

Aspects of Palaeoproterozoic orogenesis in the Gawler Craton: the c. 1850 Ma Cornian Orogeny



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Introduction

Deciphering the geological evolution of Precambrian terranes is an inherently difficult task since the boundary conditions that influenced the tectonic events recorded in the rock record are typically absent¹. Consequently, the palaeoconfigurations of Precambrian cratons and terranes are subject to much discussion, leading to the many debates as to the nature of various supercontinents in Earth history (e.g. Rodinia, Columbia) or as to the Proterozoic evolution of Australia (Myers, Shaw and Tyler 1996; Betts and Giles 2006; Neumann and Fraser 2007). Nevertheless, tools such as zircon geochronology are able to resolve aspects of the regional geological evolution in typically polydeformed and often gneissic Precambrian terranes (e.g. Moller et al. 2007).

In South Australia the major Precambrian terrane, the Gawler Craton, suffers not only from a lack of outcrop, but also from a comparatively small number of focused geochronological and geological studies able to define the regional tectonometamorphic evolution. Consequently, the framework within which mineral systems such as Olympic Dam or Challenger deposits developed has remained enigmatic. As highlighted by Hand, Reid and Jagodzinski (2007), significant ambiguities remain in terms of the timing and spatial distribution of the tectonic events within the craton, the tectonic settings of the major magmatic systems and the crust–mantle evolution of the craton through time. Since the development of effective mineral exploration strategies is increasingly reliant on integrated, data-

rich tectonic models, it is likely that the lack of systematic tectonic analysis has been a factor in companies deciding not to undertake exploration in greenfield regions and is potentially hindering current exploration programs.

Recent publication of historical zircon geochronology (Fanning, Reid and Teale 2007) and an emerging body of work from university researchers (Teasdale 1997; Betts, Valenta and Finlay 2003; Tomkins, Dunlap and Mavrogenes 2004; Swain et al. 2005; Payne, Barovich and Hand 2006) has built on the foundation work of the Geological Survey of South Australia (Drexel, Preiss and Parker 1993; Daly, Fanning and Fairclough 1998; Ferris, Schwarz and Heithersay 2002) and is shedding further light on these large-scale geological issues. In this article we present an overview of our recent work (Reid et al. 2008) on a major magmatic system on the eastern Gawler Craton, the c. 1850 Ma Donington Suite, and give evidence for a revision of nomenclature and models for Palaeoproterozoic orogenesis in the Gawler Craton. In the eastern Gawler Craton the Donington Suite forms part of the basement to both Palaeoproterozoic bimodal volcano-sedimentary successions and Mesoproterozoic magmatism, both of which contain a variety of mineralisation types and significant mineralisation potential (Daly, Fanning and Fairclough 1998). Understanding the evolution of the basement to these sequences may provide clues as to the tectonic framework within which these younger thermal and sedimentary events occurred.

Geological setting

The Donington Suite (Schwarz 2003) is a linear batholith some 60 km wide and up to 600 km in N–S extent, forming a significant component of the eastern

Gawler Craton (Fig. 1). While not itself metallogenically fertile, the Donington Suite is imaged on regional seismic cross-sections as forming the basement to Olympic Dam (Drummond et al. 2006) and hosts the mineralisation at the Carrapateena prospect (Jagodzinski et al. 2007). Predominant outcrop of the Donington Suite occurs in the southern Gawler Craton as spectacular coastal exposures on the Eyre and Yorke peninsulas.

The Donington Suite is dominated by granodiorite gneiss, but also includes a wide range of lithologies such as pyroxene-bearing charnockite, megacrystic alkali-feldspar granite and gabbro-norite along with co-magmatic mafic units (Mortimer, Cooper and Oliver 1988). Early workers considered the Donington Suite to belong to the Lincoln Complex, a rock association that was originally proposed to encompass magmatism that occurred synchronous with the Kimban Orogeny (Parker et al. 1993); however, recent revision of this nomenclature (Schwarz 2003) has seen the Donington Suite excluded from the Lincoln Complex as the timing and duration of the Kimban Orogeny has been clarified to the interval 1730–1690 Ma (Ferris, Schwarz and Heithersay 2002).

Zircon geochronology of the Donington Suite indicates that although its emplacement has been considered to be geologically instantaneous (e.g. Hoek and Schaefer 1998), SHRIMP data collected in more recent years shows ages span over a period of c. 14 million years with the suggestion of southward younging intrusive ages. Evidence of an older period of magmatic emplacement (c. 1858 Ma) appears to be confined to the Olympic Domain (Jagodzinski et al. 2007). Geochemically, Donington Suite granitoids show LREE enrichment, negative Nb, Sr, P and Ti anomalies and

¹ For example, Alpine-Himalayan geologists need only debate about the mechanisms of tectonism; they at least know where the palaeosubduction zone was. In the Gawler Craton, we cannot even agree if there was a subduction zone, or two, let alone determine its polarity.

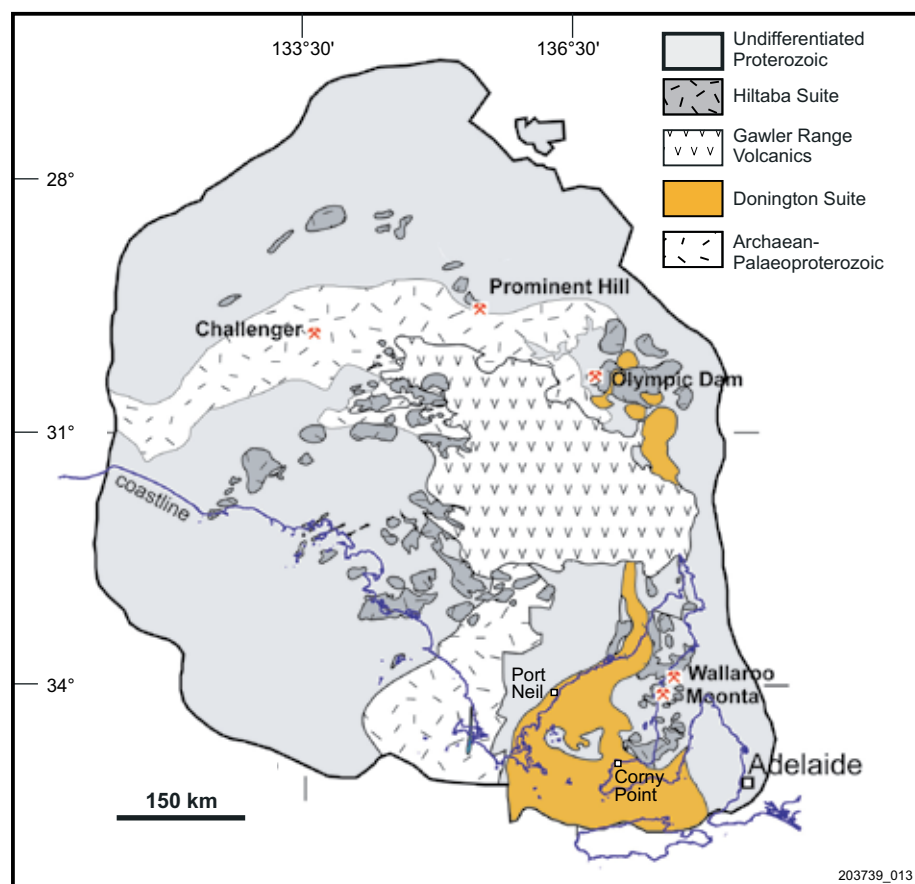


Figure 1 Location of the Donington Suite within the eastern Gawler Craton, South Australia. (After Reid et al. 2008, fig. 2a; published with the permission of the Geological Society of Australia)

have $\epsilon\text{Nd}_{1850\text{ Ma}}$ values between -2 and -4 (Schaefer 1998). The Donington Suite is thought to be derived from a mixture of moderately juvenile mafic parent and pre-existing crustal material (Mortimer, Cooper and Oliver 1988; Schaefer 1998).

The major Palaeoproterozoic orogenic phase recognised in the southeastern Gawler Craton is the Kimban Orogeny. The Kimban Orogeny was thought to have been long lived, occurring over the interval 1850 to 1700 Ma (Thompson 1969; Glen et al. 1977; Parker 1980; Daly, Fanning and Fairclough 1998; Zang and Fanning 2001). However, Hoek and Schaefer (1998) and Vassallo and Wilson (1999; 2002) have shown that a tectonic foliation developed within the Donington Suite prior to 1730–1690 Ma reworking. From these observations, Hoek and Schaefer (1998) suggested the earlier foliation indicated the occurrence of a separate tectonothermal event or orogeny, and that the latter, 1730–1690 Ma event alone should be considered as the Kimban Orogeny. This is

supported by the presence of several phases of sedimentation and volcanism between 1850 Ma and 1740 Ma, e.g. the Wallaroo Group and other units. This earlier, c. 1850 Ma event has been variously termed the ‘Lincoln Orogeny’ (Vassallo and Wilson 1999) or the ‘Neill Event’ (Ferris, Schwarz and Heithersay 2002), however, little work has focused on evaluating the structural and metamorphic expression of 1850 Ma tectonism. The following observations and results derive from study of the exposures on southern Yorke Peninsula, in particular the outcrops at Corny Point. All data and observations given below are given in full in Reid et al. (2008), to which readers are referred.

Structural constraints on 1850 Ma tectonism

The gneissic foliation within the Donington Suite is variably deformed by foliation boudinage (Fig. 2a) and intrafolial, isoclinal folding (Fig. 2b) along with zones of pervasive ductile shear (Fig. 2c). These structures themselves are deformed by tight to

open folds. Locally, weakly foliated megacrystic granite dykes appear to intrude along the axial plane of these late folds (Fig. 2d). A sample of one of these dykes yielded a SHRIMP U–Pb zircon magmatic crystallisation age of 1846 ± 4 Ma (MSWD = 1.3; $n = 25$). Thus, the apparently contractional deformation recorded within the Donington Suite must have occurred prior to 1846 ± 4 Ma, that is, soon after the emplacement of the bulk of the suite at c. 1850 Ma (Jagodzinski et al. 2007).

A series of shear zones are observed to overprint all structural fabrics within the Donington Suite on southern Yorke Peninsula. These shear zones vary from discrete metre-scale, mylonitic shear zones (Fig. 3a) to zones of pervasive reworking of the earlier fabric with minimum widths in the order of tens of metres. Importantly, these shear zones consistently show south-side-down, normal kinematics (Fig. 3b) and a shallow (15°) to moderately (60°) west-plunging stretching lineation. The geometry and stretching lineation orientation of these shear zones suggest they resulted from extension coupled with a component of dextral strike-slip deformation. At a number of localities microgranite dykes intrude and are deformed by these late stage shear zones (Fig. 3c). One of these dykes yielded a SHRIMP U–Pb zircon magmatic crystallisation age of 1843 ± 5 Ma (MSWD = 1.5; $n = 16$). Thus, these broadly extensional shear zones are therefore interpreted to have formed soon after the early contractional deformation. Notably, straight-sided mafic dykes are commonly emplaced sub-parallel to the gneissic fabric of these shear zones, and may also indicate lithospheric extension occurred at this time.

Metamorphic constraints on 1850 Ma tectonism

Corny Point is one of the few localities on southern Yorke Peninsula where diagnostic metamorphic mineral assemblages occur. At Corny Point, garnet-bearing quartzofeldspathic gneiss shows complex networks of garnet-bearing leucosomes (Figs 4a, b). These leucosomes occur in rocks that contain a biotite-defined foliation along

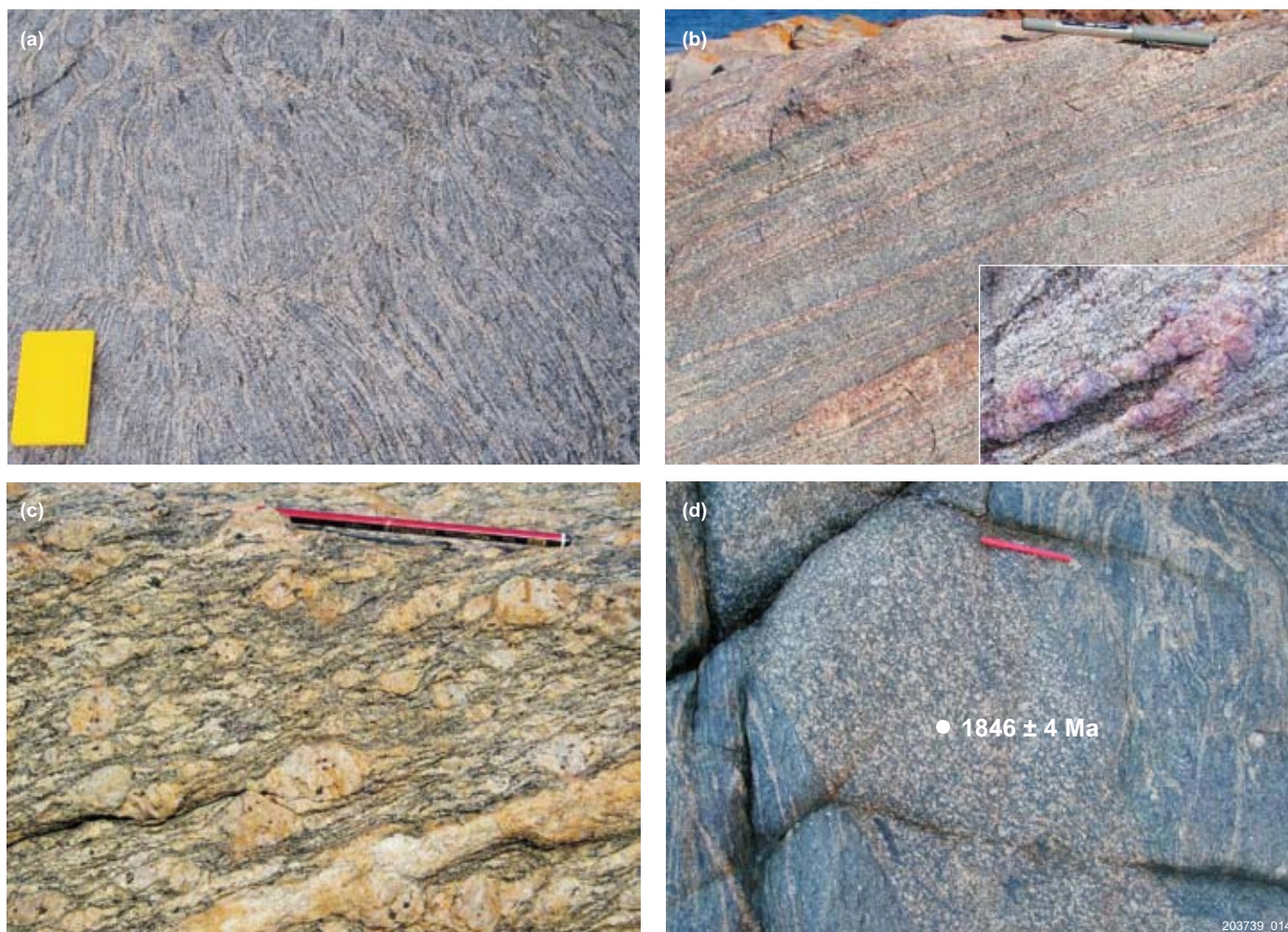


Figure 2 Compression-related structures within the Donington Suite, Yorke Peninsula. (a) Discordantly migmatized granodiorite gneiss of the Gleasons Landing Granite, deformed by foliation boudinage at Royston Head. (b) Strongly deformed layered granite-gneiss, Point Yorke. Inset shows isoclinal folds. Width of view of inset is ~10 cm. (c) Sheared megacrystic granite-gneiss of the Gleasons Landing Granite, Berry Bay. Photo taken looking west. (d) Dyke of feldspar-rich megacrystic granite, Royston Head. U–Pb zircon SHRIMP age of this syn-contractual dyke is shown. (After Reid et al. 2008, figs. 5a, b, d, e; published with the permission of the Geological Society of Australia)

with matrix of plagioclase and quartz. This suggests the leucosomes may have formed via the general reaction: biotite + sillimanite + quartz + plagioclase = garnet + melt ± K-feldspar (Spear 1993). The peak assemblage does not contain sillimanite, suggesting this reaction was terminated by the exhaustion of sillimanite and probably formed at conditions of ~6 kbar and ~750 °C. Zircons preserved within a garnet-bearing leucosome yielded a magmatic crystallisation age of 1848 ± 8 Ma along with a number of older c. 1875–2200 Ma ages, interpreted to be detrital zircons scavenged from the surrounding metasedimentary rocks.

The peak garnet has been partially replaced by intergrowths of biotite + cordierite ± sillimanite (Fig. 4c). This retrograde assemblage is a

typical response to high-temperature decompression (e.g. Harley and Carrington 2001; Pitra and de Waal 2001; White, Powell and Holland 2001). Chemical U–Th–Pb electron microprobe ages from monazites within retrograde biotite yield a minimum estimate for the timing of retrogression of ~1830 Ma (Fig. 4d) indicating decompression may be linked to the development of the broadly extensional shear zones and that the clockwise P–T path occurred during a single tectonothermal cycle.

Orogenesis in the southeastern Gawler Craton: the c. 1850 Ma Cornian Orogeny

The c. 1850 Ma event is characterised by the emplacement of the Donington

Suite into a compressional tectonic environment. Contractual deformation was terminated by high temperature, extensional to strike-slip deformation. Our U–Pb zircon geochronology shows that syn-contractual, syn-metamorphic and syn-extensional magmatism occurred within error of each other, and probably over an interval of, at most, 10 million years. Thus, in our interpretation c. 1850–1840 Ma contractional deformation and amphibolite to granulite facies peak metamorphism were transient and the entire tectonothermal cycle occurred within 10 million years.

This description of the c. 1850 Ma event shows it to be far from the simple low-strain environment envisioned previously (Mortimer, Cooper and Oliver 1988; Hoek and

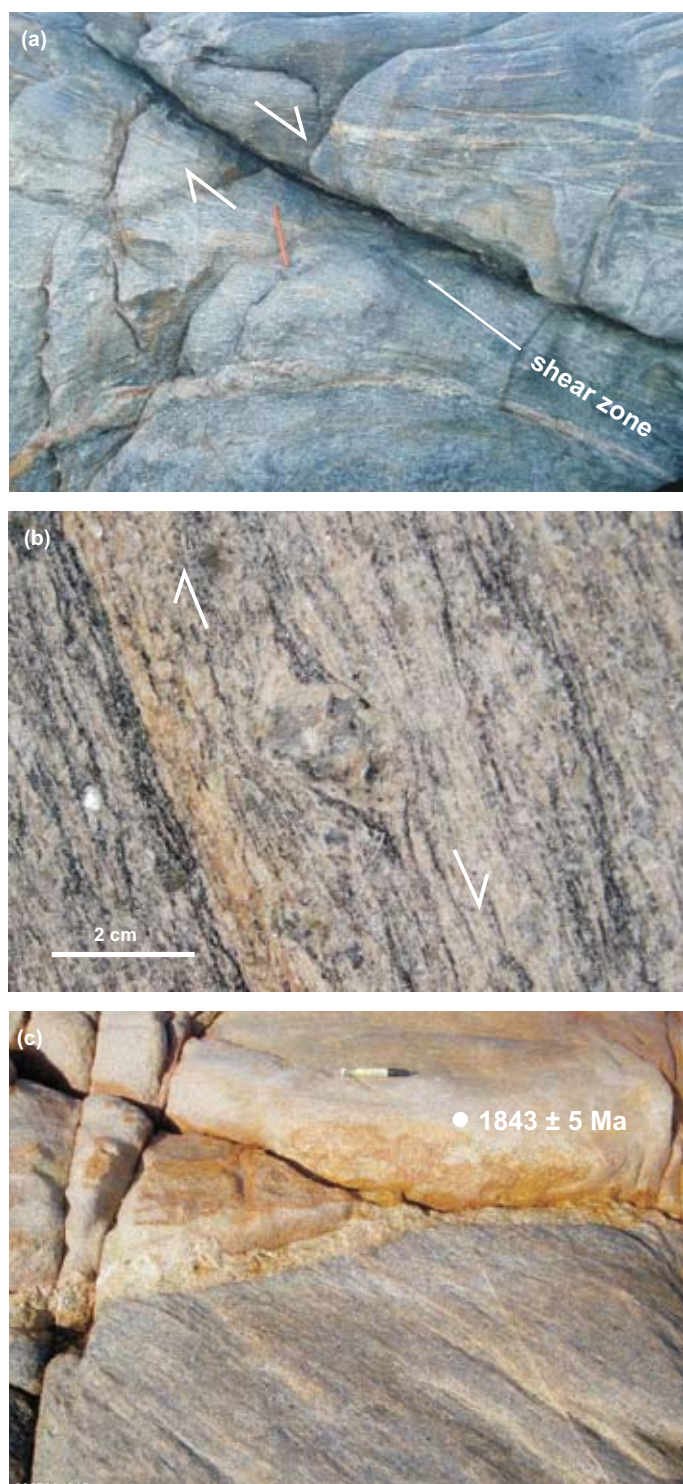


Figure 3 Extension-related structures within the Donington Suite, Yorke Peninsula. **(a)** Example of narrow high-temperature shear zone, Royston Head. **(b)** Detail of kinematic indicator (*s*-type porphyroclast) within sheared granite gneiss, indicating a south-side-down motion, The Gap. **(c)** Example of dated microgranite that crosscuts the extensional shear fabric within the Donington Suite, The Gap. U–Pb zircon SHRIMP age of this syn- to post-extensional microgranite is shown. (After Reid et al. 2008, figs. 5f, 8b (part); published with the permission of the Geological Society of Australia)

Schaefer 1998). We firstly suggest that the name for this event be revised. Previously this event was included as an early part of the Kimban Orogeny (Drexel, Preiss and Parker 1993), or has been termed the Lincoln Orogeny (Vassallo and Wilson 1999) or Neill Event (Ferris, Schwarz and Heithersay 2002).

However, these terms are unsatisfactory since they derive from localities on the Eyre Peninsula where the geological record is dominated by reworking associated with the 1730–1690 Ma Kimban Orogeny. In particular, we note that the use of the term Neill Event is highly unsatisfactory since Port Neill is the type locality of the Kalinjala Mylonite Zone (Parker 1980), which itself is the type example of a structure developed during the Kimban Orogeny. Therefore, we suggest the term *Cornian Orogeny* for this event in recognition of the excellent record of 1850 Ma tectonism preserved on Yorke Peninsula and in particular the exposures at Corny Point.

A possible tectonic setting

Detrital zircons from the Corny Point Paragneiss (Zang and Fanning 2001; Howard et al. 2006; Reid et al. 2008) yield ages as young as c.1870 Ma, suggesting the sedimentary precursor was deposited less than 20 million years prior to emplacement of the Donington Suite. The tectonic setting for the Cornian Orogeny was a system that underwent rapid switches in tectonic mode, such that a sedimentary basin underwent transient contractional deformation and granite emplacement, before reverting to a state of extension within a time interval of ~10 million years.

Changes in subduction zone dynamics play a decisive role in the deformational history of regions above and inboard of the subduction zone and rapid switches from extension to compression are well documented and may also affect regions inboard hundreds of kilometres from an active subduction zone, as has been inferred for the Lachlan Fold Belt (Collins 2002). Since there is no geochemical evidence to suggest the Donington Suite formed in a subduction zone setting (Mortimer, Cooper and Oliver 1988; Schaefer 1998; Reid et al. 2008), we suggest a tectonic scenario in which the Donington Suite formed in a (far-field?) back-arc setting as a result of extensional melting of thinned back-arc lithosphere. The deformation and metamorphism of the Cornian Orogeny may have been focused into this back-arc due to the thermal softening of the thinned lithosphere (e.g. Thompson et al. 2001), as a result of a change in subduction dynamics, such as the arrival of a buoyant collider at a far-field subduction zone.

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Figure 4 Metamorphic characteristics of metapelites at Corny Point, the Corny Point Paragneiss of Zang and Fanning (2001). (a) Garnet-biotite-quartz-feldspathic gneiss, with garnet bearing leucosomes and leucocratic layering. (b) Detail of garnet-bearing leucosome. (c) Cordierite + biotite pseudomorph of garnet. Minor sillimanite is also present in this example. Field of view 12 mm. (d) Biotite corona around garnet. Also observed are radiation damage halos caused by monazite within the biotite. Chemical U–Th–Pb dating of monazite from this sample gave an age of 1827 ± 18 Ma ($n = 35$; MSWD = 1). Field of view 8 mm. (After Reid et al. 2008, figs. 10c, e; published with the permission of the Geological Society of Australia)

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