Gondwana Research 19 (2011) 686–705

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

Lead isotope systematics of ore systems of the Macquarie Arc — Implications for arc substrate

David B. Forster [a,*], Graham R. Carr [b], Peter M. Downes [a]

[a] Geological Survey of New South Wales, Industry and Investment, New South Wales, 516 High St Maitland, NSW, 2320, Australia
[b] Commonwealth Scientific Industrial Research Organisation, Earth Science and Resource Engineering, Sydney, CSIRO Riverside Corporate Park, 11 Julius Ave, North Ryde, NSW 2113, Australia

ARTICLE INFO

Article history:
Received 14 May 2010
Received in revised form 12 November 2010
Accepted 13 November 2010
Available online 4 December 2010

Keywords:
Ore geology
Pb isotope
Macquarie Arc
Substrate

ABSTRACT

The Macquarie Arc of New South Wales hosts several major Au and Cu deposits. We present new Pb isotope results for Cadia, the Copper Hill, Little Copper Hill and Cowal deposits, along with data from the CSIRO database. The results generally plot close to established mantle growth curves and are similar to oceanic basalts. Data for individual deposits mostly have Pb model ages consistent with independent age constraints on mineralization. Intrusions associated with the Early Silurian mineralization at Cadia and Goonumbla have narrow and distinct Pb isotope signatures that we interpret to be the result of partial melting of already LILE-enriched mantle-like sources. The data suggest that deposits of the Macquarie Arc derived Pb from one or more long-lived mantle-like Pb isotope reservoirs without significant contributions of crustal Pb prior to the Benambran Orogeny. Data for the Copper Hill deposits includes unradiogenic, possibly old Pb and supports previous workers who suggested that old MORB-like basalts may occur at depth in the area. The Peak Hill deposit has the most unradiogenic signature and has the lowest $^{208}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$. These signatures closely match Cambrian MORB-like basalts in the Koonenberry Belt and are unlike Cambrian mafic rocks in Victoria. Similar rocks could form part of the substrate to other parts of the Macquarie Arc.

1. Introduction

The Ordovician to Early Silurian Macquarie Arc of eastern Australia is host to a number of large to world-class Au and Cu deposits. These include the world-class Cadia Cu–Au system (Cadia Hill, Cadia East, Cadia Quarry, Ridgeway, Big Cadia, and Little Cadia) as well as a number of large deposits such as the Goonumbla Cu–Au system, the Endeavour (E) 22, 26, 27, 28, 31 N and 48 porphyry deposits together with the E6, 7 and 44 skarns, Copper Hill and Cargo (Fig. 1a,b). Other major deposits associated with the Macquarie Arc include the Cowal system that includes the large structurally-controlled Endeavour (E) 42 Au deposit, the smaller E41 and E46 deposits — as well as the Gidginbung and Peak Hill high sulfidation epithermal systems. The geology and significance of all these deposits have been summarized by Cooke et al. (2007).

The petrochemisty and tectonics of the Macquarie Arc are poorly understood compared with other arc-related terrains (Blevin, 2002; Glen et al., 2007a; and Meffre et al., 2007). The present understanding of the tectonic setting of the Macquarie Arc is discussed by other authors in this issue (see Glen et al., 2011). In summary, the Macquarie Arc consists of four belts of volcanic-dominated rocks that range in age from Cambrian to the Early Silurian. Initially, several authors, including Scheibner (1987) and Packham (1987) suggested that these volcanic rocks formed in an intra-oceanic arc setting related to west-dipping subduction. Following this, Wyborn (1992) proposed that the volcanism was related to rifting, heating and possibly foundering of the lithospheric mantle — based largely on the "overwhelmingly shoshonitic" geochemical affinity of the rocks. More recently, Blevin and Morrison (1997); Blevin (1998) and Glen et al. (1998) have emphasized the overall calc-alkaline character of the magmatism and again supported a contemporaneous intra-oceanic island arc setting. In addition, Blevin (2002) demonstrated that intrusions at Goonumbla and Copper Hill are largely of K-enriched calc-alkaline affinity and that in some cases the source rocks likely include low-K mafic rocks or basement.

Crawford et al. (2007a,b,c) identified four major episodes of magmatism (Phases 1–4) resulting in the emplacement of porphyries and related Cu–Au mineralization in the Macquarie Arc, based on geochronological, stratigraphic and geochemical evidence. They suggested that multiple switches and intermittent cessation of subduction occurred during the Ordovician, resulting in episodic calc-alkaline and high-K calc-alkaline magmatism in Phases 1–3. Phase 3 reflects a change from high-K calc-alkaline to calc-alkaline magmatism. The arc then collided with quartz-rich turbiditic sedimentary rocks including the Adaminaby Group and Wagga Group along the paleo eastern margin of the Gondwana craton.

* Corresponding author. Tel.: +61 2 4931 6685; fax: +61 2 4931 6726.
E-mail addresses: david.forster@industry.nsw.gov.au (D.B. Forster), Graham.Carr@csiro.au (G.R. Carr), peter.downes@industry.nsw.gov.au (P.M. Downes).

1342-937X/$ – see front matter. Crown Copyright © 2010 Published by Elsevier B.V. on behalf of International Association for Gondwana Research. All rights reserved.
doi:10.1016/j.gr.2010.11.010

Volumetrically small Phase 4 intrusions were then emplaced into thickening crust during the latest Ordovician to earliest Silurian Benambran Orogenies (Glen, 2005; Glen et al., 2007a,b,d, 2011).

The nature of the substrate to the Macquarie Arc is conjectural; with a number of models having been proposed. Based on geochemical grounds, Wyborn (1992) suggested that the basement to the arc included Precambrian continental rocks. Alternatively, Glen et al. (1998); Glen et al. (2003) and Glen et al. (2007c) suggested that this basement included Cambrian oceanic crust (see also Direen et al., 2001). Glen et al. (2007d) proposed a further model, based on the interpretation of seismic reflection data and structural studies, suggesting that Ordovician volcanic rocks may structurally underlie the oldest identified unit — the Nelungaloo Volcanics (484.3 ± 2.9 Ma — Pb SHRIMP dating of zircons, Butera et al., 2001) in the Parkes district of the Junee–Narromine Volcanic Belt.

The geochemistry of the oldest rocks associated with the arc has been used by a number of authors to constrain the nature of the basement. Crawford et al. (2007b) noted that volcanic rocks of the Mitchell Formation, the oldest recognized unit in the Molong Volcanic

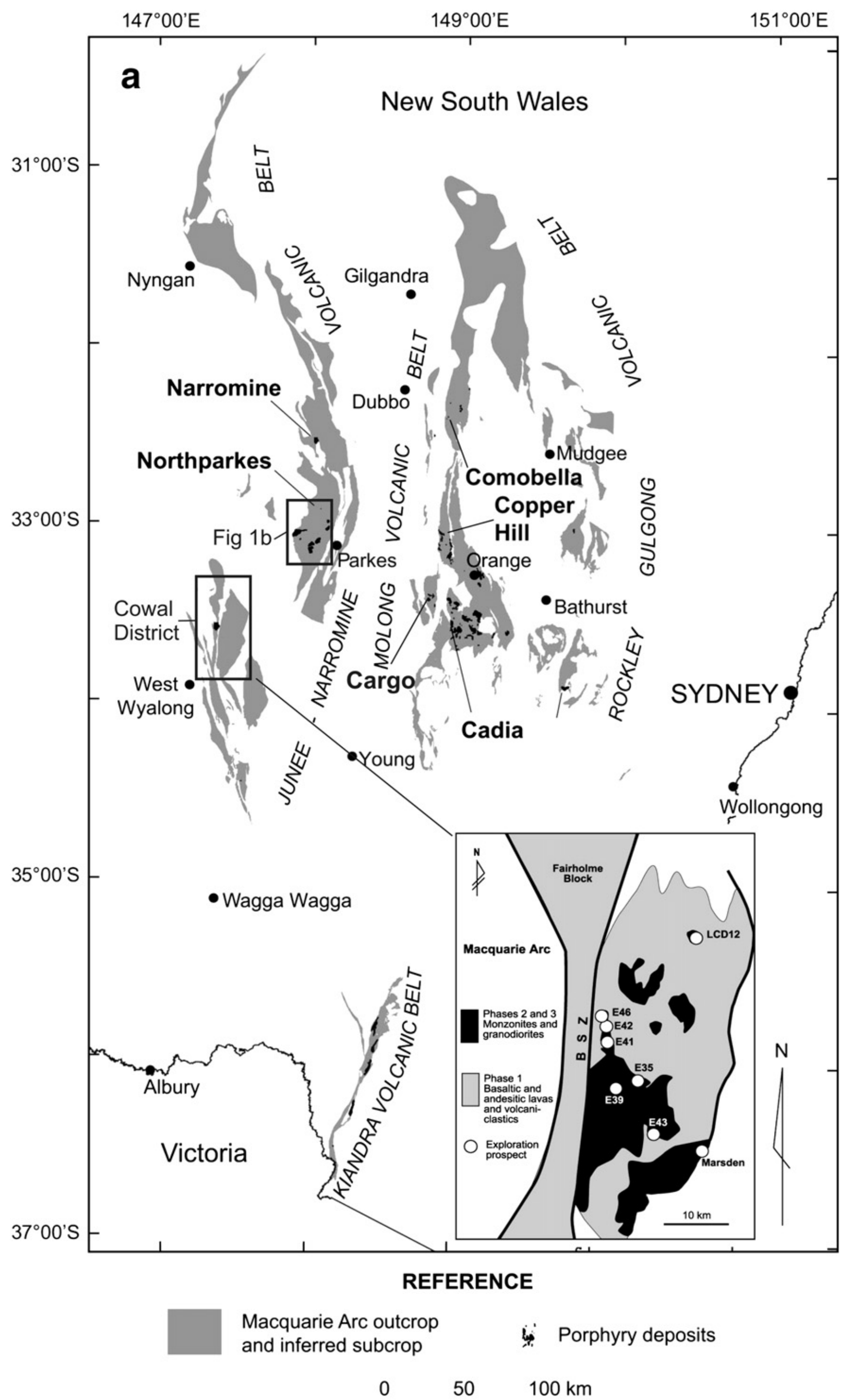

Fig. 1. a. Modified after Glen et al. (2007b) showing mapped and interpreted outcrop and subcrop of the Macquarie Arc superimposed data for deposits discussed in this study. Inset map of the Cowal district modified after Crawford et al. (2007c). b. Geological map of the Goonumbla district modified after Simpson et al. (2007) showing the location of porphyry and skarn deposits as well as fossil localities with stratigraphic ages.