Assembly of a composite granite intrusion at a releasing bend in an active Archaean shear zone

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Abstract

The Wallareenya extensional jog developed between c. 2955 and 2940 Ma at a releasing bend in the northeast-trending Tabba Tabba Shear Zone, in the Archaean Pilbara Craton of northwestern Australia. The extensional jog, or pull-apart, formed during transtensional movement along the shear zone, and was simultaneously filled by a sequence of magmas ranging in composition from gabbro to monzogranite. Magmas were emplaced through fractures that broadly conform to Riedal R1 and R2, and P fracture directions and segment the area into diamond-shaped blocks. Some of these fractures formed conduits that were used by up to five magma generations. Space for emplacement was created primarily through active extension within the evolving jog, and the emplacement age of the magmas decreases systematically westwards, tracking a paralleled migration in the main focus of extension. Away from fractures and magma conduits, horizontal sheeting shows that the magmas spread out laterally at suitable horizons such as the contact with overlying metasedimentary country rocks.

KEYWORDS: Pilbara, Western Australia, igneous intrusion, emplacement mechanism, Archaean

Introduction

A close spatial relationship has been recognized between granitic rocks and crustal-scale strike-slip shear zones and fault systems that are thought to act both as migration pathways and sites of magma emplacement (Hutton, 1988; D'Lemos et al., 1992; McNulty et al., 1996). Dilational domains, such as extensional jogs, or pull-apart structures, en echelon P-shear arrays, tension gashes, extensional duplexes, and fault splays have all been indicated as potential emplacement sites within such shear zones and fault systems (Speer et al., 1994; McNulty et al., 1996). Emplacement into these sites is thought to be passive, with simultaneous dilation and magma filling (Brown, 1994), with other processes such as ballooning by magma flow and stoping playing a local and less important role. However, the specific process by which space for magma emplacement is created is commonly obscured through a lack of preserved growth history (McNulty et al., 1996).

This study documents an Archaean composite intrusion that was emplaced into an extensional jog at a releasing bend of the crustal-scale Tabba Tabba Shear Zone, in northwestern Australia (Fig. 1). This well-exposed region has undergone only minor deformation after the development of the shear zone. A combination of geochronological studies (Nelson, 2000, 2001) and well-constrained field relationships permits an evaluation of the interrelated structural and magmatic history of the extensional jog, including magma emplacement mechanisms.

Geological setting

The Tabba Tabba Shear Zone forms the southern margin of the eastern part of the Archaean Mallina Basin and separates that basin from older crust to the southeast (Fig. 1). The east-northeasterly trending basin is one of the youngest components of the Pilbara granite–greenstone terrain and developed as an intracontinental rift basin through at least three depositional cycles or basin-forming events between c. 2970 and 2935 Ma (Smithies et al., 1999, 2001).

Preserved basin margins are either unconformities or fault zones. The northeast-trending Tabba Tabba Shear Zone can be traced for approximately 100 km, but becomes increasingly obscure, both in outcrop and in its geophysical expression, to the southwest, where it appears to terminate into a series of splays within the rocks of the Mallina Basin.

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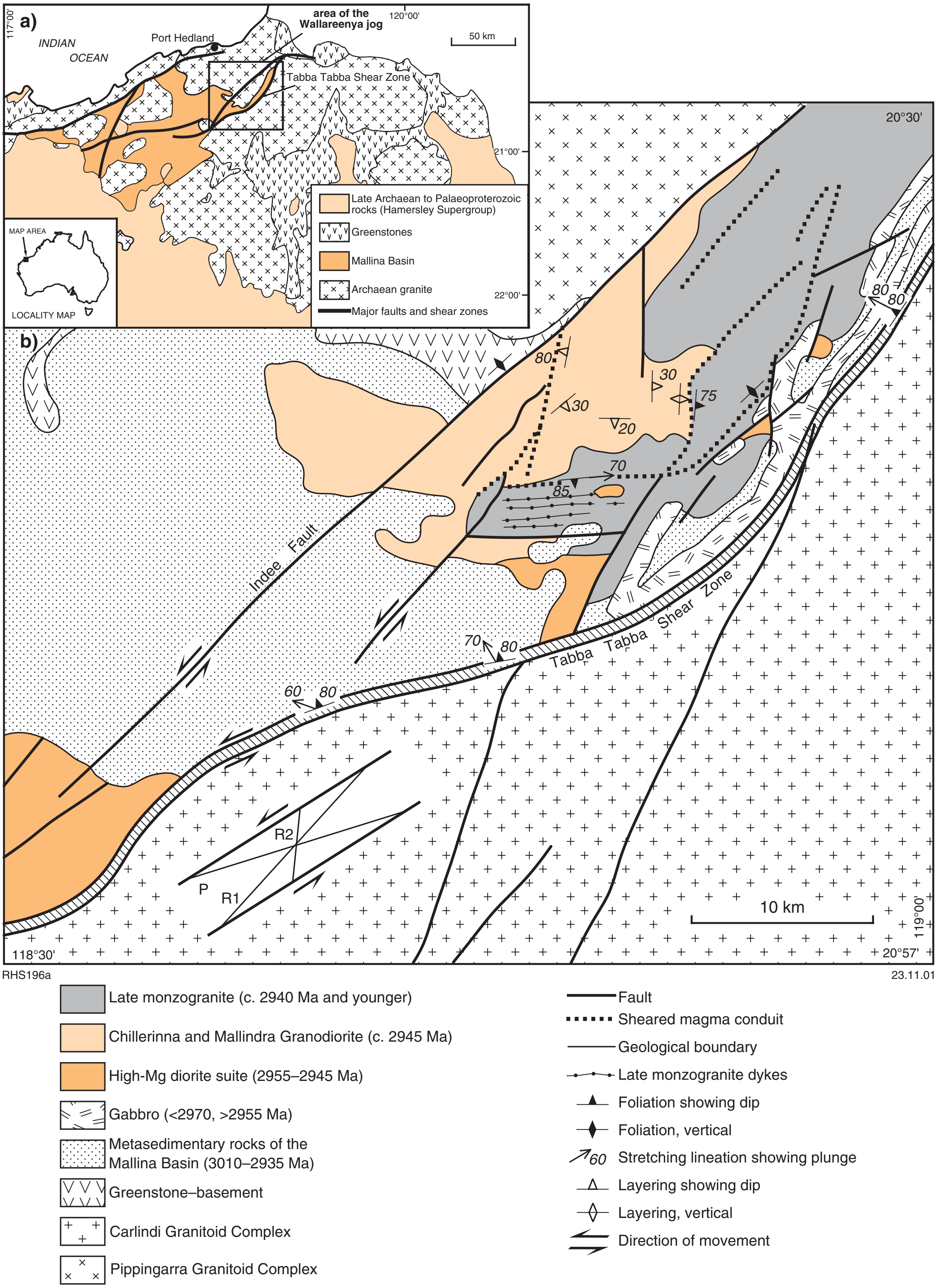

Figure 1. a) Simplified geological map of the Pilbara Craton, showing the area of the Wallareenya jog; b) Geological map of the Wallareenya area, showing the major feature of the Wallareenya jog and summary structural data. Common fracture orientations within an idealized brittle layer are also shown

Between c. 2955 and c. 2935 Ma the emplacement of locally voluminous intrusions in and marginal to the Mallina Basin was influenced by fault or shear zones or both (Smithies and Champion, 2000). Magma compositions changed significantly and systematically throughout this period from gabbroic to dioritic and grano-dioritic to granitic (Smithies and Champion, 2000). Stress regimes associated with the developing basin also changed throughout this period, from renewed extension during the 2950–2935 Ma depositional phase, to north–south compression and folding, which began at about c. 2935 Ma. The full range of this magmatism is present in the Wallareenya area (Fig. 1), adjacent to a bend in the Tabba Tabba Shear Zone.

Tabba Tabba Shear Zone

In the eastern part of the Mallina Basin, the Tabba Tabba Shear Zone forms a northeast-trending and steeply northwest dipping zone up to 3 km wide (Fig. 1). It comprises a belt of strongly foliated clastic rocks, chert, banded iron-formation, granitoids, and ultramafic to mafic intrusive and extrusive rocks, with an anastomosing system of locally mylonitized rock. The shear zone is distinctly sinusoidal in plan view, and stretching lineations, rotated phenocrysts, and S–C fabrics show that the latest major movement was dominantly normal (northwest-side down), but with a significant sinistral component. This movement reflects a generally transtensional regime, which has been correlated with the c. 2950–2935 Ma depositional phase of the Mallina Basin (Smithies et al., 2001).

Normal and sinistral movement along the sinusoidal shear zones caused extension at releasing bends (i.e. an extensional jog or pull-apart structure), and these areas appear to have been exploited by intruding magmas. Intrusive rocks account for approximately two-thirds of the exposed area within the Wallareenya extensional jog. These rocks are well exposed and detailed mapping provides a clear picture of the large-scale fault structures relating to this jog (Fig. 1). The extensional jog comprises an extensively faulted zone up to 15 km wide between the Tabba Tabba Shear Zone and the northeast-trending Indee Fault. The well-developed pattern of faults and dykes within the jog broadly conforms to Riedal R1 and R2, and P fracture directions, segmenting the area into diamond-shaped blocks, each roughly parallel to the overall orientation of the jog. The development of strong internal post-full crystallization fabrics within the granites is restricted to zones that parallel fracture planes; generally, the rocks are only weakly deformed or show well-developed magmatic foliations, consistent with passive emplacement. In the section below we outline the magmatic evolution of the Wallareenya jog.

Early gabbro

The earliest intrusive rocks within the Wallareenya jog form elongate bodies of gabbro. Although not directly dated, they intruded younger than 2970 Ma siliciclastic rocks of the Mallina Basin and were intruded by rocks of the 2955–2945 Ma Pilbara high-Mg diorite suite. The gabbro is exposed adjacent to the Tabba Tabba Shear Zone, in the southeastern part of the jog. The two elongate bodies continue northeastward, subparallel to the shear zone (Fig. 1). The gabbro outcrop forms what appears to be two consecutive doubly plunging folds. However, this structure actually resulted from the structurally controlled emplacement of the gabbro into northeast and east-northeast fractures that mark the earliest recognizable stages in the development of the Wallareenya jog.

Pilbara high-Mg diorite suite

Rocks of the Pilbara high-Mg diorite suite intrude into and to the west of the gabbro (Fig. 1). One of the diorites has been dated at 2954 ± 4 Ma (Nelson, 2000), consistent with the age of the suite elsewhere, which has been well constrained to between c. 2955 and c. 2945 Ma (Smithies and Champion, 2000). In the Wallareenya area, intrusions within the high-Mg diorite suite range from diorite to tonalite and granodiorite, and appear to have used some of the same fractures along which the gabbro intruded. West and south of the Wallareenya jog, this suite forms a linear belt of subvolcanic plutons that parallels the axis of the Mallina Basin for about 150 km. This linear pattern of intrusions suggests that the transport and emplacement of magmas within this belt was structurally controlled, probably by early basin-forming faults in the basement.

Chillerinna Granodiorite

The biotite–hornblende granodiorite to monzogranite phases of the Chillerina Granodiorite were emplaced into the Wallareenya jog at c. 2945 Ma (two samples dated at 2946 ± 3 and 2945 ± 2 Ma; Nelson, 2001). Closely related to these rocks in both composition and age are hornblende–biotite gabbro to granodiorite and tonalite intrusions collectively referred to here as the Mallindra Granodiorite. The Chillerina and Mallindra Granodiorites outcrop west of the early gabbro and the high-Mg diorite suite (Fig. 1). Both contain abundant evidence for structural controls on emplacement, in particular, shear zones that were active during (and after) emplacement.

In the central-western part of the granodiorite body, plagioclase porphyritic granodiorite has been affected by north-northeasterly trending faulting. Away from the fault, plagioclase alignment defines a magmatic flow-foliation that parallels the fault plane, suggesting that this structure may have controlled magma emplacement. Closer to the fault, this foliation is progressively overprinted by a post-magmatic (post-full crystallization) schistosity that also parallels the fault plane.

In the central portion of the Chillerinna Granodiorite, large pendants of metasedimentary rocks belonging to the Mallina Basin show that only the roof of the pluton is exposed. Importantly, while large roof-pendants are preserved, metasedimentary xenoliths are not abundant, suggesting that stoping was not the primary means of creating space for the intruding magmas.

Throughout the central portion of the Chillerinna Granodiorite, the granodiorite has been intruded, on a

Figure 2. a) Layering or banding produced by intrusion of leucocratic monzogranite into granodiorite. The scale of layering varies within a single outcrop from centimetre to millimetre scale (lens cap is ~5 cm in diameter); b) Finer scale layering than that shown in (a). Here, the layering has been chaotically folded; however, neither monzogranite or granodiorite shows significant mineral elongation or flattening, or other evidence for significant deformation in the solid state (lens cap2 is ~5 cm in diameter)

centimetre to millimetre scale, by sheets of coarse-grained and locally K-feldspar porphyritic leucocratic biotite monzogranite, with locally entrained schlieric wisps of host granodiorite (Fig. 2a). Sensitive high-resolution ion microprobe (SHRIMP) U–Pb dating of zircon (Nelson, 2001) indicates that the monzogranite (2940 ± 2 Ma) is only marginally younger than the granodiorite (2945 ± 2 Ma). These sheets collectively form up to 40% of the outcrop, producing a conspicuous layering. This layering is locally chaotically folded (Fig. 2b), but neither rock shows evidence for strong solid-state deformation, and so the folding almost certainly reflects synmagmatic movements within the magma chamber. More typically, the layering dips gently (<30°) but does not follow any regional or local pattern of deformation (Fig. 1). It possibly parallels an undulating upper contact between the granodiorite and its metasedimentary host rocks.

Along the eastern margin of the Chillerinna Granodiorite, the granodiorite–monzogranite layering steepens into a near-vertically dipping shear zone (Fig. 1). The trend of this shear zone varies from north to northeast, conforming to common fracture sets within the Wallareenya jog. Deformation within the shear is heterogeneous. Many areas are characterized by a well-developed schistosity, with a steep (>70°) stretching lineation that indicates a predominant vertical component of movement. However, the steeply dipping layering is locally only weakly deformed and preserves a magmatic fabric produced by flow-attenuated schlieren of granodiorite in monzogranite. In some unstrained zones within the shear zone, weakly to undeformed, but flow-foliated, monzogranite contains abundant xenoliths derived from numerous distinct phases of rocks of the high-Mg diorite suite and the Chillerinna Granodiorite. In a single outcrop, up to five individual magma batches can be recognized, sometimes including xenoliths in xenoliths and both sheared and unsheared varieties. We suggest that this shear zone is a magma conduit that was repeatedly exploited during evolution of the jog.

Late monzogranite

Highly leucocratic and variably K-feldspar porphyritic monzogranite has been intruded throughout the Wallareenya jog, crosscutting all previous lithologies (Fig. 1). SHRIMP U–Pb zircon ages range from 2940 ± 3 to 2928 ± 6 Ma (Nelson, 2001). The Petermarer Monzogranite is the largest and most homogeneous body, comprising massive to strongly flow-foliated monzogranite that is petrographically and chemically very similar to the monzogranite sheets intruding the central portion of the Chillerinna Granodiorite. Southeast of the Chillerinna and Mallindra Granodiorites, the late monzogranites form a composite intrusion of fine- to medium-grained rocks, locally containing abundant xenoliths of gabbro, granodiorite, monzogranite, and metasedimentary rock.

There are sheared magma conduits similar to the one described from the Chillerinna Granodiorite. Again, these shears are at or near the contacts between discrete intrusive bodies, with dominantly east-northeasterly and northeasterly trending orientations. In the southern part of the Wallareenya jog, fine-grained monzogranite also forms a series of east-northeasterly trending dykes.

Discussion

The present expression of the Tabba Tabba Shear Zone is the result of movement that postdated the main (2970–2955 Ma) depositional phase of the Mallina Basin. The relationship between the development of the Wallareenya jog and the emplacement history of magmas indicates that the shear zone was active, at least periodically, from before 2955 to c. 2945 Ma. Dating of a strongly foliated late monzogranite (Nelson, 2001) that has intruded the south-eastern edge of the Tabba Tabba Shear Zone extends the period of activity to at least 2940 ± 3 Ma. This period coincides with the latest depositional event within the Mallina Basin, estimated to have occurred between 2950 and 2935 Ma, based on the ages of detrital zircons and the age of syntectonic granite intrusion into the western parts of the Mallina Basin. The presence of gabbro and high-Mg diorite shows that the Tabba Tabba Shear Zone provides a control on the migration and emplacement of mantle-derived magmas (e.g. Smithies and Champion, 2000) and is of crustal scale.

The Wallareenya jog is a dilational jog or pull-apart structure that formed at a releasing bend in the Tabba Tabba Shear Zone during transtensional movement defined by north-block-down and sinistral displacement. The diamond-shaped jog comprises a remarkably continuous and well-developed mosaic of smaller, northeast-orientated diamond-shaped segments, defined by a network of faults, dykes, and sheared magma conduits that conform to Riedal R1 and R2, and P fracture directions (Fig. 1). The developing jog provides a mechanism that is interpreted to have controlled the emplacement of magmas, and can account for the distinct westward temporal migration in the emplacement age of magmas from <2970–2955 Ma gabbro to the 2955–2945 Ma high-Mg diorite suite to the c. 2945 Ma Chillerinna Granodiorite (Fig. 3). This relationship records a progressive westward migration in the main focus of extension within the jog, culminating in the development of the Indee Fault, and provides evidence that active extension within the jog provided the primary mechanism for creating space for simultaneous, passive magma emplacement. There is no evidence that processes such as stoping provided significant space for magma emplacement.

Magma conduits preserved within the Wallareenya jog have been used by several (up to five) separate magma batches, and have also been active zones of deformation throughout this multiple intrusive history. The clearest evidence for this is the presence of multi-generation xenolith suites, including xenoliths in xenoliths, showing a range in the degree of post-full crystallization deformation. Conduits that include xenoliths of gabbro, high-Mg diorite, Chillerinna Granodiorite, and late monzogranite have been exploited by migrating magma, at least periodically, for up to 15 m.y.

The Wallareenya jog is a well-exposed example of fracture-controlled emplacement of magmas into dilational zones related to major active shear zones. The pronounced and gently dipping layering produced by multiple sheeting of the Chillerinna Granodiorite by slightly younger monzogranite indicates that the magmas spread out laterally from these near-vertical conduits to be emplaced as sheet complexes at suitable horizons, such as the contact between the granodiorite and overlying metasedimentary rocks.

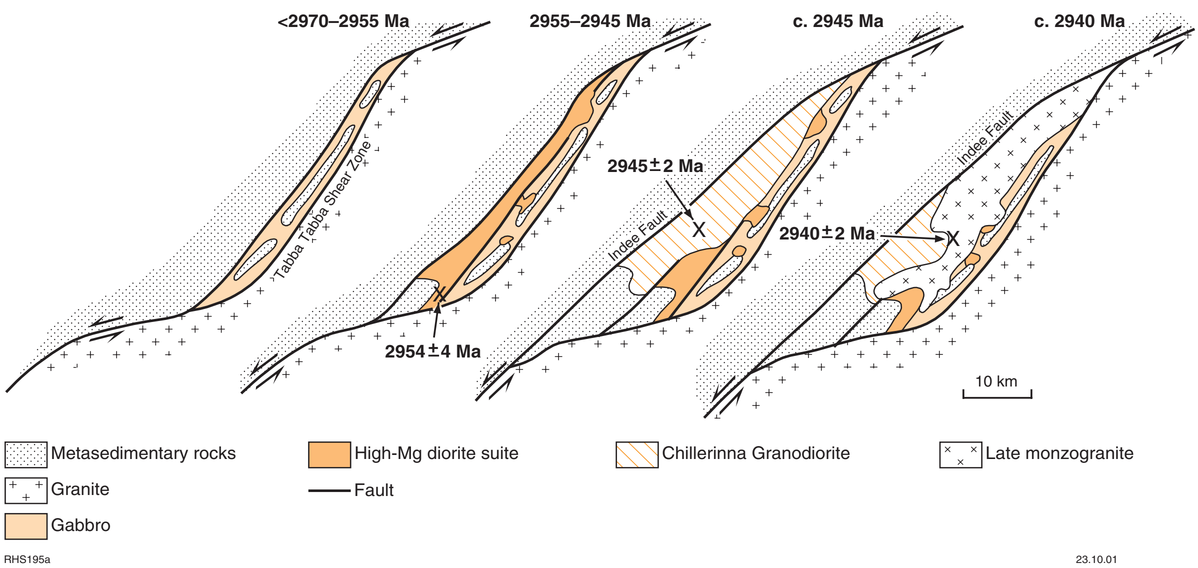

Figure 3. Sketch showing the interpreted geological evolution of the Wallareenya jog

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