New geochronology from the Albany–Fraser Orogen: implications for Mesoproterozoic magmatism and reworking

by CL Kirkland, CV Spaggiari, MTD Wingate, RH Smithies, and MJ Pawley

Abstract

The Albany–Fraser Orogen represents the Mesoproterozoic continent–continent collision of the combined North and West Australian Cratons with the combined East Antarctic and South Australian Cratons. The Kepa Kurl Booya Province is the crystalline basement of the Albany–Fraser Orogen and is divided into the Fraser, Biranup, and Nornalup Zones. Recent geochronology on the Albany–Fraser Orogen has refined our understanding of its evolution. Six samples from a transect along the eastern Biranup Zone record protolith ages of meta-igneous units between 1685 ± 8 Ma and 1657 ± 5 Ma. These ages indicate that the Biranup Zone extends from the southern Albany–Fraser Orogen to the northeast between the Yilgarn Craton and the Fraser Zone. U–Pb dating of zircons from two meta-igneous units within the Fraser Zone yields a weighted mean date of 1298 ± 4 Ma, synchronous with Stage I of the Albany–Fraser Orogeny. In contrast to the Fraser Zone, the Biranup Zone records metamorphic zircon overgrowth at 1197 ± 6 Ma, which is the first direct evidence of Stage II Albany–Fraser Orogeny activity in this part of the orogen. Dating of fracture-filling zircon, in the eastern Biranup Zone, indicates a period of crustal uplift and cooling between 1270 and 1197 Ma, consistent with separation of the Albany–Fraser Orogeny into two stages. Age similarities between the reworking of the eastern Biranup Zone and the ultra-high-temperature metamorphism of the Musgrave Province are compatible with a Mesoproterozoic extensional event in both areas at c. 1200 Ma. A temporal correlation may be made between earlier c. 1300 Ma events in the Musgrave Province and Stage I of the Albany–Fraser Orogeny, as recorded in the Fraser Zone. These early events may relate to accretion of an arc system along the Yilgarn Craton margin.

KEYWORDS: Geochronology, Albany–Fraser Orogen, Yilgarn Craton, West Australian Craton, North Australian Craton, Mawson Craton, Mesoproterozoic, U–Pb geochronology, tectonics

Convergent plate-margin processes were fundamental in assembling the various Archean–Proterozoic fragments of Australia and responsible for their reorganization into Rodinia. The Albany–Fraser Orogen (Myers, 1990) is an arcuate orogenic belt on the southern and southeastern margins of the Archean Yilgarn Craton in Western Australia (Fig. 1) that records part of this amalgamation. The predominant tectonic and metamorphic features of the belt are generally considered to have developed during the Mesoproterozoic Albany–Fraser Orogeny, which is subdivided into two stages (Clark et al., 2000): Stage I representing continental collision (c. 1345–1280 Ma), and Stage II reflecting intracratonic reactivation (c. 1215–1140 Ma). Both tectono-metamorphic stages involved oblique dextral movement and the north and northwestward transport of thrust slices (Myers, 1993; Myers, 1995). The Albany–Fraser Orogen has been divided into a foreland component (the Northern Foreland) and a basement component, defined as the pre-amalgamation, disparate, crustal fragments affected by Mesoproterozoic tectonism, named the Kepa Kurl Booya Province (Spaggiari et al., 2009).

This paper presents new zircon U–Pb geochronology and provides a geochronological framework enabling correlation with other Mesoproterozoic belts associated with the amalgamation of the combined South Australian and East Antarctic Cratons (Mawson Craton) and the combined North and West Australian Cratons.

Geological and temporal framework

The Albany–Fraser Orogen is dominated by granulite-facies paragneiss and orthogneiss intruded by late-tectonic granite plutons in the west (near Albany), and by orthogneiss and mafic granulite in the east (Fraser Zone). The Albany–Fraser Orogen is itself subdivided into a series of fault-bound tectonic units (Fig. 1). These include the Northern Foreland, pre-Stage I amalgamation basement components of the Kepa Kurl Booya Province, the Recherche and Esperance Supersuites, and various Mesoproterozoic cover rocks. The Kepa Kurl Booya Province is further divided into the Biranup Zone, the Nornalup Zone, and the Fraser Zone (Spaggiari et al., 2009).

The Biranup Zone is dominated by c. 1700–1650 Ma orthogneiss. It includes the Dalyup and Coramup Gneisses (Myers, 1995). However, both lithological units are dominated by granitic rocks with a similar crustal history and hence this distinction may not be meaningful. The origin of the Biranup Zone is unknown, but it appears to be exotic to the Yilgarn Craton. The c. 1560–1310 Ma Nornalup Zone consists of Mesoproterozoic ortho- and paragneisses (Myers, 1990; 1995). The Biranup and Nornalup Zones have been intruded by granitic rocks of the c. 1330–1280 Ma Recherche Supersuite associated with Stage I activity. Metagranitic rocks of c. 1300 to 1280 Ma age are also found in the Fraser

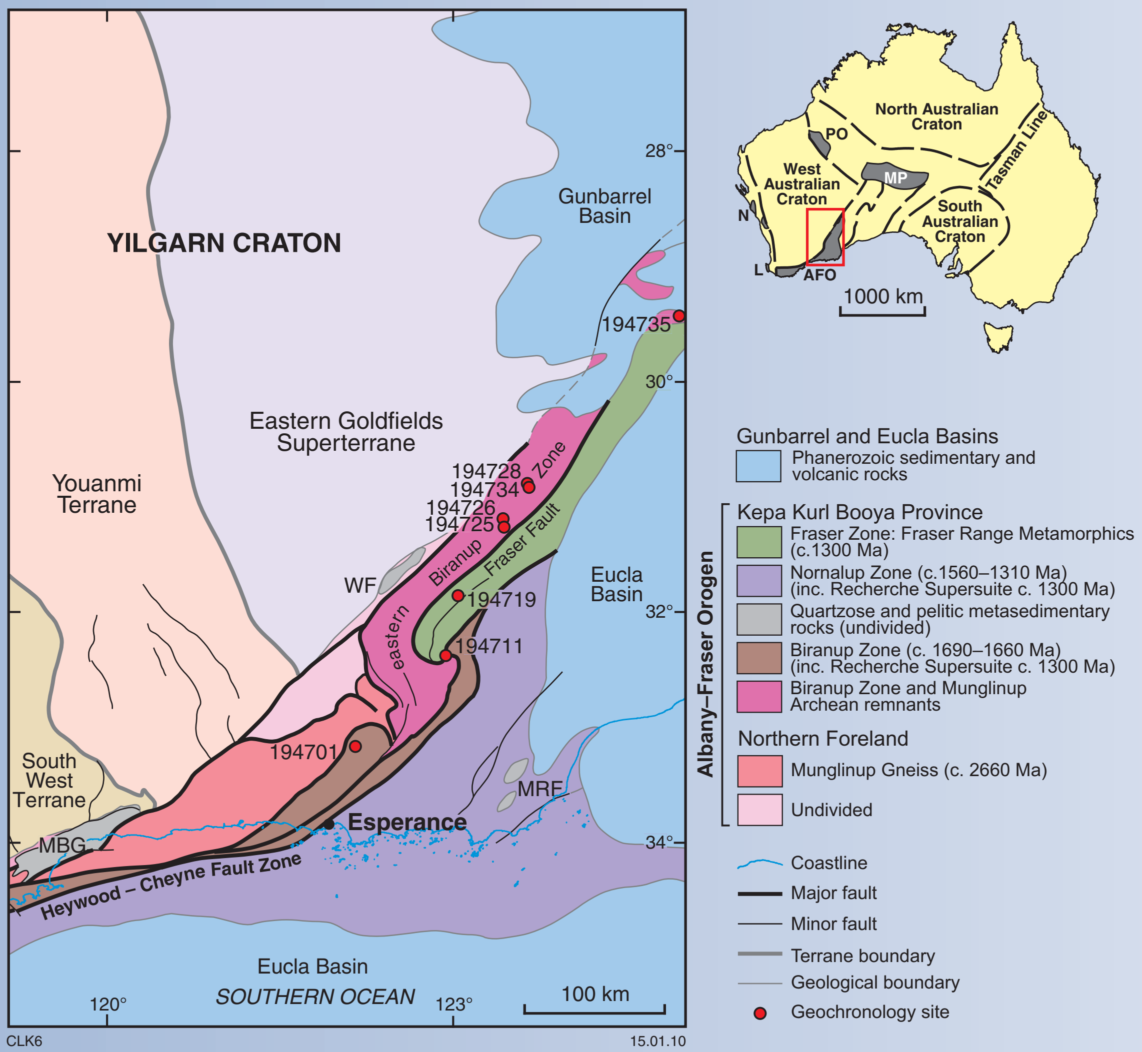

Figure 1. Preliminary geological sketch map of the eastern Albany–Fraser Orogen and east Yilgarn Craton (adapted from Spaggiari et al., 2009) showing locations of the geochronology samples. MBG = Mount Barren Group; MRF = Mount Ragged Formation; WF = Woodline Formation. Inset map shows the location of Mesoproterozoic tectonic units of Australia; MP = Musgrave Province; PO = Paterson Orogen; N = Northampton Complex; L = Leeuwin Complex; AFO = Albany–Fraser Orogen.

Range Metamorphics (De Waele and Pisarevsky, 2008) within the northeasterly trending Fraser Zone. The Fraser Range Metamorphics unit (Spaggiari et al., 2009) is a sheeted complex of gabbroic to granitic rocks with layers of variably migmatized pelitic and calcic metasedimentary rocks, all of which have been metamorphosed at high (granulite facies) temperatures close to their time of formation. Myers (1985) interpreted the mafic rocks in the Fraser Range as part of a large layered mafic intrusion, whereas Condie and Myers (1999) argued that it was the remnant of multiple magmatic arcs.

U–Pb results

U–Pb results from eight samples are presented. They are from an extensive new dataset acquired by the Geological Survey of Western Australia, which spans the entire exposed length of the eastern Albany–Fraser Orogen along the Yilgarn Craton margin (east Biranup Zone and Fraser Range Metamorphics). These results elucidate the spatial extent of Mesoproterozic tectono-metamorphic and magmatic events. The locations of the samples discussed in this paper are shown in Figure 1. Analytical methodology, U–Pb data tables, and detailed descriptions of analyses are supplied as supplementary material that is available online through the Department of Mines and Petroleum's GeoVIEW.WA integrated geoscience information system <http://www.dmp.wa.gov.au>. All geochronology results are shown on concordia diagrams (Fig. 2) and are presented in Table 1 below.

New geochronology in the context of the Fraser and eastern Biranup Zones

Two granitic samples (GSWA 194711 and 194719; Figs 1 and 2; Table 1) within the Fraser Range Metamorphics yield a weighted mean date of 1298 ± 4 Ma (MSWD = 0.045), which is interpreted as the age of magmatic crystallization, synchronous with Stage I of the Albany Fraser Orogeny. Clark et al., (1999) presented a similar age of 1293 ± 9 Ma for the crystallization of post-D1 granites. The foliation within both these samples most likely developed shortly after their emplacement; this is consistent with dates from disturbed zircon grains that suggest a radiogenic Pb-loss event soon after crystallization (Clark et al., 1999; De Waele and Pisarevsky, 2008). Within the eastern region of the Albany–Fraser Orogen syn-Stage I magmatic rocks (i.e. at c. 1300 Ma) are restricted to the Fraser Range Metamorphics (of the Fraser Zone). Outside the Fraser Zone in the eastern Biranup Zone, Stage I metamorphism and deformation resulted in the growth of homogeneous 'metamorphic' rims mantling inherited zircon seeds. The Stage I events responsible for zircon growth within the Fraser Range Metamorphics apparently did not result in a significant volume of silicate melt in the eastern Biranup Zone as no major granite bodies of this age have been found.

The southern Biranup Zone (consisting of both the Coramup and Dalyup Gneisses) comprises 1690–1660 Ma metagranitic and lesser metasedimentary rocks that have similar protolith ages to the

Table 1. Selection of new geochronology from the Fraser and Biranup Zones

Sample	*Lithology (petrology)*	*Magmatism*	*Metamorphism*	*Inheritance*
Fraser Zone				
194711	Granite (Qtz, Mc, Pl, Bt, Grt, Hbl, Ap, Zrn)	1297 ± 8 Ma		4 grains 1701–1684 Ma
194719	Granite (Qtz, Kfs, Alkf, Bt, Pl, Zrn, Ttn)	1298 ± 5 Ma		c. 1770 Ma
Biranup Zone				
194701	Orthogneiss (Pl, Qtz, Bt, Mc, Ms, Ttn, Zrn, Aln)	1685 ± 8 Ma	1203 ± 11 Ma	1749, 1766, and 1809 Ma
194725	Orthogneiss (Qtz, Pl, Kfs, Grt, Bt, Mc, Ttn, Zrn, Hbl)	1671 ± 7 Ma	1205 ± 20 Ma	
194726	Orthogneiss (Qtz, Pl, Kfs, Bt, Grt, Hbl, Ttn, Zrn)	1666 ± 11 Ma	1162 ± 39 Ma	
194734	Orthogneiss (Or, Qtz, Pl, Bt, Grt, Ap, Zrn)	1675 ± 9 Ma	1192 ± 9 Ma	c. 1780 Ma
194728	Orthogneiss (Mc, Qtz, Pl, Grt, Ttn, Bt, Zrn)	1683 ± 8 Ma	1201 ± 15 Ma	
194735	Orthogneiss (Pl, Qtz, Mc, Bt, Ep, Ttn, Ms, Ap, Zrn)	1657 ± 5 Ma	1270 ± 11 Ma & 1193 ± 26 Ma	

NOTES: Zircon U–Th–Pb ages of samples in the eastern Albany–Fraser Orogen. GSWA standard mineral name abbreviations are listed in MINEDEX. All uncertainties are at the 95% confidence level.

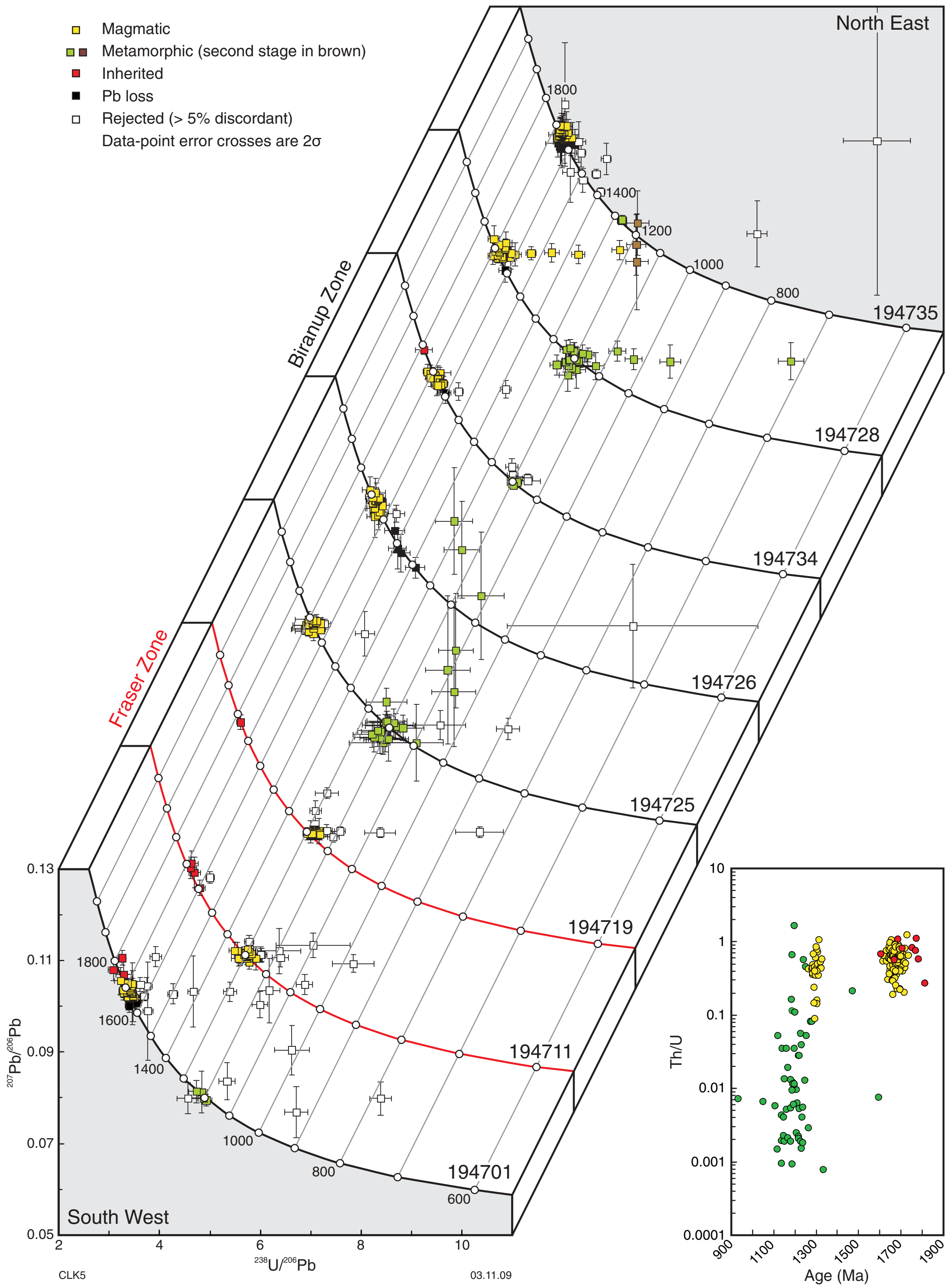

Figure 2. Stacked Tera-Wasserburg concordia diagrams for zircons analysed by ion probe

eastern Biranup Zone (Spaggiari et al., 2009). This shows that the Biranup Zone wraps around the entire southern and southeastern Yilgarn Craton margin, over a distance of at least 1200 km (Fig. 1). These gneisses lack any Archean-aged zircon inheritance, suggesting that they represent new juvenile additions to the crust, rather than pervasively reworked older crustal elements. The southern Biranup Zone rocks were metamorphosed to granulite facies conditions and intruded by the Recherche Supersuite (Nelson et al., 1995) during Stage I of the Albany–Fraser Orogeny (c. 1300 Ma), with subsequent high-temperature metamorphism during Stage II (c. 1180 Ma). No evidence of Recherche Supersuite intrusive rocks or metamorphism at this time is preserved within the eastern Biranup Zone. However, samples from this zone (GSWA 194701, 194725, 194726, 194734, 194728, and 194735; Figs 1 and 2; Table 1) do record Stage II zircon overgrowth at c. 1200 Ma. These zircon overgrowths show a range of Th/U ratios from values similar to those in magmatic crystals to dominantly lower values of around 0.001 (Fig. 2). As the Th/U compositions of the metamorphic overgrowths appear distinct from those in magmatic grains this implies a crystallization process in which the overgrowths had elemental exchange with their surrounding matrix.

Zircon overgrowths in samples from within the Biranup Zone provide a detailed picture of its Mesoproterozoic evolution. For example, zircons in GSWA 194735 record 1270 ± 11 Ma, high U, overgrowths that have developed on 1657 ± 5 Ma magmatic cores (Fig. 3). These grains were then fractured and subsequently overgrown by a later phase of homogeneous low-U rims at 1197 ± 6 Ma (weighted mean of six samples; MSWD = 1.3). These later rims most likely developed during zirconium-liberating metamorphic reactions, rather than during partial melting, as they infill fractures and retain no evidence of magmatic textures. This indicates a period of crustal uplift and cooling after the c. 1270 Ma zircon growth, prior to the development of zircon rims at c. 1200 Ma. The timing of this uplift is identical to that in the Fraser Range Metamorphics, which were exhumed to less than ~400 MPa sometime between 1288 Ma and 1260 Ma (Clark et al., 1999). It is also consistent with the interpretation of Stage I basement-derived detrital zircons within Stage II rocks in the eastern Nornalup Zone. This was interpreted to reflect extension and uplift and provided key evidence for the subdivision of the Albany–Fraser Orogeny into its two stages (Clark et al., 2000). This implies a shared uplift history between the eastern Biranup, Nornalup, and Fraser Zones, after Stage I.

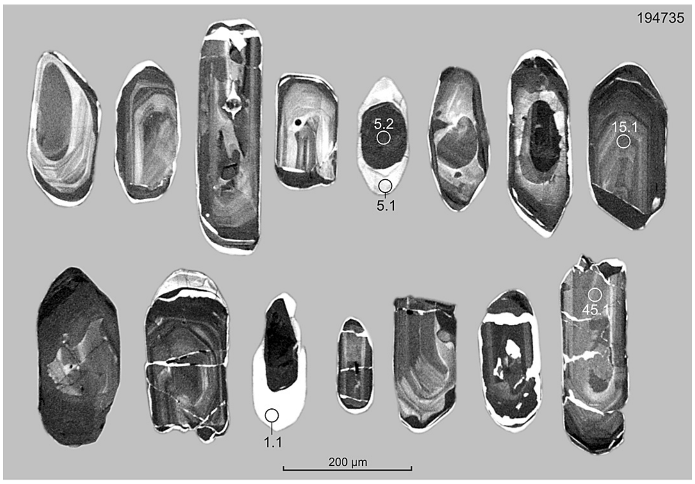

Figure 3. SEM cathodoluminescence (CL) images of selected zircon grains from the dated sample GSWA 194735 (for location see Fig. 1). Ellipses indicate analysed regions labelled with the spot identification.

There is no evidence of Stage II events within the Fraser Zone, yet Stage II ages are prolific throughout the Biranup Zone. Preservation of pre-1250 Ma Rb–Sr cooling ages in the Fraser Range Metamorphics also indicates a lack of Stage II activity in that area (Fletcher et al., 1991). Inherited zircons within Stage I intrusive units of the Fraser Range Metamorphics, although limited, have ages similar to intrusive material within the Biranup Zone. This is compatible with the intrusive bodies of the Fraser Range Metamorphics passing through rocks of similar age to the Biranup Zone on their emplacement pathway. However, no evidence of a comparable Stage I thermal event in the eastern Biranup Zone is preserved. The earliest zircon-rim growth in the eastern Biranup Zone is recorded at c. 1270 Ma, but this is at least 10 Ma younger than the emplacement of granites in the Fraser Range Metamorphics and the Recherche Supersuite. Moreover, this c. 1270 Ma event appears to be recorded as metamorphic zircon overgrowths rather than as magmatic grains. Both the Fraser and Biranup Zones appear to have a comparable timing of uplift and cooling, between Stages I and II. The Fraser Fault represents a major structural boundary between the eastern Biranup and Fraser Zones. This feature may have placed the Fraser Zone at a higher structural level that was less conducive to zircon growth or regrowth. This suggests that the Fraser Fault was active during Stage II, juxtaposing the two zones.

Comparison with the Musgrave Province

The Mesoproterozoic to Neoproterozoic Musgrave Province lies at the convergence of Australia's main Proterozoic structural trends (Fig. 1), and shares certain chronological similarities with the Albany–Fraser Orogen (Wade et al., 2008).

This section highlights these similarities. Figure 4 presents a comparison of the geochronology from each region.

Intrusive rocks with protolith ages between c. 1330 and 1300 Ma form a significant component of the western part of the Musgrave Province (Howard et al., 2007; Smithies et al., 2009). The crustal

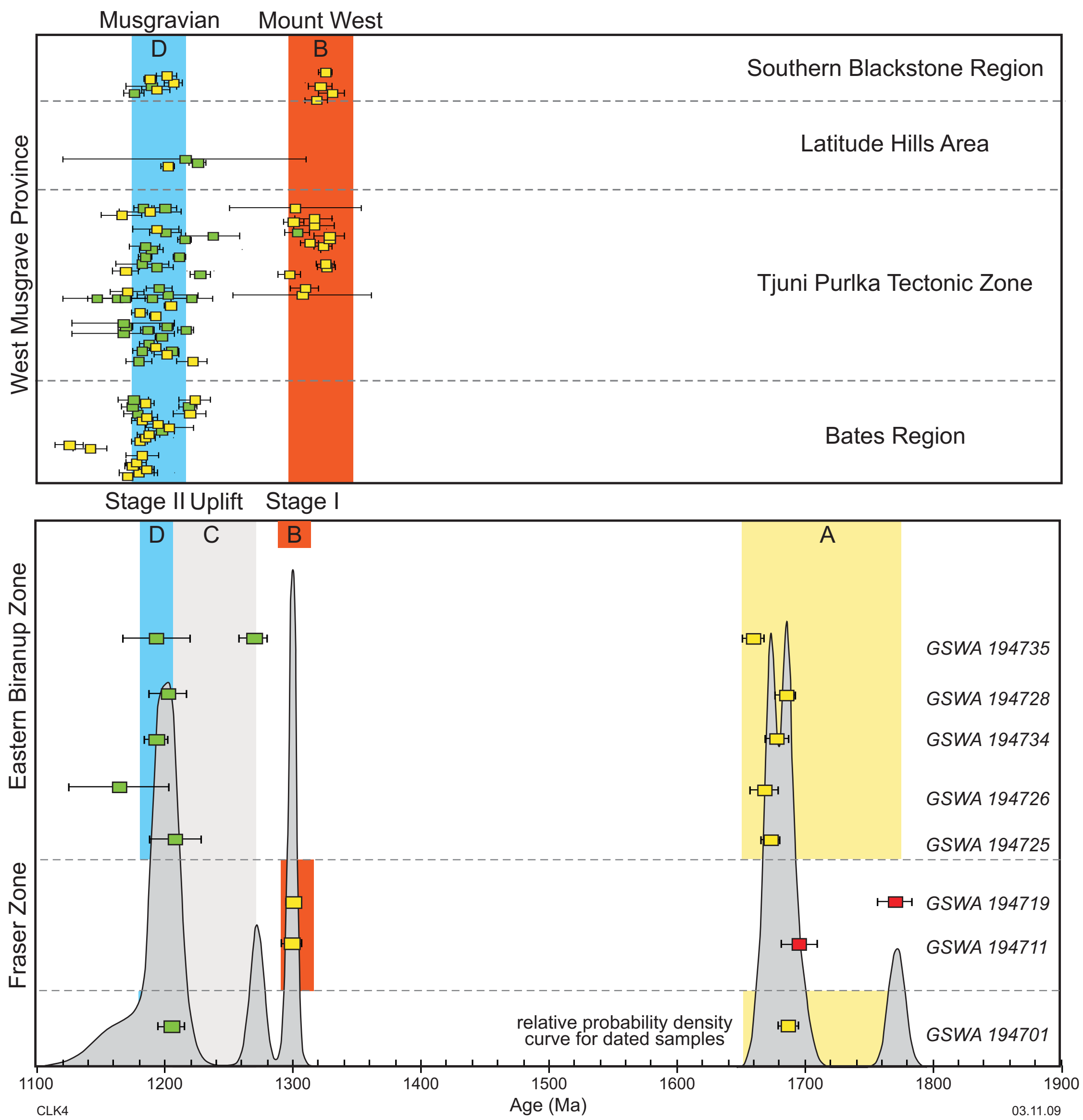

Figure 4. Space–time plot for dated samples of the Albany–Fraser Orogen compared to those from the west Musgrave Province. Each symbol represents the weighted mean age of zircon grains or parts of crystals, from a single sample, interpreted to date the following processes: metamorphism (green rectangles); inheritance (red rectangles); magmatism (yellow rectangles). Time frame (A) indicates intrusion of 1680 Ma granites and a suite of granitic to gabbroic rocks, with distinct mingling and hybridization textures, dated at c. 1665 Ma, which were emplaced into <1690 Ma psammitic to semipelitic rocks of the eastern Biranup Zone. (B) indicates c. 1300 Ma magmatism corresponding to Stage I events in the Albany–Fraser Orogen and the Mount West Orogeny in the Musgrave Province. (C) indicates brittle fracturing and uplift within the Fraser and Biranup Zones. (D) indicates metamorphic zircon growth in the Biranup Zone and ultra-high temperature events during the Musgrave Orogeny.

event that produced such melts has been termed the Mount West Orogeny. The age of this event is similar to Stage I of the Albany–Fraser Orogeny and specifically overlaps with the range of mafic to felsic components within the Fraser Range Metamorphics and the Recherche Supersuite. Several studies have suggested that the 1350 Ma and 1290 Ma events in the Albany–Fraser Orogen involved convergence and suturing of the West Australian Craton and the Mawson Craton, with the subducting oceanic slab dipping to the southeast (Clark et al., 2000). The tectonic setting of Mount West granites is unclear, but the granites retain a subduction-like geochemistry similar to Andean-style continental-arc magmas. Mount West Orogeny granites also have juvenile Nd- and Hf-isotopic compositions consistent with a continental arc setting (Smithies et al., 2009). Such a correlation leads to wider associations of the Musgrave Province and Albany–Fraser Orogen with other Mesoproterozoic (Grenvillian) orogenic belts.

The Musgrave Orogeny (1219–1155 Ma) is interpreted to reflect a period of intracratonic extension and is synchronous with Stage II tectonothermal activity in the Albany–Fraser Orogen. Stage II commenced with high-temperature metamorphism of the eastern Nornalup Zone and the Biranup Zone between 1225 and 1215 Ma (Clark et al., 2000; Bodorkos and Wingate, 2008). This was followed by emplacement of the c. 1210 Ma Gnowangerup–Fraser Dyke Suite (Wingate et al., 2000). Dawson et al. (2003) interpreted the Gnowangerup–Fraser Dyke Suite as the thermal impetus for peak metamorphism during early Stage II activity. Stage II events recorded in the Albany–Fraser Orogen are widespread in the Biranup and Nornalup Zones and include pluton emplacement as well as prolific growth of metamorphic zircons. In the southern Biranup Zone granulite facies metamorphism took place at c. 1180 Ma and re-occurred between 1170 and 1150 Ma (Spaggiari et al., 2009). In the eastern Biranup Zone metamorphic zircon growth is defined at 1197 ± 6 Ma, slightly earlier than the widespread c. 1180 Ma high-temperature metamorphism within the southern Biranup Zone. Significant extension during Stage II of the Albany–Fraser Orogeny is evident in Biranup Zone rocks at Bremer Bay where leucosomes formed in the necks of boudins at c. 1180 Ma (Spaggiari et al., 2009). The range of Stage II ages throughout the Biranup Zone would appear to reflect either protracted extension or various phases of metamorphism in an extensional to transpressional regime. Protracted extension is consistent with the tectonic scenario proposed for the West Musgrave Province, where repeated or continuous ultra-high-temperature metamorphism appears to have spanned the period, encompassing both the c. 1200 Ma and c. 1180 Ma events recognized in the Albany–Fraser Orogen.

Conclusions

The eastern Biranup Zone is composed of 1690–1650 Ma granitic to gabbroic intrusions. This indicates that the late Paleoproterozoic Biranup Zone extends from the southern Albany–Fraser Orogen to the northeast and girdles the Yilgarn Craton on its southern and eastern margins.

Two strongly foliated granitic samples within the Fraser Range Metamorphics yield a weighted mean date of 1298 ± 4 Ma (MSWD = 0.045), which is interpreted as the age of magmatic crystallization during Stage I of the Albany–Fraser Orogeny. A major foliation-forming event within the Fraser Zone must have developed after c. 1300 Ma.

The eastern Biranup Zone preserves no evidence of Stage I intrusive activity. However, evidence of Stage II metamorphic overprinting is widespread, as indicated by the development of low-uranium zircon overgrowths at 1197 ± 6 Ma. Within the eastern Biranup Zone, high-U zircon overgrowths are fractured and overgrown with a later phase of metamorphic zircon. This indicates a period of crustal uplift and cooling between 1270 and 1197 Ma. The timing of this uplift is comparable with that in the Fraser and Nornalup Zones.

The Mount West Orogeny of the Musgrave Province and Stage I of the Albany–Fraser Orogeny, at c. 1300 Ma, share a similar timing and may reflect accretion of an arc to the Yilgarn Craton. However, the general plate configuration is different in each region, which may account for some of the individual complexities in their magmatic history. The Musgrave Province is located on a junction between the North, West, and South Australian Cratons, whereas the Albany–Fraser Orogen is on a linear margin between the West Australian Craton and the Mawson Craton (the combined East Antarctic and South Australian Cratons). Similarities in both age and tectonic environment during the Stage II reworking of the Biranup Zone, and the ultra-high-temperature metamorphism of the Musgrave Province imply that a Mesoproterozoic extensional phase caused intrusive and metamorphic events in both regions during the period from 1200 to 1180 Ma.

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