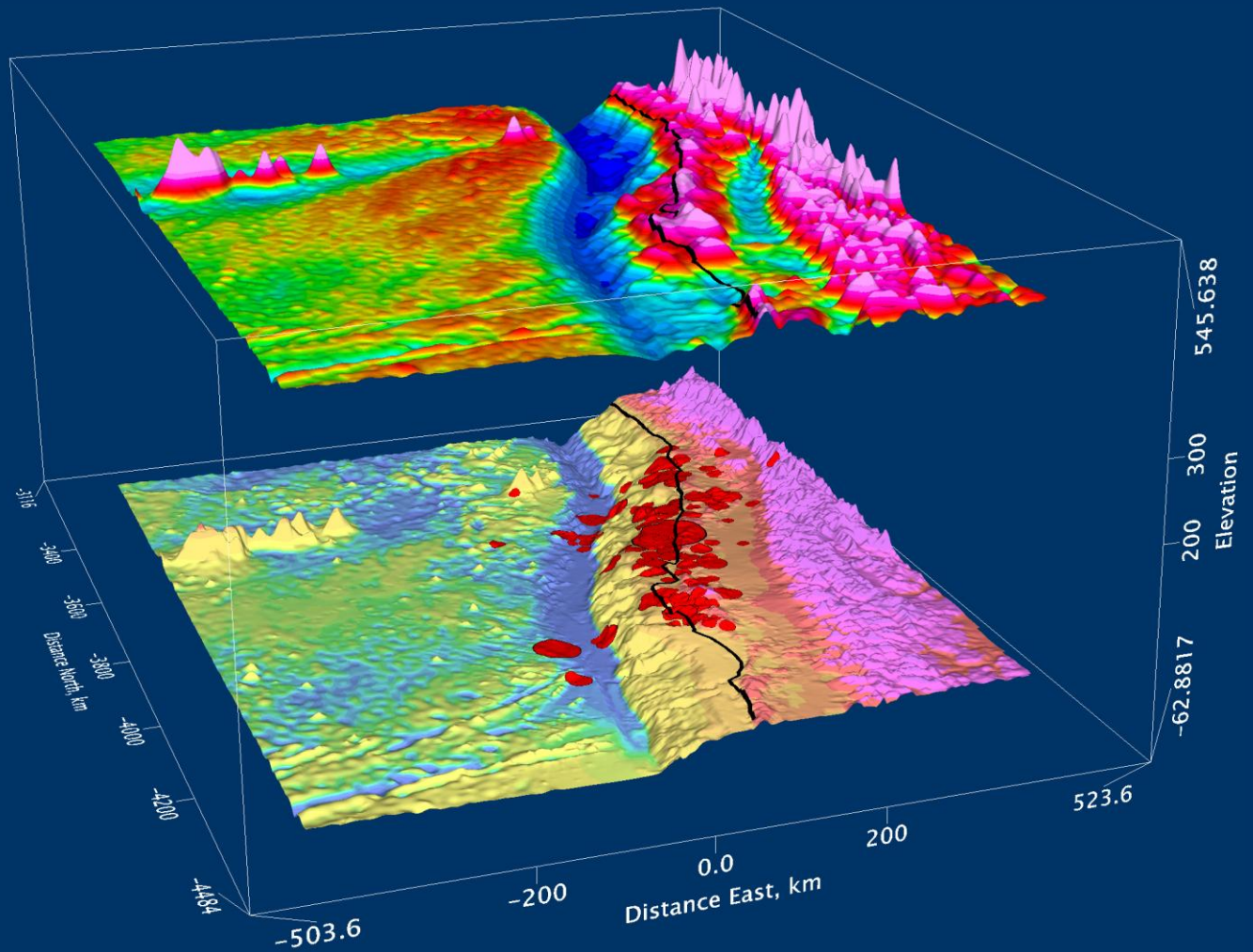
Forearc geology from free-air gravity—implications for co-seismic slip during the 2010, 1985, and 1960 Chile earthquakes

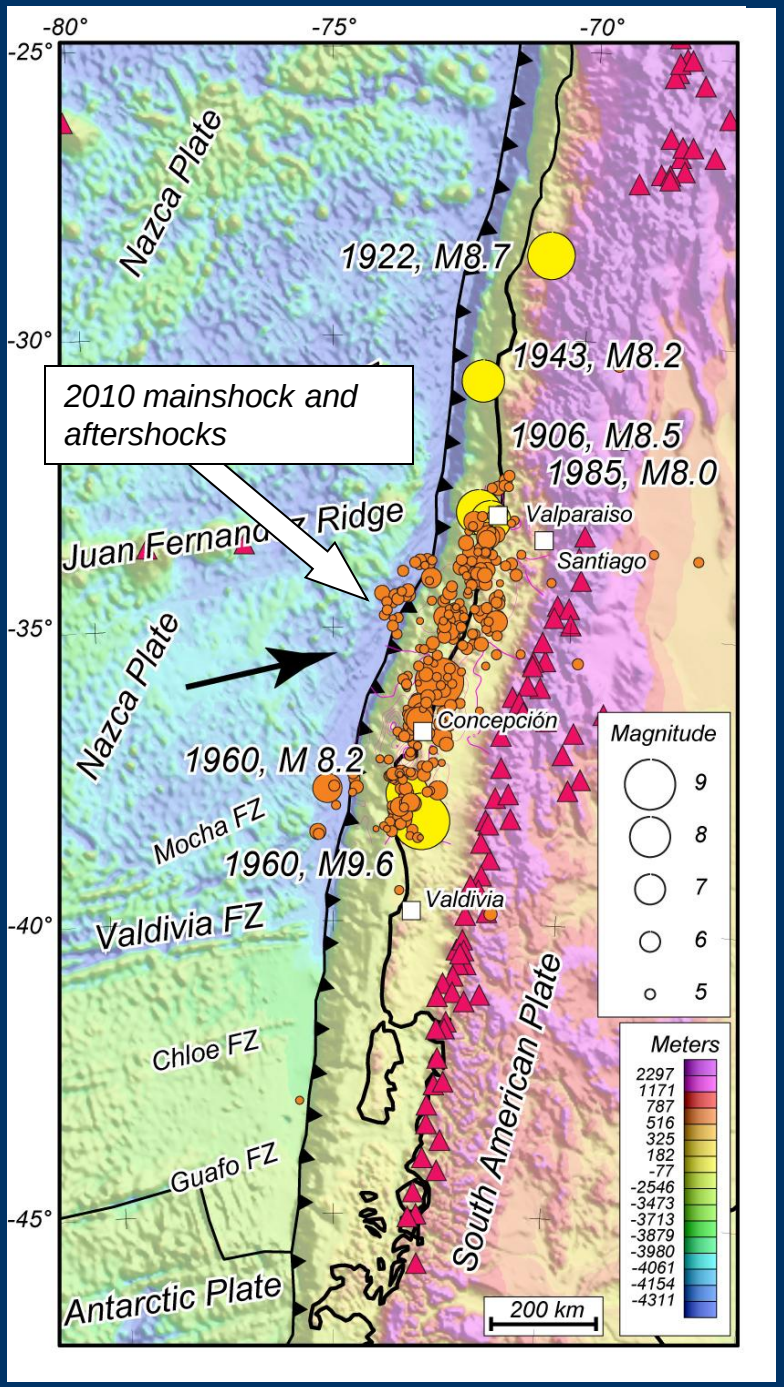
Rick Blakely, Ray Wells, and Katie Keranen



Greatest slip during historic great earthquakes favors subduction zones with key geologic factors:

- ✓ *High sediment influx into the trench*
  (e.g., Ruff, 1989; Scholl et al., in prep.)
- ✓ *Large basins within well-developed forearc terrace*
  (Wells et al., 2003; Song and Simons, 2003)
- ✓ *Presence of accretionary prisms*
  (von Huene and Scholl, 1991)

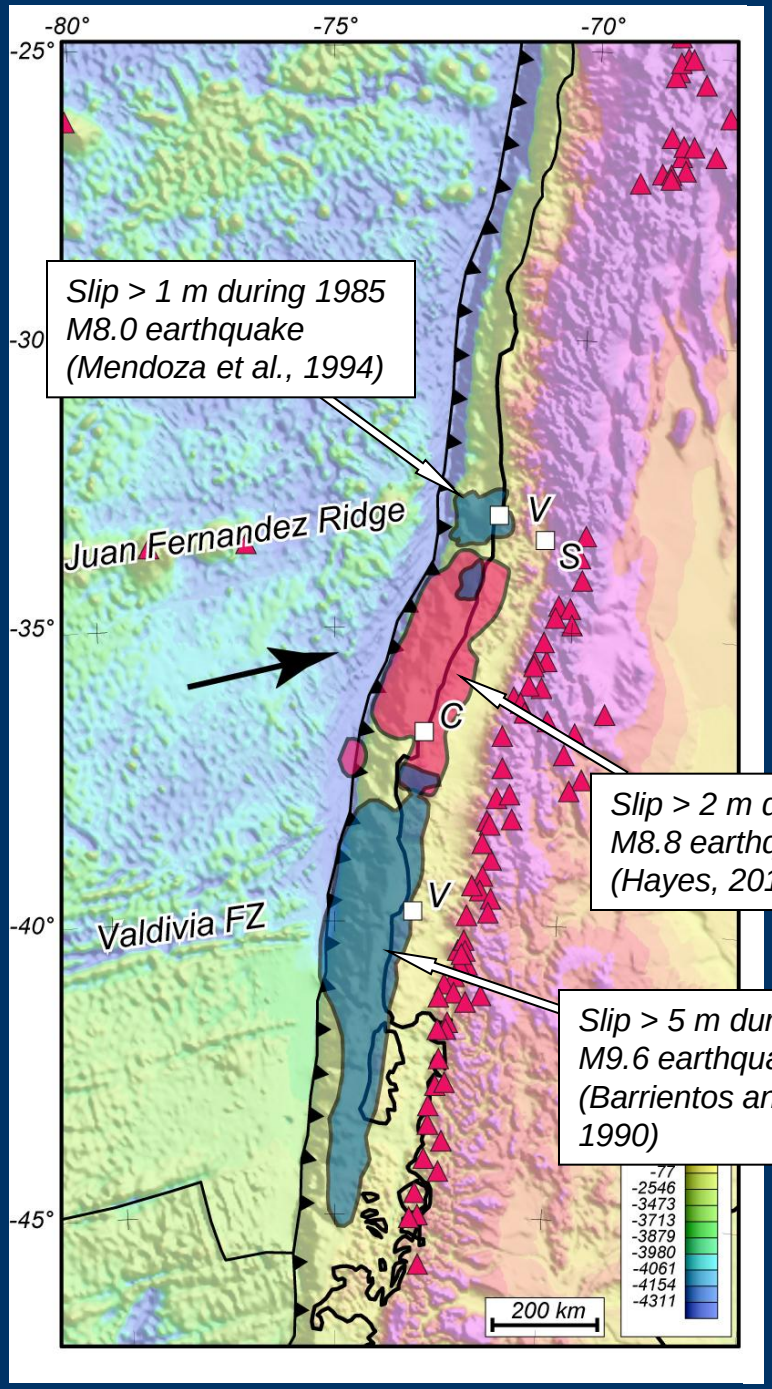
Satellite free-air gravity provides a consistent measure of several of these geologic factors.



The 2010 rupture occurred within a trench segment bounded by the Juan Fernandez ridge and the Valdivia fracture zone.

The northern limit of rupture corresponds with the northern limits of arc volcanism and a pronounced onshore forearc basin.

The rupture filled the gap between the 1960 and 1985 great earthquakes.



Greatest slip during the 2010 rupture fits snugly between slip that occurred in 1960 and 1985.

Although the magnitude of slip was highly variable, the three earthquakes together affected the entire region, from the Juan Fernandez ridge to the triple junction.

Megathrust earthquakes favor trenches with high sediment influx

(Ruff, 1989; Scholl et al., in prep.)

The offset between the trench axis and gravity minimum is affected by the amount of sediment in the trench

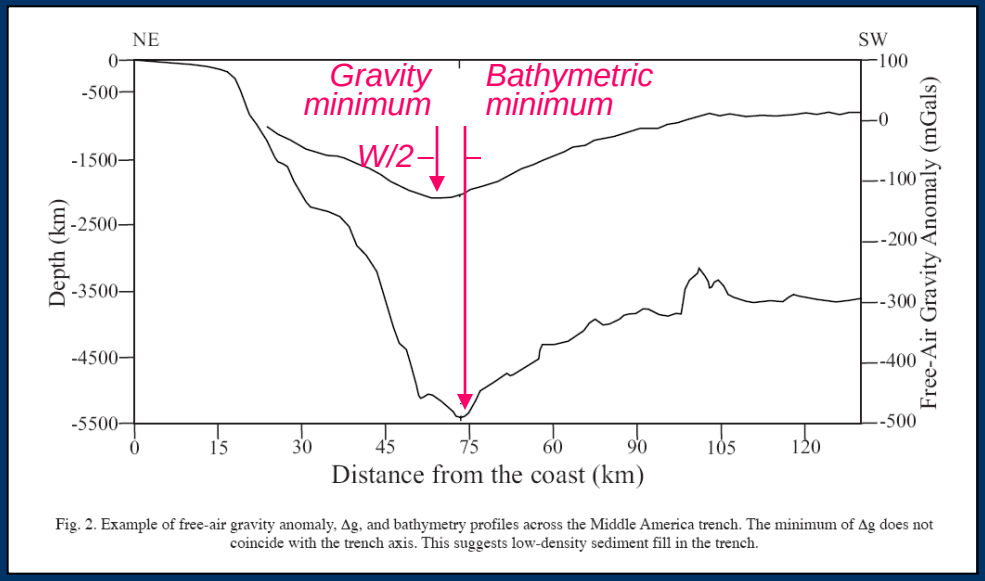


Fig. 2. Example of free-air gravity anomaly, Δg, and bathymetry profiles across the Middle America trench. The minimum of Δg does not coincide with the trench axis. This suggests low-density sediment fill in the trench.

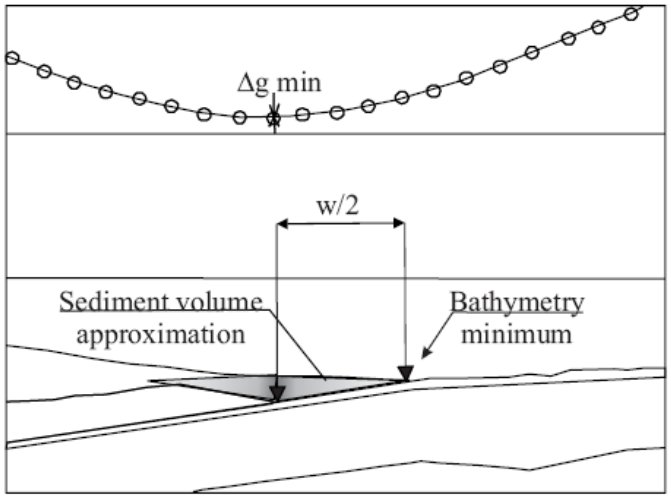
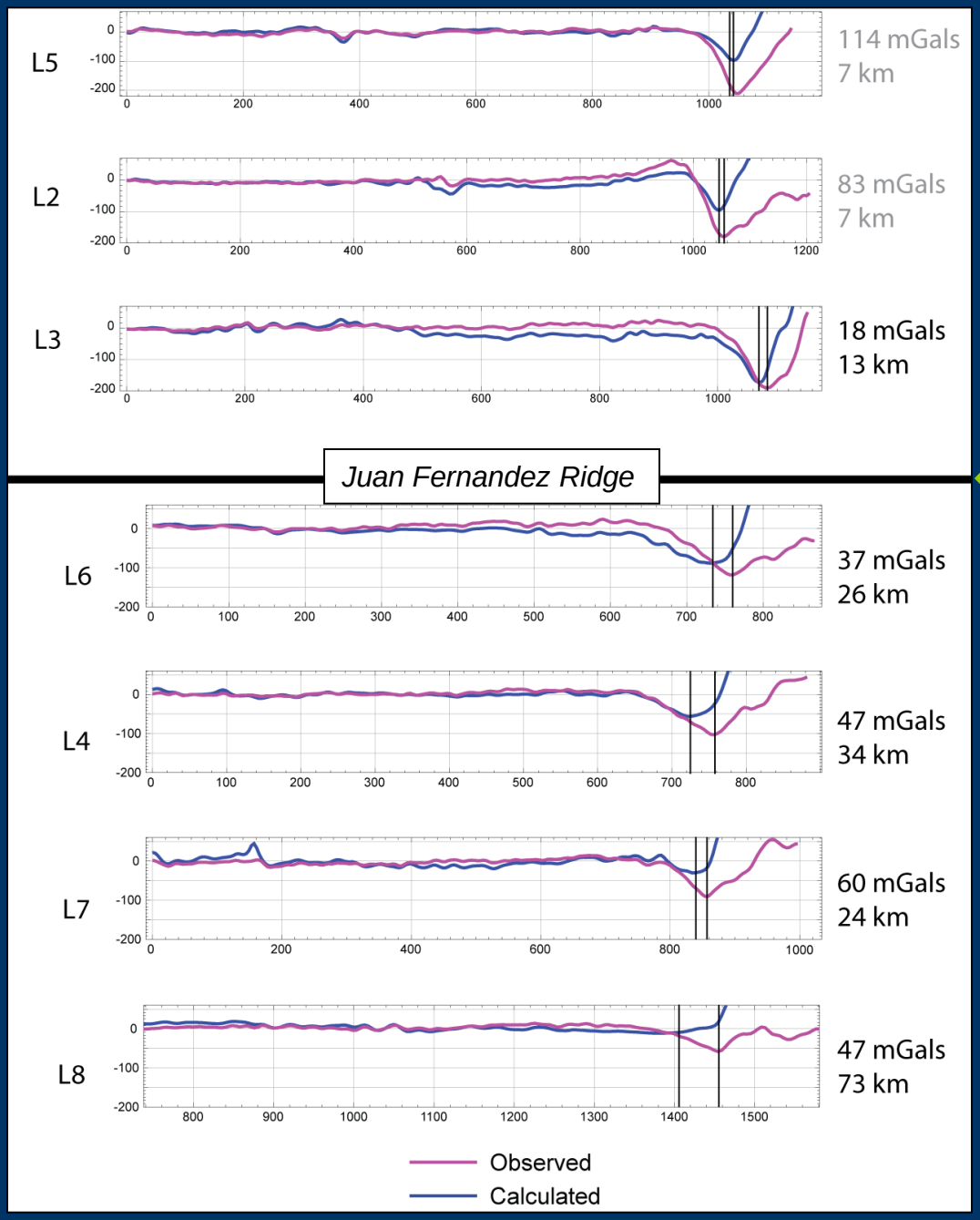


Fig. 6. Geometric approximation of the specific sediment fill volume. Grey areas representing sediment fill are determined using the difference between the locations of gravimetrical and bathymetric minima and the modeled ocean floor surface. W/2 is the half width of the sedimentary fill.

Manea et al., 2003 – Middle America Trench

Offsets between gravity minimum and trench axis increase sharply south of the Juan Fernandez Ridge, where MCS data show an increase in sediment thickness.



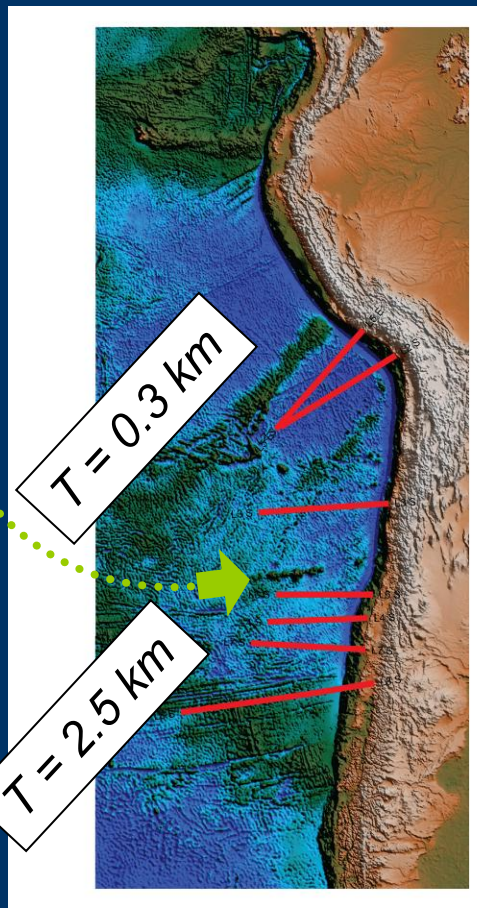
N

MCS = 0.3 km

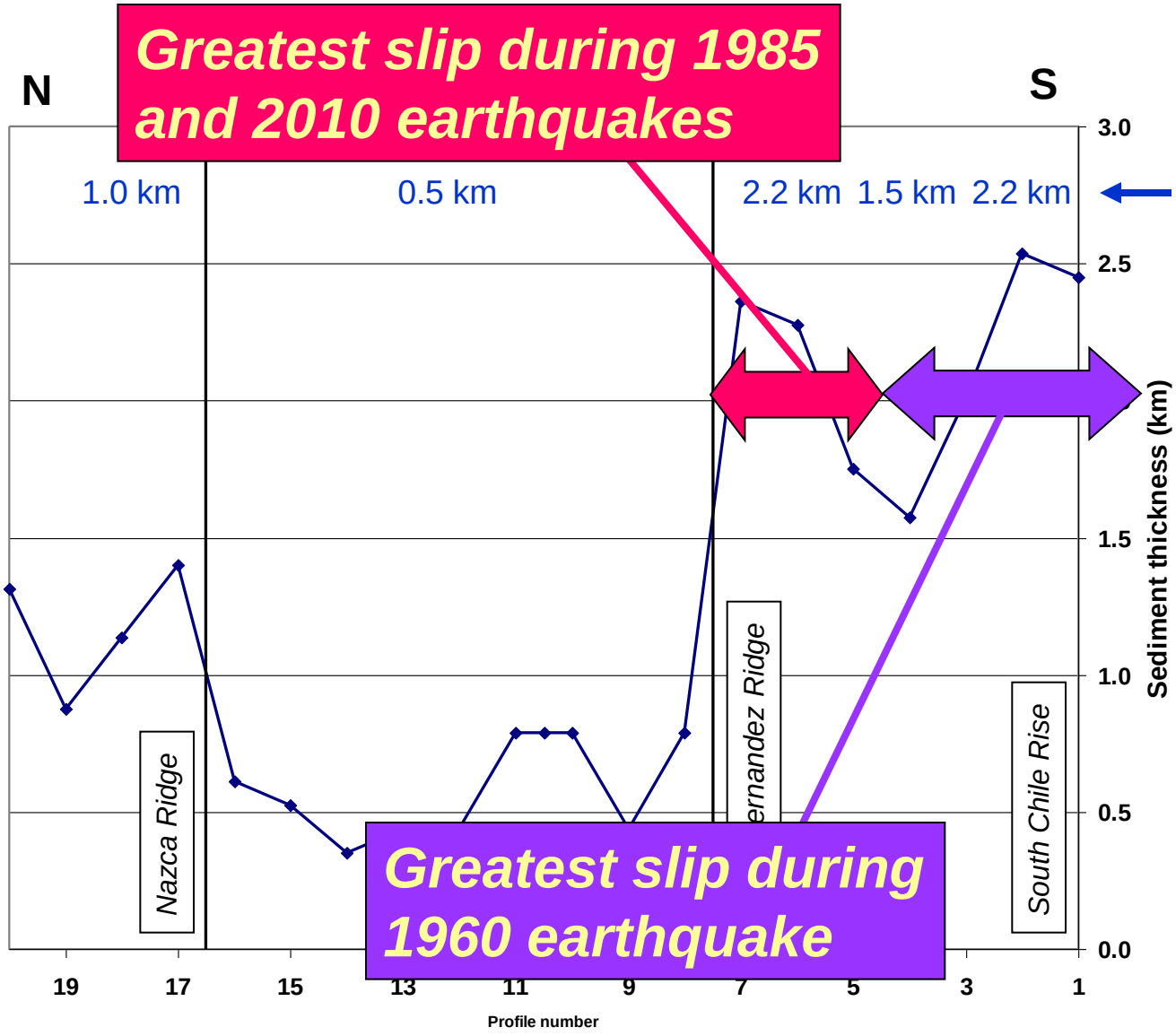
MCS = 2.5 km

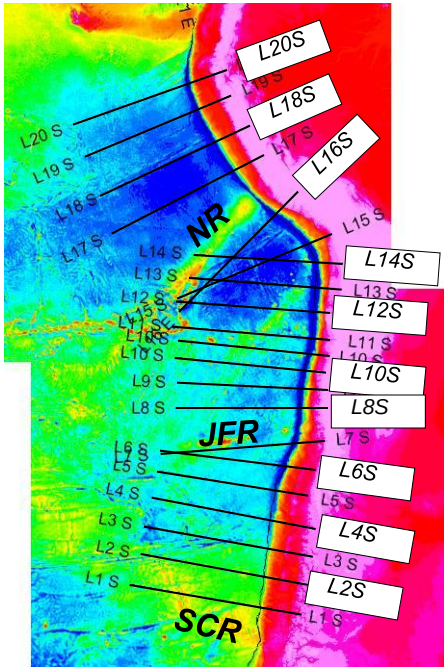
S

JFR



Greatest slip during the 1960, 1985, and 2010 earthquakes occurred where thickest trench sediments are predicted

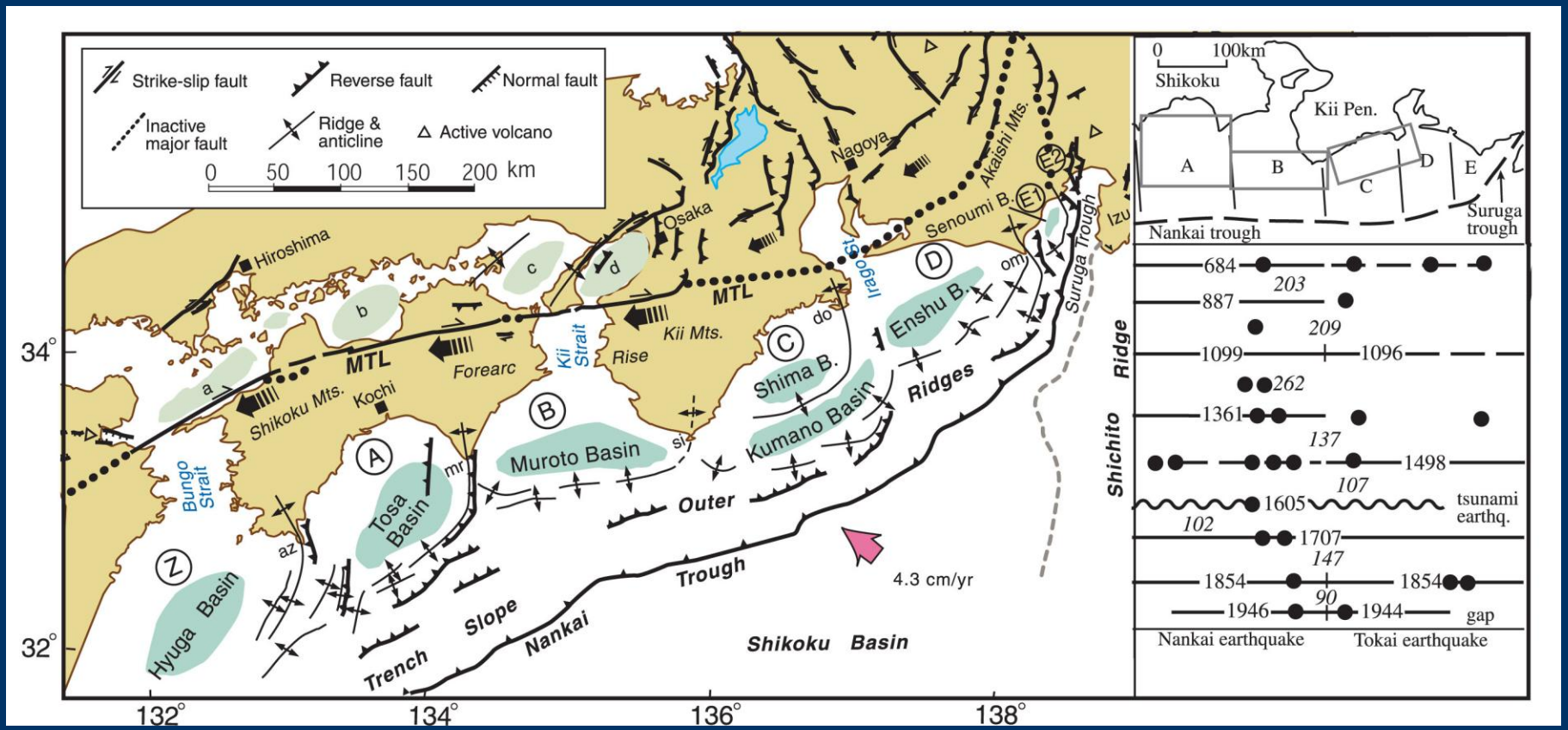




Megathrust earthquakes are associcated with a well-developed forearc terrace and large sedimentary basins

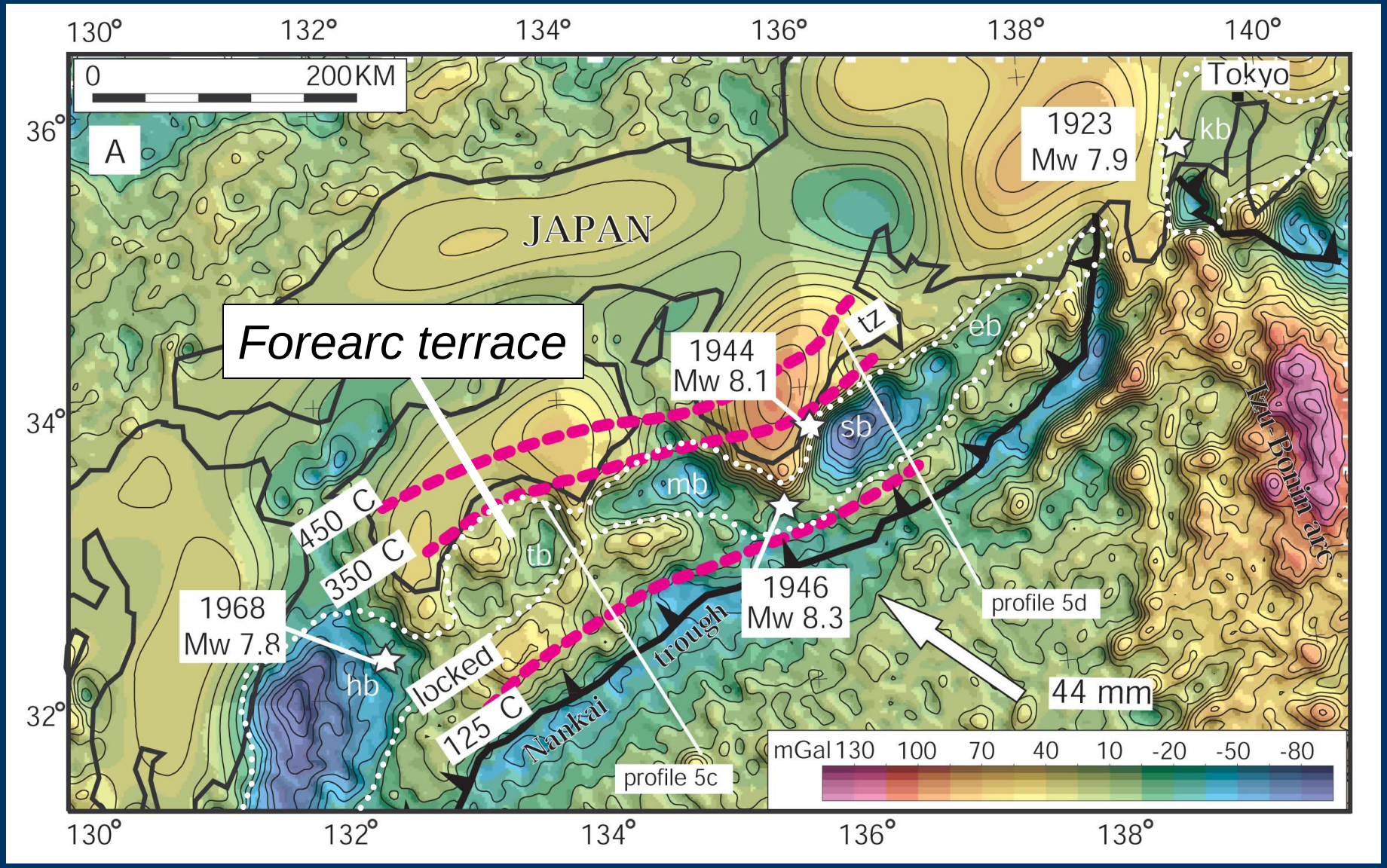
(Wells et al., 2003; Song and Simons, 2003)

Nankai Trough, Japan



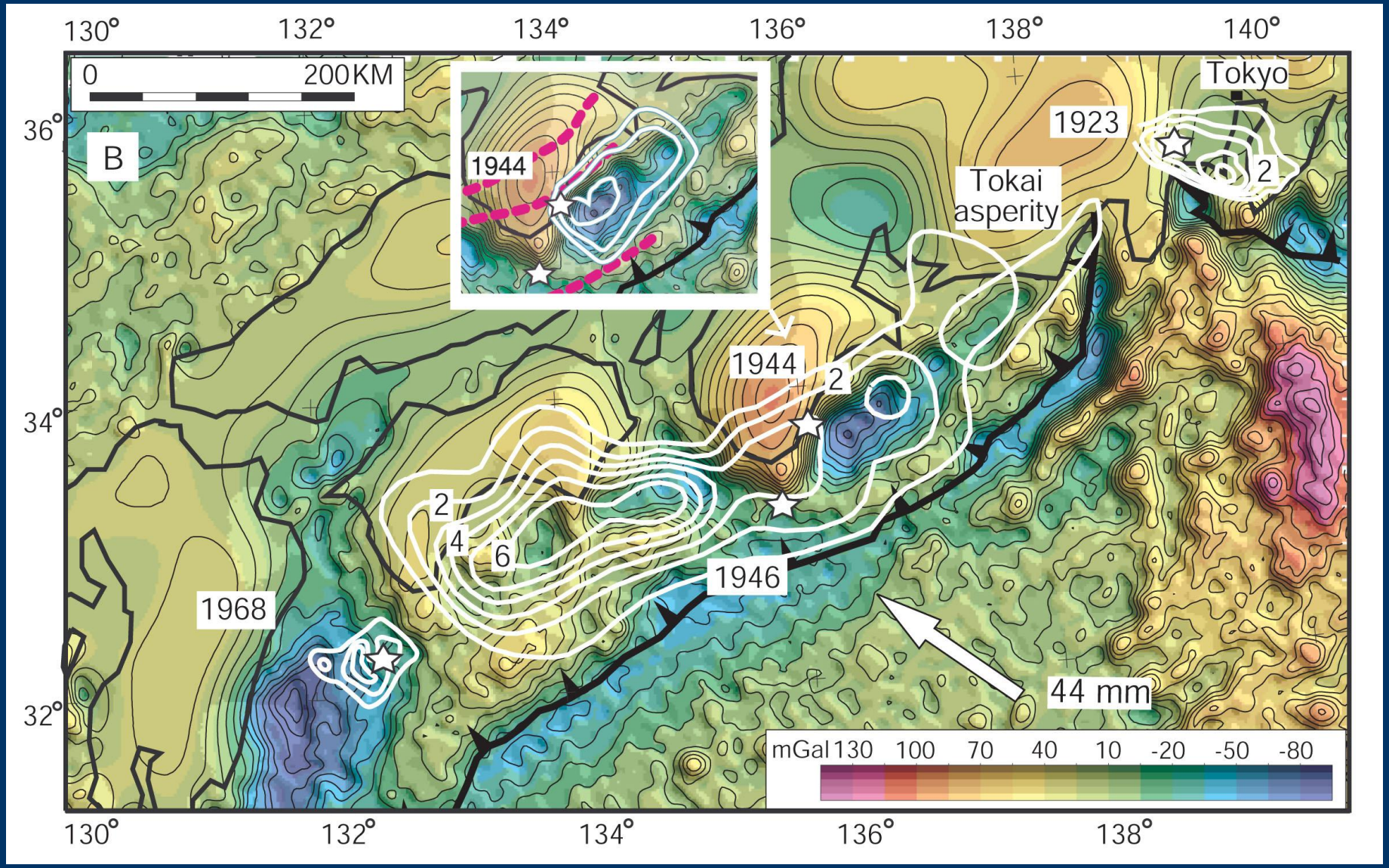
- *Great earthquakes centered on forearc basins (Mogi, 1969; Ando, 1975)*
- *1300 year history shows repeated rupture of similar source zones (Ando, 1975; Sugiyama, 1994; Ishibashi and Satake, 1998).*

Nankai Trough, SW Japan - Free-air Gravity



From Wells et al. (2003); thermal contours from Hyndman and Wang (1995)

Coseismic slip from geodetic and seismic inversions

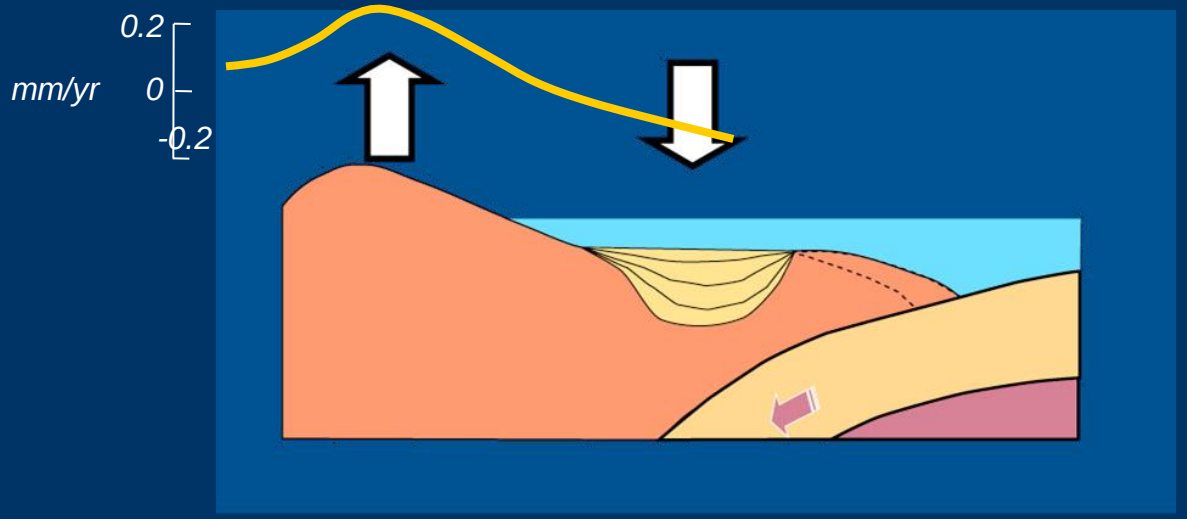


Slip contours in m from Sagiya and Thatcher (1999), Sagiya (1999), Wald and Sommerville (1995), Yagi et al (1998), Kikuchi and Yamanaka (2001).

Why does slip correlate with gravity lows?

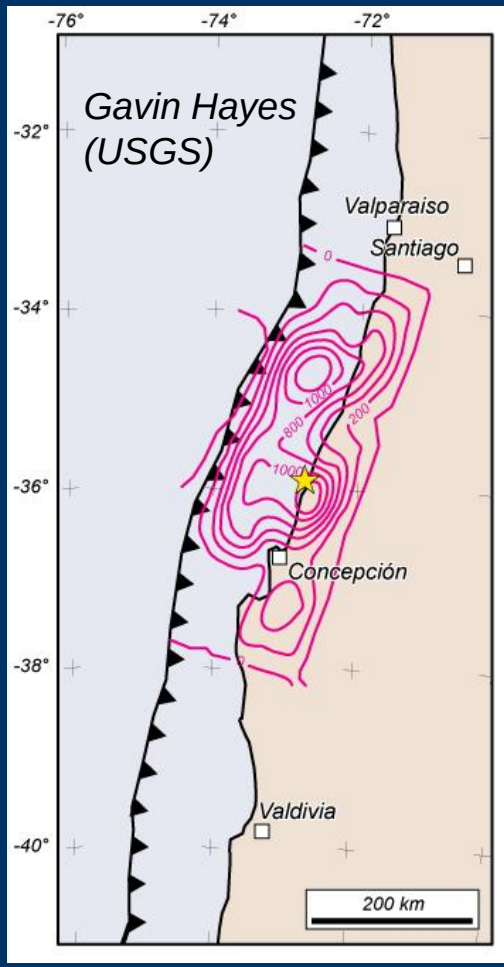
Basins could form if some of the interseismic subsidence is not fully recovered during earthquakes (some of the deformation is permanent).

Upper-plate geology determines specific regions favorable for basin formation.

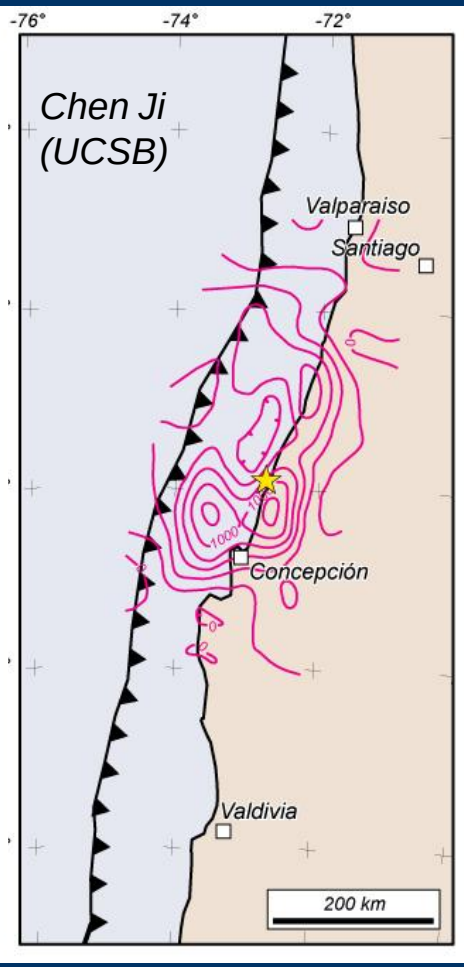


For the 2010 earthquake, at least 8 finite-fault models have been presented thus far, most showing 2 asperities. Asperities are offshore in solutions that use onshsore data (e.g., InSAR).

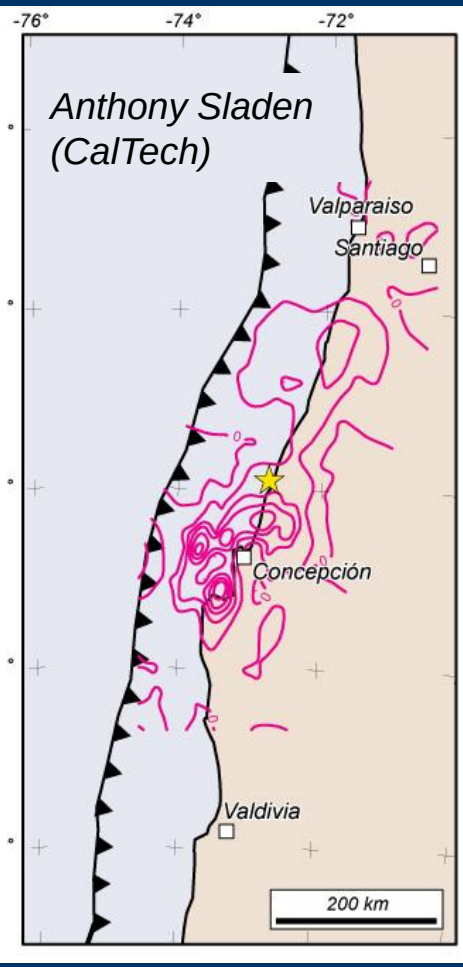
From teleseismic data



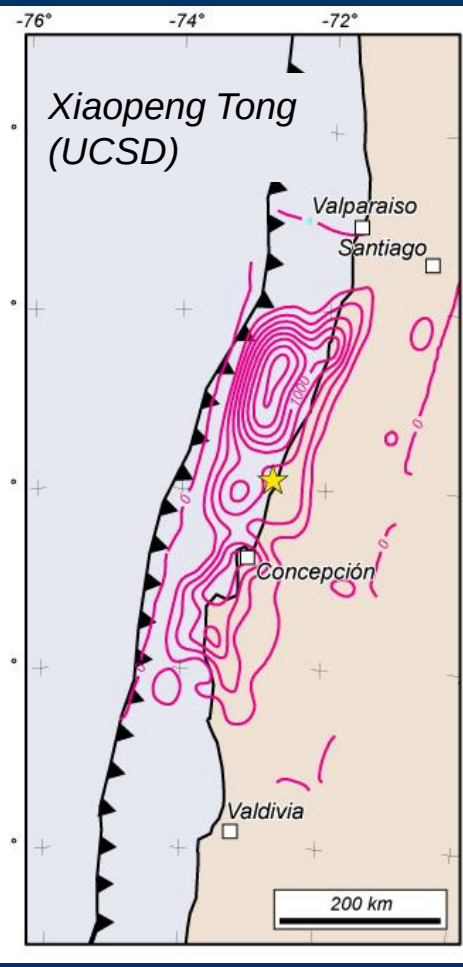
From teleseismic data



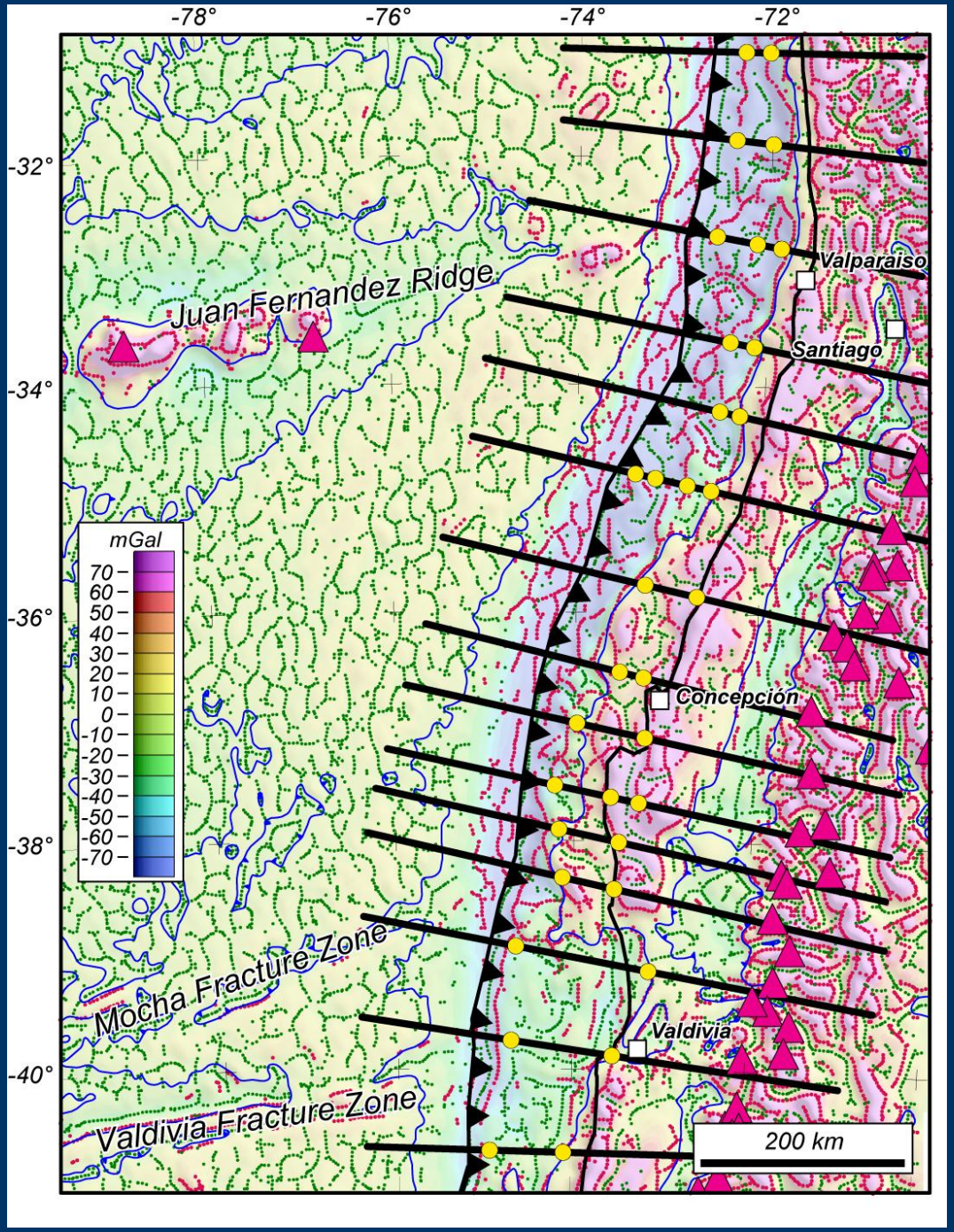
From teleseismic and GPS data



From InSAR and GPS data



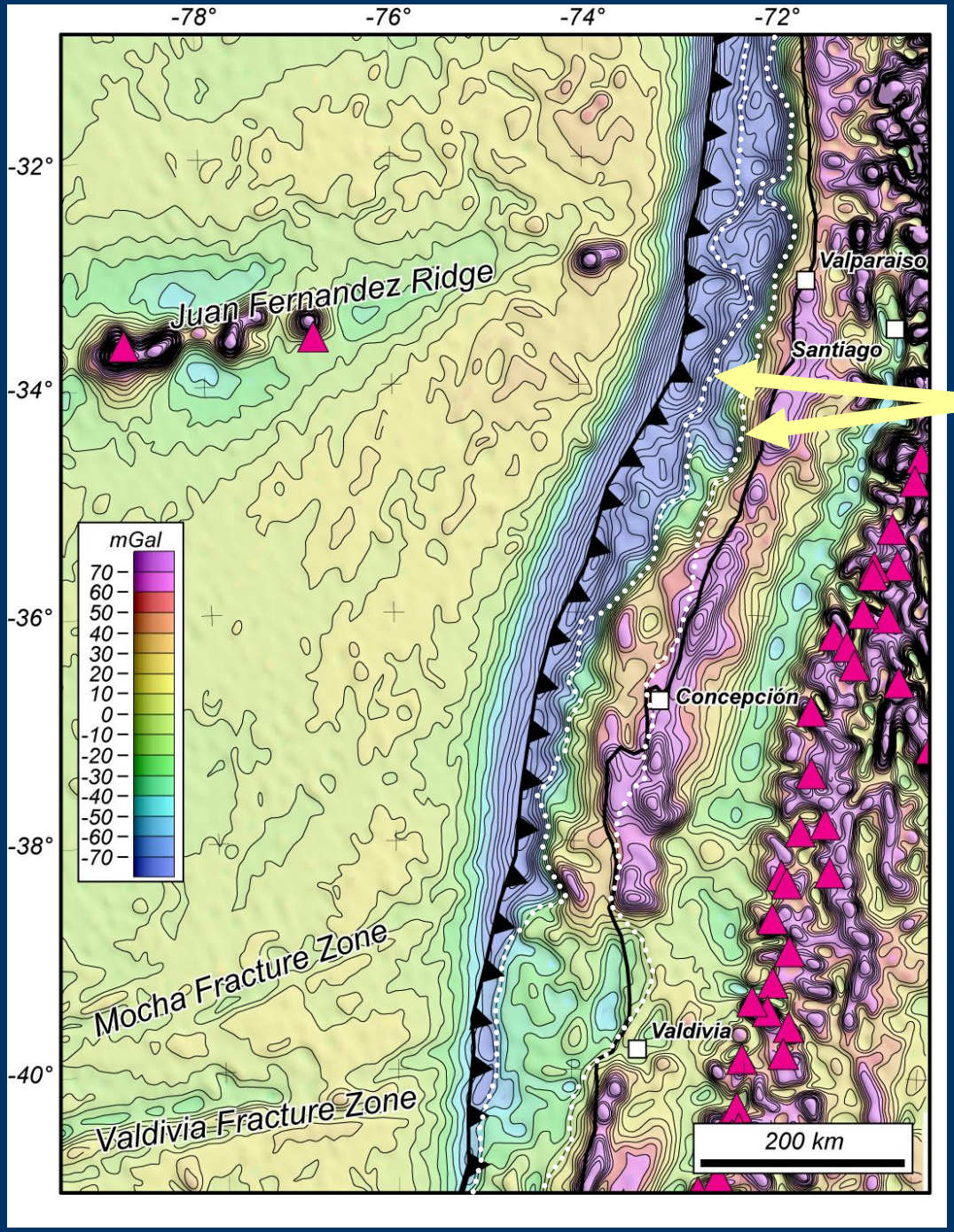
Contours = slip at 200 cm intervals; star = epicenter



The following slides show an interpretation of forearc geology based on free-air gravity anomalies.

We used horizontal gradients (red dots), gravity minima (green dots), and individual profiles to assist with the interpretation.

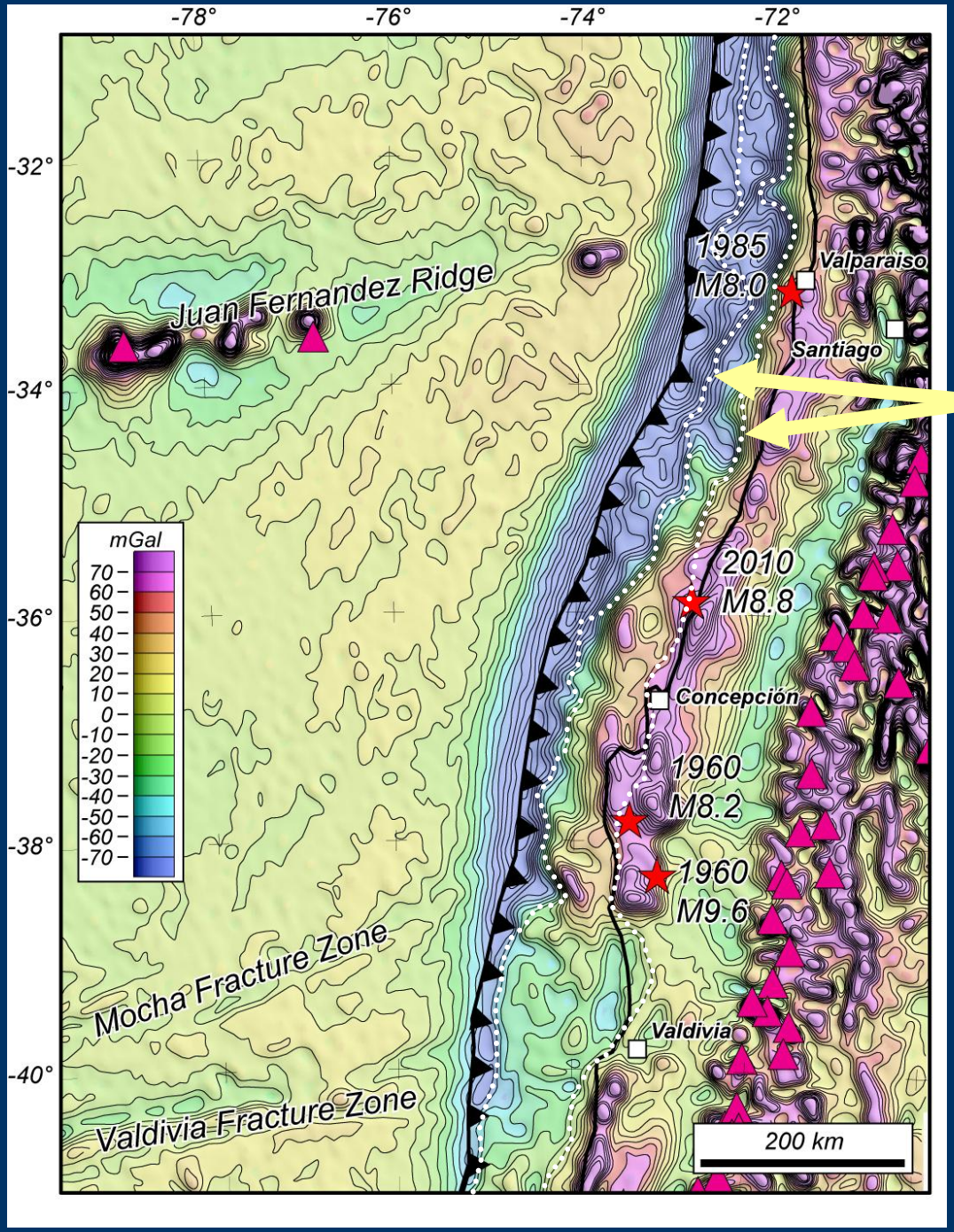
Two examples…



The gravitational expression of the Chile margin is dominated by trench and coast-range anomalies.

Two strong trench-parallel gradients lie between these anomalies.

The inboard and outboard gradients together define a terrace-like feature that extends the length of the margin.



The gravitational expression of the Chile margin is dominated by trench and coast-range anomalies.

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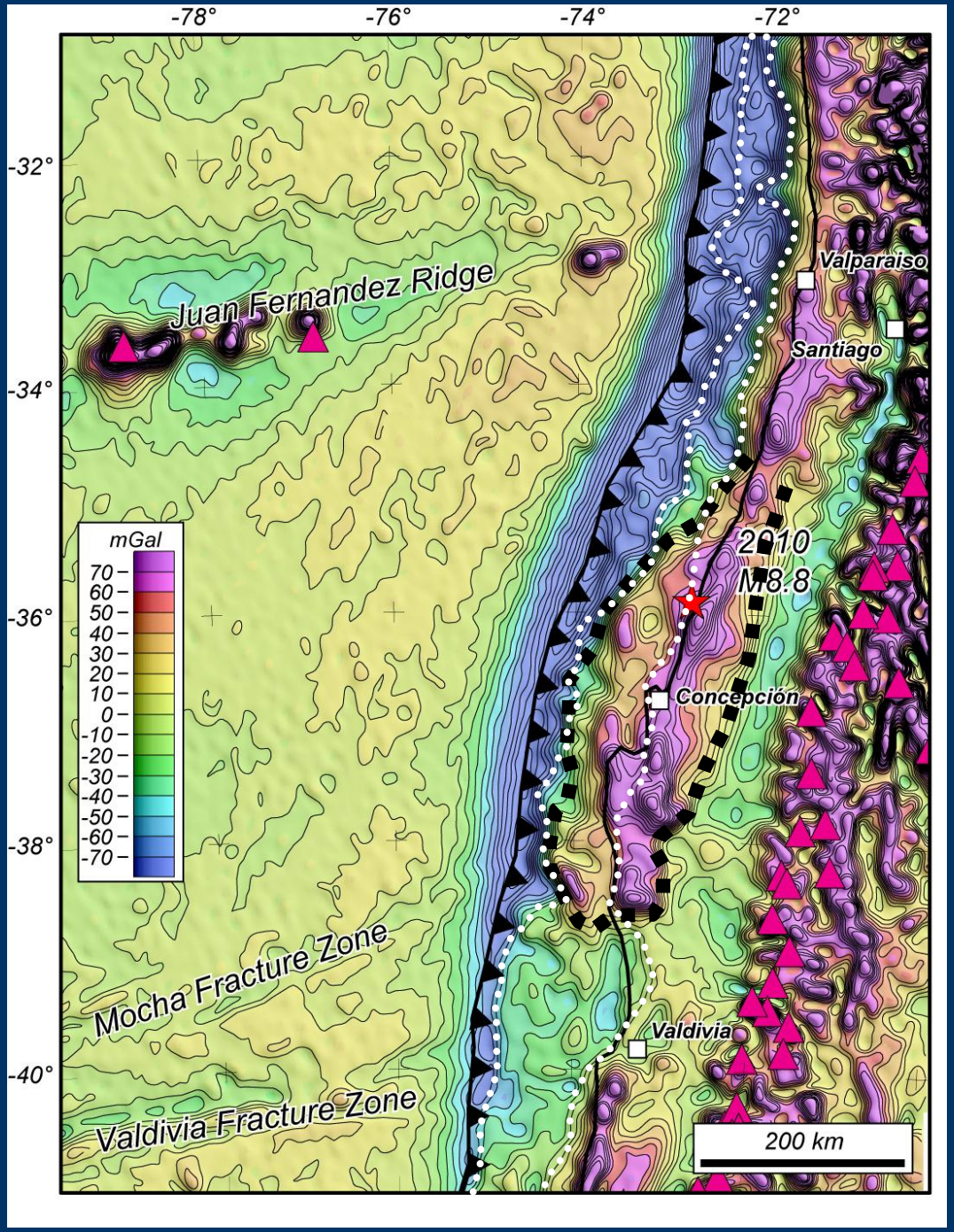
The inboard and outboard gradients together define a terrace-like feature that extends the length of the margin.

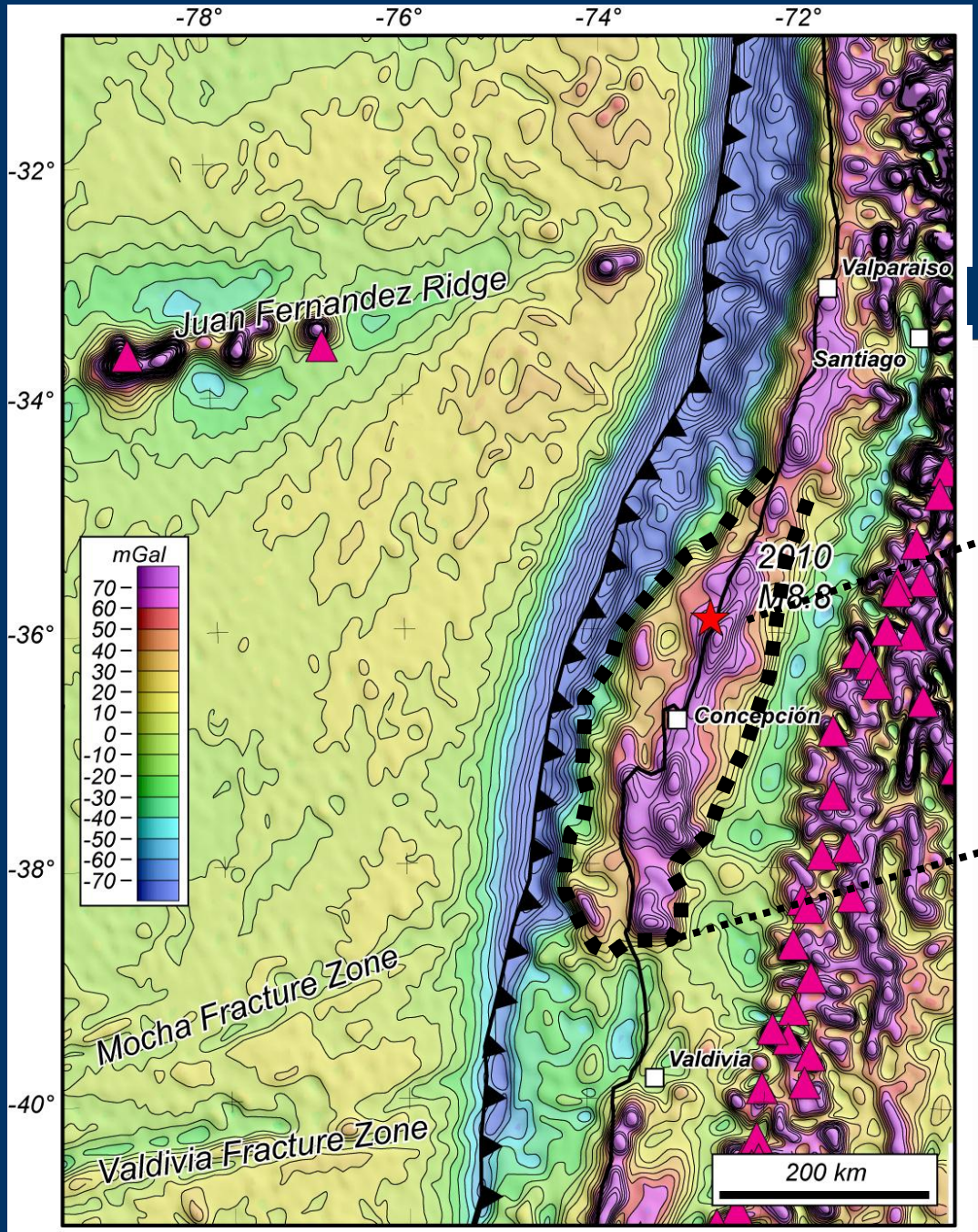
The 2010, 1985, and 1960 epicenters lie along the inboard gradient.

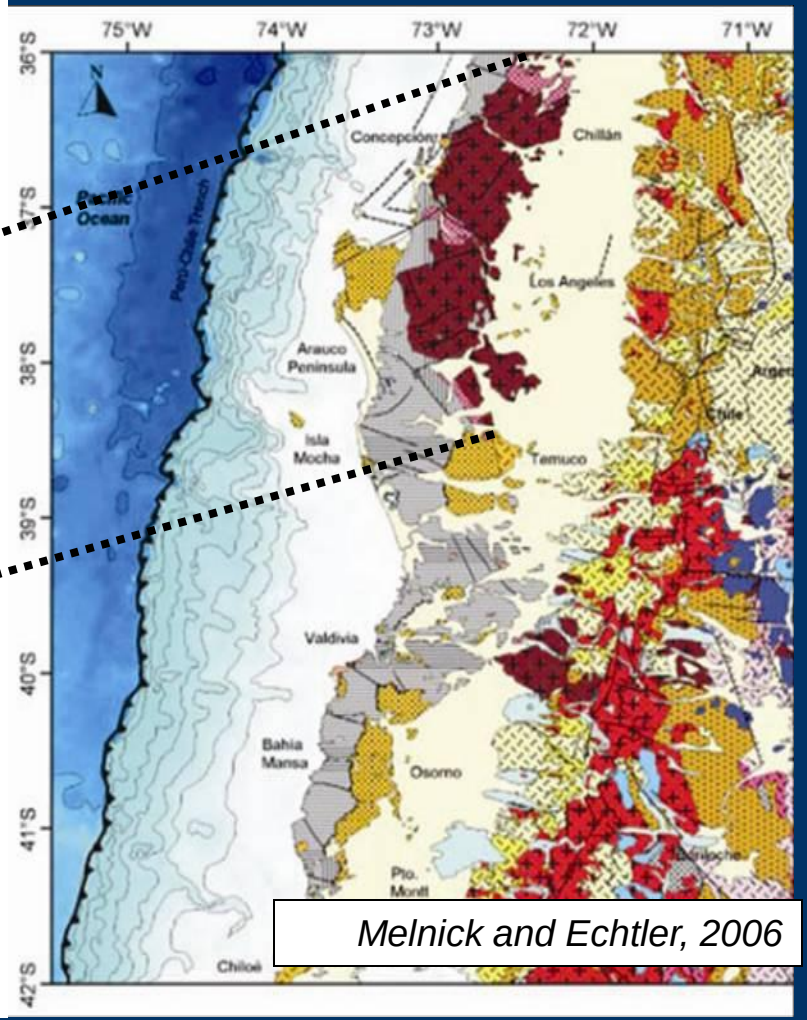


The trench anomaly is interrupted by a pronounced gravity anomaly, which we call the "Concepción buttress."

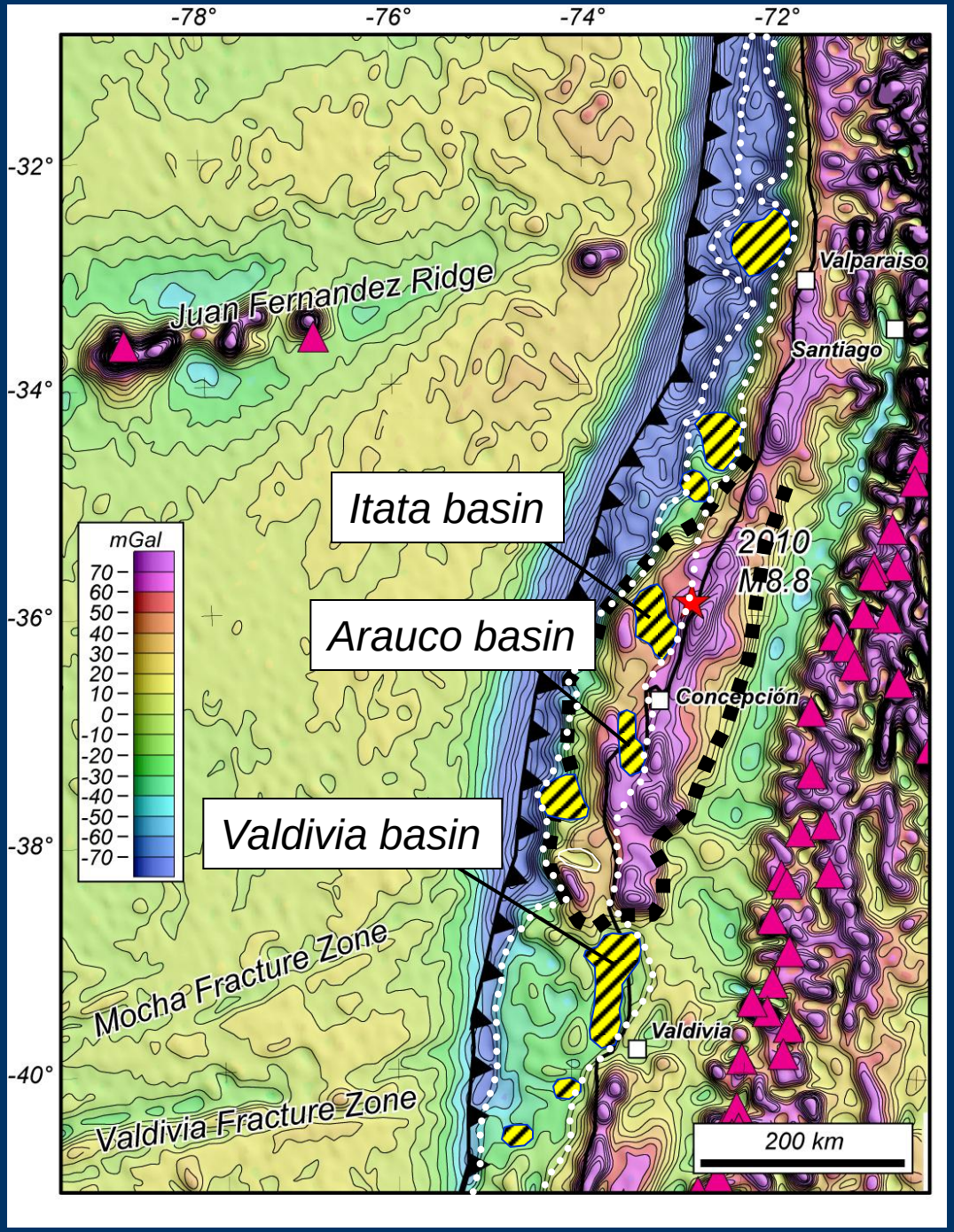
The gravity terrace passes over the Concepción buttress and appears to be deflected by it. The terrace is superimposed on the inherited basement of the Concepción buttress.

The Concepción buttress reflects a Paleozoic plutonic terrane exposed onshore. The terrrane extends nearly to the trench axis and may influence subduction.



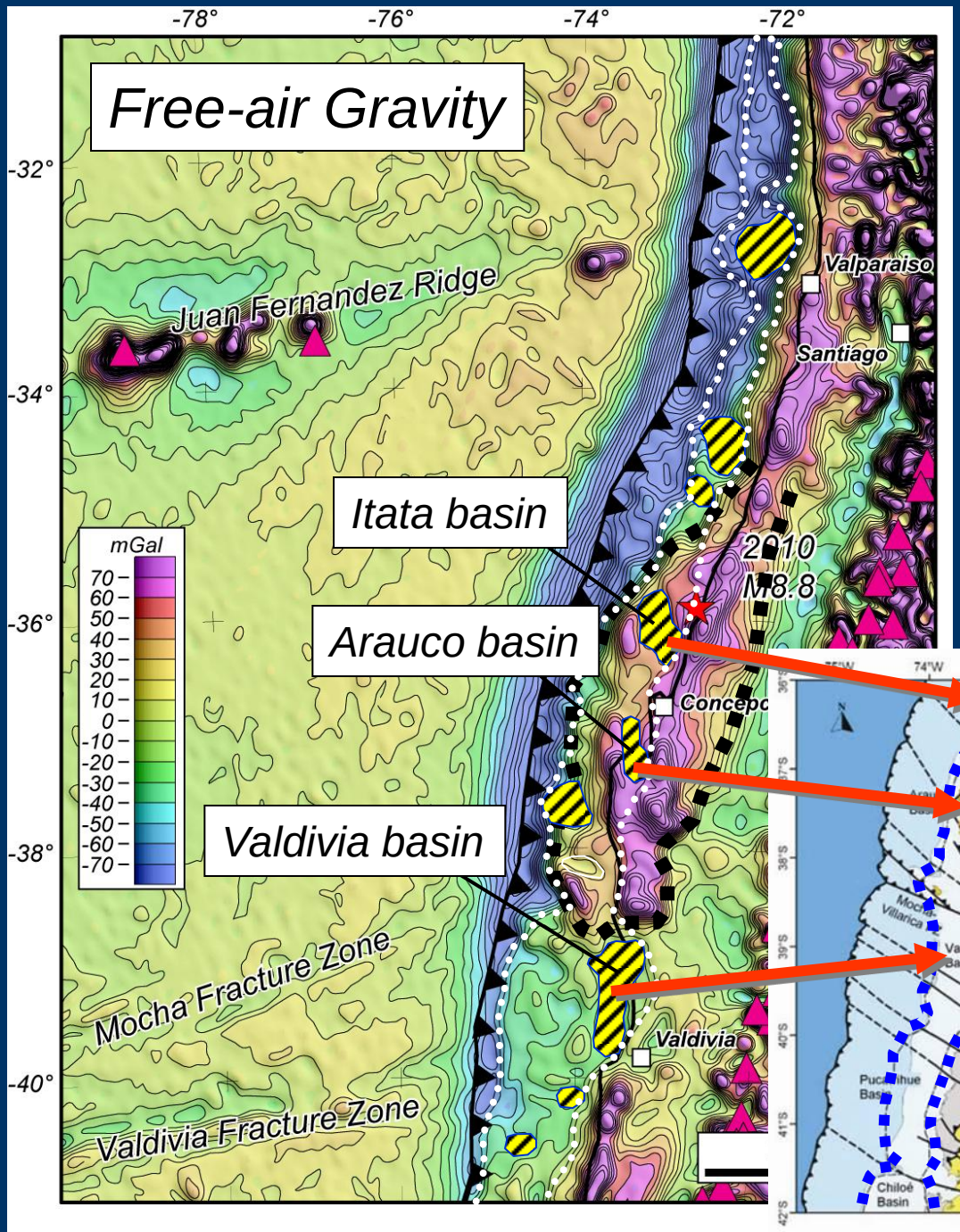


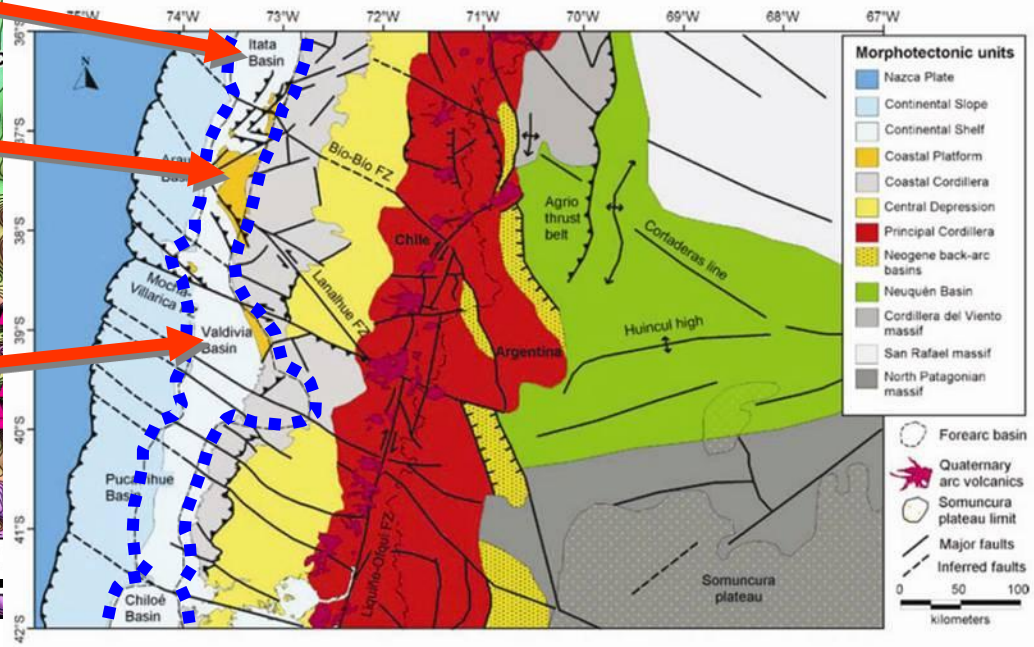
Melnick and Echtler, 2006



The terrace is punctuated by gravity lows, some of which correspond with mapped sedimentary basins.

Where basins are mapped (dashed blue lines below), they correspond to the gravity lows.

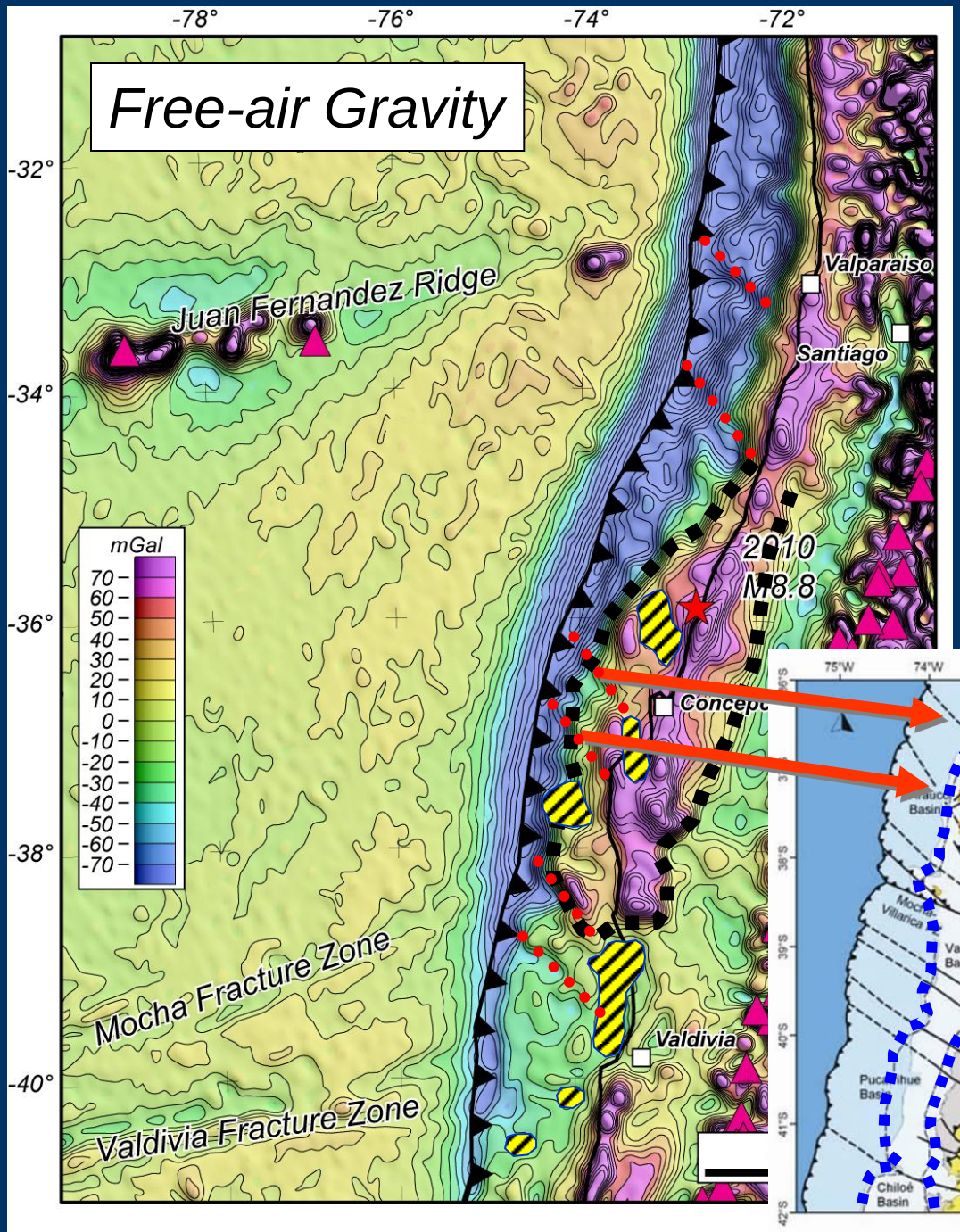




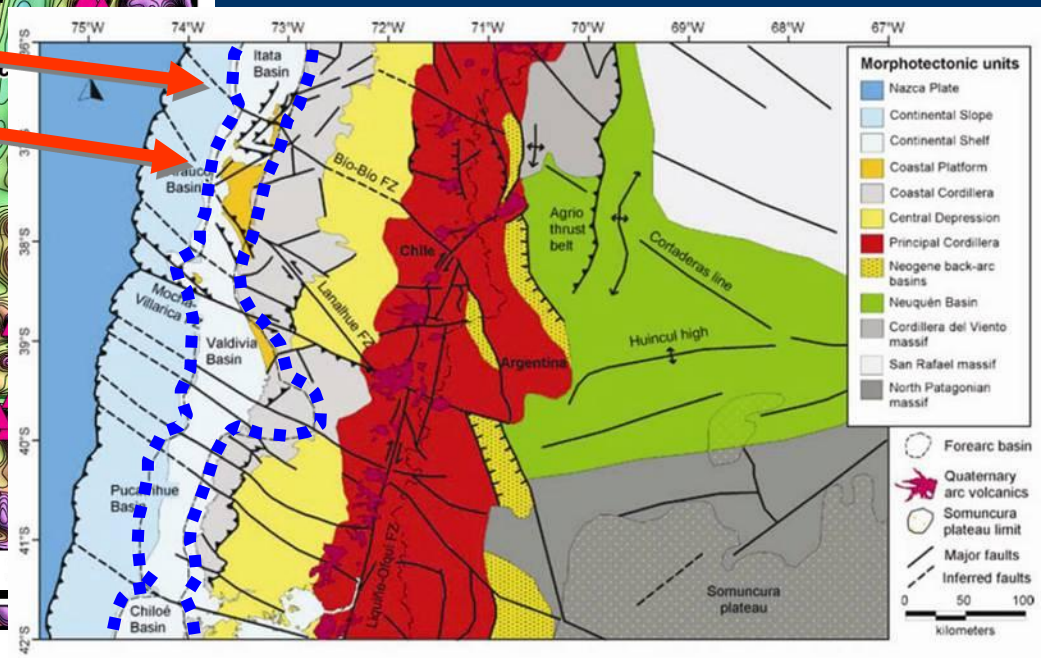
Melnick and Echtler, 2006

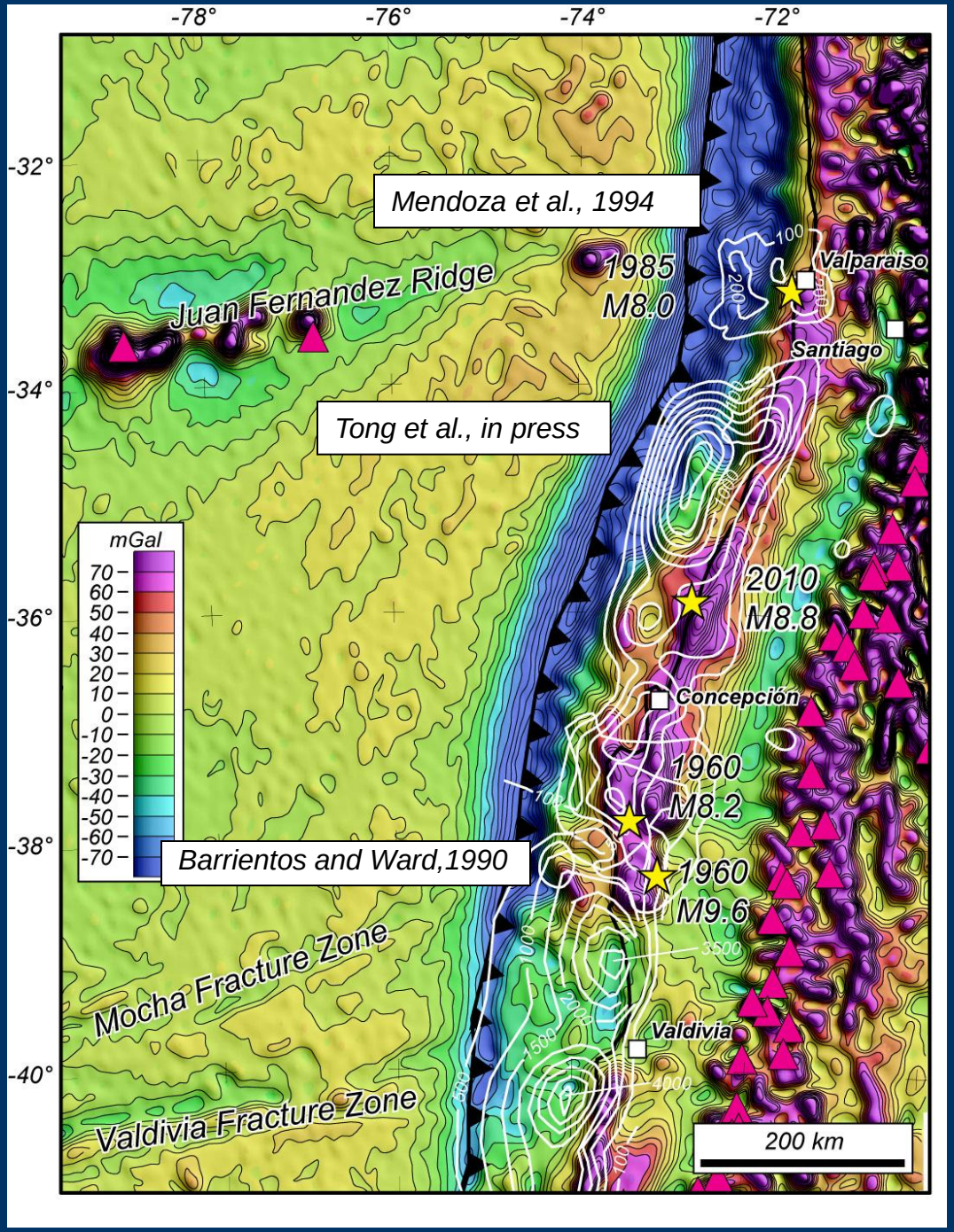
Northwest-striking gradients may be right-lateral faults?

(ala Hiroo Kanamori!)



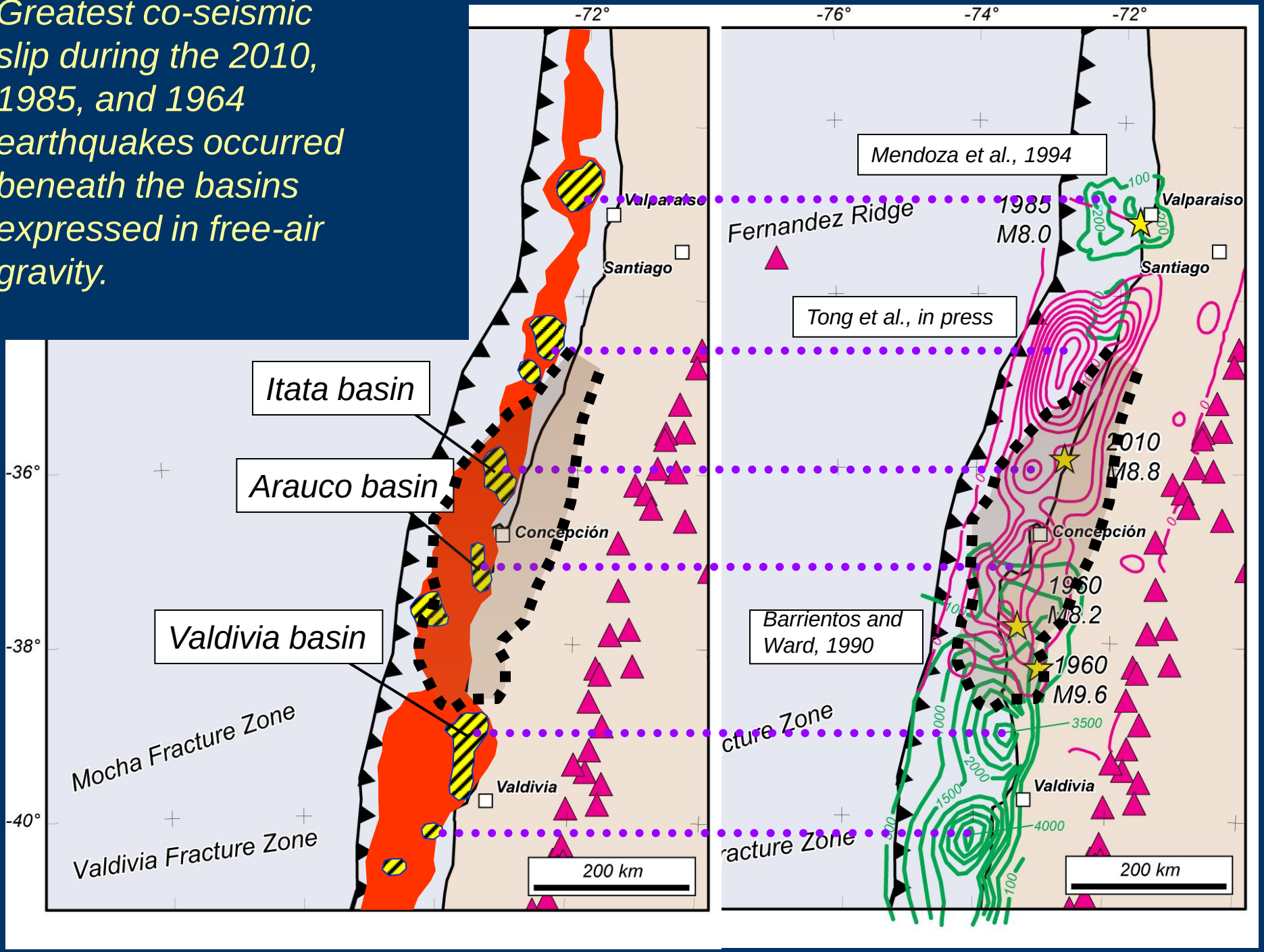
Melnick and Echtler, 2006





The 1964, 1985, and 2010 Chile earthquakes initiated along the inboard margin of the forearc terrace. Greatest slip, however, occurred seaward from initial rupture but still within the terrace.

Greatest co-seismic slip during the 2010, 1985, and 1964 earthquakes occurred beneath the basins expressed in free-air gravity.



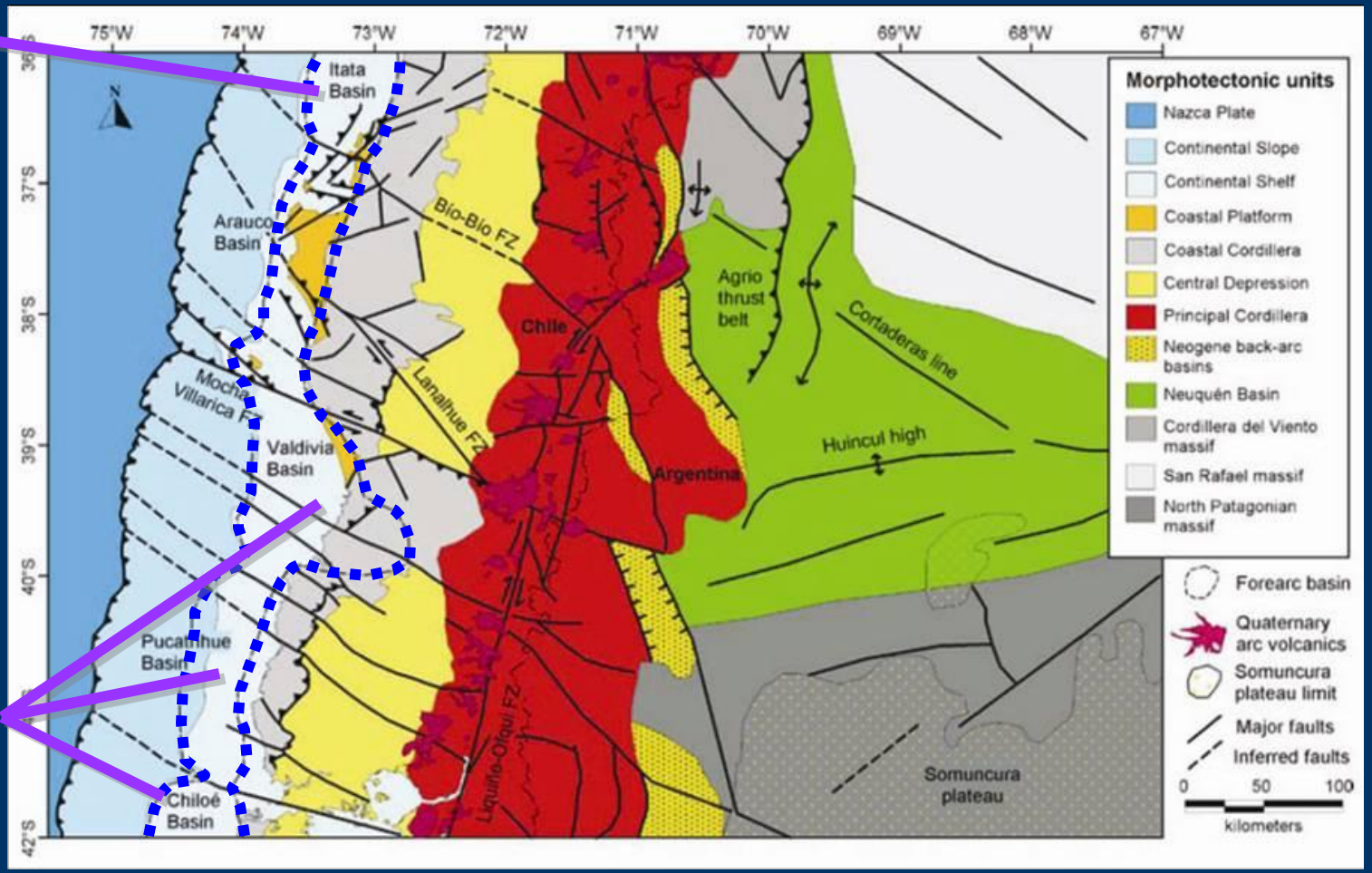
Summary

- *The 2010 M_W 8.8 earthquake fills a gap between the 1960 Mw 9.5 and 1985 M_W 8.0 earthquakes.*
- *The 1960 and 2010 earthquake ruptures coincide with a segment of the S. Chile trench characterized by thick sediment fill.*
- *Finite fault slip models for the 2010 event have considerable variability, but most show largest slip (>10 m) under the forearc terrace and its basins.*
- *Satellite gravity reveals that all three earthquakes initiated beneath the coastal gravity high and ruptured into adjacent basin-centered gravity lows, where most of the slip occurred.*
- *The Concepción gravity high, a Paleozoic plutonic terrane that extends offshore at the Concepción Peninsula, is a lower slip region that separates the high slip patches in 1960 and 2010.*

Mapped sedimentary basins coincide with high slip areas in 1960 and 2010.

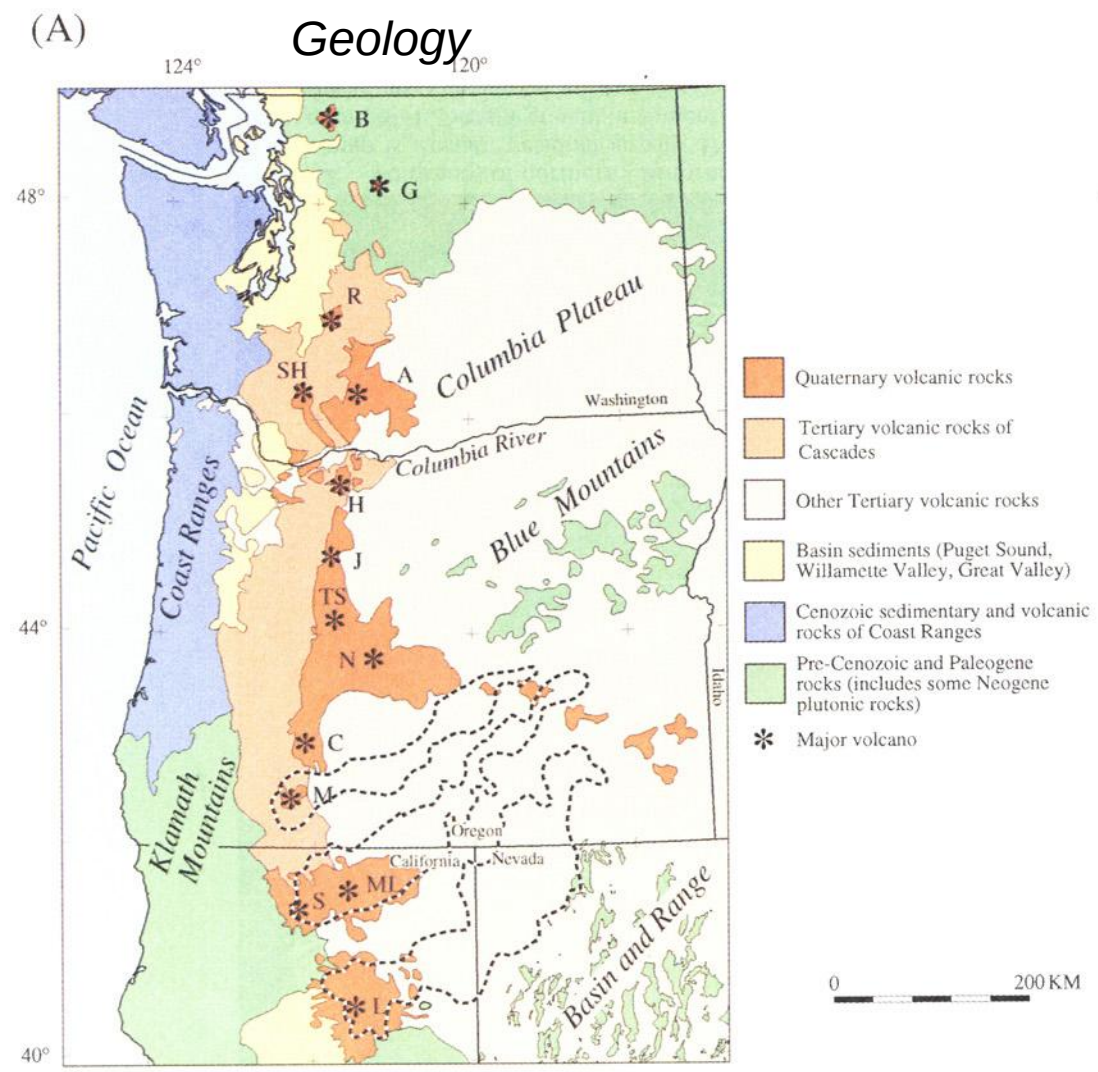
High slip area in 2010

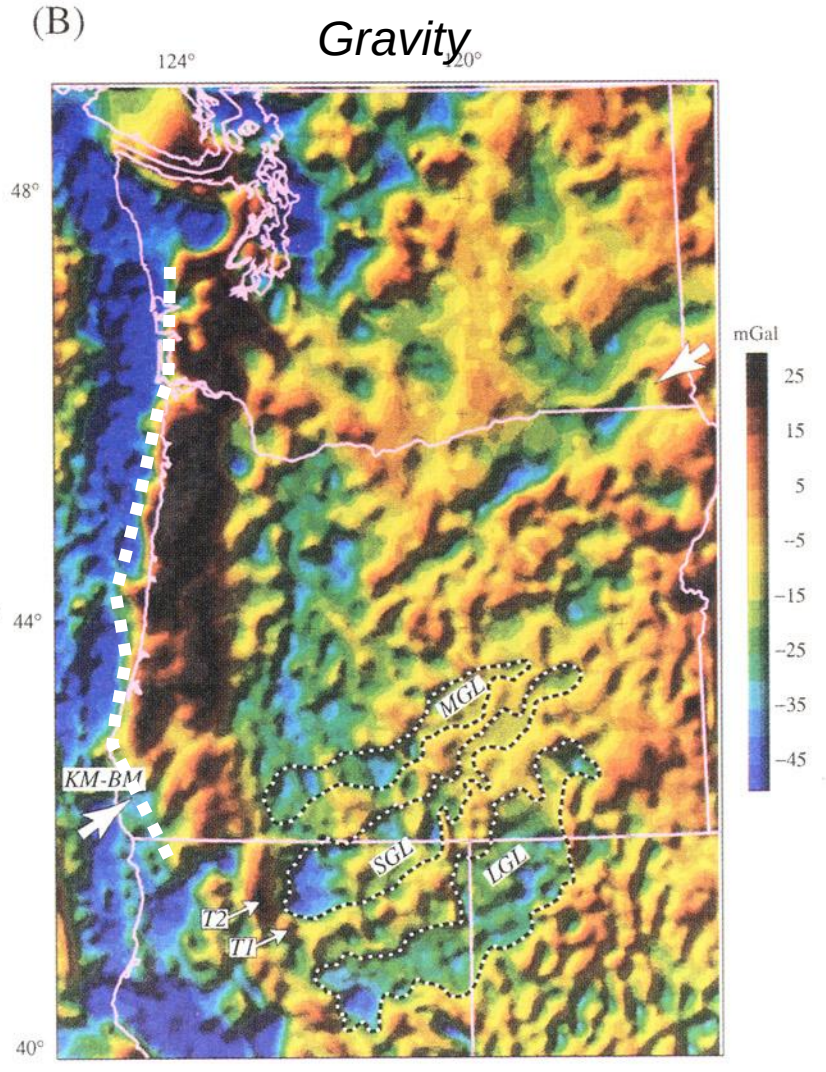
High slip areas in 1960



Melnick and Echtler, 2006

Cascadia Margin





Blakely et al., 1997