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Melting of a subduction-modified mantle source: A case study from the Archean Marda Volcanic Complex, central Yilgarn Craton, Western Australia

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Subduction processes on early earth are controversial, with some suggestions that tectonics did not operate until the earth cooled to a sufficient point around the Archean–Proterozoic boundary. One way of addressing this issue is to examine well-preserved successions of Archean supracrustal rocks. Here we discuss petrography, whole-rock chemical and isotopic data combined with zircon Hf isotopes from andesites, high-magnesium andesites (HMA), dacites, high-magnesium dacites (HMD), rhyolites and coeval felsic intrusive rocks of the c. 2730 Ma Marda Volcanic Complex (MVC) in the central Yilgarn Craton of Western Australia. We demonstrate that these rocks result from melting of a metasomatized mantle source, followed by fractional crystallization in a crustal magma chamber. Contamination of komatiite by Archean crust, to produce the Marda Volcanic Complex andesites, is not feasible, as most of these crustal sources are too radiogenic to act as viable contaminants. The $\varepsilon Nd_{(2730)}$ of MVC andesites can be produced by mixing 10% Narryer semi-pelite with komatiite, consistent with modelling using Hf isotopes, but to achieve the required trace element concentrations, the mixture needs to be melted by about 25%. The most likely scenario is the modification of a mantle wedge above a subducting plate, coeval with partial melting, producing volcanic rocks with subduction signatures and variable Mg, Cr and Ni contents. Subsequent fractionation of cognate phases can account for the chemistry of dacites and rhyolites.

1. Introduction

In Western Australia's Archean Yilgarn Craton, ultramafic, mafic and felsic volcanic rocks, and siliciclastic and chemically-precipitated sedimentary rocks (greenstones) are the focus of exploration for gold, nickel, base metals and iron ore (Angerer et al., 2012; Blewett et al., 2012; McCuaig et al., 2010). However, the combined effects of greenschist–amphibolite facies metamorphism, deformation, and surface weathering mean that the greenstones preserve little of their original mineralogy or texture. This, combined with the limited outcrop and structural dismemberment of the greenstone belts introduces significant difficulties in understanding not only stratigraphy but also depositional setting. Understanding the latter has implications for mineral exploration, in that particular styles of mineralization are related to certain tectonic settings (e.g., Kuroko-type volcanic-hosted massive sulfides and convergent margins, Sawkins (1990); Ni–Cu–PGE deposits and large igneous provinces, Arndt et al. (2003), Lightfoot and Hawkesworth (1997)). One of the few datasets that can preserve original information about greenstones and cast some light on tectonic setting is geochemistry, at both the rock and mineral scale.

At convergent margins, mafic to intermediate volcanic rocks have a 'subduction signature' characterised by depletion in high field strength elements (HFSE; e.g., Nb and Ta) relative to low field strength elements (LFSE; e.g., Rb, Sr, Ba, Th) and the light rare earth elements (LREE, La–Sm). The reasons for this chemical signature are much debated, but there is strong evidence that it results from partial melting of the mantle wedge which has been modified by an aqueous or silicate based fluid rich in LFSE and LREE derived from the downgoing slab (e.g., Defant et al., 1991; Gamble et al., 1999; McCulloch and Gamble, 1991; Price et al., 1999, 2005; Shimoda et al., 1998; Tatsumi, 2001; Tatsumi and Hanyu, 2003). As Archean successions rarely preserve independent evidence for subduction (e.g., accretionary prisms, patterns of seismic activity), caution must be exercised in translating this geochemical signature to older successions. Furthermore, rocks with andesite chemistry can be generated by other means (see summary of processes in Tatsumi et al., 2008), including fractional crystallization of mantle-derived basaltic magma, lower crustal anatexis of a crustal underplate, mixing of felsic and mafic magma (± crustal contamination), hydrous mantle melting, interaction of slab melts with mantle, and dehydration melting of subducted oceanic crust. Of these, only the last two require magma generation at a convergent margin, but this does not necessarily require the magma to be erupted at a subduction zone. In a discussion of

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Archean greenstones of the Pilbara Craton, Smithies and Champion (2000), Smithies (2002), and Smithies et al. (2004) argued that the chemistry of high-Mg diorite was best explained by melting of a mantle source modified by a slab melt, yet as these rocks were intruded into an anorogenic setting, they argued that source modification had taken place approximately 60 Ma before melting.

In this paper, we discuss the whole-rock major, trace, REE and Nd isotope chemistry, and also Hf isotopes in zircon, from a particularly well preserved succession of c. 2730 Ma volcanic and coeval intrusive rocks of the Marda Volcanic Complex (MVC) in the northern central part of the Archean Yilgarn Craton of Western Australia (Fig. 1). These greenstones are unusual in that that they are only weakly deformed and preserve igneous textures. We use compositional data to evaluate the petrogenesis of the MVC and to examine the tectonic setting in which they were deposited. Our findings have implications for other regions where melting of a subduction modified mantle source may have occurred and for understanding Archean petrogenetic processes.

2. Regional geology

The MVC is composed of subaerial andesitic, dacitic and rhyolitic volcanic flows with subordinate felsic fragmental rocks, cropping out over an area of approximately 700 km^2 in the Southern Cross Domain, Youanmi Terrane, of the central Yilgarn Craton of Western Australia (Fig. 1). The geology of the MVC was first described in

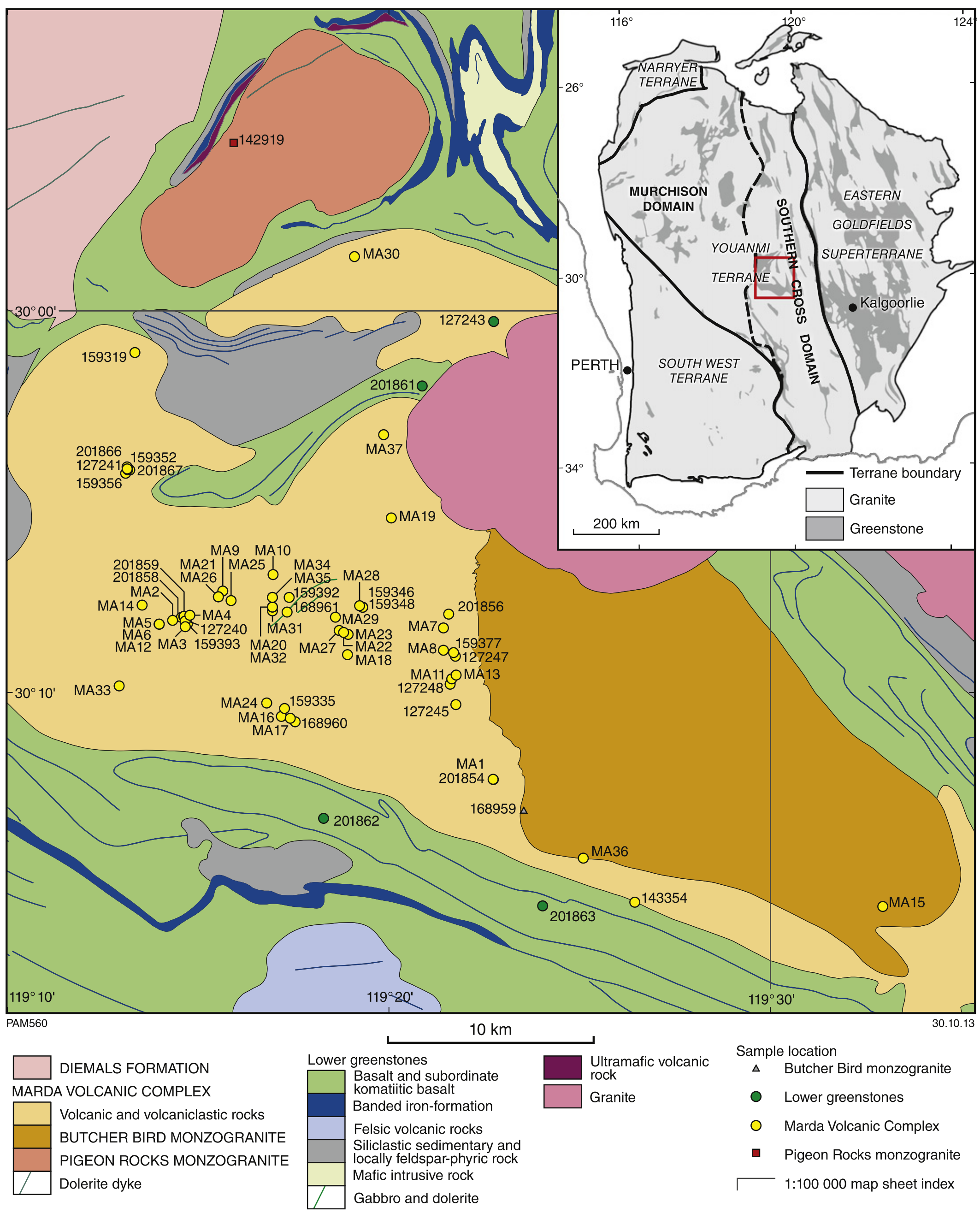

Fig. 1. Simplified bedrock geology of the Southern Cross Domain, showing the extent of the Marda Volcanic Complex (MVC) and sample locations (yellow circles) and samples from the lower greenstone (green circles). 127243 is a thin sliver of lower greenstone within the Marda succession. Also shown are samples from the Pigeon Rocks Monzogranite (142919) and the Butcher Bird Monzogranite (168959). Inset shows terrane and domain subdivision of the Yilgarn Craton (Cassidy et al., 2006).