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Incremental pluton emplacement during inclined transpression

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ABSTRACT

Multidisciplinary investigations suggest that many igneous plutons were assembled incrementally, through emplacement of discrete magma batches. Internal pluton contacts between different units can be remarkably cryptic and/or complex in nature. This presents a major challenge in understanding both how repeated intrusions were emplaced relative to each other, and in their relationships with regional deformation. Here we present the results of a multidisciplinary study from a Neoarchean pluton exposed in the Yilgarn Craton of Western Australia. Our new structural, geophysical, geochemical and geochronology datasets indicate that the pluton was emplaced incrementally along an active, inclined transpressional shear zone. Structural relationships indicate that magmatic to high-temperature solid-state fabrics locally postdate a mid- to upper-greenschist tectonic fabric in an adjacent older unit. We consider these relationships as diagnostic of incremental emplacement, indicating that the shear zone recorded several cycles of strain softening and hardening, in relation to the syntectonic emplacement of discrete magma pulses, followed by syndeformational cooling down to upper-greenschist facies conditions. Our data also suggest that pluton growth occurred through over-accretion of progressively more evolved magma pulses.

1. Introduction

Recent multidisciplinary investigations, namely increasingly precise geochronology and high-quality geophysical data, indicates that many plutons result from accretion of discrete, smaller bodies, reflecting repeated pulses of magmatic activity (de Saint Blanquat et al., 2011 for a review). This relatively new view contrasts with the classical assumption that plutons represent a single magma intrusion emplaced in the crust quasi-instantaneously. Numerical simulations indicate that magma composition, emplacement rates of individual magma batches, cooling rates and emplacement geometry are key factors controlling the fate of a pluton emplaced incrementally and its relationships with the tectonic environment (Annen, 2011).

The concept of incremental pluton emplacement has several implications for the spatial and temporal thermal evolution of the continental crust, for the style and spatial distribution of metamorphism, partial melting and assimilation of country rocks. This growing body of knowledge poses substantial challenges to field geologists to reconcile geochronology and geophysical data with field observations. In fact, boundaries between distinct magma batches can be both remarkably cryptic (Annen, 2011) and extremely complex (e.g. Žák and Paterson, 2005). Hence, a major challenge is to understand how subsequent magma batches were emplaced relative to each other, within the same pluton. In other words, there is a need to identify mesoscale and microscale criteria diagnostic of incremental pluton emplacement (de Saint Blanquat et al., 2011).

Other challenges arise from establishing the relationship between incremental pluton emplacement and shear zone evolution. During orogeny, significant pressure gradients can be generated along steep crustal-scale structures, allowing for the cyclical and efficient extraction of overpressurized melt from its deep crustal source (de Saint-Blanquat et al., 1998). Rheological models suggest that feedback between deformation and magmatism in oblique-slip fault systems may induce short-lived and cyclical weakening-then-hardening of the continental crust, in relation to episodic and repeated channelling of magma batches along steep structures (Handy et al., 2001). Such transient rheological fluctuations should produce multiple superposed fabrics, where, for example, early magmatic structures are overprinted by high- to moderate-temperature solid-state fabrics, in turn postdated by younger magmatic events. However, to the best of our knowledge, such field examples have rarely been described.

In this paper we present a case study from a Neoarchean pluton exposed in the Yilgarn Craton of Western Australia. Our new data show the nature of superposition of subsequent generations of magmatic and solid-state fabrics, and provide some meso- and microstructural criteria that we interpret as diagnostic of syntectonic incremental pluton emplacement. Structural constraints are then combined with recently acquired geophysical, geochemical and geochronology datasets, to provide insights into the four-dimensional evolution of the pluton.

2. Geological setting

The Youanmi Terrane forms most of the western half of the Archean Yilgarn Craton (inset in Fig. 1) and includes ca. 2960–2720 Ma greenstone successions intruded by ca. 2815–2600 Ma granitic rocks

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(Van Kranendonk et al., 2012). Field and geophysical data indicate that the Youanmi Terrane is dissected by a network of terrane-scale shear zones (length >100 km, Fig. 1 in Zibra et al., 2013b). In some domains these structures may be parts of conjugate systems, in which simple shear-dominated segments are linked by pure shear-dominated zones, reflecting a prolonged period of far-field east–west shortening (Chen et al., 2001). Where exposed, these shear zones generally show a steep gneissic foliation, associated with a shallow-plunging mineral or stretching lineation (Vearncombe, 1998).

We studied the Cundimurra Shear Zone (Fig. 1), which includes the Cundimurra Pluton (Zibra, 2011) and its metamorphic aureole, developed within host greenstones. This shear zone is partly equivalent to the southernmost portion of the "Meekatharra Structural Zone" (Spaggiari, 2006). Geochronology and field data indicate that the Cundimurra Pluton postdates emplacement of the adjacent Lakeside and Yarraquin plutons (Fig. 1). The latter are approximately N-trending composite batholiths associated with migmatites (ca. 100 by 50 km-wide in map view), which were linked to large-scale, syn-magmatic shear zones, not readily detectable in geophysical images (cf. Figs. 6 and 7 in Wyche et al., 2013), accommodating the emplacement of granite–migmatite domes at ca. 2700 Ma (Zibra et al., 2013b).

The Cundimurra Pluton is north-trending and approximately 185 km-long, with its long axis subparallel to the trend of the major terrane-scale structures (inset in Fig. 1). Near the northern termination it is ca. 3–5 km wide, where it is truncated by the post-tectonic Garden Rock Granite (emplaced at ca. 2617 Ma, Table 2). In the generally poorly-exposed southern part it reaches a maximum width of ca. 30 km (Fig. 1), occupying a total area of about 2360 km^2. The pluton intruded at the present-day base of the ca. 2830–2800 Ma Norie Group (Van Kranendonk et al., 2012; Zibra, 2011). Primary intrusive relationships are generally preserved, as indicated by granite and pegmatite dykes within the present-day base of greenstone units, and by metre-

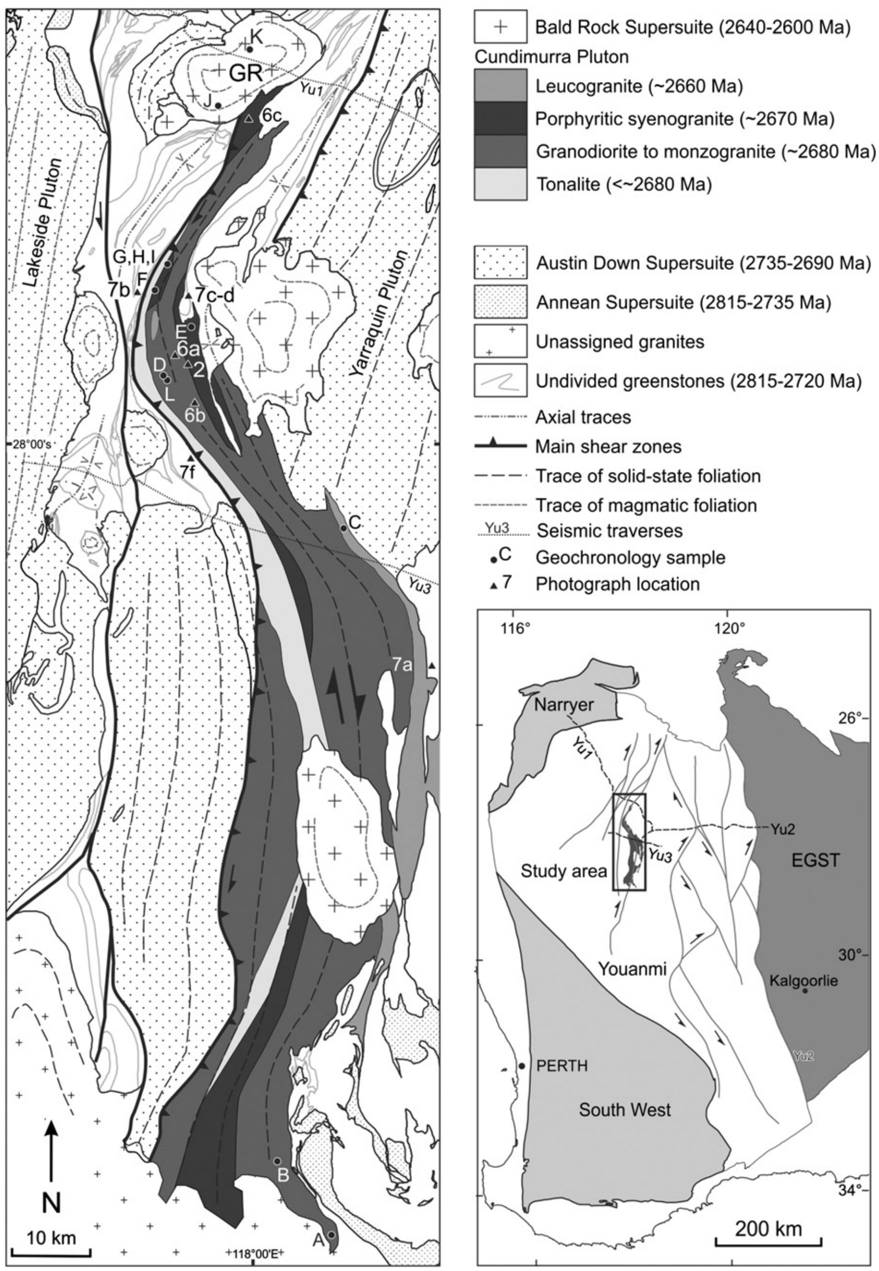

Fig. 1. Geological sketch map of the Cundimurra Pluton. Letters (A–N) show location of geochronology samples. Numbers indicate location of corresponding field photographs. "GR" indicates the Garden Rock Granite. Inset in the lower right corner shows the location of the studied pluton in the context of the terrane-scale shear zone network in the central part of the Yilgarn Craton. Terrane nomenclature after Cassidy et al. (2006).