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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

Anonymous Referee #2

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General comments

Goodge has developed an idea that has appeared in the literature over the past few years regarding the possible impact of high heat producing rocks on sub-glacial heat flow in Antarctica. This is an important problem given both the potentially significant impacts of sub-glacial heat flow variations on ice sheet behaviour, and the established (possibly flawed) approach of using literature averages for surface heat flow in ice sheet models. It is also an interesting area of cross-disciplinary science, and obviously a suitable topic for Cryosphere. Goodge's paper contributes to our understanding of sub-glacial heat flow variation by measuring the heat-producing-element enrichment for a

limited number of assumed bedrock lithotypes sampled from moraine systems. These data are then used to estimate sub-glacial heat flow and a conclusion of average sub-glacial heat flow for East Antarctica is made. The paper is generally well-written and easy to follow but I am a bit concerned that there is insufficient new data, and caveats on the sample size and interpretation method are not adequately outlined. The sample set is very small (five localities and 18 samples) yet the conclusions are extrapolated to draw conclusions about the regional heat flow that are not necessarily justified.

Specific comments

There are many assumptions used in the calculations that rapidly take the reader from simple U, Th and K concentrations of a few eroded rock clasts to calculations of sub-glacial heat flow across a vast area of East Antarctica. Both a mantle heat flow, and a heat contribution from the lower crust are assumed. A length scale for heat production distribution vertically within the crust is also assumed (see further discussion below). Although I fully understand the difficulties of constraining sub-glacial geology, better constraints on mantle heat flow (from seismic velocity data for example) could be used.

The analytical approach for heat-producing element determination is fairly standard and in a geoscience paper would be included only as an appendix. I do understand that for a non-specialist geoscience audience it may be more appropriate in the main text.

U and Th are known to be highly mobile elements in the near surface environment or where there is fluid flow. It would be interesting to look at the Th/U ratios (can this be added to Table 1) and the issue of mobilisation (loss or gain) of these elements to help establish that these values reflect primary igneous ratios. Also, heat producing elements, particularly U and Th, generally reside in accessory minerals such as zircon. It would be good to better characterise the samples used here. Are petrographic images or CL images available to see where the heat producing elements may be concentrated? Were the samples large or small? Do the samples show evidence for weathering that may indicate mobilisation of U and/or Th?

Why are two different formulae to calculate heat production used here? The differences between the two methods are not explained. It is also not explicit that equations (1) and (2) refer to Methods 1 and 2.

I am not sure it is meaningful to compare these few new data to the average of the CAHFP (page 7, line 3). The CAHFP dataset includes a very large number of individual analyses that are also referenced with outcrop area. I think it is much more interesting to look at the natural range of heat production variation, rather than individual averages. Even within HPE enriched terranes, many rocks have around average heat production. This is perhaps best shown in recent work on the HPE enriched Proterozoic rocks of Australia (McLaren & Powell, JGSL, 2014). Because of the sample size issue, I am wary that there is insufficient data to dismiss the idea of elevated heat flow extending from Australia to beneath the East Antarctic ice sheet.

The author has adopted the approach of Sandiford & McLaren and Perry in estimating the vertical distribution of heat producing elements within the crust. Yet the methodology applied here relies on estimates of all parameters and is somewhat circular. Similarities in age and thickness to the Canadian and Scandinavian shields are noted but not justified with evidence in the text and need to be explained. Moreover, it is not clear to me how the measured heat production values allow a calculation of surface heat flow when other lithotypes are not considered (granites will only even be a fraction of total crustal volume). As noted on page 8 (lines 29-30) the lack of constraints on mantle heat flow, lower crustal heat production and the vertical distribution of heat producing elements contribute to very high overall uncertainties. Adopting a hr value of 7 km based on other cratonic regions doesn't take into account the potential impact of thin but highly heat producing rocks.

The potential for high heat producing rocks to be residing in the upper-middle crust (rather than on the bedrock surface permitting sampling by glacial ice) is also not ad-

dressed. The presence of these would have significant implications for sub-glacial heat flow and should be at least raised as a possibility in the Discussion section.

I think parts of the Conclusion are repetitive and unless there are specific organisational requirements for the journal, the Discussion and Conclusion sections be merged and repetition removed.

This work is important and should be further developed with additional data and more sophisticated modelling of possible/likely heat flow scenarios using additional geophysical and geological evidence. Alternatively, the current paper should include more appropriate caveats on data interpretation prior to publication.

Technical corrections

Page 3, Line 31 – change radioactive to radiogenic Figure 2 – abbreviations not explained Table 1 – it would be helpful to have the lithotype listed alongside the other sample details, also the error on the age and justification for that age being an intrusive age is required Page 7, line 20 – the model of heat production decreasing exponentially with depth is one end member Page 9, line 8 – include the value of n used for calculation of the arithmetic mean

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