Enigmatic Intraplate Volcanism:
A geochronological and geochemical approach for the Marie Byrd Seamounts (Antarctica) and the Christmas Island Seamount Province (Indian Ocean)

DISSERTATION

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Der Dekan

Hiermit erkläre ich, dass ich die vorliegende Doktorarbeit selbständig und ohne Zuhilfenahme unerlaubter Hilfsmittel erstellt habe. Weder diese noch eine ähnliche Arbeit wurde an einer anderen Hochschule im Rahmen eines Prüfungsverfahrens vorgelegt, veröffentlicht oder zur Veröffentlichung vorgelegt. Ferner versichere ich, dass die Arbeit unter Einhaltung der Regeln guter wissenschaftlicher Praxis der Deutschen Forschungsgemeinschaft entstanden ist.

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ABSTRACT:

In the world's oceans, the Hawaii-Emperor Seamounts, the Walvis Ridge and associated Seamount Province as well as the Ninetyeast Ridge and Louisville seamounts are well established examples for age progressive intraplate volcanism related to active upwelling of hot mantle in a stationary plume sensu Wilson (1963). Several seamounts in the Southwest Pacific or in the Northeast Indian Ocean, however, do not comply with the classical mantle plume theory. The South West Pacific, in particular the Amundsen and Bellingshausen Sea off the shelf of Marie Byrd Land (Westantarctica), is an area with several intraplate magmatic events that produced the Marie Byrd Seamounts, Peter I Island and the De Gerlache Seamounts at distinct time intervals, which cannot be explained by a stationary mantle plume. Bathymetric data of the Marie Byrd Seamounts in the Amundsen Sea reveals that the province consists of 8 large volcanic edifices and additional 30 minor volcanic structures (ridges). Further east, the De Gerlache Seamounts and the large active volcanic Island Peter I are situated in the Bellingshausen Sea.

One major goal of this study was to analyze bathymetric and volcanological data to provide an overview about the morphological characteristics of the Marie Byrd Seamounts and Peter I Island. With a detailed $^{40}Ar/^{39}Ar$ data set on mineral separates, the ages of the Marie Byrd Seamounts and the submarine base of Peter I Island were constrained in order to understand their temporal and spatial evolution. Further geochemical and petrological investigations aimed to characterize the geochemistry of the mantle sources and causes of melt generation that led to the formation of the Marie Byrd Seamounts, Peter I Island and De Gerlache Seamounts.

The first chapter of this study contains new $^{40}Ar/^{39}Ar$ ages of 65-56 Ma of the Marie Byrd Seamounts indicating that these intraplate volcanoes are not directly linked to the activity of a mantle plume as they do not align with spatially age progressive volcanism. The new ages from the eastern submarine flank of Peter I Island indicate that the submarine shield stage is about 1.5 million years older than subaerial volcanism based on earlier ages K-Ar ages of Prestvik and Duncan 1991.

In addition major and trace elements and Sr-Nd-Hf-Pb (double spike) isotope measurements were carried out for all 3 locations. These data reveal for the Marie Byrd Seamounts, the De Gerlache Seamount and Peter I Island that the lavas possess Ocean Island Basalts (OIB) signatures. The isotopic source flavour of the Marie Byrd Seamounts and De

Gerlache Seamounts contains a distinct μ ($\mu = {}^{238}U/{}^{204}Pb$) HIMU component mixed with a depleted, possibly Pacific-MORB, component similar to Late Cretaceous–Cenozoic volcanics of the Hikurangi Seamounts off New Zealand (Hoernle et al. 2010), intraplate volcanic fields in New Zealand (e.g. Tappenden 2003), sub-Antarctic islands (Panter et al. 2006) and the West Antarctic rift system (WARS) (e.g. Rocholl et al. 1995). These observations suggest a common mantle source for these volcanic provinces. On the contrary Peter I Island displays a strong enriched mantle (EM) affinity probably caused by shallow mantle recycling of a continental fragment. In the absence of a long-lived hotspot, reactivation of HIMU material, initially accreted to the base of continental lithosphere during the pre-rifting stage of Marie Byrd Land/Zealandia, is proposed to generate magmatism forming the Marie Byrd Seamounts. Continental insulation flow (King and Anderson 1989) is suggested as the likely mechanism to transfer the sub-continental accreted plume material into the shallow oceanic mantle. Crustal extension at the southern boundary of the Bellingshausen Plate (Wobbe et al. 2012) may have triggered adiabatic rise of the HIMU material from the base of Marie Byrd Land to form the Marie Byrd Seamounts. The De Gerlache Seamounts are most likely related to a preserved zone of lithospheric weakness underneath the De Gerlache Gravity Anomaly.

Aspects of the onland geology of Marie Byrd Land (MBL) and Ellsworth Land in West Antarctica are subject of the second chapter to explore the history of the magmatism prior to intraplate magmatism in the Amundsen and Bellingshausen Sea. The West Antarctica coastline provides a very oblique cross section across the Mesozoic-Paleozoic orogenic belts of Gondwana. Pankhurst et al. 1998 divided MBL into two geological provinces, Ross Province in the west and Amundsen Province in the east, with the boundary at c. 140° W. The Amundsen Province is a Permian to Mesozoic Gondwana margin with a batholithic belt. To get a better geochronological and geochemical understanding about this remote and thus largely unsampled part of Antarctica, samples from the coastline of the Pine Island Bay, extending from eastern MBL to western Ellsworth Land, were investigated in terms of geochronology and geochemistry. ${}^{40}Ar/{}^{39}Ar$ dating yielded closure temperatures of c. 147 to 98 Ma for dioritic and granitic plutonic rocks and an age range of c. 97 to 95 Ma for granitoid and trachyandesitic dikes. Their major and trace element compositions show an I-type subduction-related chemistry. Therefore, the new data reveal that Mesozoic subduction-related magmatism occurred from 147-95 Ma in the Pine Island Bay region which is consistent with previously published U-Pb and K–Ar ages of I-type granitoids (Mukasa & Dalziel 2000). The oldest estimated oceanic age of easternmost MBL is c. 90 Ma (Eagles et al. 2004a). This means that the eastern MBL region experienced a short rift phase of less than

5-7 m.y., before the subduction arc of the hinterland was converted to a Late Cretaceous passive margin. The change from subduction to rifting has been related to forces acting upon the plate margins by interaction of the palaeosubduction zone at the Zealandia/MBL margin of Gondwana with the Pacific-Phoenix spreading centre (e.g. Bradshaw 1989), the collision of the Hikurangi Plateau with Zealandia (e.g. Davy et al. 2008), and/or the activity of a mantle plume (Weaver et al. 1994, Storey et al. 1999, Hoernle et al. 2010). In contrast to Late Cretaceous mafic alkaline dikes of MBL studied by Storey et al. (1999), the Sr-Nd-Pb isotopic composition of the dikes investigated in this study does not reveal a HIMU component in the source of the melt but indicates an EM like mantle source. This could either reflect derivation from a metasomatized mantle wedge source (possibly by melts from subducted marine sediments), or contamination of mantle derived melts by continental crust during ascent and prolonged crustal residence.

The last chapter includes a major and trace element study of volcanics from another diffuse intraplate volcanic province in the northeastern Indian Ocean, the Christmas Island seamount province (CHRISP). This province extends in E-W direction and thus orthogonal to the NNE-direction of plate motion in the Wharton Basin, which provides clear indications that the seamount province cannot have formed over a stationary mantle plume (Wilson 1963). The purpose of this study was to use major and trace elements to elaborate whether the trace element composition of the CHRISP can be generated by shallow recycling of continental lithosphere at mid-ocean ridges following the model by Hoernle et al. (2011) which was based on radiogenic isotopes. Trace element data of the most mafic samples confirm that an enriched and a depleted endmember have contributed to the composition of the CHRISP. The enriched endmember, being most pronounced in the Christmas Island sub-province, is characterized by an increase in incompatible elements and LREE and thought to be related to lamproitic melts derived from subcontinental lithospheric mantle (SCLM). The depleted endmember is a MORB-like component, marked by depletion in incompatible elements. Mixing calculations indicate that the most primitive samples from Christmas Island can be generated by 25-30% lamproitic and 75-70% MORB melts. Despite the limited data set from unaltered mafic samples the trace element modeling suggest that the CHRISP volcanics can be generated by mixing of lamproitic and E-MORB melts and thus being consistent with the model of Hoernle et al. (2011).

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