Unveiling lithosphere heterogeneity beneath the East Antarctic Ice Sheet in the Wilkes Subglacial Basin

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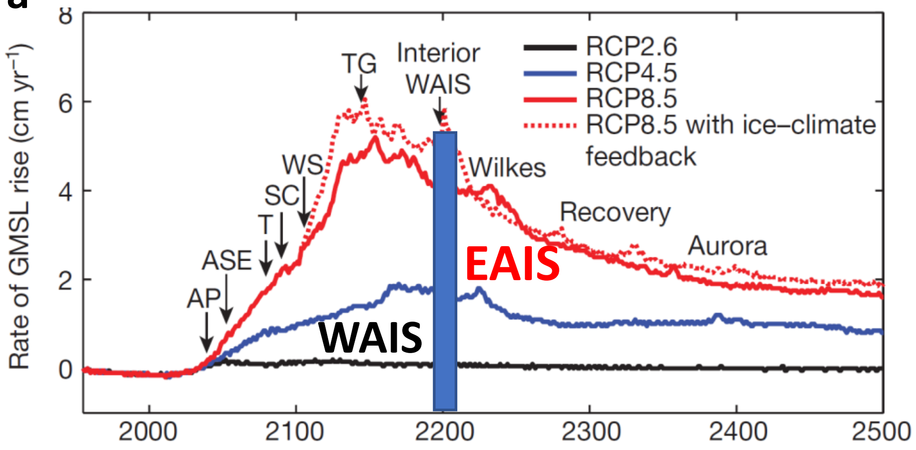
Wilkes Subglacial Basin (WSB) - one of the largest marine-based sectors of the EAIS

ARTICLE 31 MARCH 2016 | VOL 531 | NATURE | 591
doi:10.1038/nature17145

Contribution of Antarctica to past and future sea-level rise

Robert M. DeConto[1] & David Pollard[2]

a



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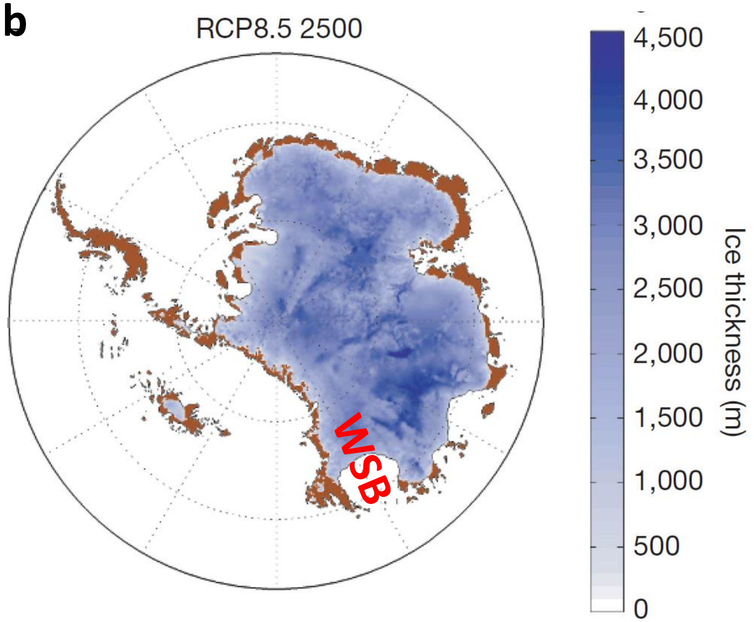
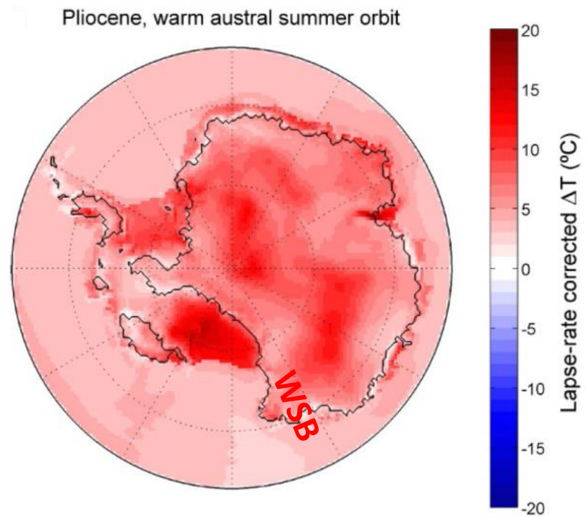


a- *Rate of future sea-level rise & timing of major retreat and thinning for the WAIS & EAIS*. Note significant predicted longer-term contributions from the Wilkes Subglacial Basin region (**DeConto & Pollard, 2016, Nature**).

b- *Predicted ice sheet configuration in year 2500* showing significant retreat in the northern Wilkes Subglacial Basin.

c



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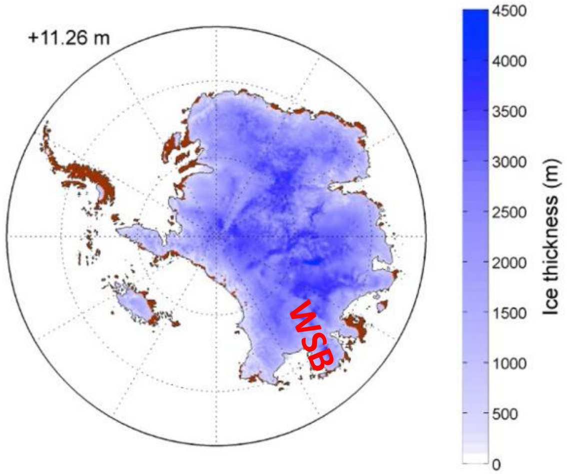
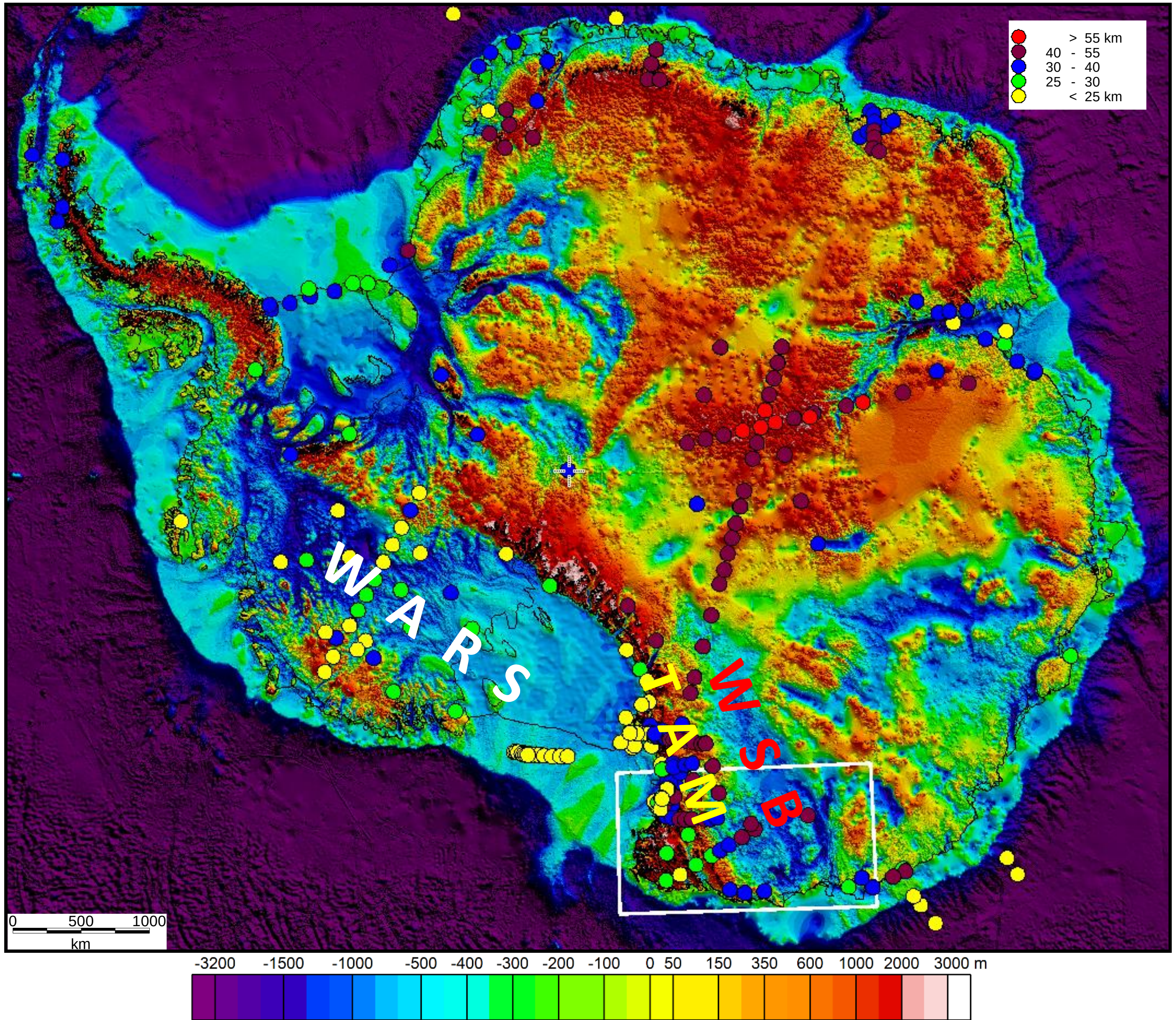


c- *Past behaviour of the Antarctic Ice Sheet during the warm mid-Pliocene- as a potential analogue for future warming*. (**DeConto & Pollard, 2016, Nature**).

b- *Maximum predicted mid-Pliocene ice sheet retreat*. Note partial collapse of the EAIS in the northern Wilkes Subglacial Basin region.

Wilkes Subglacial Basin- a major tectonic feature in East Antarctica



Location of our study area in the Wilkes Subglacial Basin (WSB) (white rectangle) superimposed on BedMachine bed topography (**Morlighem et al., 2020, Nature Geoscience**) *& a compilation of crustal thickness ranges from seismology* (updated from **An et al., 2015, JGR**).

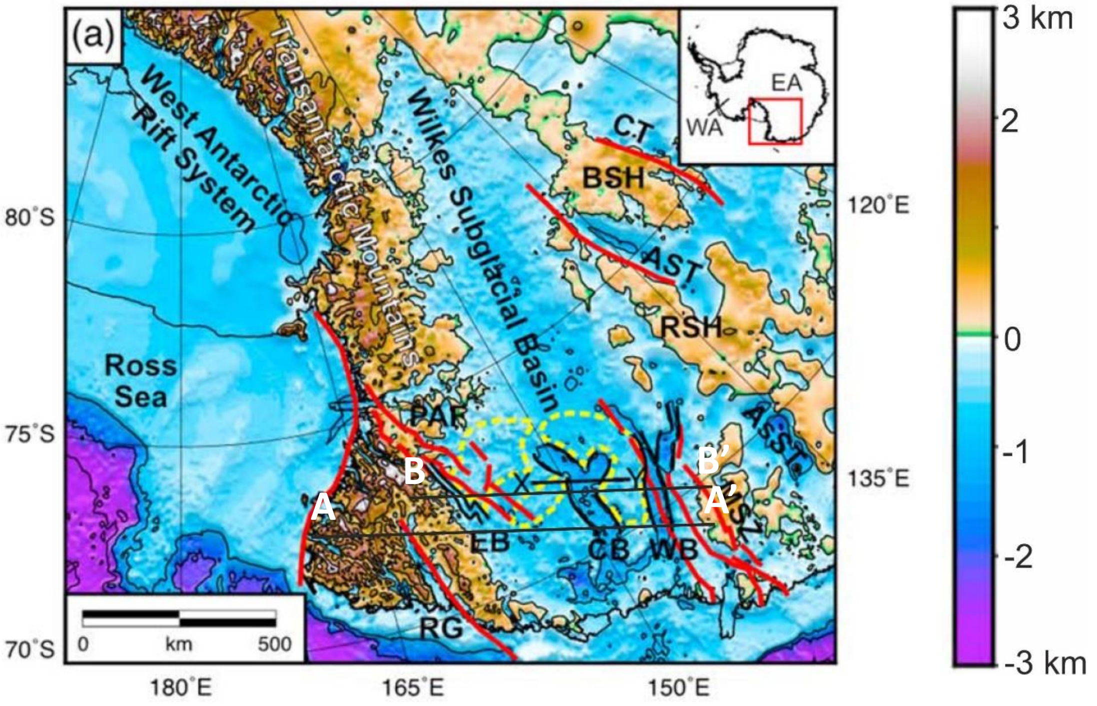
The Wilkes Subglacial Basin (WSB) is a major tectonic feature in East Antarctica. It stretches for ca 1400 km from the edge of the Southern Ocean, where it is up to 600 km wide towards South Pole, where it is less than 100 km wide.

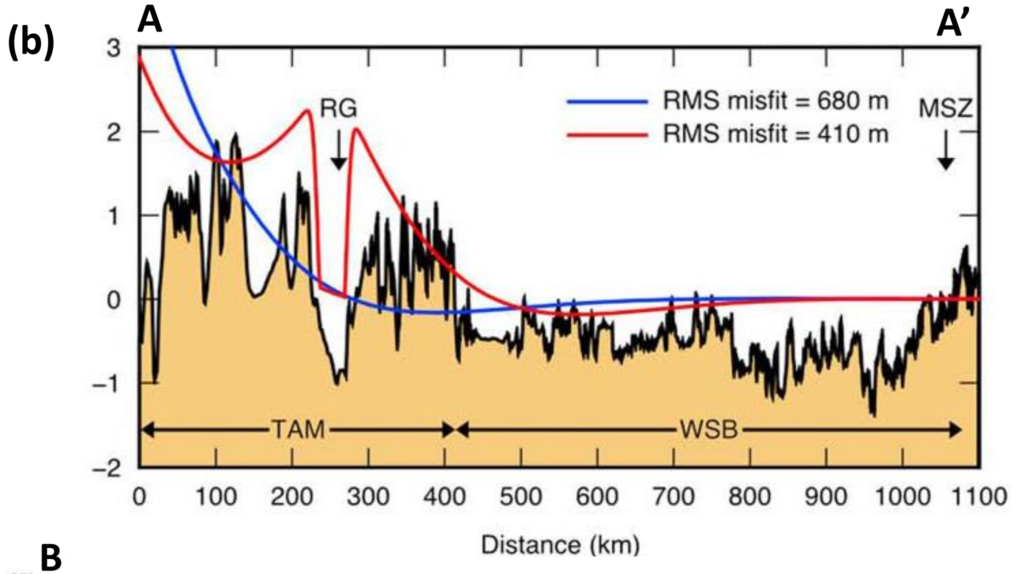
While basins in the West Antarctic Rift System exhibit thin (ca 25-20 km thick) crust, the Wilkes Subglacial Basin is inferred from passive seismic studies to be underlain by ca 40 km thick crust (e.g **Hansen et al., 2016, JGR**).

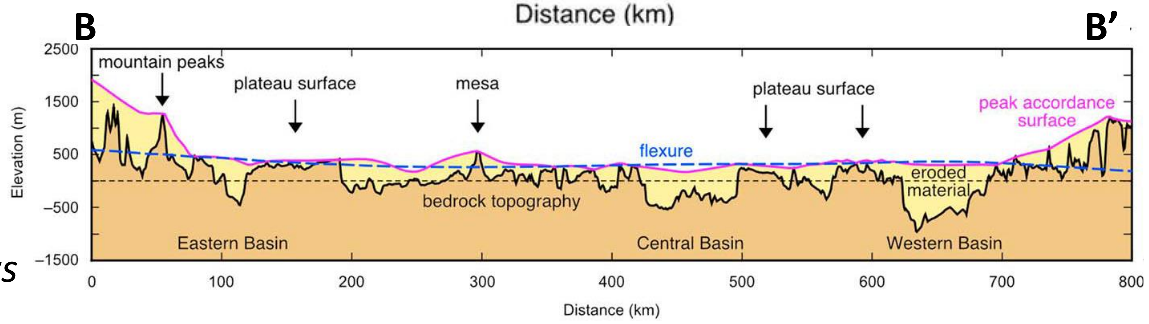
The thicker crust imaged by passive seismics is consistent with flexure of the more rigid East Antarctic lithosphere in response to uplift of the adjacent Transantarctic Mountains (TAM) (e.g. **ten Brink et al., 1997, JGR**).

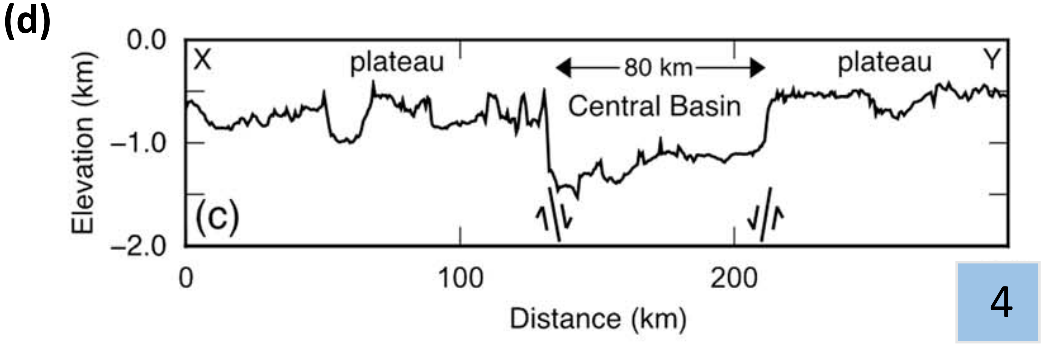
However, alternative models based on gravity studies and numerical modelling infer a crustal root beneath the TAM & relatively thinner crust beneath the WSB (e.g. **Bialas et al., 2007, Geology**).

Wilkes Subglacial Basin- long-wavelength flexure and narrower glacially over-deepened grabens









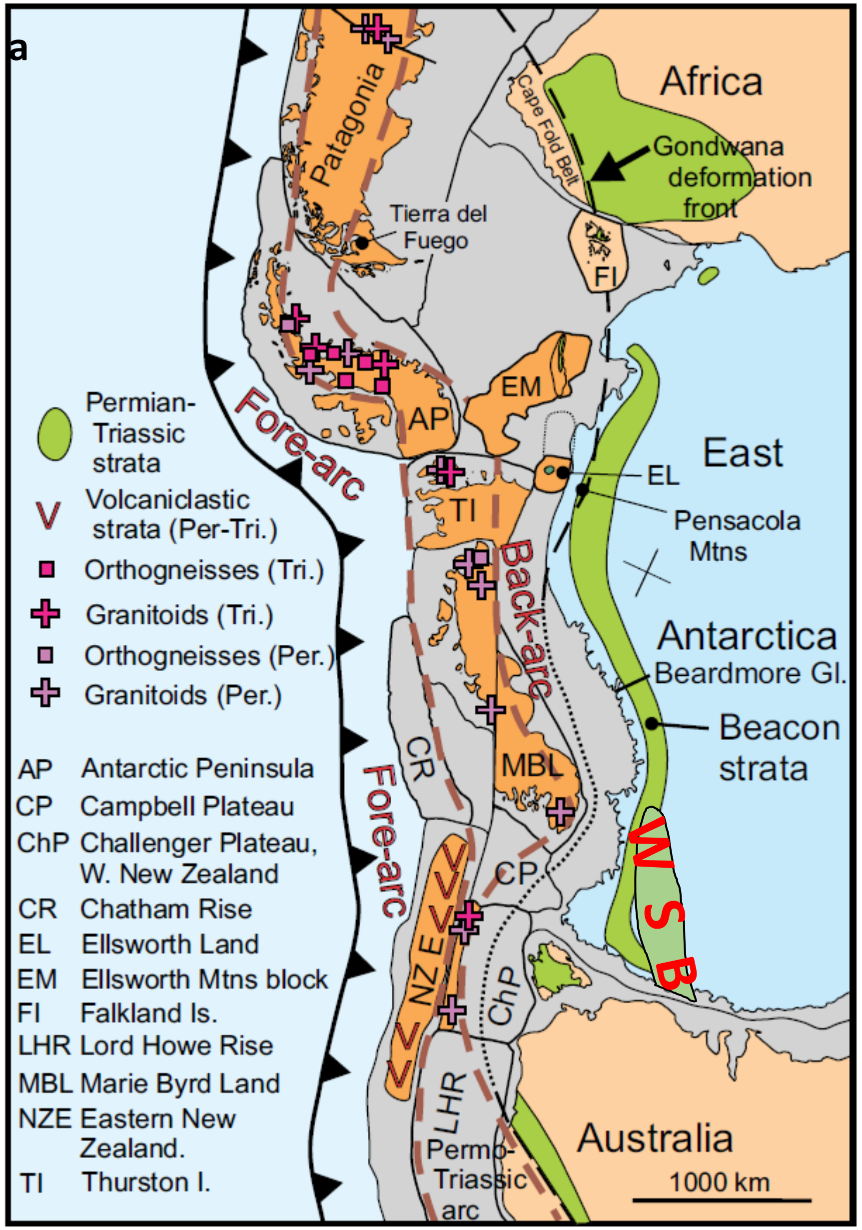
(a) Location of new flexural modelling profiles across the Wilkes Subglacial Basin (**Paxman et al., 2019, JGR**). *Red lines show major faults; yellow dashed line shows flat lying subglacial bedrock plateaus* (**Paxman et al., 2018, GRL**).

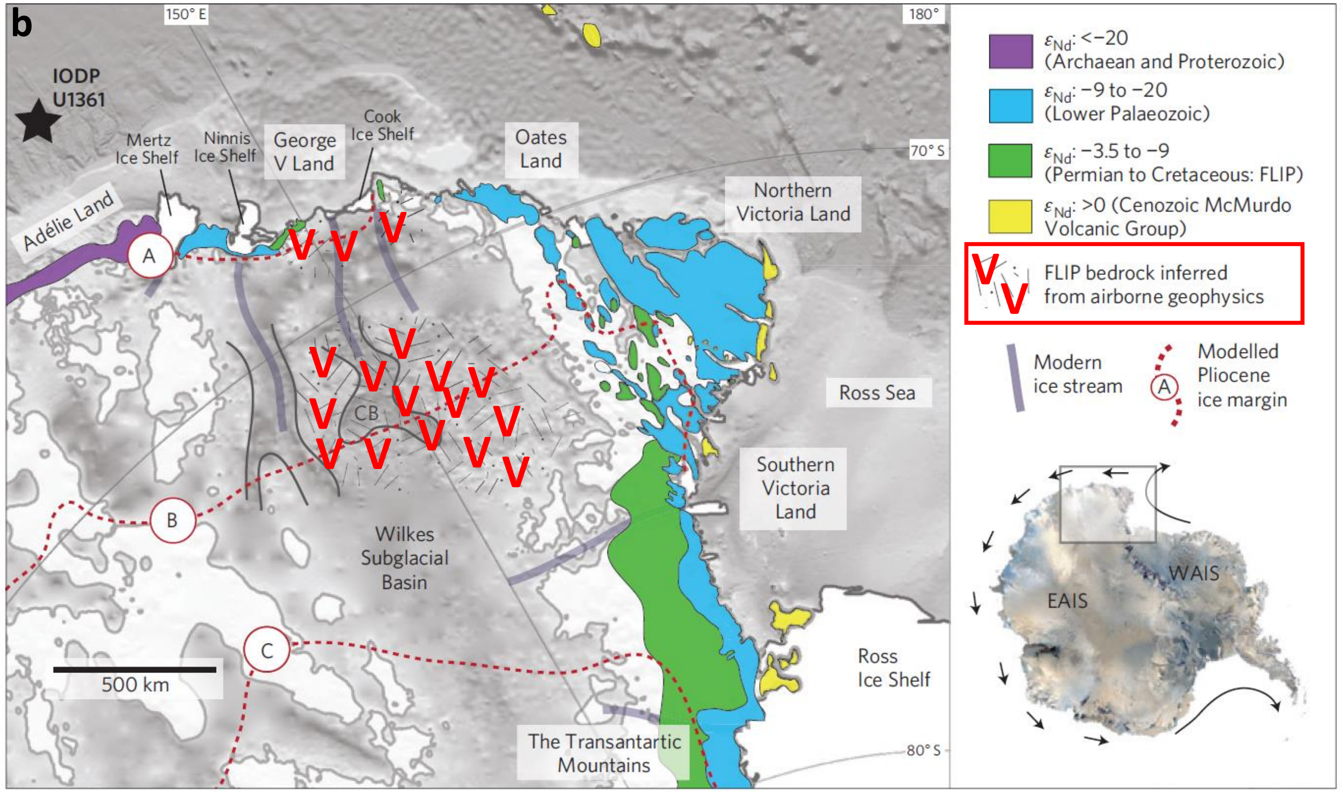
(b) Flexural responses to Cenozoic TAM uplift and Rennick Graben faulting.

(c) Glacial erosion focussed along the narrower Eastern, Central and Western basins (**Ferraccioli et al., 2009, Tectonophysics**) *within the Wilkes Subglacial Basin.*

(d) Graben system in the Central Basin region where Beacon sediment and Jurassic magmatism have been modelled from aeromagnetic data (**Ferraccioli et al, 2009**).

Beacon Superbasin and Jurassic Ferrar Large Igneous Province in the Wilkes Subglacial Basin



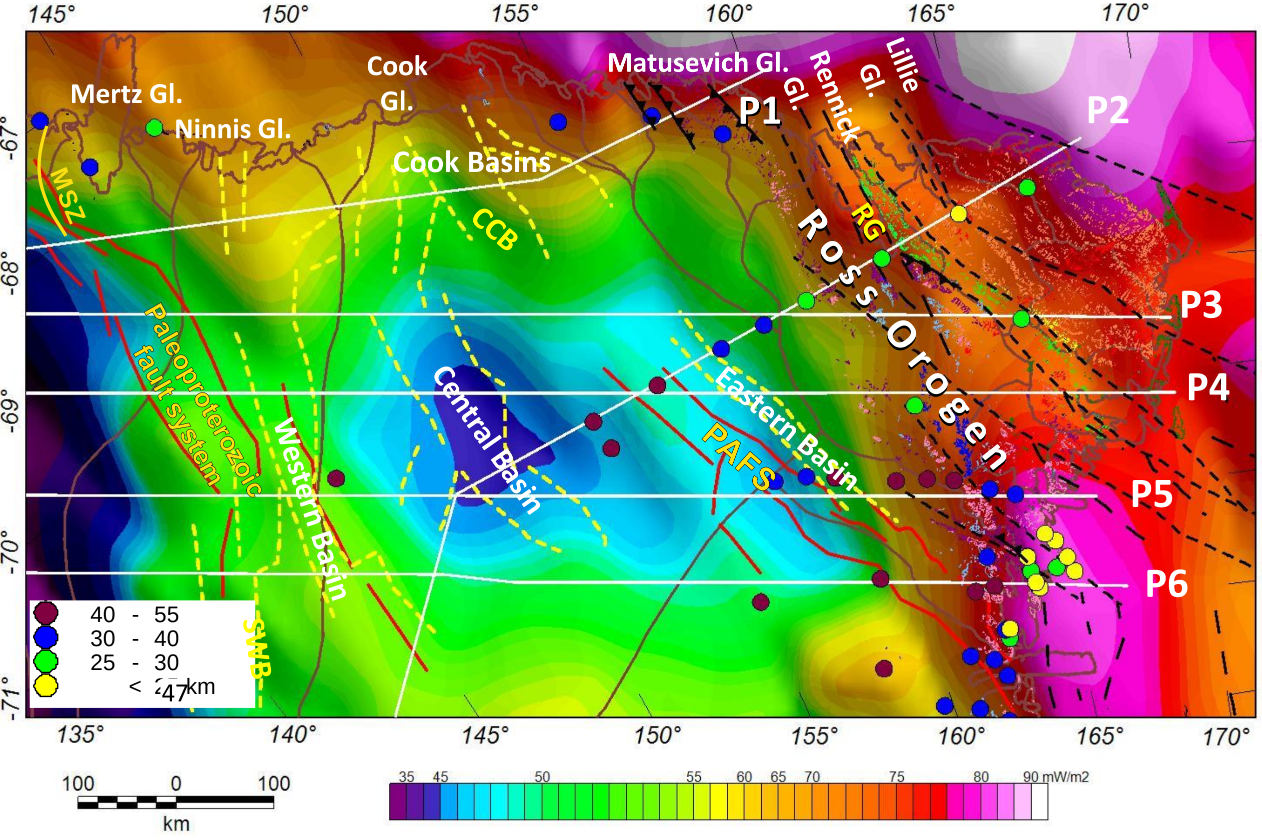


a. Aerogeophysical interpretation revealing the extent of the Beacon Superbasin within the Wilkes Subglacial Basin region (Ferraccioli et al., 2009) superimposed on Gondwana reconstruction (modified from Elliot et al., 2017, Geosphere).

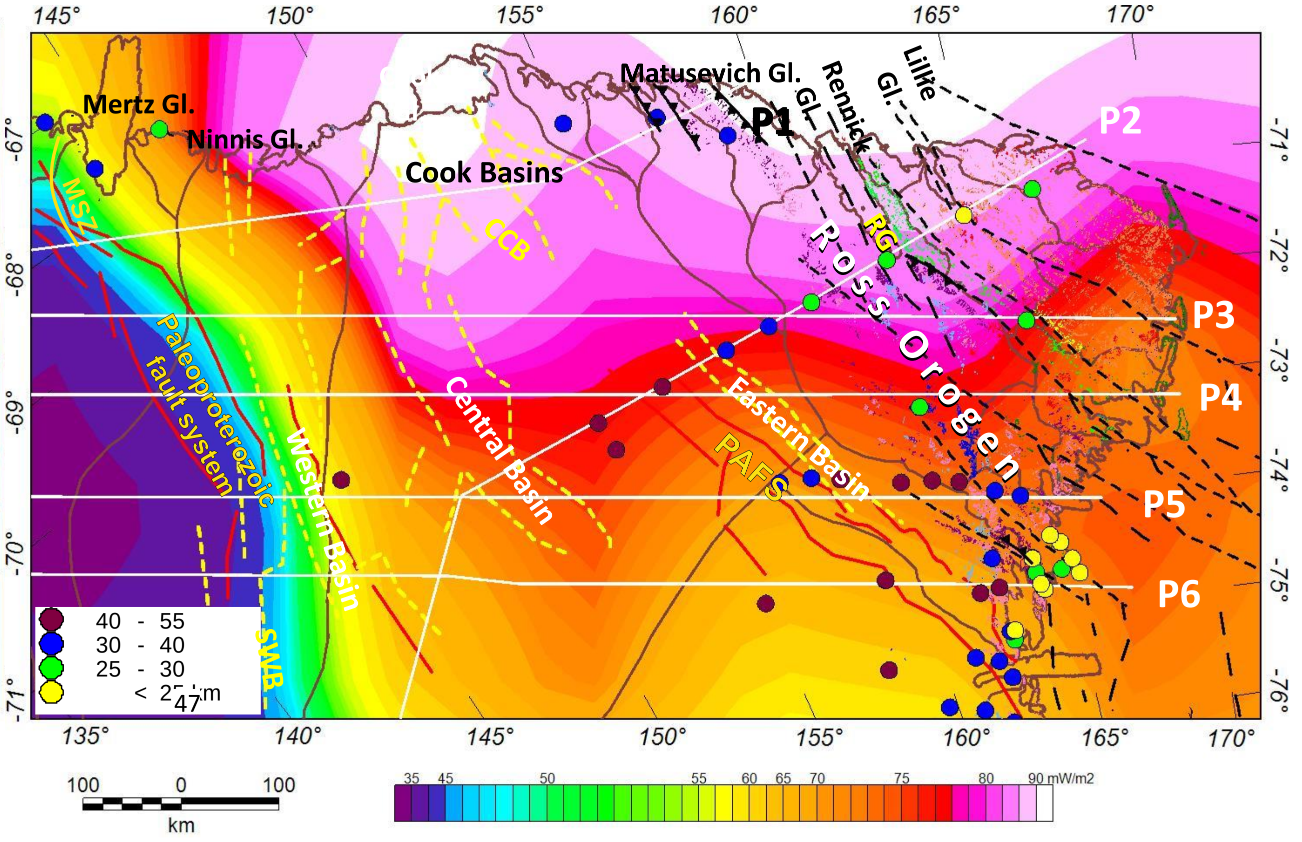
b. Rocks of the Jurassic Ferrar Large Igneous province rocks have been inferred within the Wilkes Subglacial Basin from aerogeophysics (Ferraccioli et al., 2009) & by studies of subglacial geology from IODP drilling (modified from Cook et al., 2013, Nature Geoscience).

Regional Geothermal Heat Flux comparison in WSB

Geothermal Heat Flux model An et al. 2015



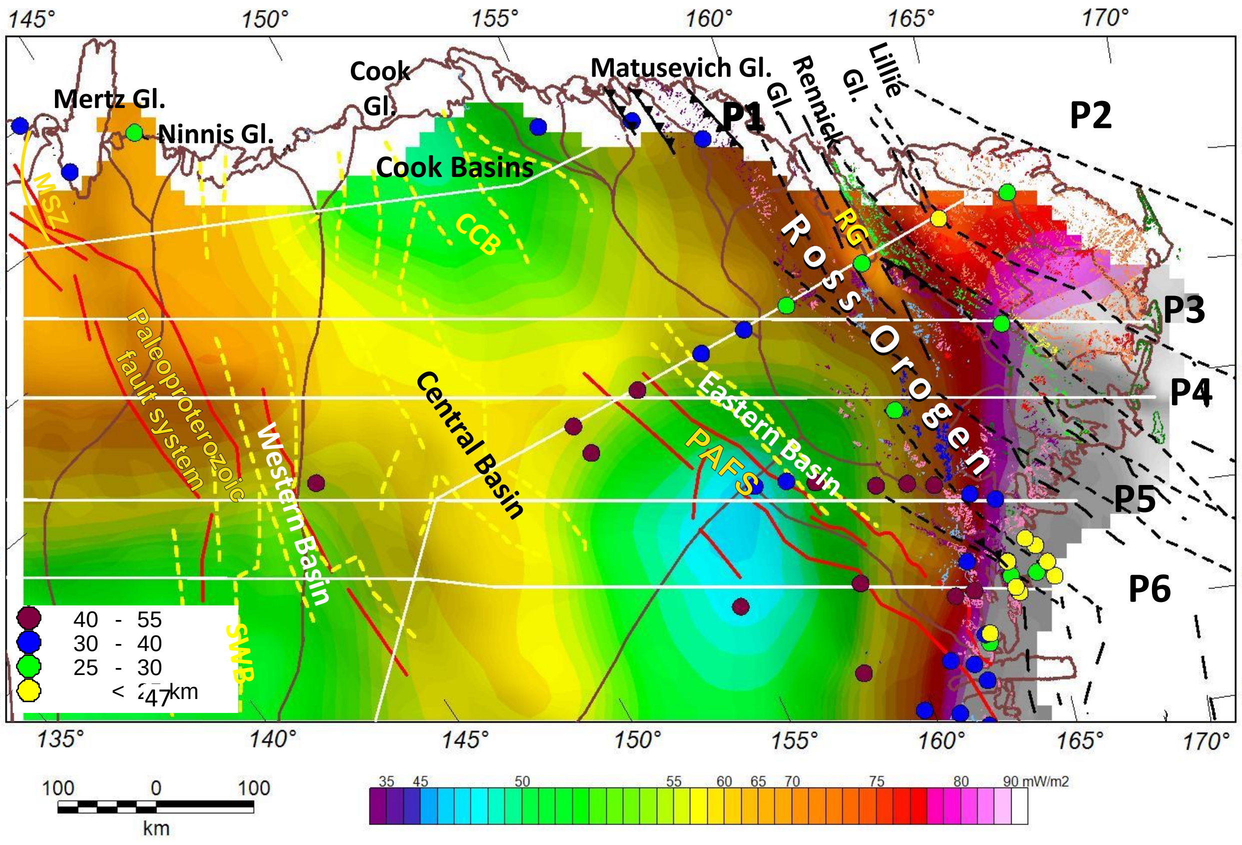
Geothermal Heat Flux model Maule et al. 2005



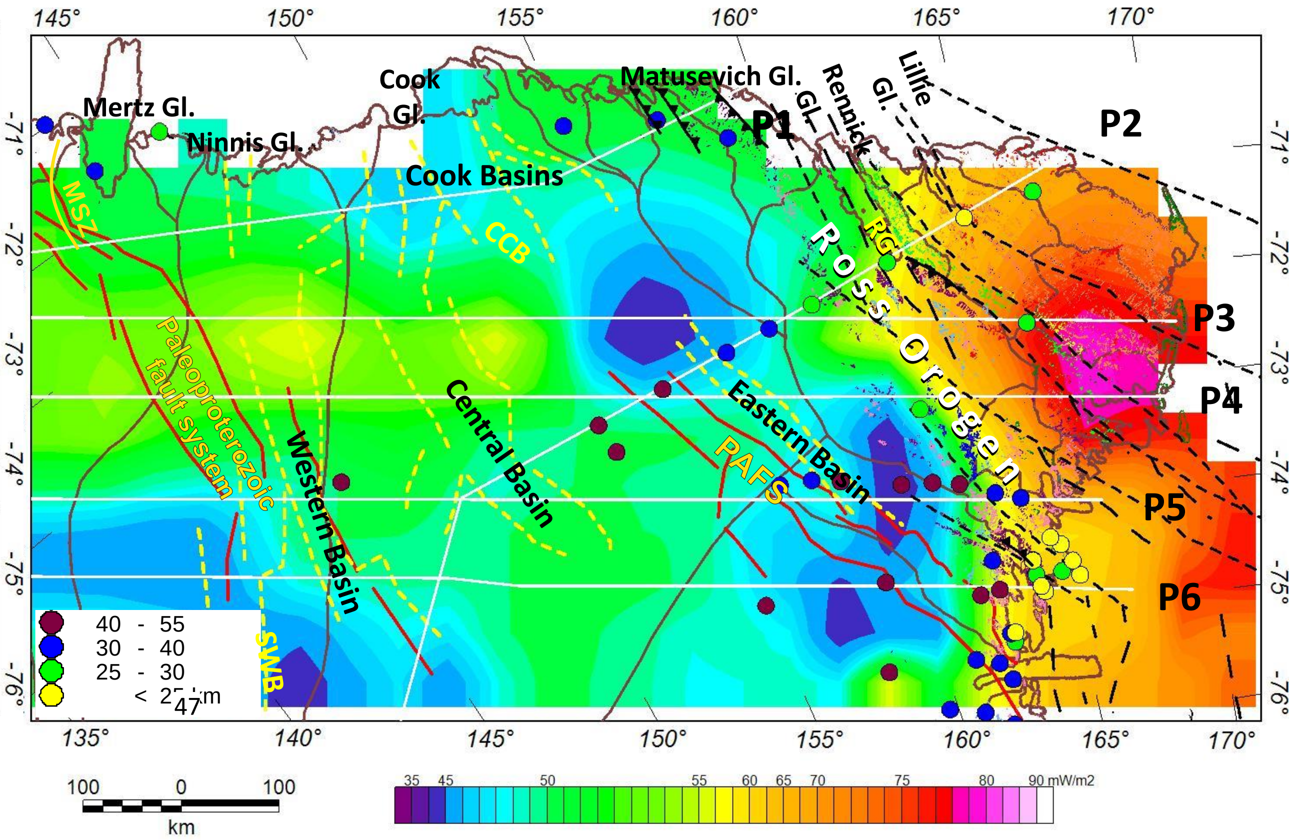
- Note large differences in Geothermal Heat Flux estimation between different studies

Regional Geothermal Heat Flux comparison in WSB

Geothermal Heat Flux model Martos et al. 2017



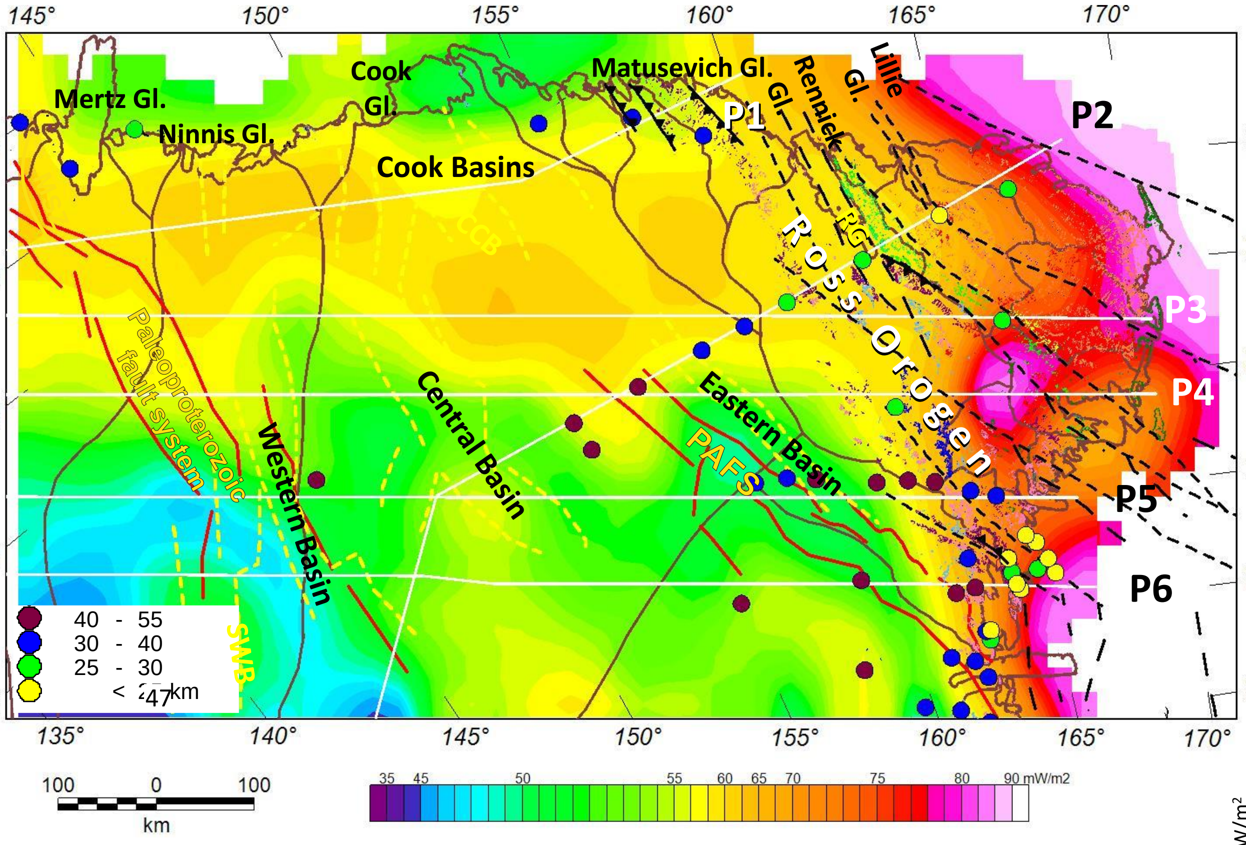
Geothermal Heat Flux model Shen et al. 2017

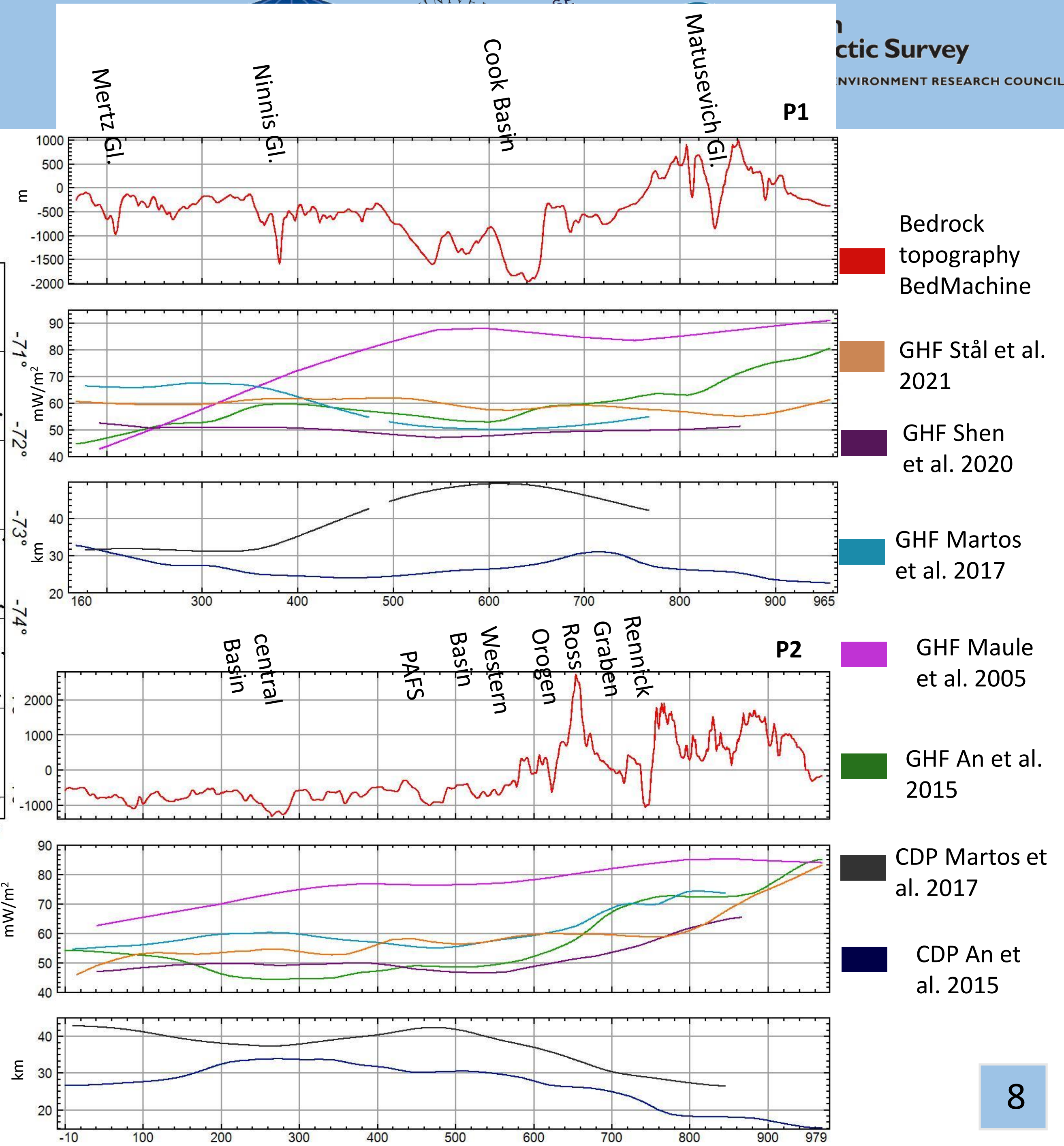


- Note large differences in Geothermal Heat Flux estimation between different studies

Regional Geothermal Heat Flux comparison in WSB

Geothermal Heat Flux model Stål et al. 2021





- Note large differences in Geothermal Heat Flux estimation between different studies

Regional Geothermal Heat Flux comparison on profiles in WSB

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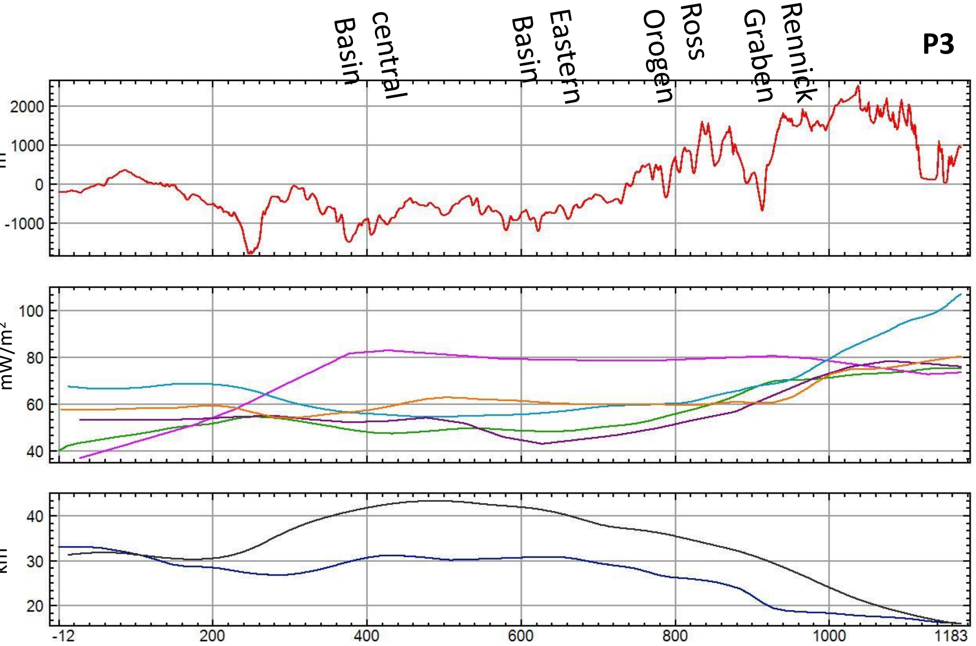

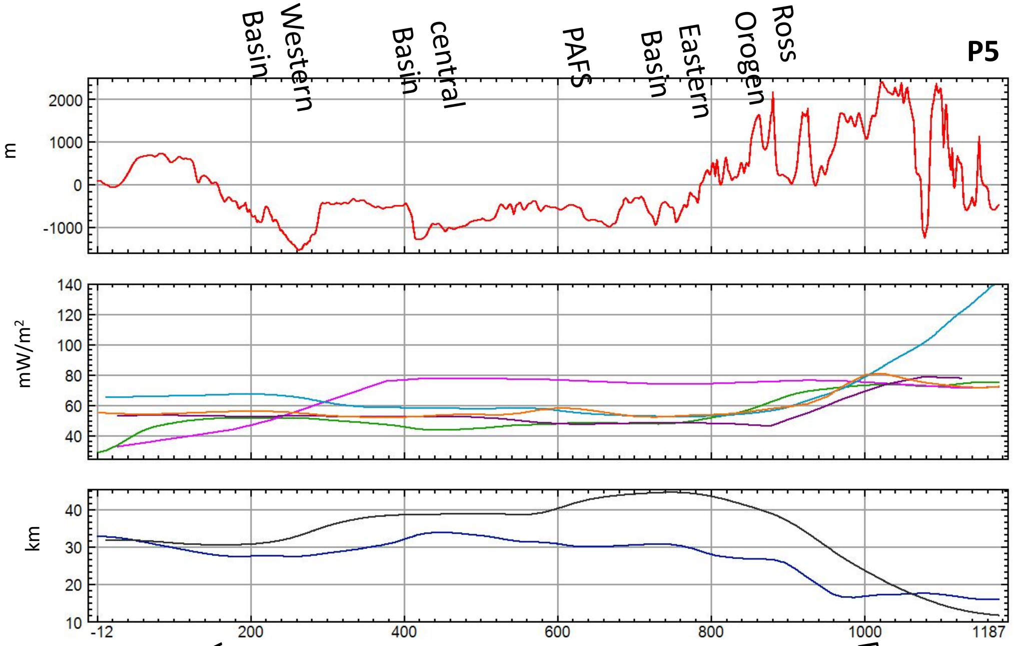

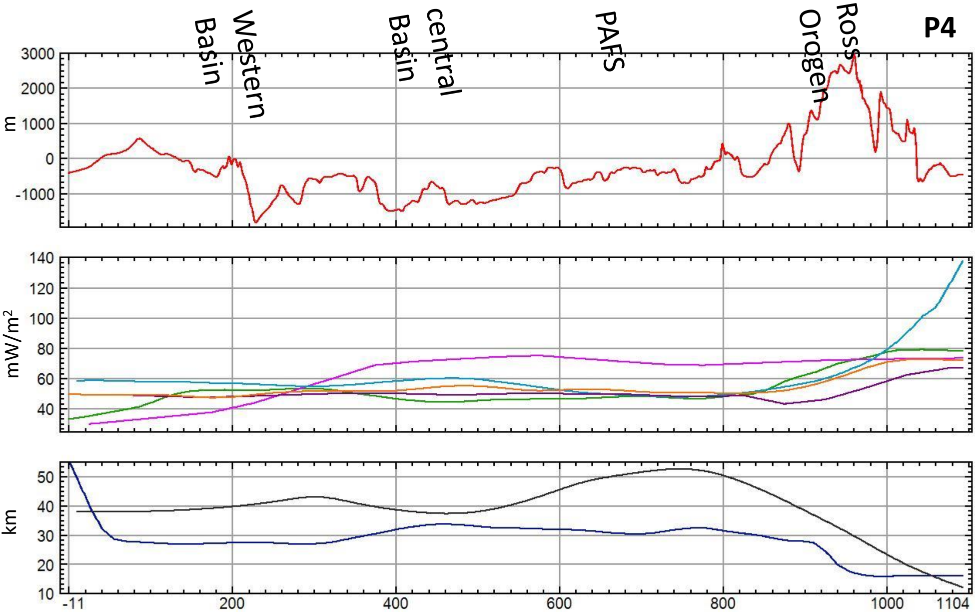

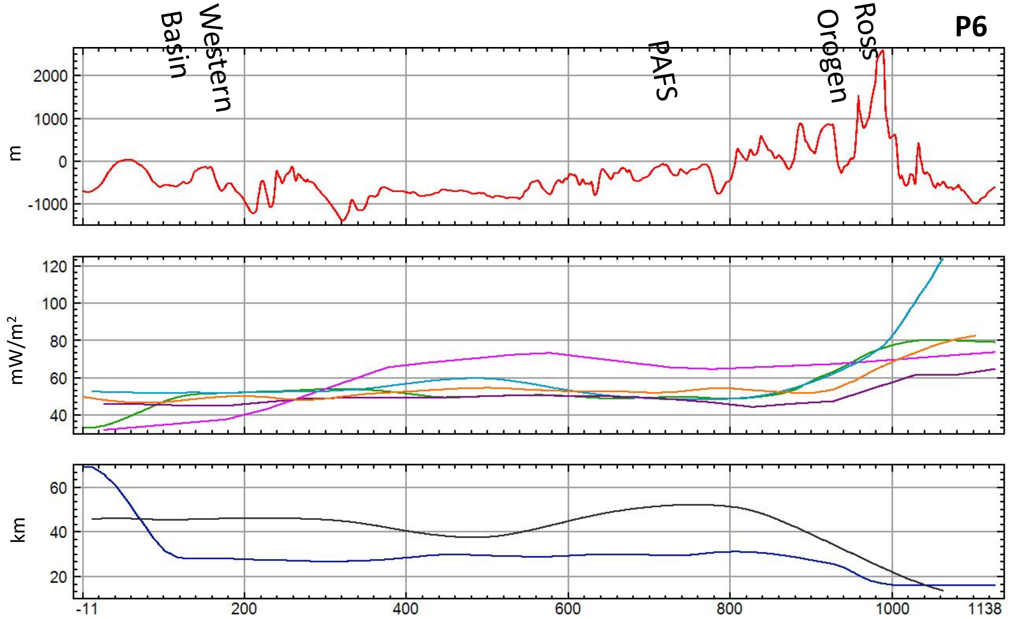

Bedrock topography BedMachine

GHF Stål et al. 2021

GHF Shen et al. 2020

GHF Martos et al. 2017

GHF Maule et al. 2005

GHF An et al. 2015

CDP Martos et al. 2017

CDP An et al. 2015

Regional Geothermal Heat Flux difference maps

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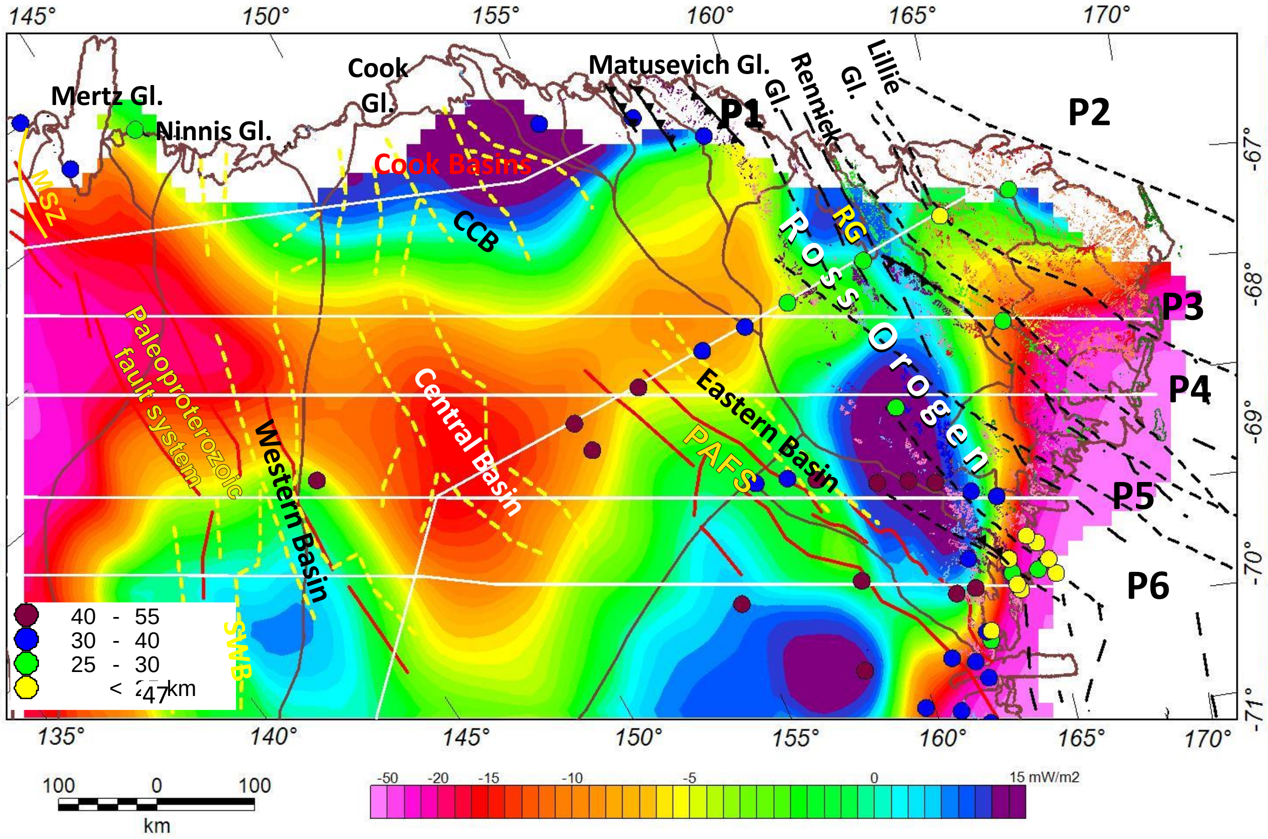
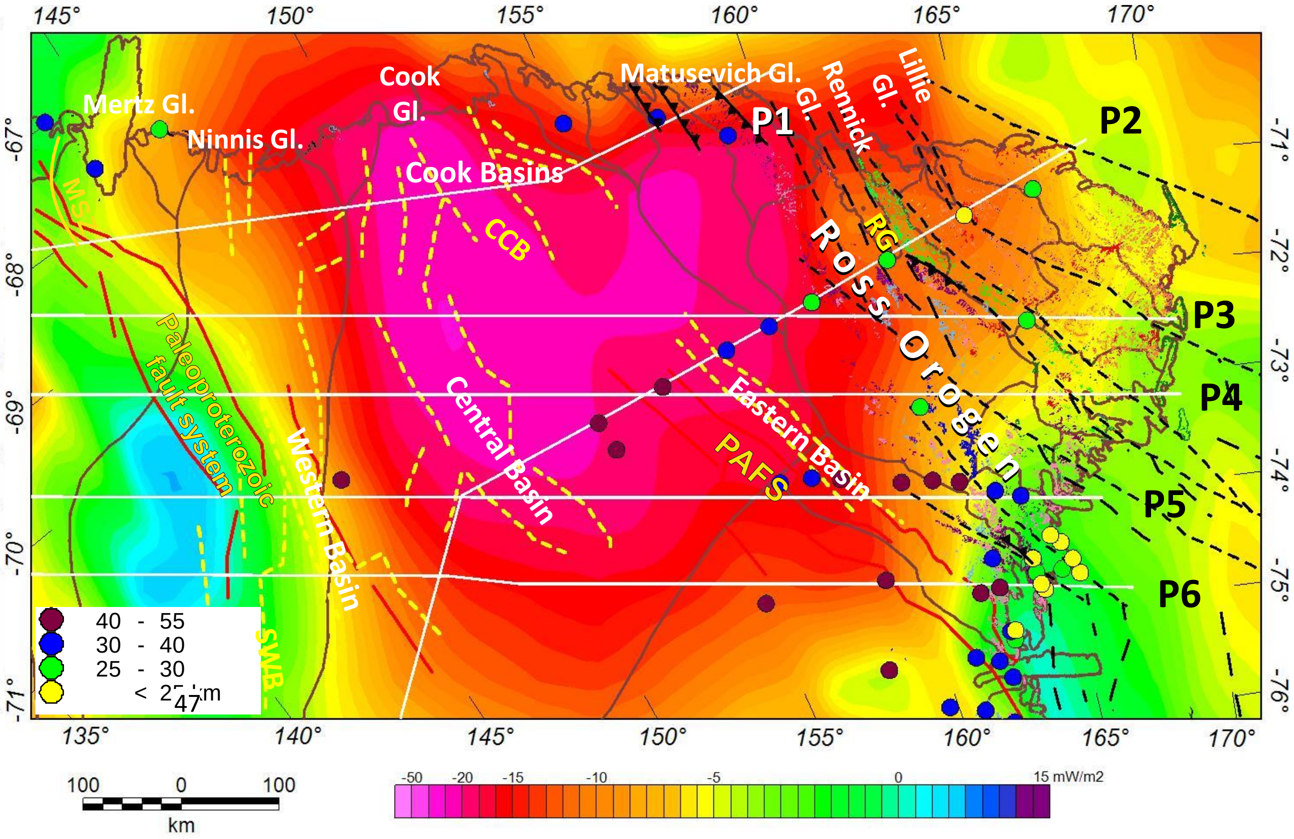
Difference An et al. 2015 and Martos et al. 2017



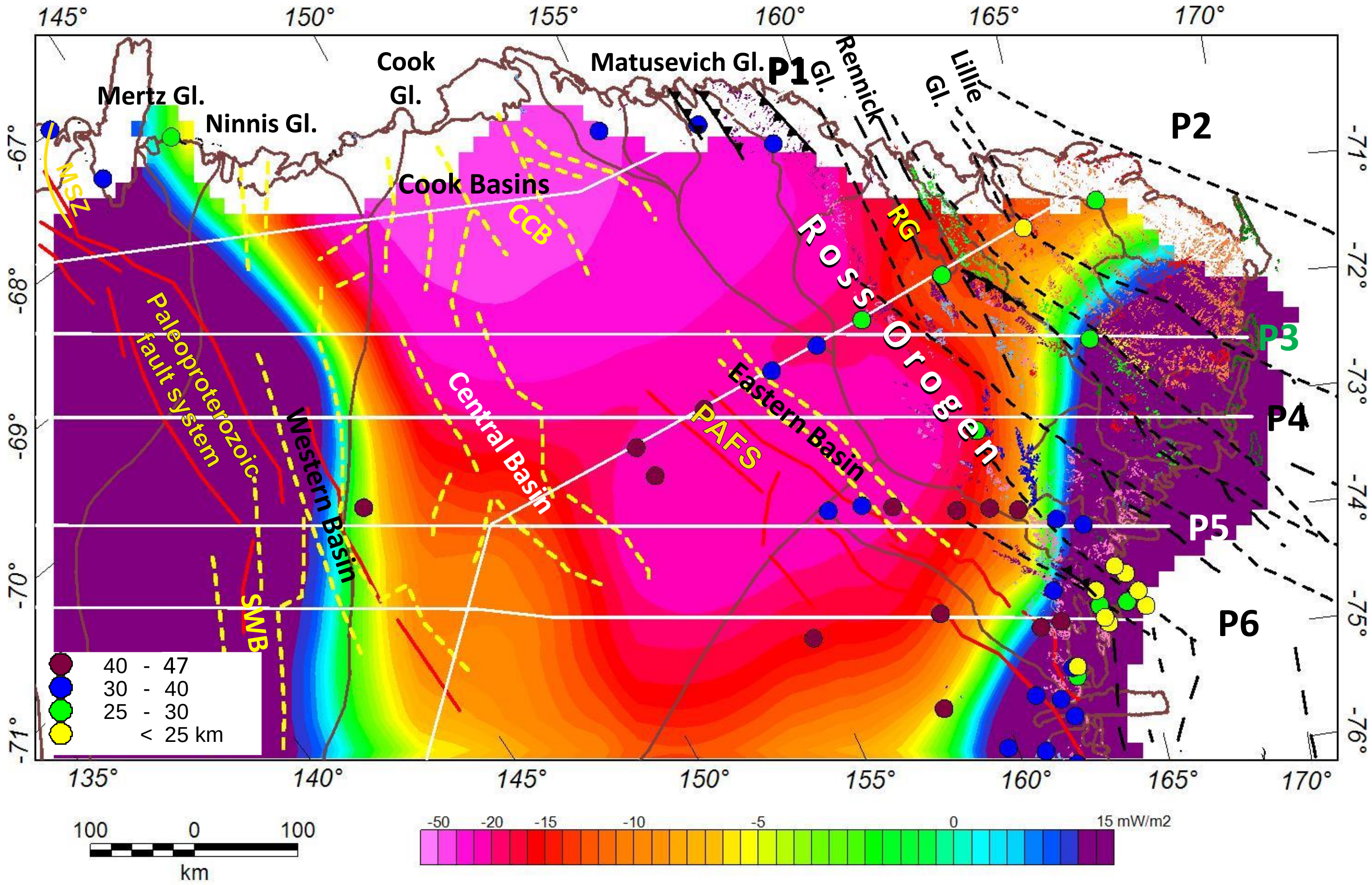
Difference An et al. 2015 and Maule et al. 2005



- Note large differences in Geothermal Heat Flux estimation between different studies

Regional Geothermal Heat Flux difference maps

Difference Martos et al. 2017 and Maule et al. 2005



- Note large differences in Geothermal Heat Flux estimation between different studies

Regional Curie Depth Point (CDP) comparison in WSB

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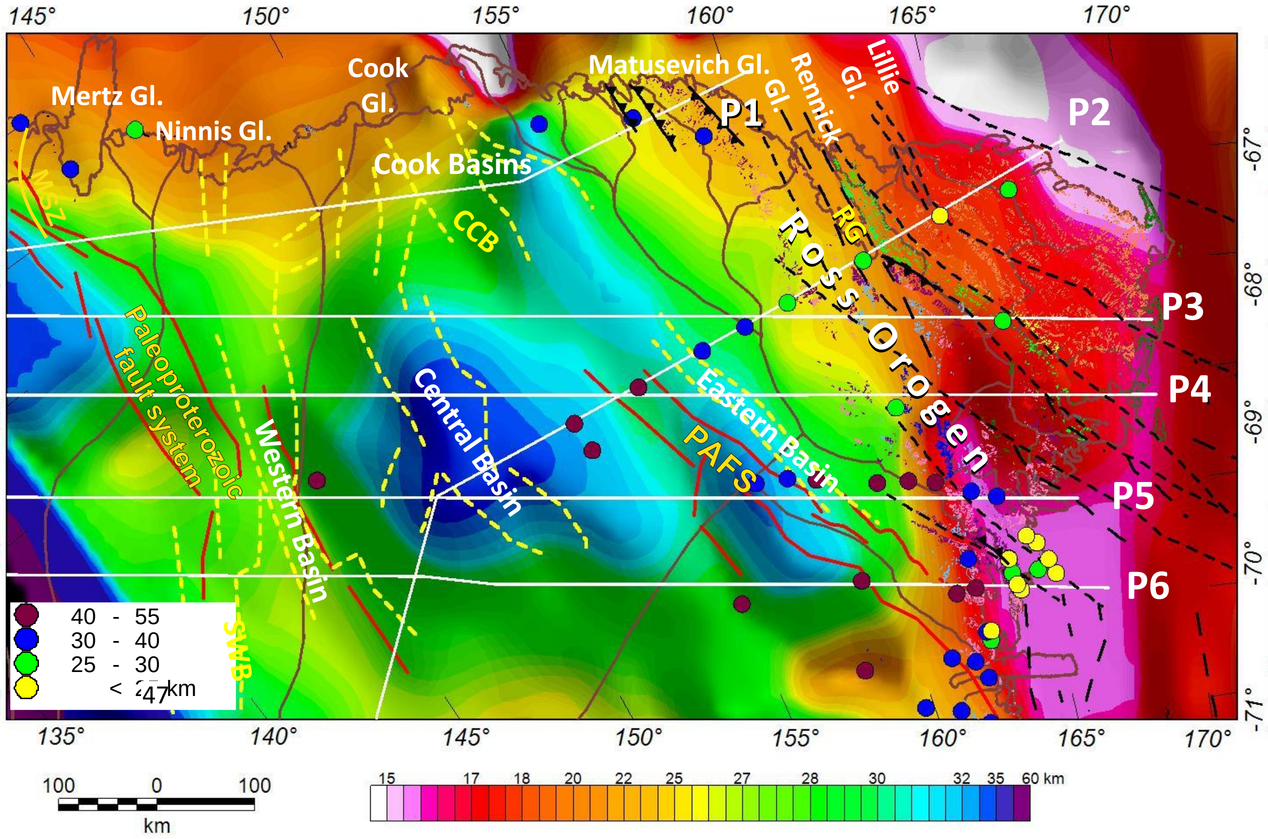
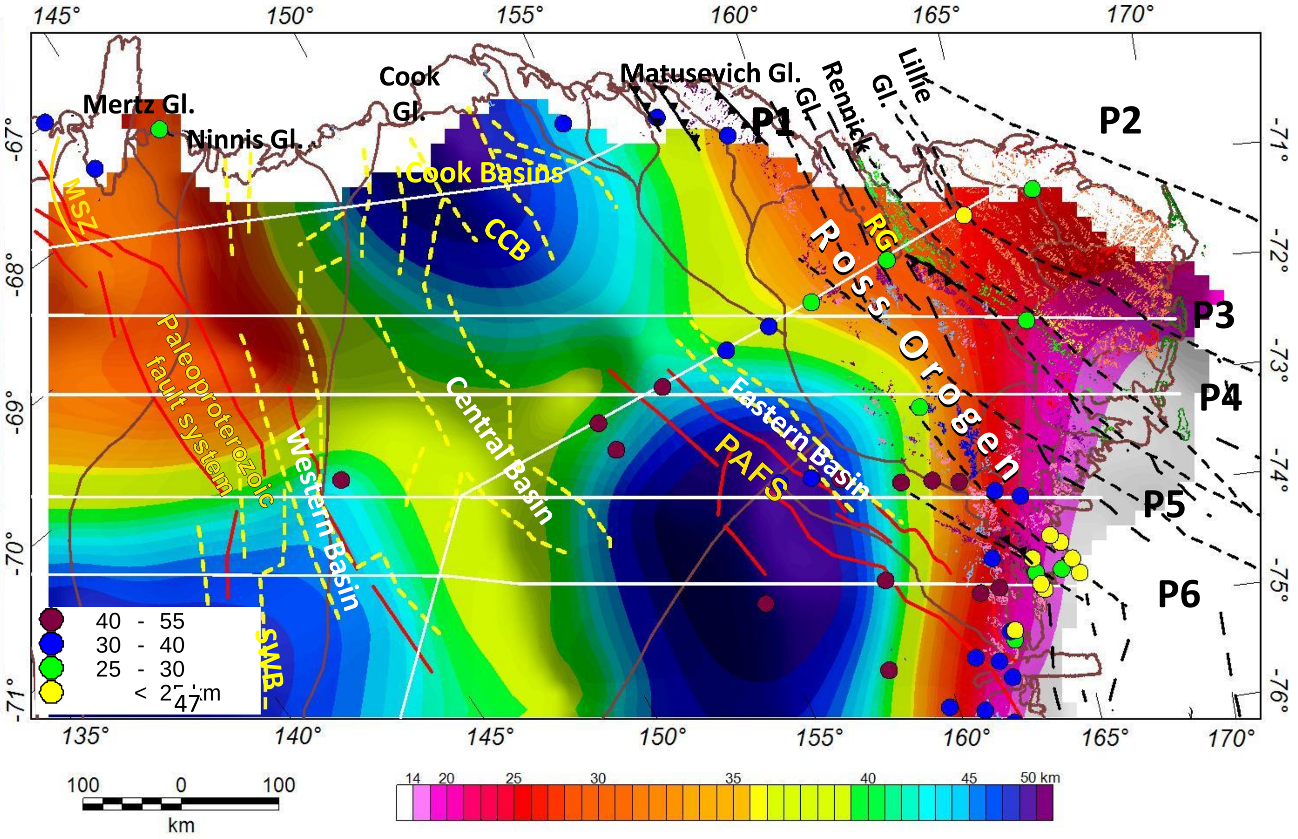
Curie Depth Point model An et al. 2015



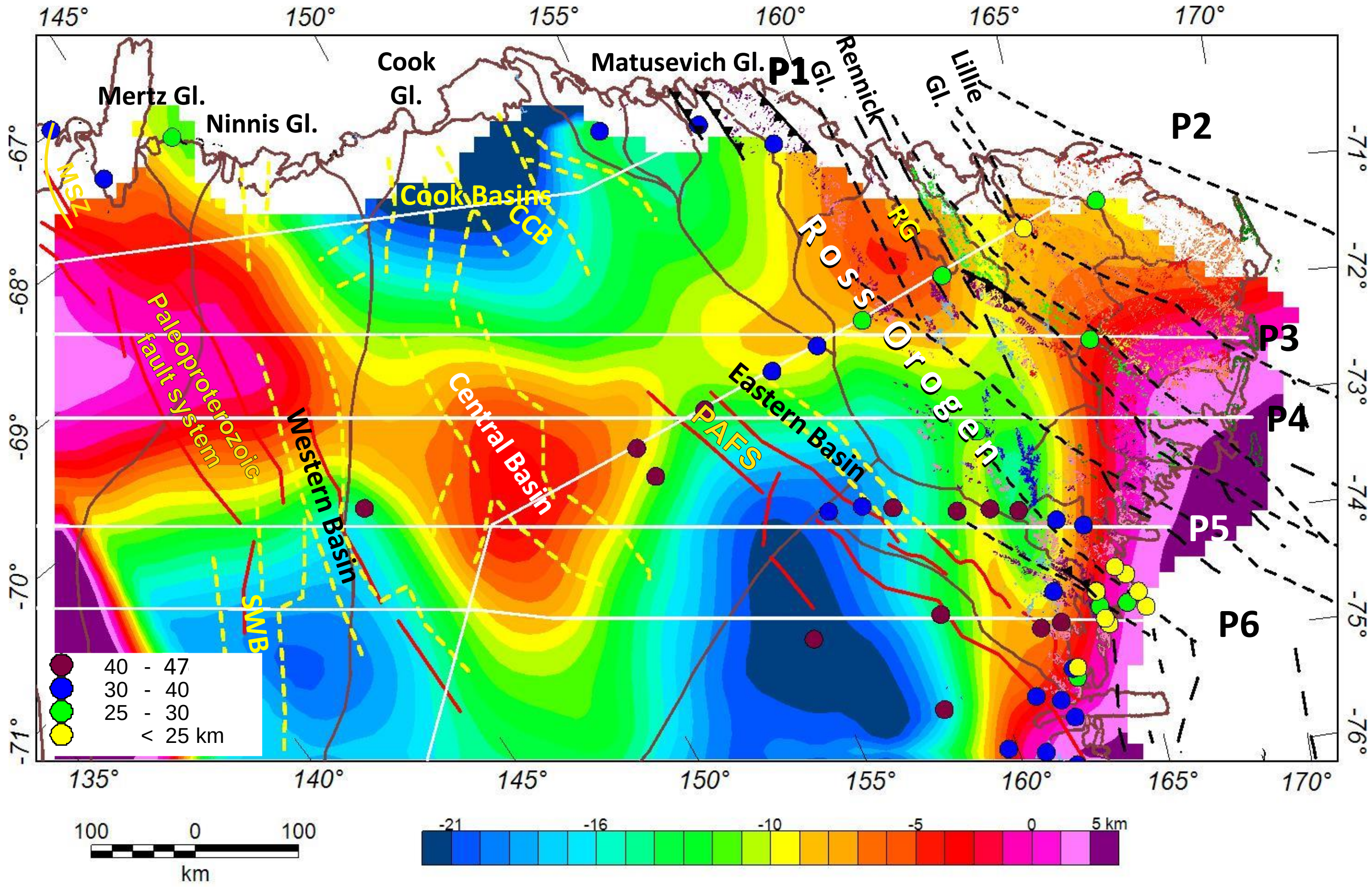
Curie Depth Point model Martos et al. 2017



- Note large differences in Curie Depth point estimation between different studies

Regional Curie Depth Point (CDP) difference map

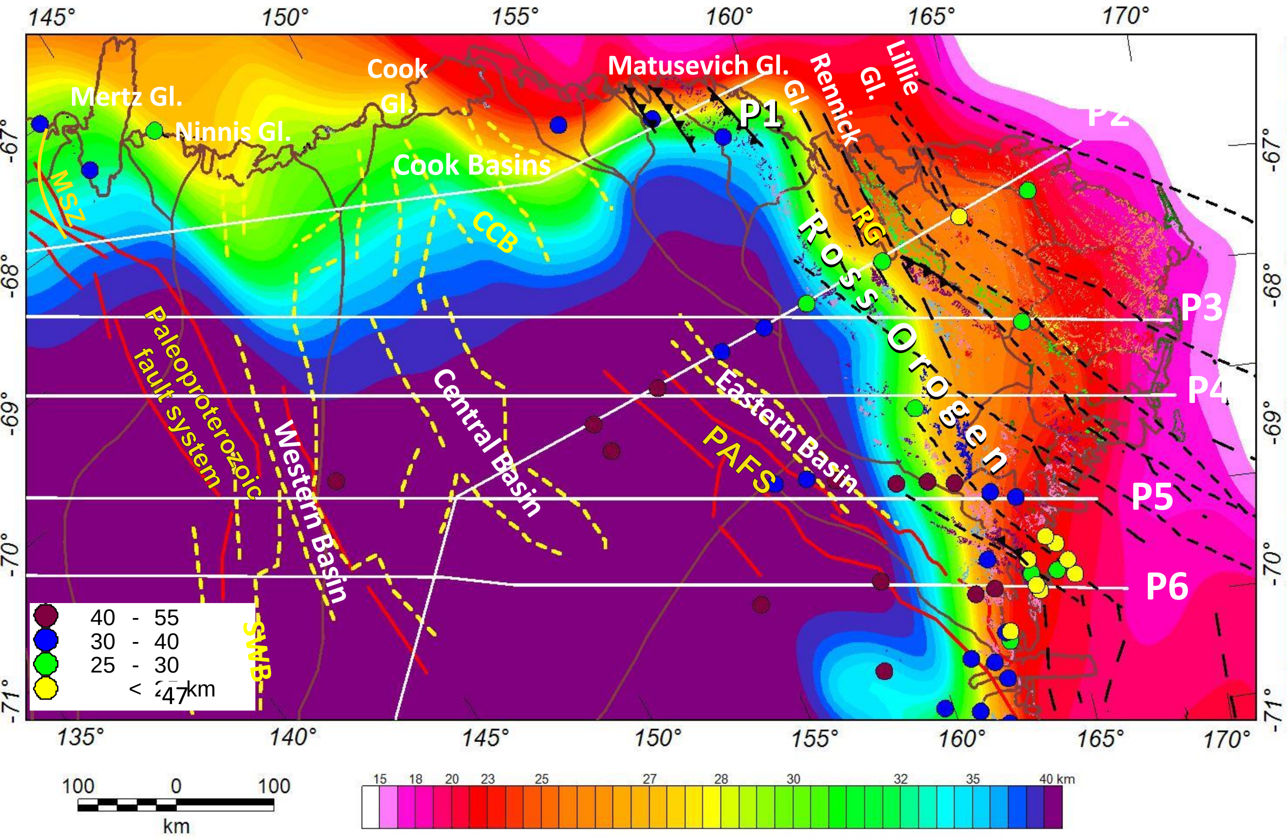
Difference in CDP An et al. 2015 and Martos et al. 2017



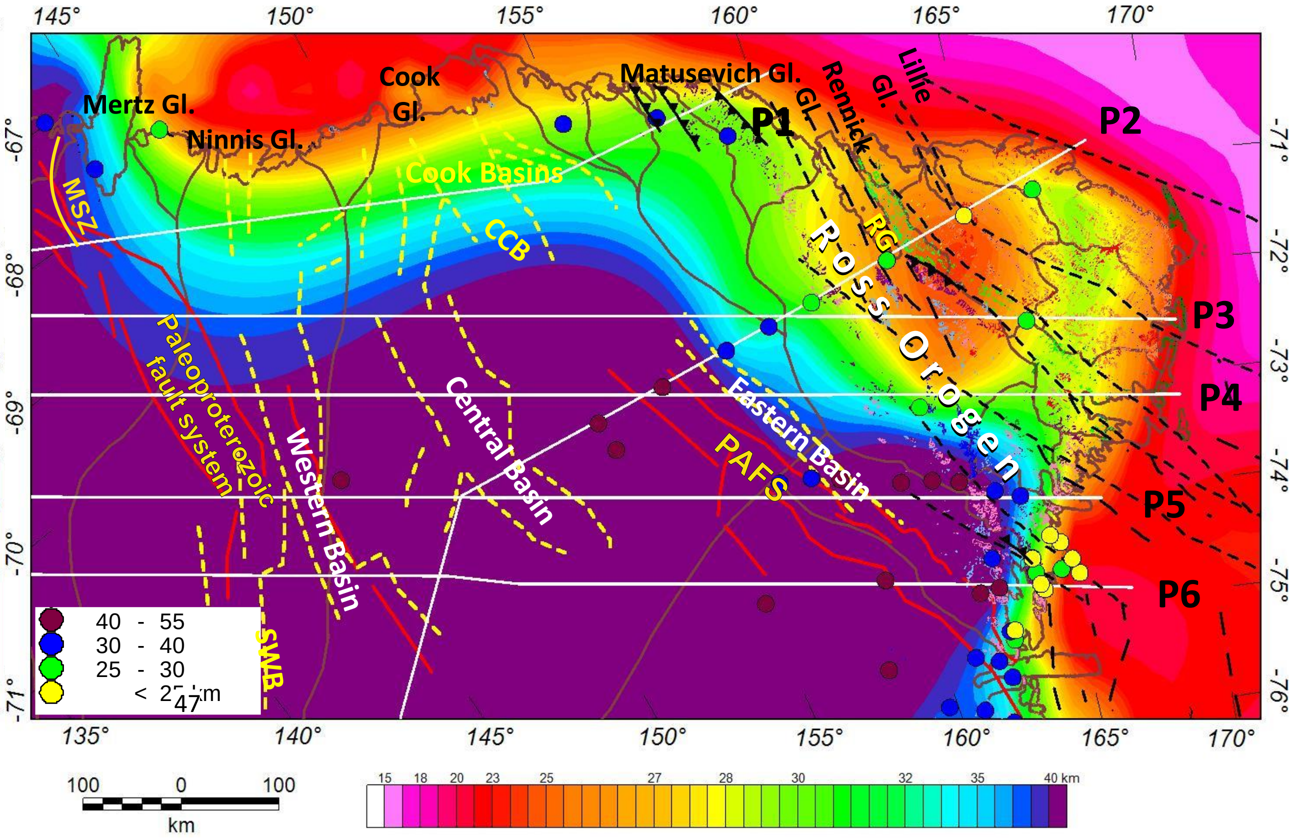
- Note large differences in Curie Depth point estimation between different studies

Comparison of crustal thickness in WSB

Crustal thickness An et al. 2015



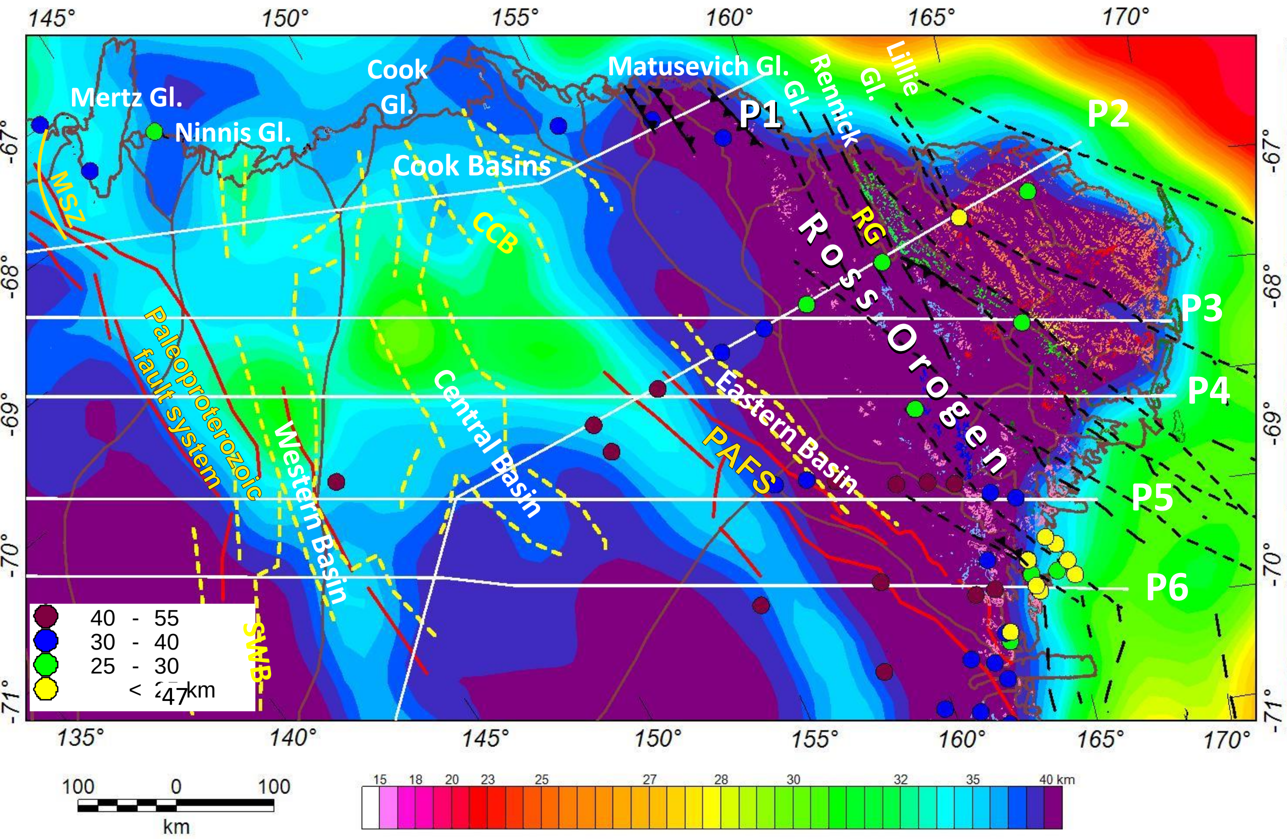
Crustal thickness merged from Shen et al. 2020, An et al. 2015 seismic stations with the continental margin from Pappa 2019



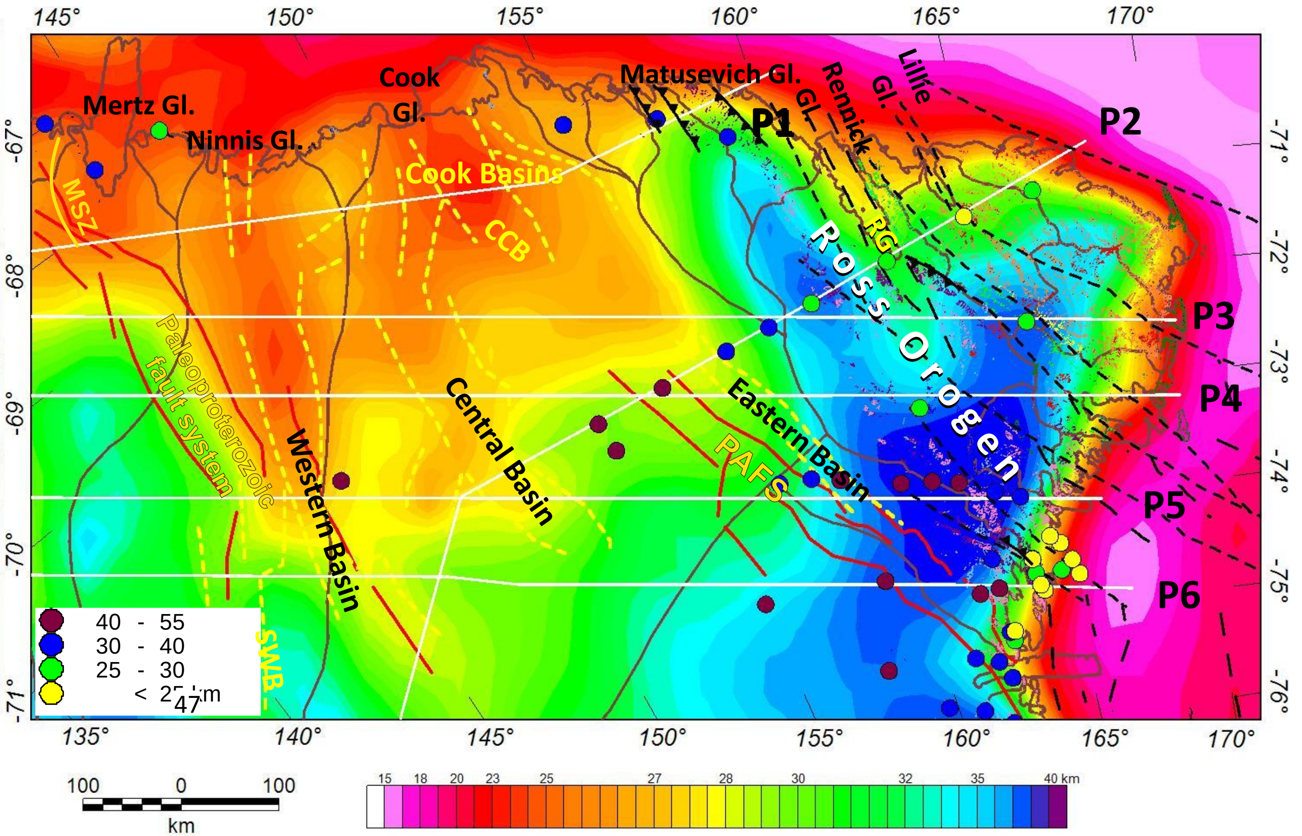
- Crustal thickness derived from seismology

Comparison of crustal thickness in WSB

Crustal thickness Kusznir et al. 2014



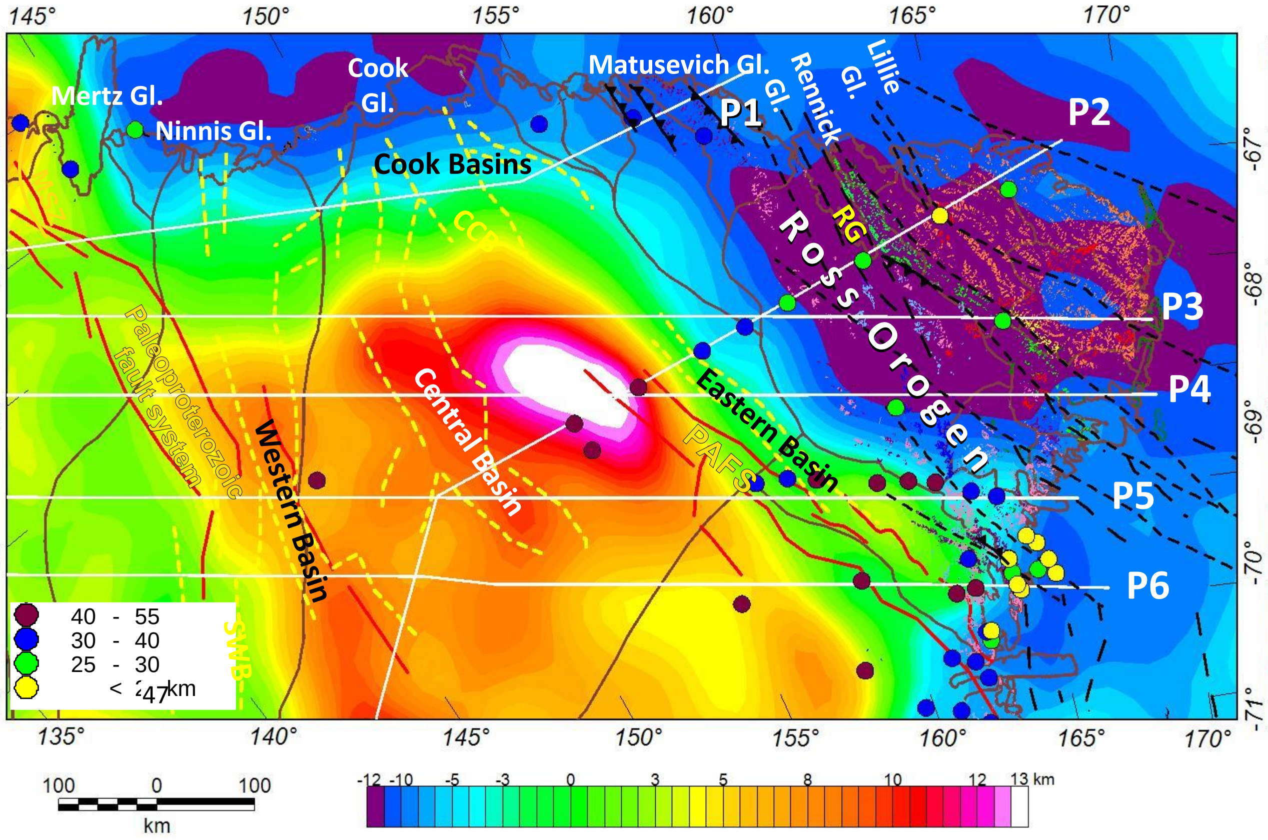
Crustal thickness Pappa et al. 2019



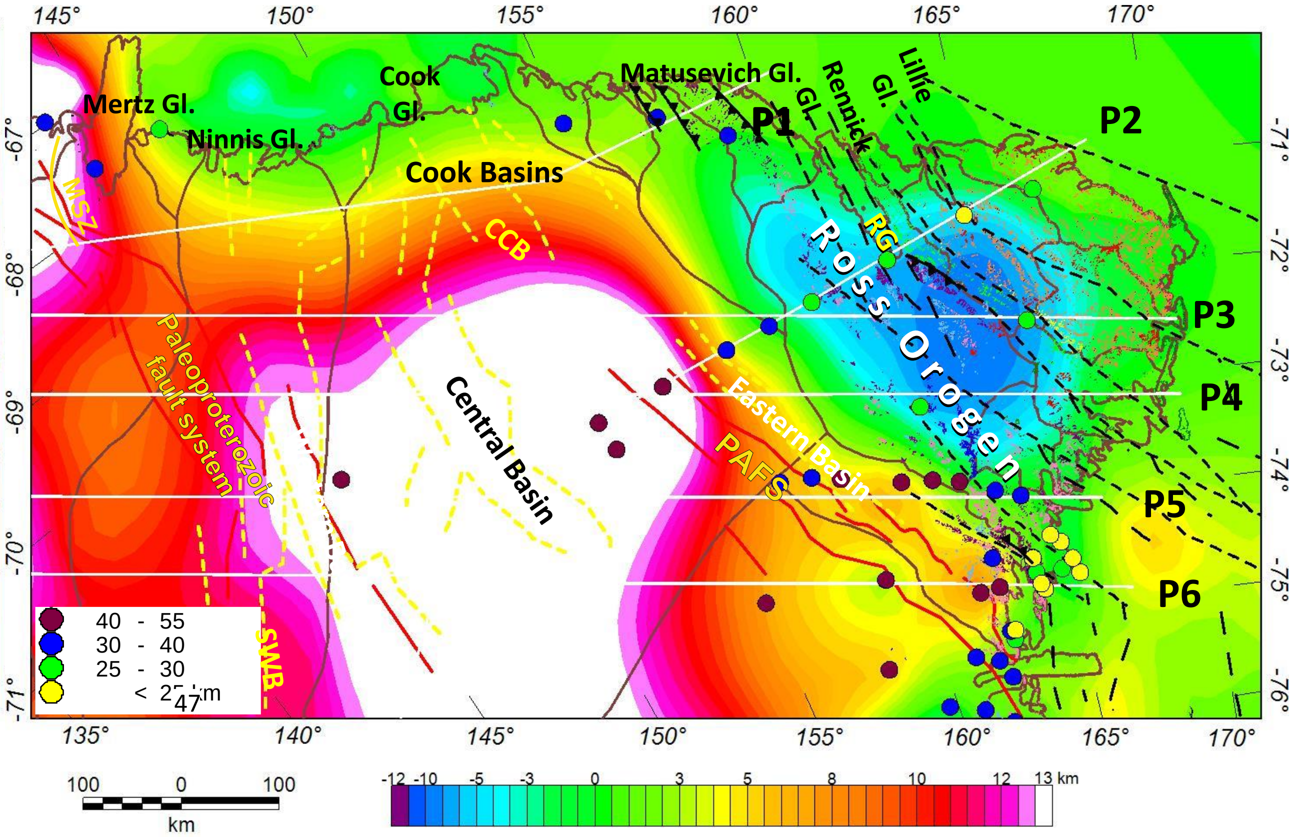
- Crustal thickness derived from gravity inversion / modelling

Comparison of crustal thickness in WSB

Difference in crustal thickness from seismic compilation to Kusznir et al. 2014



Difference in crustal thickness from seismic compilation to Pappa et al. 2019

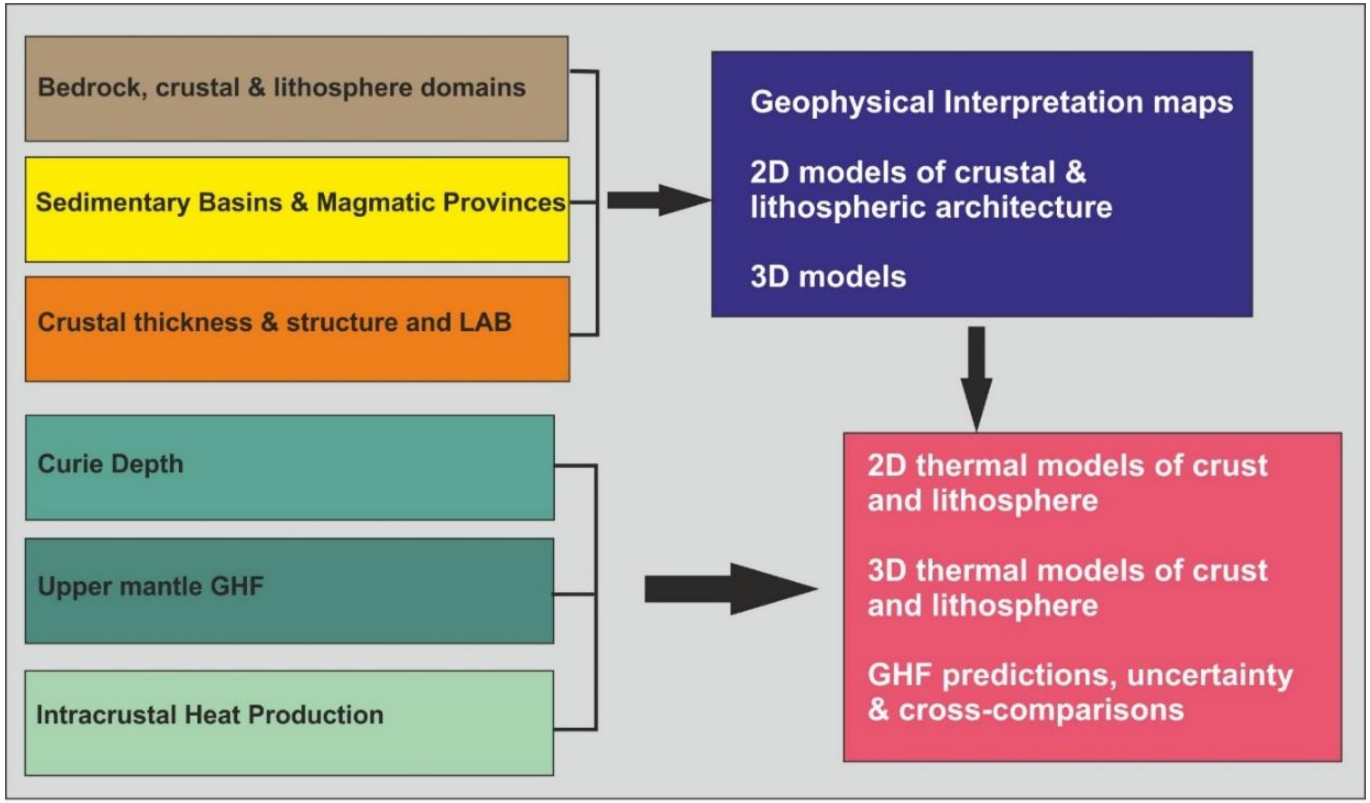


- Seismic consist of a merged grid containing crustal thickness estimations from Shen et al. 2020, An et al. 2015 seismic stations and the continental margin from Pappa 2019
- Note large difference in crustal thickness between gravity and seismological estimations. Large variation in crustal thickness has strong implications on Geothermal Heat Flux estimation.

Novel integrate thermal modelling approach

- Current GHF estimation for WSB show large differences and fall short in representing regional scale geological features.
- Current estimations of Antarctic GHF are derived from continental-scale analyses. Most of those estimates (with the exaptation of machine learning approaches Lösing et al 2020 and statistical analysis Stål et al 2021) are based on single observation e.g. Magnetics, Seismology, Gravity etc.
- We propose an integrated modelling approaches to estimate regional scale GHF a combination of airborne radar and aeromagnetic data, crustal and lithosphere thickness estimations from both satellite and airborne gravity and independent passive seismic constraints complimented with geological information.
- Our new approach links geophysical modelling tightly to regional geology.

Workflow



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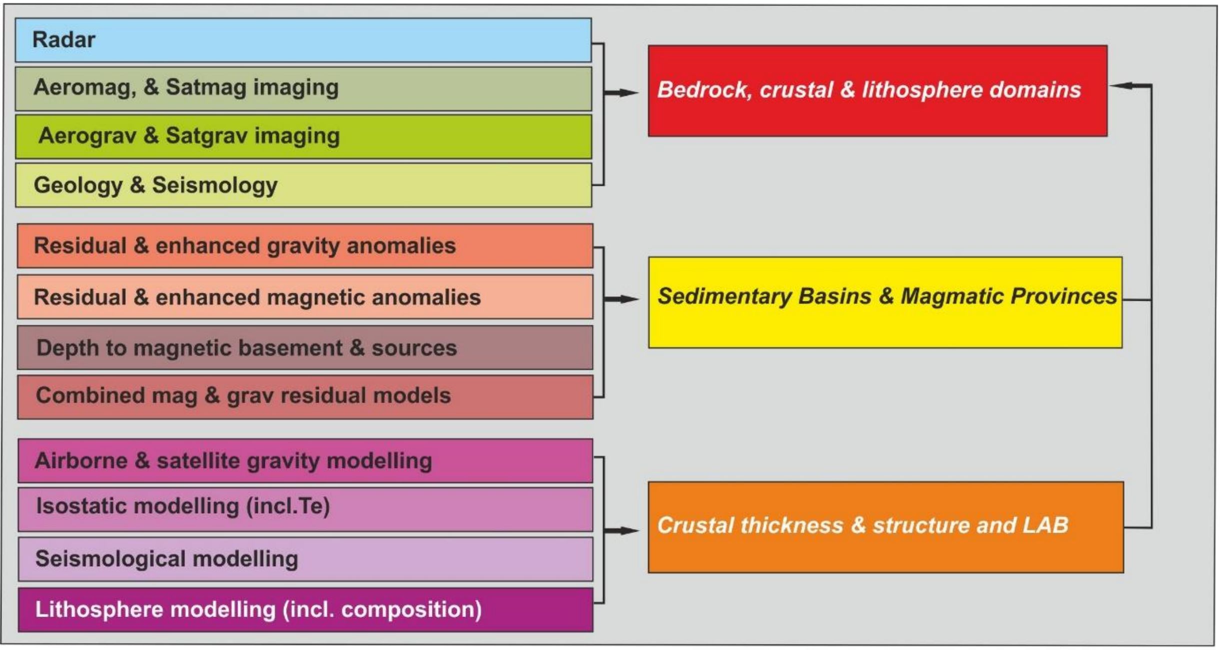
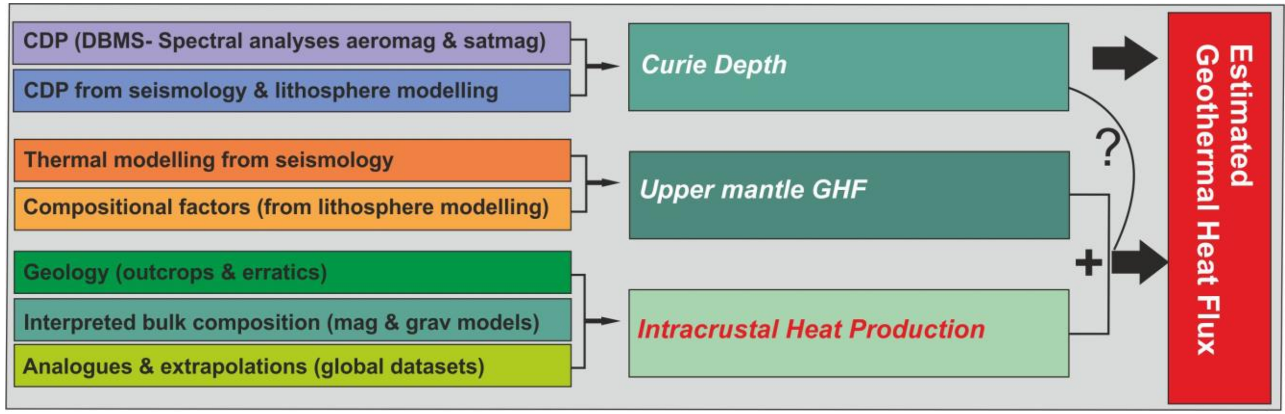
Novel integrate thermal modelling approach

Define Crustal and lithospheric structure



Define thermal boundary conditions within the lithospheric structure



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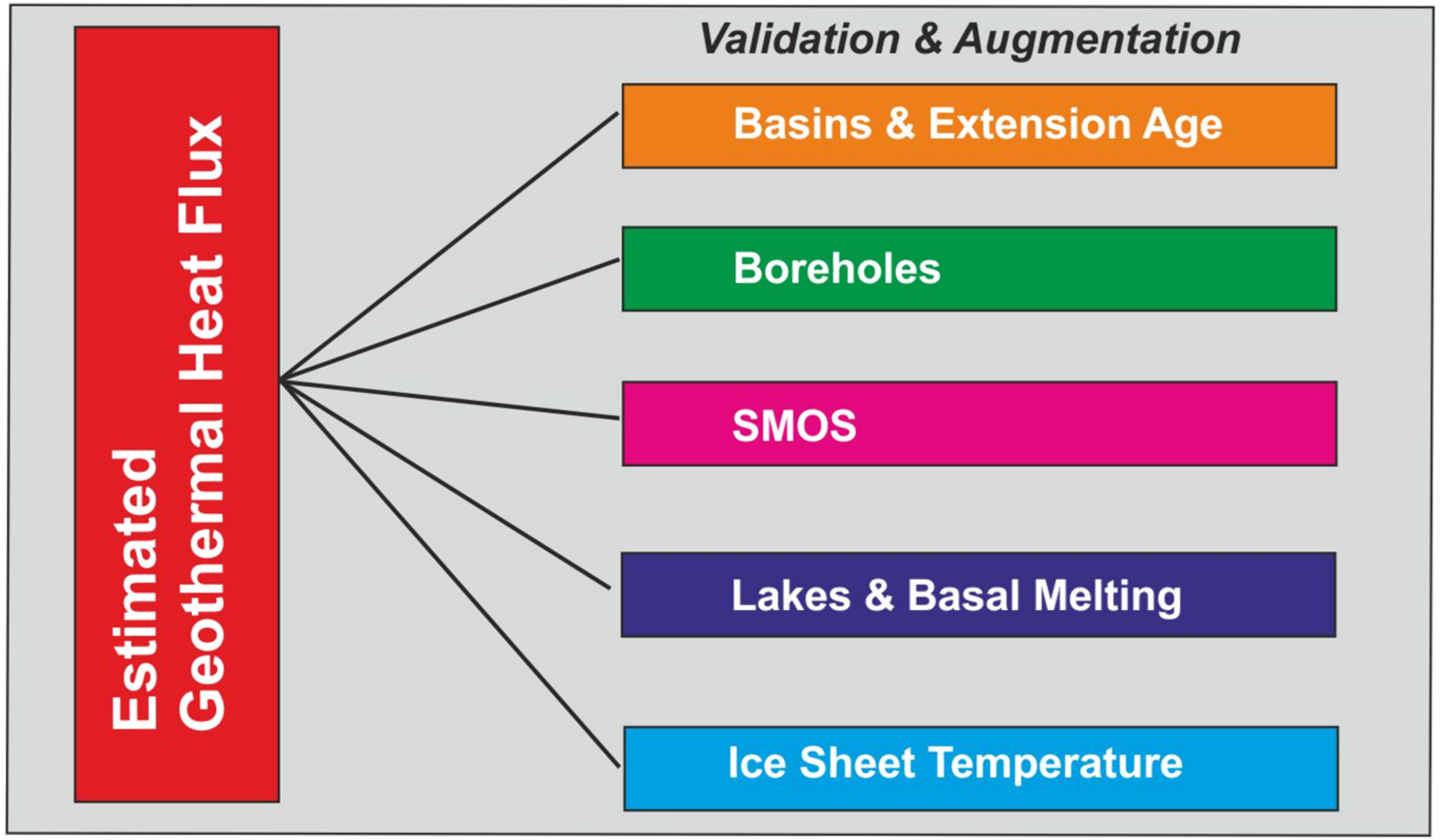
Novel integrate thermal modelling approach

Validate GHF estimation against independent Observables



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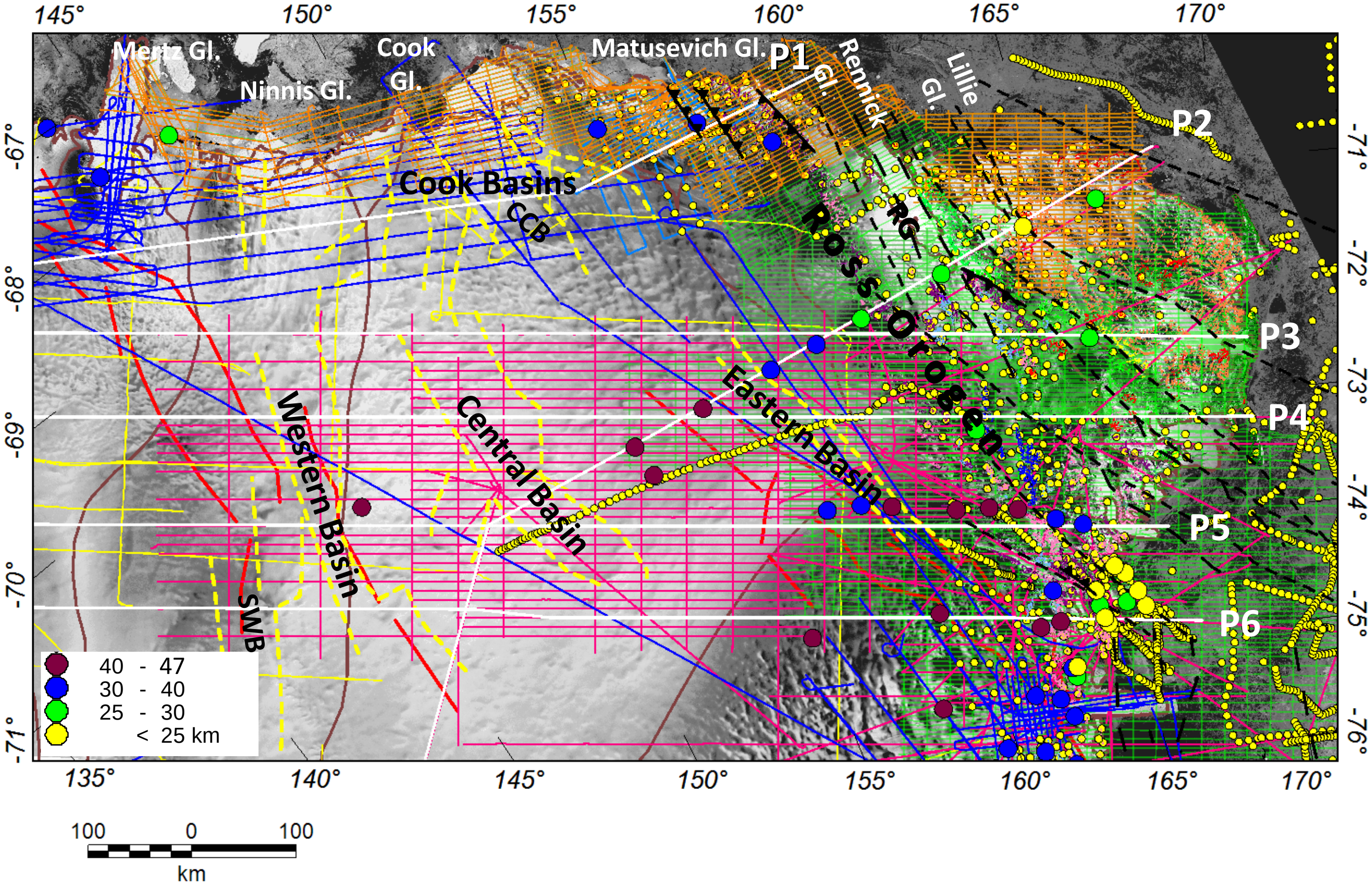
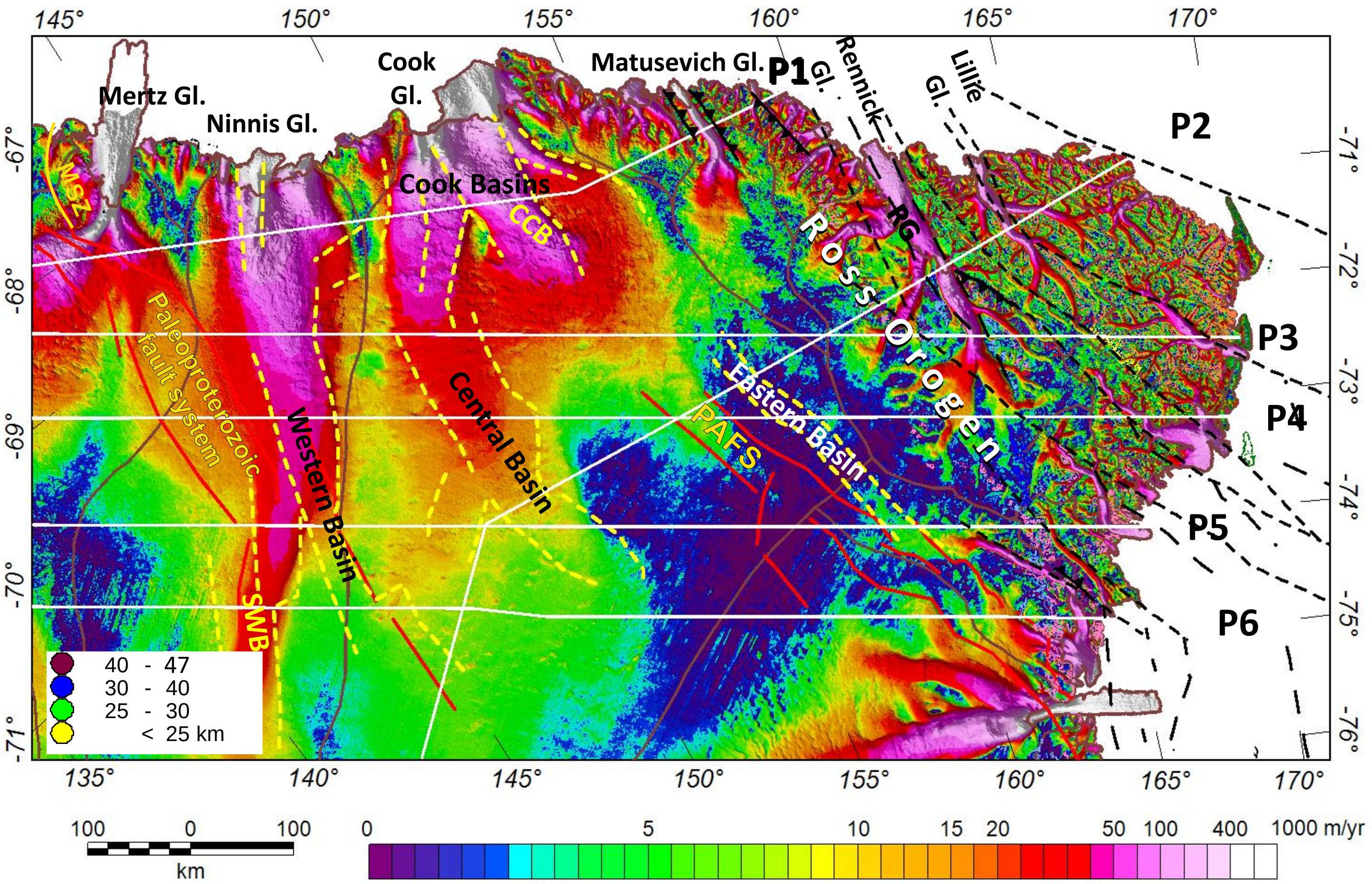
Crustal and Lithospheric heterogeneity imaged in WSB



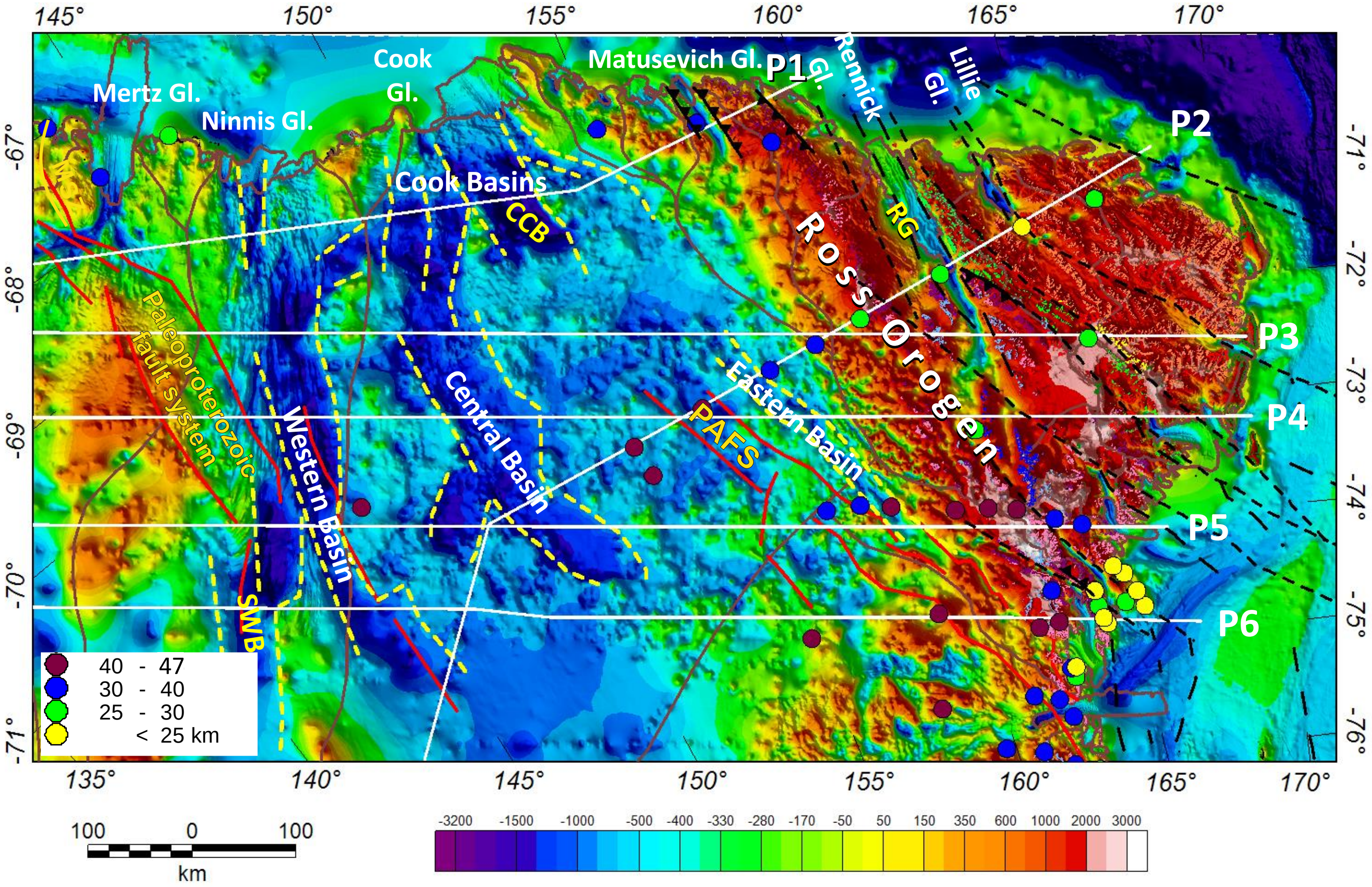
ICECAP- blue
WISE-ISODYN- magenta
Flight lines (airborne radar)
GANOVEX VIII- pale blue
SPRI- yellow
Flight lines (aeromagnetic)
BACKTAM- orange
GITARA, GANOVEX, WIBEM, MAGANTER- green
Land & marine gravity (small yellow dots)
Passive seismic stations (large coloured dots)
Dashed yellow lines indicate sub-basins in the WSB. Solid white lines show selected profiles that we plan to model as part of the new ESA 4D Antarctica project (but not shown here) to investigate subglacial geology, crust and lithosphere heterogeneity in the WSB and TAM region.

Ice velocity map



- Note the location of the major glaciers including the Mertz, Ninnis, Cook ice shelf, Matusevich, Rennick and Lillie glaciers.
- Geology in the northern Victoria Land
- Segment of the TAM from PNRA-GANOVEX teams.
- Major basement fault systems flank the WSB. These are traced from aeromagnetic imaging and include the newly proposed Paleoproterozoic fault system related to the exposed Mertz Shear Zone (Di Vincenzo et al., 2007, Prec. Res.) and the Prince Albert Fault System (Ferraccioli & Bozzo, 2003, Geol. Soc. London).

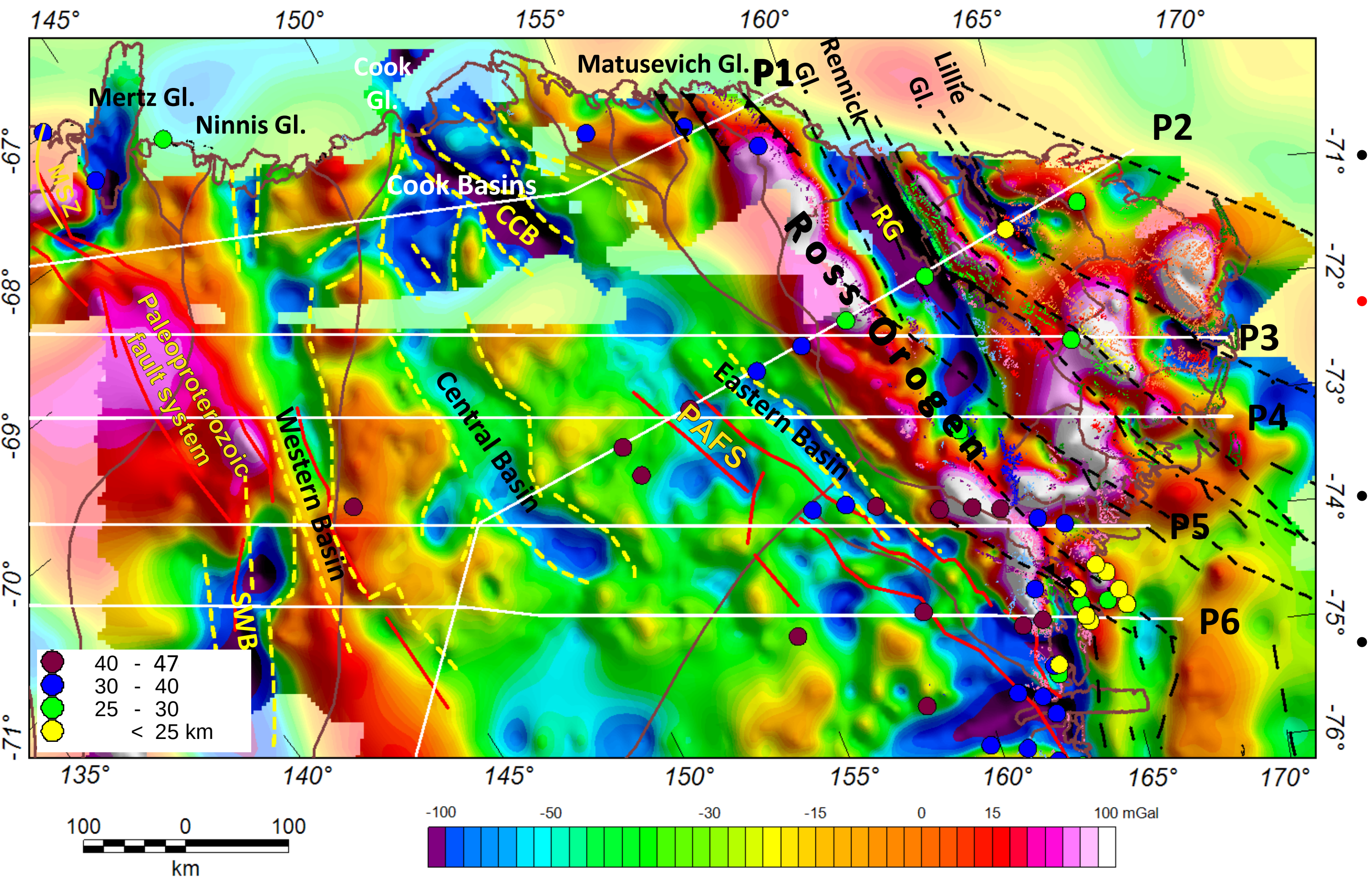
Bedrock topography in the WSB and adjacent TAM



- Shaded relief image of bedrock topography in the Wilkes Subglacial Basin and TAM from BedMachine (Morlighem et al., 2020,Nature Geoscience).

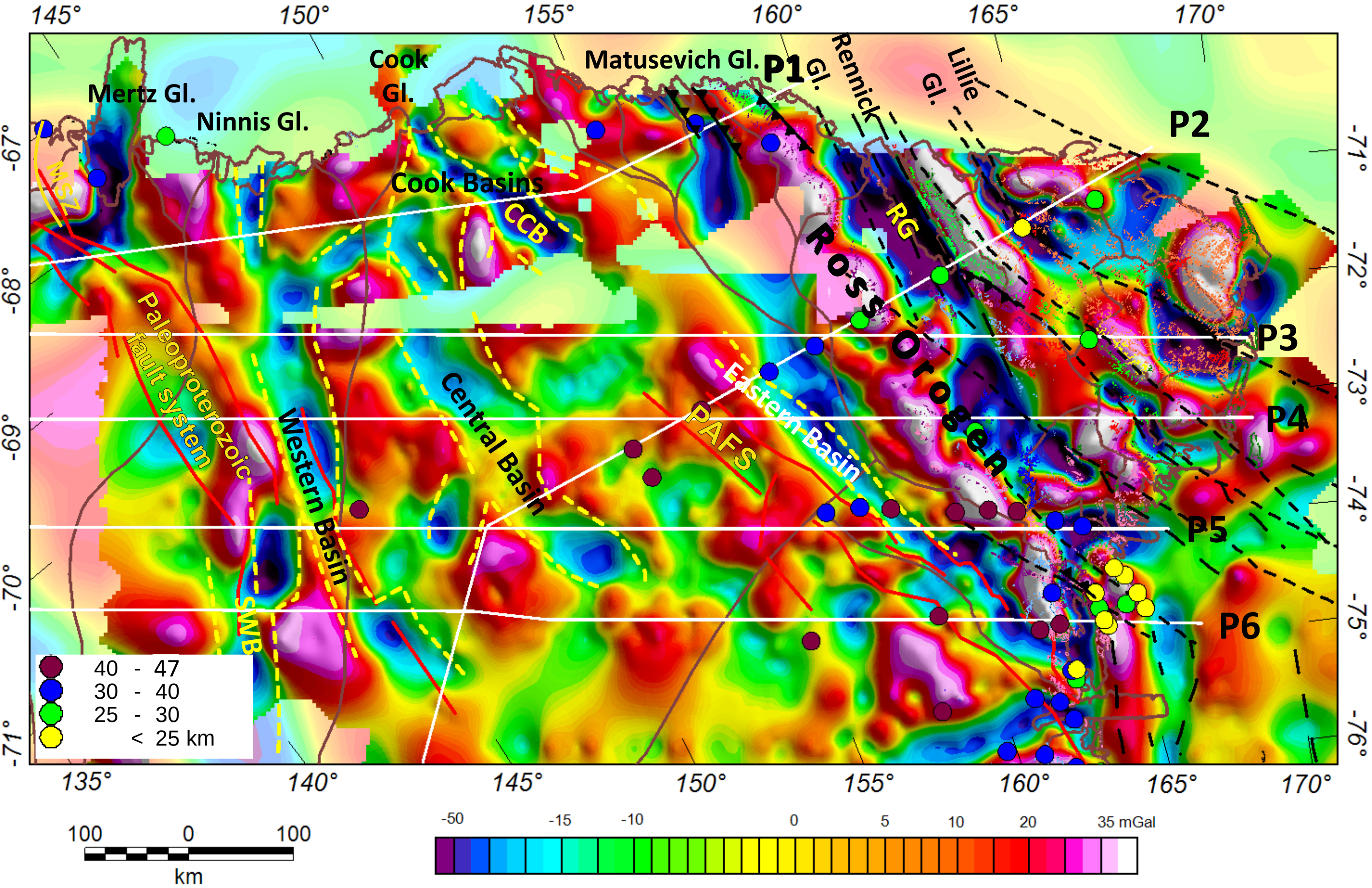
- Note the deep Cook Basins, where the bedrock deepens inland of the grounding zone of the Cook ice shelf ice streams. There is a potential connection between these newly imaged coastal subglacial basins and the previously identified Central Basin in the interior of the EAIS.

New Free-Air Gravity Anomaly Map in the Wilkes Subglacial Basin and adjacent TAM



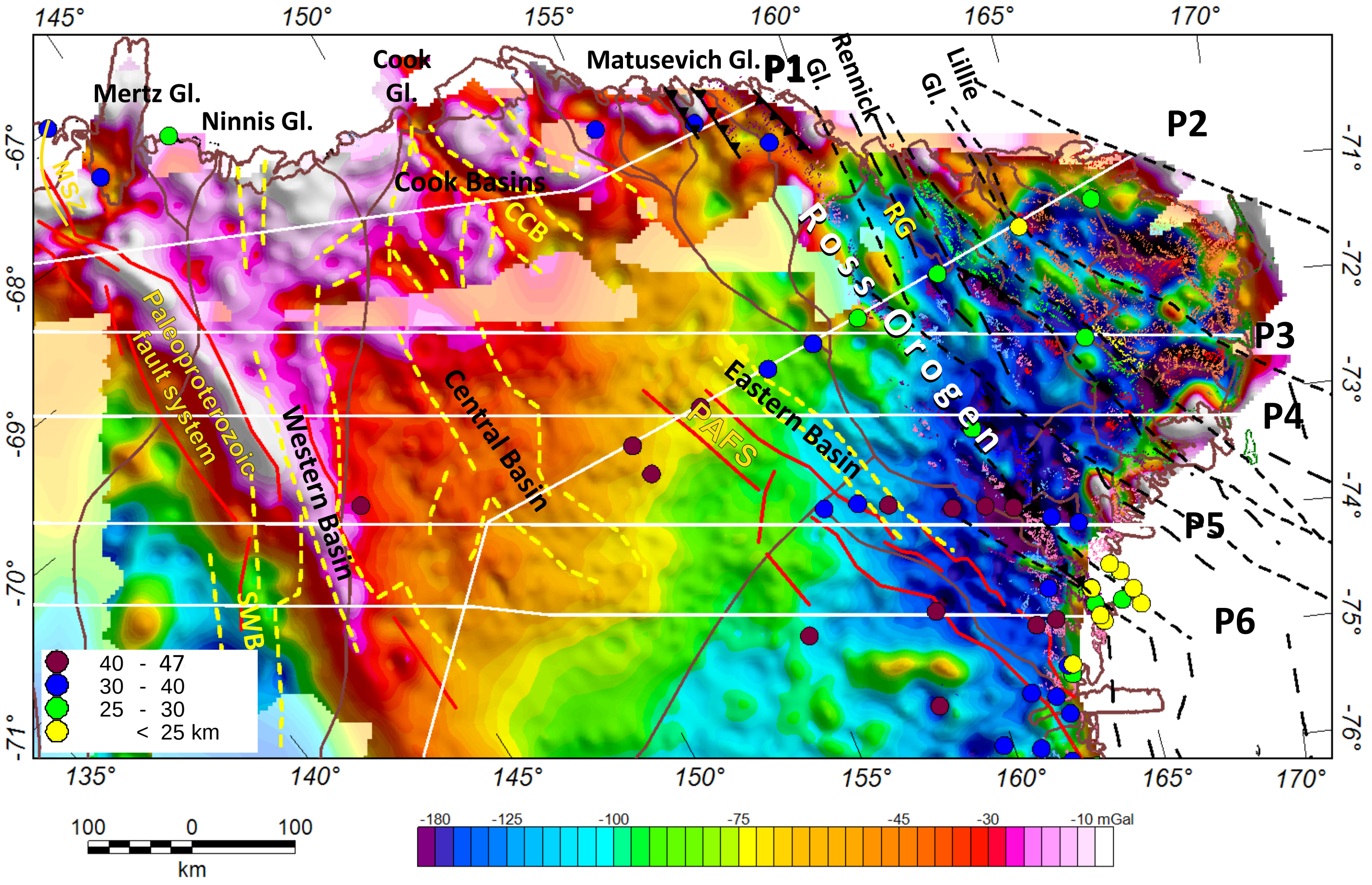
- New shaded relief image of Free-Air gravity in the Wilkes Subglacial Basin and adjacent TAM.
- Note the prominent Free-Air gravity low over the central Cook Basin (CCB) that resembles the low over the northern Rennick Graben (RG).
- The central Cook Basin lies on strike with the previously imaged Eastern Basin and the Prince Albert Fault System.
- Satellite-derived gravity anomalies (Zingerle et al, 2019; TIM R6e gravity field model) are shown as a transparent backdrop to help fill in data voids.

New high-pass filtered Free-Air gravity map



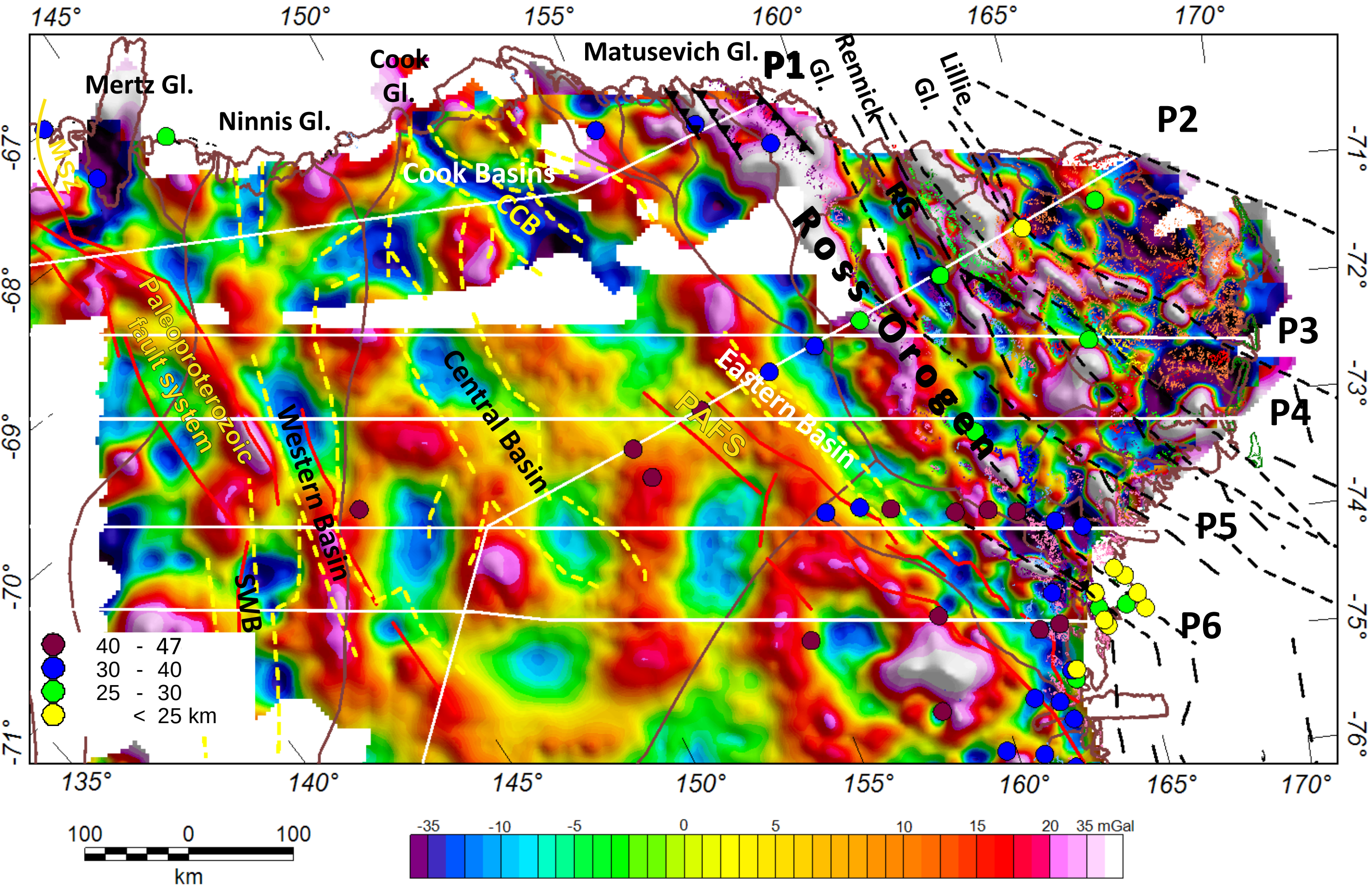
High-pass filtered map obtained by subtracting low-pass filtered anomalies at 200 km wavelength (twice the min. wavelength resolved by GOCE satellite gravity). The map enhances sub-basins within the WSB including the newly identified CCB. Note linear low connecting the thrusts of Matusevich Gl. with the Eastern Basin flanking the PAFS.

New Bouguer Gravity Anomaly Map in the WSB and adjacent TAM



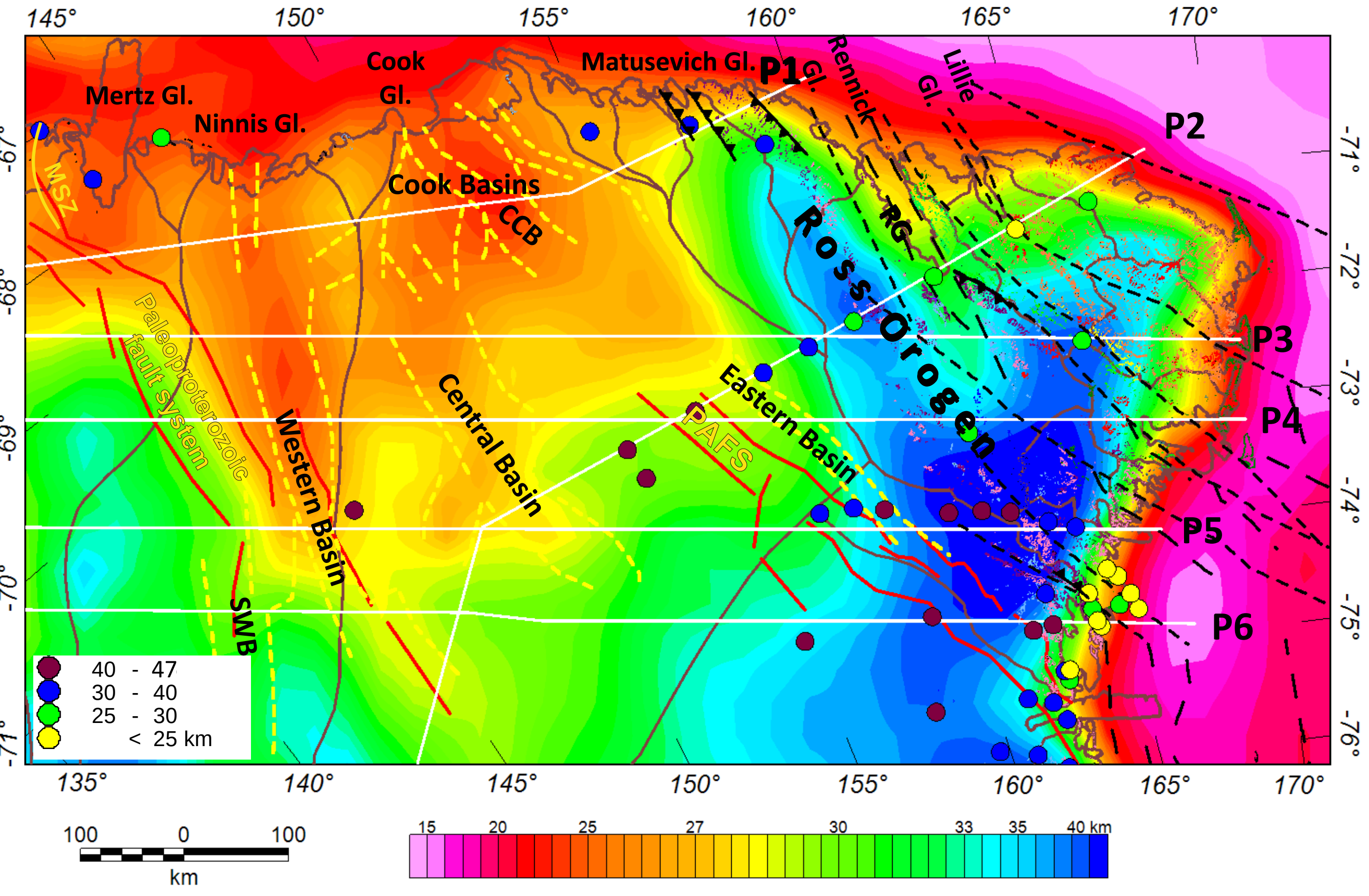
- New shaded relief Bouguer gravity anomaly image for the Wilkes Subglacial Basin and adjacent TAM.
- Note the contrast between the regional low over the thick crust of the TAM & Eastern Basin region and the highs over the Cook Basins area.
- A more subdued high is imaged over the Central Basin region.
- A remarkable linear gravity high flanks the proposed Paleoproterozoic fault system inferred from aeromagnetic data.

New Bouguer gravity residual map



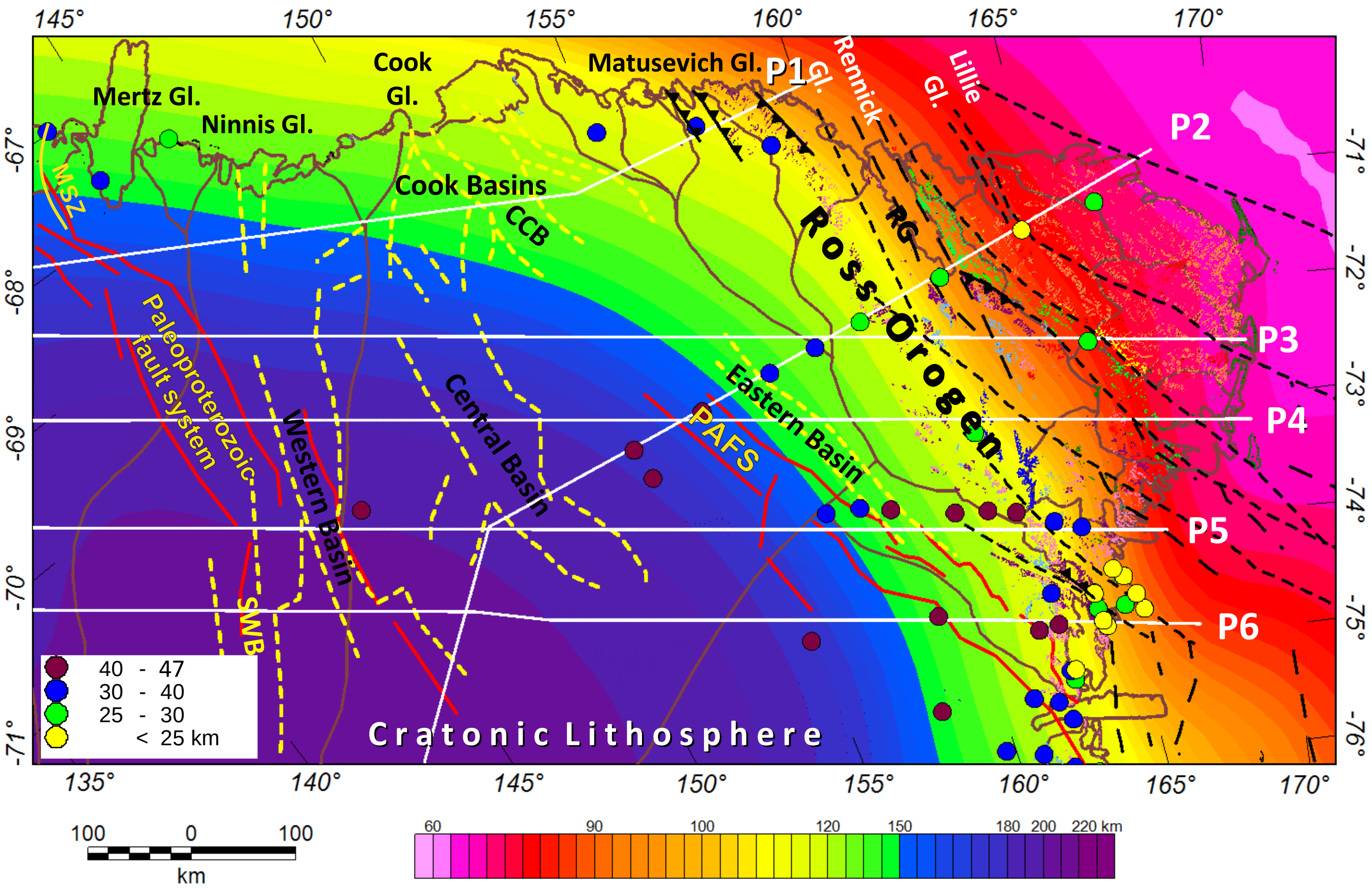
Bouguer gravity residual map obtained by subtracting GOCE satellite gravity anomaly field from the airborne derived Bouguer gravity anomaly grid. The map enhances the heterogeneity in gravity signatures of different sub-basins of WSB. Note in particular the linear low over the CCB interpreted as revealing a graben or pull apart basin

Satellite-gravity derived Crustal Thickness Map in the WSB and TAM



- Satellite-gravity derived crustal thickness map for the Wilkes Subglacial Basin and TAM from recent lithospheric modelling of Pappa et al., (2019, JGR).
- The model images linear regions of ca 25 km thick crust beneath the Cook Basins and Western Basin & ca 27 km thick crust beneath the Central Basin. This is thinner than the ca 31 km thick crust previously modelled from airborne gravity (Jordan et al., 2013, Tectonophysics).
- There are currently no passive seismic stations to help constrain, validate or refute these gravity results. We plan to compute alternative models, that include anomalously dense Precambrian crust in place of thin crust.

Satellite-gravity derived Lithosphere Thickness in the WSB and TAM

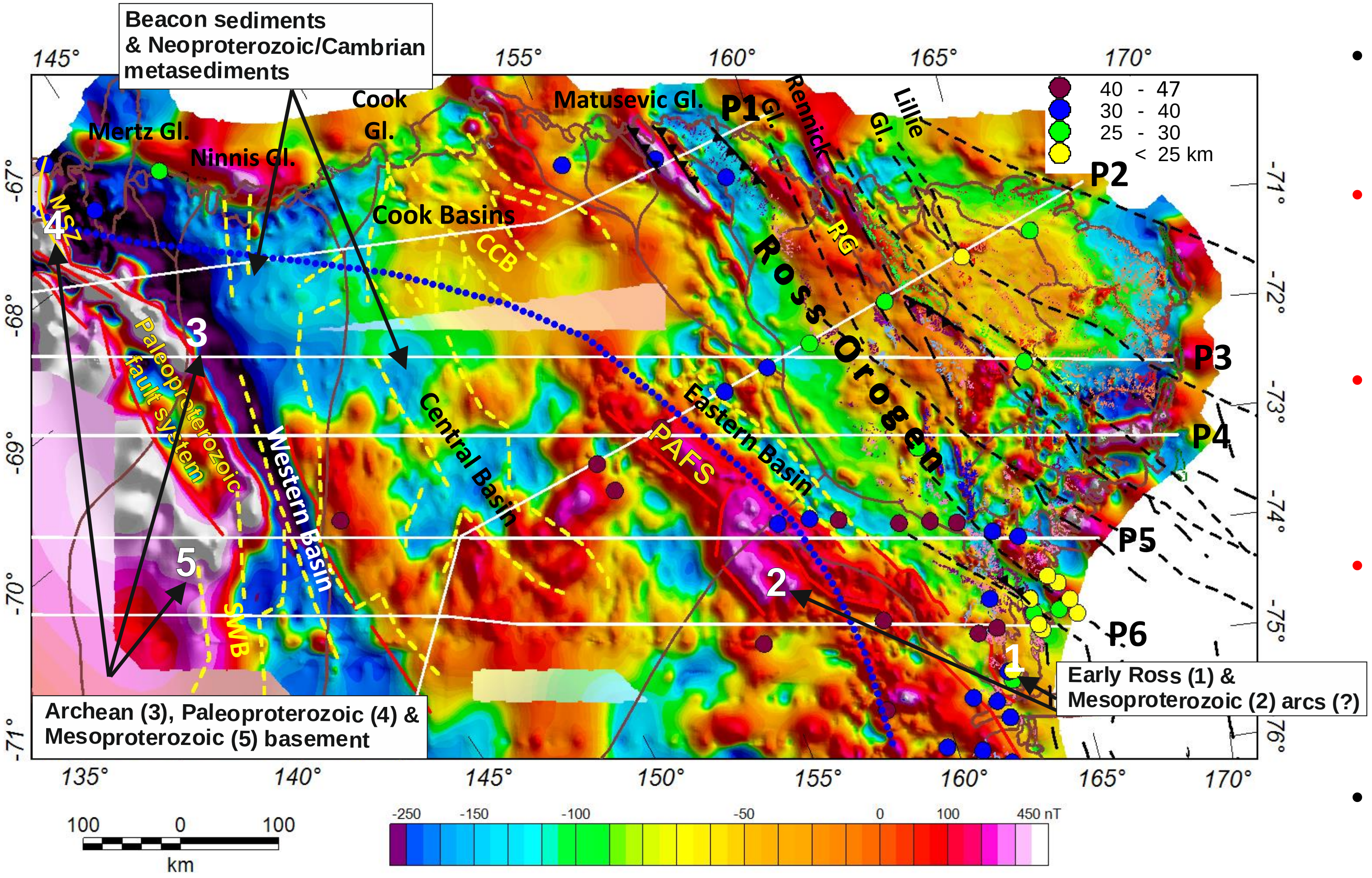


- Satellite-gravity derived lithosphere thickness for the Wilkes Subglacial Basin and adjacent TAM from recent lithospheric modelling of Pappa et al., (2019, JGR).

- The model indicates that the WSB is underlain by thick cratonic lithosphere (150-220 km thick), while thinner lithosphere (ca 120 km thick) underlies the adjacent Ross Orogen.

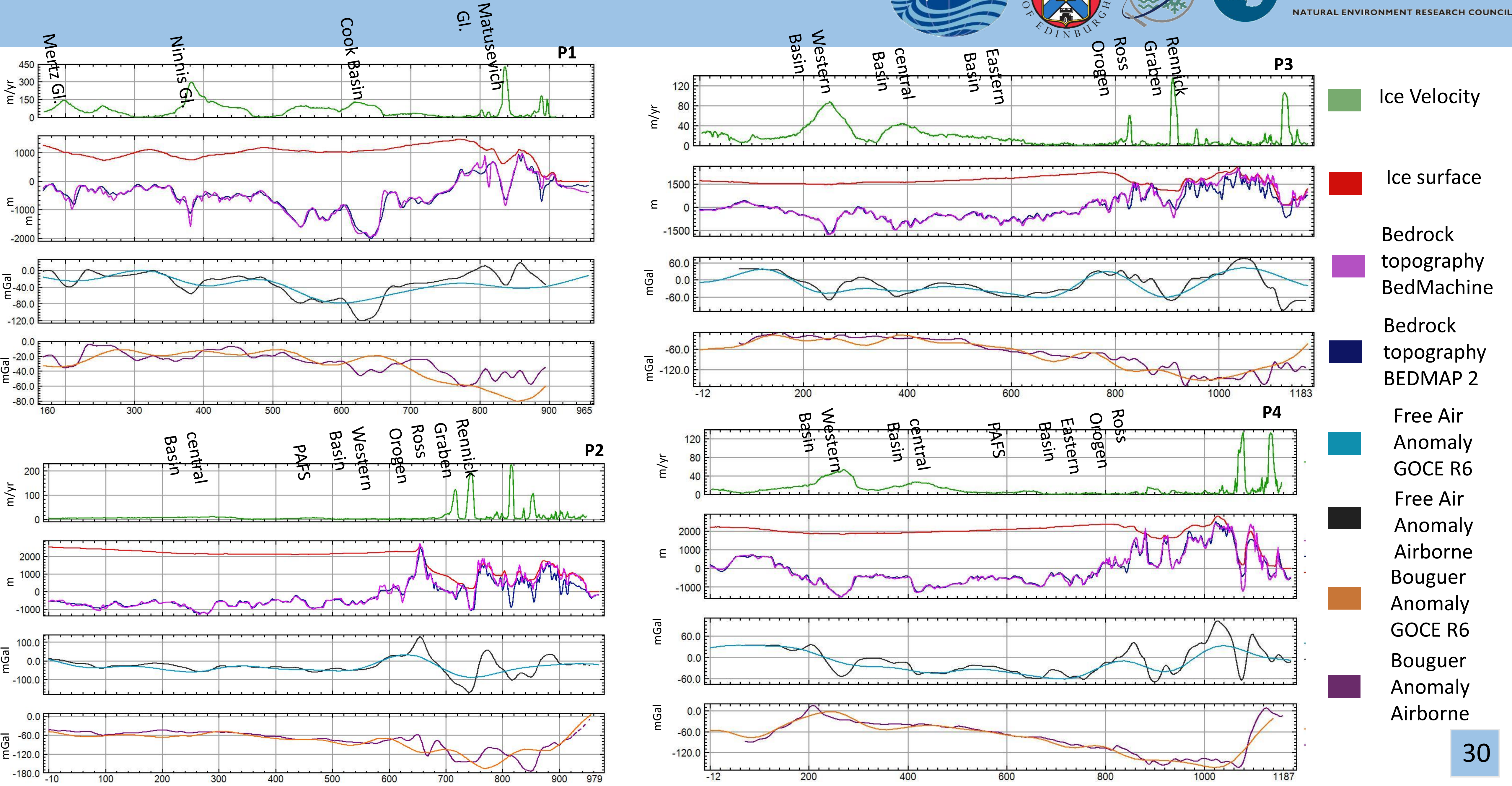
- The South Western Basin (SWB) is underlain by particularly thick lithosphere (ca 220 km), while the coastal Cook Basins appear to be underlain by ca 120 km thick lithosphere. The lithosphere may have been thinned here during Mesozoic (?) to Cenozoic break-up between Australia and East Antarctica (Eagles 2019).

New aeromagnetic anomaly map of the WSB and TAM

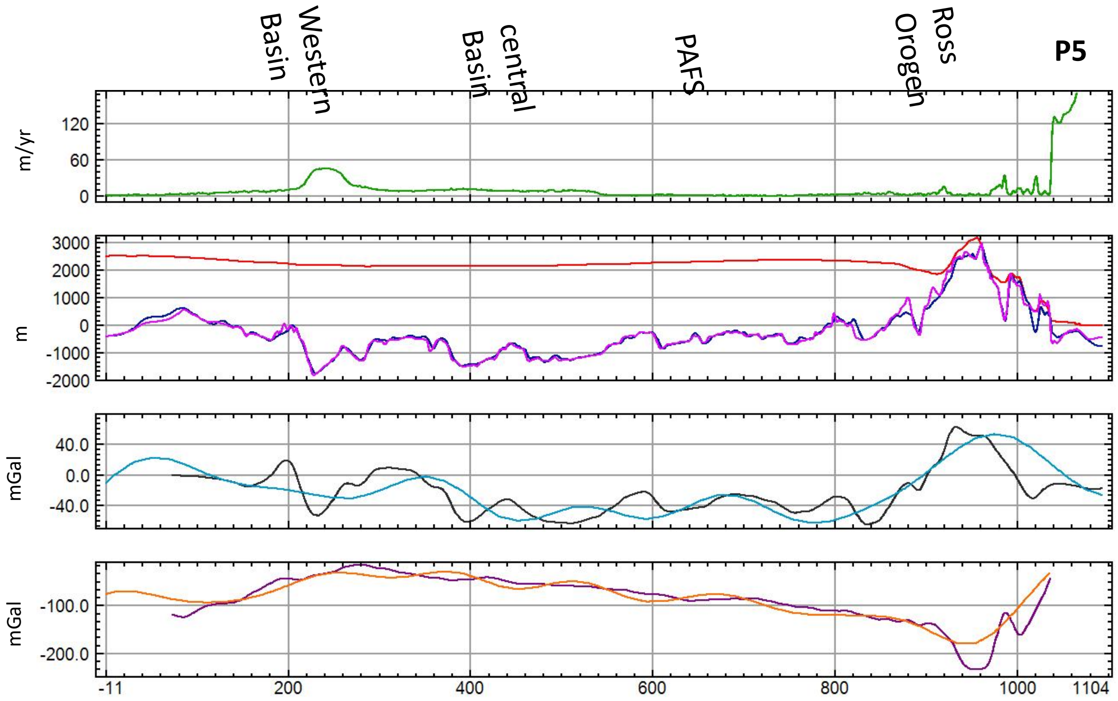


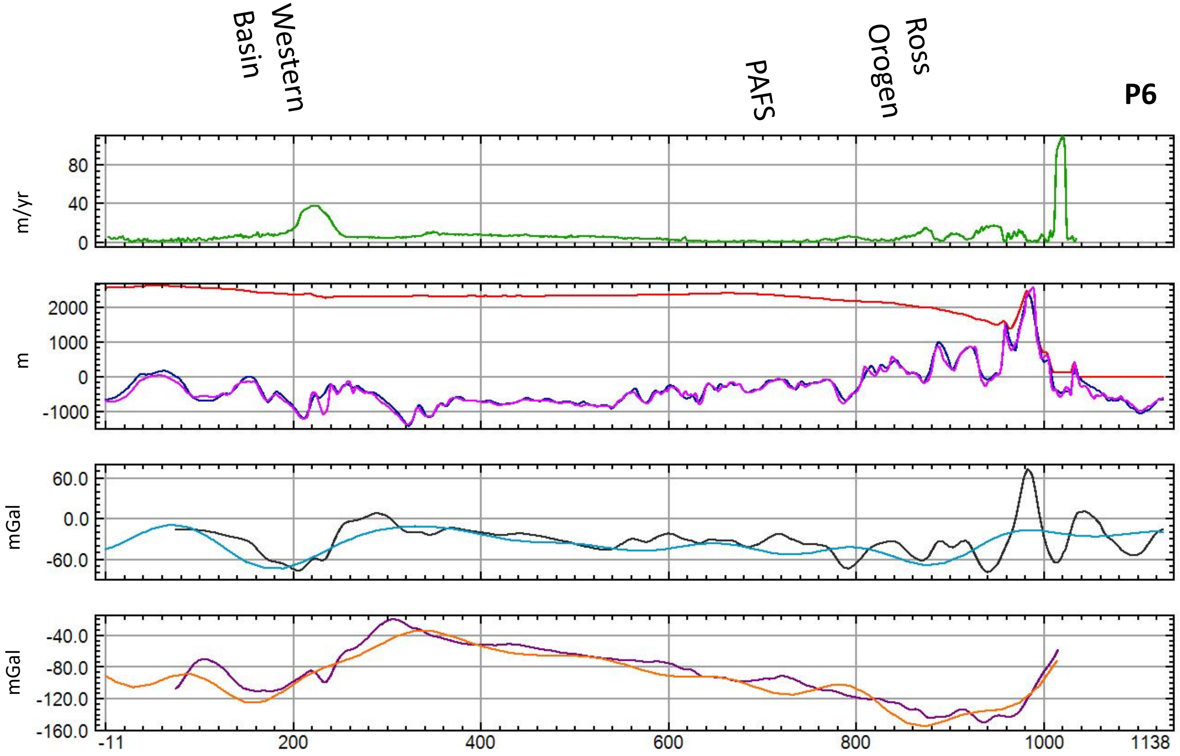
- New aeromagnetic anomaly map of the Wilkes Subglacial Basin and adjacent TAM.
- The aeromagnetic image helps unveil the cryptic and likely composite Precambrian basement of the Wilkes Subglacial Basin.
- Magnetic lows delineate areas where basement is likely buried deeper beneath Beacon sediments and thicker late Neoproterozoic to early Cambrian metasediments.
- **Such heterogeneity in basement and cover rocks in the WSB is a key finding for future assessments of Geothermal Heat Flux (GHF) variability beneath this key sector of the EAIS.**
- Dotted blue line denotes the edge of the thick cratonic lithosphere as modelled from satellite gravity data.

Comparison of gravity products on profiles



Comparison of gravity products on profiles





Ice Velocity

Ice surface

Bedrock topography BedMachine

Bedrock topography BEDMAP 2

Free Air Anomaly GOCE R6

Free Air Anomaly Airborne

Bouguer Anomaly GOCE R6

Bouguer Anomaly Airborne

Conclusion

- The Wilkes Subglacial Basin hosts a large and potentially unstable marine-based sector of the East Antarctic Ice Sheet.
- Recent continent scale GHF estimates show large differences and partially don’t represent the Crustal and Lithospheric heterogeneity in WSB
- Our new aerogeophysical and satellite images reveal heterogeneity in its subglacial geology, crust and lithosphere.
- We propose that buried beneath Beacon and older (likely early Cambrian to Late Neoproterozoic) sediments in the Wilkes Subglacial Basin lies a cryptic and composite Precambrian basement terrane.
- The heterogeneity in subglacial geology, crust and lithosphere beneath the Wilkes Subglacial Basin has significant additional implications for future assessments of Geothermal Heat Flux in this key sector of the EAIS.

Next steps

- 2D & 3D Lithospheric models for WSB
- 3D thermal structure model for WSB based on the lithospheric models

Thank you !

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