The journal regrets that due to a publication oversight, Barham et al. (2019) was not published alongside the relevant Comment in volume 47 no. 8 (Mitchell, 2019). The entire Reply is published herewith (volume 47 no. 9).

Forum Reply

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Spot the difference: Zircon disparity tracks crustal evolution

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We thank Mitchell (2019) for his interest in our paper concerning temporally-framed detrital zircon disparity analysis, and its example application to understanding crustal evolution. Our colleague presents two main, but ultimately flawed, comments taking issue with our use of (i) geographic grouping, and (ii) Kolmogorov-Smirnov (KS) tests.

While disparity-through-time analysis is established in some areas of geoscience (e.g., paleontology; Guillerme and Cooper, 2018), its use with detrital zircon data is novel. Mitchell inaccurately conflates the approach with classic source-to-sink detrital zircon provenance studies. Although the temporal-disparity approach we present could be applied at the basin scale, we evaluate global-scale homogeneity/heterogeneity of zircon populations. The justifications for, and limitations of, the geographic grouping of detrital zircon data were discussed at length by us (Barham et al., 2019). It is abundantly clear that we recognize that the aggregated mosaics of crustal fragments constituting the current continental arrangements do not necessarily reflect geologically coherent entities throughout Earth history. Geographic grouping is used only as a spatially unitized reference frame for the purposes of disparity analysis through time.

Mitchell claims geographic grouping renders a “majority of each data set essentially arbitrary”. However, this statement is demonstrably incorrect. Statistical tests of disparity versus the supercontinent cycle presented by us prove that this grouping remains sensitive to at least the last 2 Ga of global continental break-up and assembly (50% of the timeframe). Mitchell’s error appears, in part, to be assuming we are only looking for local similarities within and between geographically restricted terranes, rather than attempting to capture global disparity using geographic binning as a reference frame. Further support for our interpretation is evident when a completely different geographic grouping is used. Tracking detrital zircon disparity through the same 4 Ga of Earth history (200 Ma intervals) using a hemispheric division (North vs. South), reveals a statistically correlated pattern tracing the supercontinent cycle (Table 1). Although more muted, this simplistic geographic grouping still demonstrates increasing “global” detrital zircon similarity during supercontinent intervals, and decreasing similarity during continent dispersion.

TABLE 1. PEARSON CORRELATION OF DISPARITY VERSUS SUPERCONTINENT CYCLE FOR DIFFERENT GEOGRAPHIC GROUPINGS

Confidence of correlation with supercontinent timings of Barham et al. (2019)	Nearest Neighbor (ANN) from MDS	Centroid distance (CD) from MDS	SH-NH from KS	SH-NH from MDS
	>99%	>99%	>94%	>97%

Note: ANN—approximate nearest neighbor; MDS—Multi-Dimensional-Scaling; SH—Southern Hemisphere; NH—Northern Hemisphere; KS—Kolmogorov-Smirnov.

Whilst any geographic grouping could potentially homogenize age signatures of amalgamated crustal regions, this cannot increase absolute disparity measures. Consequently, Mitchells suggestion that a pronounced disparity at 2.5 Ga is “largely an artifact of the cratons being grouped having no geologic meaning” is erroneous, given the inability of mixing to make a merged age population more age-peak-distinctive than its component sub-populations. Mixing will effectively smear age peaks, pushing grouped age populations towards a more homogeneous average that, when compared against other groups, would only act to conceal genuine disparity excursions. For all of the above reasons, the issue of geographic grouping raised by Mitchell is moot.

Mitchell accepts that the KS test similarity metric (KSD) is a standard technique in detrital zircon studies, but contends that a major limitation (i.e., that the technique is based on the single maximum difference between samples) was omitted from our work. In reality, this fundamental aspect of the KS test and other limitations, are clearly explained in the associated citations and general literature (Vermeesch, 2013, 2018; Ibañez-Mejia et al., 2018). Mitchell goes on to attempt to show that the KS test has limited ability to correctly distinguish the dissimilarity of two pairs of age populations, where one pair appears more similar than the other on a standard age probability density plot (Fig. 1). However, in contrast to that portrayed by Mitchell, KSD values are not measured from a probability density plot, but from the separation between populations in cumulative distribution space (Massey, 1951). Synthesis of the age spectra presented by Mitchell demonstrates the age populations can be readily compared, and the degree of similarities between pairs easily differentiated via the KS test (Fig. 1). While Mitchell’s presentation of the KS test is thus inaccurate, we agree that “If statistics is [sic] either misused…then arguably more harm is being done than help”.

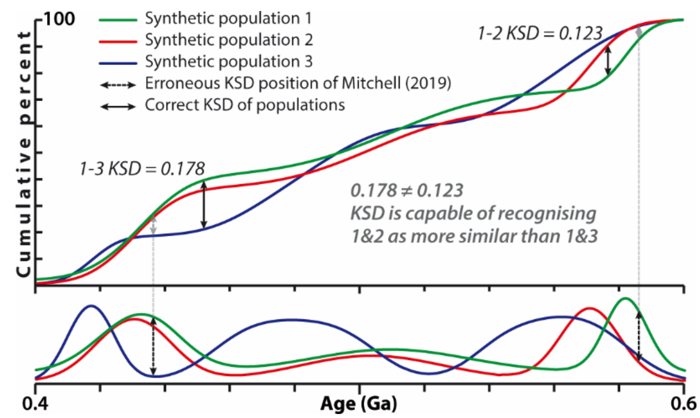

Figure 1. Age probability density plot and corresponding cumulative age distribution plot demonstrating correct measurement of the KSD metric.

Finally, we recognize Multi-Dimensional-Scaling (MDS) is imperfect, e.g., maintaining exact relative similarities between age populations in a two-dimensional plot. Nonetheless, rerunning temporal disparity analysis of the same age data using just KSD values, indicates >99% confidence in a positive correlation with the original MDS-derived disparity measures of Barham et al. (2019). Both quantitative similarity tests (KS, Kuiper, etc.) and MDS visualizations can be integrated to (1) accurately quantify detrital zircon disparity, *and* (2) effectively interrogate geological reasons for disparity variations through time, respectively. The proposed KSD-MDS temporal-disparity metric remains a powerful tool to track the evolution and efficiency of basin to crustal-scale zircon homogenization processes.

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