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Cenozoic intraplate volcanism on New Zealand: Upwelling induced by lithospheric removal

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Abstract

Diffuse intraplate volcanism spanning the Cenozoic on the North, South, Chatham, Auckland, Campbell and Antipodes Islands of New Zealand has produced quartz tholeiitic to basanitic/nephelinitic (including their differentiates) monogenetic volcanic fields and large shield volcanoes. New $^{40}Ar/^{39}Ar$ ages, combined with published age data, show no correlations among age, location or composition of the volcanoes. Continuous volcanism in restricted areas over long time periods, and a lack of volcanic age progressions in the direction and at the rate of plate motion, are inconsistent with a plume origin for the intraplate volcanism. Although localized extension took place during some episodes of volcanic activity, the degree of extension does not correlate with erupted volumes or compositions. Major and trace element data suggest that the silica-poor volcanic rocks (primarily basanites) were derived through low degrees of partial melting at deeper depths than the more silica-rich volcanic rocks (alkali basalts and tholeiites) and that all melts were produced from ocean island basalt (OIB)-type sources, containing garnet pyroxenite or eclogite. The Sr–Nd–Pb isotope data indicate that the silica-poor rocks were derived from high time-integrated U/Pb (HIMU)-type sources and the silica-rich rocks from more enriched mantle (EM)-type sources, reflecting greater interaction with lithosphere modified by subduction beneath Gondwana. The first-order cause of melting is inferred to be decompression melting in the garnet stability field of upwelling asthenosphere, triggered by removal (detachment) of different parts of the subcontinental lithospheric keel throughout the Cenozoic. In some cases, large thicknesses of keel were removed and magmatism extended over many millions of years. Decompression melting beneath a thick craton generates melts that are likely to be similar to those from the base of the mid-ocean-ridge melting column. At mid-ocean ridges, however, these melts never reach the surface in their pure form due to the swamping effect of larger-degree melts formed at shallower depths. Different volcanic styles in part reflect the mode of removal, and size and shape of detached parts of the lithospheric keel. Removal of continental lithospheric mantle could be an important process for explaining the origin of diffuse igneous provinces on continental lithosphere.

Keywords: intraplate volcanism; continental diffuse igneous province; New Zealand; $^{40}Ar/^{39}Ar$ ages; geochemistry; lithospheric removal/detachment

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1. Introduction

Since the plate tectonic model achieved wide acceptance, intraplate volcanism has been primarily attributed to mantle plumes [1], which now are generally presumed to represent cylindrical regions of mantle upwelling (~100–300 km in diameter) from a thermal boundary layer such as the core/mantle boundary. The mantle plume model is, however, being increasingly questioned, leading to the global "Great Plume Debate" (e.g. http://www.mantleplumes.org). The major alternative to the plume model for intraplate volcanism in continental areas is decompression melting of upwelling shallow mantle that results from tectonic thinning of the lithosphere (e.g. [2]). Neither of these models, however, can adequately explain diffuse volcanism known from many continental areas globally.

New Zealand's South Island has been the site of numerous temporally and spatially dispersed episodes of intraplate volcanism throughout the Cenozoic (Fig. 1). This intraplate volcanism has produced: 1) scattered, low-volume alkalic dikes (e.g. Alpine Dikes) and monogenetic volcanic fields (e.g. Waipiata volcanics), 2) several cubic kilometers of tholeiitic volcanic rocks erupted from

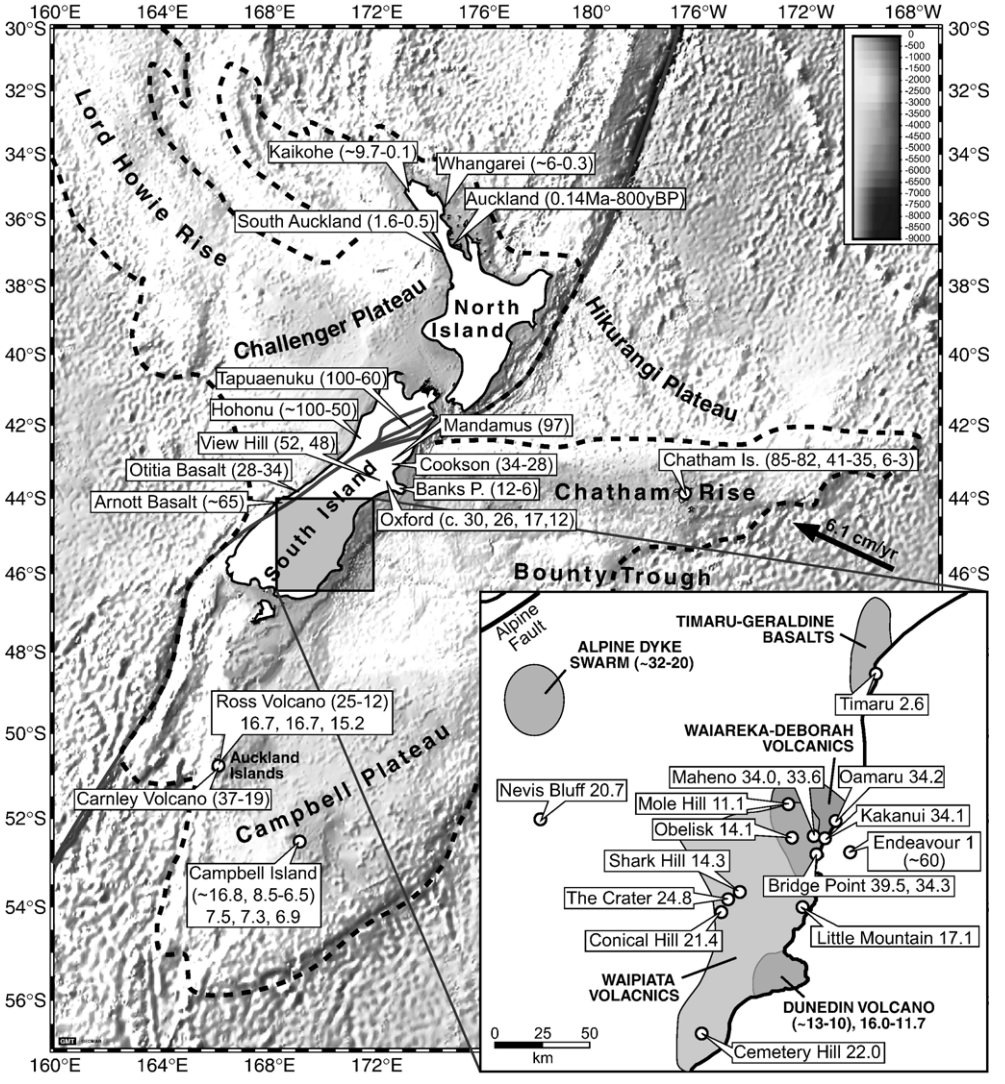

Fig. 1. Overview map of the Zealandia micro-continent, summarizing the published age data. Bathymetry is based on satellite altimetry and ship depth soundings [71]. Shading (see key in upper right hand corner) refers to water depth in meters. Inset: Blow-up map of Otago and southern Canterbury, South Island, showing the $^{40}Ar/^{39}Ar$ age data for intraplate volcanism from this study. Numbers beside the named localities give ages in Ma. Those without parentheses are Ar/Ar ages from this study (Table 1); those within parentheses are K/Ar and other dates from publications referred to in the text. Plate motion vector is from [43].