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The Cosmos greenstone succession, Agnew-Wiluna greenstone belt, Yilgarn Craton, Western Australia: Geochemistry of an enriched Neoarchaean volcanic arc succession

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ABSTRACT

The geodynamic setting of the Neoarchaean Eastern Goldfields Superterrane (EGS) of the Yilgarn Craton is the subject of debate. Some authors propose plume models, while others advocate variants on a subduction accretion model for the origin of mineralised greenstone belt sequences. Felsic volcanism in the Kalgoorlie Terrane, the westernmost terrane of the EGS, is considered to have a tonalite-trondhjemite-granodiorite/dacite (TTG/D) geochemical affinity. The Cosmos greenstone succession, which lies in the Agnew-Wiluna greenstone belt (AWB) of the Kalgoorlie Terrane, contains several komatiite-hosted nickel sulphide deposits, the volcanic footwall to which consists of an intercalated succession of fragmental and coherent rocks ranging in composition from basaltic andesite to rhyolite. Light rare earth elements (LREEs) and large ion-lithophile elements (LILEs) are strongly enriched relative to high field strength elements (HFSEs) across all volcanic units, and the rocks display strong positive Pb and negative Nb anomalies. These geochemical characteristics resemble closely those of modern high-K calc-alkaline to shoshonite continental arc successions. Contrasting REE, LILE and HFSE concentrations, coupled with assimilation-fractional crystallisation (AFC) modelling, shows that the intercalated dacitic and andesitic volcanic rocks within the footwall succession are not co-genetic. Xenocrystic zircons within the felsic volcanic lithologies indicate that some assimilation of older continental crust contributed to the generation of the footwall volcanic sequence. The geochemical characteristics of the Cosmos volcanic succession indicate that parental melts were derived via partial melting of enriched peridotite that had been contaminated by subducted crustal material within the mantle wedge of a subduction zone. In contrast, two younger felsic porphyry intrusions, which cross-cut the volcanic succession, have a distinct TTG/D affinity. Therefore, these intrusions are considered to be generated via partial melting of a subducting slab and are related to local high-Ca granitoid intrusions. The Cosmos volcanic succession represents the first extrusive high-K calc-alkaline to shoshonitic volcanic arc sequence described in the Kalgoorlie Terrane and, coupled with age dating of the stratigraphy, is indicative of formation in a long-lived volcanic arc setting active from 2736 Ma to later than 2724 Ma. The composition and geochemical affinity of the volcanic footwall succession to the Cosmos komatiite-hosted nickel-sulphide deposits contrasts with the majority of felsic volcanic rocks within the AWB and also the wider Kalgoorlie Terrane, suggesting that the overall architecture of this region is more complex than is currently thought. Our conclusions not only have consequences for recent models of the tectonic evolution of the EGS but also contribute to the debate on the operation of plate tectonics during the late Archaean in general. The arc affinity of the Cosmos volcanic succession, containing abundant high-K calc-alkaline andesite lavas, provides further support for the operation of plate tectonics in the Neoarchaean.

1. Introduction

Identifying the geological processes responsible for the derivation of Archaean greenstone belt sequences, such as in the Canadian Superior Craton and the Australian Yilgarn Craton, is vital for determining the possible existence of plate tectonics during the Archaean (e.g., Barnes et al., 2012; Bédard et al., 2013; Czarnota et al., 2010; Wyman, 2013).

Abbreviations: AWB, Agnew-Wiluna greenstone belt; EGS, Eastern Goldfields Superterrane; TTG/D, tonalite–trondhjemite–granodiorite/dacite.

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The origin of greenstone belt sequences within the Eastern Goldfields Superterrane (EGS) of the Yilgarn Craton of Western Australia (Fig. 1), which are commonly associated with komatiite-hosted nickel sulphide deposits, has been debated for over 25 years. Workers generally support either a plume-dominated model (e.g., Barnes et al., 2012; Campbell and Hill, 1988; Fiorentini et al., 2012; Trofimovs et al., 2004) or variants on a subduction accretion model (e.g., Barley et al., 2008; Czarnota et al., 2010; Gee and Swager, 2008; Kositcin et al., 2008; Nelson, 1997, 1998). Recently, Barnes et al. (2012) proposed a mantle plume model based on the composition of basalts throughout the EGS, broadly along the lines of a plume model proposed by Campbell and Hill (1988). Such plume models largely preclude the possibility of arc development and subsequent terrane accretion within the EGS. In contrast, Czarnota et al. (2010) provided a holistic review of the tectonic history of the EGS, which built on the work of Barley et al. (2008), and favoured a para-autochthonous convergent margin model linking all terranes of the EGS within a westward dipping subduction zone.

Understanding the tectonic setting of mineralised greenstone belt sequences has important implications both for future exploration and for understanding the geodynamics of Archaean volcanism. Geochemical analysis of individual Archaean greenstone terranes to infer a likely tectonic setting is often challenging. Within a single terrane there are often dozens of greenstone belt sequences that are, to varying degrees, poorly exposed, deeply weathered, highly metamorphosed and strongly deformed. Here we present major, trace and rare earth element (REE) geochemical data for the Neoarchaean Cosmos volcanic sequence, which lies within the Agnew-Wiluna greenstone belt (AWB) in the north of the Kalgoorlie Terrane (Fig. 1) and contains several komatiite-hosted nickel sulphide ore deposits, in an attempt to resolve the relative contribution and interaction of fractional crystallisation, crustal assimilation and source composition in the formation of the Cosmos footwall volcanic succession. These data are also used here to determine the succession's likely tectonic setting and to demonstrate that melt generation processes and tectonic evolution can be resolved even in a relatively small greenstone sequence.

2. Regional geology

The EGS comprises the eastern part of the Yilgarn Craton and features linear, bimodal (mafic–ultramafic and felsic), volcanic 'greenstone belt' sequences, with minor clastic sedimentary sequences and banded iron formations. These are sandwiched between voluminous elongate granitoid plutons intruded between 2760 and 2620 Ma (Fig. 1). SHRIMP U-Pb zircon ages indicate a major peak in volcanism between 2720 and 2650 Ma (Fig. 1), with lesser peaks at 2950 Ma and 2810 Ma (Cassidy et al., 2006; Nelson, 1997, 1998).

The Cosmos mine is situated on the western edge of the Agnew-Wiluna greenstone belt, on the north-western edge of the Kalgoorlie Terrane, which forms the westernmost terrane of the EGS. The AWB contains some of the world's most economically significant nickel sulphide deposits including Mount Keith, Perseverance and Yakabindie (Fig. 1). Mineralised ultramafic successions within the Kalgoorlie Terrane have a modal emplacement age of ~2707 Ma (Kositcin et al., 2008) and are commonly associated and intercalated with felsic and intermediate volcanic sequences. Examples include Black Swan (Hill et al., 2004), Perseverance (Barnes et al., 1988; Trofimovs et al., 2003), Boorara (Trofimovs et al., 2004) and Mount Keith (Fiorentini et al., 2012; Hill et al., 1995; Rosengren et al., 2008). Dacite is, volumetrically, the dominant volcanic rock type within the AWB, although lithologies range from

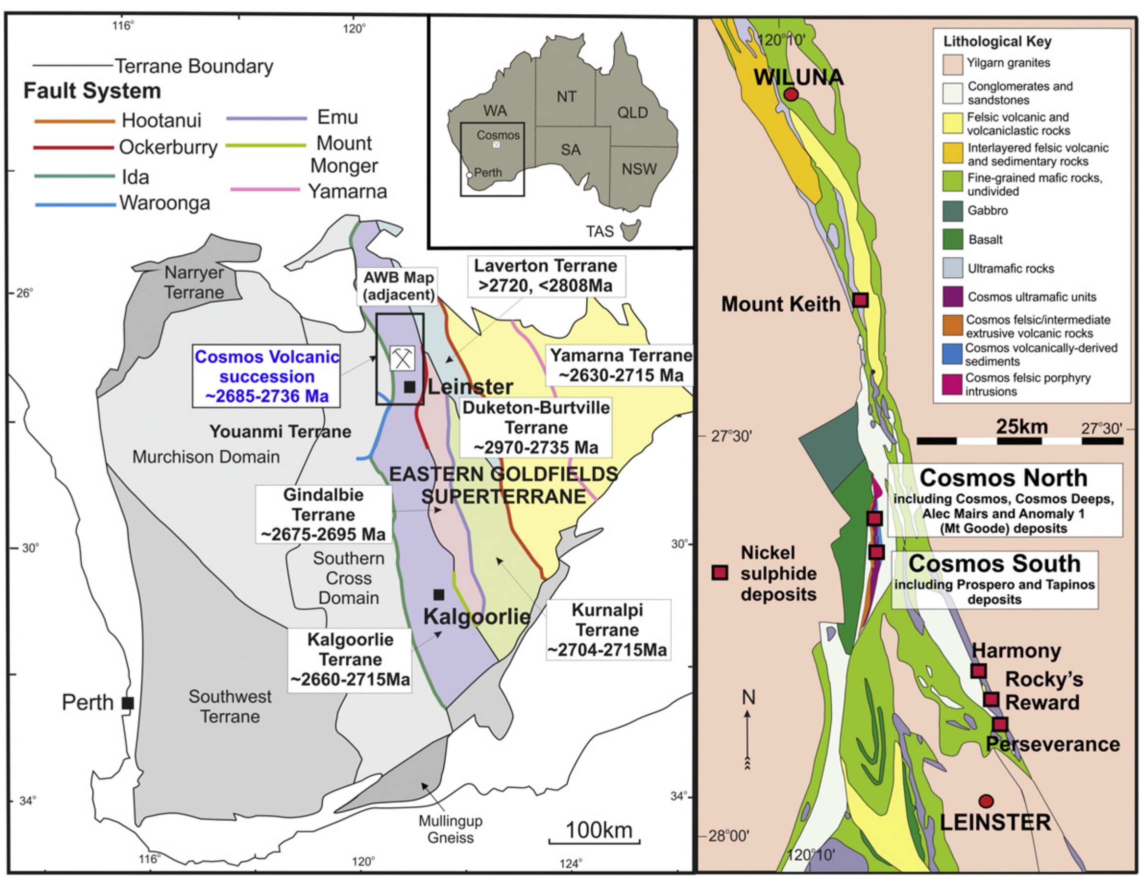

Fig. 1. Location maps of the Cosmos mine site within the AWB and its position within the EGS of the Yilgarn Craton, highlighting terrane boundaries and the approximate ages of the different terranes (modified after Cassidy et al., 2006; de Joux et al., 2013). U-Pb ages from Kositcin et al. (2008) and Pawley et al. (2012).