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Jurassic Arc: Reconstructing the lost world of eastern Gondwana

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SUPPLEMENTARY PAPERS

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Supplementary file A. List of samples used for U-Pb geochronology in this study (PDF).

Supplementary file B. U-Pb geochronological datasets (Excel file).

Supplementary file C. List of samples used for Lu-Hf analysis in this study (PDF).

Supplementary file D. Lu-Hf isotope analytical datasets (Excel file).

Supplementary file E. Analytical setup and procedures used (PDF).

Supplementary file F. Crustal addition rate calculations (PDF).

Supplementary file G. Supplementary Figure 1. Plotted εHf data with isotopic evolution curves (PDF).

Crustal Addition Rate Calculations

Rationale

A subduction complex demarcates the position of the east Gondwana continental margin in the Late Carboniferous (ca. 320 Ma), approximately when the dominant tectonic regime switched from contractional to extensional (Jessop et al., 2019). As this subduction complex lies considerably inboard in reconstructions of pre-breakup east Gondwana, it can be inferred that continental crust east of this complex (much of which constitutes the largely submerged continent of Zealandia; Sutherland et al., 2020) was generated in the period dominated by extensional margin processes after 320 Ma, and before the cessation of subduction-related magmatism by ca. 45 Ma (Matthews et al., 2015).

The granitic rocks of the Late Carboniferous-Permian (i.e. after ca. 320 Ma) New England Orogen are widely accepted to represent Paleozoic continental arc magmatism on an accretionary margin (Kemp et al., 2009; Jessop et al., 2019). Their consistent strongly positive zircon εHf values of +5 to +10 (Kemp et al., 2009) are very similar to those presented here for the GAS detrital record (+8 to +12), suggesting a similar magmatic style persisting throughout the Late Paleozoic and most of the Mesozoic.

As presented U-Pb geochronological data and Hf isotopic data extend through the Mesozoic to ca. 95 Ma, and demonstrates quasi-continuous magmatism and remarkably continuous strong positive Hf isotopic trends throughout this period, the duration of the east Gondwana continental arc can be estimated as at least **~225 Myr** (i.e. ca. 320 to 95 Ma). These strongly positive εHf values indicate the addition of vast volumes of juvenile crust to the east Gondwana margin over this 225 Myr period. Calculation of the rates at which this juvenile crust was added, and comprehension of the mechanisms by which it was added, are imperative to plate tectonic reconstructions and the modelling of Phanerozoic crustal growth rates.

The proportion of the GAS detrital zircon record younger than 320 Ma is **42.6%** (2962 out of 6955 detrital zircons), therefore we infer that 39.5% of the GAS fill volume was derived from this juvenile zircon-bearing crust*. The volume of the GAS basin fill is approx. **1.5 x 10^6 km^3** (Veevers, 2001; Bryan et al., 2012), which translates to 639,000 km^3 (42.6% x 1.5 x 10^6 km^3**)**. However, as only ca. 94% of Hf isotopic analyses returned juvenile (positive) εHf values (Fig. 3; GSA Data Repository[1]), the juvenile crustal contribution to the GAS sedimentary record is more accurately estimated at **600,660 km^3** (94% x 639,000 km^3). In addition, the Ceduna Delta (MacDonald et al., 2013; Lloyd et al., 2016) hosts large volumes of sediment recycled from the Upper Cretaceous strata of the Eromanga Basin (Lloyd et al., 2016). U-Pb zircon geochronology of the upper lobe of the Ceduna Delta (Santonian-Maastrichtian) indicates approx. **42.2%** of its zircon record postdates 320 Ma (MacDonald et al., 2013; Lloyd et al., 2016). The volume of the upper Ceduna Delta lobe is estimated to be **366,786 km^3** (126,000 km^2 x 2.9 km; Lloyd et al., 2016), which translates to 154,783 km^3 (42.2% x 366,786 km^3). 69.6% of hafnium isotopic analyses of post 320 Ma zircons returned juvenile (positive) εHf values (Lloyd et al., 2016), so the juvenile crustal contribution to the sedimentary record of the upper Ceduna Delta lobe can be estimated as **107,729 km^3** (69.6% x 154,783 km^3). Together, the basinal sedimentary fill volume derived from this juvenile, zircon-bearing crust through the Mesozoic is approximately **708,389 km^3**.

The onshore, post 320 Ma proportion of the New England Orogen must be included in calculations of juvenile crustal growth rates. Using the latest outcrop maps of the New England Orogen (Jessop et al., 2019), a surface area of juvenile igneous addition of ca. 200,000 km^2 is estimated. By using an estimated crustal thickness of 38 km, which is the global average (Reymer and Schubert, 1984) a New England Orogen juvenile crustal volume of **7.6 x 10^6 km^3** is calculated.

The submerged crustal volume of Zealandia must also be accounted for in these calculations, as it must have been added to the east Gondwana margin after ca. 320 Ma. Sutherland et al. (2020)

reported a Zealandia crustal area of 3 x 10^6 km^3 and a thickness of 18 km, resulting a crustal volume of **5.4 x 10^7 km^3**. However, the paucity of age and isotopic data on submerged Zealandia limit evaluation of the proportion of juvenile crust (i.e., newly generated crust) in Zealandia versus recycled material from older orogens of the Tasmanides.

As the proportion of juvenile crust should increase with proximity to the arc, the **42.6%** value derived from the GAS fill can be considered as a minimum threshold of juvenile igneous contribution to the offshore crustal volume.

From the tectonic reconstruction depicted in Fig. 4, based on Matthews et al. (2015) and Sutherland et al. (2020), a constrained arc length of **2500 km** (encompassing the north-south extent of the GAS) is inferred.

Calculations

Crustal addition rates to the east Gondwana margin through the Late Paleozoic and Mesozoic can be estimated using the following calculations, modified after Reymer and Schubert (1984).

Variables		
a	Juvenile, post 320 Ma contribution to GAS and Ceduna Delta fills	**708,389 km^3** (This Study)
b	Juvenile, post 320 Ma igneous contribution to onshore New England Orogen	**7.6 x 10^6 km^3** (This Study)
c	Zealandia Crustal Volume	**5.4 x 10^7 km^3** (Sutherland et al., 2020)
d	Juvenile, post 320 Ma contribution to Zealandia (Min)	**42.6%** (This Study)
e	Arc Length	**2500 km** (This Study)
f	Arc Duration	**225 Myr** (This Study)

Minimum Crustal Growth Rate

$$\|\{[(\boldsymbol{a}+\boldsymbol{b})+(\boldsymbol{c}*\boldsymbol{d})]\div\boldsymbol{e}\}\div\boldsymbol{f}\| = \mathbf{55.67\ km^3\ km^{-1}\ Myr^{-1}}$$

(Minimum crustal volume generated per km of strike length per Myr)

* These crustal growth rate calculations involve caveats, for example that the relative abundance of zircons of different ages can be linearly correlated with eruptive volume, and the zircon fertility of different plutons does not differ significantly.

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