Petrogenesis and source of lavas from seamounts in the Adare Basin, Western Ross Sea: Implications for the origin of Cenozoic magmatism in Antarctica

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Summary The Adare Basin Seamounts (ABS) consist of 100's of relatively small eruptive centers that are randomly distributed over an area of ~20,000 km^2 in the Adare Basin and on the adjacent continental shelf of the western Ross Sea, north Victoria Land (Fig. 1). Preliminary interpretations based on the geochemistry of dredged lavas indicate that the ABS are intimately related to intraplate alkaline volcanism in the west Antarctic rift system. Models for the origin and cause of volcanism in west Antarctica often disagree and are based almost exclusively on volcanic rocks erupted through continental lithosphere. The study of ABS lavas offers a more pristine view of sources for magma and differentiation processes unfettered by continental crust.

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Background

The fundamental cause of Cenozoic magmatism associated with the West Antarctic Rift System (WARS) is a matter of strong debate and has been explained by a miscellany of models. Volcanic lavas from the WARS have been dated to be as old as at least Oligocene (LeMasurier and Thomson, 1990) although a few could be as old as Eocene (Rocchi et al., 2002) and generally have large ratios of high-field strength elements (HFSE - e.g. Ta, Nb, Ti) to large ion lithophile elements (LILE - e.g. Rb, Ba, Sr). Neodymium, Sr and Pb isotopic data show them to resemble ocean island basalts (OIB) with HIMU (high time-integrated $^{238}U/^{204}Pb$ or high μ) affinity (e.g. Hart et al., 1997; Finn et al., 2005). The HIMU isotopic signature of OIB ($^{206}Pb/^{204}Pb$ ~22 and $^{87}Sr/^{86}Sr$ ~ 0.7028 and $^{3}He/^{4}He$ 5-7 R/Ra) is often attributed to oceanic lithosphere subducted and stored in the deep mantle and transported back to the surface via mantle plumes (e.g. Hofmann, 2003). In continental settings the debate on the origin of the OIB-HIMU signature centers on the relative contribution to magmas from a variety of sources including deep mantle plumes, convecting asthenosphere, metasomatised lithosphere and crust (e.g. Pilet et al., 2005).

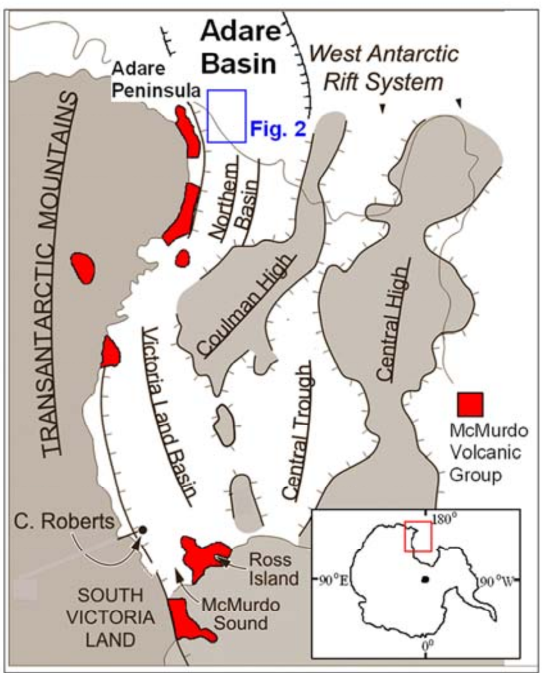

Figure 1. Map of western Ross Sea region, showing major basins, submarine highs and volcanism associated with the WARS. Modified from Harwood et al. (2002).

For simplicity, we classified the plethora of models for the source and origin of WARS magmatism into two end-member groups. One end-member group links the overall geochemical and tectonic features of WARS magmatism to the activity of a single large plume or of several smaller plumes (e.g. Kyle et al., 1991; Behrendt et al., 1992). Other investigators (e.g. Lanyon et al., 1994) argue for an older plume source that entered the upper mantle beneath Gondwana in the Mid- to late Cretaceous; such a plume activity also played a key role in Antarctic-New Zealand breakup and the opening of the Tasman Sea. Another variant of the plume model purports that the source of WARS and alkaline intraplate igneous rocks found throughout the SW Pacific that also have OIB-HIMU type character (e.g. Coombs et al., 1986) is coming from an ancient plume head that was fossilized in the uppermost mantle prior to Gondwana breakup (e.g., Rocholl et al., 1995; Panter et al., 2000).

The other end-member model calls upon alkaline magmatism without plume origin. For example, Fitzgerald et al. (1986) propose WARS magmatism to be due to passive rifting whereas Tessensohn and Wörner (1991) attribute its origin through active rifting. Rocchi et al. (2002; 2005) suggest that the upper mantle source for WARS alkaline magmas was metasomatically enriched during late Cretaceous extension and was melted in the Cenozoic due to reactivation of preexisting translithospheric faults (Rocchi et al., 2002; 2005) or warm asthenospheric upwelling into thin-spots at the base of the lithosphere (Finn et al., 2005). On the other hand, Finn et al. (2005) propose that Cenozoic volcanism is a response to the sudden detachment and sinking of subducted slabs into the lower mantle in the Eocene causing vertical and lateral flow that triggered melting of a previously metasomatised mantle lithosphere. Panter et al. (2006) suggest that the metasomatism and generation of the HIMU source for volcanism may be the result of a multi-stage process of enrichment and partial dehydration of upwardly convecting mantle wedge material and its long-term storage (>100 to ~500 m.y.) beneath the proto-Pacific margin of Gondwana.

Adare Basin

To assess these existing but often conflicting models on mantle geodynamics and control on magmatism in the WARS, we have collected lava samples from volcanic seamounts in the Adare Basin in the western Ross Sea, Northern Victoria Land (Fig. 1), which we collectively called the Adare Basin Seamounts (ABS). This pilot study was funded by NSF-OPP to test the feasibility of recovering in-situ ABS lava samples by dredging during the marine geophysical survey cruise (NBP0701) in Dec. 2006 – Jan. 2007 (S. Cande, Chief Scientist), and to evaluate the potential of ABS lavas for geochemistry and $^{40}Ar/^{39}Ar$ dating. The ABS have been previously identified through ocean bottom bathymetry (Davey, 2004; S. Jacobs and S. Cande, unpubl. Data). They consist of hundreds of relatively small volcanic centers that are randomly distributed over an area of ~20,000 km^2 in the Adare Basin and on the adjacent continental shelf, to the north of the Northern Basin and east-northeast of Cape Adare (Fig. 1). The cluster of volcanic seamounts directly east of Cape Adare, which we designate as southern ABS (Fig. 2), were erupted through a thick (~2000 m) pile of sediments that have been accumulating in the Adare Basin since its opening ~43 Ma (e,g. Cande et al., 2000; Stock and Cande, 2002). However, the sediments may be much younger considering the unexpectedly young age (Oligocene to mid-Miocene) of sediments discovered in Cape Roberts cores to the south in the Victoria Land Basin (Cape Roberts Science Team 1999; 2000). Their intrusive relationships with the sediments combined with their youthful morphology suggest that the southern ABS were formed contemporaneously with the other Cenozoic volcanoes in west Antarctica. The other group of seamounts located in the northern Adare Basin (Fig. 1) are situated directly on the oceanic crust. Thus they cannot be older than the northern Adare Basin crust, which is considered to be ~40 Ma. Moreover, some of the northern ABS were erupted within the rift basin of the Adare Trough, which ceased spreading ~26 Ma (e.g. Stock and Cande, 2002).

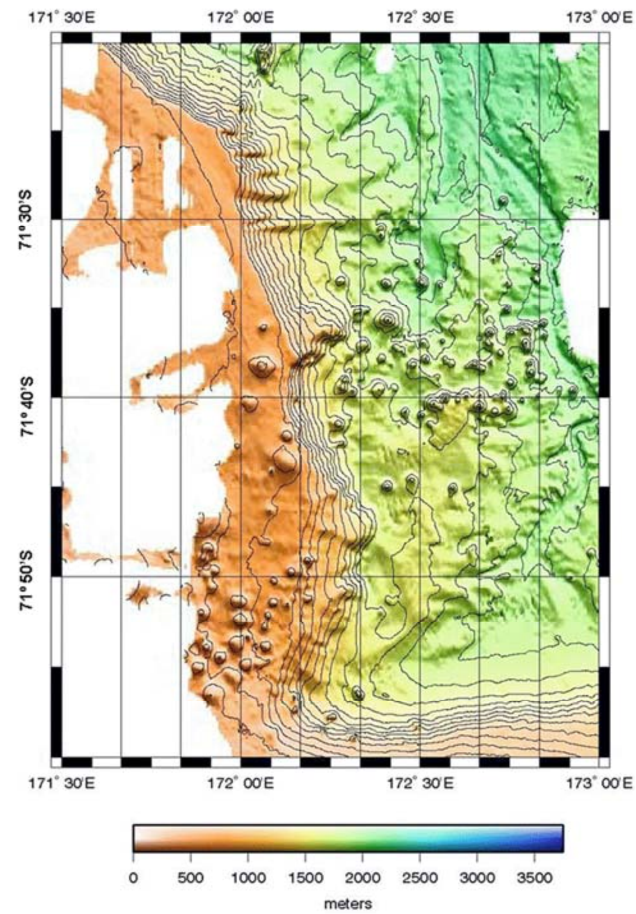

Figure 2. Topographic map of the seafloor east of Cape Adare (see Fig. 1), showing clusters of small conical seamounts on the continental shelf (lower left) and in the southern ABS >1500 m bsl (near the center). S. Jacobs and S. Cande (unpub. data).

Petrography-Geochemistry

Our dredging program is the first to successfully obtain in-situ lava samples from seamounts on the continental shelf (~600 to 400 m bsl) and within the deep ocean basin (~2000 to 1400 m bsl). We collected 48 lava samples from these seamounts and 10 samples from three separate areas of exposed oceanic crust in the western escarpment of the Adare Trough. Overall the lavas are fine-grained, porphyritic and vesicular with phenocrysts and microphenocrysts of olivine, pyroxene, feldspars and opaque oxides (e.g., magnetite) set, predominantly within a glassy groundmass. Radial intergrowths (variolitic texture) of plagioclase and/or pyroxene in the glassy groundmass of some lavas are fairly common. Other samples show minor alteration of olivine to iddingsite and vesicles are filled with calcite and clays (amygdaloidal texture). However, a significant proportion of the lavas contain relatively fresh glass or have microcrystalline groundmasses dominated by feldspar. Amphibole occurs as a groundmass phase in lava from a large, isolated seamount located in the central Adare Basin. Preliminary analysis of selected ABS lavas show that they

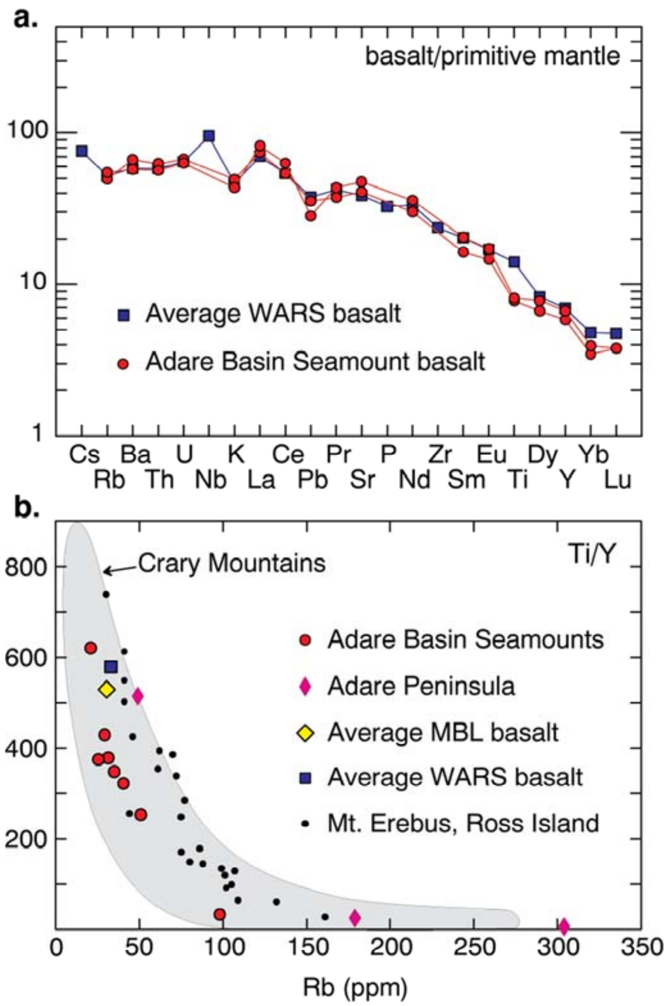

Figure 3. Geochemical plots comparing ABS and WARS lavas. **a**. basalts are compared on a primitive mantle normalized multi-element plot. **b**. Ti/Y versus Rb plot of ABS lavas compared to lavas from the Adare Peninsula and other WARS volcanoes.

range from mafic to felsic (MgO >6 to <1 wt.%; Ni >300 to <10 ppm), are alkaline (K_2O >1 to <5 wt.%; Ba >600 to <100 ppm), light rare earth element (LREE) enriched (La/Yb_N ~25), and seven of the eight samples analyzed for Sr isotopes have low $^{87}Sr/^{86}Sr$ ratios (≤0.7029). These preliminary findings suggest that volcanism within the Adare Basin is petrogenetically akin to continental volcanism in west Antarctica. The compositional signature of our oceanic basalts are similar to average basalt from the continental sector of the WARS (Fig. 3a). Specifically, ABS lavas can be compared to lavas from the Adare Peninsula (Fig. 3b), which is part of the Hallett volcanic province of northern Victoria Land and the closest land deposits (<40 km from the continental shelf seamounts). The Adare Peninsula samples are ~13 to ~1 m.y. old, are alkaline in composition (LeMasurier and Thomson, 1990) and have low $^{87}Sr/^{86}Sr$ (~0.7029) ratios (Hart and Kyle, 1994). Interestingly, the spectrum of compositions for the eight ABS samples analyzed thus far is nearly as broad as the range of lavas from large polygenetic volcanoes such as Mt. Erebus and the Crary Mountains in Marie Byrd Land (Fig. 3b).

Conclusions

The lithologic and compositional similarities between ABS and WARS lavas, as well as other continental intraplate lavas from the southwest Pacific that share OIB-HIMU type affinities, offer compelling support for an inherent connection between their mantle sources. Furthermore, the coupled extensional history of the oceanic and continental sectors in the northern Ross Sea, along with the broadly coincident age of the volcanic activity, strongly suggest that both continental and oceanic volcanism were triggered by the same fundamental mechanism. We believe that by virtue of the oceanic setting of the ABS, the geochemistry of our samples can provide better constraints on the petrogenesis and compositional signature of the mantle source and will offer new and valuable insight as to the underlying cause of alkaline magmatism in this region of the SW Pacific.

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