Geodynamic controls on giant metallogenic provinces: Insights from gold provinces in southeast Australia

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Abstract. The geodynamic processes that control large-scale accumulations of ore are poorly understood. It has commonly been suggested that massive ore deposits are generated through a combination of factors in the Earth's system. In the Lachlan Fold Belt of southeastern Australia, world-class orogenic gold and porphyry gold-copper deposits formed simultaneously at ~440 Ma in distinct tectonic settings. The driving mechanism that controlled the extraordinary temporal coincidence of these deposits remains largely unexplained. We propose that the interplay of a mega-subduction system and mantle processes could explain the generation of the giant ~440 Ma gold deposits and related metallogenic, tectonic, magmatic and sedimentary events elsewhere in Australia.

Keywords. Metallogeny, giant ore deposits, 440 Ma, Gondwana, mega-subduction, mantle upwelling

1 Introduction

The Lachlan Fold Belt in southeastern Australia is host to a variety of mineral deposit types, and is internationally recognized as being an area of extraordinary gold endowment (e.g. Bierlein et al. 2002). A disproportionally large number of mineralisation ages for gold deposits in the Lachlan Fold Belt concentrate around 440 Ma (e.g. Perkins et al. 1995; Foster et al. 1998). These include the world-class lode-gold deposits at Bendigo, Stawell and Ballarat, and the porphyry copper-gold deposits at Cadia and Northparkes. Although these deposits reflect distinct mineralisation styles that formed in different tectonic settings (e.g. Gray et al. 2002), their similar formation ages record an extraordinary coincidence for which the driving mechanism remains enigmatic. Similarly, the first-order controls on large ore accumulations formed throughout Earth history remain a matter of debate. To gain insight in what processes control the coincident deposition of world-class ore deposits in distinct tectonic settings, we focus on the ~440 Ma event in Australia.

Throughout most of the Palaeozoic, Australia was situated on the margin of Gondwana inboard of a giant subduction system that essentially surrounded the supercontinent (Fig. 1). We propose that changes of subduction zone dynamics, for instance slab break-off, along continental margins are controlling factors for the generation of large ore deposits. In a supercontinent - mega-subduction zone setting, break-off of a portion of the subducting slab could account for the formation of extraordinary large ore deposits.

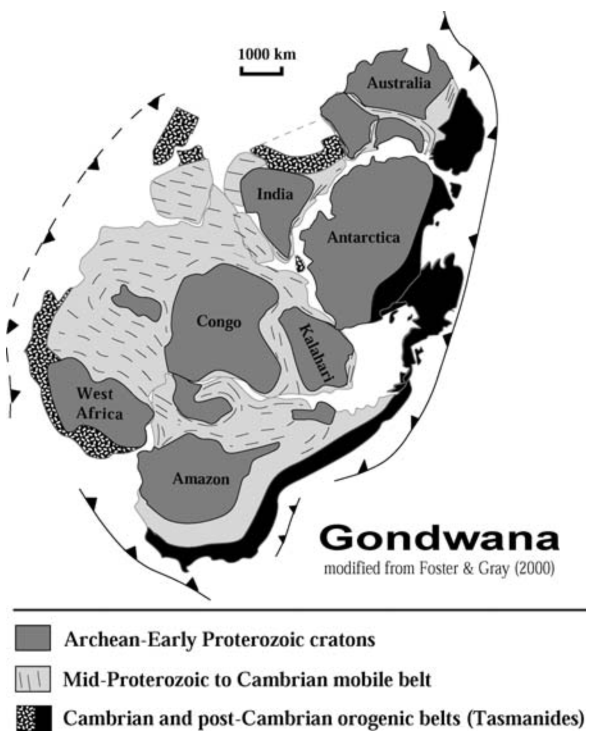

Figure 1: Gondwana surrounded by a mega-subduction zone around the Ordovician – Silurian boundary. Active subduction occurred on the margin of the Australian craton (top-right), where the Tasman Fold Belt System (or Tasmanides) was formed

Table 1: Summary of ~440 Ma gold deposits in the Lachlan Fold Belt based on $^{40}Ar/^{39}Ar$ geochronology

Deposit	Style	Tonnage	Age (Ma)	Reference
Ballarat East	or	67.9	455 ± 2	Foster et al. (1998)
			~440 Ma	Bierlein et al. (2001)
Bendigo	or	693.2	439 ± 2	Foster et al. (1998)
			442 ± 4	Bierlein et al. (2001)
Browns Creek	sk	28.5	425 ± 4.5	Ewers et al. (2002)
Cadia	por	259.6	440 ± 3	Perkins et al. (1995)
Copper Hill	por	16.8	447 ± 5	Ewers et al. (2002)
Fosterville	or	>4	381 ± 2	Bierlein et al. (2001)
Gidginbung	por		461.5 ± 4.7	Perkins et al. (1995)
Glendale	por		439.3 ± 2	Perkins et al. (1995)
Goonumbla	por		440 ± 1.1	Perkins et al. (1995)
Lake Cowal	por	99.6	439.6 ± 1.0	Perkins et al. (1995)
North Parkes	por	1.4	439 ± 1.1	Perkins et al. (1995)
Sheahan-Grants	sk		440	Ewers et al. (2002)
Stawell	or	123.9	439 ± 2	Foster et al. (1998)
Tarnagulla	or	>20	419 ± 2	Bierlein et al. (2001)
Wattle Gully	or		441 ± 3	Foster et al. (1998)

Abbreviations: or = orogenic gold; sk = skarn; por = porphyry Au-Cu.

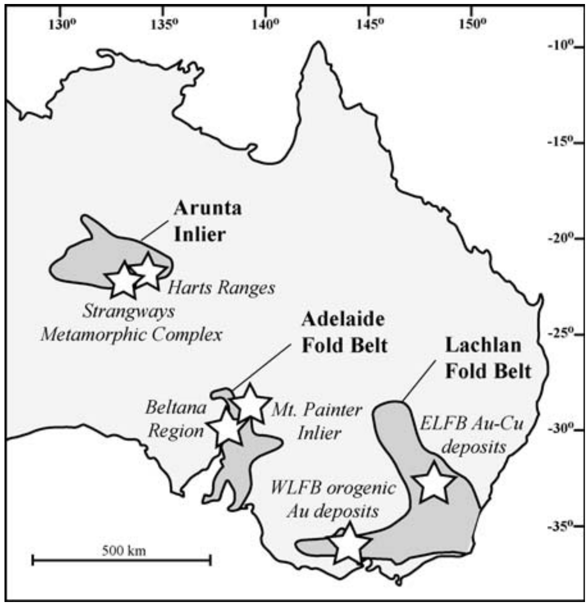

Figure 2: Distribution of ca. 440 Ma ages and events in Australia. Stars indicate ~440 Ma localities; see text for details. WLFB / ELFB = Western / Eastern Lachlan Fold Belt

2 The ~440 Ma event in Australia

The occurrence of a significant large-scale event is suggested based on the abundance of ~440 Ma aged events in Central and Eastern Australia. Their distribution is illustrated in Figure 2 and includes the following events:

1. Simultaneous orogenic lode gold and porphyry gold-copper mineralisation in the Lachlan Fold Belt (e.g. Bierlein et al. 2002; Table 1).
2. Large-scale geodynamic changes in the Lachlan Fold Belt (e.g. Vandenberg et al. 2000; Vos et al. 2003).
3. A magmatic-hydrothermal event in the Mt. Painter Inlier, southern Australia (Elburg et al. 2003).
4. Extensive lead-zinc mineralization in the Flinders Ranges, southern Australia (Groves et al. 2003).
5. Large-scale geodynamic changes in the Arunta Inlier, central Australia (e.g. Mawby et al. 1999; Scrimgeour and Raith, 2001; Hand et al. 2002).

3 Slab break-off – a possible driving force?

We suggest that the simultaneous occurrence of events in Australia that include the genesis of world-class gold deposits is caused by a single broadly synchronous phenomenon around 440 Ma. We hypothesise that an episode of mantle upwelling has been triggered by slab break-off along a portion of the mega-subduction zone outboard of south-eastern Australia at ~440 Ma. The introduction of heat and fluids in response to mantle upwelling caused the generation of the massive gold provinces in south-eastern Australia. The magnitude of this event was such that it is considered to have caused a ripple effect that intiated changes in lithospheric conditions elsewhere in Austrilia.

Throughout Earth history, a connection between heat anomalies and gold mineralisation has been recognised (e.g. Barley et al. 1998; De Boorder et al. 1998; Goldfarb et al. 2001). In addition, most Mesozoic to recent orogenic gold mineralisation in the Pacific Rim has been associated with accretion of arcs or oceanic plateaus and rapid migration of subduction zones (Goldfarb et al. 1998). During these processes, peripheral orogens undergo major crustal contraction and crustal thickening (Collins 2003).

Previous studies in southeastern Australia suggest that subduction lock-up in response to subduction of a buoyant seamount or arc collision occurred along the southeast Australian margin at ca. 455 Ma and controlled crustal contraction inboard of the subduction system (e.g. Glen et al. 1998; Squire and Miller 2003). While such a process might explain regional geodynamic changes in the Lachlan Fold Belt, it fails to account for the wider occurrence of events at 440 Ma elsewhere in Eastern and Central Australia. As part of the mega-subduction zone system surrounding Gondwana, we envisage that the arrival of a buoyant seamount or arc in the subduction system would have created a regional heterogeneity. At ~440 Ma, a portion of detached following subduction resistance outboard of southeastern Australia.

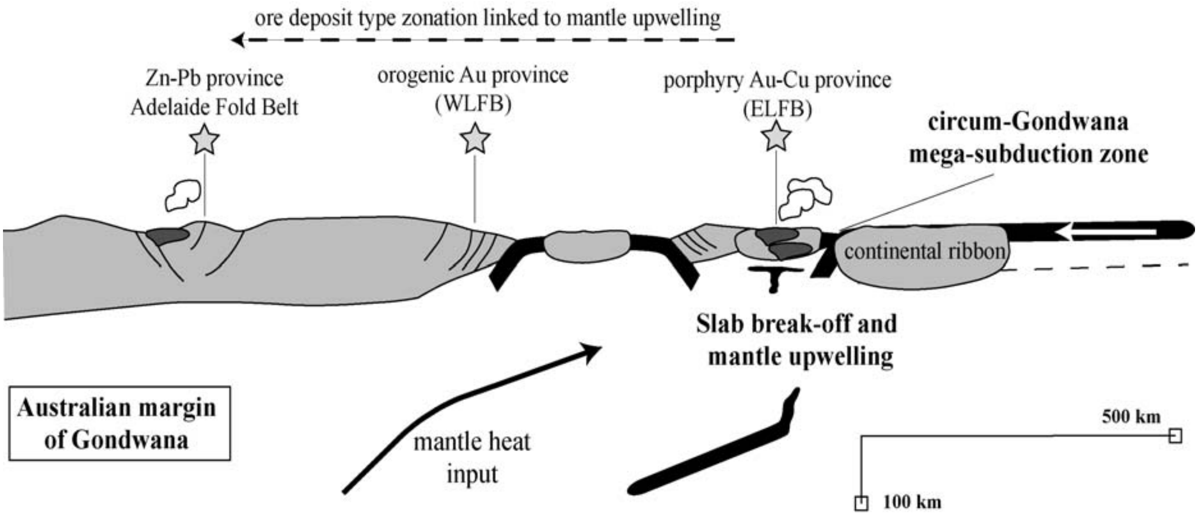

Figure 3: Schematic cross-section of southeastern Australia around 440 Ma illustrating break-off of a portion of the mega-subduction zone on the margin of Gondwana. Slab break-off triggers mantle upwelling, which in turn controls the generation of world-class mineral deposits provinces, including the world-class orogenic and porphyry gold-copper provinces in the western and eastern Lachlan Fold Belt (ELFB and WLFB, respectively). Due to the giant scale of the subduction system, related effects were propagated far inboard of the subduction margin and caused geodynamic changes elsewhere in Australia

The removal of the cooling effect from subduction allowed mantle upwelling and depressurisation and caused significant changes in the geodynamic framework in the southeast Australian portion of Gondwana. The instantaneous introduction of mantle heat has played an important role in ore deposition as well as other magmatic and tectonic events and depositional changes that occurred around 440 Ma elsewhere in Australia. The interplay of these processes is illustrated in Figure 3.

4 A crucial role for slab break-off in the generation of giant ore deposits?

Could generation of giant ore deposits have been controlled by heat anomalies associated with slab break-off and related effects? De Boorder et al. (1998) recognised a spatial correlation between hot regions in the lithosphere as indicated by results from seismic tomography that are interpreted to represent detachment of a cold slab or lithospheric root and mineralised areas in the European Alpine Belt. Metallogenic provinces like the Witwatersrand basin and Palaeoproterozoic basins of West-Africa are also suggested to reflect the interactions of mantle plumes with long-lived convergent margin systems (Barley et al. 1998). Kerrich and Wyman (1990) proposed a model for Archaean lode-gold mineralisation that includes metamorphic dehydration of submarine volcanic and sedimentary rocks following terrane accretion and cessation of active subduction. Clearly, heat anomalies along long-lived convergent margins form a crucial element in models for world-class mineralisation. The long-lived nature of convergent margins allows long-term enrichment of the margin lithosphere in response to repeated episodes of arc and marginal-basin magmatism, and subduction (Barley et al. 1998). However, the mechanism that triggers generation of world-class metallogenic provinces during these episodes is poorly understood.

The coincidence of the genesis of giant ore deposits with anomalous thermal conditions along subduction margins as illustrated in this paper and elsewhere (e.g. Qiu and Groves 1999) suggests that instantaneous changes in subduction dynamics, like slab break-off, play a crucial role in the generation of giant ore deposits.

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