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GR Focus

# Granitoid events in space and time: Constraints from igneous and detrital zircon age spectra

Kent C. Condie [a,*], Elena Belousova [b], W.L. Griffin [b], Keith N. Sircombe [c]

[a] *Department of Earth & Environmental Science, New Mexico Institute of Mining & Technology, Socorro, NM 87801, USA*
[b] *GEMOC, Department of Earth & Planetary Sciences, Macquarie University, Sydney, NSW 2109, Australia*
[c] *Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia*

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ABSTRACT

The goal of this study is to evaluate the global age distribution of granitoid magmatism and juvenile continental crust production with U/Pb isotopic ages from igneous and detrital zircons, and with Nd isotopic data. Granitoid age peaks, which are largely defined by TIMS data, are narrow and precise in contrast to detrital peaks that are often broad and hump-shaped due to the larger uncertainties of SHRIMP and LAM-ICPMS data. Granitic age peaks do not always have detrital counterparts and vice versa. Possible contributing factors to this mismatch are removal of crustal sources by erosion, inadequate sampling of granitoids because of cover by younger rocks, or small age peaks hidden by large age peaks in detrital spectra.

Seven igneous peaks are found on five or more cratons or continents (3300, 2700, 2680, 2500, 2100, 1900 and 1100 Ma) and seven detrital peaks occur on three or more continents (2785, 2700, 2600, 2500, 1900, 1650 and 1200 Ma). Nd isotope distributions suggest important additions of juvenile continental crust at 2700, 2500, 2120, 1900, 1700, 1650, 800, 570 and 450 Ma. Tight clusters of craton ages occur for Superior–Karelia, Sao Francisco–Nain, and Kaapvaal–Siberia in the early Archean and for Wyoming–Kaapvaal–Slave, Superior–Nain, and West Africa–Amazonia in the late Archean. The global 2700-Ma peak is not a simple spike, but involves several peaks between 2760 and 2650 Ma. Events older than 3700 Ma are limited to the Yilgarn, Slave, Nain and North China cratons, and events between 2600 and 2500 Ma are widespread only in East Asia, Central and East Africa, and India.

Single, short-lived mantle plume events at 2700 and 1900 Ga (or any other time) cannot easily account for prolonged episodes of granitoid magmatism during the Precambrian. The causes of geographically widespread and geographically restricted events are probably not the same.



**Contents**



* Corresponding author.
*E-mail address:* kcondie@nmt.edu (K.C. Condie).

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## 1. Introduction

The episodic nature of granitic magmatism was recognized many years ago and major episodes were identified at 2.7 and 1.9 Ga (Gastil, 1960; Stein and Hofmann, 1994; Condie, 1998). From an ever-increasing number of U/Pb zircon ages, and especially detrital zircon ages, it is now possible to re-evaluate the distribution of granitoid-forming episodes both in space and time. One important question is whether 2.7 and 1.9 Ga are the only periods of enhanced granitoid magma production in the last 4 Ga. A related question is whether or not two global mantle plume events at 2.7 and 1.9 Ga (Condie, 1998, 2000) can explain the episodic growth of continental crust formation. Detrital zircon age distributions enhance our ability to sample large regions of continental crust not easily accessible in outcrop. In fact, some crustal provinces may have been largely removed by uplift and erosion so that evidence for their existence now resides chiefly in the detrital zircon record. Matching of granitoid age spectra between continents and cratons provides another constraint for proposed configurations of super-continents (Bleeker, 2003; Pesonen et al., 2003). Such information should also be important in verification of a possible crustal age gap between 2.4 and 2.2 Ga (Condie et al., 2005, in press).

The results of this study show that it is difficult to understand and interpret the differences between igneous and detrital age spectra. Both spatial and temporal distributions of granitoid-forming episodes are significantly more complex than suggested by earlier investigations. Furthermore, a model with two "one-pulse" mantle plume events at 2.7 and 1.9 Ga faces difficulties in explaining the distribution of episodes of granitoid magmatism and juvenile continental crust formation during the Precambrian.

## 2. Spectral analysis of zircon ages

Over 7000 high-precision U/Pb isotopic ages of igneous rocks and over 18,000 isotopic ages of detrital zircons are included in the database upon which age spectra are constructed (Appendix A). To maximize the use of high-quality data, only single-zircon ages obtained by SHRIMP (sensitive high-resolution ion microprobe), TIMS (thermal ionization mass spectrometry) or LAM ICP-MS (laser ablation microprobe inductively coupled plasma mass spectrometer) are included in the compilation. While TIMS dates have the highest precision, the distribution of isotopic ages measured by each of these methods yields similar age patterns, and hence results from all three methods have been combined in the final analysis. Igneous data come from granitic rocks of all compositions (diorite to granite) and <5% from felsic volcanics. Most isotopic ages are from syn- to slightly post-tectonic granitoids, but post-deformational granites (including A-type granites) closely related to orogenic systems are also included. Although parent rocks of detrital zircons cannot be precisely identified, most detrital zircons appear to have granitoid sources based on their geochemistry (Belousova et al., 2002). The majority of detrital zircon ages are from Australia and Laurentia, and a large proportion of pre-3.5-Ga ages are from the 3.0–2.7 Ga Jack Hills quartzites and Narryer Gneiss in the northwestern Yilgarn craton in Australia (Dunn et al., 2005; Harrison et al., 2005). As expected, detrital age spectra show more peaks and more complexity with decreasing age of deposition. At least in part, this is due to recycling of older detrital zircons. If zircon ages are identified as metamorphic ages *not associated with granitoid plutonism* by the original investigators, they are not included in the compilation, and hence the great majority of the compiled zircon ages, both igneous and detrital, are believed to represent magmatic ages.

Each igneous zircon age represents data from three or more single zircons meeting one of two requirements: 1) the *average* U/Pb age is less than 10% discordant and has a 1 σ uncertainty less than 20 My, or 2) the age is an upper discordia intercept with a 1 σ error less than 20 My. Thus, each igneous age is a "multiple" zircon age in contrast to detrital ages, each of which represents a single zircon grain (or domain therein). Only zircon core ages are included from SHRIMP and LAM ICP-MS analyses. Detrital zircon ages with >10% discordancy are not included in the spectral analysis. Caution is warranted in interpreting LAM ICP-MS detrital ages since down-hole age variations in ablation pits in single zircons are not monitored in some analyses. To partially address this problem, those detrital ages with 1 σ uncertainties >80 My are not included in the study; this filter eliminates <5% of the total detrital ages available. Decreasing this uncertainty filter to <30 My has no affect on peak locations, but eliminates large numbers of ages as well as some age peaks in regions of the continents where few zircon ages are available. Hence, our final analysis of detrital data uses the 80-My uncertainty filter. We also compared results for both igneous and detrital data using 1 σ and 2 σ uncertainties of ages, but found no differences in age peak locations, and hence results are reported using 1 σ uncertainties. Due to the relatively small number and the irregular distribution of young U/Pb zircon igneous ages, only isotopic ages ≥400 My are discussed in this study. ENd(T) data for whole rocks from which zircon ages are available are given in Condie et al. (in press).

To characterize age spectra, igneous and detrital ages are analyzed as probability density plots, both with and without histograms, using the approach of Sircombe (2004). Optimum bin size was determined by Isoplot software. One of the problems in identifying "real" spectral peaks is that large peaks often partially mask smaller peaks, especially in the detrital data. Peak height is quantified by integrating the area beneath each peak, using two different approaches (Sircombe, 2004): summing the number of ages beneath each density probability peak from a spreadsheet, and by using bin counts from histograms. Peak uncertainties, expressed as one standard deviation of the mean, are calculated using a Gaussian event simulator developed at GEMOC. Some age spectra, and especially igneous spectra, are complex with many peaks (Figs. 1a and 2a). The highly resolved peaks in igneous spectra reflect a bias of the high-precision TIMS results, which dominate the igneous data. In contrast, detrital peaks are often broad and hump-shaped due to the larger uncertainties of SHRIMP and LAM ICP-MS ages (Figs. 1b and 2b). Monte Carlo simulation studies assuming independent age errors confirm that the broad peaks and relatively simple age spectra for detrital zircons reflect, at least in part, the large uncertainties on single zircon age measurements. Age "spikes" superposed on these humps, as illustrated by the European detrital spectrum in Fig. 2b, may be real or may be spurious, if caused by only one or two single zircons with low errors.

Another problem in analyzing age spectra is that of identifying age peaks with widespread geographic distributions. Peak height is one measure of importance, although intense sampling from small geographic regions can greatly bias the relative importance of a peak. The number of cratons on which a given peak occurs is another measure of geographic importance. Cumulative peak height, as measured by the total number of ages per peak, and number of cratons on which a given peak is recognized are summarized in Figs. 3 and 4 from data in Appendix A. Zircon age spectra are divided into two time windows (4400–2300 and 2300–400 Ma) and results for each continent are summarized in Figs. 5 and 6 as probability density plots.