectonic reconstruction of the South Pacific and West Antarctic Margin, *Geochem. Geophys. Geosyst.*, *5*, Q07002, doi:10.1029/2003GC000657.

Furumoto, A. S., J. P. Webb, M. E. Odegard, and D. M. Hussong (1976), Seismic studies on the Ontong Java plateau, 1970, *Tectonophysics*, *34*, 71–90, doi:10.1016/0040-1951(76)90177-3.

Gladczenko, T. P., M. F. Coffin, and O. Eldholm (1997), Crustal structure of the Ontong Java Plateau: Modeling of new gravity and existing seismic data, *J. Geophys. Res.*, *102*(B10), 22,711–22,729, doi:10.1029/97JB01636.

Gohl, K., G. Uenzelmann-Neben, and N. Grobys (2011), Growth and dispersal of a Southeast African large igneous province, *S. Afr. J. Geol.*, *114*, 379–386, doi:10.2113/gssajg.114.3-4.379.

Granot, R., J. Dyment, and Y. Gallet (2012), Geomagnetic field variability during the Cretaceous Normal Superchron, *Nat. Geosci.*, *5*(3), 220–223, doi:10.1038/ngeo1404.

Gutscher, M. A., J. L. Olivet, D. Aslanian, J. P. Eissen, and R. Maury (1999), The "lost Inca Plateau": Cause of flat subduction beneath Peru?, *Earth Planet. Sci. Lett.*, *171*(3), 335–341, doi:10.1016/S0012-821X(99)00153-3.

Hoernle, K., F. Hauff, P. van den Bogaard, R. Werner, N. Mortimer, J. Geldmacher, D. Garbe-Schönberg, and B. Davy (2010), Age and geochemistry of volcanic rocks from the Hikurangi and Manihiki oceanic Plateaus, *Geochim. Cosmochim. Acta*, *74*, 1–24, doi:10.1016/j.gca.2010.09.030.

Ingle, S. P., J. J. Mahoney, H. Sato, M. F. Coffin, J.-I. Kimura, N. Hirano, and M. Nakanishi (2007), Depleted mantle wedge and sediment fingerprint in unusual basalts from the Manihiki Plateau, central Pacific Ocean, *Geology*, *35*(7), 595, doi:10.1130/G23741A.1.

Inoue, H., M. F. Coffin, Y. Nakamura, K. Mochizuki, and L. W. Kroenke (2008), Intrabasement reflections of the Ontong Java Plateau: Implications for plateau construction, *Geochem. Geophys. Geosyst.*, *9*, Q04014, doi:10.1029/2007GC001780.

Ishikawa, A., E. Nakamura, and J. J. Mahoney (2005), Jurassic oceanic lithosphere beneath the southern Ontong Java Plateau: Evidence from xenoliths in alnöite, Malaita, Solomon Islands, *Geology*, *33*(5), 393–396, doi:10.1130/G21205.1.

Ishikawa, A., T. Kuritani, A. Makishima, and E. Nakamura (2007), Ancient recycled crust beneath the Ontong Java Plateau: Isotopic evidence from the garnet clinopyroxenite xenoliths, Malaita, Solomon Islands, *Earth Planet. Sci. Lett.*, *259*(1-2), 134–148, doi:10.1016/j.epsl.2007.04.034.

Ito, G., J. Lin, and C. W. Gable (1996), Dynamics of mantle flow and melting at a ridge-centered hotspot: Iceland and the Mid-Atlantic Ridge, *Earth Planet. Sci. Lett.*, *144*(1-2), 53–74, doi:10.1016/0012-821X(96)00151-3.

Ito, G., J. Lin, and D. Graham (2003), Observational and theoretical studies of the dynamics of mantle plume–mid-ocean ridge interaction, *Rev. Geophys.*, *41*(4), 1017, doi:10.1029/2002RG000117.

Karlstrom, L., and M. A. Richards (2011), On the evolution of large ultramafic magma chambers and timescales for flood basalt eruptions, *J. Geophys. Res.*, *116*, B08216, doi:10.1029/2010JB008159.

Klosko, E. R., R. M. Russo, E. A. Okal, and W. P. Richardson (2001), Evidence for a rheologically strong chemical mantle root beneath the Ontong–Java Plateau, *Earth Planet. Sci. Lett.*, *186*(3), 347–361, doi:10.1016/S0012-821X(01)00235-7.

Kokfelt, T. F., C. Lundstrom, K. Hoernle, and F. Hauff (2005), Plume–ridge interaction studied at the Galápagos spreading center: Evidence from 226 Ra–230 Th–238 U and 231 Pa–235 U isotopic disequilibria, *Earth Planet. Sci. Lett.*, *234*, 165–187, doi:10.1016/j.epsl.2005.02.031.

Koppers, A. A. P., and H. Staudigel (2005), Asynchronous bends in Pacific seamount trails: A case for extensional volcanism?, *Science*, *307*, 904–907, doi:10.1126/science.1107260.

Larson, R. L. (1997), Superplumes and ridge interactions between Ontong Java and Manihiki Plateaus and the Nova-Canton Trough, *Geology*, *25*(9), 779–782, doi:10.1130/0091-7613(1997)025 < 0779:SARIBO>2.3.CO;2.

Larson, R. L., and C. Chase (1972), Late Mesozoic Evolution of the Western Pacific Ocean, *Geol. Soc. Am. Bull.*, *83*(12), 3627–3644, doi:10.1130/0016-7606(1972)83[3627:LMEOTW]2.0.CO;2.

Larson, R. L., R. A. Pockalny, R. F. Viso, E. Erba, L. J. Abrams, B. Luyendyk, J. Stock, and R. Clayton (2002), Mid-Cretaceous tectonic evolution of the Tongareva triple junction in the southwestern Pacific Basin, *Geology*, *90*, 67–70, doi:10.1130/0091-7613(2002)030 < 0067:MCTEOT>2.0.CO;2.

Liu, L., M. Gurnis, M. Seton, J. Saleeby, R. D. Müller, and J. M. Jackson (2010), The role of oceanic plateau subduction in the Laramide orogeny, *Nat. Geosci.*, *3*(5), 353–357, doi:10.1038/ngeo829.

Luyendyk, B. (1995), Hypothesis for Cretaceous rifting of East Gondwana caused by subducted slab capture, *Geology*, *23*(4), 373–376.

Mahoney, J. J., M. Storey, R. A. Duncan, K. J. Spencer, and M. S. Pringle (1993), Geochemistry and geochronology of Leg 130 basement lavas: Nature and origin of the Ontong Java Plateau, *Proc. Ocean Drill. Program Sci. Results*, *130*, 3–22, doi:10.2973/odp.proc.sr.130.040.1993.

Mann, P., and A. Taira (2004), Global tectonic significance of the Solomon Islands and Ontong Java Plateau convergent zone, *Tectonophysics*, *389*(3-4), 137–190, doi:10.1016/j.tecto.2003.10.024.

Matthews, K. J., M. Seton, and R. D. Müller (2012), A global-scale plate reorganization event at 105 − 100 Ma, *Earth Planet. Sci. Lett.*, *355-356*(c), 283–298, doi:10.1016/j.epsl.2012.08.023.

Maus, S., et al. (2009), EMAG2: A 2–arc min resolution Earth Magnetic Anomaly Grid compiled from satellite, airborne, and marine magnetic measurements, *Geochem. Geophys. Geosyst.*, *10*, Q08005, doi:10.1029/2009GC002471.

Miura, S., K. Suyehiro, M. Shinohara, N. Takahashi, E. Araki, and A. Taira (2004), Seismological structure and implications of collision between the Ontong Java Plateau and Solomon Island Arc from ocean bottom seismometer–airgun data, *Tectonophysics*, *389*(3-4), 191–220, doi:10.1016/j.tecto.2003.09.029.

Mochizuki, K., M. F. Coffin, O. Eldholm, and A. Taira (2005), Massive Early Cretaceous volcanic activity in the Nauru Basin related to emplacement of the Ontong Java Plateau, *Geochem. Geophys. Geosyst.*, *6*, Q10003, doi:10.1029/2004GC000867.

Mortimer, N., K. Hoernle, F. Hauff, J. M. Palin, W. J. Dunlap, R. Werner, and K. Faure (2006), New constraints on the age and evolution of the Wishbone Ridge, southwest Pacific Cretaceous microplates, and Zealandia–West Antarctica breakup, *Geology*, *34*(3), 185–188, doi:10.1130/G22168.1.

Müller, R. D., W. R. Roest, and J. Y. Royer (1998), Asymmetric sea-floor spreading caused by ridge–plume interactions, *Nature*, *396*, 455–459, doi:10.1038/24850.

Musgrave, R. J. (1990), Paleomagnetism and tectonics of Malaita, Solomon Islands, *Tectonics*, *9*(4), 735–759, doi:10.1029/TC009i004p00735.

Musgrave, R. J. (2013), Evidence for Late Eocene emplacement of the Malaita Terrane, Solomon Islands: Implications for an even larger Ontong Java Nui oceanic plateau, *J. Geophys. Res. Solid Earth*, *118*, 2670–2686, doi:10.1002/jgrb.50153.

Nakanishi, M., K. Tamaki, and K. Kobayashi (1992), A new Mesozoic isochron chart of the northwestern Pacific Ocean: Paleomagnetic and tectonic implications, *Geophys. Res. Lett.*, *19*(7), 693–696, doi:10.1029/92GL00022.

Nakanishi, M., Y. Nakamura, M. F. Coffin, K. A. Hoernle, and R. Werner (2015), Topographic expression of the Danger Islands Troughs and implications for the tectonic evolution of the Manihiki Plateau, western equatorial Pacific Ocean, *GSA Spec. Pap.*, *511*, 195–220, doi:10.1130/2015.2511(11).

Pietsch, R., and G. Uenzelmann-Neben (2015), The Manihiki Plateau—A multistage volcanic emplacement history, *Geochem. Geophys. Geosyst.*, *16*, 2480–2498, doi:10.1002/2015GC005852.

Reyners, M. (2013), The central role of the Hikurangi Plateau in the Cenozoic tectonics of New Zealand and the Southwest Pacific, *Earth Planet. Sci. Lett.*, *361*, 460–468, doi:10.1016/j.epsl.2012.11.010.

Ribe, N. M. (1996), The dynamics of plume-ridge interaction: 2. Off-ridge plumes, *J. Geophys. Res.*, *101*(B7), 16,195–16,204, doi:10.1029/96JB01187.

Ribe, N. M., and W. L. Delattre (1998), The dynamics of plume—ridge interaction—III. The effects of ridge migration, *Geophys. J. Int.*, *133*(3), 511–518, doi:10.1046/j.1365-246X.1998.00476.x.

Ribe, N. M., U. R. Christensen, and J. Theissing (1995), The dynamics of plume-ridge interaction, 1: Ridge-centered plumes, *Earth Planet. Sci. Lett.*, *134*(1-2), 155–168, doi:10.1016/0012-821X(95)00116-T.

Richardson, W. P., E. A. Okal, and S. Van der Lee (2000), Rayleigh–wave tomography of the Ontong–Java Plateau, *Phys. Earth Planet. Inter.*, *118*(1), 29–51, doi:10.1016/S0031-9201(99)00122-3.

Ridley, V. A., and M. A. Richards (2010), Deep crustal structure beneath large igneous provinces and the petrologic evolution of flood basalts, *Geochem. Geophys. Geosyst.*, *11*, Q09006, doi:10.1029/2009GC002935.

Riisager, P., J. Riisager, X. Zhao, and R. S. Coe (2003), Cretaceous geomagnetic paleointensities: Thellier experiments on Pillow lavas and Submarine basaltic glass from the Ontong Java Plateau, *Geochem. Geophys. Geosyst.*, *4*(12), 8803, doi:10.1029/2003GC000611.

Sager, W. W. (2006), Cretaceous paleomagnetic apparent polar wander path for the Pacific plate calculated from Deep Sea Drilling Project and Ocean Drilling Program basalt cores, *Phys. Earth Planet. Inter.*, *156*(3-4), 329–349, doi:10.1016/j.pepi.2005.09.014.

Sandwell, D. T., R. D. Müller, W. H. F. Smith, E. Garcia, and R. Francis (2014), New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure, *Science*, *346*(6205), 65–67, doi:10.1126/science.1258213.

Seton, M., et al. (2012), Global continental and ocean basin reconstructions since 200Ma, *Earth Sci. Rev.*, *113*(3-4), 212–270, doi:10.1016/j.earscirev.2012.03.002.

Sinton, J., R. Detrick, J. P. Canales, G. Ito, and M. Behn (2003), Morphology and segmentation of the western Galápagos Spreading Center, 90.5°–98°W: Plume-ridge interaction at an intermediate spreading ridge, *Geochem. Geophys. Geosyst.*, *4*(12), 8515, doi:10.1029/2003GC000609.

Sutherland, R., and C. Hollis (2001), Cretaceous demise of the Moa plate and strike-slip motion at the Gondwana margin, *Geology*, *29*(3), 279–282, doi:10.1130/0091-7613(2001)029 <0279:CDOTMP>2.0.CO;2.

Taylor, B. (2006), The single largest oceanic plateau: Ontong Java-Manihiki-Hikurangi, *Earth Planet. Sci. Lett.*, *241*, 372–380, doi:10.1016/j.epsl.2005.11.049.

Tejada, M. L. G., J. J. Mahoney, C. R. Neal, R. A. Duncan, and M. G. Petterson (2002), Basement geochemistry and geochronology of Central Malaita, Solomon Islands, with implications for the origin and evolution of the Ontong Java Plateau, *J. Petrol.*, *43*(3), 449–484, doi:10.1093/petrology/43.3.449.

Timm, C., K. Hoernle, R. Werner, F. Hauff, P. van den Bogaard, P. Michael, M. F. Coffin, and A. A. P. Koppers (2011), Age and geochemistry of the oceanic Manihiki Plateau, SW Pacific: New evidence for a plume origin, *Earth Planet. Sci. Lett.*, *304*, 135–146, doi:10.1016/j.epsl.2011.01.025.

Timm, C., et al. (2014), Subduction of the oceanic Hikurangi Plateau and its impact on the Kermadec arc, *Nat. Commun.*, *5*, 4923, doi:10.1038/ncomms5923.

Uenzelmann-Neben, G. (2012), The expedition of the research vessel "Sonne" to the Manihiki Plateau in 2012 (So 224), in *EPIC3Berichte zur Polar- und Meeresforschung, Reports on Polar and Marine Research*, vol. 672, 111 pp., Alfred Wegener Inst. for Polar and Mar. Res., Bremerhaven, Germany.

Viso, R. F., R. L. Larson, and R. A. Pockalny (2005), Tectonic evolution of the Pacific–Phoenix–Farallon triple junction in the South Pacific Ocean, *Earth Planet. Sci. Lett.*, *233*(1-2), 179–194, doi:10.1016/j.epsl.2005.02.004.

Weatherall, P., K. M. Marks, M. Jakobsson, T. Schmitt, S. Tani, J.-E. Arndt, M. Rovere, D. Chayes, V. Ferrini, and R. Wigley (2015), A new digital bathymetric model of the world's oceans, *Earth Space Sci.*, *2*, 331–345, doi:10.1002/2015EA000107.

Wessel, P., and L. W. Kroenke (2008), Pacific absolute plate motion since 145 Ma: An assessment of the fixed hot spot hypothesis, *J. Geophys. Res.*, *113*, B06101, doi:10.1029/2007JB005499.

Whittaker, J. M., J. C. Afonso, S. Masterton, R. D. Müller, P. Wessel, S. E. Williams, and M. Seton (2015), Long-term interaction between mid-ocean ridges and mantle plumes, *Nat. Geosci.*, *8*(6), 479–483, doi:10.1038/ngeo2437.

Winterer, E. L., P. L. Lonsdale, J. L. Matthews, and B. R. Rosendahl (1974), Structure and acoustic stratigraphy of the Manihiki Plateau, *Deep Sea Res. Oceanogr. Abstr.*, *21*(10), 793–813, doi:10.1029/JB084iB11p06003.

Wobbe, F., K. Gohl, A. Chambord, and R. Sutherland (2012), Structure and breakup history of the rifted margin of West Antarctica in relation to Cretaceous separation from Zealandia and Bellingshausen plate motion, *Geochem. Geophys. Geosyst.*, *13*, Q04W12, doi:10.1029/2011GC003742.

Worthington, T. J., R. Hekinian, P. Stoffers, T. Kuhn, and F. Hauff (2006), Osbourn Trough: Structure, geochemistry and implications of a mid-Cretaceous paleospreading ridge in the South Pacific, *Earth Planet. Sci. Lett.*, *245*(3-4), 685–701, doi:10.1016/j.epsl.2006.03.018.