Post-Giles Event evolution of the Musgrave Province constrained by (multi-method) thermochronology

by

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The Musgrave Province is a Mesoproterozoic orogen exposed at the junction between the North, West, and South Australian Cratons. Over the last decade, the Geological Survey of Western Australia (GSWA) has focused its efforts in identifying and characterizing the crust-forming events of the west Musgrave Province (see Howard et al., 2015 for review). However, the post-Mesoproterozoic exhumation history of the province remains poorly known. We show that the interpretation of previous and new field mapping, deep seismic reflection, and U–Pb and Ar–Ar geochronological data impose significant constraints on the evolution of the province after the 1085–1040 Ma Giles Event, requiring revision of the evolution of parts of central Australia.

Geology of the west Musgrave Province

The oldest known rocks of the west Musgrave Province are poorly exposed gneisses of the c. 1600 Ma Warlawurru Supersuite and granitic rocks of the c. 1400 Ma Papulankutja Supersuite (Howard et al., 2011; Quentin de Gromard et al., 2016). The first main tectono-magmatic event identified is the Mount West Orogeny during which granitic rocks of the 1345–1293 Ma Wankanki Supersuite were emplaced and volcano-sedimentary rocks of the 1340–1270 Ma Wirku Metamorphics were deposited (Smithies et al., 2010; Howard et al., 2011; Evins et al., 2012). All of these rocks were metamorphosed at ultra-high temperature during the Musgrave Orogeny which was also accompanied by the emplacement of the 1220–1150 Ma Pitjantjatjara Supersuite (Edgoose et al., 2004; Smithies et al., 2010). The Musgrave Province refers to all rocks formed during, or affected by, the Musgrave Orogeny and constitutes the basement to rocks of the 1085–1040 Ma Giles Event. Volcano-sedimentary rocks of the c. 1085 Kunmarnara Group are interpreted as the lowermost unit deposited during the Giles Event (Evins et al., 2010). Igneous rocks formed during the Giles Event belong to the Warakurna Supersuite and include the layered mafic–ultramafic Giles intrusions, mixed and mingled gabbros and leucogranites, Alcurra Dolerite intrusions and bimodal volcanic rocks of the Talbot Supervolcano (Howard et al., 2009; Evins et al., 2010; Smithies et al., 2015). Apart from minor mafic dyke intrusion at c. 1000, 825 and 750 Ma (Wingate et al., 1998), the Musgrave Province is commonly regarded as tectonically quiescent until intracontinental reactivation during the 580–520 Ma Petermann Orogeny. Deformation during the Petermann Orogeny produced east-trending crustal-scale faults and shear zones that dissect the entire Musgrave Province (Lambeck and Burgess, 1992; Camacho and McDougall, 2000; Aitken et al., 2009). Metamorphic conditions during the Petermann Orogeny approached eclogite facies south of the Woodroffe Thrust, and amphibolite facies or lower in the north-verging Petermann Nappe Complex (Scrimgeour and Close, 1999; Edgoose et al., 2004; Raimondo et al., 2010).

Structure and thermochronology of the west Musgrave Province

The study area is subdivided, from south to north, into the Talbot Sub-basin, the Mitika area, and the Wanarn area (Fig. 1). The Wanarn area, between the Mitika Fault and the Woodroffe Thrust, represents a gneissic core that formed after the Giles Event.

The structure of the Talbot Sub-basin is characterized by a west- to northwest-trending open anticline and south-directed reverse faults (Fig. 1). Ar–Ar analyses of muscovite from kyanite-bearing schists yielded a date of c. 715 Ma. Igneous zircons from a nearby metagranitic rock yielded a U–Pb date of 1079 ± 8 Ma, interpreted as the time of crystallization of the granite protolith. U–Pb titanite dates from this rock show a bimodal population. One population yielded results ranging from c. 1100 to 942 Ma. The latter date is interpreted as the time the granite cooled below 600 °C (the retention temperature of the U–Pb system in titanite). The second population of titanite dates yielded a peak at 715 ± 7 Ma, similar to the Ar–Ar date. The c. 715 Ma date is interpreted as the age of metamorphic growth of muscovite and titanite resulting from thickening of the Talbot Sub-basin during north–south compression.

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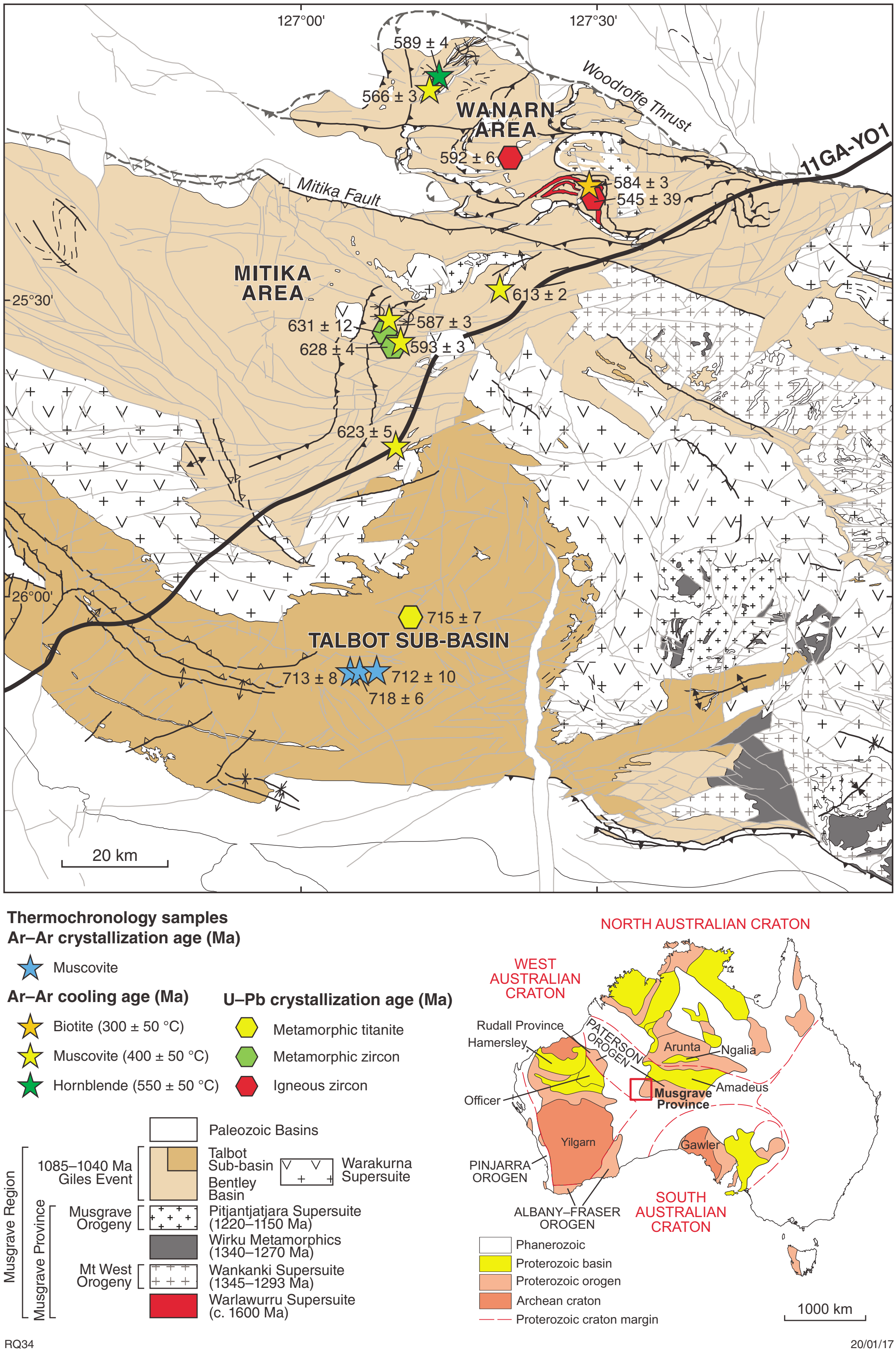

Figure 1. Interpreted bedrock geology map of the study area (tectonic map of Australia is inset for location) showing the thermochronology sample locations and the trace of the deep seismic reflection profile 11GA-YO1

The structure of the Mitika area consists of a west-verging fold and thrust system. Zircon overgrowths from garnet–kyanite schists yielded U–Pb dates of c. 630 Ma, interpreted as the time of peak metamorphism during east–west shortening. This was followed by exhumation and cooling below 400 °C (the retention temperature of argon in muscovite) at c. 590 Ma, dated by Ar–Ar on muscovite. The lower-grade periphery of the Mitika area cooled below 400 °C at 623 ± 5 Ma to the south and 613 ± 2 Ma to the north.

The Wanarn area is a zone of complex ductile deformation where basement rocks of the Musgrave Province are tectonically interleaved with rocks of the Kunmarnara Group. Pegmatite veins intruding the Kunmarnara Group yield U–Pb zircon dates of 592 ± 6 Ma and 545 ± 39 Ma, interpreted as the age of pegmatite crystallization. The southern Wanarn area cooled below 300 °C at 584 ± 3 Ma, while the northern area cooled below 550 °C at 589 ± 4 Ma, as indicated by Ar–Ar analyses of biotite and hornblende, respectively. This suggests differential cooling of the Wanarn area and that minor pegmatitic melt was generated and crystallized during exhumation. The northern Wanarn area was then cooled below 400 °C at 567 ± 3 Ma, as indicated by Ar–Ar analyses of muscovite.

A lengthy period of post-Giles Event tectono-metamorphic evolution

The deep seismic reflection line 11GA-YO1 runs northeast through the west Musgrave Province (Fig. 1). A reinterpretation of the seismic section is proposed (Fig. 2). Thermochronology data projected onto this section clearly show the overall younging of ages toward the north, expressing an overall northward exhumation over a period of nearly 200 Ma. This period partly overlaps, but largely pre-dates, the 580–520 Ma Petermann Orogeny. Thus, the Musgrave Province preserves a much lengthier post-Giles tectono-metamorphic history than previously recognized.

These results indicate that the exhumation of the exposed part of the Musgrave Province is not the sole result of the 580–520 Ma Petermann Orogeny. Rather, it spanned a much longer time period that started as early as c. 715 Ma. This period is marked by discrete events in central Australia: north–south shortening at c. 715 Ma, followed by 630–615 Ma east–west shortening, and finally 590–565 Ma northeast–southwest shortening related to the Petermann Orogeny. All these events involved fluid mobility as indicated by muscovite, titanite and zircon growth as well as pegmatite generation.

The reinterpretation of the seismic section forms the backbone of a time–temperature-constrained evolution model (Fig. 3). The geothermal gradient used in the model is non-linear and derived from published P–T estimates (e.g. 600 °C at 6 kbar and 750 °C at 12 kbar, Scrimgeour and Close, 1999; Raimondo et al., 2010; Walsh et al., 2013). Line-length balancing of the section south of the Woodroffe Thrust, using the base of the Kunmarnara Group as a marker line, indicates a total shortening of 67 km (i.e. –27%), where 90% (i.e. 59 km) of the total shortening is concentrated in the Wanarn Area alone.

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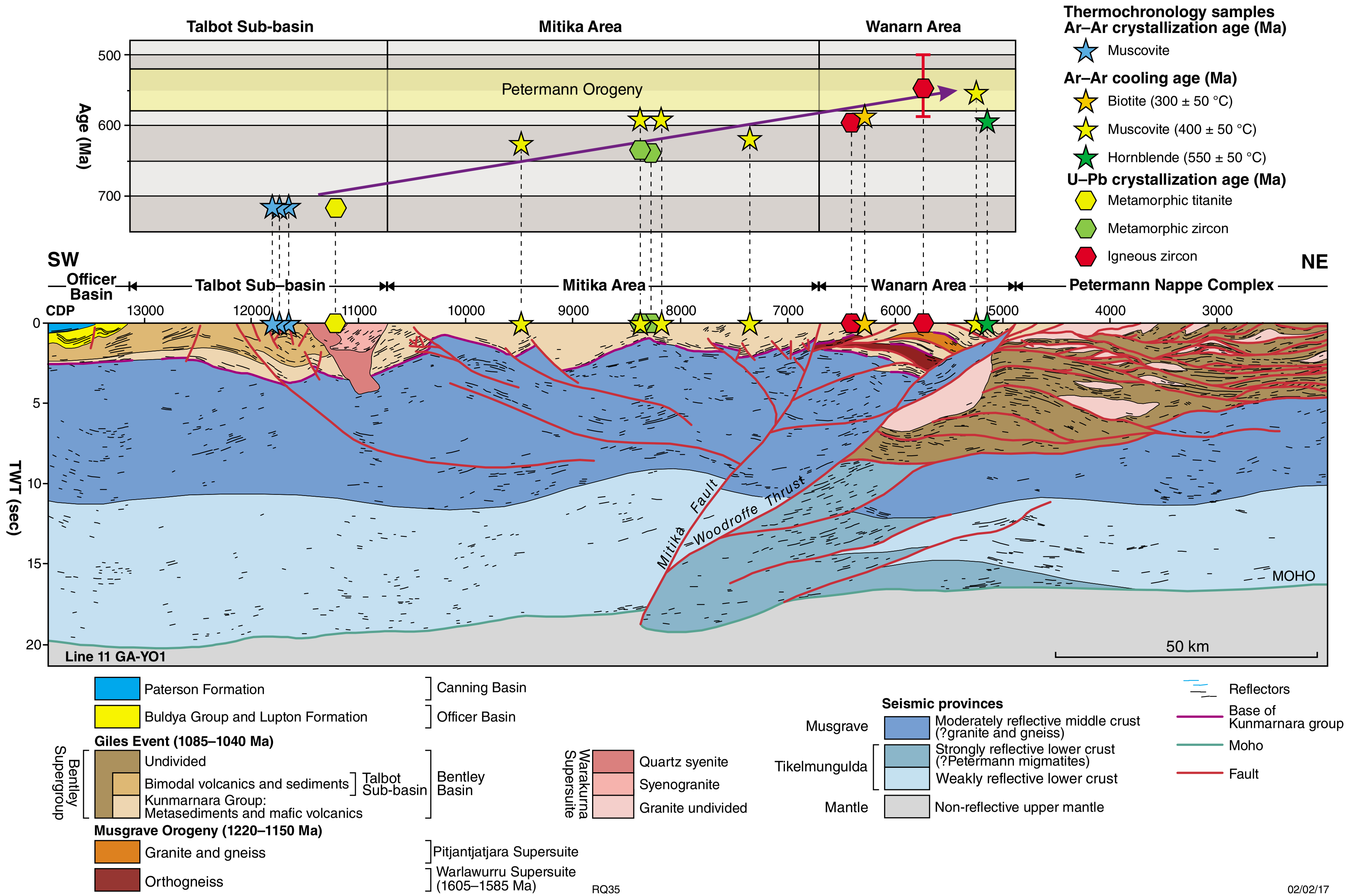

Figure 2. Interpreted seismic section with projected thermochronology samples. The top panel shows a date vs distance plot showing the north-eastward younging of ages. An error bar is shown where the error exceeds the size of the symbol.

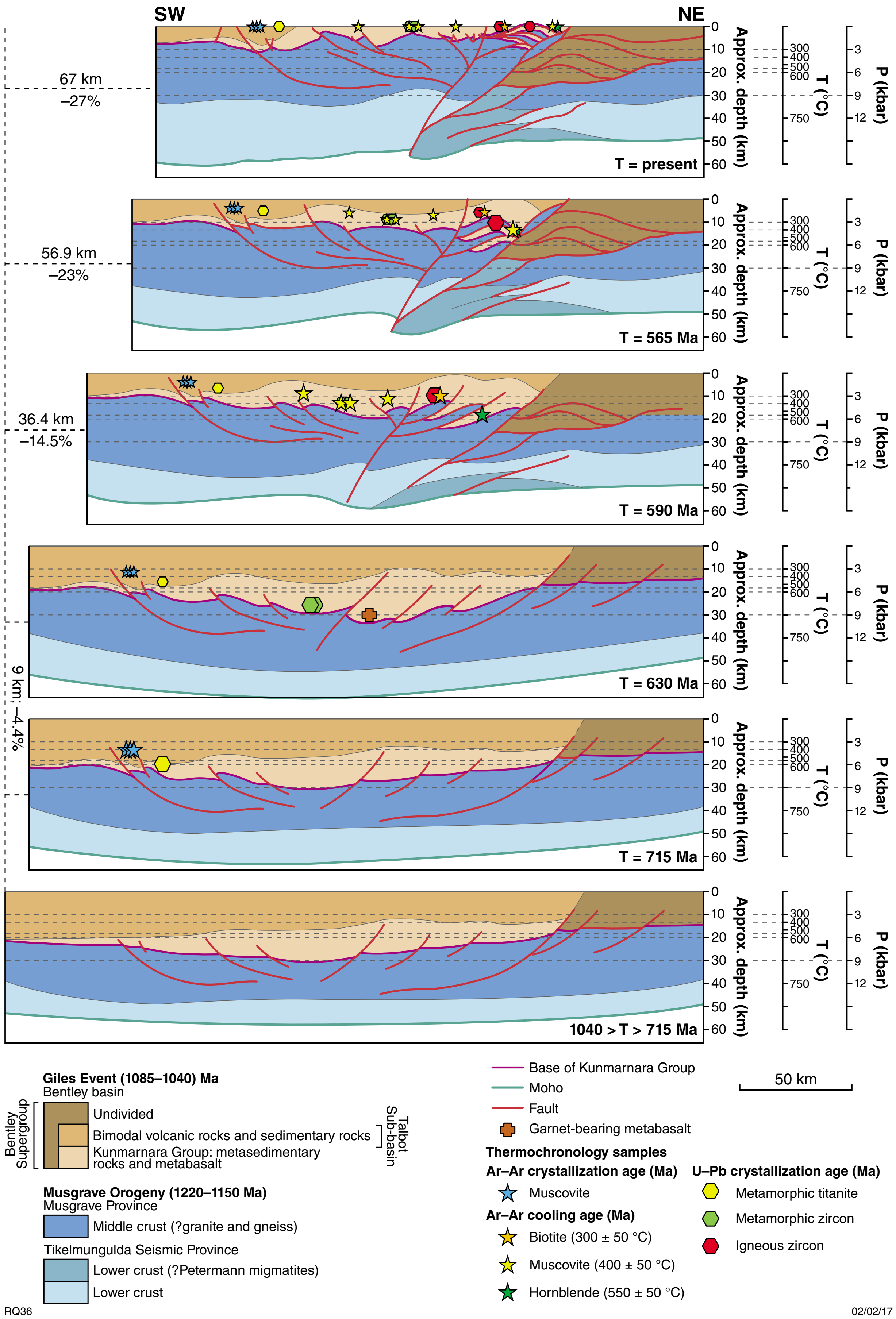
SW
NE
67 km
–27%
56.9 km
–23%
36.4 km
–14.5%
9 km; –4.4%
T = present
T = 565 Ma
T = 590 Ma
T = 630 Ma
T = 715 Ma
1040 > T > 715 Ma
Approx. depth (km)
T (°C)
P (kbar)
0
10
20
30
40
50
60
300
400
500
600
750
3
6
9
12
Giles Event (1085–1040) Ma
Bentley basin
Bentley Supergroup
Undivided
Bimodal volcanic rocks and sedimentary rocks
Kunmarnara Group: metasedimentary rocks and metabasalt
Talbot Sub-basin
Musgrave Orogeny (1220–1150 Ma)
Musgrave Province
Middle crust (?granite and gneiss)
Tikelmungulda Seismic Province
Lower crust (?Petermann migmatites)
Lower crust
Base of Kunmarnara Group
Moho
Fault
Garnet-bearing metabasalt
50 km
Thermochronology samples
Ar–Ar crystallization age (Ma)
Muscovite
Ar–Ar cooling age (Ma)
Biotite (300 ± 50 °C)
Muscovite (400 ± 50 °C)
Hornblende (550 ± 50 °C)
U–Pb crystallization age (Ma)
Metamorphic titanite
Metamorphic zircon
Igneous zircon
RQ36
02/02/17

Figure 3. **(left) Time–temperature constrained evolution model showing amount of calculated shortening over time. The geothermal gradient used is 30 °C/km for the first 20 km and 7.5 °C/km for the next 20 km (see text for references). Line-length balanced and reconstructed only south of the Woodroffe Thrust. Granites of the Warakurna Supersuite and rocks of the Canning and Officer Basins were omitted deliberately.**

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