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Two episodes of regional-scale Precambrian hydrothermal alteration in the eastern Pilbara, Western Australia

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ABSTRACT

Two regional-scale hydrothermal events have been identified and mapped in the Precambrian rocks of the eastern Pilbara, Western Australia. The first post-dates lithification and tilting of the 2630 ± 6 Ma Carawine Dolomite and pre-dates the 1317 ± 11 Ma Manganese Group. It involved epithermal, mostly silica alteration with subordinate carbonate and minor chlorite and hematite. The most significant result of this event was the development of a regional-scale silica carapace (known as the Pinjian Chert Breccia) on the Carawine Dolomite, ranging from a few metres (?) to about 100 m thick.

The second event comprised two phases. The first phase involved regional-scale hematite (±quartz) mineralisation that was broadly synchronous with deposition of the Manganese Group. The second involved regional-scale dissolution of Carawine Dolomite and local precipitation of barite and manganese oxide. It post-dates lithification of the lower part of the Manganese Group and was either synchronous with, or post-dated, deposition of the upper part of the Group.

This study highlights the important roles of bedding-parallel aquicludes and unconformities in Precambrian hydrothermal systems, the role of physical and chemical variations in lithologies in controlling the locations of alteration and mineralisation, and shows that ancient crustal fractures acted, repeatedly, as fluid conduits. It also shows that Precambrian hydrothermal events in non-magmatic rocks in non-orogenic settings can be intense and widespread, affecting thousands of square kilometres. Further, by dating such events, links can be made between relatively undeformed sedimentary successions and seemingly unrelated Precambrian orogens. The study also challenges a long-standing, supergene-based model for the formation of silica and manganese in the eastern Pilbara and adds a new component to the Pilbara iron ore story.

1. Introduction

This paper describes several linked studies that, collectively, challenge long-standing views about the genesis of siliceous rocks and manganese (and hematite) deposits in the eastern Pilbara of Western Australia. It shows, for the first time, that much of the Pinjian Chert Breccia, most manganese and hematite mineralisation, and other alteration are hydrothermal rather than supergene.

Much of the supporting data is based on mapping, field observations and petrography and is, therefore, descriptive. These data are complemented by a pilot fluid inclusion study, a new SHRIMP zircon U-Pb age of a major stratigraphic unit, local and regional-scale structural observations and whole rock geochemistry. Descriptive summaries are tabulated and supported by photographs. Expanded descriptions, with additional figures, and a description and discussion of the fluid inclusion study are given in Supplementary information 1.

Importantly, this is not a study of manganese deposits per se. Rather it is an overview of the Neoarchean(?) to Mesoproterozoic alteration history of the area. The genesis of manganese deposits is discussed as part of this history, and a new model for manganese mineralisation is presented. However, manganese is regarded as just one rock type resulting from a continuum of events and is treated equally with brecciation, silica alteration, hematite miner-

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alisation and other alteration facies. Individual manganese deposits are not discussed, partly for the reasons outlined above but also because they are poorly documented, with much of the information being outside the public domain (see Supplementary information 2 for sources of public domain information).

The word 'manganese' is used from hereon for both the element Mn and complex mixtures of manganese oxides. Unless more specifically identified, the group of manganese minerals variously called cryptomelane, psilomelane, manganomelane or wad is here called 'manganomelane'.

2. Geological setting

The hydrothermal processes discussed in this paper affect most Precambrian rocks in the eastern Pilbara. This necessitates a review of the entire succession with an emphasis on the most relevant lithologies and structures (Table 1).

2.1. Pilbara Craton (Paleoarchean to Mesoarchean)

The pre-Fortescue Group rocks of the Pilbara Craton constitute a geologically and geophysically well-defined Archean terrain that is partly covered by Neoarchean to Paleoproterozoic rocks and surrounded by younger Proterozoic to Phanerozoic rocks (Fig. 1). Exposed rocks span a time period of about 700 Myr, ranging in age from ca 3530 Ma to ca 2830 Ma (e.g., Van Kranendonk et al., 2006). The craton comprises variably deformed and metamorphosed granitic complexes and individual granitic intrusions with intervening belts of supracrustal rocks.

Of greatest importance to younger alteration and mineralisation is an array of NE-trending, episodically active crustal fractures (Fig. 1). The age of initiation of these regional-scale fractures is unknown, though there is evidence for movements as old as ca 3000 Ma (Smith et al., 1998; Zegers, 1996; Zegers et al., 1998).

2.2. Mount Bruce Supergroup (Neoarchean to Paleoproterozoic)

The Mount Bruce Supergroup is an unconformity-bounded unit that overlies older Archean basement and is restricted to the Pilbara Craton. It comprises a maximum cumulative stratigraphic thickness of nearly 14 km of sedimentary and volcanic rocks that crop out over an area of more than 100,000 km^2 (Hamersley Province). The Supergroup is divided lithostratigraphically into three groups, which are, from oldest to youngest, the Fortescue, Hamersley and Turee Creek Groups (Halligan and Daniels, 1964; MacLeod et al., 1963; Trendall, 1979; Fig. 1).

Sedimentary and volcanic structures and textures are mostly well preserved due to the very low metamorphic grade (Rasmussen et al., 2005b; Smith et al., 1982) and low internal strain. In the central Pilbara Craton, the rocks are mostly shallow dipping and most lack tectonic cleavages. However, Paleoproterozoic to Neoproterozoic deformations have affected these rocks towards the eastern and southern margins of the craton, resulting in tectonic cleavages, increased metamorphic grade, and folding and faulting of variable intensity.

The Fortescue Group is a succession of terrigenous sedimentary rocks, minor carbonate sedimentary rocks, mafic lavas, rare komatiites, mafic tuffs, felsic lavas, felsic tuffs, reworked mafic and felsic volcanic rocks, comagmatic mafic sills and dykes and intrusive felsic rocks (e.g., Blake, 1990, 1993; Hickman, 1983; Thorne and Trendall, 2001). Excluding the Jeerinah Formation, at the top of the Group (Figs. 2 and 3), the succession ranges in age from ca 2775 Ma to ca 2715 Ma (Arndt et al., 1991; Blake et al., 2004). The Jeerinah Formation is a 100 m to 500 m thick succession of mudrocks (some carbonaceous and pyritic), cherts (some pyritic), dolomites, mafic volcarenites, basalts and felsic volcaniclastic rocks. Ages for the Jeerinah Formation, based on isotopic dating, range from ca 2715 Ma to ca 2630 Ma (Arndt et al., 1991; Blake et al., 2004; Rasmussen and Fletcher, 2010; Trendall et al., 2004).

An array of NNE-NE-trending fractures formed during the formation of the lower part of the Fortescue Group on the northern Pilbara Craton (Fig. 1), and earlier structures in a similar orientation were reactivated. In addition to moving episodically since the Neoarchean, these fractures provided pathways for Neoarchean magmas and Neoarchean and younger hydrothermal fluids.

The Hamersley Group in the eastern Pilbara comprises the Marra Mamba Iron Formation and Carawine Dolomite (Figs. 2 and 3). The Pinjian Chert Breccia (Fig. 3), described in the Geoscience Australia Stratigraphic Units Database (http://dbforms.ga.gov.au/pls/www/geodx.strat_units.sch_full?wher=stratno=15260) as 'Chert breccia and poorly bedded chert. Interpreted to be a siliceous replacement deposit formed by karstic weathering of the Carawine Dolomite.', is included in the Mount Bruce Supergroup on some published maps (Williams and Trendall, 1996a,b,c) but is excluded on others (Thom et al., 1979; Williams, 2005; Williams and Hickman, 2007).

Recent mapping has shown that the Pinjian Chert Breccia is not a single coherent stratigraphic unit. Rather, it is an amalgam of several rock 'units' that have similar aerial photograph characteristics. To date, the following units have been resolved within the Pinjian Chert Breccia and units mapped as Tertiary siliceous breccia.

1) The Silicified Zone of a Precambrian hydrothermal alteration event (Fig. 4) that includes several facies (see Section 5.2).
2) The Dissolution Zone of a Precambrian hydrothermal alteration event (Fig. 4), which is almost invariably strongly weathered (see Section 7.2.1).
3) Sedimentary rocks most probably of the Manganese Group.
4) Relatively minor areas of Carawine Dolomite.
5) Areas of Permian to Tertiary cover.

The Carawine Dolomite crops out sporadically over an area of about 8000 km^2 in the eastern Pilbara where it mostly overlies the Jeerinah Formation (Figs. 2 and 3). It probably covers a significantly larger area beneath Mesoproterozoic rocks. Drill holes at Ripon Hills (RHDH2A; Fig. 2) and Pearana Rock Hole (WDDH1; Fig. 2) intercepted about 200 m and at least 500 m of Carawine Dolomite, respectively (Richards, 1985; Stevens, 1993). The succession is mostly gently dipping, with steeper dips close to faults, and local internal folded zones that may be related to large-scale soft-sediment deformation.

There are no stratigraphic divisions within the Carawine Dolomite, and the lateral and vertical distribution of its various sedimentary facies is unknown. While the Carawine Dolomite is described as a carbonate ramp (e.g., Murphy and Sumner, 2008), very little is known about its depositional and geotectonic setting other than interpretations of local depositional environments.

Jahn and Simonson (1995) determined a Pb/Pb whole rock isochron date from surface samples of Carawine Dolomite carbonates of 2541 ± 32 Ma, which was interpreted to be the time of diagenesis of these rocks. Woodhead et al. (1998) determined a Pb/Pb whole rock isochron date from drill hole samples of Carawine Dolomite carbonates of 2548 +26/−29 Ma, which was interpreted to be the time of deposition or early diagenesis of the Carawine Dolomite. However, Rasmussen et al. (2005a) determined a U-Pb SHRIMP date of 2630 ± 6 Ma for zircons from a tuff near the base of the Carawine Dolomite at Ripon Hills. This date is interpreted to be a depositional age, and therefore the Pb/Pb isochron dates are interpreted to be the age of late diagenesis or, more probably,