The Magmatic History of the Mt. Herbert Volcanic Group and the Akaroa Volcanic Complex, Banks Peninsula, New Zealand

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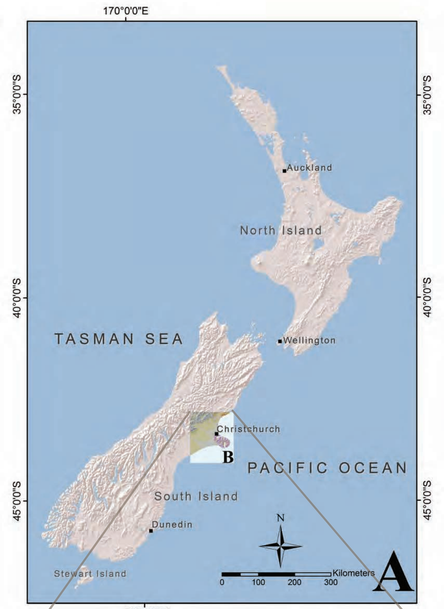
Abstract

Banks Peninsula, situated southeast of Christchurch, New Zealand, is comprised of a sequence of volcanic rocks erupted 5.8-12 million years ago. From oldest to youngest the rocks include: Lyttelton Volcanic Complex (VC), Mt. Herbert Volcanic Group (VG), Akaroa VC, and Diamond Harbour VG. Having erupted in the center of the Zealandia tectonic plate, this region represents an example of intraplate volcanism but the deep subsurface processes driving volcanism remain uncertain. 20 samples were collected from the co-erupted Mt. Herbert VG and Akaroa VC and analyzed for whole-rock geochemistry and mineral chemistry.

This new data were integrated with previously published geochemical data to produce a comprehensive database of 700 samples collected across the entire peninsula. Trends within the Mt. Herbert VG and the Akaroa VC suggest fractional crystallization is primarily responsible for the geochemical differences between the volcanic products observed. An evaluation of whole-rock geochemical trends for the four volcanic groups show patterns of magmatic evolution that are nearly identical for Mt. Herbert and Akaroa, but different for the older Lyttelton VC and the younger Diamond Harbour VG. From this comparison, it appears that three distinct magma generation events must be accounted for in any future model for the volcanic history of Banks Peninsula.

Trace element data from each of the four groups are consistent with an intraplate setting for volcanism. Uniformly LREE enriched patterns are consistent with partial melting of an enriched mantle source. The details of this mantle source remain unclear, as a progression of a pyroxenite-type source for the older Lyttelton VC to a peridotite-type source for the late stage Akaroa VC suggested by previous workers requires re-evaluation when a more comprehensive dataset is considered.

Introduction



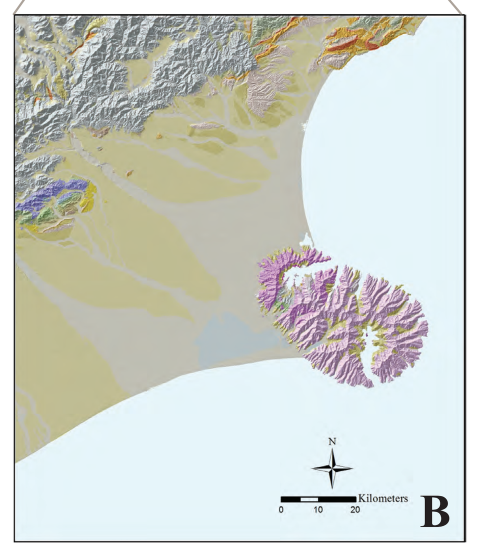


Figure 1: Maps of the study region. **A)** Banks Peninsula, the colored box which is enlagred in (B), juts into the Pacific Ocean just south of Christchurch on the South Island, ~150km from the Alpine Fault Zone. Adapted from the Christchurch QMAP geologic map quadrant produced by Forsyth, Barrell & Jongens (2008).

Situated adjacent to the east coast of the South Island of New Zealand, Banks Peninsula is a Miocene-Pliocene aged suite of volcanic rocks produced primarily in a period 12 - 5.8 million years ago of intraplate volcanism in the Zealandia tectonic plate (Fig A&B). The forces driving this volcanism are currently unclear, as no evidence for typical mechanisms for intraplate activity, such as mantle hotspotting, has been found. Three uncertainties exist in current literature which need to be resolved before a comprehensive model for the origin and evolution of volcanism at Banks Peninsula can be developed. These are:

1) the tectonic context of volcanism
2) how many magma generation events occurred to produce the units observed
3) the magma source material

This research addressed the latter two of these questions in a multi-component study involving:

1) The collection of a representative suite of samples from the heart of the peninsula and use them to generate all new geochemical and mineralogical data
2) The compilation of a comprehensive database of existing geochemical data from published authors for the entire peninsula
3) The use of this data to evaluate the evolution of the Mt. Herbert VG and Akaroa VC
4) The determination of the differences between the two groups
5) The comparison of these trends with other lava groups on the peninsula

Regional Geology

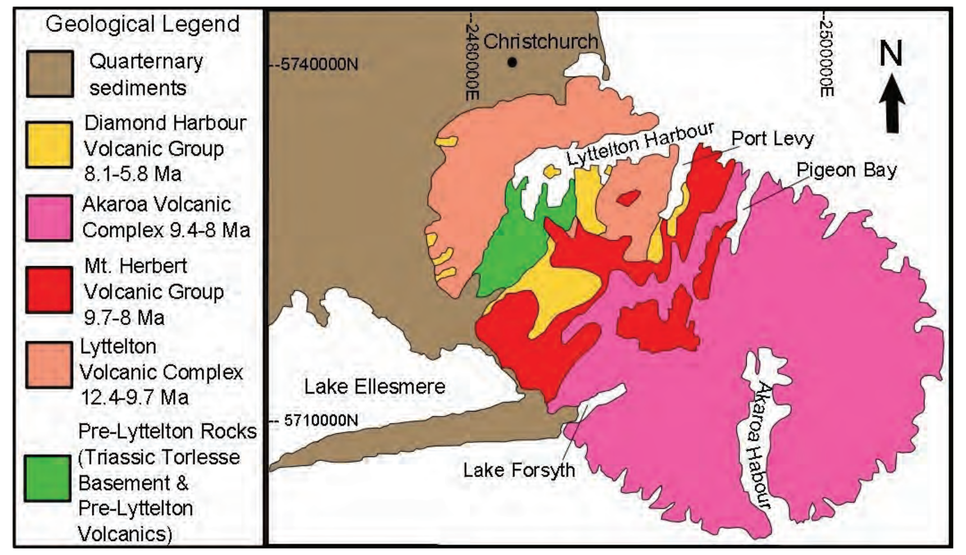


Figure 2: A simplified Geologic Map of Banks Peninsula, which shows the geographic distributions of the primary rock groups which are exposed at the surface. Adapted from Hampton (2010, Fig 6.1) with some adjustments made based on Sewell (1993, Fig 1), Forsyth et al. (2008), and Ring & Hampton (2012).

Study Area

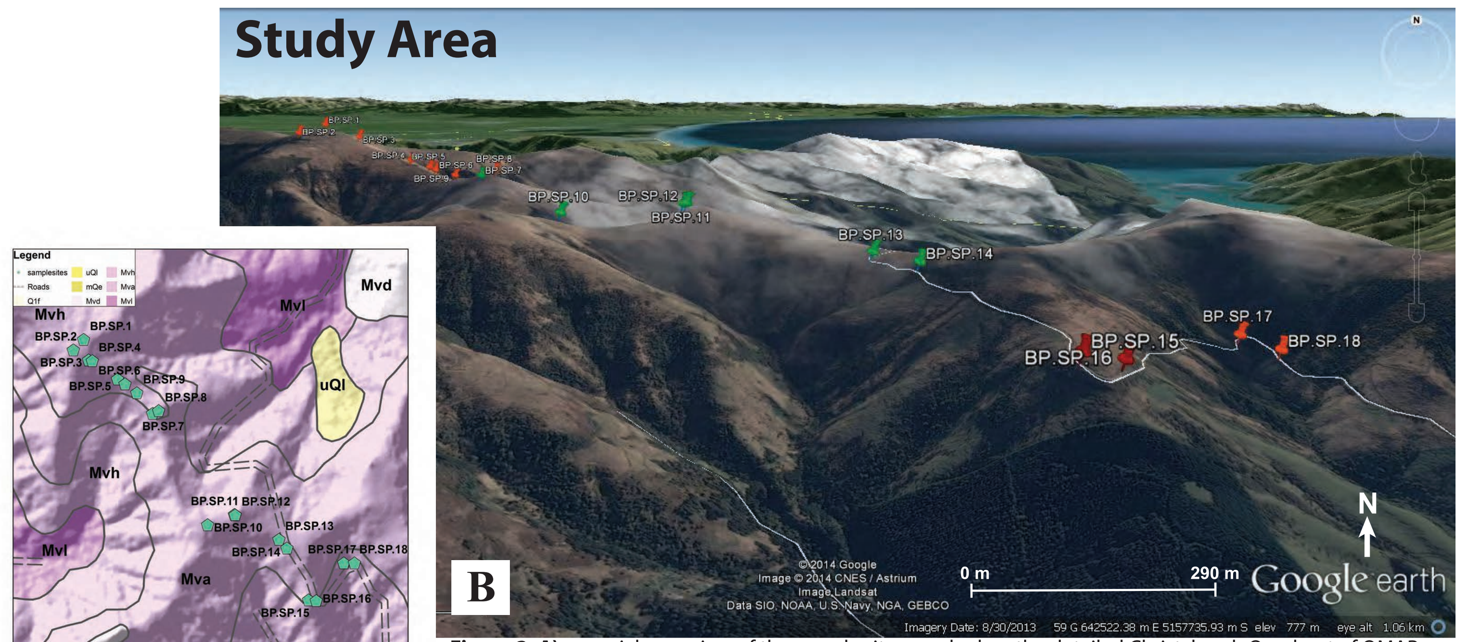
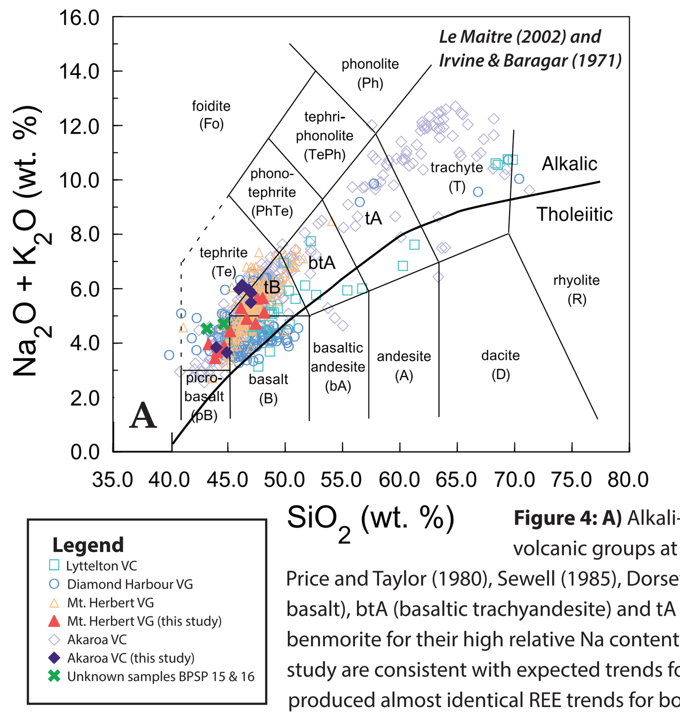


Figure 3: A) an aerial map view of the sample sites, marked on the detailed Christchurch Quadrant of QMAP geologic map superimposed on a hillshade to show topography. **B)** An oblique view looking north at the study area with pins to mark sampling locations., which span two geologic units and which progress topographically from Mt. Herbert peak to sea level. Orange marks Mt. Herbert samples, green marks Akaroa, and the red indicates uncertain samples taken from the boundary between the two. A goal of the study was to see if the whole-rock geochemistry of these two units was distinct enough that these two samples could be categorized as one or the other based on their chemistry. (See **Whole-Rock Chemistry**).

Whole-Rock Chemistry



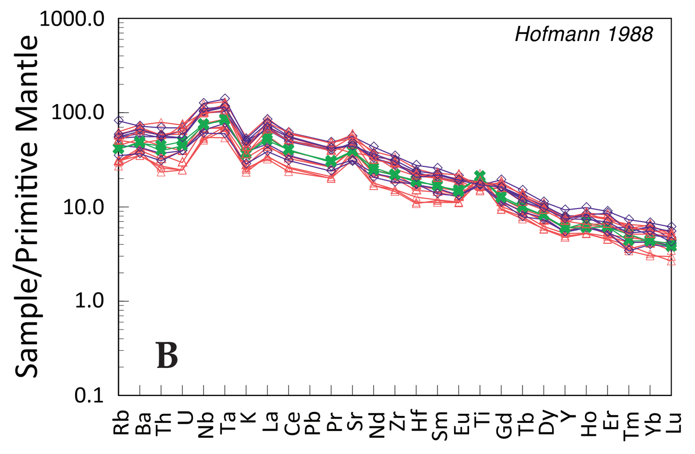
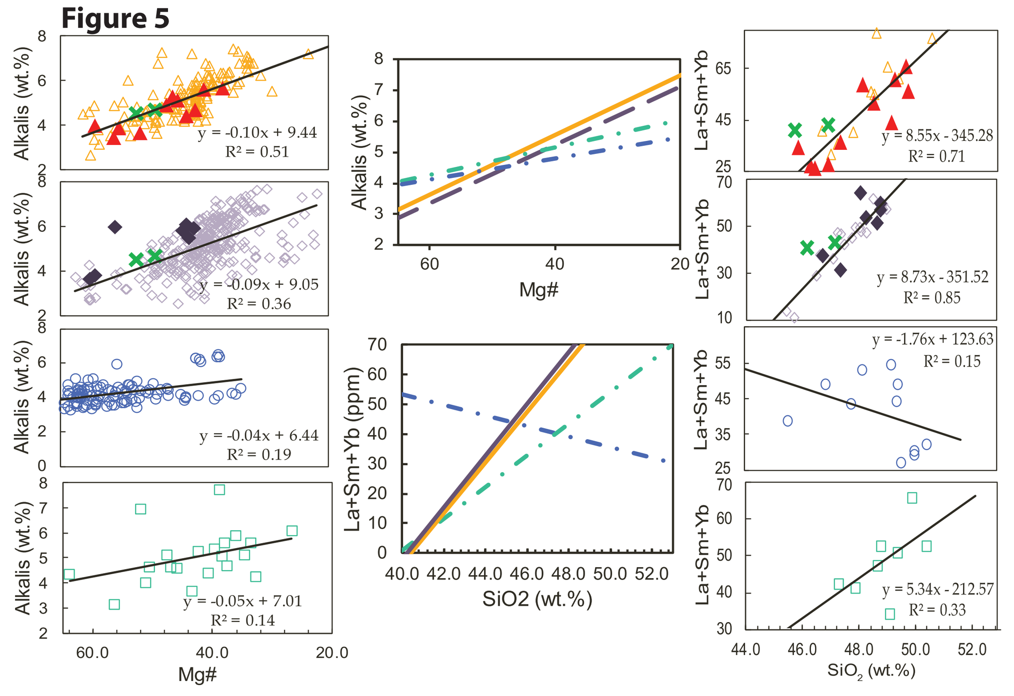


Figure 4: A) Alkali-Si discrimination diagram for a compilation of 700 data points across the four volcanic groups at Banks Peninsula. Data are from this study (opaque shapes) as well as from Price and Taylor (1980), Sewell (1985), Dorsey (1988), Hartung (2008), and Timm *et al.* (2009). Samples in the tB (trachy basalt), btA (basaltic trachyandesite) and tA (trachyandesite) fields can be further classified as hawaiite, mugearite, and benmorite for their high relative Na content (Na_2O-2.0>K_2O). **B)** Extended rare-earth element plots for samples from this study are consistent with expected trends for intraplate volcanics. With few exceptions, data from the rest of the database produced almost identical REE trends for both Akaroa VC and Mt. Herbert VG rocks.

Figure 5

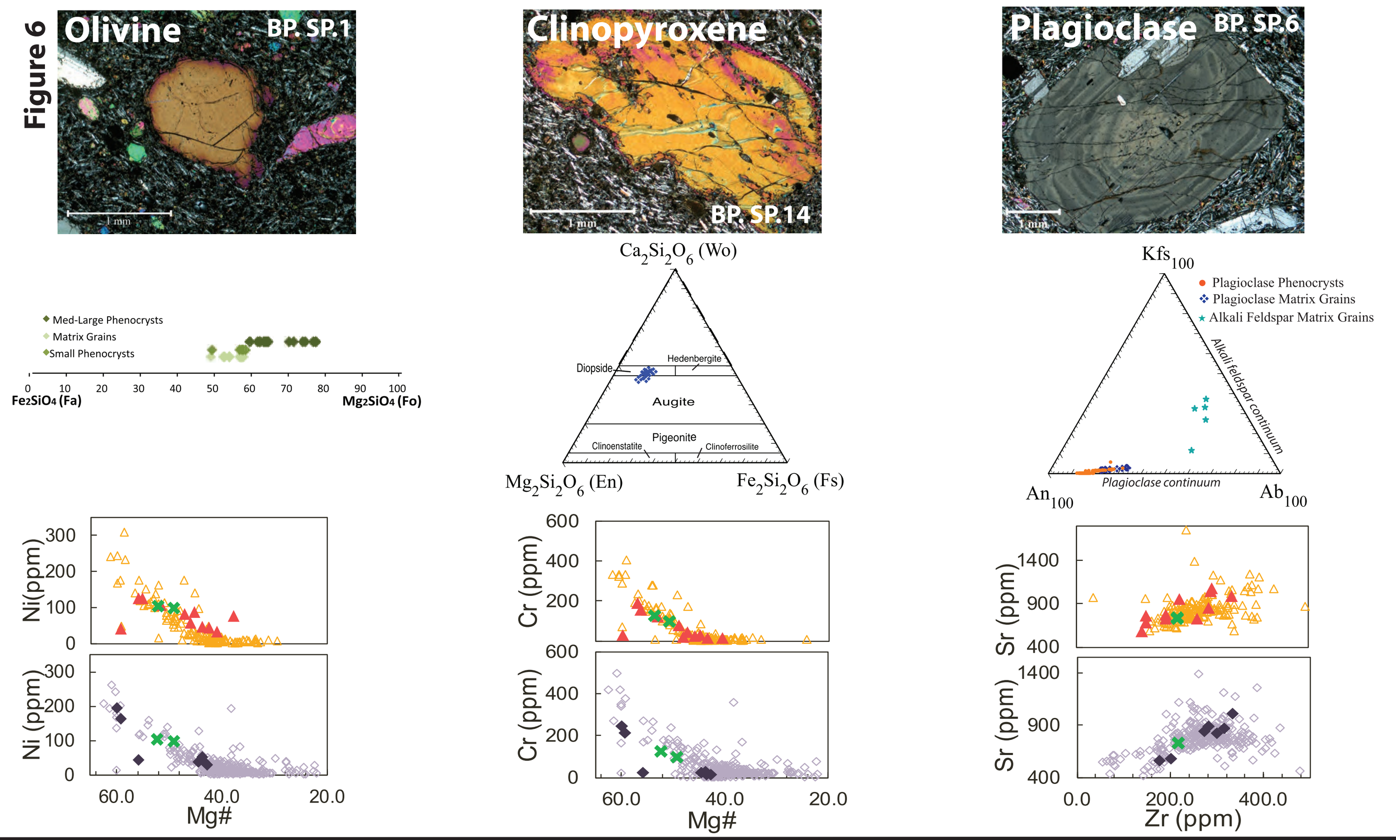


Mt. Herbert VG and Akaroa VC rocks show very similar trends. Lyttelton VC and Diamond Harbour VG vary more inconsistently, both relative to each other and relative to Akaroa and Mt. Herbert. Samples BPSP 15 &16 do not consistently favor either the Akaroa or the Mt. Herbert trends. Results suggest that three separate magma generation events occurred to produce, in order, the Lyttelton VC, the Mt. Herbert VG and Akaroa VC magmas, and the Diamond Harbour VG.

Mineral Chemistry

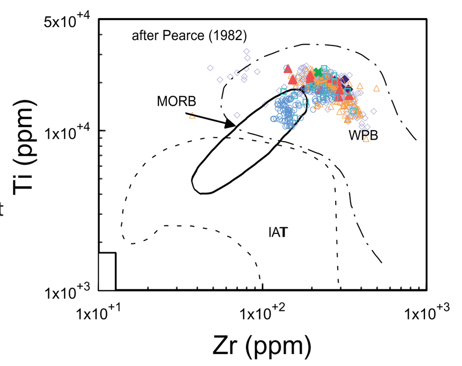
The abundance of minerals as phenocrysts and matrix grains varies by sample, but generally includes some combination of plagioclase, olivine, clinopyroxene, titanomagnetite and ilmenite, and rare occurrences of alkali feldspar as matrix grains. Mineral chemistries are typically more mafic in phenocrysts than in matrix grains and in phenocryst cores than in rims, suggesting fractionation accounts for much of the differences between whole-rock chemistries of individual samples within a unit group (Figure 6). Whole-rock trends in Ni and Cr are consistent with early crystallization of olivine and clinopyroxene, respectively, in mafic melts. Sr, a proxy for calcic plagioclase crystallization, does not give the same fractionation trend. Zoning patterns in plagioclase phenocrysts suggest plagioclase residence time was high and plagioclase grains were exposed to multiple mafic injections and/or migrated significantly in a compositionally zoned magma chamber prior to eruption.

Figure 6



Magmatic Origins

Figure 7: Magma-type discrimination diagram for tectonic origin. All basalts from Banks Peninsula qualify as Within Plate Basalts (WPB), though Diamond Harbour is distinct from the general trend of the others. Symbols carry over from legend in **Whole-Rock Chemistry**.



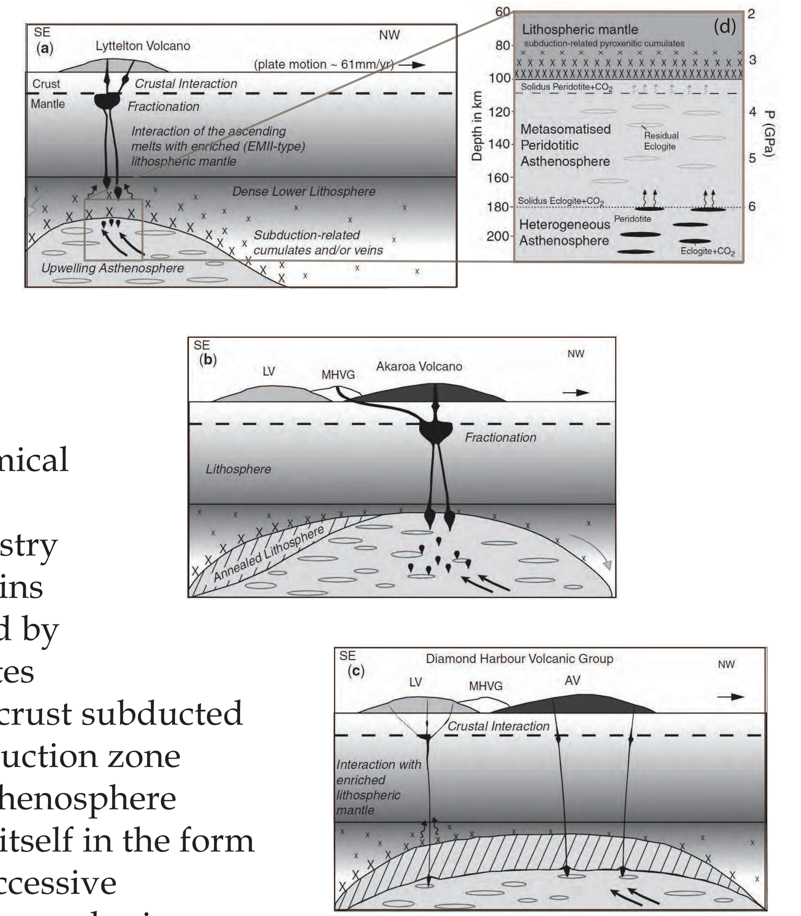


Figure 8: Schematic from Timm *et al.* (2009, Figs 12&13) of two delamination events resulting in volcanism at Banks Peninsula.

When a robust database is applied, geochemical signatures for all groups is consistent with intraplate volcanism (Figure 7). The geochemistry of the magma source material, however, remains ambiguous. The leading hypothesis, published by Timm *et al.* (2009: hardcopy on table), postulates that residual, hydrothermally altered oceanic crust subducted into the asthenosphere at the Gondwana subduction zone generated an instability at the lithosphere- asthenosphere boundary (Figure 8). This instability resolved itself in the form of two lithospheric detachment events and successive upwelling and decompression melting of asthenospheric material. Their model is consistent with this study's findings that three parent magmas generated the lavas extruded at Banks Peninsula (Figure 8a-c).

Implications

The conclusions of Timm *et al.* (2009) regarding on probable magma source chemistry (Figure 8d), which were based on analysis of 56 samples, become less certain when the same methods are applied to a dataset of 700 samples. The database compiled for this study contains ample data for the Akaroa and Mt. Herbert groups but more data are needed for the Lyttelton VC and the Diamond Harbour VG before a thorough model for magmatic evolution can be developed. Such analysis must also integrate the batch model of Hampton (2010) to account for the cyclic patterning in whole-rock chemistry observed for discrete sections of the stratigraphy. Additional isotopic data are necessary to precisely characterize melt source chemistry, which in turn would contribute to the devlopment of a comprehensive model for the origin and evolution of magmatism at Banks Peninsula. For now, this study provides a significant start to that overall goal.

Acknowledgements

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