New age constraints for Cu–Au(–Mo) mineralisation and regional alteration in the Olary–Broken Hill region

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The Curnamona Province, including the Broken Hill Domain and its giant Pb–Zn–Ag deposit, is emerging as a significant Cu–Au(–Mo) province owing to the recent discoveries of the Portia, White Dam, and Kalkaroo prospects. New $^{40}Ar/^{39}Ar$ data for hydrothermal muscovite at the Mundi Mundi Cu–Au prospect, hosted by <1720-Ma metasediments, implies a minimum age of ~1500 Ma for Fe-oxide–associated Cu–Au mineralisation. In conjunction with key geological and geochemical signatures, this Mesoproterozoic constraint enhances the potential of the Curnamona Province as a host to Cu–Au–Fe systems similar to those at Olympic Dam and/or Cloncurry–Tennant Creek.

A novel dating technique — single-mineral step-leach analysis of Pb isotopes — applied to date titanite associated with

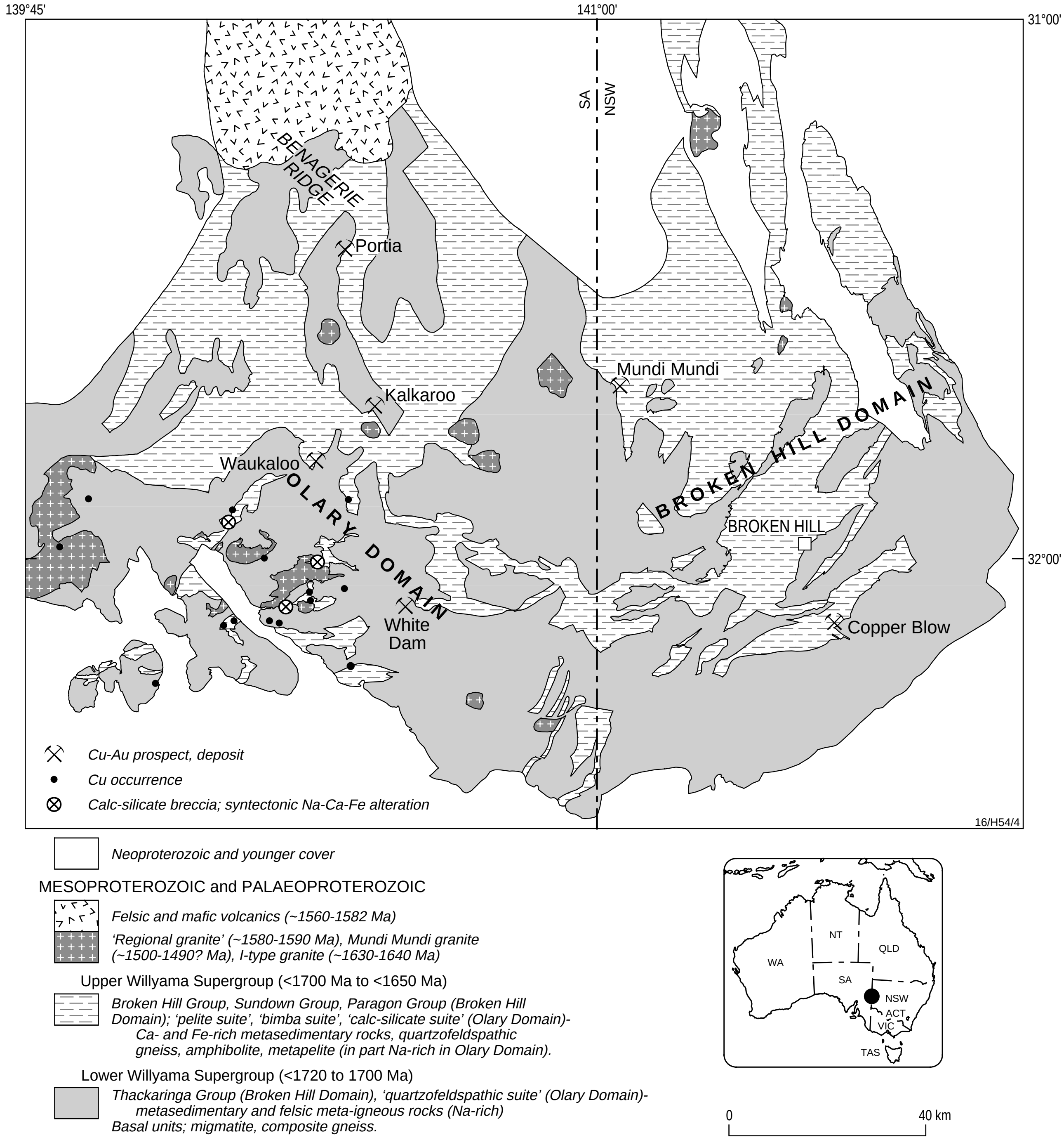


Fig. 27. Simplified geology of part of the Curnamona Province (after Laing et al. 1996: 'Interpreted solid geology of the Curnamona Province, 1:500,000 scale', Department of Mines & Energy, South Australia).

syntectonic regional Na–Ca–Fe metasomatism has yielded a $^{207}Pb/^{206}Pb$ isochron age of 1660 ± 33 Ma. Although this alteration may represent earlier and/or deeper-level high-temperature hydrothermal activity relative to Cu–Au(–Mo) deposition, it is indicative of a regional-scale flux of fluids with a metal-carrying capacity. As such, it is viewed as a positive factor for the prospectivity of Fe-oxide-associated Cu–Au(–Mo) in the province.

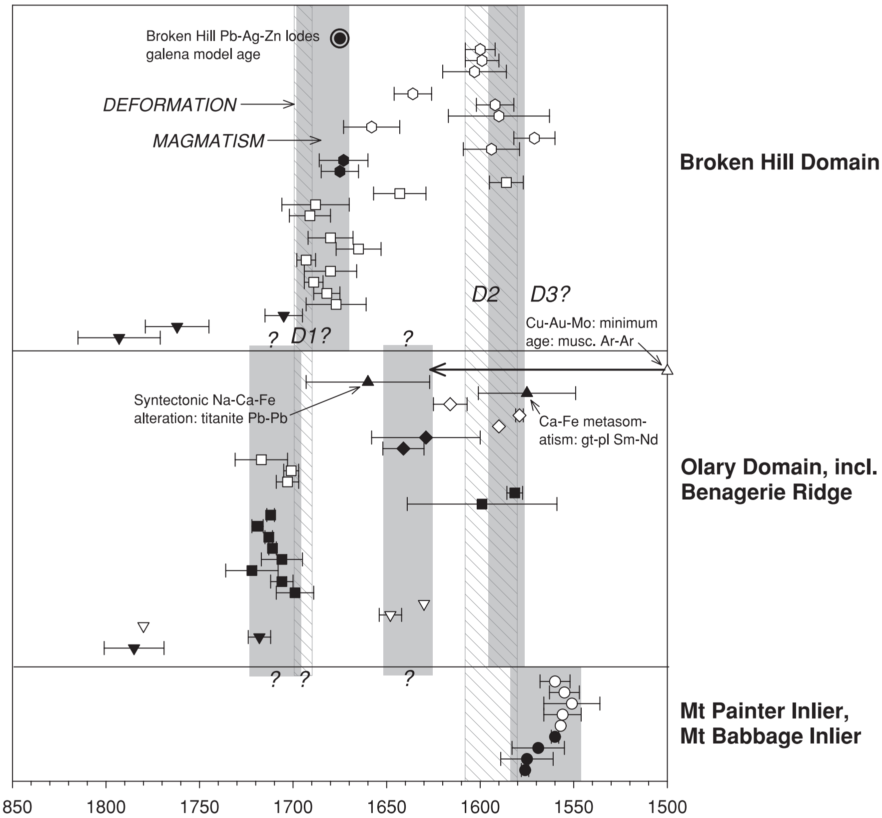
As part of the Broken Hill Exploration Initiative* (BHEI), AGSO is leading a multidisciplinary study of the Cu–Au(–Mo) metallogenic framework of the Curnamona Province. This study is applying geological, geochemical, stable-isotopic, and geochronological methods to resolve the timing and key components of Cu–Au mineralising systems, and relationships with regional alteration zones. Recently acquired high-resolution aeromagnetic, gravity, and gamma-ray spectrometric datasets provide the basis for a new perspective on the metallogeny and prospectivity of this largely concealed terrane.

Cu–Au(–Mo) mineralisation

Palaeoproterozoic metasediments of the Willyama Supergroup host a range of epigenetic Cu–Au(–Mo) systems of growing exploration significance, as well as numerous prospects of stratabound Ba, Zn, Pb, Ag, and Co (Fig. 27). Copper–gold deposits in the Olary Domain occur within a few hundred metres of the interface between the 'pelite suite' (upper part: ≤1650 Ma; Page et al. 1998: in AGSO Record 1998/25, 89–93) and underlying calc-silicate-rich metasediments of the 'Bimba suite' and 'calc-silicate suite' (informal stratigraphic nomenclature after Clarke et al. 1986: Precambrian Research, 34, 107–137). Felsic volcanics and ?sills within the lower parts of the 'calc-silicate suite' and underlying 'quartzofeldspathic suite' were emplaced at <1720–1700 Ma (Fig. 28; Ashley et al. 1996: Lithos, 38, 167–184; Page et al. 1998: op. cit.).

The Olary Cu–Au(–Mo) systems are broadly stratabound, although the disseminated and stockwork deposits are locally transgressive to compositional layering, and partly fracture- or fault-controlled. The larger Cu–Au(–Mo) systems are associated with hydrothermal magnetite ± hematite (except White Dam; see below), and the Copper Blow deposit in the Broken Hill Domain occurs in a shear-related magnetite ironstone (Skirrow & Ashley 1998: in AGSO Record 1998/25, 104–108). Microstructural and paragenetic observations at the Mundi Mundi Cu–Au prospect and other deposits indicate multiple generations of magnetite crystallisation, including disseminated premineralisation and later syndeformational hydrothermal stages. Some if not all Cu–Fe sulphide and Au mineralisation was associated with this hydrothermal magnetite and attendant potassic alteration, which includes combinations of reddish K-feldspar or albite, biotite, carbonate, amphibole, quartz, and uncommon muscovite. Late-stage chloritisation of hydrothermal biotite was widespread throughout the northern Olary region. Minor late veins of carbonate–quartz–chlorite ± fluorite ± chalcopyrite ± barite are common in the Benagerie Ridge area.

The White Dam deposit is distinguished from most other Olary Cu–Au(–Mo) systems by higher Au/Cu ratios and by very low iron-oxide content (McGeogh & Anderson 1998: in AGSO Record 1998/25, 69–71). Gold and disseminated molybdenite, chalcopyrite, and pyrite are localised partly within quartzofeldspathic veins/segregations in quartz–feldspar–biotite gneiss.



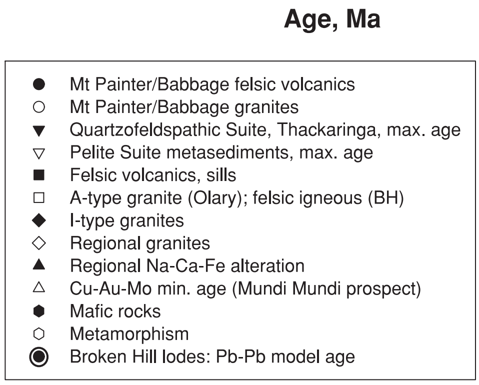


Fig. 28. Summary of the Curnamona Province's magmatic and deformation events based on SHRIMP geochronology, and new $^{40}Ar/^{39}Ar$ (muscovite) and Pb–Pb step-leach (titanite) constraints on hydrothermal events. SHRIMP data from Page & Laing (1992: op. cit.), Ashley et al. (1996: op. cit.), Ashley et al. (1997: op. cit.), Donaghy et al. (1998: in AGSO Record 1998/25, 17–20), Fanning et al. (1998: in AGSO Record 1998/25, 30–35), Page et al. (1998: op. cit.), Nutman & Ehlers (1998: op. cit.). Garnet–plagioclase (gt–pl) Sm–Nd age from Kent et al. (submitted to Lithos). Broken Hill galena Pb–Pb model age (errors unknown) from Sun et al. (1994: op. cit.). 1690–1700-Ma age of D1 based on Gibson (1998: in AGSO Record 1998/25, 38–40).

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Regional alteration

Regionally extensive zones of alteration are prominent in both the Olary and Broken Hill Domains (Ashley et al. 1997: Mines & Energy, South Australia, Report Book 97/17; Ashley & Plimer 1998: Geological Society of Australia, Abstracts, 49, 14). Styles include pre- or early tectonic sodic metasomatism in both domains; and syntectonic Na–Ca–Fe alteration, garnet ± epidote replacements, and potassic–iron-oxide–carbonate alteration, which are confined mainly to the Olary Domain (Skirrow & Ashley 1998: op.cit.). The effects of pre- or early tectonic sodic metasomatism are largely stratabound and pervasive within the quartzo-feldspathic, calc-silicate and lower pelite suites in the Olary Domain, and within the Thackaringa Group in the Broken Hill Domain (Fig. 27). They are overprinted by fabrics associated with D_2 in the scheme of Clarke et al. (1986: op. cit.). Abundant disseminated magnetite ± pyrite in some sodic plagioclase-rich ('albitite') assemblages reflects coupled Na–Fe metasomatism during this early alteration.

The products of syntectonic Na–Ca–Fe alteration overprint the early sodic metasomatic effects. Accordingly, albite ± clinopyroxene ± amphibole ± garnet vein networks and calc-silicate-matrix breccias occur widely and preferentially within the calc-silicate suite (e.g., Cathedral Rock; Yang & Ashley 1994: 'Proceedings of the AMF symposium on Australian research in ore genesis', Australian Mineral Foundation, Adelaide, 16.1–16.5). The matrix of the breccias is composed of clinopyroxene and/or amphibole ± albite ± titanite ± quartz ± magnetite ± hematite. Clasts and host rocks are intensely albitised within tens to hundreds of metres of breccia bodies. These Na–Ca–Fe alteration effects were localised by upright folding and brittle–ductile shearing, and at least in part postdate ~1630–1640-Ma I-type granites, yet are cut by granite dykes affiliated(?) with the minimally altered ~1580–1590-Ma 'regional granite' suite (Fig. 28). The relationship of the syntectonic Na–Ca–Fe alteration to metasomatic zones of massive garnet ± epidote ± plagioclase (1575 ± 27 Ma, Sm–Nd; Kent et al. submitted to Lithos) is unclear at present. Fluids involved in the formation of calc-silicate-matrix breccias and garnet-rich alteration zones were generally oxidised hot (450–550°C) hypersaline brines capable of leaching and transporting metals (Yang & Ashley 1994: op. cit.; Ashley & Plimer 1998: op. cit.; R.G. Skirrow & P. Ashley, unpublished data).

New geochronological results

Muscovite with grainsize 0.2–1.0 mm separated from gold-bearing quartz–magnetite–chalcopyrite–K-feldspar veins cutting upper-greenschist–lower-amphibolite-facies Palaeoproterozoic pelitic and albitite rocks at the Mundi Mundi prospect (Fig. 27) yielded a disturbed $^{40}Ar/^{39}Ar$ spectrum with a total fusion age of 1496 ± 9 Ma (Fig. 29). Although this spectrum is complex, we may infer that initial closure to argon loss occurred before ~1500 Ma. This age is considered a minimum for vein formation and Cu–Au introduction. The oldest apparent age steps suggest a >1500-Ma component of uncertain origin. Thermal disturbance after ~1350 Ma has resulted in young initial steps. The source of the disturbance may have been the Delamerian Orogeny (520–450 Ma), which resulted in widespread resetting of $^{40}Ar/^{39}Ar$ ages farther south, west, and east in the Olary Domain (Bierlein et al. 1996a: Mineralogy & Petrology, 58, 1–22) and Broken Hill Domain (Harrison & McDougall 1981: Earth and Planetary Science Letters, 55, 123–149) but apparently had less effect in the Mundi Mundi prospect area.

Titanite in syntectonic calc-silicate-matrix breccia has been dated by the Pb step-leach technique for single minerals (cf. Frei & Kamber 1995: Earth and Planetary Science Letters, 129, 261–268). A titanite separate was treated with nitric acid in five steps ranging from 10 minutes to 15 hours, and the residue dissolved in hydrofluoric acid. Ludwig's (1989: US Geological Survey, Open File Report OF–88–0557) software resolved a five-point $^{207}Pb/^{206}Pb$ isochron age of 1660 ± 33 Ma (MSWD 5.8; HNO_3 steps). This preliminary result suggests that a regional-scale Na–Ca–Fe metasomatic and deformation event predated the ~1600-Ma peak of the Olarian orogeny (Page & Laing 1992: Economic Geology, 87, 2138–2168). Further work is in progress to verify the Pb–Pb result. A U–Pb zircon ion-probe age of 1641 ±11 Ma for I-type 'tonalite' in the Olary Domain (Ashley et al. 1997: op. cit.), which is overprinted by the effects of calc-silicate alteration and brecciation, provides a possible maximum age for this style of alteration. Correlation of I-type magmatism with the 1640–1660-Ma metamorphic–deformation event postulated by Nutman & Ehlers (1998: Precambrian Research, 90, 203–238) in the Broken Hill Domain remains problematical (Fig. 28).

Implications for Cu–Au(–Mo) exploration

Knowledge of the absolute timing of Cu–Au(–Mo) mineralisation in the Curnamona Province is critical to exploration models, yet there have been few geochronological constraints. Copper–gold deposits occur in Adelaidean sequences in the region, implying at least some mobilisation of Cu–Au after ~800 Ma. Based on $^{40}Ar/^{39}Ar$ dating,

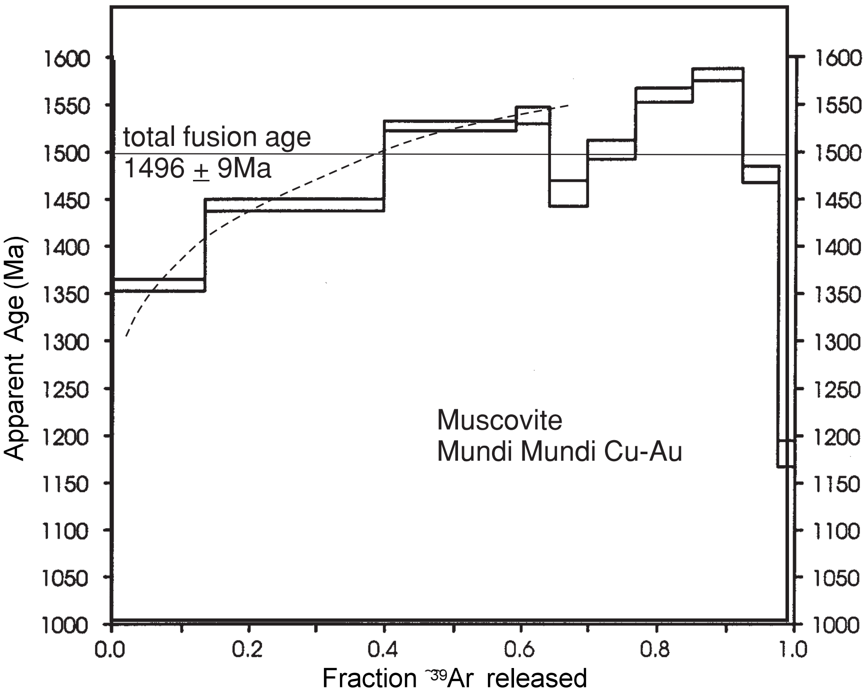

Fig. 29. $^{40}Ar/^{39}Ar$ step-heating spectrum for hydrothermal muscovite associated with Cu–Au mineralisation, Mundi Mundi prospect (Fig. 27). Widths of apparent age steps are 1-σ errors.

Bierlein et al. (1996a: op. cit.) proposed that epigenetic Cu–Au–quartz and Pb–Zn ± Cu-carbonate vein deposits in the Olary Domain were emplaced during the Delamerian Orogeny. By comparison, lead-isotope signatures of least-radiogenic galena and Fe-, Zn-, and Cu-sulphides in stratabound and epigenetic mineralised veins in the Olary Domain are consistent with the Meso–Palaeoproterozoic Pb-isotope signature of the Broken Hill orebody (Sun et al. 1994: AGSO Research Newsletter 24, 19–20; Bierlein et al. 1996b: Australian Journal of Earth Sciences, 43, 177–188; Lawie et al. 1997: Geological Society of Australia, Abstracts, 44, 44).

The $^{40}Ar/^{39}Ar$ data for Mundi Mundi are a further indication of a Mesoproterozoic (or older) age for Cu–Au mineralisation in the Curnamona Province, corroborating earlier suggestions based on geological evidence (e.g., Ashley & Plimer 1998: op. cit.) and lead isotopes (Bierlein et al. 1996b: op.cit.). Several key components of Proterozoic Cu–Au–Fe mineral systems are present in the Curnamona Province: (i) ~1580–1590-Ma granitoids resembling the Hiltaba Suite (Wyborn et al. 1998: in AGSO Record 1998/25, 123–126), (ii) abundant hydrothermal magnetite and hematite, (iii) Cu–Au(–Mo) association and anomalous LREE, Ba, and F (R.G. Skirrow, unpublished data), (iv) potassic, 'red rock', and precursor Na–Ca–Fe regional alteration, and (v) syn- to late tectonic timing of at least some Cu–Au deposition (Conor 1996: in W.V. Preiss, compiler, "Resources '96 Convention", Mines & Energy, South Australia, Abstracts, 40–41; Skirrow 1999: in C.J. Stanley et al., editors, 'Mineral deposits: processes to processing — proceedings of the fifth biennial SGA meeting and the tenth quadrennial IACOD meeting, London, 22–25 August 1999', A.A. Balkema, Rotterdam, 1361–1364). In conjunction with these characteristics, the ~1500-Ma minimum age of Cu–Au provides further support for Olympic Dam-style mineralisation (~1590 Ma; Johnson & Cross 1995: Economic Geology, 90, 1046–1063) and/or Cloncurry–Tennant Creek-style Cu–Au–Fe mineral systems in the Curnamona Province.

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