Sedimentological and biogeochemical controls on sediment-hosted base metal deposits in the McArthur Basin

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Introduction

This study is part of a three year (2016–2019) collaborative project between the Northern Territory Geological Survey (NTGS) and CSIRO Mineral Resources, which focuses on better understanding the geology and occurrences of sediment-hosted base metals mineralisation in the Proterozoic McArthur Basin, northern Australia. More specifically, this project represents a multidisciplinary approach to further characterise mineral systems in the McArthur Basin. Individual components of this study include a refined 3D geological model of the greater McArthur Basin, deformation fluid flow modelling of the Batten Fault Zone (**Figure 1**), and a sedimentological and biogeochemical assessment of the Proterozoic middle McArthur Group (**Figure 2**). Here we provide a brief overview of currently undertaken individual studies that comprise the sedimentology and biogeochemistry component.

Regional geology

The unmetamorphosed and weakly deformed Paleo- to Mesoproterozoic McArthur Basin is exposed in the northeastern part of the Northern Territory of Australia (**Figure 1a**). Together with the stratigraphically equivalent but metamorphosed Mount Isa Basin in northwestern Queensland, it represents a wold-class base metals province hosting most of the world's known Proterozoic clastic-dominated sediment-hosted Pb-Zn deposits (Cooke *et al* 2000). The McArthur Basin comprises five unconformity-bounded depositional packages (Rawlings 1999). The late Paleoproterozoic Glyde package hosts the mixed carbonate-siliciclastic McArthur Group in the Batten Fault Zone, a structural domain in the southern McArthur Basin (**Figure 1a, b**) where synsedimentary transtension led to sediment accumulation in a series of northeast-trending sub-basins and paleohighs (eg McGoldrick *et al* 2010). Organic-rich mudrocks of the ca 1640 Ma Barney Creek Formation (middle McArthur Group) deposited in these sub-basins are the most important host strata for sediment-hosted Pb-Zn deposits, such as the giant HYC Zn-Pb deposit at McArthur River (**Figure 1b**).

Individual studies

Tectonostratigraphic evolution of the middle McArthur Group

Since the Barney Creek Formation is the most important host-unit for clastic-dominated sediment-hosted base metals deposits in the McArthur Basin, it is essential

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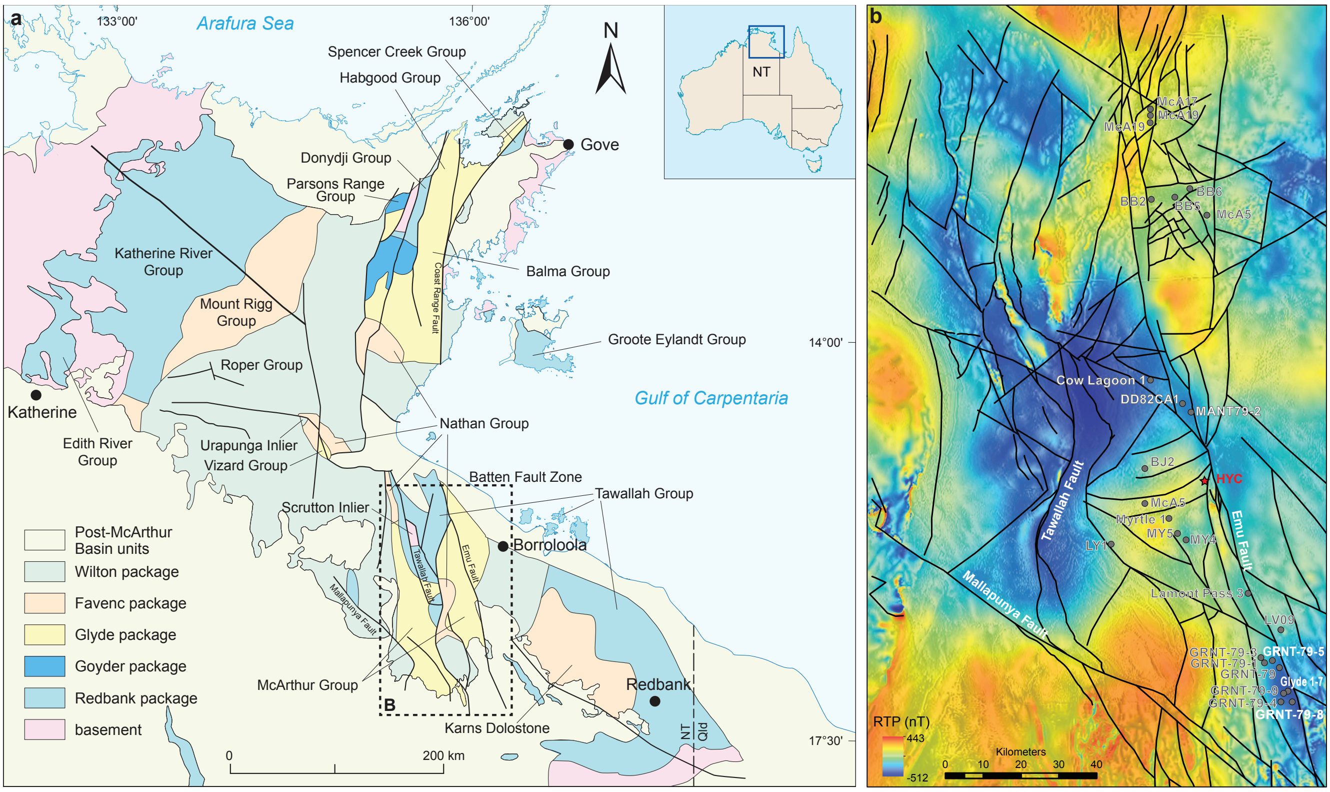

Figure 1. Simplified geological map of the McArthur Basin and magnetics of the Batten Fault Zone. (**a**) Spatial distribution of depositional packages across the McArthur Basin (modified after Ahmad *et al* 2013, Rawlings 1999). (**b**) Magnetics of the Batten Fault Zone, shown by the inset in (a). The locations of wells used in this study are also shown.

to understand basin architecture and evolution during sediment accumulation. However, this study will also include under- and overlying stratigraphic units (Myrtle Shale to Lynott Formation, ie the entire middle McArthur Group; **Figure 2**) as lateral facies and thickness changes in these coarse siliciclastic and carbonate units will provide important additional information on basin architecture.

About 20 to 30 drill cores (**Figure 1b**) intersecting the middle McArthur Group in the Batten Fault Zone will be logged at high resolution. The drill cores are mostly arranged in north–south direction along the Emu Fault, one of the most important structural features in the Batten Fault Zone, allowing us to produce a ca 180 km-long north–south transect across this structural domain. This transect will be complemented by a series of short (<20 km) east–west transects. Based on core logging, a detailed facies analysis is currently being undertaken to reconstruct depositional environments and to better understand their stratigraphic and spatial distribution. Regional scale correlation of stratigraphic units in the logged drill cores will be reconstructed using carbon isotope chemostratigraphy, sequence stratigraphy and available wireline logs.

The main outcome of this study will be a detailed, regional scale, sedimentological and tectonostratigraphic framework of the middle McArthur Group in the Batten Fault Zone, in which additional data, such as geochemistry, can be integrated.

Paleoredox conditions, distal footprint evaluation, and multiple sulfur isotope geochemistry of the Barney Creek Formation

Genetic models for clastic-dominated sediment-hosted Pb-Zn deposits assume that mineralisation occurs as the result of the reaction of an oxic metalliferous brine with a reduced host rock or anoxic seawater. Therefore, it is crucial to reconstruct water column redox conditions during deposition of the Barney Creek Formation.

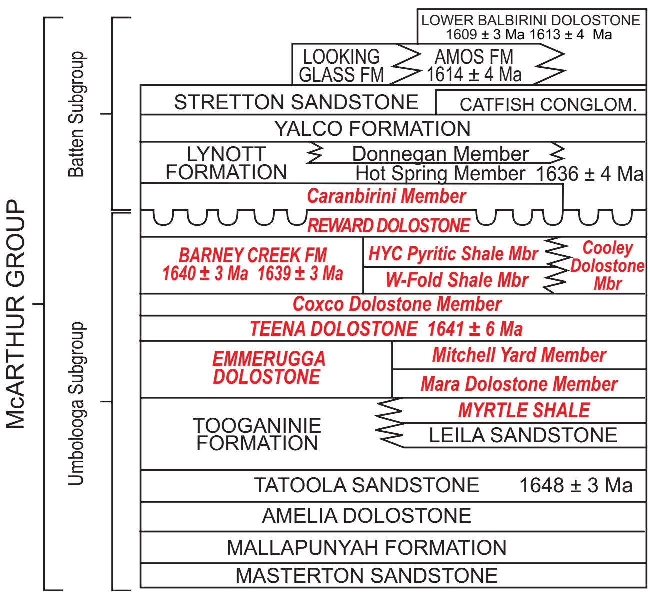

Figure 2. Stratigraphy of the McArthur Group in the Batten Fault Zone. Units in red are the focus of this project.

Furthermore, euxinia (anoxic seawater with free hydrogen sulfide) is generally considered to be of major importance as it provides a large reservoir of hydrogen sulfide for precipitation of sulfidic ore minerals. Euxinic conditions are important in both syngenetic models that assume base metals sulfide formation in the water column (Large *et al* 1998; for recent review see Wilkinson 2013), and in early diagenetic models that focus on the downward percolation of dense metalliferous brines into unconsolidated sediments (Sangster 2002) or sub-seafloor lateral migration of brines along permeable strata (Wilkinson 2013).

To further assess the stratigraphic and spatial distribution of oceanic redox conditions, we will tie a biogeochemical dataset into the geological framework established during the tectonostratigraphy study. This dataset will include iron speciation and whole rock geochemistry, with a particular focus on the redox-sensitive trace metals Mo, U, and V. This project will result in a 3D-reconstruction of the distribution of oxic, euxinic, and ferruginous (anoxic and free Fe(II)) conditions during deposition of the Barney Creek Formation in the Batten Fault Zone. This will enable us to identify regions and stratigraphic intervals that represent chemical traps for base metals, which, together with deformation and fluid flow modelling, will result in identifying potential hot spots for base metals mineralisation.

Incorporation of whole rock geochemistry into the tectonostratigraphic framework will also permit the systematic testing of the distribution of Zn, Pb, and other commodities, as well as pathfinder elements like Tl. This will allow us to systematically assess previously proposed alteration indices and potentially develop new geochemical methods to identify distal footprints.

Since base metals exploration in the McArthur Basin is focused on sulfide deposits, it is important to better understand the marine sulfur cycle during deposition of the Barney Creek Formation. This will be achieved by integrating multiple sulfur isotope geochemistry into the tectonostratigraphic framework. Multiple sulfur isotopes will provide important information on sulfate availability and the relative importance of different sulfur metabolisms during deposition.

Zn isotopic and mineralogical composition of the HYC Zn-Pb deposit

The regional scale geological and biogeochemical studies described above will be complemented by Zn isotopic and high-resolution mineralogical studies of the HYC Zn-Pb deposit at the McArthur River mine. The Zn isotopic composition of sediment-hosted Zn deposits has previously been shown to exhibit systematic variation among different deposits within a district (Kelley *et al* 2009), among different generations of sphalerite, and within individual lodes and deposits from the centre to the periphery (Zhou *et al* 2014). Rayleigh fractionation has been suggested as dominant Zn isotope fractionating process. A systematic trend of increasing Zn isotope ratios from south to north in the Red Dog district of northern Alaska, for example, has been interpreted as reflecting isotopic evolution of a Zn-bearing fluid that originated from a hydrothermal system in the south and migrated northwards. During the migration, isotopically light sphalerite precipitated at several locations, forming individual deposits, and leaving behind a progressively enriched fluid (Kelley *et al* 2009). In deposits of the Sichuan-Yunnan-Guizhou Pb-Zn district in south-western China, the Zn isotopic composition of sphalerite in individual deposits systematically increases from early to late stage sulfides, and also from the centre of the ore body to the periphery of single deposits (Zhou *et al* 2014). If these observations reflect the general behaviour of Zn isotopes in sediment-hosted mineral systems, it might be possible to apply Zn isotopes as vector towards the hydrothermal source of sediment-hosted Zn deposits.

Two complementary Zn isotope studies will be carried out at the HYC Zn-Pb deposit. The first study will focus on the bulk rock Zn isotope composition in two different drill cores, one from the centre and one from the fringe of the deposit. The second study will use a micro drill to distinguish between individual sphalerite laminae and generations using samples from the same two drill cores.

The Zn isotope studies will be supported by whole rock geochemistry and petrographic studies. Furthermore, the small size of sulfide minerals at HYC (eg Ireland *et al* 2004) highlights the need to apply high-resolution imaging techniques. Therefore, we will study the mineralogical characteristics and trace element distribution of ore samples from HYC using the Maia detector array at the Australian Synchrotron. This allows us to collect high-resolution images up to ~100 M pixels in size of entire thin sections in only a few hours (Fisher *et al* 2014). This project will shed light on the mineralising processes at HYC and will provide further insight into the distribution of certain trace elements of interest, for example the pathfinder element Tl.

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