Ore Geology Reviews 82 (2017) 170–180

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeo

Primary diagenetic copper carbonate at the Malbunka copper deposit, Amadeus Basin, Northern Territory, Australia

Erik B. Melchiorre [a,b,*], Dehne McLaughlin [c], Ralph Bottrill [d], Jay Hight [a]

[a] Department of Geology, California State University, 5500 University Parkway, San Bernardino, CA 92407, USA
[b] Department of Earth Sciences, University of California Riverside, 900 University Avenue, Riverside, CA 92521, USA
[c] Malbunka Copper Mine, 5 Tenth Avenue, West Moonah, Tasmania 7009, Australia
[d] Mineral Resources Tasmania, PO Box 56, Rosny Park, Tasmania 7018, Australia

ARTICLE INFO

Article history:
Received 17 August 2016
Received in revised form 5 November 2016
Accepted 8 November 2016
Available online 7 December 2016

Keywords:
Azurite
Malachite
Carbon isotope
Thermometry
Diagenesis

ABSTRACT

The Malbunka copper deposit, located about 220 km west of Alice Springs, in the Northern Territory of Australia, may be a rare example of primary formation of copper carbonate mineralization. This deposit consists of unusual azurite disks up to 25 cm diameter, and lesser amounts of secondary azurite crystals and malachite. Carbon isotope values of the copper carbonate minerals are consistent with formation from groundwater-dissolved inorganic carbon. Oxygen isotope thermometry formation temperature estimates are 5–16 °C above ambient temperatures, suggesting the copper carbonates formed at a depth between 0.3 and 1.6 km in the Amadeus Basin. Azurite fluid inclusion waters are rich in boron, chlorine, and other elements suggestive of dilute oil basin formation fluids. In addition, presence of euhedral tourmaline with strong chemical zonation suggest that this was a low temperature diagenetic setting. The strong correlation of structures associated with hydraulic fracturing and rich copper carbonate mineralization suggest a strongly compartmentalized overpressure environment. It is proposed that copper carbonates of the Malbunka deposit formed when deep, copper-rich formation fluids were released upward by overpressure-induced failure of basin sediments, permitting mixing with carbonate-rich fluids above. This work bears directly upon exploration for a new type of primary copper deposit, through understanding of the conditions of genesis.

1. Introduction

The Malbunka Copper Mine is located on Ltalaltuma Aboriginal Trust lands, approximately 220 km west of Alice Springs, in the Northern Territory of Australia (Fig. 1). Copper mineralization was discovered at Malbunka in the 1950s by the Aboriginal artist Albert Namatjira, and was originally known as the Namatjira Prospect. The deposit was prospected in the 1960s with bulldozer cuts and a 40 m long adit driven at 5 degrees down the slope of the anticlinal axis. The deposit was deemed to be not economic at the time, because of a low grade and small tonnage. Access to the site requires a travel permit from the Central Land Council. The site became noted in the 1970s for an unusual and attractive association of blue azurite disks on a white clay matrix. These mineral specimens were first reported in print by Sullivan (1979), where he describes azurite sun specimens from the mine that were sold at shows in Europe. The mine site is operated under Northern Territory Mineral Lease 29,494 by Dehne McLaughlin, for production of mineral specimens, with the consent of the traditional Aboriginal owners. A detailed history and description of the operations is provided in McLaughlin and Grant (2012).

1.1. Deposit geology and mineralogy

The oil-bearing Amadeus Basin, of which the Arumbera Sandstone is a distinctive member, is a sequence of marine and terrestrial deltaic-fluvial sediments deposited from the late Precambrian to the Devonian (Fig. 1). The Arumbera Sandstone is the key reservoir in the Dingo and Orange gas fields (e.g., Ambrose, 2006). It was uplifted starting in the late Devonian and faulted and folded in a major compressional event between 400 and 300 Ma (Haines et al., 2001). Seismites are common in the Arumbera Sandstone and are present in the mine site sandstone bounding the kaolinite lens (Girardi, 2012; McLaughlin and Grant, 2012).

The Malbunka copper deposit occurs in the Namatjira Formation; a mixed carbonate and clastic sequence with sandstone,

* Corresponding author at: Department of Geology, California State University, 5500 University Parkway, San Bernardino, CA 92407, USA.
E-mail addresses: emelch@csusb.edu (E.B. Melchiorre), dehne.mclaughlin@bigpond.com (D. McLaughlin), ralph.bottrill@stategrowth.tas.gov.au (R. Bottrill).

http://dx.doi.org/10.1016/j.oregeorev.2016.11.021
0169-1368/

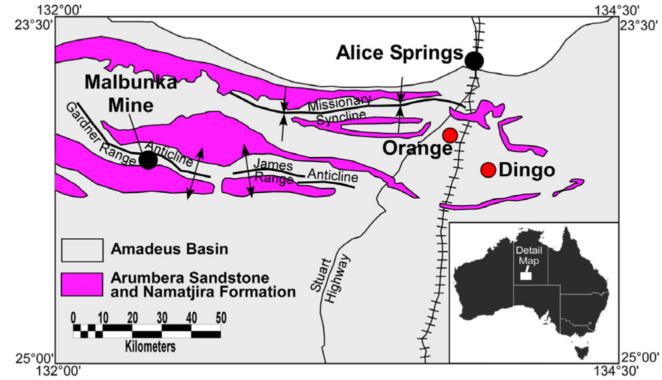

Fig. 1. Index map of the study area, showing extent of the Amadeus Basin, the Dingo and Orange gas fields, the limits of the Arumbera Sandstone and Namatjira Formation, and locations of major geological structures.

carbonate mudstone and shale. The Namatjira formation is Eocambrian in age (Lindsay, 1987; Mapstone and McIlroy, 2006), and is only known in the Gardiner Range of the Amadeus Basin. The Namatjira Formation is the lateral equivalent of the Arumbera Sandstone, as described by Warren and Shaw (1995). Edgoose (2013) advises that the Eninta Sandstone is now mapped as Arumbera Sandstone. The Arumbera Sandstone can be up to 1300 m thick and is copper-bearing over a wide area. In Ellery Creek, about 100 km from the mine, the formation hosts malachite, covellite, chalcocite, and possibly chalcopyrite and cuprite (Freeman et al., 1987). Laurie et al. (1991) also point out the affinity of copper for the Arumbera Sandstone, and postulated that these deposits formed from copper-rich basin brines. Salt diaparism and associated halotectonics in the Amadeus Basin is likely to have a base metal association and should be considered in formulating exploration strategies (Dyson and Marshall, 2005).

At the Malbunka copper deposit, disk-shaped azurite masses occur within a white to red kaolinite lens up to 2.75 m thick and bounded below and above by grey clay-rich Arumbera Sandstone (Fig. 2). The clay lens is fault-bounded with approximate lateral dimensions of 50 by 40 m and has the appearance of a channel deposit with bedding structures. This kaolinite lens occurs at the crest of the Gardiner Range Anticline and outcrops beside roadsides across the Central basin to the west and north in the West MacDonnell National Park (Cook, 1968; Fig. 1).

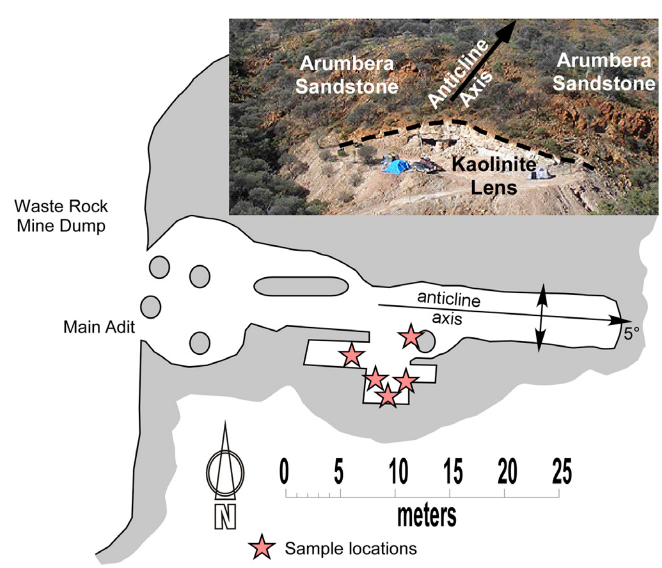

Fig. 2. Plan map of Malbunka mine workings, showing general structure and sample locations. The inset photo shows geology (blue tent and white truck for scale).

Azurite is the most common copper mineral found in the deposit. Light to deep blue disks of azurite are normally from 2.5 to 13 cm in diameter and rarely reach 25 cm in diameter (Fig. 3). These azurite specimens have a unique discoidal form, and are comprised of numerous small flat crystals of azurite arranged in radial and concentric forms (McLaughlin and Grant, 2012). They occupy bedding planes, relic thrust fault planes, and joints in the white and less commonly the red kaolinite host. The off white colour of the kaolinite in the azurite rich portions of the mineralized bed is probably due to bleaching of the clay by the mineralizing solutions (McLaughlin and Grant, 2012). Higher concentrations of iron oxide or lack of bleaching, gives the kaolinite a red colour for at least two thirds of the layer (Fig. 4). In rare cases, azurite crystal clusters (Fig. 5) and 3-dimesional rounded to oblate malachite nodules are evident in bedding planes, clefts and channels in the hanging wall, soft sediment flow planes, and fractures in the kaolinite. The azurite is at its highest concentration within 30 cm of the upper sandstone in a series of up to five thin horizontal bedding planes. In the bedding plane closest to the upper sandstone large diameter (13–25 cm) azurite specimens are found, sometimes in direct contact with the sandstone. Azurite disks, exposed in mine entrance support pillars, are also present in the kaolinite within 30 cm of the contact of the kaolinite with the lower footwall sandstone, but are not persistent throughout the footwall area of the kaolinite lens. Azurite occurs occasionally as large light blue disks in iron oxide rich kaolinite throughout the kaolinite lens.

Malachite is occasionally found in the deposit, and occurs in two forms. The first, and most common, is as disks of oblate spheroidal or ellipsoid forms which appear to be unrelated to pseudomorphous replacement of azurite (Fig. 6a). These forms rarely exhibit crystal growth structures. The second, and rarer malachite occurrence, is pseudomorphous replacement of azurite disks. These often display faithful crystal replacement (Fig. 6b). Atacamite is abundant in the upper and lower sandstone, and rims the kaolinite-sandstone contact, and occurs as disseminated fine-grained crystals. Chrysocolla is rare in the deposit, and has only been reported from the lower sandstone in association with atacamite (McLaughlin and Grant, 2012). Traces of chalcocite, covellite, digenite, and cuprite are also reported as fracture fillings and small masses. A highly fractured and copper-mineralized zone which may have served as a primary fluid conduit is exposed below the clay unit.

The unusual occurrence of azurite as flattened disks was attributed by Sullivan (1979) to azurite replacement of marine life or algae. Warren and Shaw (1995) report that the lower Arumbera Sandstone has yielded specimens of the soft-bodied Ediacarian fauna and that there is a diversity of trace fossils in the upper Arumbera Sandstone. The Ediacarian organism *Dickinsonia costata* does indeed bear a crude resemblance to the general size and shape of the azurite disks, as does *Aspidella terranovica* (Fig. 7).

2. Methods

2.1. Sample preparation and mineralogical characterization

Samples of azurite and malachite were collected and cleaned of white clay matrix. For each locality, a single disk or nodule was selected, then subdivided for analysis by different methods. Material for scanning electron microscope (SEM) and electron microprobe (probe) analysis were prepared using the standard methodology of microanalysis laboratories around the world (e.g., Goldstein et al., 2003; Reed, 2005). Samples for stable isotope