Bathymetry and geological structures beneath the Ross Ice Shelf at the mouth of Whillans Ice Stream, West Antarctica, modeled from ground-based gravity measurements

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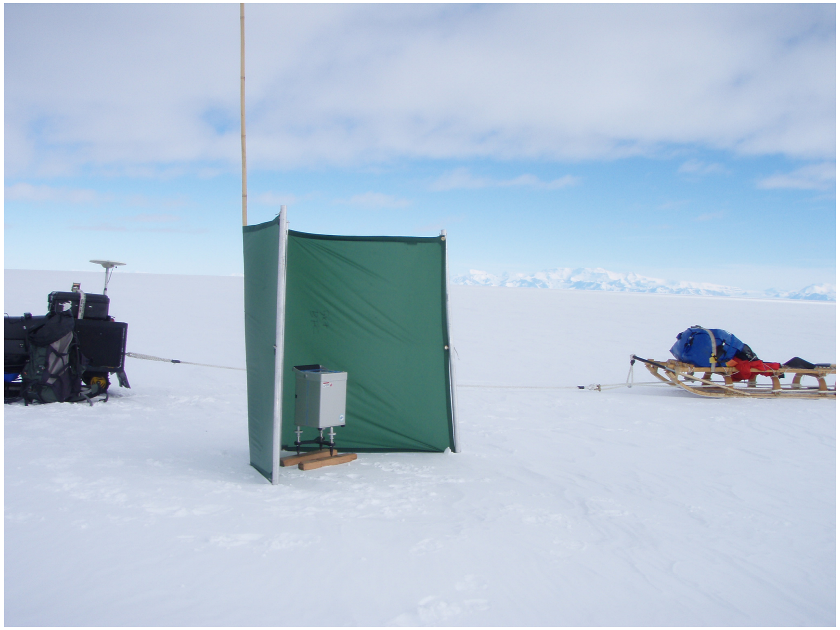
WISSARD Grounding Zone Camp, 2011-12

WISSARD grounding zone geophysical survey



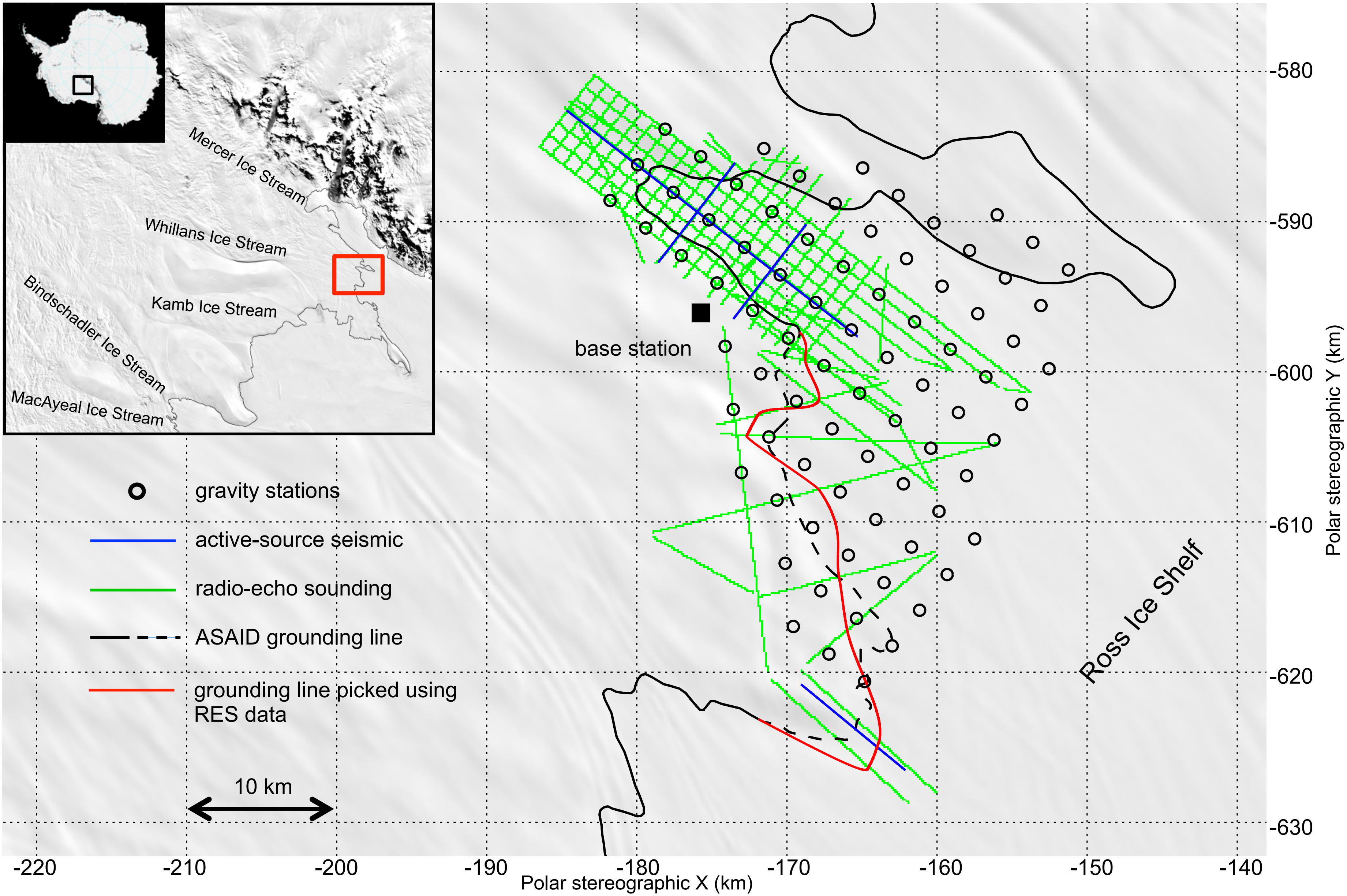
CG-5 Autograv relative gravimeter

- Grounding zones of ice sheets and contiguous ice shelves are important in understanding ice sheet dynamics.
- Grounding zone of Whillans Ice Stream is relatively stable, why?
  - Active-source seismic: ice thickness, water column thickness, some sediment structure
  - Radio-echo sounding: ice thickness, dielectric properties of ice base, ice internal layers
  - GPS (kinematic and long-term): ice surface elevation, ice velocity, tides
  - Gravity: gravity anomalies due to subsurface density structures which can be used to model subsurface structures

- Active-source seismic is the best way to image the subsurface (high-resolution) but expensive and very labor-intensive
- Gravity is low-resolution and inversion of gravity data is a non-unique problem, but better spatial coverage
- Gravity inversion constrained by active-source seismic data to model bathymetry and subsurface geological structures beneath the ice shelf

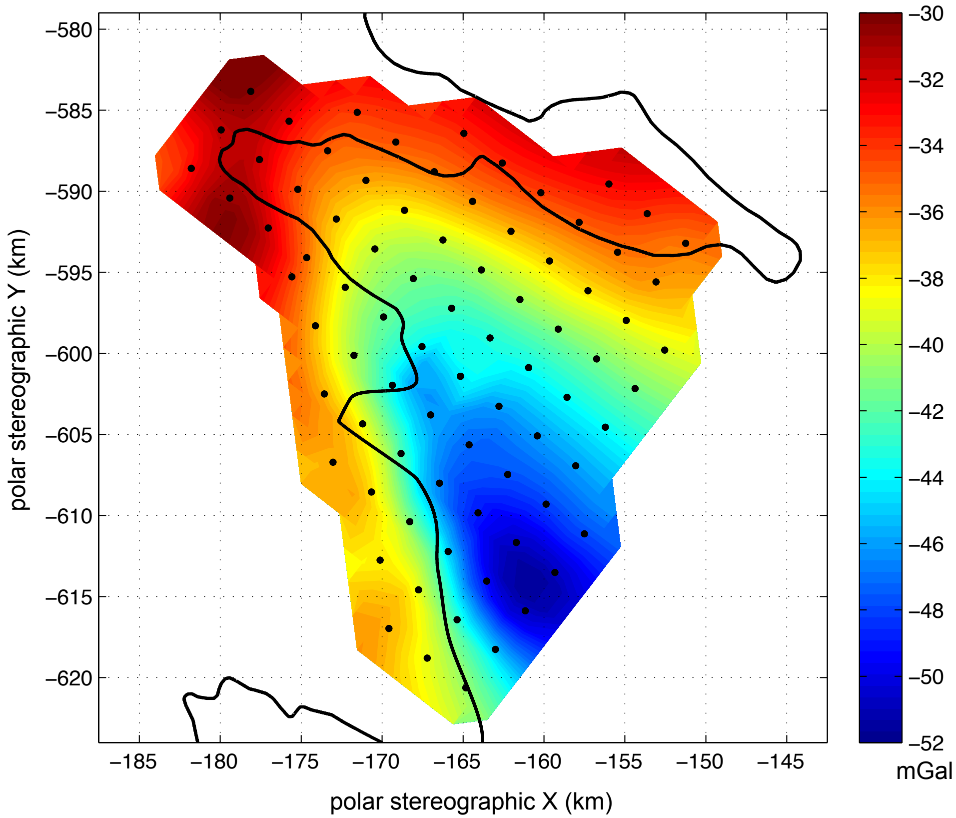
- Gravity measurements
  - grid pattern, 3-km spacing
  - 80 stations, repeat measurements at 16 stations
  - Accuracy: 0.111 mgal (RMS of crossover differences at 16 stations)

WISSARD grounding zone geophysical survey



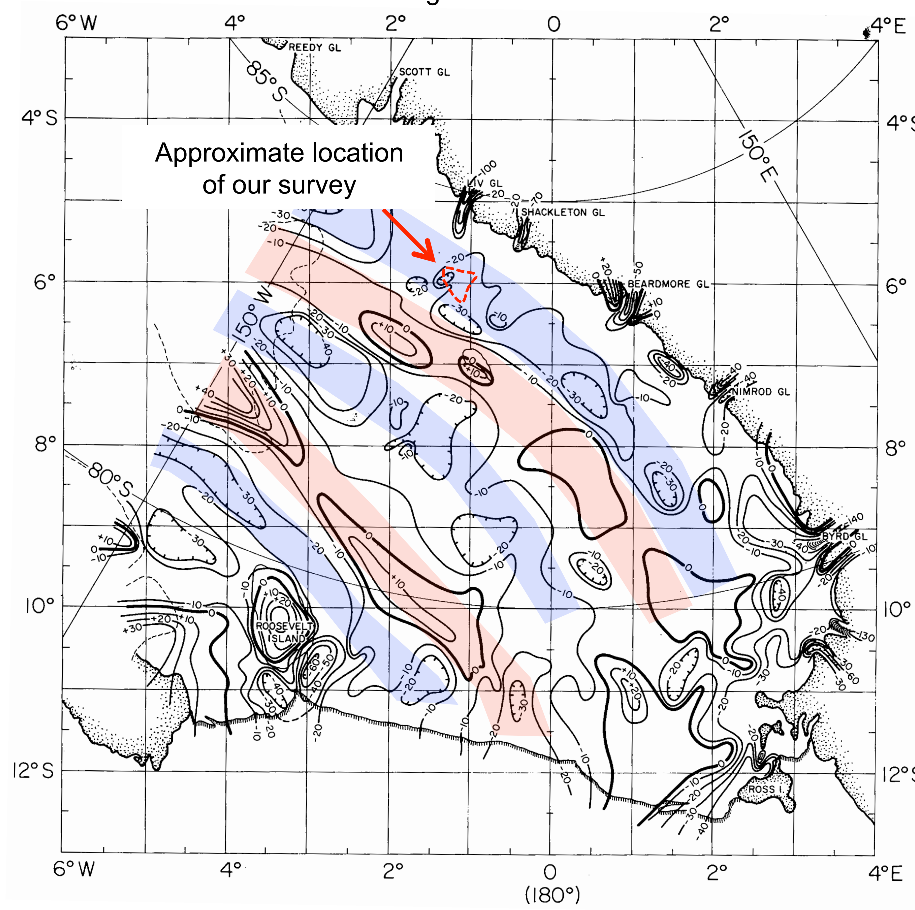
WISSARD grounding zone gravity survey

Free-air gravity anomaly map



Free-air gravity anomaly from Greischar et al. (1992)

~55-km grid over Ross Ice Shelf

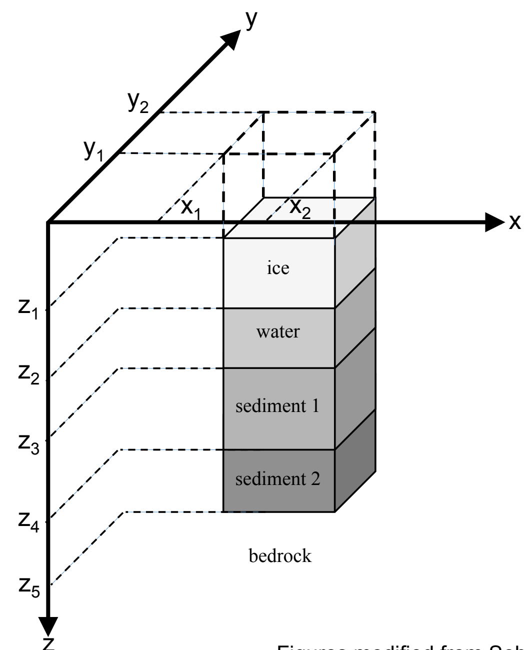


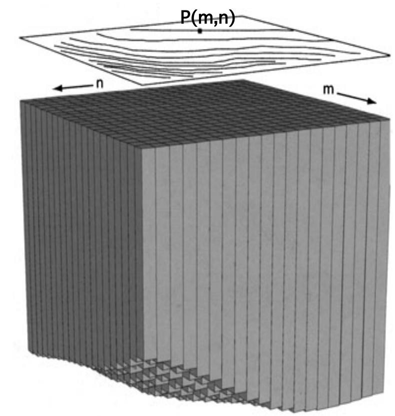
Gravity inversion

- 5-layered model, seismic survey detected a clear horizon within the sediment package
- Till layer not included since it is only up to 19 m, gravity anomaly from such a layer is 0.2 mGal at the most
  - ice : ρ = 890 kg/m^3
  - sea water: ρ = 1028 kg/m^3
  - upper sediment layer: ρ = 2013 kg/m^3 (40% porosity)
  - lower sediment layer: ρ = 2177 kg/m^3 (30% porosity)
  - bedrock: ρ = 2670 kg/m^3
- Gravity anomaly from each layer in a prism is calculated from the density contrast with the bedrock

- Inversion with Very Fast Simulated Annealing (VFSA)
  - minimize the misfit between the observed and modeled gravity anomalies
  - 1.5 by 1.5 km grid
  - 5000 samples that reasonably fit the observed gravity anomaly are used to derive the posterior probability density (PPD) of the model
  - mean of the PPD is presented as the preferred model, with 95% confidence interval as the uncertainty bounds
  - ice thickness from RES, thicknesses of water column and upper sediment layer from seismic data
  - grounding-line positions fixed with those of ASAID + RES

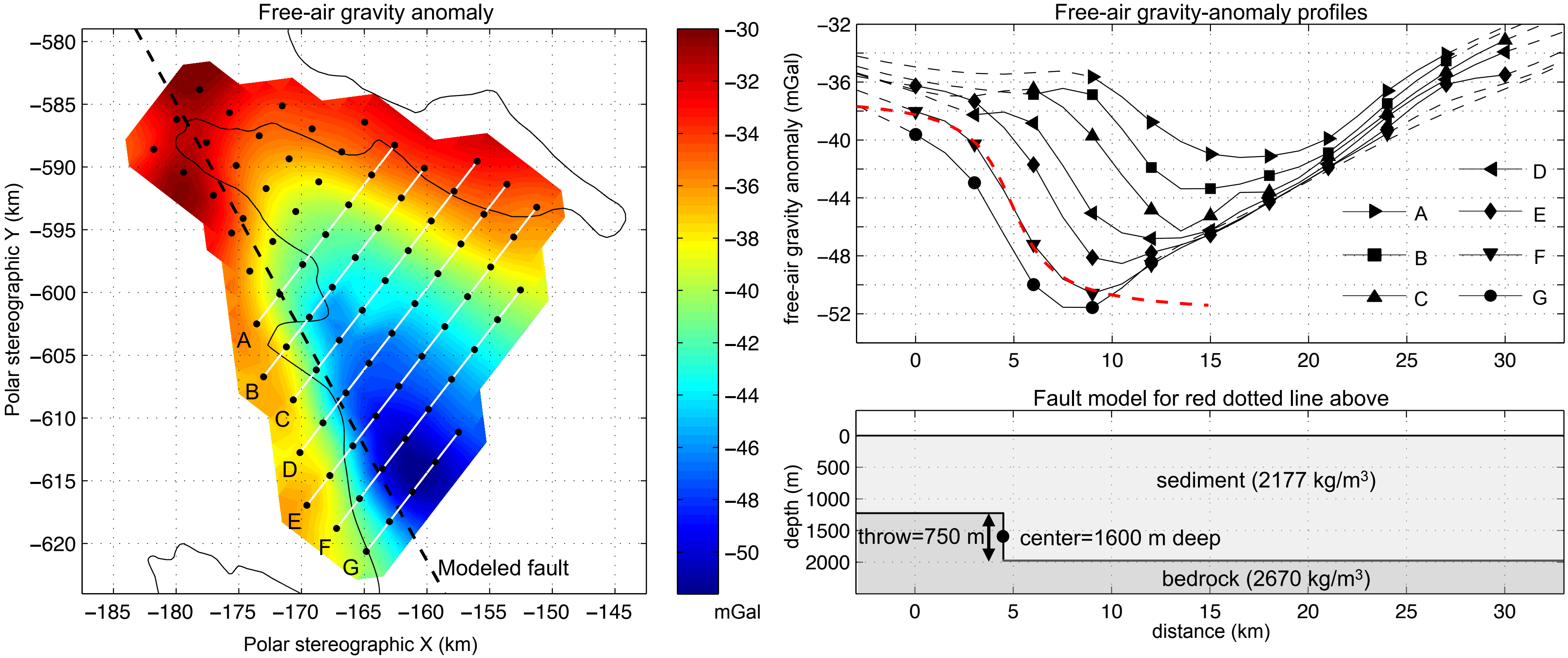
3-D gravity anomaly of rectangular prisms (Plouff, 1976)





Figures modified from Seber et al. (2001)

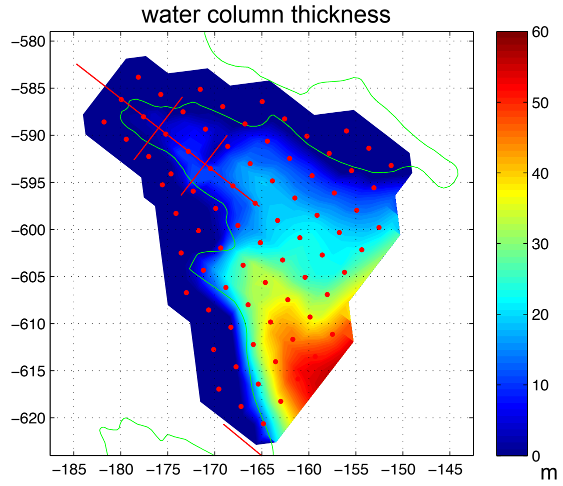
Gravity inversion

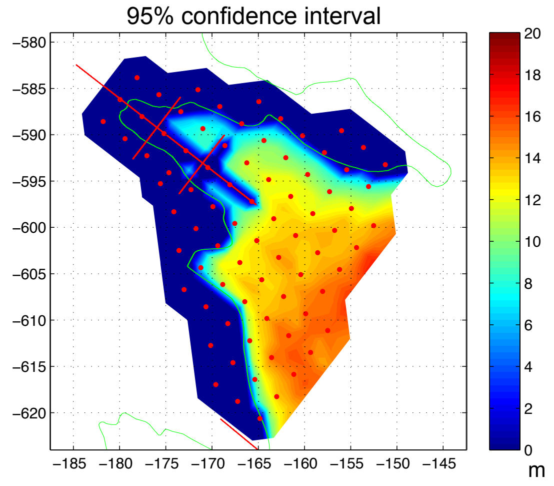


- Steep gravity gradients (2-3 mgal/km), indicative of a vertical or near-vertical fault
- Direction of the fault determined from maximum gravity gradients in 2-D profiles
- Steepest gravity gradient (profile F) can be modeled by a vertical fault with 750 m throw, with its center buried at 1600 m deep, assuming all the gravity anomaly is caused by the vertical fault

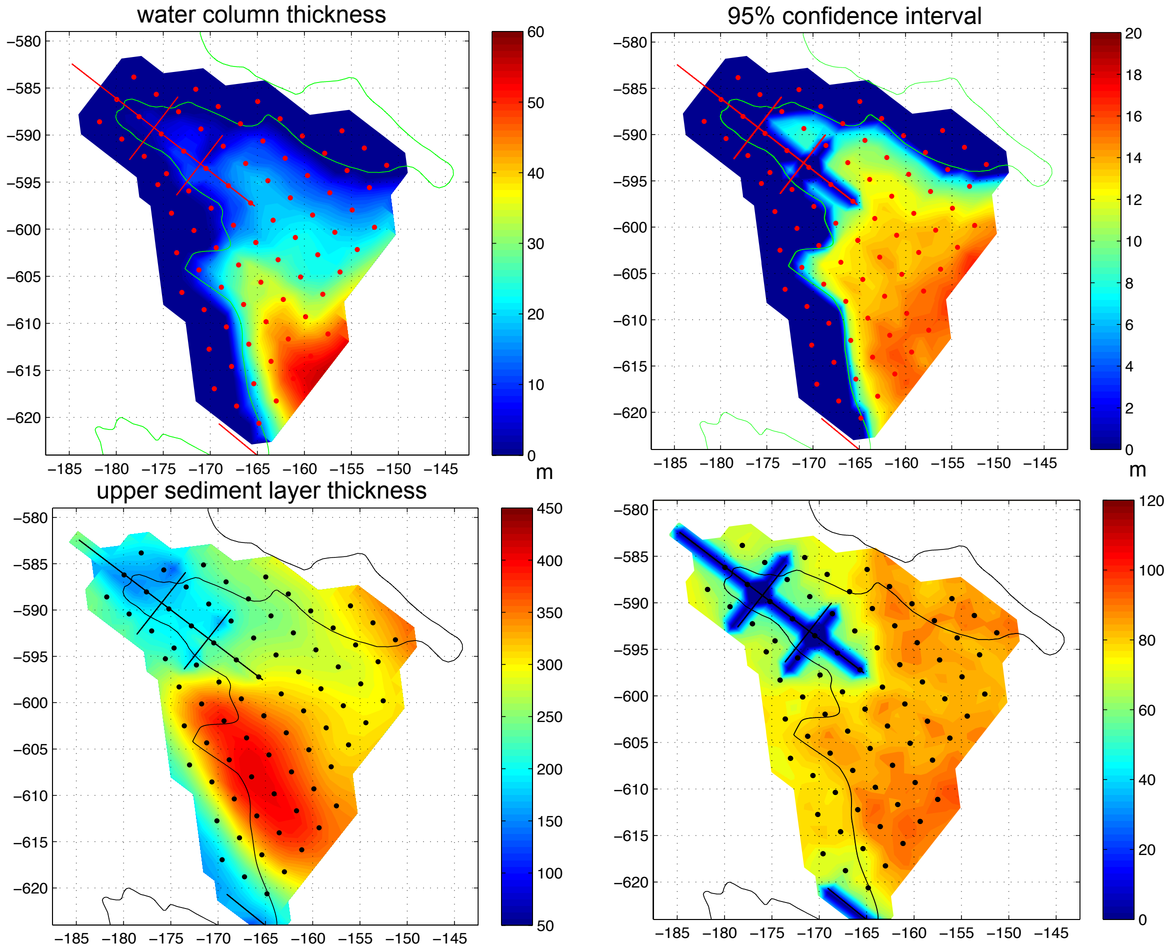
  ➔maximum depth of bedrock constrained to 2000 m in the inversion
- Similar structures observed elsewhere on Ross Ice Shelf and Siple Coast from previous gravity and seismic surveys

Gravity inversion - results

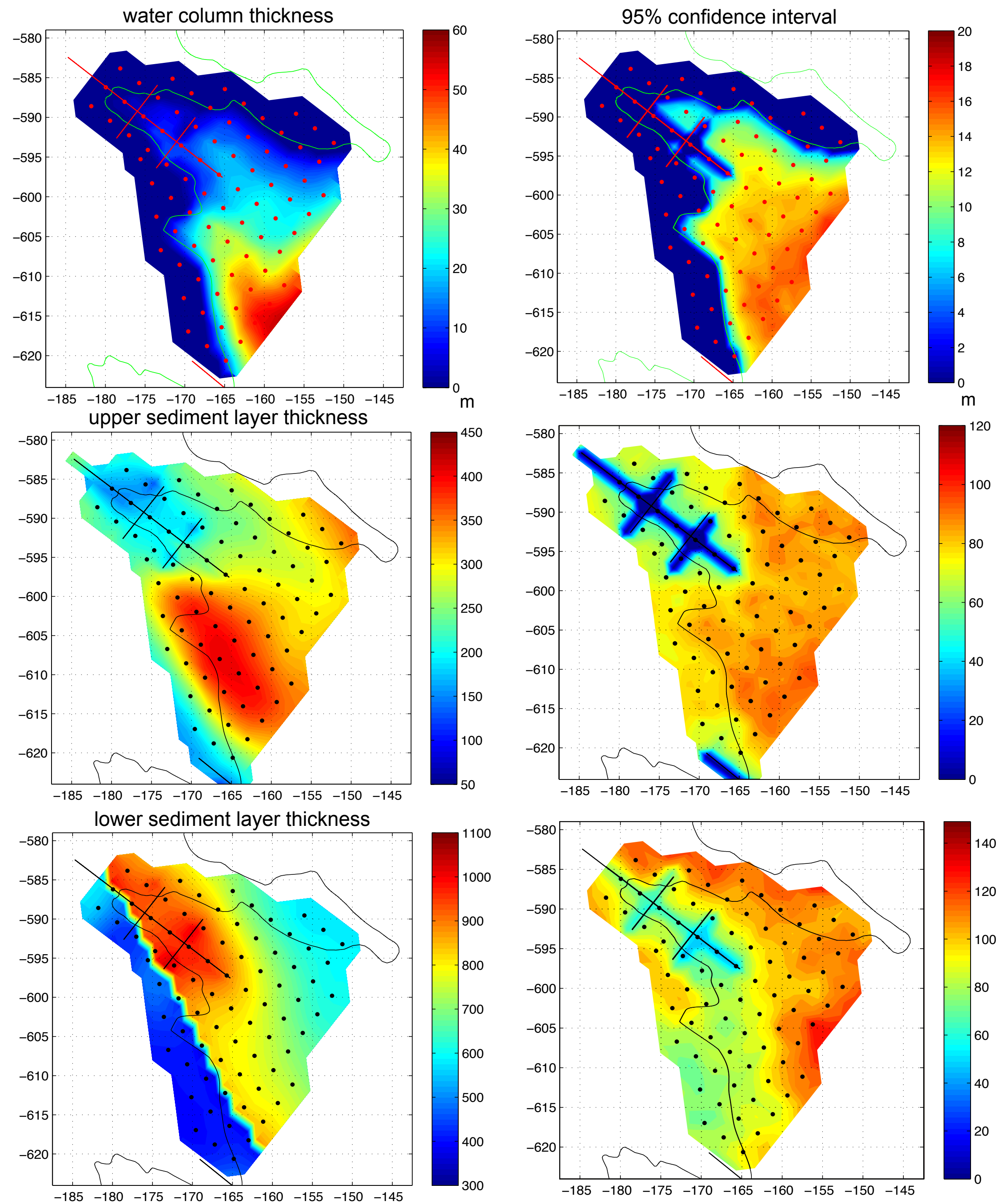




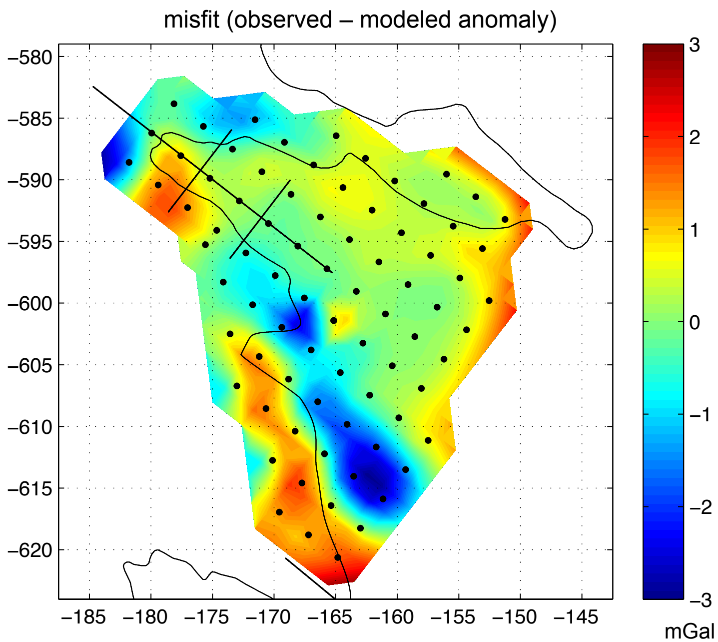
Gravity inversion - results

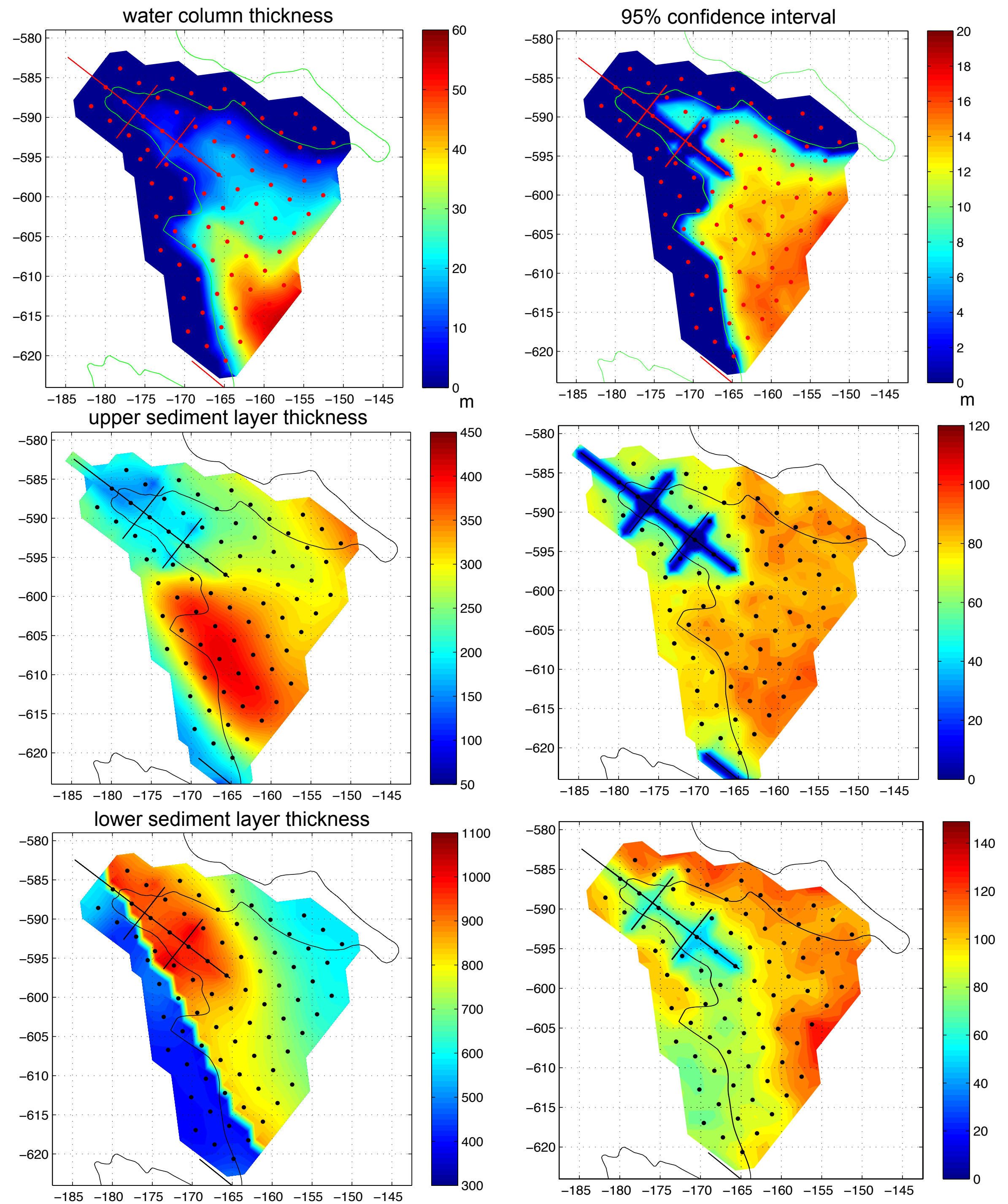


Gravity inversion - results

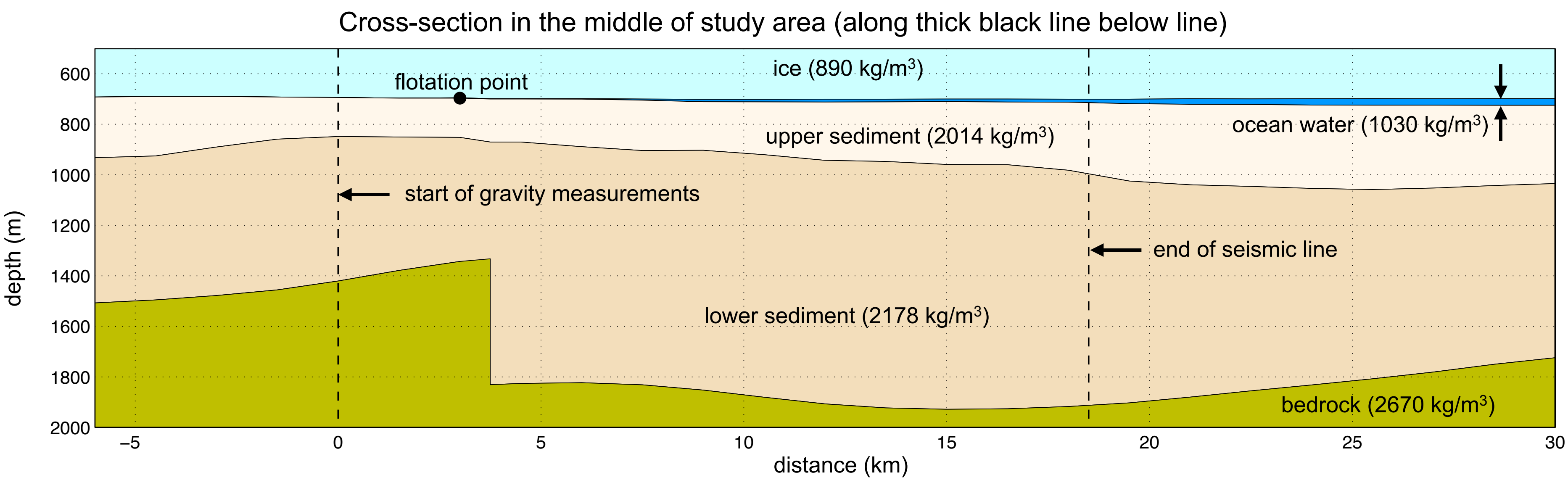


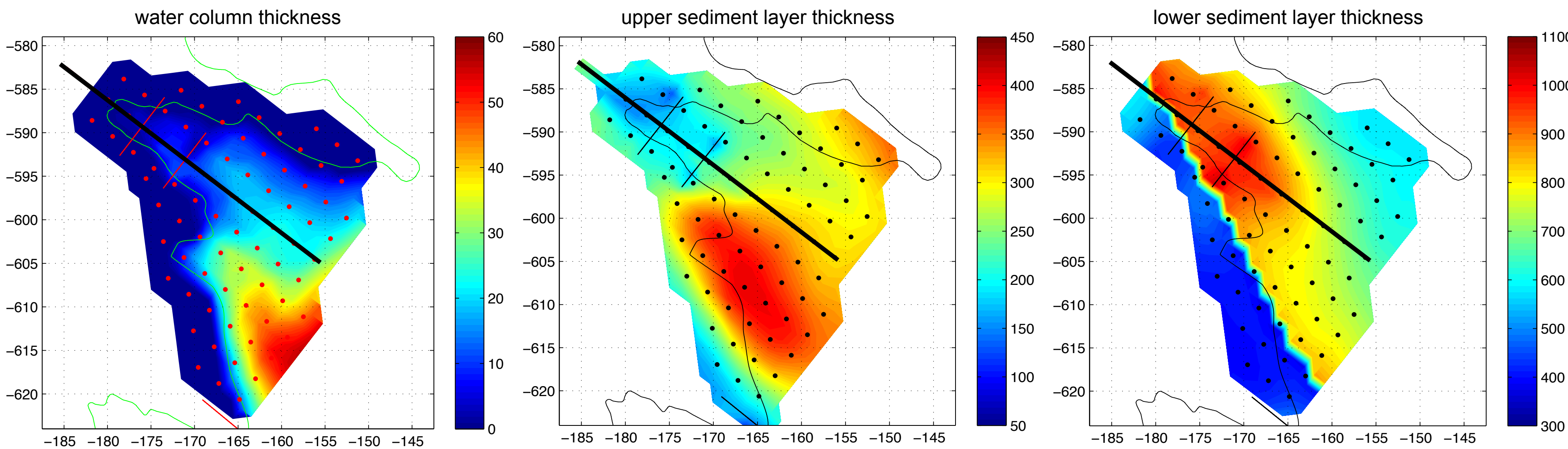
Gravity inversion - results



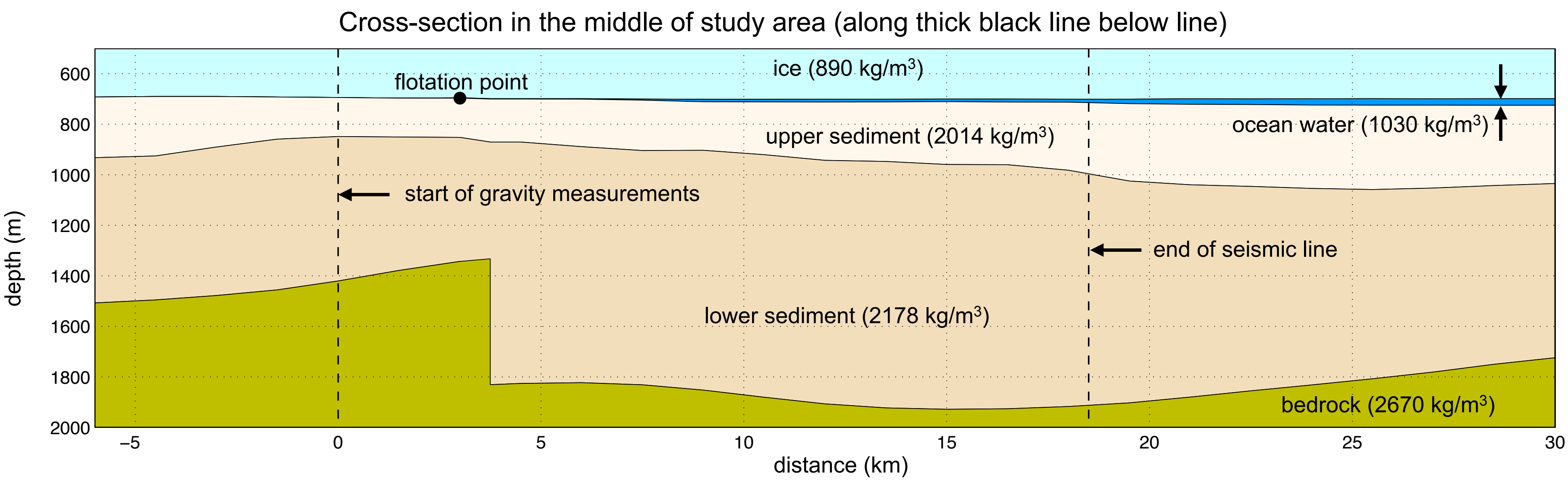


Gravity inversion - results





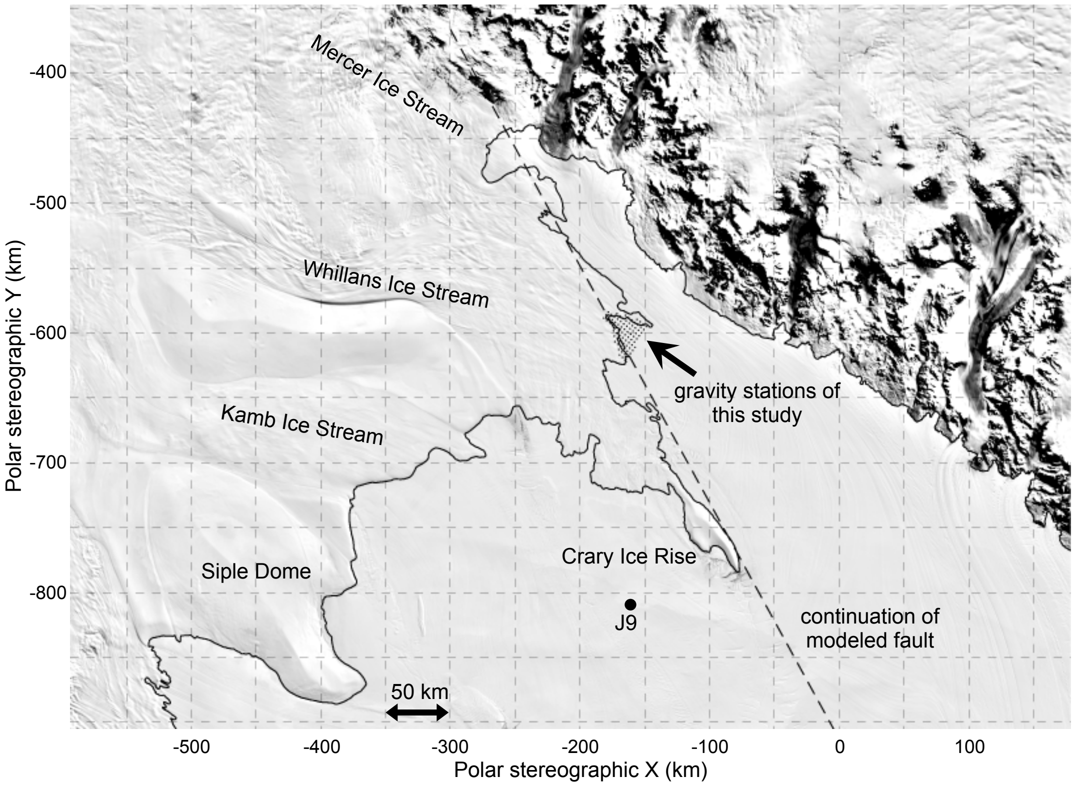
Gravity inversion – results and implications



- Thin water column (<50 m) with small slope (<0.01%) suggest well-mixed ocean
  - ➔ slower melting of ice shelf than thicker, stratified water column
  - ➔ slower sedimentation from dirty basal ice that is more distributed over a long distance from the grounding line

- Grounding line is subparallel to the transition of thinner to thicker upper sediment on one side of the embayment, may pinch out near the study area
- Fault is subparallel to the grounding line
  - ➔ Holocene-grounding line retreat may have stabilized near the present grounding line partly due to local topographic high
  - ➔ local sediment deposition leading to stabilizing feed-backs

Gravity inversion - results



RIGGS seismic refraction survey (Robertson et al., 1982)

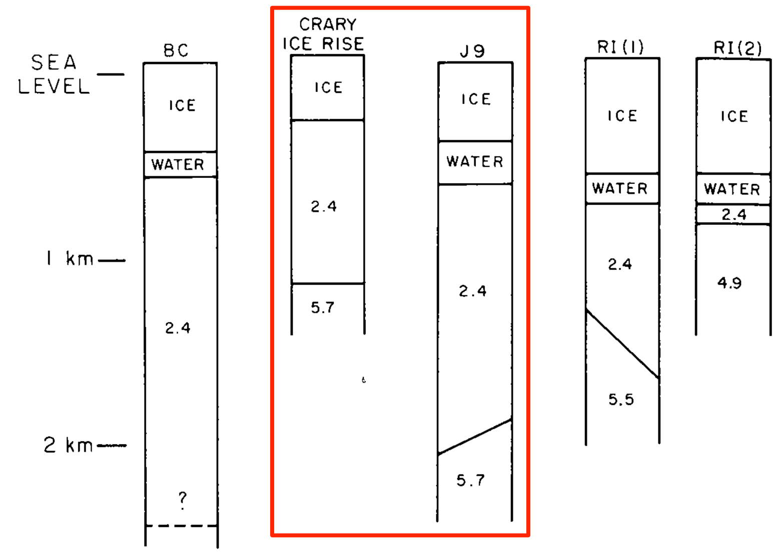


Figure 140.5. Seismic sections at station BC, Crary Ice Rise, station J9, and station RI; RI(1) is the preferred interpretation and RI(2) is an alternate interpretation. Numbers are seismic velocities in km/sec.

Summary

- Water column is thin under the ice shelf with low slope, suggesting tidally well-mixed ocean water, leading to slower basal melting than in thick water column
- Upper sediment layer is thinnest near the modern grounding line, modeled fault in bedrock is also subparellel to a part of the modern grounding line, current grounding line is controlled in part due to the subglacial geology
- Modeled fault lines up with one side of Crary Ice Rise, origin of CIR is possibly tectonic
- Subglacial geology is important in formation of the Siple Coast
- Study area is relatively small, more multi-technique geophysical surveys desired

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