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Four distinct pulses of volcanism built the Melanesian Border Plateau: Implications for oceanic mid-plate superstructure formation

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A R T I C L E I N F O

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A B S T R A C T

The ocean basins contain numerous volcanic ridges, seamounts and large igneous provinces (LIPs). Numerous studies have focused on the origin of seamount chains and LIPs but much less focus has been applied to understanding the genesis of large volcanic structures formed from a combination or series of volcanic drivers. Here we propose the term Oceanic Mid-plate Superstructures (OMS) to describe independent bathymetric swells or volcanic structures that are constructed through superimposing pulses of volcanism, over long time periods and from multiple sources. These sources can represent periods when the lithosphere drifted over different mantle plumes and/or experienced pulses of volcanism associated with shallow tectonic drivers (e.g. plate flexure; lithospheric extension). Here we focus on the Melanesian Border Plateau (MBP), one example of an OMS that has a complex and enigmatic origin.

The MBP is a region of shallow Pacific lithosphere consisting of high volumes of volcanic guyots, ridges and seamounts that resides on the northern edge of the Vitiaz Lineament. Here we reconcile recently published constraints to build a comprehensive volcanic history of the MBP. The MBP was built through four distinct episodes: (1) Volcanism associated with the Louisville hotspot likely generating Robbie Ridge and some Cretaceous seamounts near the MBP. (2) Construction of oceanic islands and seamounts during the Eocene when the lithosphere passed over the Rurutu-Arago hotspot. (3) Reactivation of previous oceanic islands/seamounts and construction of new volcanos in the Miocene when the lithosphere passed over the Samoa hotspot. (4) Miocene to modern volcanism driven by lithospheric deformation and/or westward entrainment of enriched plume mantle due to toroidal mantle flow driven by the rollback of the Pacific plate beneath the Tonga trench. The combination of these processes is responsible for ~222,000 km^2 of intraplate volcanism in the MBP and indicates that this OMS was constructed from multiple volcanic drivers.

1. Introduction

The ocean basins are dotted with numerous seamounts and ridges as well as larger volcanic structures like large igneous provinces (LIPs). Much of the attention of the intraplate volcanic community has been placed on LIPs. There are a variety of definitions for what constitutes a LIP but most commonly it is defined as anomalous pulses of typically mafic volcanism that produce magma volumes of 0.1 to 80 Mkm^3 within a few million years (e.g. Ernst 2014). The emplacement of LIPs typically has a large environmental consequence and as such understanding the timing and drivers of LIP volcanism is vital (Bryan and Ferrari, 2013; Ernst et al., 2021). However, there are numerous features in the ocean basins that appear LIP-like in volume, but available age constraints indicate multiple pulses or long-lived volcanism (e.g. Central Line

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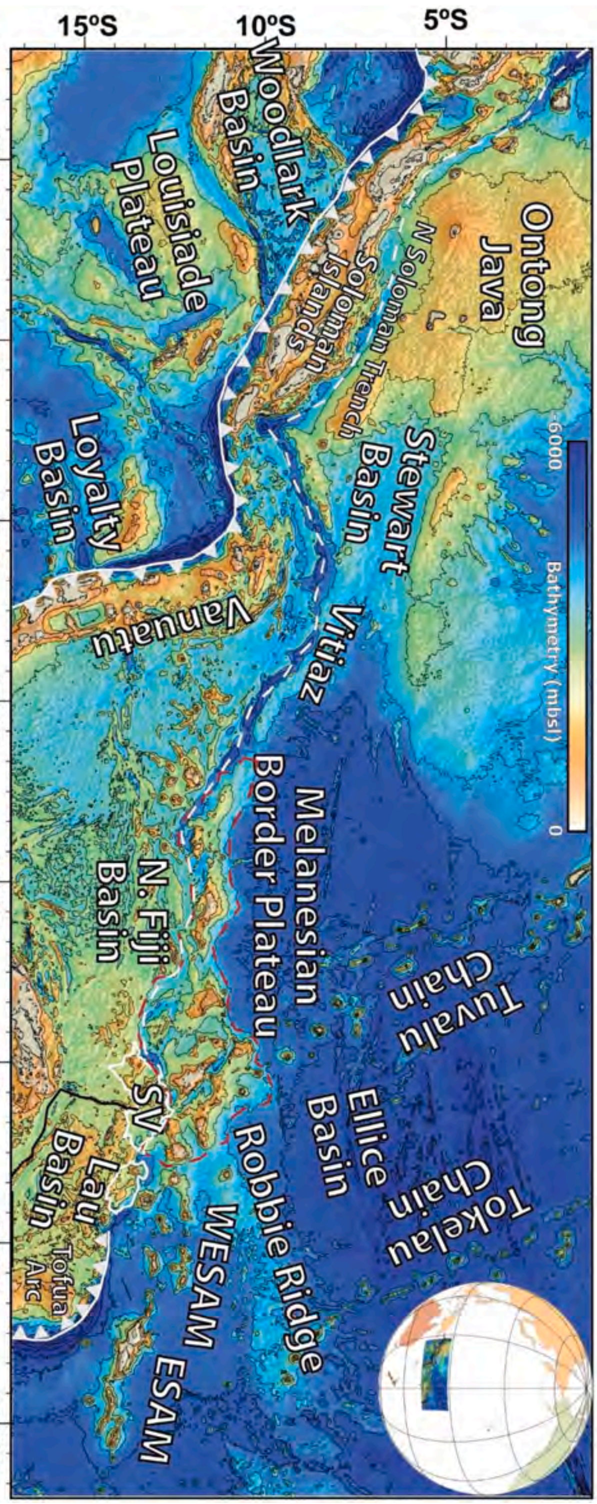

Fig. 1. A bathymetric map of the Southwestern Pacific and Northeastern Australian Plate regions. Key geologic features relevant to this study are highlighted. The active subduction zones are shown with solid white lines while paleo boundaries are shown with dashed lines. The location of the MBP is outlined with red dashed lines. The approximate divide between the Lau Basin and North Fiji Basin is shown with a solid black line. SV = South Vitiaz crustal block; WESAM = Western Samoa Seamounts; ESAM = Eastern Samoa Seamounts.

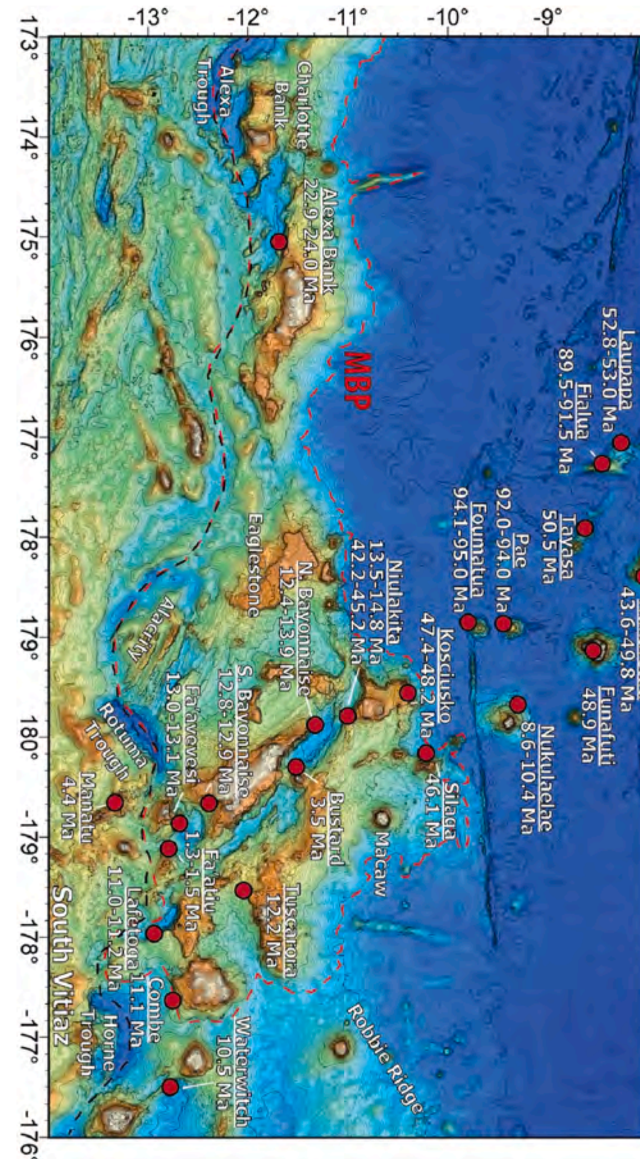

Fig. 2. The Melanesian Border Plateau with $^{40}Ar/^{39}Ar$ age determinations for dredged lava flow samples shown (Hart et al., 2004; Koppers et al., 2011; Konrad et al., 2018; Finlayson et al., 2018; Price et al., 2022). The dashed black line shows the approximate location of the Vitiaz Lineament while the red dash outline the general extent of the MBP. Some key features are noted.

Islands Ridge, Mid-Pacific Mountains; Winterer et al., 1993; Davis et al., 2002; Pockalny et al., 2021). In order to increase clarity between feature terminology and geodynamic origin, here we introduce the term Oceanic Mid-plate Superstructure (OMS). An OMS constitutes a volcanic structure (e.g. an individual seamount or large continuous bathymetric swell) that was built through multiple pulses of volcanism from distinct geodynamic drivers. We tentatively propose a minimum time gap between pulses of >7 Ma to makes sure typical post-erosional/rejuvenated volcanism is not a factor in OMS classification (defined further in the Discussion section). Understanding the distribution and origin of these OMS structures has the potential to provide vital constraints on the 'top down' and 'bottom up' sources of intraplate volcanism, the drivers of dynamic topography as well as punctuated versus gradual deep Earth-ocean chemical exchange.

One potential OMS is the Melanesian Border Plateau (MBP; Figs. 1, 2), which appears to have volcanic structures sourced from multiple processes (Brocher, 1985; Pelletier and Auzende, 1996; Hart et al., 2004;

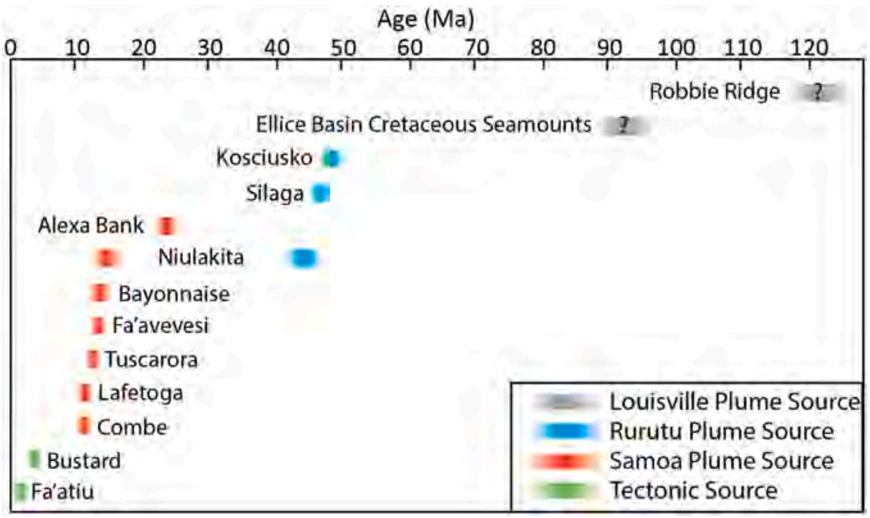

Fig. 3. A timeline for volcanism within the Melanesian Border Plateau. The age of the underlying Robbie Ridge and if the Ellice Basin Seamounts extend into the MBP is hypothesized here but not confirmed. See discussion for the origin of the various age constraints and proposed geodynamic drivers.

Konrad et al., 2018; Finlayson et al., 2018; Price et al., 2022). The MBP is a loosely defined region of Pacific lithosphere that covers ~222,000 km^2 and contains at least 25 distinct volcanic structures. The Pacific lithosphere beneath the MBP formed during the Cretaceous Normal Superchron (122 – 83 Ma; Granot et al., 2012) and as such the exact ages are not known. The MBP stretches from Charlotte Bank in the west to Combe Bank in the east, and in the south borders the Vitiaz Lineament, which is interpreted to be a paleo-subduction zone boundary between the Pacific and Indo-Australian Plates (Brocher, 1985; Fig. 2). That subduction component stopped when the massive Ontong Java Plateau docked with the trench and caused the Vanuatu Trench in the west to reverse its subduction direction while the eastern Vitiaz boundary switched to more complicated and poorly understood subduction and transform motions (Kroenke, 1972; Brocher, 1985; Pelletier and Auzende, 1996; Schellart et al., 2004; Martin, 2013). The eastern Vitiaz is hypothesized to have been choked at a later time when the MBP collided with the trench (Martin, 2013; Gill et al., 2022). Alternatively, the eastern Vitiaz (e.g. south of the MBP and Samoa seamount regions) represents remnant scars from a subduction-transform edge propagator fault generated from the Tonga Trench advancing eastward and tearing the Pacific lithosphere (Hart et al., 2004; Govers and Wortel, 2005). The Vitiaz region is generally seismically inactive today (Baxter et al., 2020) but some evidence for continual deformation along the lineament is present (Pelletier and Auzende, 1996). Therefore, the Vitiaz does not appear to represent a standard plate boundary but rather serves as a diffusive region of deformation between the Pacific to the north and the backarc basins (Lau and North Fiji) to the south (e.g. Stewart et al., 2022). The MBP has poorly defined paleo-plate borders due in part to subsequent volcanism, local plate uplift, and crustal deformation (Pelletier and Auzende, 1996) as well as minimal mapping, sampling and geophysical surveys of the region (Brocher, 1985; Sinton et al., 1985; Pelletier and Auzende, 1996).

Here we focus on the origin of the MBP and its relationship to the proximal Cretaceous Ellice Basin Seamounts (Finlayson et al., 2018), Tuvalu Seamount Chain (Konrad et al., 2018; Finlayson et al., 2018) and Western Samoan Seamount Province (WESAM; Hart et al., 2004; Koppers et al., 2011; Finlayson et al., 2018; Price et al., 2022). These new and compiled observations indicate that the MBP region was constructed from at least three, and likely four, distinct volcanic episodes starting in the Cretaceous and continuing into the present day. The drivers for regional volcanism include lithosphere interaction with at least two hotspots, plate flexure, entrainment of plume material in mantle flow, and tectonic deformation. These observations cement the MBP region as a valuable type example of multiple tectonomagmatic phenomenon generating oceanic mid-plate superstructures.

2. Methods and data

This work focuses on the previously published lava flow ^{40}Ar/^{39}Ar age determinations and lithophile isotope geochemistry from the MBP region (Hart et al., 2004; Koppers et al., 2011; Konrad et al., 2018; Finlayson et al., 2018; Price et al., 2022), WESAM and Eastern Samoa Seamount Province (ESAM) (Hart et al., 2004; Koppers et al., 2011; Price et al., 2022), and Tuvalu Seamount Chain region (Konrad et al., 2018; Finlayson et al., 2018) (Fig. 2). Fig. 3 shows the hotspot track reconstructions of the Louisville, Rurutu-Arago and Samoa hotspots, assuming fixed mantle plumes, using the absolute plate motion (APM) model of Konter et al. (2023), which is a modified version of the Koppers et al. (2001) model. A modeled hotspot track represents the timing and location that the lithosphere would have overridden a fixed hotspot. The lava flows and tracks are color coded by age, which serves to highlight several major temporal groupings. Fig. 4 displays the ^{143}Nd/^{144}Nd and ^{206}Pb/^{204}Pb values for submarine lava flows from the region (Jackson et al., 2010; Finlayson et al., 2018; Price et al., 2022). Fig. 5 shows a plate reconstruction using GPlates software (Müller et al., 2018) employing the current plate boundary deformation adjusted fixed hotspot global APM model and plate boundaries (Young et al., 2019; Müller et al., 2019; Torsvik et al., 2019; Cao et al., 2022).

3. Discussion

Age determinations of lava flows from the MBP region range from 1.3 to 45 Ma (Hart et al., 2004; Koppers et al., 2011; Konrad et al., 2018; Finlayson et al., 2018; Price et al., 2022; Fig. 2) with at least three distinct pulses of regional volcanic activity (Figs. 3, 4). Below we discuss the origin and consequence of each of these volcanic episodes starting from oldest to youngest.

3.1. *Cretaceous volcanism in the Melanesian Border Plateau region*

The first potential phase of volcanism (outside of crustal accretion) that represents the base of the eastern MBP is Robbie Ridge (Figs. 1, 2). Robbie Ridge is a ~SW-NE trending swell that extends from the eastern MBP to Manihiki Plateau (Winterer et al., 1974; Pelletier and Auzende, 1996; Taylor, 2006). Although unsampled, the ridge is believed to be part of the larger ca. 123 Ma Ontong-Java-Nui LIP based on plate

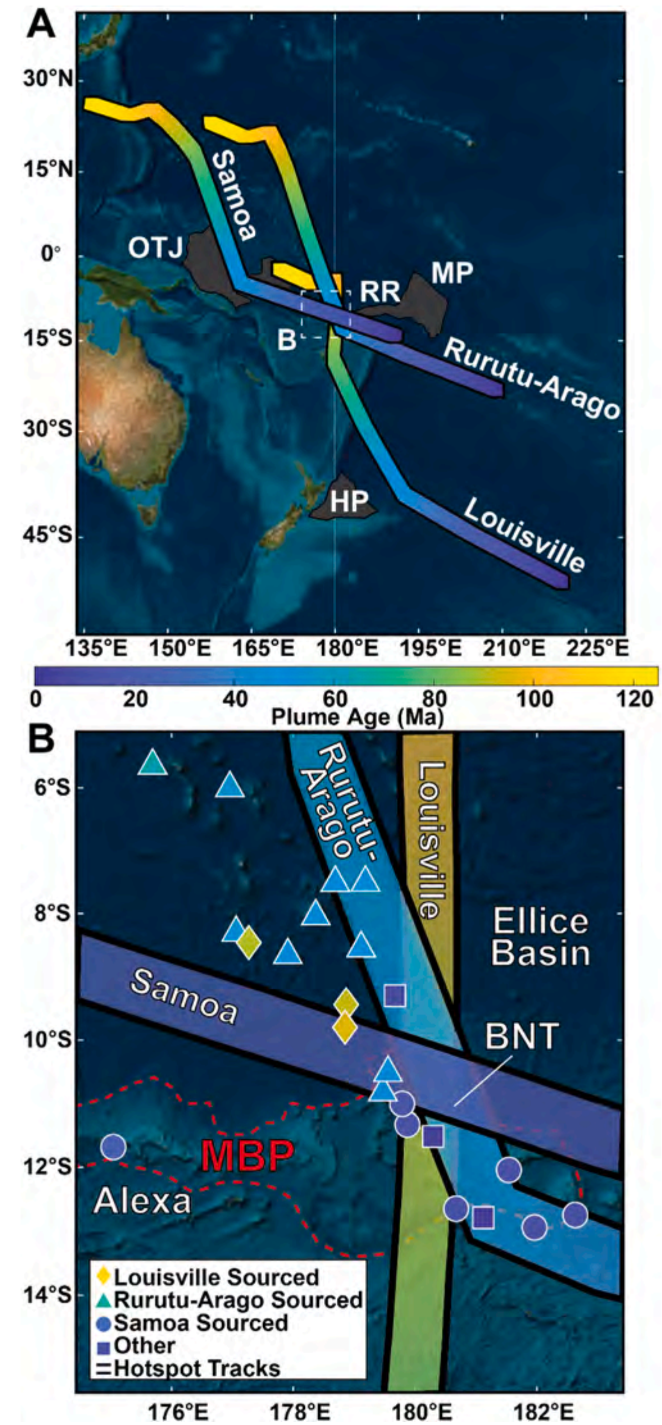

Fig. 4. The modeled hotspot tracks for the Samoa, Rurutu-Arago and Louisville hotspots superimposed on the modern MBP region. The tracks were calculated using the preliminary APM model of Konter et al. (2023) using the hotspot locations suggested in Koppers et al. (2021). Both the modeled hotspot tracks and lava flow locations are color coded by age. Note that this is a fixed hotspot model and is not adjusted for any independent mantle plume motion. (A) A regional view that shows the three main hotspot tracks of interest. The outlines of the Ontong Java Plateau (OTJ), Robbie Ridge (RR), Manihiki Plateau (MP) and Hikurangi Plateau (HP), which all constitute the massive Ontong Java-Nui LIP are shown (Taylor, 2006). (B) The MBP (red dashed line) and neighboring regions with dated lava flows locations shown. BNT = Bayonnaise-Niulakita-Tuscarora OMS, which is the independently modeled intersection of the three projected hotspot tracks.

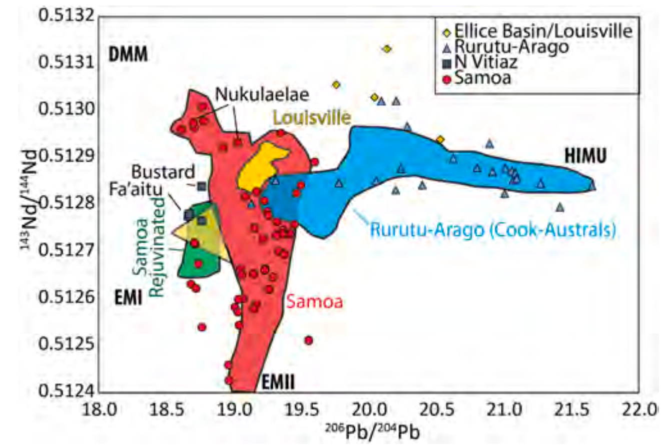

Fig. 5. The $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$ constraints for submarine lava flow samples from the MBP and neighboring regions. Data from Jackson et al. (2010), Finlayson et al. (2018) and Price et al. (2022). The subaerial Samoa, rejuvenated Samoan volcanism and Rurutu-Arago fields from Price et al. (2022) and references therein. The Louisville field is from the submarine seamount data of Vanderkluysen et al. (2014).

reconstructions that propose Robbie Ridge originally resided in the now Stewart Basin gap (Fig. 1) of the eastern Ontong-Java Plateau (Taylor, 2006; Chandler et al., 2012). The Robbie Ridge bathymetric swell continuously trends into the eastern region of the MBP (Fig. 2) and the anomalously thick lithosphere likely underplates the MBP region as well (Pelletier and Auzende, 1996). Thus, this underplating may be partly responsible for why the seafloor depth in the eastern MBP is shallower than the proximal WESAM region (Fig. 1).

Another likely early phase of volcanism is based on observations of three late Cretaceous seamounts on the southwestern side of the Tuvalu Chain (95–90 Ma; Finlayson et al., 2018; Figs. 2, 4**b**). Based on the ages and Sr-Nd-Pb-Hf isotopic ratios, Finlayson et al. (2018) inferred the seamounts are enriched relative to mid-ocean ridge basalts and likely formed in an intraplate setting (Fig. 5). Konter et al. (2023) interprets the seamounts as being sourced from the Louisville hotspot. This interpretation is based on an updated Pacific APM model from the Rurutu-Arago and Samoa chains in the 100–80 Ma timeframe (e.g. Koppers et al. 2003, Konter et al. 2008). When applied to the modern Louisville hotspot, a modeled hotspot track shows relatively strong agreement with the Cretaceous seamounts in the Ellice Basin (Fig. 4) and successfully connects the Louisville hotspot to the Ontong Java Plateau at ca. 120 Ma. If these seamounts represent ancient hotspot derived volcanism, then it is feasible that the MBP south of the Ellice Basin seamounts, which lies on the reconstructed trace of the Louisville hotspot track (and reflects the ~N—NW motion of the Pacific plate from 95 to 80 Ma), contains remnants of late Cretaceous volcanism. This observation requires that the spreading of Ellice Basin ceased and the Manihiki microplate became fused to the Pacific before 100 Ma (Davidson et al., 2023). This would provide an anomalous, albeit kinematically feasible, scenario wherein the Robbie Ridge formed from initial Louisville plume activity at ~120 Ma (Taylor, 2006; Konter et al., 2023), rifted away from the primary structure along the Manihiki microplate from ~119–105 Ma (Davidson et al., 2023), fused back to the Pacific plate and then drifted over the Louisville hotspot a second time. Thus, despite not yet being sampled in the MBP, it is likely that some seamounts, or bases of seamounts in the MBP, were initially constructed by Cretaceous hotspot activity and perhaps buried by subsequent period of volcanism related to passage over other hotspots (see below).

3.2. *Eocene volcanism within and near the Melanesian Border Plateau*

The next measured phase of volcanism at the MBP is associated with

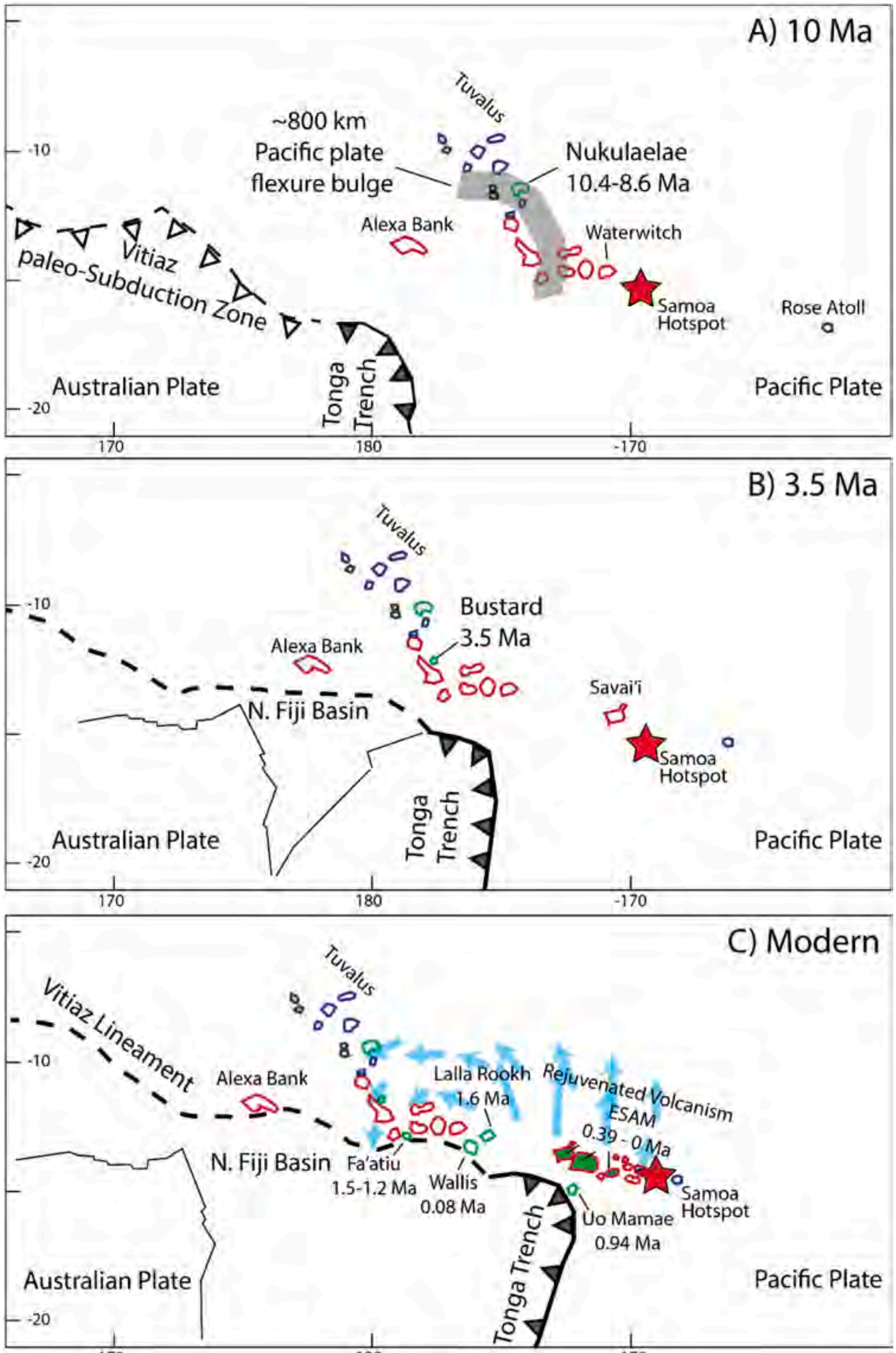

Fig. 6. Tectonic reconstructions of the Vitiaz-Tonga-MBP-Samoa region using the plate motion models and boundary locations of Müller et al. (2019). Note that in all time slices the location of the Vitiaz lineament and whether it is entirely or partly subducting Pacific lithosphere is only approximate. (A) At 10 Ma, the Vitiaz-Tonga system is progressing NE wards and would potentially flex the lithosphere at 800 km (grey shading) generating small scale petit-spot volcanism at Nukulaelae Seamount (see text for details). (B) At 3.5 Ma, the location of Bustard Seamount is likely too far from the hotspot to be driven by SIMU processes. However, the proximity to the Tonga Trench indicates that local plate flexure or subduction transform edge faults can be responsible for the plate deformation. (C) Modern day, the modeled mantle toroidal flow (blue arrows; traced from the models of Strak and Schellart 2018) is continually entraining Samoa plume material westwards while transform and lithospheric tearing from the advance of the Tonga trench deforms the lithosphere in the WESAM and MBP regions.

the lithosphere passing over the Rurutu-Arago hotspot at ca. 48–45 Ma, consistent with the modeled reconstruction of the Rurutu-Arago hotspot in Fig. 4. Konrad et al. (2018) and Finlayson et al. (2018) reported six lava flow samples dredged from Kosciusko, Silaga and Niulakita seamounts that yielded HIMU (high μ or $^{238}U/^{206}Pb$; Zindler and Hart, 1986) mantle isotopic signatures with ages that range from 48 to 42 Ma, consistent with a Rurutu-Arago plume source (Figs. 4, 5). The Rurutu-Arago plume has recently sourced seamounts in the

Cook-Australs region with similar isotopic signatures (e.g. Chauvel et al. 1992, 1997, Rose and Koppers 2019, Jackson et al. 2020) as well as Rose Atoll (25 Ma; Buff et al., 2021), which resides directly east of the active Samoa hotspot. To the northwest of the MBP resides the Tuvalu seamount chain (Fig. 1), where the isotopically HIMU seamounts continue the Rurutu-Arago age progression, which further extends into the Gilbert Ridge (47–73 Ma; Konrad et al., 2018; Finlayson et al., 2018). The Rurutu-Arago hotspot derived seamounts in the 48 – 25 Ma timeframe are directly observed to be, or inferred to be, subsequently covered by volcanic products from the younger Samoan volcanism (Jackson et al., 2010; Finlayson et al., 2018), as we discuss below.

3.3. Miocene volcanism within and near the Melanesian Border Plateau

The fourth phase of volcanism is consistent with the age progression of the Samoa hotspot. Age determinations for lava flows from Niulakita (15–13 Ma; Finlayson et al., 2018), Bayonnaise (14–12 Ma; Koppers et al., 2011; Finlayson et al., 2018), Tuscarora (12 Ma; Finlayson et al., 2018), Fa'avevesi (13 Ma; Koppers et al., 2011) and Alexa Bank (24 Ma; Hart et al., 2004) all have ages and isotopic chemical signatures consistent with the Samoa hotspot track (Fig. 5). However, the geometry of the Samoa hotspot track is inconsistent with APM model projections, which has been interpreted as evidence for significant motion of the Samoan plume (Hart et al., 2004). Regardless, based on geochemical and geochronological data from available dredge samples the bulk of the MBP, or at least the veneer that covers the MBP, appears to have been built from Samoa hotspot volcanism (Fig. 2).

The same dredge (RR1310-D27) that recovered the Eocene HIMU basalts from Niulakita also recovered 15–13 Ma lava flow samples with EMII (Enriched Mantle II; Zindler and Hart, 1986) isotopic affinities – consistent with a Samoan plume source (Finlayson et al., 2018). This indicates that some of the individual volcanoes in the MBP were built in two distinct phases associated with the 'hotspot highway' (Jackson et al., 2010), wherein the lithosphere passed over the Rurutu-Arago hotspot at ca. 48–42 Ma, then those volcanic structures were reoccupied at ca. 15–12 Ma, when the lithosphere passed over the Samoan hotspot. The reactivation of the same seamount structure implies that pre-existing structural weaknesses or conduits in the lithosphere may be preferential sites for new magma migration when a region overrides a different hotspot. This phenomenon is well known, and also occurs at Cook-Austral volcanoes (Chauvel et al., 1997; Jackson et al., 2020). This dual pulse of hotspot volcanism, together with the source of the earlier modeled Louisville volcanism in the region, is at least partly responsible for the large volume of the guyots in the eastern MBP region such as the Bayonnaise-Niulakita-Tuscarora Bank swells (Figs. 2, 4).

The basins surrounding Niulakita, Bayonnaise and Tuscarora Banks have seismic reflection evidence for thick sedimentary deposits (0.4 to 1.4 s two-way travel times) with three inferred unconformities (Pelletier and Auzende, 1996). The large volume of sediments is likely derived from the erosion of the banks, which were once subaerial (Pelletier and Auzende, 1996). Based on the seismic, chronologic and petrologic evidence available, we hypothesize that the deep unconformity observed in the basin sedimentary sequences represents two pulses of island erosional runoff, first from the Rurutu-Arago plume derived ocean islands at ca. 45 Ma, then by the later reoccupation by the Samoa plume to form new islands at ca. 15 Ma. The sediments beneath the deepest unconformity likely were derived from Cretaceous volcanic structures in the region. Together, these three pulses of volcanism contributed to the extraordinary size of the MBP. After the bulk of the MBP was built by overriding three hotspots, smaller scale volcanism occurred throughout the region due to the tectonic response associated with the advancement and collision of the Vitiaz.

3.3.1. Nukulaelae seamount

The oldest volcanism near the MBP that is not directly hotspot related is the enigmatic young rejuvenated volcanism found on Nukulaelae seamount (10.4–8.6 Ma; Finlayson et al., 2018; Fig. 2). Nukulaelae resides within the Tuvalu Seamount chain and is sandwiched between the Rurutu-Arago hotspot derived HIMU seamounts Silaga (46 Ma) and Funafuti (49 Ma) (Konrad et al., 2018; Finlayson et al., 2018). Finlayson et al. (2018) grouped the recovered Nukulaelae lava flows with other MBP Samoan hotspot derived volcanism given the similar isotopic chemistry (depleted to slightly EMII mantle isotopic signatures; Fig. 5). However, the lava flows were emplaced >500 km to the NE of the contemporaneous Samoa-related Waterwitch seamount at 10.4 Ma as well as >600 km from the predicted hotspot location at 8.6 Ma (Fig. 6**a**). This large spatial displacement makes it unlikely to have been sourced directly from the Samoan plume. Instead, we explore the idea of Tonga Trench driven petit-spot style volcanism or long distance plume melt channelization as alternative explainations.

Petit-spot volcanism refers to low volume melt generated from the far-field flexure of a subducting plate (e.g. Hirano et al. 2008, Hirano 2011). In the western Pacific, the zone of flexure and petit-spot volcanism can extend out to 800 km from the subduction trench (Hirano et al., 2019). Nukulaelae is predicted to have been ~800 km from the NE extent of the paleo-Tonga trench at 10 Ma (using the paleo-plate boundary model of Seton et al., 2020; Fig. 6**a**) and ~750 km at 8.6 Ma. Therefore, one feasible option for the origin of the Miocene volcanism is that plate flexure drove localized rejuvenated volcanism on the seamount. However, the plate flexure model struggles to explain why the isotopic composition of Nukulaelae lava flows are similar to Samoa derived volcanism (Fig. 5).

An alternative model for the young Nukulaelae volcanism invokes long-distance melt channelization. Instances of plume melt or mantle channelization have been documented to distances greater than 800 km (e.g. Mittal and Richards 2017, Hua et al. 2023, Naif et al. 2023). Particularly relevant to Nukulaelae volcanism is the work of Naif et al. (2023), which documents that sub lithospheric channelization of Galapagos plume material can be transported over 1000 km to produce sills and lava flows across the Cocos plate. Thus, it is reasonable that Samoa hotspot derived material could've flowed from beneath the over-thickened lithosphere of the MBP region ~500–750 km northward to produce the sampled lava flows on Nukulaelae seamount.

3.4. Pliocene to recent volcanism within and near the Melanesian Border Plateau

The most recent phase of volcanism in the MBP occurred between 3.5 Ma and recent, is likely not directly hotspot related, and has been a topic of considerable debate (e.g. Hawkins and Natland 1975, Duncan 1985, Hart et al. 2004, Koppers et al. 2011, Strak and Schellart 2018, Reinhard et al. 2019, Price et al. 2022). The $^{40}Ar/^{39}Ar$ age determination evidence for Pliocene volcanism in the MBP comes from the 3.5 Ma Bustard volcano and the 1.5–1.3 Ma Fa'atiu seamount (Figs. 2, 3; Price et al., 2022). However, coarse geophysical evidence suggests more widespread young volcanic cones in the MBP (Pelletier and Auzende, 1996) and 0.2 Ma lava flows were reportedly recovered from Bayonnaise (Japan International Cooperation Agency, 1989). It is important to note that the 0.2 Ma constraint is from an older K/Ar age that contained high atmospheric ^{40}Ar percentages and should be considered suspect. However, young non-hotspot related volcanism is also common in the WESAM, including 1.6 Ma volcanism on Lalla Rookh (Hart et al., 2004), 0.08 Ma volcanism on Wallis (Price et al., 1991) as well as unusually voluminous rejuvenated volcanism in the ESAM region (e.g. Hawkins and Natland 1975, Duncan 1985, Reinhard et al. 2019, Price et al. 2022).

Most models of 'non-hotspot' derived volcanism in the WESAM/MBP region argue the primary geodynamic driver is related to the E-NE migration of the Tonga-Kermadec subduction zone over the past 5 Ma (e.g. Ruellan et al. 2003). The driver of volcanism has been argued to (1) relate to 'petit-spot' style volcanism (e.g. Hirano 2011) wherein flexure of the down going Pacific plate causes localized asthenosphere upwelling (± entrained plume material) and melting across the Samoan hotspot track (Konter and Jackson, 2012; Reinhard et al., 2019; Price et al., 2022). (2) Toroidal mantle flow generated by the forward progressions and geometry of the Tonga-Kermadec arc and subducting Pacific slab, which entrains Samoan plume material north, then westward around the northern edge of the down going slab, and finally into the back-arc basins in the south (Hart et al., 2004; Druken et al., 2014; Strak and Schellart, 2018). There is a vertical component of these flow fields that can initiate decompression melting distal from the trench (e.g. Strak and Schellart 2018). Here we reassess these hypotheses in light of recent age determinations from Bustard and Fa'atiu seamounts within MBP.

The oldest Pliocene volcanic episode recorded in the MBP is from a 3.5 Ma lava flow at Bustard Seamount — a small shield volcano protruding out of the basin between Bayonnaise and Tuscarora Bank structures (Fig. 2; Price et al., 2022). This basinal shield volcano is modeled to have resided over 800 km from the Samoa hotspot and ~300 km north of the Tonga Trench at the time of eruption (Fig. 6**b**). Strak and Schellart (2018) proposed that subduction-induced mantle upwelling (SIMU) was responsible for the anomalously young volcanism in the WESAM region. The SIMU model argues the rapid rollback of the Pacific slab subducting beneath the eastward progressing Tonga Trench generates a toroidal mantle flow field (e.g. blue arrows Fig. 6**C**) that entrains thermochemically anomalous Samoa plume material north and westward, wherein the mantle then upwells and melts via decompression. Strak and Schellart (2018) argue the SIMU induced volcanism among the WESAM started at ca. 5 Ma and could have sourced volcanism starting at 4 Ma as far as 740 km west of the hotspot. This model effectively explains much of the more recent non-hotspot volcanism in the WESAM (e.g. <2 Ma; Fig. 6**C**). However, the typical modeled flow fields at 5 Ma (~5 cm/yr or 50 km/Ma; see Fig. 5 in Strak and Schellart, 2018) would still only transport plume material ~75 km to the N—NW over 1.5 Myrs. This transport rate is currently too slow to explain volcanism at Bustard, which resided >800 km from the hotspot at 3.5 Ma. Therefore, based on the current knowledge of mantle flow vectors in the region, it is unlikely that SIMU derived volcanism sourced Bustard Seamount.

Bustard Seamount resides within the basin NE of Bayonnaise, which was interpreted to represent a ~150°N trending normal fault that is consistent with an abundance of 100–150°N normal faults in the MBP region (Pelletier and Auzende, 1996). These faults may have been derived from plate stressors associated with subducting the Pacific plate beneath the Vitiaz Trench (e.g. Schellart et al. 2004, Martin 2013, Gill et al., 2022). Alternatively, the faults represent remnant scars of subduction-transform edge propagator faults that were generated from tearing the Pacific plate while the Tonga Trench advanced eastward (Hart et al., 2004; Govers and Wortel, 2005). Alacrity Seamount (Fig. 2) is broken into discrete ridges that trend in the orientation of the paleo Vitiaz Trenches, which shows the effect of lithospheric stress due to subduction and/or transform processes. Similar examples of heavy normal faulting and disaggregation of a seamount prior to subduction has been noted on trenches elsewhere, such as the Japan (Mogi and Nishizawa, 1980) and Tonga-Kermadec Trenches (Fryer and Smoot, 1985). Interestingly, these normal faults are not apparent east of the MBP region, where the seamounts were primarily constructed from Samoan hotspot volcanism between 11 and 0 Ma.

The timing that subduction ceased in the eastern Vitiaz (e.g. the lineament south of Alexa Bank and eastward) is unknown — assuming the trenches represent paleo-subduction zones (Pelletier and Auzende, 1996; Schellart et al., 2004; Martin, 2013) and not subduction-transform edge propagator fault scars (Hart et al., 2004; Govers and Wortel, 2005). The continuous nature of the Samoan age progressions imply that no subduction of the Samoa chain occurred east of Alexa. Provided this lack of subduction, it is highly unlikely that Rurutu-Arago derived seamounts in the 45–25 Ma timeframe (between Niulakita and Rose Atoll) were subducted either. Previous plate reconstructions infer that collision between the N Fiji basin and the MBP occurred between 12 and 10 Ma, and caused the localized subduction to cease (Schellart et al., 2004; Martin, 2013). In this scenario, subduction would have ceased while volcanism was active on Tuscarora Bank, Lafetoga and/or Combe (Fig. 2). This model would explain the lack of deformation observed on Samoan hotspot derived seamounts younger than 11 Ma. Alternatively, Gill et al. (2022) proposed a later time (8–4 Ma) for the cessation of eastern Vitiaz subduction based on the inference that Samoan Seamounts west of Alexa Bank were being actively subducted and controlling the chemistry of some Miocene Fijian volcanics. Regardless of exactly when the Vitiaz subduction ceased, deformation in the region is continuous until today (e.g. Pelletier and Auzende, 1996). The location of Bustard, within an extensional basin and the location of Fa'atiu, within a paleo-trough (Fig. 2), indicates that lithospheric deformation/extension is what most likely drove volcanism (e.g. Price et al. 2022). Thus, the fourth phase of volcanism in the MBP is tectonic driven and as such the OMS will likely continue to be slowly built up in the near geologic future.

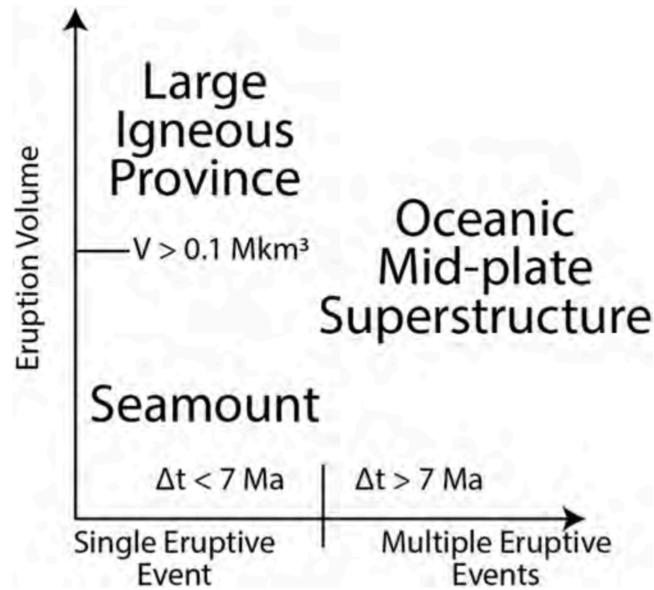

Fig. 7. A schematic classification of the difference between a seamount, LIP and OMS. The classification of a LIP here is based on Ernst (2014), where a LIP constitutes more than 0.1 Mkm^3 of primarily mafic volcanism emplaced within a limited timeframe (<5 Ma).

3.5. *Pacific oceanic mid-Plate superstructures*

The Pacific plate has a long and complex history of intraplate volcanism and therefore, OMS are bound to be constructed. The Pacific plate overrides the large low-shear velocity province (LLSVP) 'Jason' (e.g. Burke and Torsvik 2004, Boschi et al. 2007, Burke et al. 2008). Since multiple plumes are seismically imaged or modeled to arise from the edges and interior of Jason and produce hotspots on the Pacific plate (e.g. French and Romanowicz 2015, Koppers et al. 2021), there is likely to be multiple instances of volcanic structures drifting over multiple hotspots at different times. In addition, some intraplate volcanoes are constructed through volcanism associated with lithospheric extension (e.g. Castillo et al. 2010, O'Connor et al., 2015, Mather et al. 2020) or shear-driven upwelling (e.g. Conrad et al. 2011, Ballmer et al. 2013) that could later be reoccupied by hotspots or melts from a different tectonic driver.

Here we define an OMS as a volcanic structure, which could be an individual seamount structure or a single defined swell with superimposed volcanoes (e.g. Bayonnaise-Niulakita-Tuscarora in the eastern MBP) that has been built from multiple episodes of volcanism from different mantle reservoirs or processes (Fig. 7). We suggested a minimal measured time gap of 7 Ma for a structure to be classified as an OMS.

Table 1
Some examples of oceanic mid-plate superstructures on the pacific plate.

OMS	Ages (Ma)	Volcanic Driver	2nd Ages (Ma)	Volcanic Driver	Latitude	Longitude	Ref
Mokumanamana (Necker)	77.7	Unknown	12.1–9.9	Hawaii HS	23.5	−164.6	1, 2
Ogasawara Plateau - Michelson Ridge	104.3	Unknown HS	55	Unknown	25.8	144.0	3
Seth Seamount	139	Unknown	114	Unknown	23.8	148.8	4
Allison Guyot	111.2	Unknown HS	101	Unknown	18.5	−179.4	5
Bach Ridge	74	Euterpe HS	47–54	Extension	26.6	−159.0	6; 7
Rurutu	13.0–14.7	Macdonald HS	1.1–1.5	Rurutu-Arago HS	−22.5	−151.3	8, 9, 10, 11, 12
Aitutaki	9.53	Rurutu-Arago HS	1.4–1.9	Rarotonga HS	−18.9	−159.7	8, 9, 10, 11, 12
Central Line Island Ridge	76–70	Unknown	36; 59	Unknown	3.5	−159.1	13; 14

HS = hotspot; Unknown = multiple drivers offered or debated; 1 = Clague and Dalrymple 1975; 2 = Jicha et al. (2018); 3 = Hirano et al. (2021); 4 = Koppers et al. (2003); 5 = M and R, 1995; 6 = Pringle, 1992; 7 = O'Connor et al., O'Connor et al., 2015; 8 = Diraison 1991; 9 = Chauvel et al. (1997); 10 = Hanyu et al. (2013); 11 = Rose and Koppers (2019); 12 = Jackson et al. (2020); 13 = Schlanger et al. (1984); 14 = Davis et al. (2002).

This is due to the most common definition of oceanic LIP construction taking place within 5 Ma (Ernst, 2014), and the observation that volcanism on seamounts can be continuous for up to 7 Ma, especially when considering post-erosional volcanism (e.g. Pringle et al. 1991, Clague and Sherrod 2014). A key aspect of defining an OMS is that the volcanic episodes have distinct chronologic, chemical and/or geomorphic characteristics.

As mentioned earlier, hotspot volcanism has the potential to thin and weaken the lithosphere and thus provide pre-existing conduits that guide melt migration when the lithosphere passes over a second hotspot. There are already numerous examples of individual seamounts that were generated from multiple magmatic sources (Table 1). Mokumanamana (formerly Necker Island), on the Northwest Hawaiian Ridge has a late Cretaceous aged base with younger Miocene Hawaiian hotspot volcanism superimposed (Clague and Dalrymple, 1975). The Rurutu and Aitutaki islands in the Cook-Australs have clear evidence of being constructed from multiple hotspots (e.g. Rurutu-Arago, Macdonald, and/or Rarotonga hotspots; Chauvel et al., 1992; 1997; Rose and Koppers, 2019; Jackson et al., 2020). Thus, OMS are likely a common feature wherever multiple hotspots exist in relatively close proximity like the Pacific and African plates.

Currently, there are a few examples of large (>50,000 km^2) OMS that exist on the Pacific plate with two additional clear examples. The first large OMS is the western mid-Pacific Mountains, which contains a large bathymetric swell with numerous guyots and ridges superimposed. Although minimally sampled, the ages of the western mid-Pacific Mountain lava flows range from 128 – 88.5 Ma (Ozima et al., 1977; Winterer et al., 1993; Pringle and Dalrymple, 1993; M and R, 1995) indicating it represents an OMS and not a LIP as sometimes suggested (e.g. Madrigal et al. 2016, Fletcher et al. 2020). The second large volcanic swell is the Central Line Islands Ridge (Table 1), which is a clear example of an OMS. The ridge consists of a >250,000 km^2 bathymetric swell with numerous seamounts, rises, guyots and ridges superimposed. Current age determinations for the features range from 76 to 36 Ma (Schlanger et al., 1984; Davis et al., 2002) and its formation has been inferred to represent multiple pulses of regional extension (Davis et al., 2002) or from migrating over multiple hotspots (Pockalny et al., 2021). Numerous other poorly explored features, such as the Hess Rise and Tuamotus likely also represent OMS, however despite their prominent aerial extent (>300,000 km^2), they remain relatively unexplored.

Some features like the Ontong Java Plateau would be both a LIP and an OMS according to our proposed nomenclature. That is, the bulk of the Ontong Java Platea was built as a LIP from 117 to 108 Ma (e.g. Davidson et al. 2023) but superimposed are additional volcanic structures from other sources at ca. 90, 65, 44, 34 and 25–20 Ma (Shimizu et al., 2015; Tejada et al., 1996; Tejada et al., 2002; Tejada et al., 2004; Tejada et al., 2015; Hanyu et al., 2017), making the structure an OMS. Given the potential environmental consequences of a massive short-lived flood basalt event (e.g. Deccan and Siberian traps; Svensen et al., 2009; Schoene et al., 2015), understanding whether a large bathymetric feature represents an OMS or a LIP is vital for modeling deep-Earth to surface chemical exchange. OMS have the potential to tell complex regional mantle and tectonic stories and are worthy of future detailed sampling and geophysical exploration.

4. Conclusions

The MBP represents an OMS that was constructed in four separate pulses: (1) Early to Late Cretaceous Louisville Plume-derived volcanism likely sourced the underlying Robbie Ridge as well as Cretaceous aged seamounts in the region. (2) The MBP lithosphere overrode the Rurutu-Arago hotspot in the Eocene, generating oceanic islands and seamounts. (3) The lithosphere then overrode the Samoa hotspot in the Miocene, reoccupying some volcanic conduits and reconstructing new islands and seamounts. (4) The collision of the Vitiaz-Tonga trench system with the MBP, coupled with possible westward toroidal entrainment of Samoa plume material generated continuous low-volume volcanism from 3.5 Ma to recent.

CRediT authorship contribution statement

Kevin Konrad: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Andrea Balbas:** Writing – review & editing. **Valerie A. Finlayson:** Writing – review & editing. **Matthew G. Jackson:** Writing – review & editing. **Jasper G. Konter:** Writing – review & editing. **Anthony A.P. Koppers:** Writing – original draft. **Allison A. Price:** Writing – review & editing. **Bernhard Steinberger:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data is previously published.

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