Abracadabra — dating hydrothermal mineralization and fluid flow in a long-lived crustal structure

by

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The Proterozoic Capricorn Orogen (Fig. 1a) is a major tectonic zone that records the assembly of the West Australian Craton from the Archean Pilbara and Yilgarn Cratons and the Glenburgh Terrane. Assembly was followed by a long history of tectonic reworking and reactivation focused along a series of major crustal structures, some of which are spatially associated with hydrothermal mineral deposits (Johnson et al., 2013), implying a link between hydrothermal fluid flow and the generation or reactivation of these structures. The Abra polymetallic deposit (Fe, Pb, Zn, Ba, Cu, Au, Ag, Bi, and W) is the largest base metal accumulation in the Capricorn Orogen, and is located close to the crust-cutting Lyons River – Quartzite Well fault zone (Fig. 1a). Despite being discovered in the early 1980s, the tectonic setting, age, and style of mineralization are still not precisely known. Robust radiometric dates for the timing of sediment deposition and hydrothermal mineralization are essential for understanding the geological history of this long-lived orogen and the processes that formed the ore deposits.

The Abra deposit

The Abra polymetallic deposit is a blind, stratabound, hydrothermal deposit that is hosted in sedimentary rocks of the Mesoproterozoic Edmund Group (Fig. 1; Pirajno et al., 2009; Rasmussen et al., 2010a; Thorne et al., 2009; Vogt and Stumpfl, 1987). Mineralization occurs within a structural corridor at the eastern end of the Jillawarra Sub-basin (Vogt, 1995), close to the junction of two major faults, the northeast-trending Bujundunna Fault and the easterly trending Quartzite Well Fault (Fig. 1b). The latter is interpreted to be an extension of the Lyons River Fault (Fig. 1a), which is a major crustal suture between the Pilbara Craton and the Glenburgh Terrane of the Gascoyne Province (Johnson et al., 2013). The southern margin of the structural corridor is delineated by the Coodardoo South Fault (Fig. 1b).

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The main mineralization is hosted within both the Irregully Formation and the lower alluvial-fan deposits of the Kiangi Creek Formation (Fig. 2a), but not in the unconformably overlying deltaic to deep-marine facies of the Kiangi Creek Formation (Thorne et al., 2009). This relationship suggests that the timing of the Abra mineralization broadly coincided with a period of active growth faulting, alluvial-fan sedimentation, and minor felsic volcanism during deposition of the lower part of the Kiangi Creek Formation. However, isolated barite–chalcopyrite–dolomite–galena veins, up to 10 mm wide, are present in the overlying deltaic to deep-marine facies, implying a second generation of mineralization and hydrothermal activity after the deposition of the upper part of the Kiangi Creek Formation.

U–Th–Pb phosphate dating

In situ U–Th–Pb SHRIMP geochronology of xenotime intergrown with magnetite–hematite–galena from the ore zone yields a weighted mean $^{207}Pb/^{206}Pb$ age of 1594 ± 10 Ma (n = 14, MSWD = 2.6), although individual analyses provide a range of concordant dates from as old as c. 1610 Ma to as young as c. 1590 Ma (Fig. 3a). These ages indicate a prolonged period of hydrothermal activity, with the main phase of mineralization occurring at c. 1595 Ma. Hydrothermal monazite from the ore zone gives $^{207}Pb/^{206}Pb$ ages of 1375 ± 14 Ma (n = 16, MSWD = 0.99), interpreted to represent a hydrothermal event post-dating the main phase of mineralization (Fig. 3b). Monazite in samples distal to mineralization yield weighted mean $^{207}Pb/^{206}Pb$ ages of 1221 ± 14 Ma (n = 5, MSWD = 1.04) and 995 ± 18 Ma (n = 6, MSWD = 1.3), interpreted as records of discrete episodes of hydrothermal fluid flow, tentatively dating the development of regional barite–chalcopyrite–dolomite–galena veins (Fig. 3b).

Depositional age of the Edmund Group

The new ages obtained from the ore zone at Abra also provide critical constraints for the timing of deposition of the host Edmund Group sedimentary rocks. The oldest

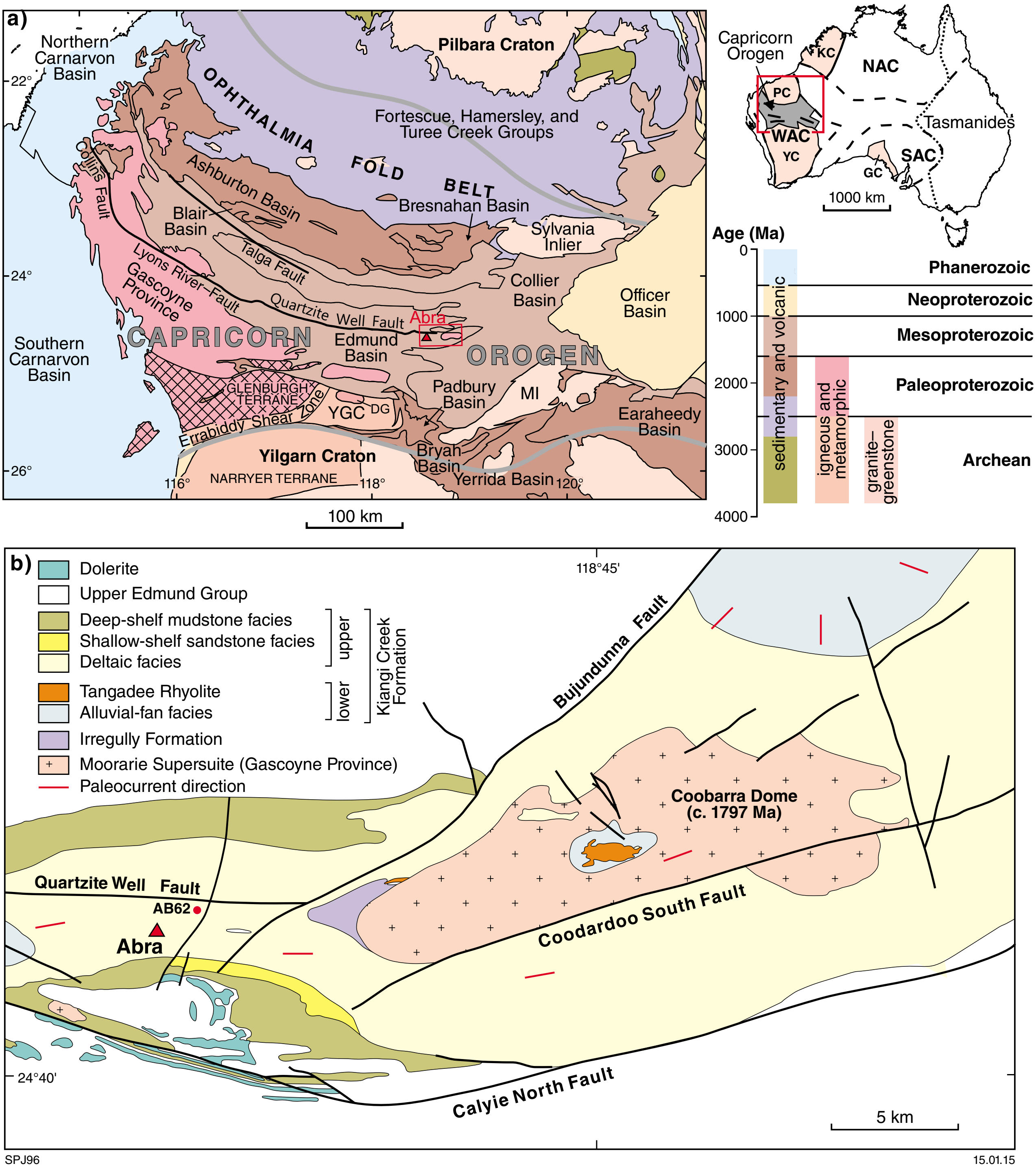

Figure 1. a) Regional geological setting of the Mesoproterozoic Edmund Group within the Capricorn Orogen, showing the location of the Abra polymetallic deposit. Abbreviations: DG, Discretion Granite; GC, Gawler Craton; KC, Kimberley Craton; MI, Marymia Inlier; NAC, North Australian Craton; PC, Pilbara Craton; SAC, South Australian Craton; WAC, West Australian Craton; YC, Yilgarn Craton; YGC, Yarlarweelor Gneiss Complex; b) interpreted bedrock geology of the area showing the location of Abra in relation to the major structures and depositional facies of the Kiangi Creek Formation

coherent age component of hydrothermal xenotime in the ore zone, dated at c. 1610 Ma, provides a minimum age for deposition of the Irregully Formation and alluvial-fan facies of the Kiangi Creek Formation. The youngest detrital zircons from the stratigraphic sequence are dated at c. 1679 Ma (from the underlying Mount Augustus Sandstone; Martin et al., 2008), indicating that the basal part of the Edmund Group must have been deposited sometime between c. 1679 and 1610 Ma. As the upper part of the Kiangi Creek Formation and overlying Edmund Group rocks are unmineralized, they must have been deposited after the main phase of hydrothermal mineralization — the youngest phosphate date is c. 1590 Ma. This indicates that the lower and upper parts of the Edmund Group are separated by a major unconformity that represents a time break of at least 20 Ma. In the Jillawarra Sub-basin this unconformity is interpreted to be within the Kiangi Creek Formation, but this break is not recognized elsewhere in the Edmund Basin. It is possible that the identity of the lower alluvial-fan sequence at Abra has been misidentified and could instead represent part of the Gooragoora Formation (Fig. 2b). Thus, the major unconformity would coincide with the regional unconformity at the base of the Kiangi Creek Formation, which is recognized throughout much of the Edmund Basin.

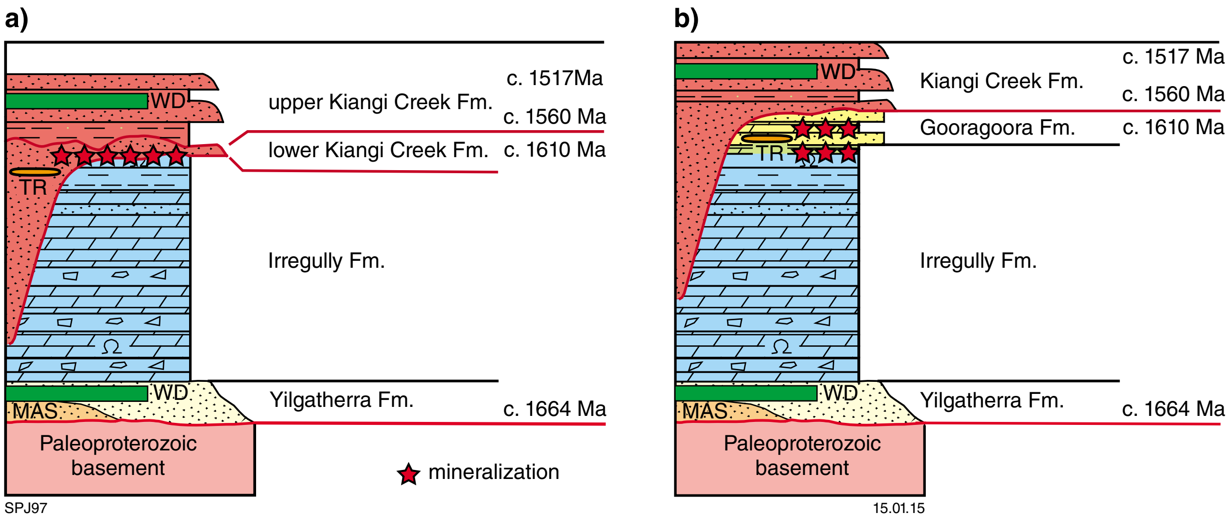

Figure 2. **Alternative interpretations of the stratigraphy of sedimentary rocks at Abra, showing the location of unconformities (red lines) and new age constraints for deposition: a) shows the traditional interpretation where the lower alluvial-fan facies belongs to the lower part of the Kiangi Creek Formation; whereas b) shows a new interpretation with the lower alluvial-fan facies forming part of the Gooragoora Formation. Abbreviations: MAS, Mount Augustus Sandstone; TR, Tangadee Rhyolite; WD, Waldburg Dolerite**

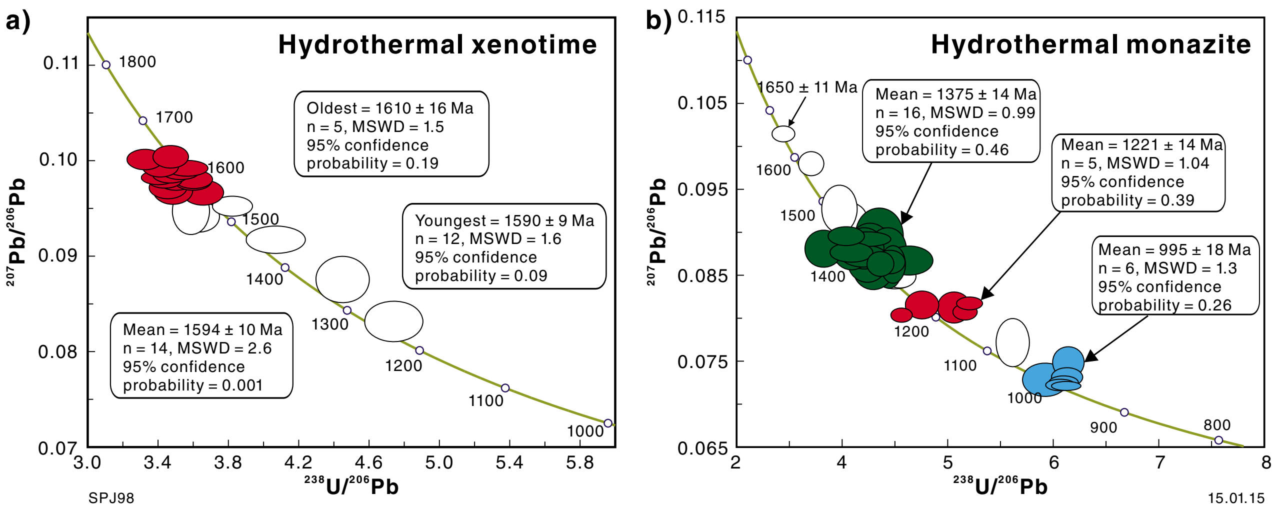

Figure 3. **Tera-Wasserburg concordia plots of the U–Pb data for: a) hydrothermal xenotime from the ore zone of the Abra deposit; b) hydrothermal monazite from the ore zone and distal to mineralization**

Summary

Mineralization at Abra was synchronous with the deposition of sediments into the lower part of the Edmund Basin between c. 1610 and 1590 Ma. Crustal extension, basin formation (including the formation of the Jillawarra Sub-basin) and sedimentation was controlled by the reactivation of major, pre-existing crustal structures including the Lyons River – Quartzite Well, Talga, Mount Vernon, and Bujundunna Faults (Cutten et al., 2011; Johnson et al., 2013). These major structures, particularly the Lyons River – Quartzite Well Fault, appear to have played an important role in a mineral systems setting, acting as deep-plumbing systems that focused fluid flow from the mantle, or mid- to lower crust, into the upper crust (Wyborn et al., 1994). The episodic growth of hydrothermal monazite and xenotime demonstrates that this fault system was reactivated numerous times over at least a 600 Ma period (from c. 1610 to 995 Ma), with the fault system being the locus for hydrothermal fluid flow during these reworking events.

Monazite and xenotime represent ideal chronometers for investigating the complex histories of hydrothermal mineralization and fluid flow in major crustal structures, and can be used to help to unravel the geological evolution of complex intracratonic orogens.

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