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Early deformation in the Eastern Goldfields, Yilgarn Craton, Western Australia: A record of early thrusting?

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ABSTRACT

The earliest pervasive deformation events in the Archaean Eastern Goldfields Superterrane of the Yilgarn Craton are partly obscured by subsequent deformation and pre-date rocks exposed over large areas. As a result, uncertainty exists about the nature, timing and role that early deformation events played in controlling regional architecture and gold mineralization in this world-class metallogenic province. The Daisy Milano mining camp in the southern Kurnalpi Terrane has opened up new exposures in relatively old geological sequences, which record structures that pre-date the main ENE-WSW D_2 shortening event. These D_1 structures represent the earliest pervasive deformation events in the Eastern Goldfields Superterrane and are characterized by a pervasive bedding-parallel foliation ($S_1//S_0$) that accommodated NW-verging thrusting. The same foliation planes also accommodated normal movement verging to the SE, interpreted to indicate periods of stress relaxation. Alternatively, thrusting and normal movement could have been contemporaneous, defining a pure shear event. D_1 structures are overprinted by steeply dipping, NNW-striking foliation planes that are axial planar to folds and local crenulation cleavage (F_2 folds). This second foliation is parallel to and overprints post-D_1, sub-vertical, plagioclase-phyric tonalite dikes, at the margins of which the Daisy Milano gold deposits formed. Deposits occur stratigraphically below moderately SW-dipping ultramafic layers that are sub-parallel to the early thrust foliation and acted as impermeable caps to mineralizing fluids. Mineralization occurs also in NE-SW to ENE-WSW quartz veins in the hinge zones of open and gently plunging F_2 folds in a competent dolerite sill. Mineralization was either synchronous with or post-dated D_2. Two samples of tonalite dikes at Daisy Milano were analyzed using zircon LA-ICP-MS U–Pb geochronology and yielded ages of 2687 ± 7 Ma and 2676 ± 9 Ma, placing an upper bound on the timing of D_2 and gold mineralization at Daisy Milano, and a lower bound on the timing of D_1.

1. Introduction

The concentration of orogenic "lode" gold deposits in the Eastern Goldfields Superterrane in the Yilgarn Craton has led to considerable efforts in understanding the nature, history and geometry of its rock sequences. Gold mineralization is controlled by structures, as well as lithological and structural complexity, which create the necessary conditions for focusing migration of mineralizing fluids (Davis et al., 2010; Hodkiewicz et al., 2005; Weinberg et al., 2004). The relative timing between mineralization and structural evolution of the Eastern Goldfields Superterrane has been a matter of great interest and debate. While many deposits may have been formed late in the structural evolution (Davis et al., 2001; Groves et al., 2000), there is evidence for protracted mineralization (Bateman et al., 2001; Bucci et al., 2004; Davis et al., 2010; Davis and Maidens, 2003; Witt, 2001). Weinberg and van der Borgh (2008) have argued that some small deposits in the region of Leonora were associated with the earliest, D_1, and the latest, D_5, extensional events. In any case, early structures played a significant direct or indirect role in controlling gold deposition (e.g., Miller et al., 2010). However, little is known about the nature of the earliest structures because of overprinting by later deformation, or because it is simply not recorded by the younger rocks exposed.

The nature of the first deformation event, D_1, has proven to be elusive and has been used to include any structure that pre-dates the well-developed ENE-WSW shortening D_2 event. The southern part of the Kurnalpi Terrane (Fig. 1) is composed of rock sequences ranging in age from 2720 to 2690 Ma (Barley et al., 2008). These

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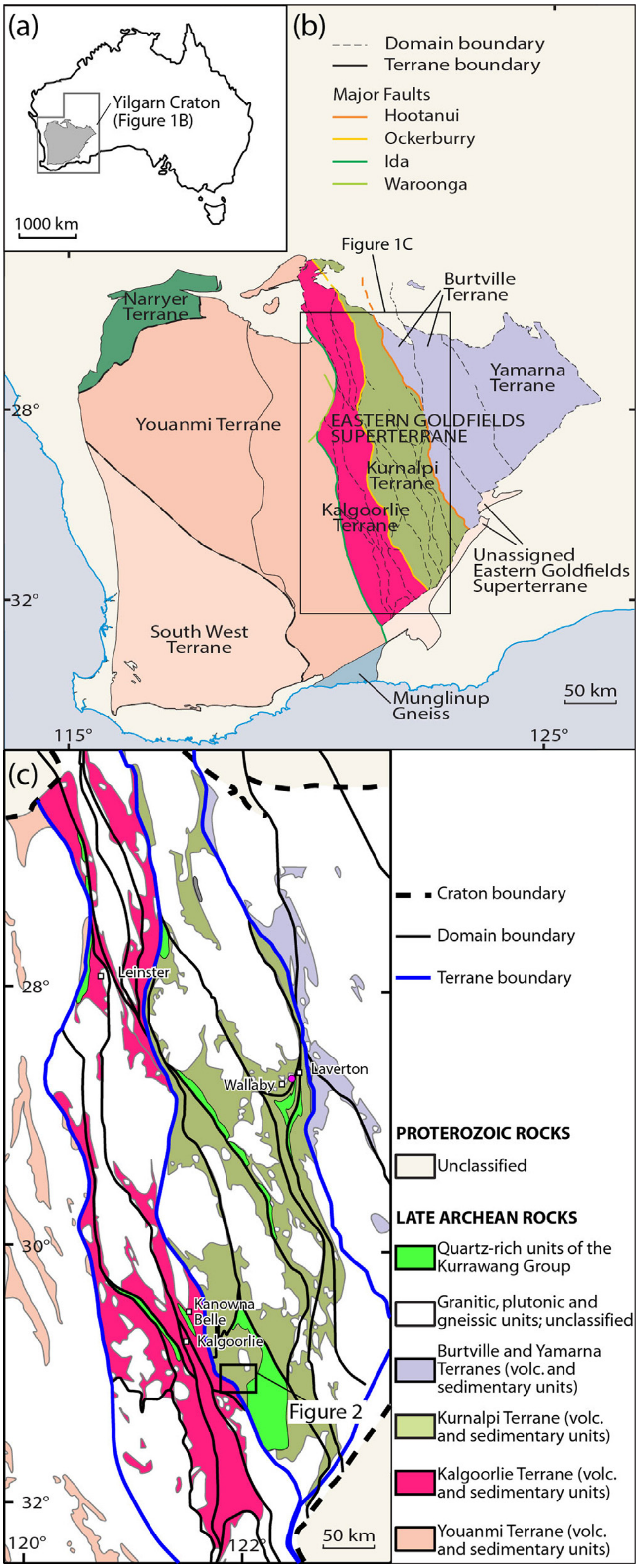

Fig. 1. Simplified geological maps of the basement rocks in the Yilgarn Craton, Western Australia. (a) Location of Yilgarn Craton in Australia. (b) Location of Kalgoorlie, Kurnalpi, Burtville, and Yamarna Terranes of the Eastern Goldfields Superterrane in the eastern Yilgarn Craton. (c) Simplified geological map of the Kalgoorlie and Kurnalpi Terranes. The location of Fig. 2 is shown. Figures modified after McGoldrick et al. (2013).

are relatively old compared to rocks exposed in the better known Kalgoorlie Terrane to the west. Recent open-cut mining in the Daisy Milano mining camp in the Kurnalpi Terrane provides an opportunity to access quality exposures and drill cores recording early structures. We start this paper with a brief summary of the current views on the structural evolution of the Eastern Goldfields Superterrane and a short description of the geology of the Kurnalpi Terrane and of the mining camp. This is followed by a structural study of the mining camp. We number the structures described according to their local overprinting relationships, and subsequently discuss their link to the regional deformation events. We then present U–Pb zircon dating results of two tonalite intrusions dikes and use the results to bracket the timing of D_1 and gold mineralization.

2. Regional geology

2.1. Structural evolution

Earlier work divided deformation in the Eastern Goldfields Superterrane into four main crustal shortening phases, D_1–D_4 (e.g., Swager, 1997; Weinberg et al., 2003b; Witt and Swager, 1989), and more recently other deformation events have been added, modifying this early framework to account for more detailed data and to include extensional events (e.g., Blewett et al., 2010; Czarnota et al., 2010; Weinberg and van der Borgh, 2008). As summarized in Blewett et al. (2010), major extension occurred during basin development and deposition of the greenstone sequences in the Eastern Goldfields between 2720 Ma and 2670 Ma (e.g., Groves and Batt, 1984; Hammond and Nisbet, 1992; Miller et al., 2010; Squire et al., 2010; Swager and Griffin, 1990; Swager, 1997; Williams and Currie, 1993; Williams et al., 1989; Williams and Whitaker, 1993). This extensional event is thought to control the broad NNW-trending grain of the region (Blewett et al., 2010), but just how these earliest structures are inferred and interpreted remains ambiguous (Miller et al., 2010).

In the central-northern part of the Kalgoorlie Terrane, D_1 has been described as an extensional phase of isoclinal recumbent folding and subhorizontal nappe-type movement (Archibald et al., 1978; Martyn, 1987; Williams and Currie, 1993). Passchier (1994) described a poly-directional extensional event related to the development of early recumbent folds. High-grade granitic domes were interpreted as early metamorphic core complexes developed during extension and post-dating greenstone deposition (Williams and Whitaker, 1993). Foliations at the outer margins of one such dome close to Leonora, in the central-northern part of the Kalgoorlie Terrane, have radial, down-dip lineation and record normal movement indicative of granite dome exhumation in relation to the surrounding greenstone sequence (Weinberg and van der Borgh, 2008). Structures in this area were interpreted by these authors to result from poly-directional extension, contemporaneous with granite doming rather than a metamorphic core complex (Williams and Currie, 1993), which is typically associated with uni-directional extension.

As noted by Swager (1997), evidence for early extension in the southern part of the Kalgoorlie Terrane is ambiguous, although he accepted that extension may have preceded the first major shortening D_1 event that he and others documented. D_1 shortening south of Kalgoorlie is characterized by major north-verging thrusting (Knight et al., 1993; Martyn, 1987; Swager and Griffin, 1990; Witt and Swager, 1989) leading to regional scale recumbent folds and repetition of the stratigraphy (Martyn, 1987; Swager, 1997). Martyn (1987) suggested that most, if not all contacts between mafic–ultramafic assemblages and felsic volcanic-sedimentary suites in the Mount Hunt area south of