Heterogeneous structure of Antarctic crust for solid-earth and cryosphere interaction research

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November 16, 2022

Abstract

Knowing the heterogeneous crustal structure is essential for understanding the ice dynamics, glacial isostatic adjustment (GIA) and tectonic history in Antarctica. For example, geothermal heat flux (GHF) is a major boundary condition for ice dynamics and the crust thickness and its composition (mafic or felsic) are important factors in GHF. Meanwhile, the GIA signal and its gravity response are essential for detecting mass-balance change and predicting future sea-level change. Errors in the density model used, which may be over 10%, will propagate into the gravity calculations. In this study, we use gravity inversion constrained by seismic depth estimation to recover the heterogeneous crustal structure of Antarctica, and estimate its uncertainties. Specifically, we modify by inversion the density of the uppermost mantle, the crustal density, the Moho depth, and the sedimentary cover thickness with an ensemble model with different density/geometry variation constraints. The output models indicate the most representative model of Antarctic crustal structure within the capacity of the method and current data constraints. Our preliminary results show that crustal density varies between 2.75 to 2.95 g/cm^3 while the Moho depth varies between 22 km in Ross Ice Shelf and 54 km in Gamburtsev Subglacial Mountains. Low-density sedimentary basins are modelled at up to 10 km thickness beneath the ice shelf, and 3 km inland of Antarctica. Model also shows mantle density varies from 3.25 to 3.35 g/cm^3. These density and thickness variations indicate likely substantial differences in crustal heat production, crustal rheology, and the expected GIA response of Antarctica's crust.

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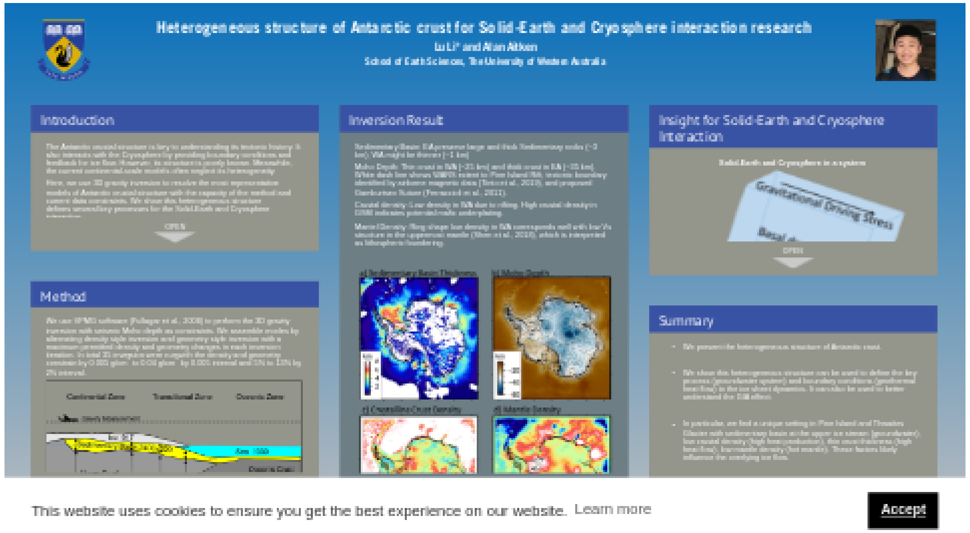

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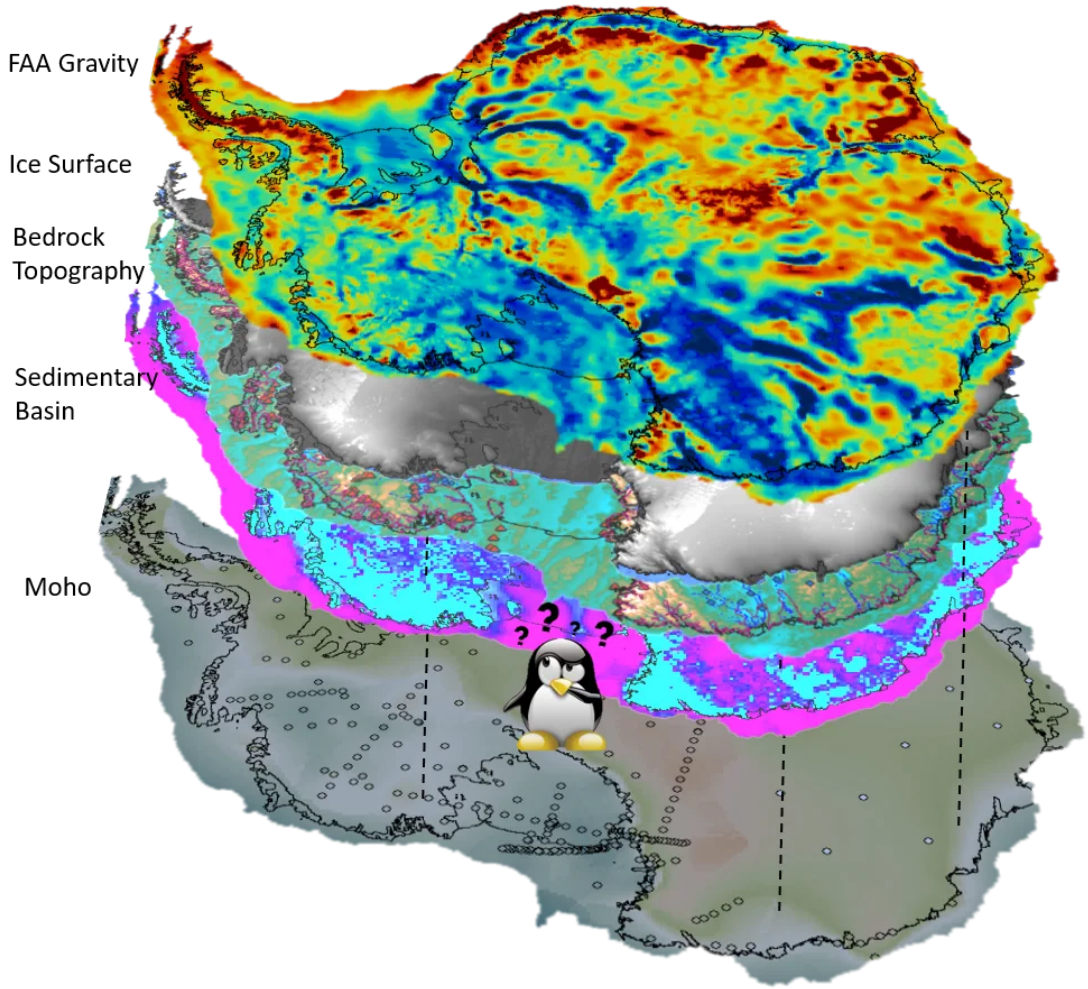
INTRODUCTION

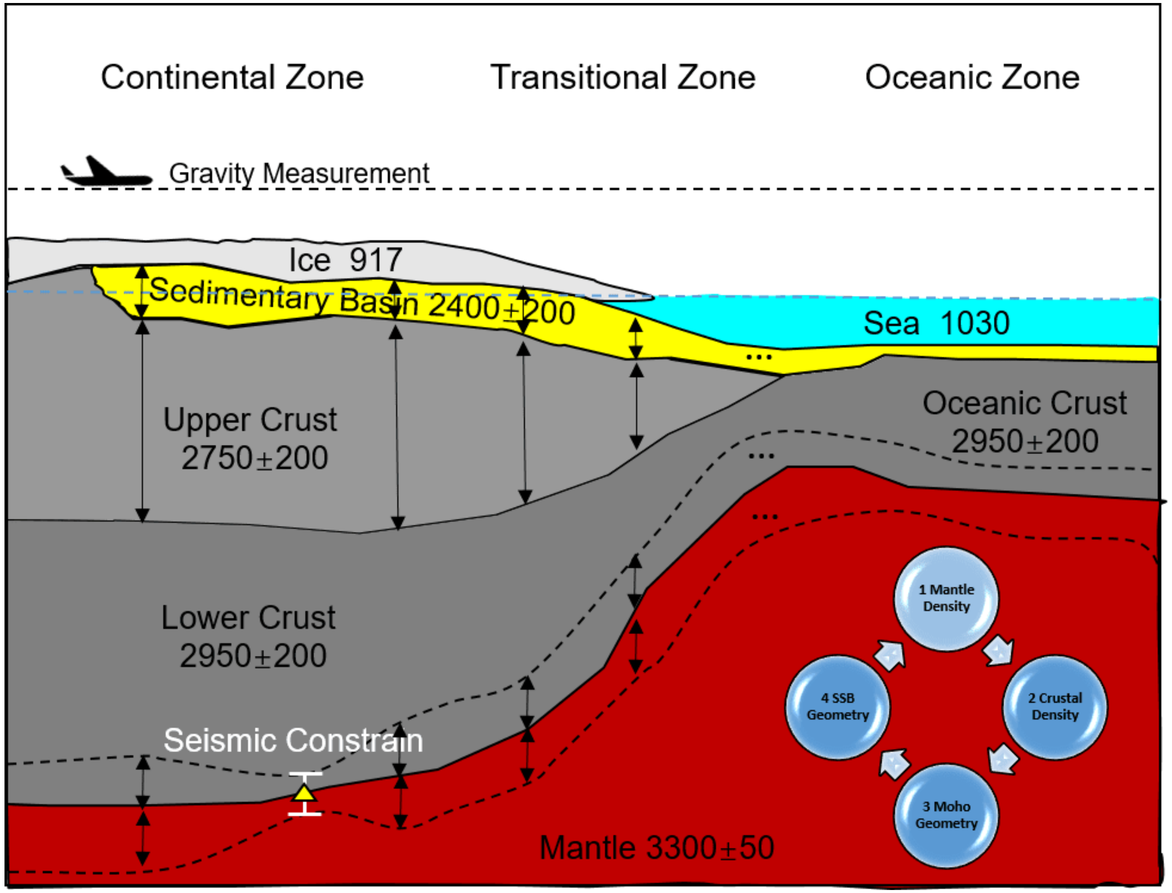
The Antarctic crustal structure is key to understanding its tectonic history. It also interacts with the Cryosphere by providing boundary conditions and feedback for ice flow. However, its structure is poorly known. Meanwhile, the current continental-scale models often neglect its heterogeneity.

Here, we use 3D gravity inversion to resolve the most representative models of Antarctic crustal structure with the capacity of the method and current data constraints. We show this heterogeneous structure defines several key processes for the Solid-Earth and Cryosphere interaction.



METHOD

We use VPMG software (Fullagar et al., 2008) to perform the 3D gravity inversion with seismic Moho depth as constraints. We assemble modes by alternating density style inversion and geometry style inversion with a maximum permitted density and geometry changes in each inversion iteration. In total 35 inversion were run with the density and geometry constrain by 0.005 g/cm^3 to 0.04 g/cm^3 by 0.005 interval and 5% to 13% by 2% interval.



In each inversion cycle, we have 4 inversion styles. We solve the mantle density first, followed by the density of crust. We then change the geometry of Moho, and sedimentary basin thickness respectively. We run 1 iteration in each inversion style and repeat the inversion cycle 4 times. This gives us a total of 16 interactions for solving the gravity misfit in each model.

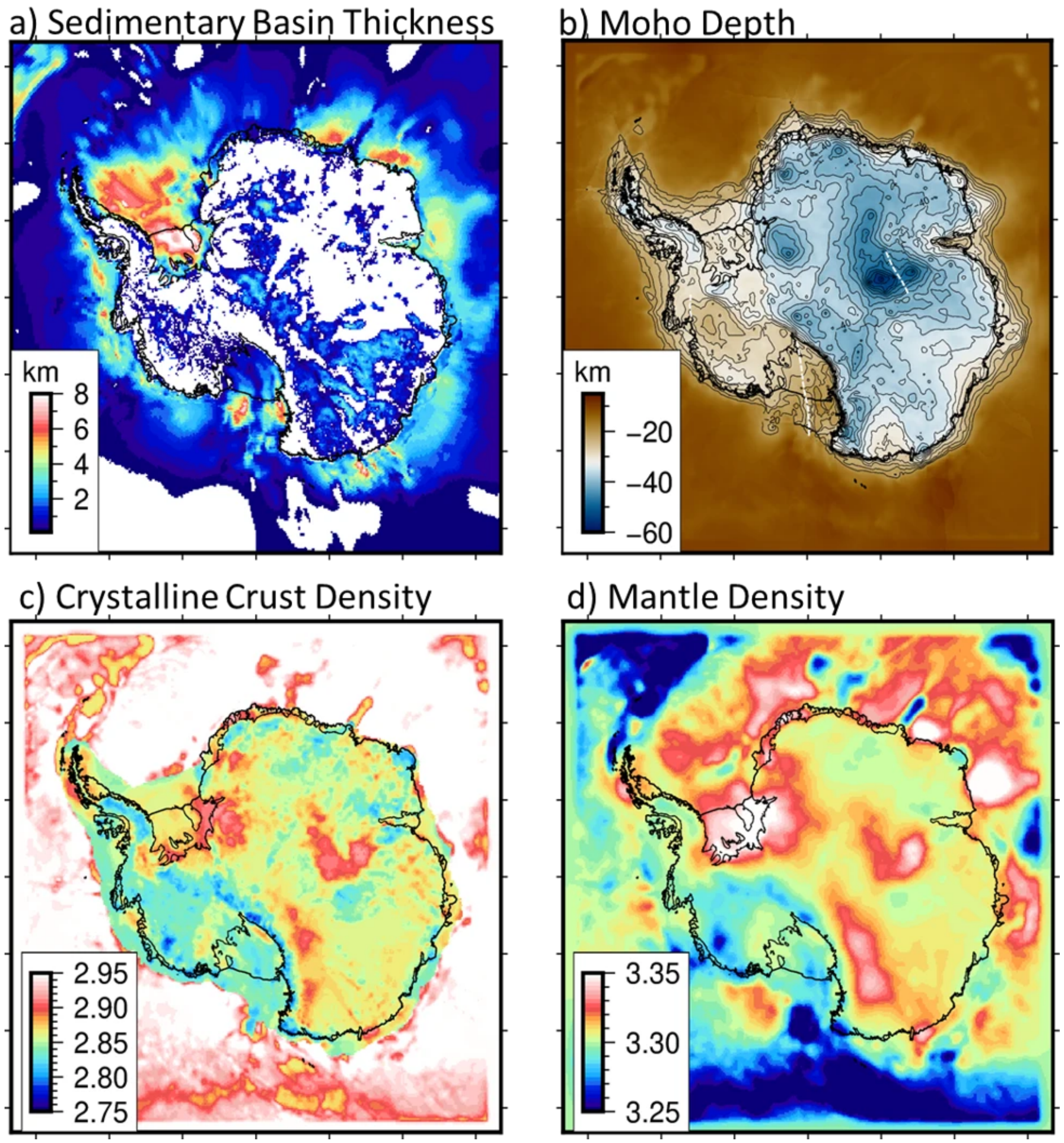
INVERSION RESULT

Sedimentary Basin: EA preserve large and thick Sedimentary rocks (~3 km), WA might be thinner (~1 km)

Moho Depth: Thin crust in WA (~25 km) and thick crust in EA (~35 km). White dash line shows WARS extent to Pine Island Rift, tectonic boundary identified by airborne magnetic data (Tinto et al., 2019), and proposed Gamburtsev Suture (Ferraccioli et al., 2011).

Crustal density: Low density in WA due to rifting. High crustal density in GSM indicates potential mafic underplating.

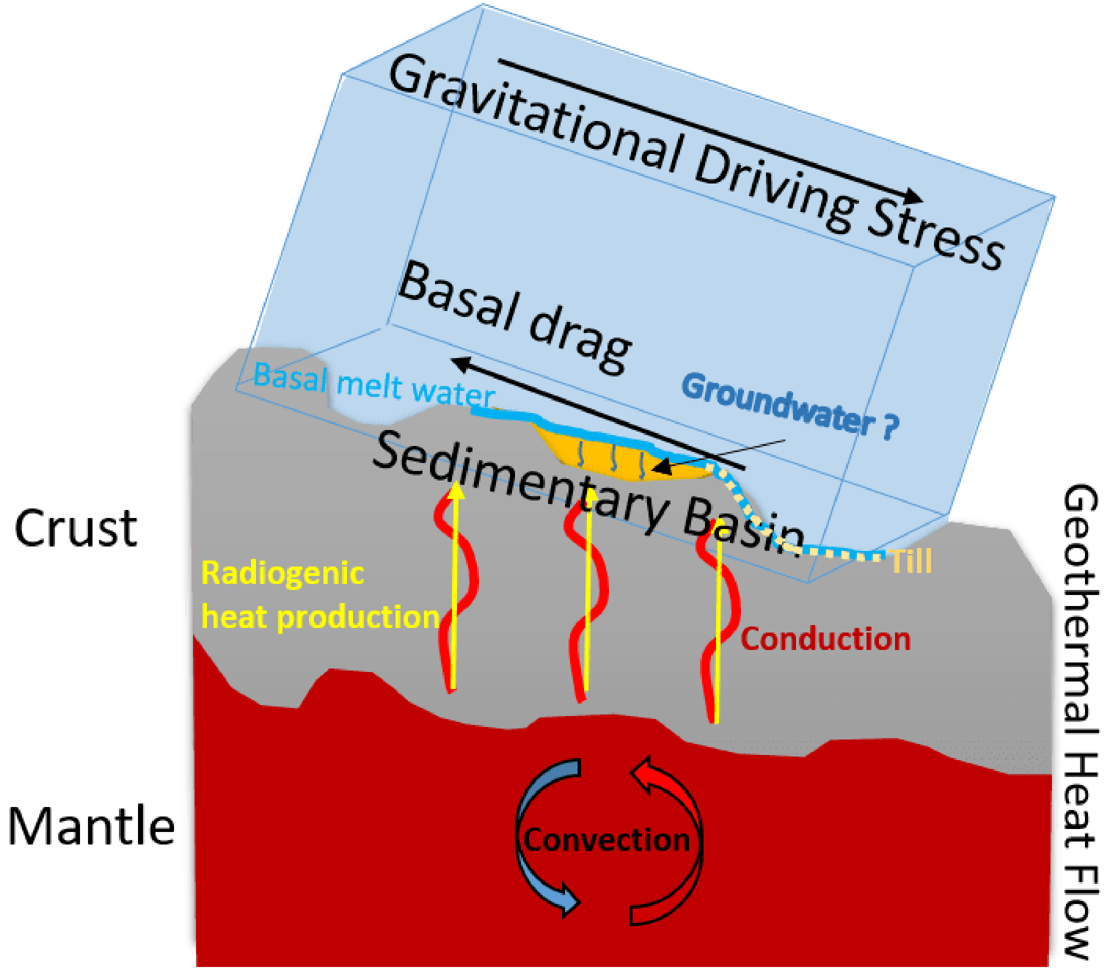
Mantel Density: Ring shape low density in WA corresponds well with low Vs structure in the uppermost mantle (Shen et al., 2018), which is interpreted as lithospheric foundering.



Li and Aitken (in prep)

INSIGHT FOR SOLID-EARTH AND CRYOSPHERE INTERACTION

Solid-Earth and Cryosphere in a system



Physics + Boundary Conditions

What can we get from the crust model?

1. Groundwater System (Porosity)

Ice sheet unloading cause groundwater discharge into the ice sheet system (Gooch et al., 2016). We show the link of sedimentary basin density with its porosity:

$$\phi = \frac{2.65 - \rho_{SSB}}{2.65 - 1}$$

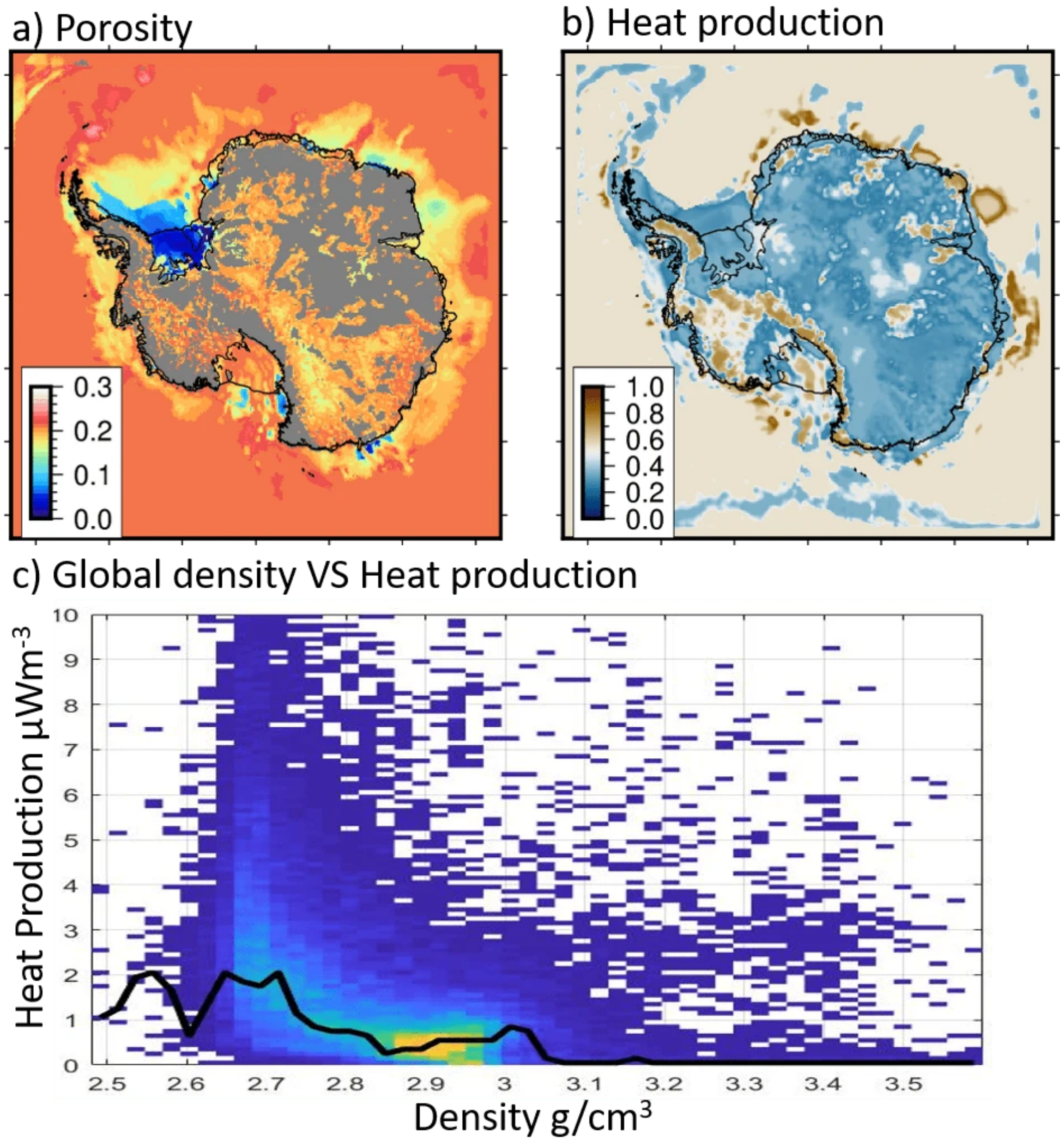
2. Heat Production

We check the relationship of rock density with heat production based on the Global whole-rock geochemical database (Gard et al., 2019).

The result indicates Pind Island and Thwaites Glacier sectors are associated with high heat production.

3. Crust Rheology

Neglecting the Sedimentary Basin cover tend to overestimate the Effective Elastic Thickness (Kaban et a., 2018). Considering the heterogeneous Sedimentary Basin and crustal density is essential to constrain the elastic properties of lithosphere. It acts as an important component for the GIA (Glacial Isostatic Adjustment).


a) Porosity
0.3
0.2
0.1
0.0
b) Heat production
1.0
0.8
0.6
0.4
0.2
0.0
c) Global density VS Heat production
Heat Production µWm-3
10
9
8
7
6
5
4
3
2
1
0
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
Density g/cm3

SUMMARY

- We present the heterogeneous structure of Antarctic crust.

- We show this heterogeneous structure can be used to define the key process (groundwater system) and boundary conditions (geothermal heat flow) to the ice sheet dynamics. It can also be used to better understand the GIA effect.

- In particular, we find a unique setting in Pine Island and Thwaites Glacier with sedimentary basin at the upper ice stream (groundwater), low crustal density (high heat production), thin crust thickness (high heat flow), low mantle density (hot mantle). These factors likely influence the overlying ice flow.

AUTHOR INFORMATION

Thanks for visiting the poster!

Looking forward to any questions and discussion :)

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ABSTRACT

Knowing the heterogeneous crustal structure is essential for understanding the ice dynamics, glacial isostatic adjustment (GIA) and tectonic history in Antarctica. For example, geothermal heat flux (GHF) is a major boundary condition for ice dynamics and the crust thickness and its composition (mafic or felsic) are important factors in GHF. Meanwhile, the GIA signal and its gravity response are essential for detecting mass-balance change and predicting future sea-level change. Errors in the density model used, which may be over 10%, will propagate into the gravity calculations.

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