Unveiling signs of old supercontinents by satellite gravity gradients and curvature attributes with special focus on Antarctica

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Introduction

The role of Antarctica in the evolution of Gondwana is still under discussion. Satellite data can assist in defining tectonic boundaries and subsurface geology in remote areas, which contain hidden imprints of supercontinents of the Proterozoic or even older.

Here, we analyse the potential of satellite gravity gradients derived by the GOCE satellite mission to delineate tectonic boundaries. From the satellite gradients we compute curvature attributes and discuss these in a plate tectonic framework of the Phanerozoic. Especially for Antarctica and the conjugate parts of Australo-Antarctic, the isostatic corrected satellite products provide meaningful insights.

Data

- Gravity gradients grids of GOCE at 225 km height[1] (Fig. 1a)
- Topographic correction of satellite gradients[1] using *ETOPO1*[2] and *Bedmap2*[3]. For more details see poster of Pappa et al.[4]
- Compute Moho depth due to isostatic load of topography using tesseroids
  - Combined Pratt-Airy Moho model (Fig. 3)
  - Reference Moho depth 30 km, density contrast 400 kg/m³
  - Correct gradients for effect of density contrast of Moho (Fig. 1b)

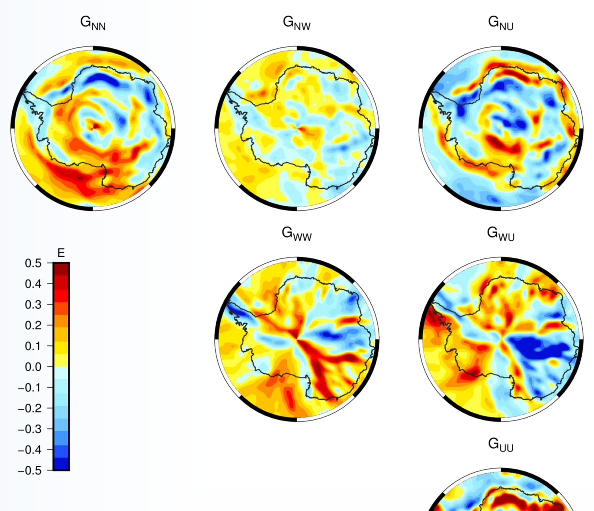


Fig. 1a: GOCE gravity gradients at 225 km height.

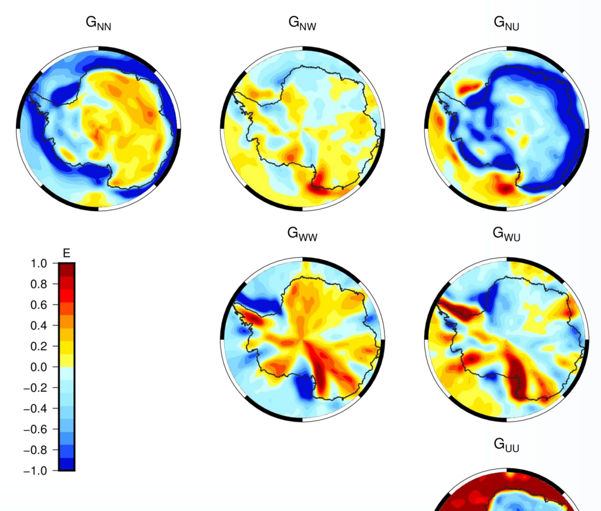


Fig. 1b: GOCE gravity gradients, corrected for topographic masses and isostatic Moho depth.

Methods

From the corrected gravity gradients curvature attributes can be computed[5,6]. The following formulas represent selected curvature attributes **Minimum Curvature** (K_{min}), **Maximum Curvature** (K_{max}) and **Shape Index** (SI). Fig. 2 reflects the qualitative meaning of curvature in terms of geology.

$$K_{min} = -\frac{G_{NN} + G_{WW} + 2\sqrt{G_{NW}^2 + G_{UV}^2}}{2g}$$

$$K_{max} = -\frac{G_{NN} + G_{WW} - 2\sqrt{G_{NW}^2 + G_{UV}^2}}{2g}$$

$$SI = \frac{2}{\pi}\tan^{-1}\frac{-G_{NN} - G_{WW}}{2\sqrt{G_{NW}^2 + G_{UV}^2}}$$

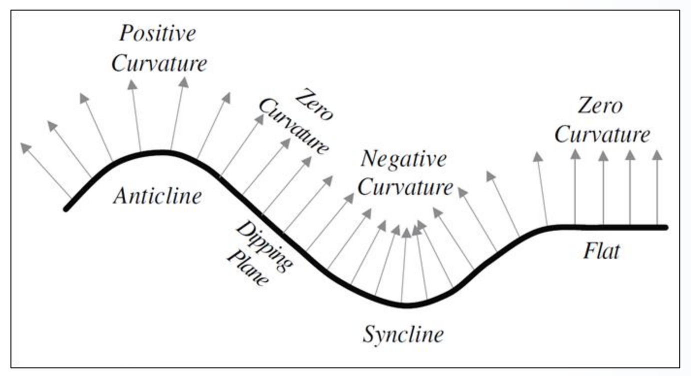


Fig. 2: Sign convention of curvature attributes[6]. Geological interpretation of curvature can be adopted to potential fields, as shown in the formulas.

Results

Isostatic curvature of Antarctica

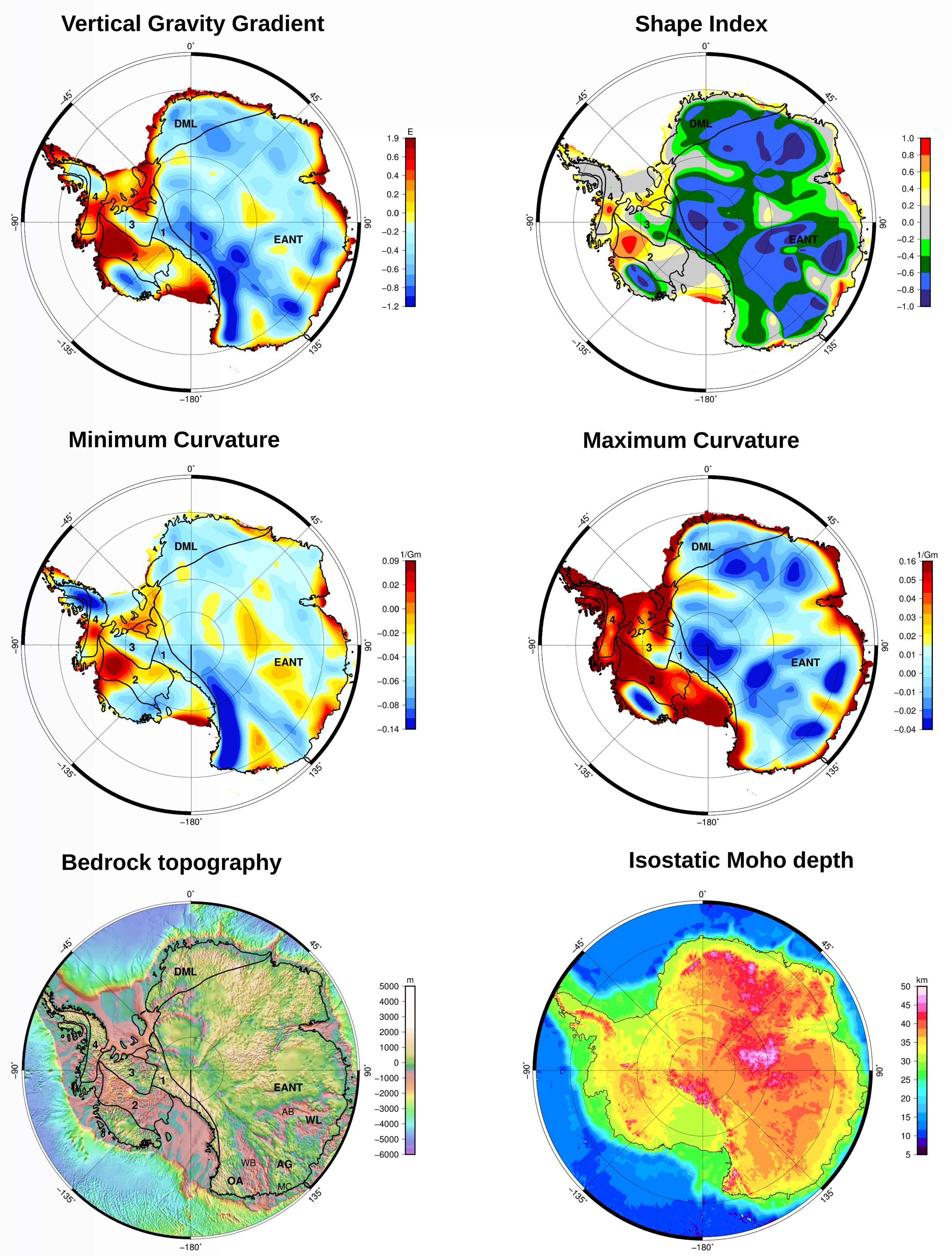


Fig. 3: Colourbars of figures are scaled for better visualisation. Contour lines show tectonic boundaries from global compilation[7]. EANT=East Antarctica, DML=Dronning Maud Land, 1: Transantarctic Mountains, 2: Marie Byrd Land, 3: Ellsworth Withmore Mountains, 4: Antarctic Peninsula. Additional features in bedrock topography: OA=Oates Land, WB=Wilkes Basin, AG=Terre Adélie King George V Land, AB=Aurora Basin, WL=Wilkes Land, MC=Mawson Craton

- Predominantly negative curvature on continents, positive curvature for oceans
- Curvature components of Antarctica correlate with different tectonic features
  - g_{uu} and K_{min} reflect Transantarctic Mountains and subglacial basins (Wilkes Basin, Aurora Basin)
  - SI and K_{max} show cratonic East Antarctica as negative anomaly. Small-scale intracratonic basins are also resolved
  - Wilkes Land and Terre Adélie King George V Land appear as negative anomalies, intersected by positive anomaly
- Low correlation of Moho depth with curvature attributes
- Curvature attributes are implemented in plate reconstruction software GPlates (Fig. 4)

Australo-Antarctic Pangaean framework

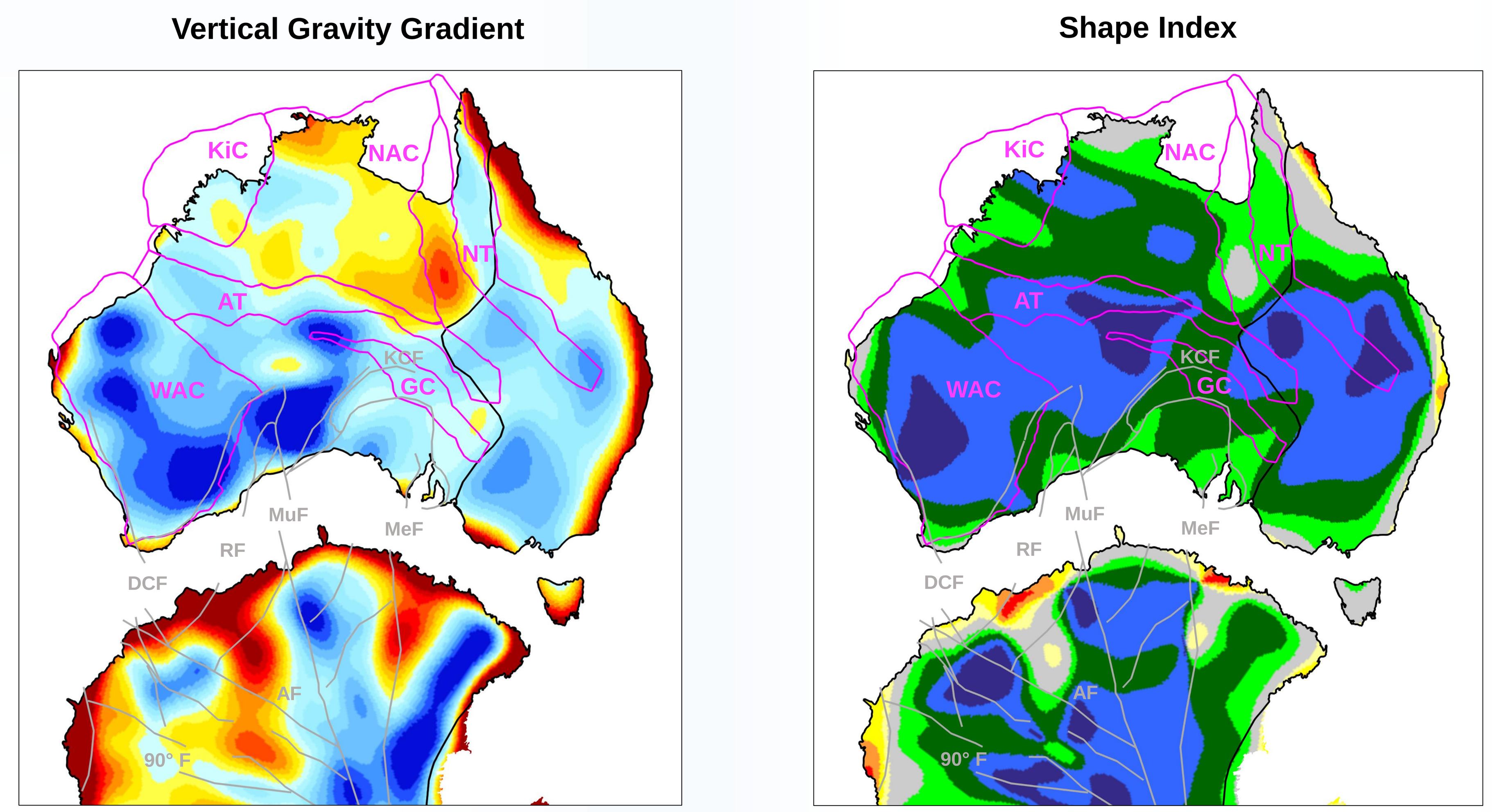
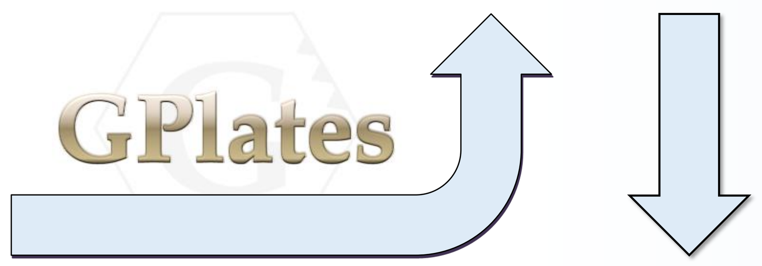


Fig. 4: Vertical Gradient (left) and Shape Index (right) in Pangaean framework, visualised in *GPlates*. Black lines: tectonic units[7], magenta lines: contours of Palaeoproterozoic terranes[8], grey lines: fault zones[9]. KCF=Karari-Coompana Fault, DCF=Darling-Conger Fault, RF=Rodona Fault, MuF=Mundrabilla Fault, MeF=Mertz Fault, AF=Aurora Fault, 90 F=90 degree Fault; WAC=West Australian Craton, KiC=Kimberley Craton, NAC=proto-North Australian Craton, GC=Archaean Gawler Craton; AT=Aileron Terrane, NT=Numil Terrane.



A clear correlation between the Palaeoproterozoic terranes (magenta lines) and the curvature products for Australia can be seen. These terranes make up the core of the proposed supercontinent Nuna (or Columbia) and its boundaries are derived by crustal-scale seismic reflection, as well as regional gravity and aeromagnetic data. The curvature products validate the terranes of old supercontinents and can support geological understanding.

What about Antarctica?

For Antarctica there is only limited amount of geophysical data and comprehensive and integrated knowledge of geophysics and geology is still lacking for its interior. The sparse correlation of curvature attributes to airborne derived fault zones underpins the fact that the detailed kinematics and geometry of ancient plate motions have not been fully understood yet.

Conclusion

- Curvature analysis of satellite gravity data can be an important tool to delineate tectonic boundaries
- Curvature attributes correlate with tectonic features
- Correlation of anomalies of curvature with geology of Antarctica is challenging
- Independently proposed Palaeoproterozoic terranes of Australia have been validated

Implications for plate tectonic reconstructions:

- Curvature products are very helpful to identify signatures of old supercontinents
- Anomalies of Antarctica relate to processes that are not fully understood

Plate tectonic models of the Proterozoic should be revised!

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