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The Cryosphere
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Interactive comment on "Crustal heat production and estimate of terrestrial heat flow in central East Antarctica, with implications for thermal input to the East Antarctic ice sheet" *by* John W. Goodge

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I am grateful to the reviewer for positive comments and a statement about the value of the work. The author agrees with the reviewer that these data provide a valuable 'cross-check' for comparison with other approaches to estimating subglacial heat flow in Antarctica. As noted in separate comments, a unique aspect of the present data set is the association of rock properties with radiometric ages, thereby providing age control to the sample suite.

1. Regarding the number of samples analyzed, a similar concern was raised by Reviewer 2, and these concerns are addressed here. It would, of course, be helpful to

have a larger sample set and taken from a potentially larger catchment area. The original purpose of the clast sampling was to obtain a representative set of samples from the ice-covered East Antarctic craton in order to address questions of crustal age, composition, and history. The stated goal of the project was to investigate crustal evolution using age and isotopic constraints. That project included sampling of moraines at over a dozen sites ranging across >1,500 km of the Transantarctic Mountains (TAM). In the field, samples of any rock that represented potential Precambrian shield basement were collected. Thus, the sampling was effectively randomized. Over 300 clasts were obtained. Most of the useful yield was from only 5 sites; the others were dominated by clasts of Beacon sediment or Ferrar dolerite eroded from the TAM. A major effort was undertaken to screen the samples and set aside any with Ross Orogen (∼500 Ma) ages, in order to focus solely on the Precambrian crustal history of the shield interior. This involved a significant amount of reconnaissance-type U-Pb geochronology that is normally not done as part of a petrologic study. After culling the sample suite, detailed work of mineral analysis, mineral separation, precise U-Pb geochronology, geochemical analysis, O-isotope analysis, and Hf-isotope analysis were completed over a period of several years. Work on additional samples was simply not feasible. The results of this crustal history project were published in Precambrian Research in 2017 (Goodge et al, cited). It should be emphasized that it is ONLY with high-quality age data that it is possible to then use this sample suite to constrain the interior heat-flow of East Antarctica. In the absence of age data, the origin of the clasts is completely unconstrained and a large fraction of any samples studied could well be sampling the TAM orogen or younger Beacon cover which is largely irrelevant to questions of subglacial heat flow in the craton interior. Thus, simply sampling moraines to obtain a large set of geochemical data without geochronology is likely to produce misleading results. The text in Section 2 has been revised substantially to expand upon and clarify the overall approach taken.

2. Regarding choice of samples, please see above comment and explanation added to the manuscript. To address the specific question raised here, the following revisions

have been completed: a) the names of sample sites are explicitly included in the text, differentiating the two Lonewolf Nunatak subsites A and B; b) Lonewolf Nuntaks, at the southern margin of Byrd Glacier was simply the singlemost productive site that was sampled. Presumably this is because the Byrd ice stream is among the fastest outlet glaciers traversing the TAM and capable of significant glacial erosion. It is numerically over-sampled compared to other sites, yet it contains a full range of clast ages between 1.2 and 2.0 Ga so is likely to be representative of the craton interior. c) Four sites (AGA, MRA, MSA, and TNA) were dominated by granitoids with Ross Orogen ages (18 samples) and two of these sites (AGA and MRA) yielded no pre-Ross rocks at all so are not included in this study. d) Figure 2 has been modified to show all the sites sampled, with only the three sites LWA/LWB, MSA, and TNA identified for this study. e) Manuscript text is modified to explain these points.

3. Regarding interpretation about sources in greater Wilkes Land, this is a valid point. Manuscript text is modified in section 4.3 to state that the potential sample area represents a more limited part of the Wilkes Land region.

4. Exploting ice flow… This is an interesting idea, but unfortunately the sample size is too small (coarse) to resolve any patterns related to individual drainages across the area. A comment to this effect was added in the Discussion section of the revised manuscript.

5. Minor revisions

a. The work of Fisher et al. (2015) does indeed represent a subglacial measurement in the area near Subglacial Lake Whillans, but as noted elsewhere in the manuscript the extremely high (anomalous) crustal heat flow value obtained is highly perturbed by advective heat transfer associated with flowing water at the base of the ice stream. As such, this measurement does not give an accurate representation of terrestrial heat flow at the base of an ice sheet. Although their result is informative of subglacial process at the Whillans Ice Stream, it does not constrain terrestrial heat flow, the subject

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of this contribution. Text revised. Also note, however, a paper just published by Begeman et al. (2017) provides a new estimate of heat flow in West Antarctica obtained by sediment probe and this work is cited in the revised manuscript.

b. Other revisions made as suggested by the reviewer.

c. Shape of catchment is not possible to address. There are published models for the extent of the Antarctic ice sheets over time (e.g., Pollard, DeConto, Scherer, etc.) and for the inheritance of subglacial drainage based on preglacial fluvial landscape (e.g., Jamieson), but to my knowledge no models are available predicting the configuration of the catchment area in which these samples were transported.

d. See above response to sample collection and sample size, including expanded explanation provided in Section 2 of text. The affect of sample size on interpretation is treated in the Discussion.

e. Two formulations to calculate heat production from geochemical compositions are commonly used, both based on rock density and concentration of the heat-producing elements U, Th and K. The approaches are both based on an original algorithm by Rybach (1988), modified with slightly different parameters. Both methods were included in this contribution simply for the purposes of comparison, and in order that these values could more easily be compared with results from other areas that use either of the calculations. Manuscript text was revised to clarify this point.

f. Comparison with global examples.... Revised for clarification with specific citations. Note a new reference âĂŤ recently published in 2017 âĂŤ was added (Artemieva et al., 2017) on heat production in granitic rocks. Some further revisions and updates provided in the preceding paragraph as well.

g. A suggestion concerning hr... This is a very good idea that was not considered previously. It is a good suggestion for an independent way to assess uncertainty in this parameter. A survey of bed topography using Bedmap data across the catchment area

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shows a general range of subglacial relief of 1500-2000 m, depending on how far to extend the catchment area up the flank of the Gamburtsev Subglacial Mountains. The manuscript text is revised to add this perspective.

Note: References are updated with new citations added in support of revisions and with some newly published papers of relevance (e.g., Artemieva et al., 2017; Begeman et al., 2017).

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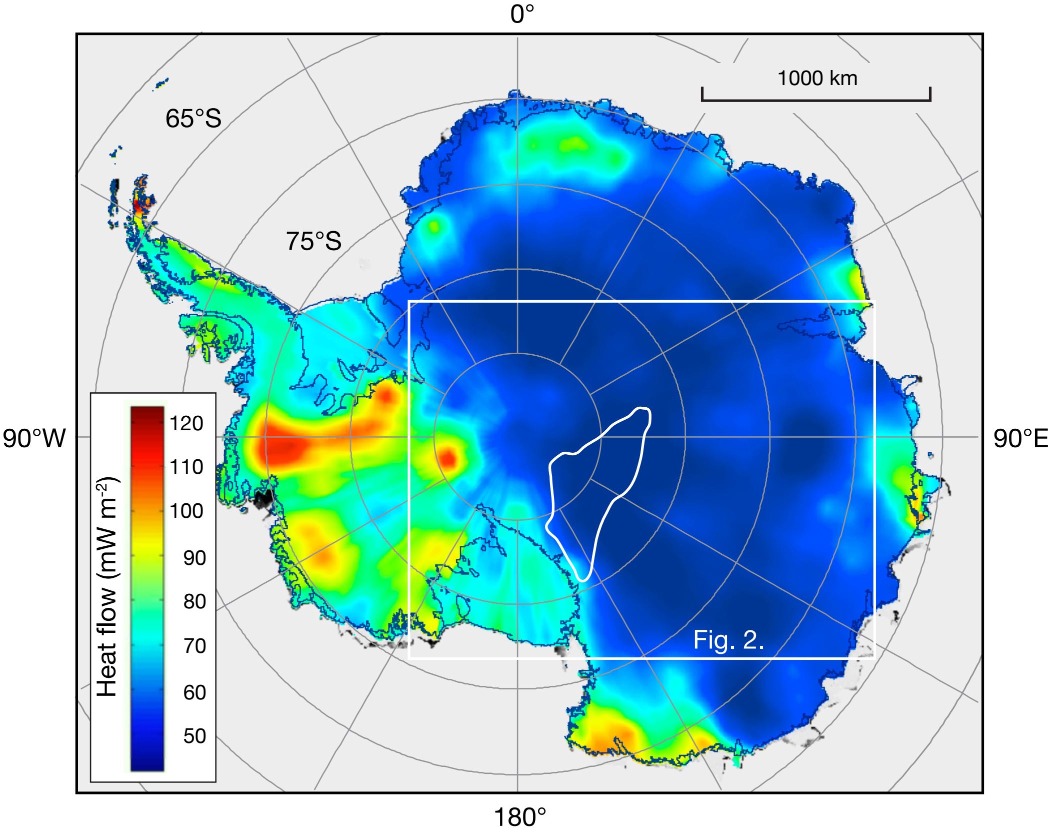

Fig. 1. Figure 1: Terrestrial heat flow in Antarctica.

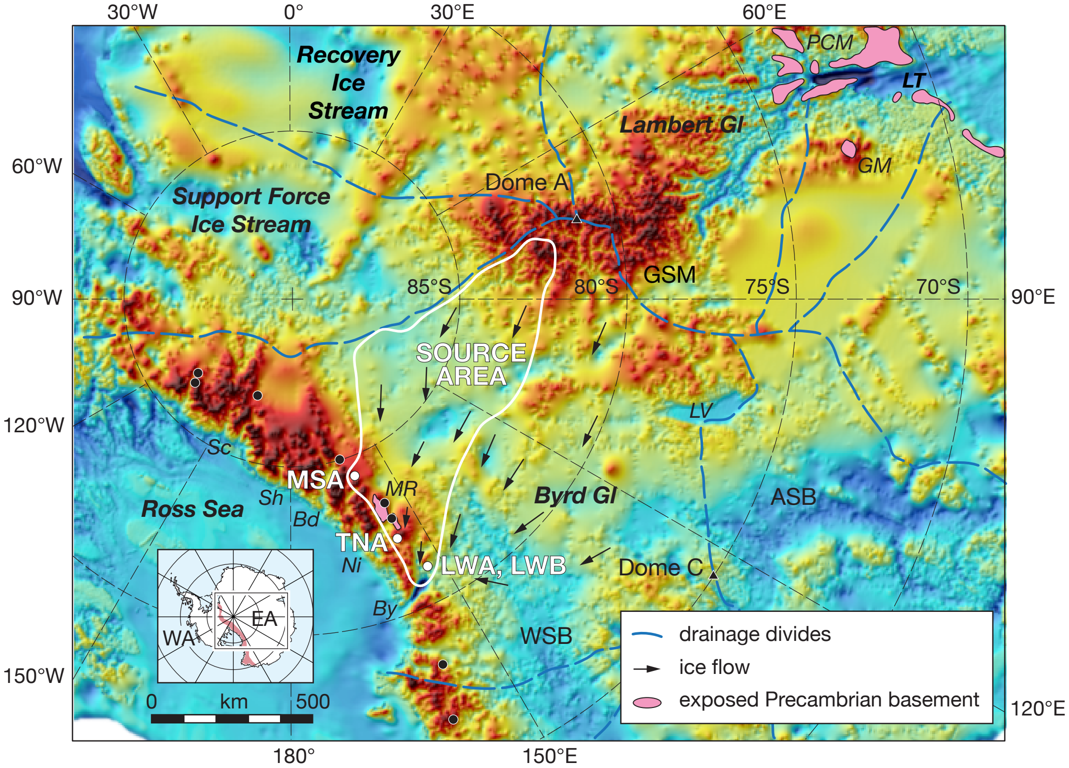

Fig. 2. Figure 2: Map showing potential source areas for dated glacial igneous clasts.

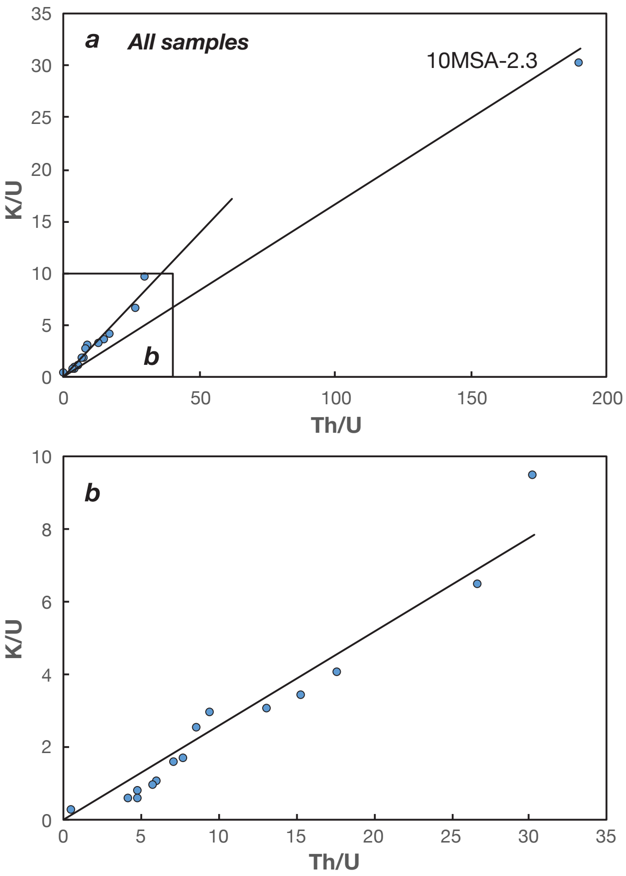

Fig. 3. Figure 3. (a) Plot of Th/U vs. K/U in glacial igneous clasts.

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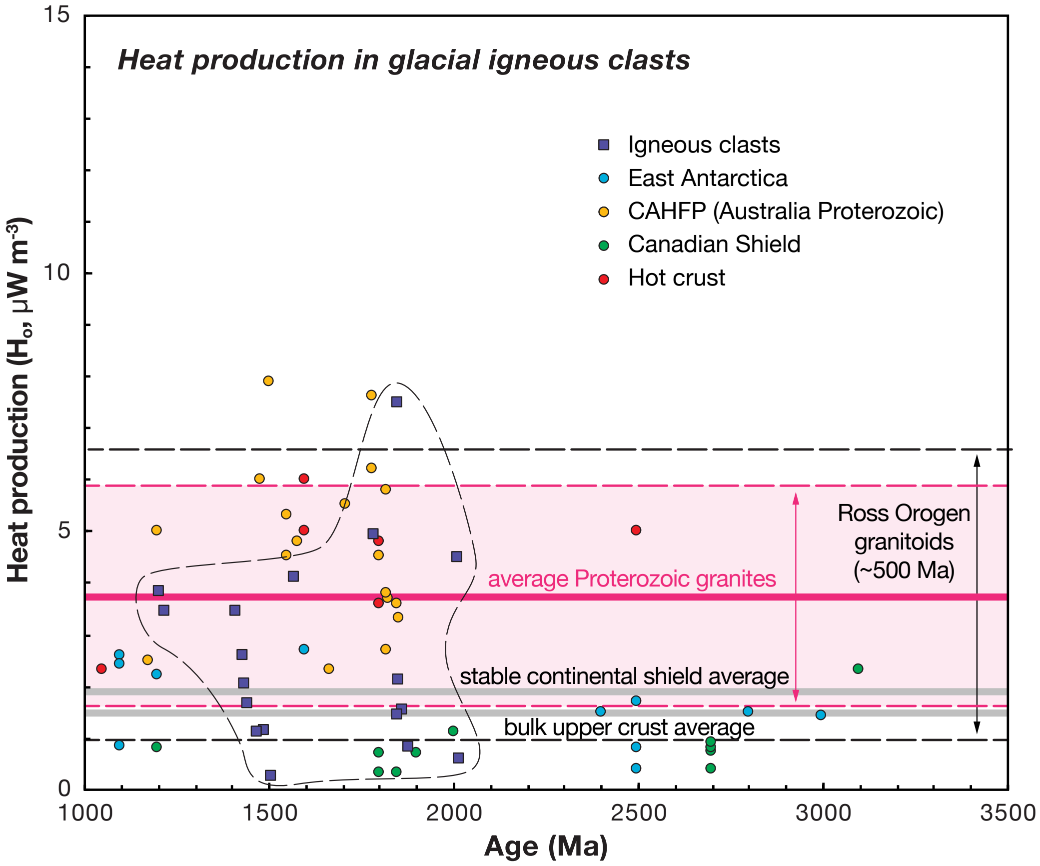

Fig. 4. Figure 4. Plot of surface heat production (Ho) vs. age for igneous glacial clasts.

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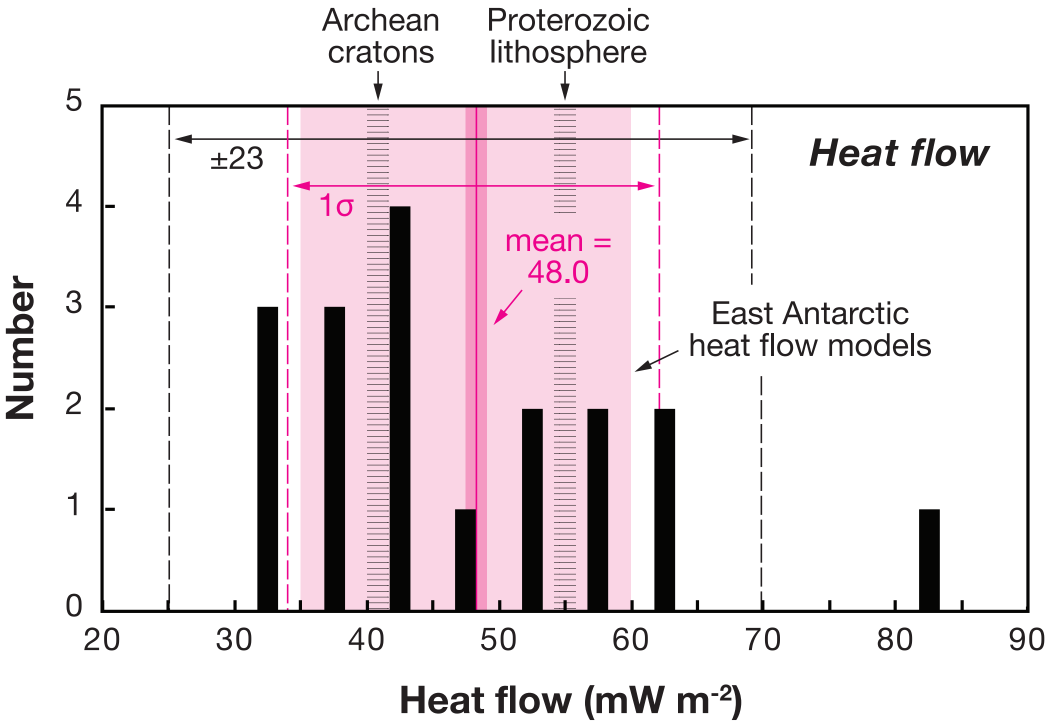
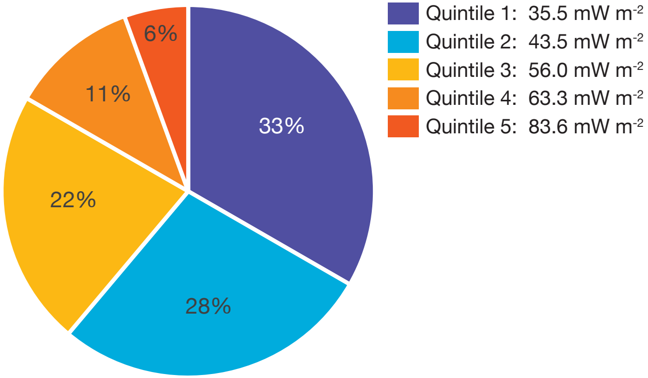
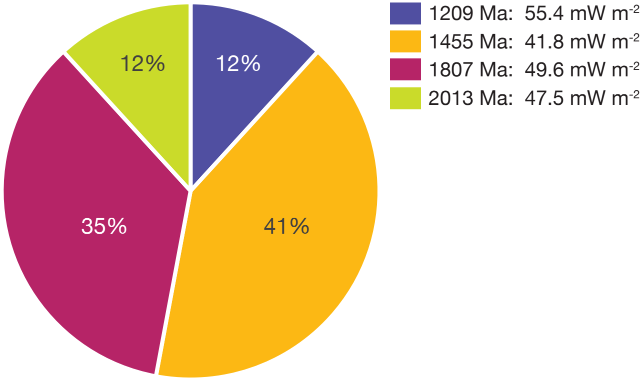


Fig. 5. Figure 5. Histogram of heat flow values estimated from heat production in the glacial clasts.



a Heat flow distribution by quintile



b Heat flow distribution by age group

Fig. 6. Figure 6: Summary pie diagrams showing distribution of heat flow estimates from this study.