SuRfAce processes, Tectonics and Georesources: The Andean foreland basin of Argentina

Lecture 1: Tectonics of the Central Andes: non-collisional mountain building at hemispheric scale

Manfred R. Strecker

Universität Potsdam
Deutsches Geoforschungszentrum Potsdam
University consortium of Buenos Aires
University consortium of Salta, Jujuy, Cuyo and Tucumán

Lecture 1, Nov 15, 2018

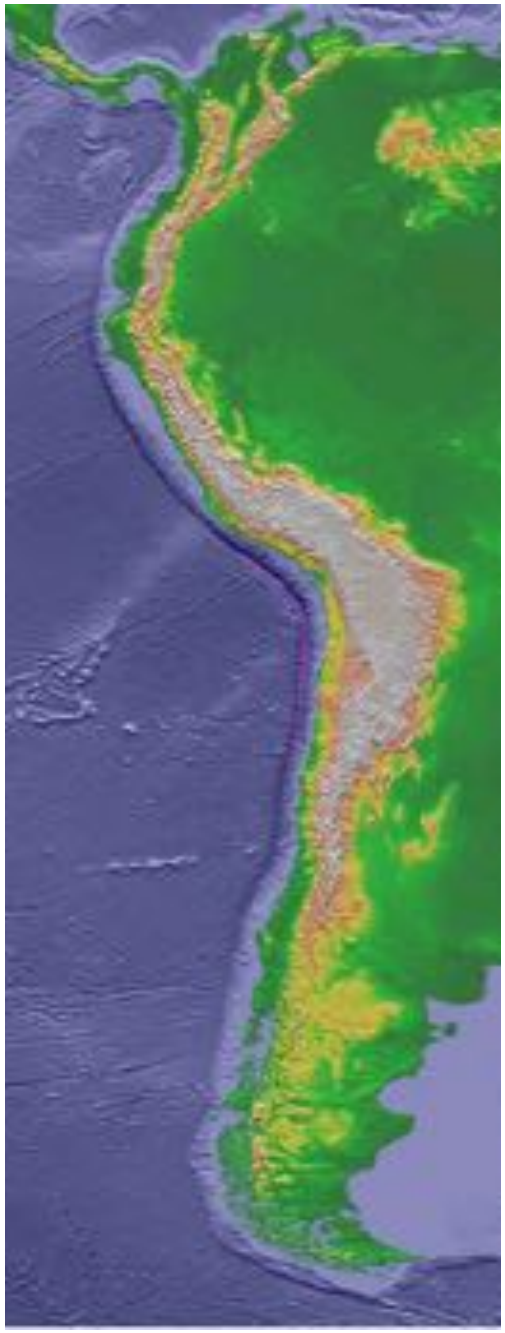
Today's topics:

(1) The Andes: general characteristics

(2) Seismicity, coastal uplift, seismotectonic segments

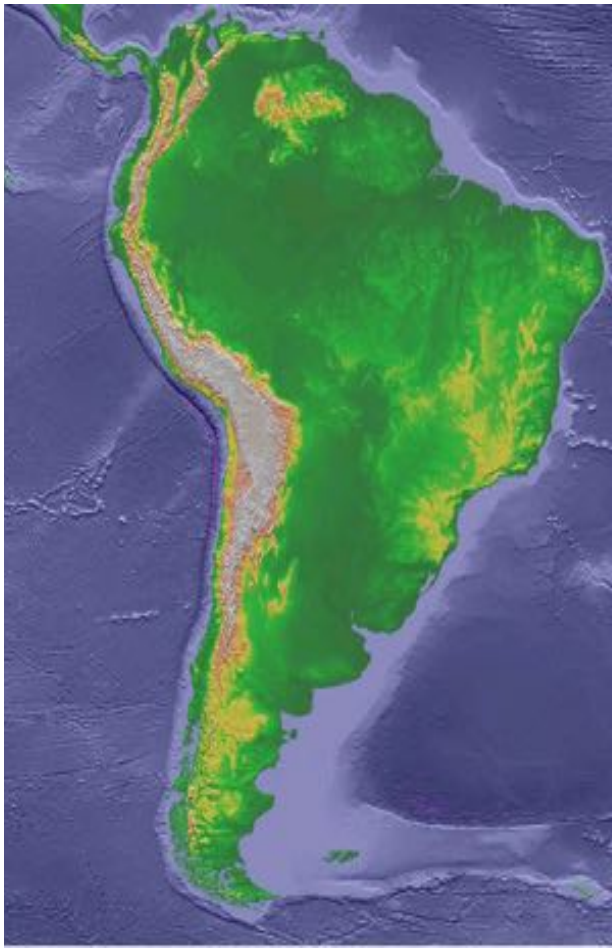
(3) Plate geometry & structural provinces

(4) The Andes: a hemispheric-scale orographic barrier

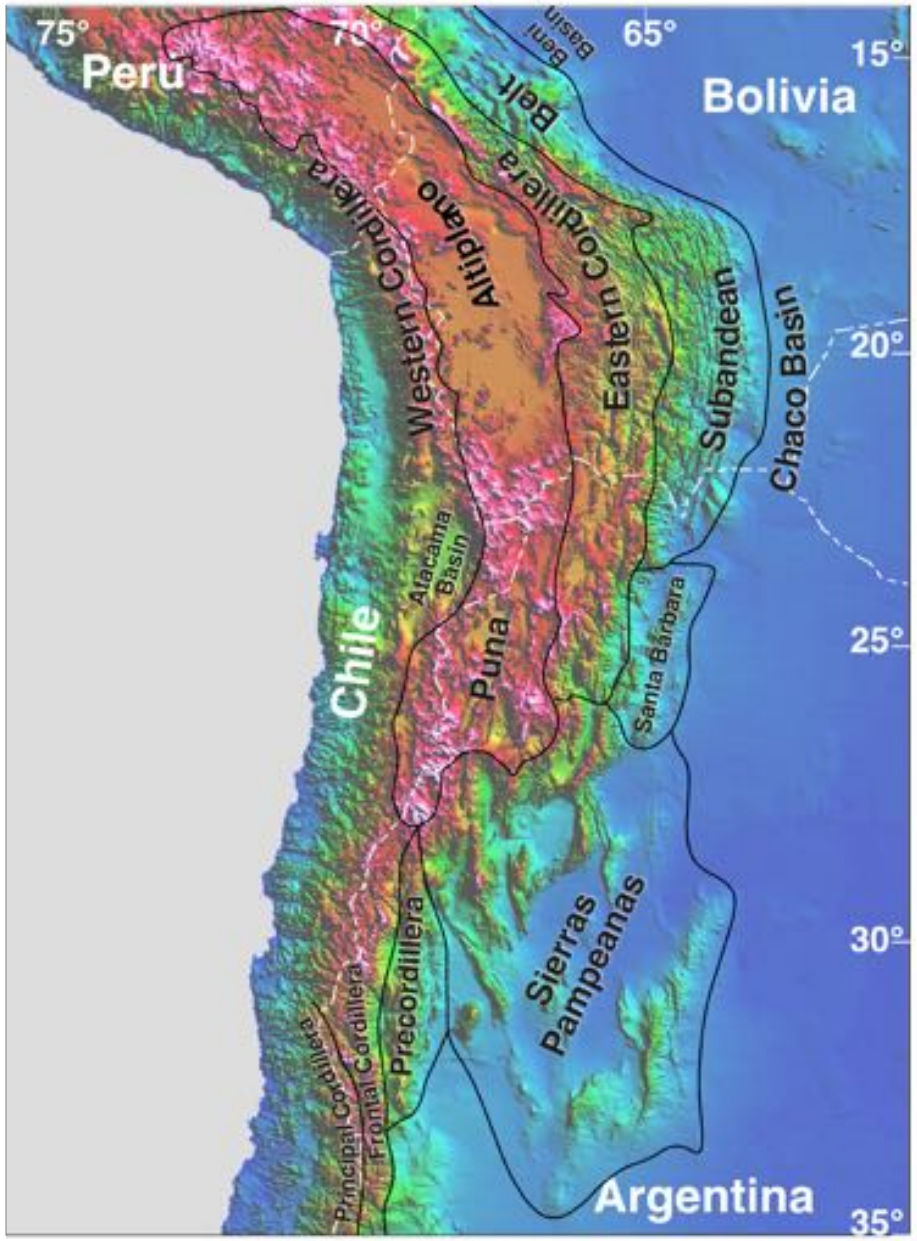


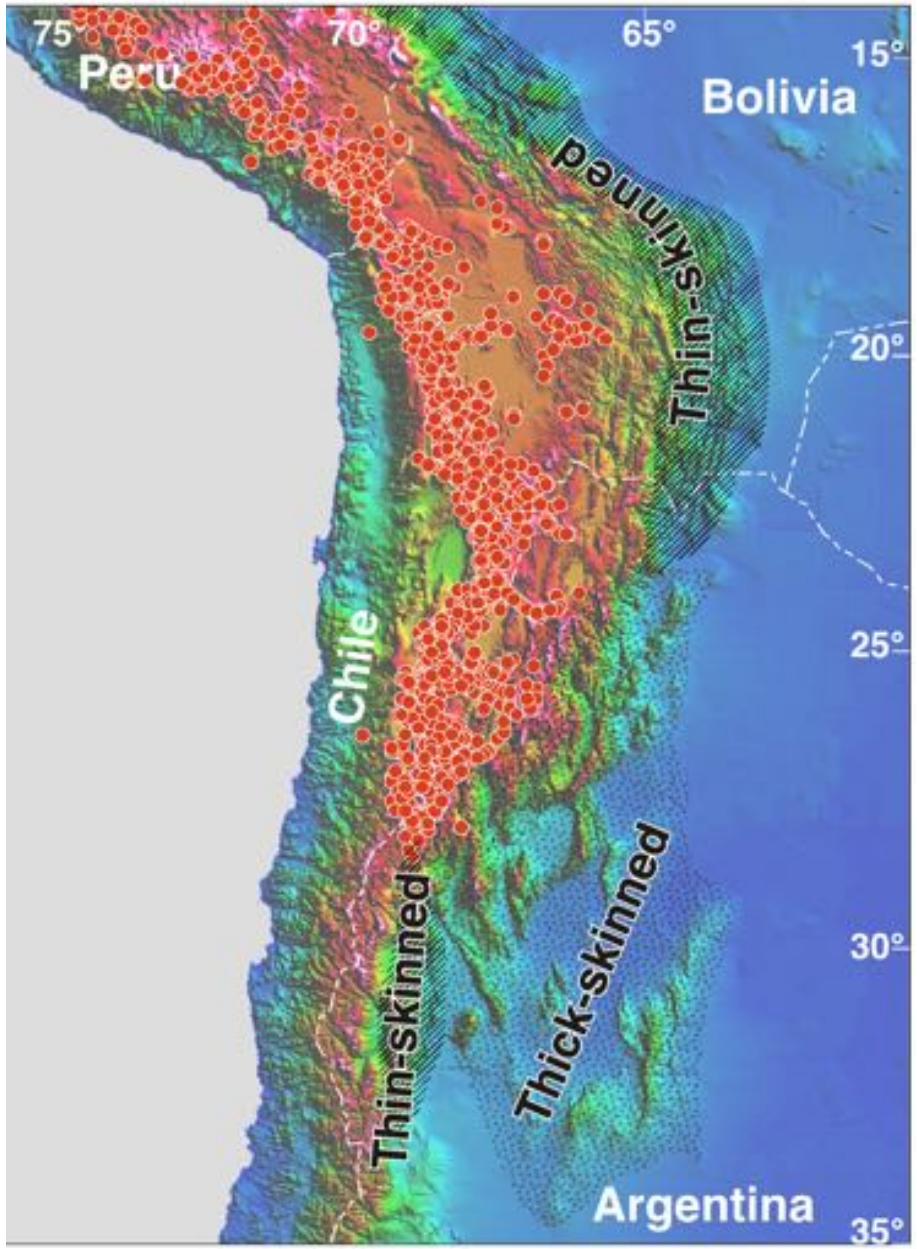
(1) The Andes: general characteristics

- Active subduction orogen, megathrust earthquakes
- 7000 km long; speciation corridor & barrier
- Different climate zones along strike, extreme rainfall gradients
- Changing subduction geometries
- Magmatic & amagmatic segments
- Important metallogenic and hydrocarbon resources
- Bathymetric anomalies that impact deformation
- 2nd largest plateau on Earth



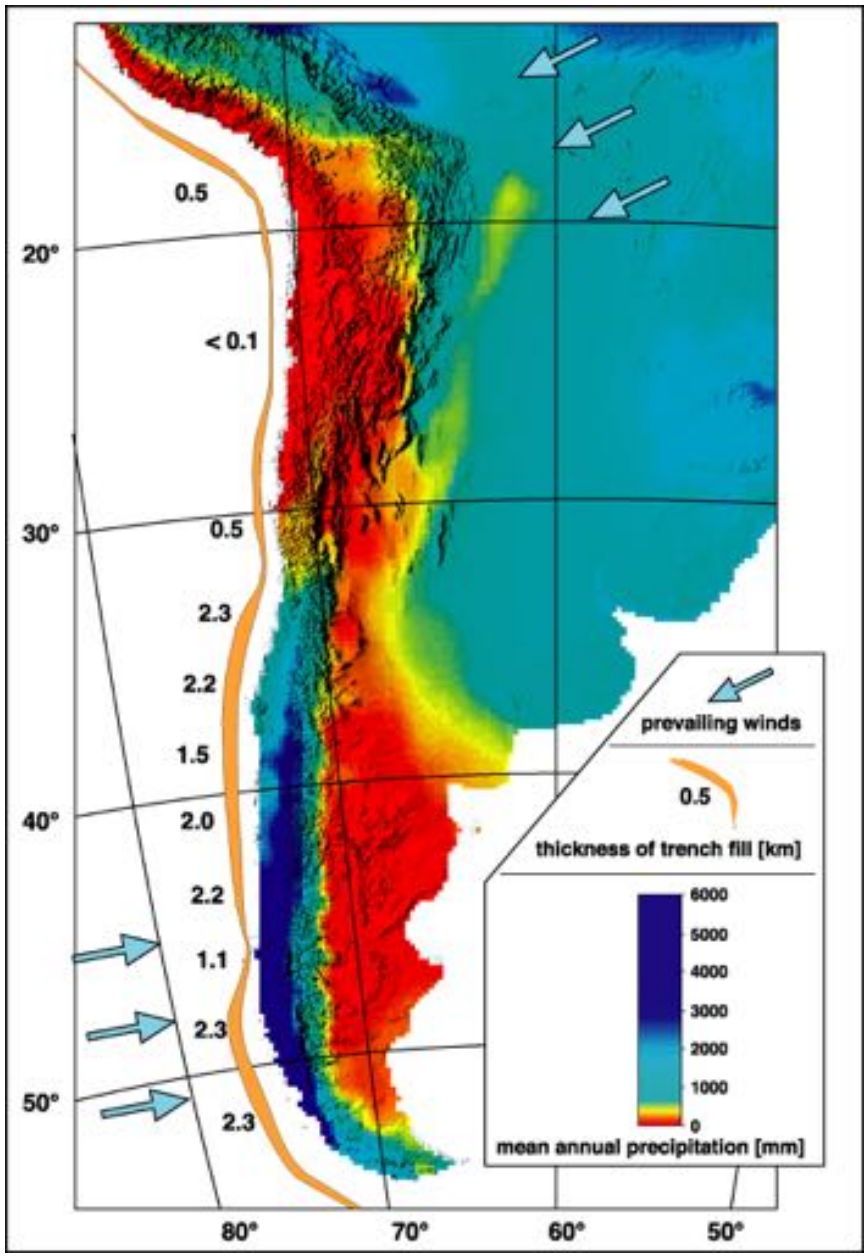
Central Andes: tectonic provinces, earthquakes & volcanoes - steep vs. flat subduction geometries

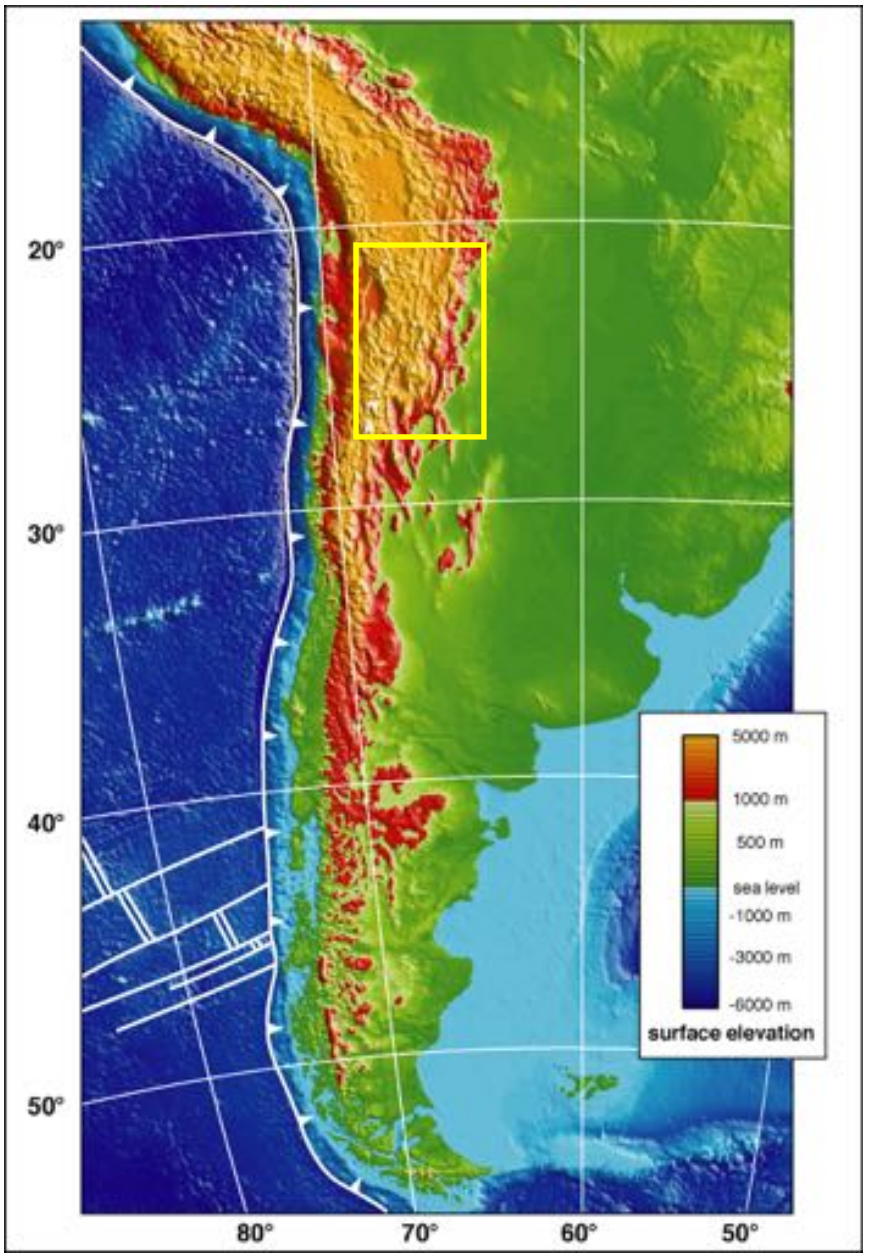




Modified after Jordan et al., 1983, GSAB and Cahill et al., 1988, Tectonics

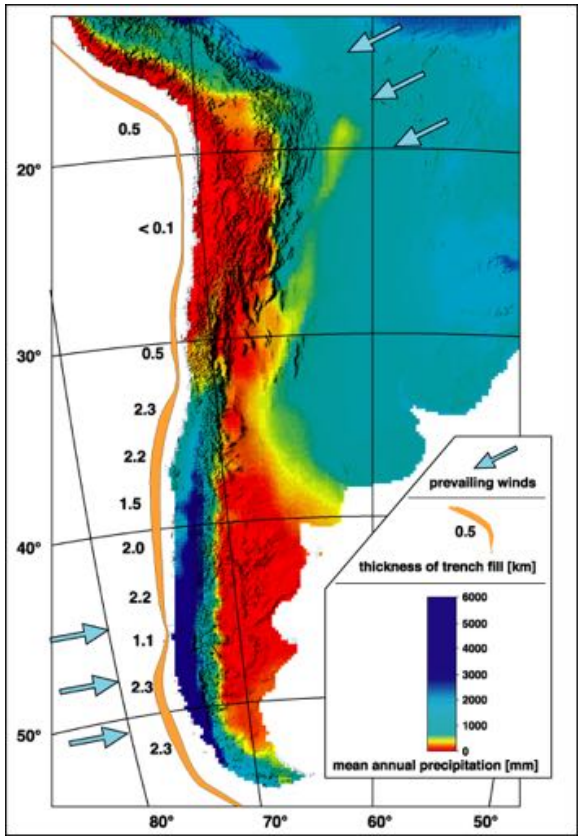
Topography and asymmetry in Andean precipitation





modified after WMO, 1997; Bangs and Cande, 1999, Tectonics; Strecker et al., 2007 Ann. Rev. Earth & Planet. Sci.

Climatic controls on metal resources: supergene enrichment of porphyry coppers (Cu, Ag, Au) – leaching requires availability of water



Hartley and Rice, 2005, Mineralium Deposita

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Universität Potsdam
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University consortium of Buenos Aires
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Lecture 3, Nov 29, 2018

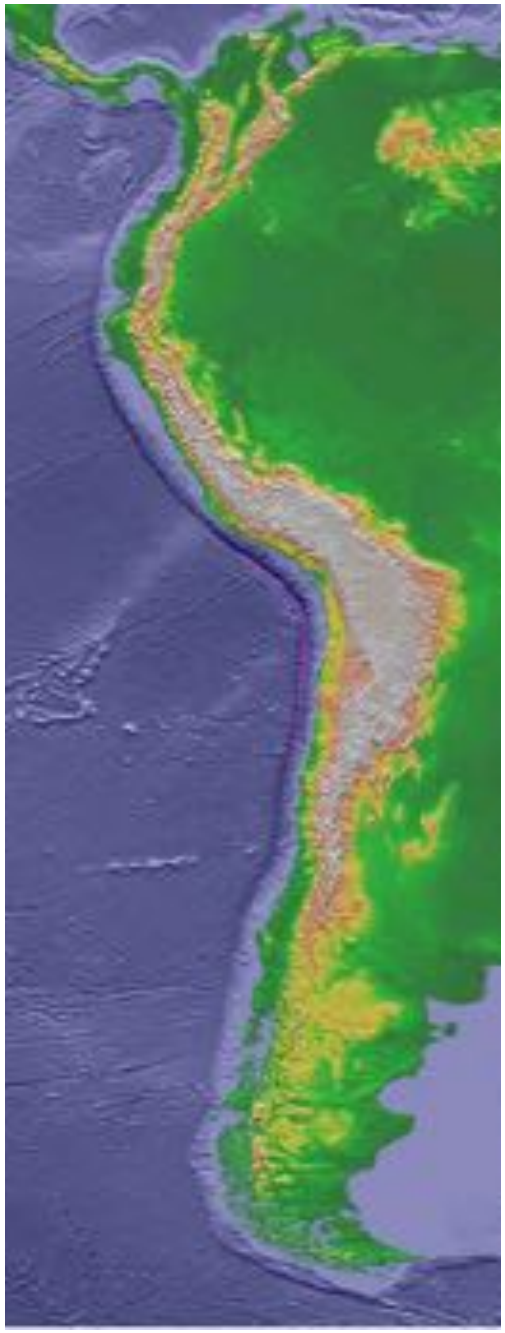
Topics:

(1) The Andes: general characteristics

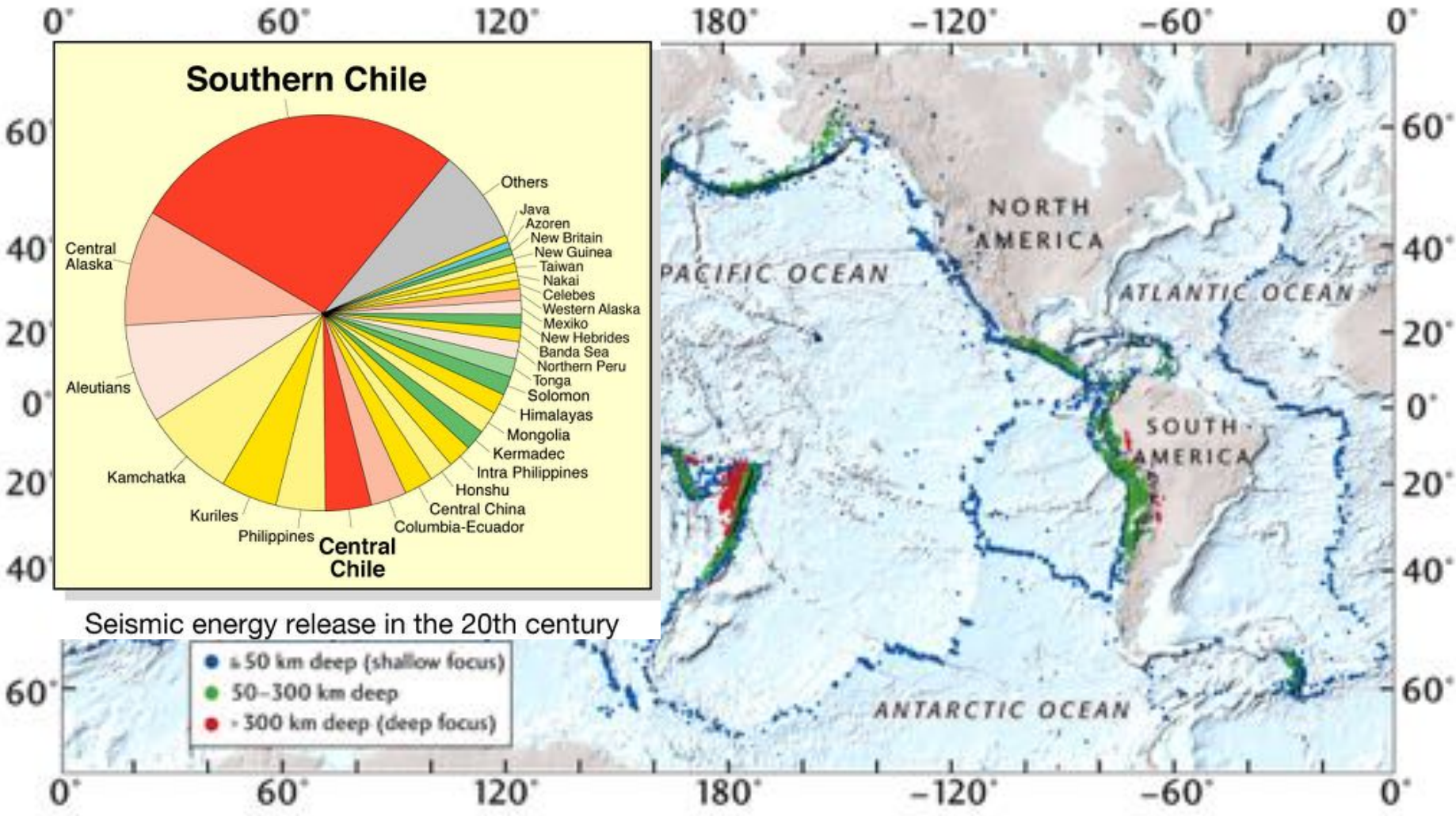
(2) Seismicity, coastal uplift, seismotectonic segments

(3) Plate geometry & structural provinces

(4) The Andes: a hemispheric-scale orographic barrier



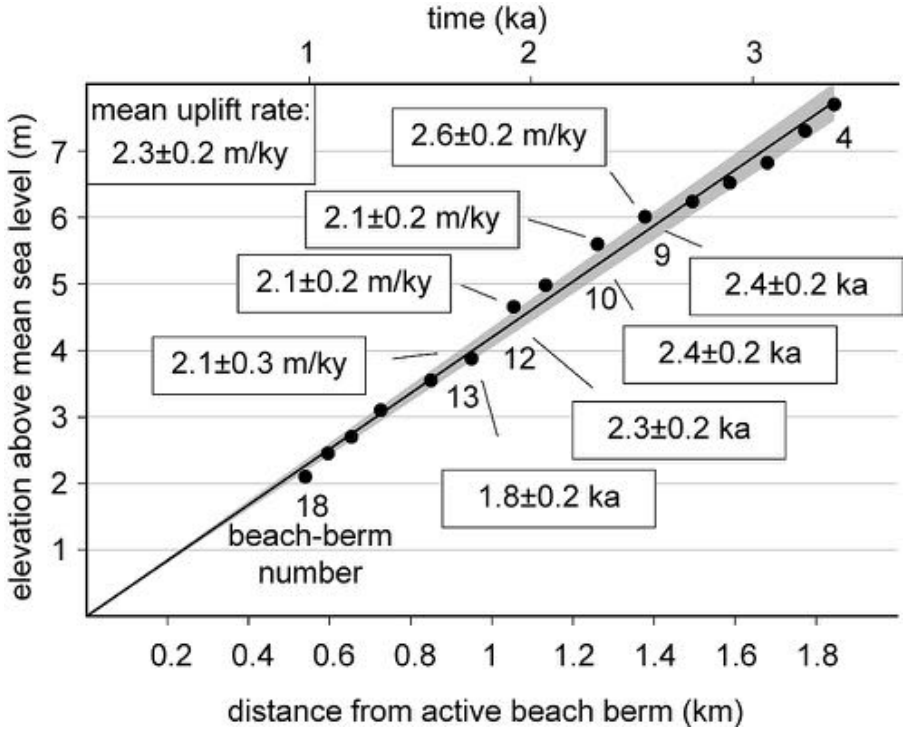
(2) Seismicity, coastal uplift & seismotectonic segments

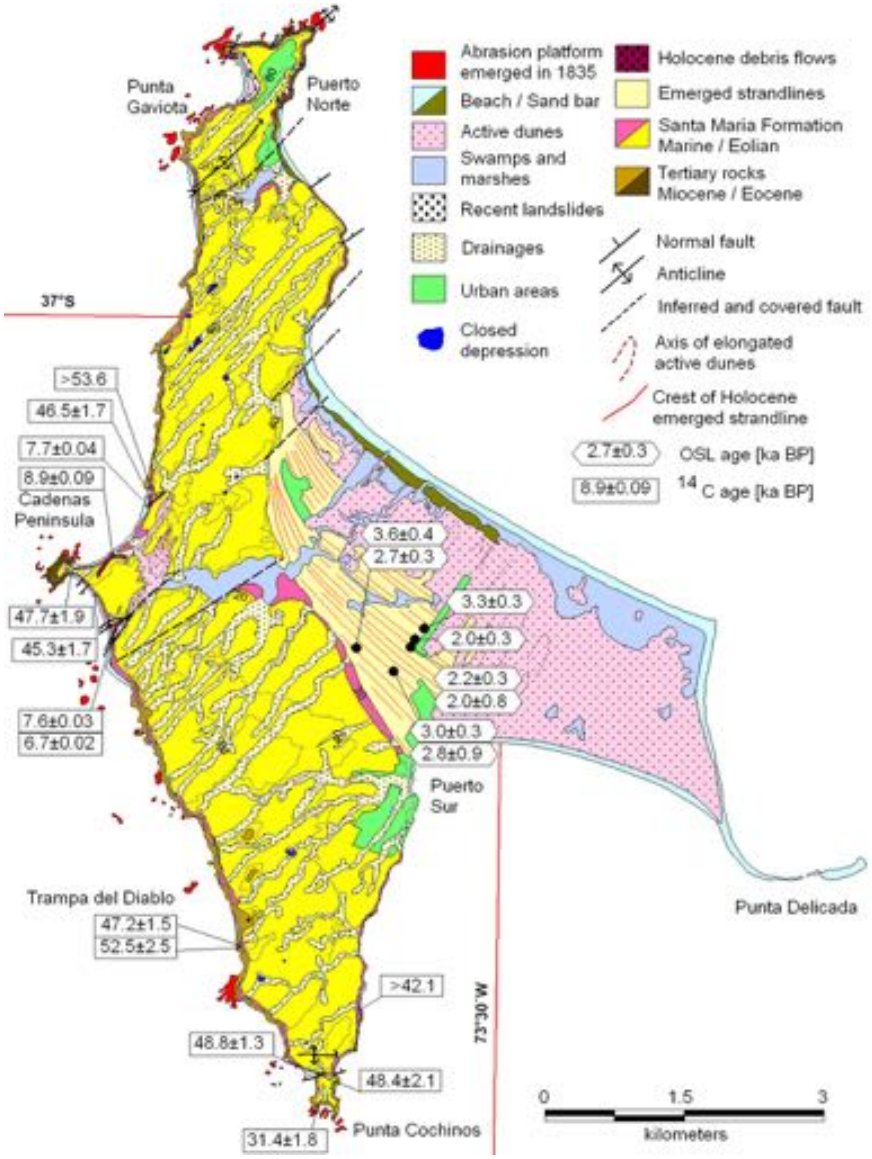


Modified after Scholz, 1990, Press & Siever, 2001
and unpubl. data from TIPTEQ team

The Concepción and Valdivia earthquakes of Chile, 1835 & 2010

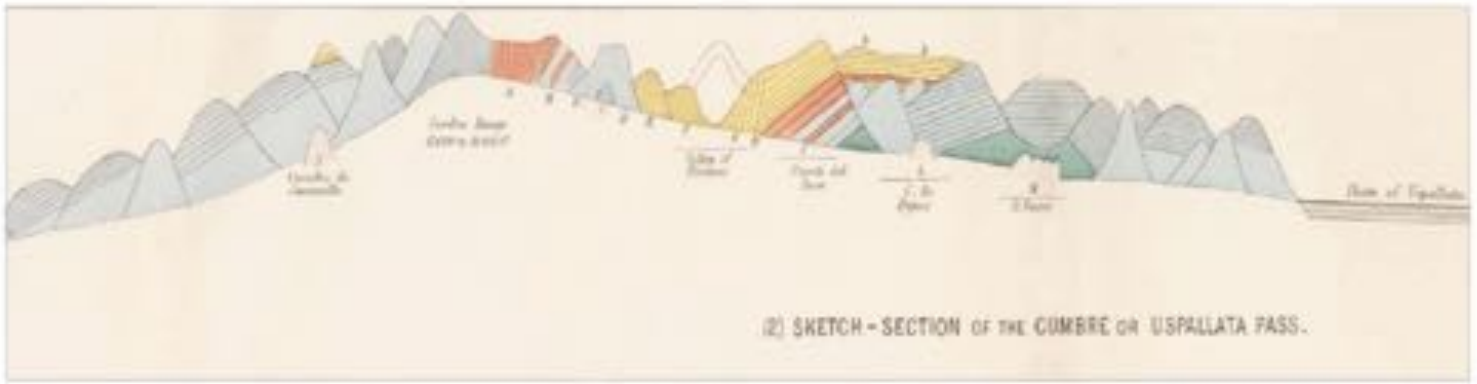
Earthquakes and coastal uplift: Santa Maria Island, Chile

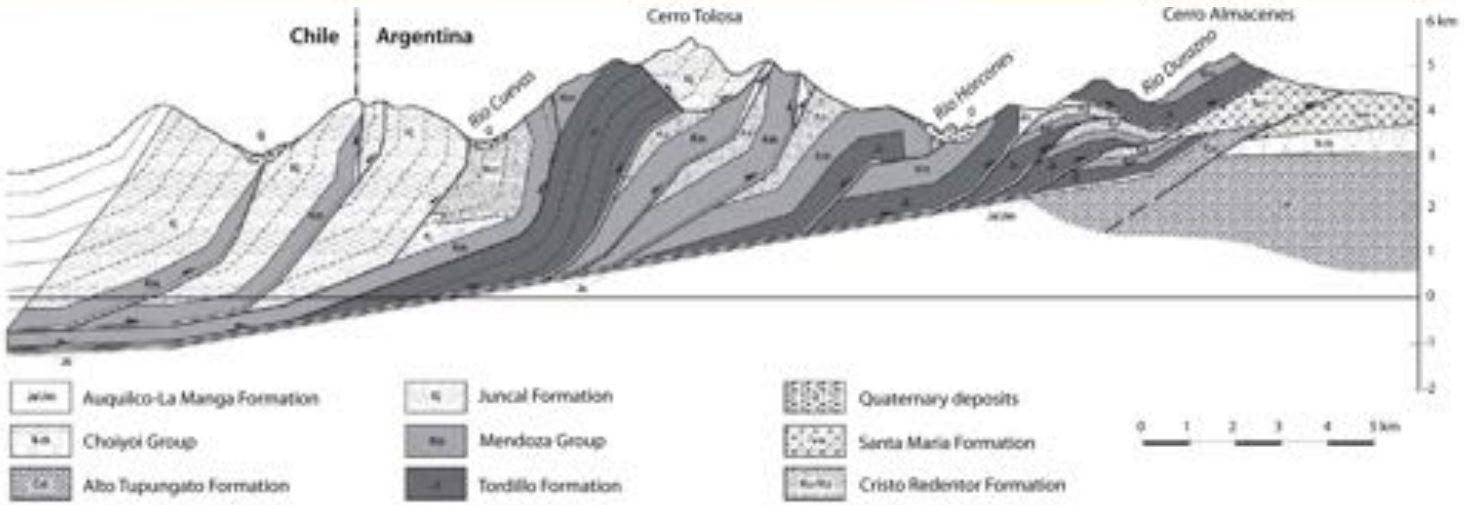




Bookhagen et al., 2006, GRL

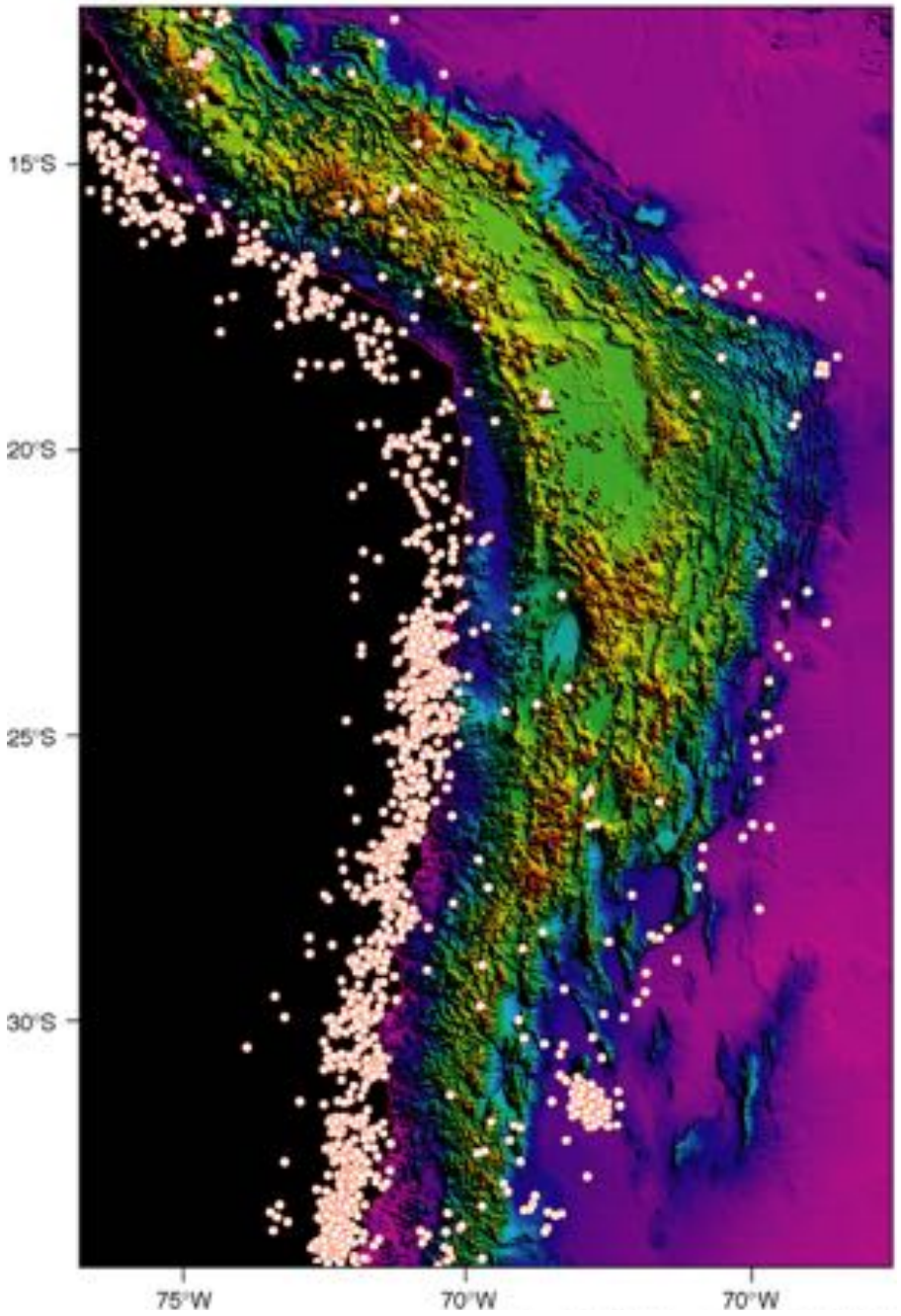
Darwin's first theory

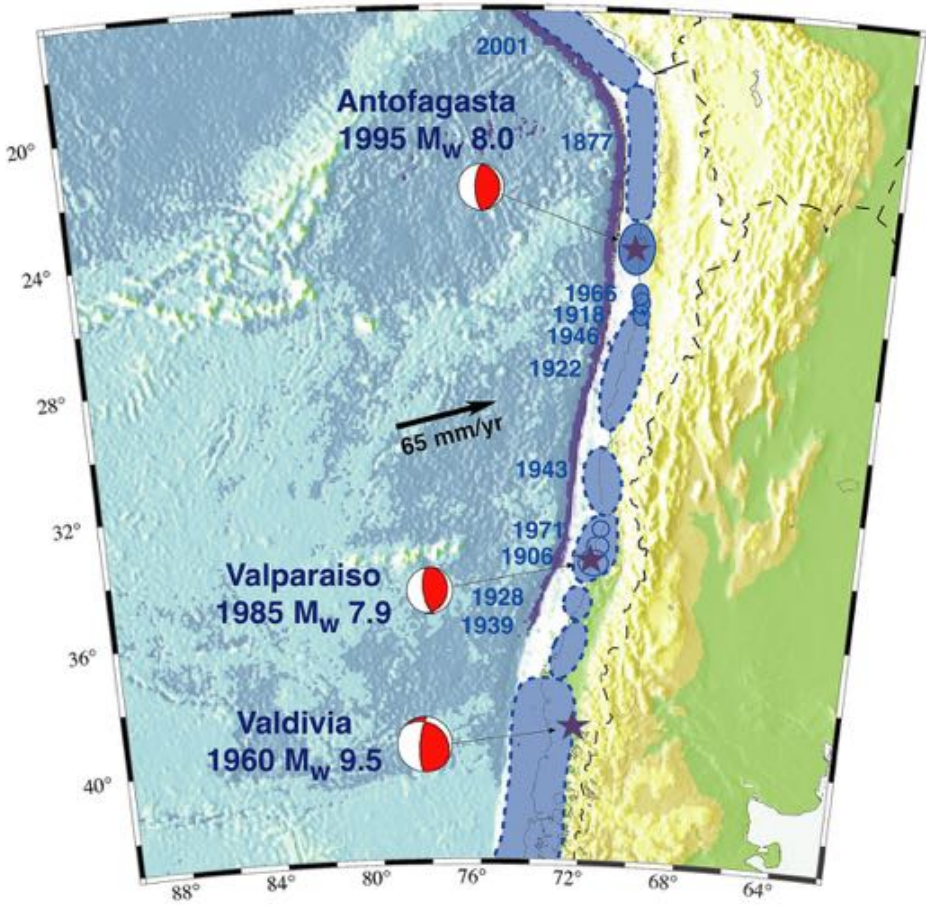




C. Darwin, The Voyage of the Beagle, V. Ramos, 2009; Rev. Geol. Argentina

Crustal seismicity (D<60 km, M>4.5)





Seismicity data from Engdahl et al., 1998

(3) Plate geometry & structural provinces of the Central Andes

Flat - slab region: Precordillera and Sierras Pampeanas

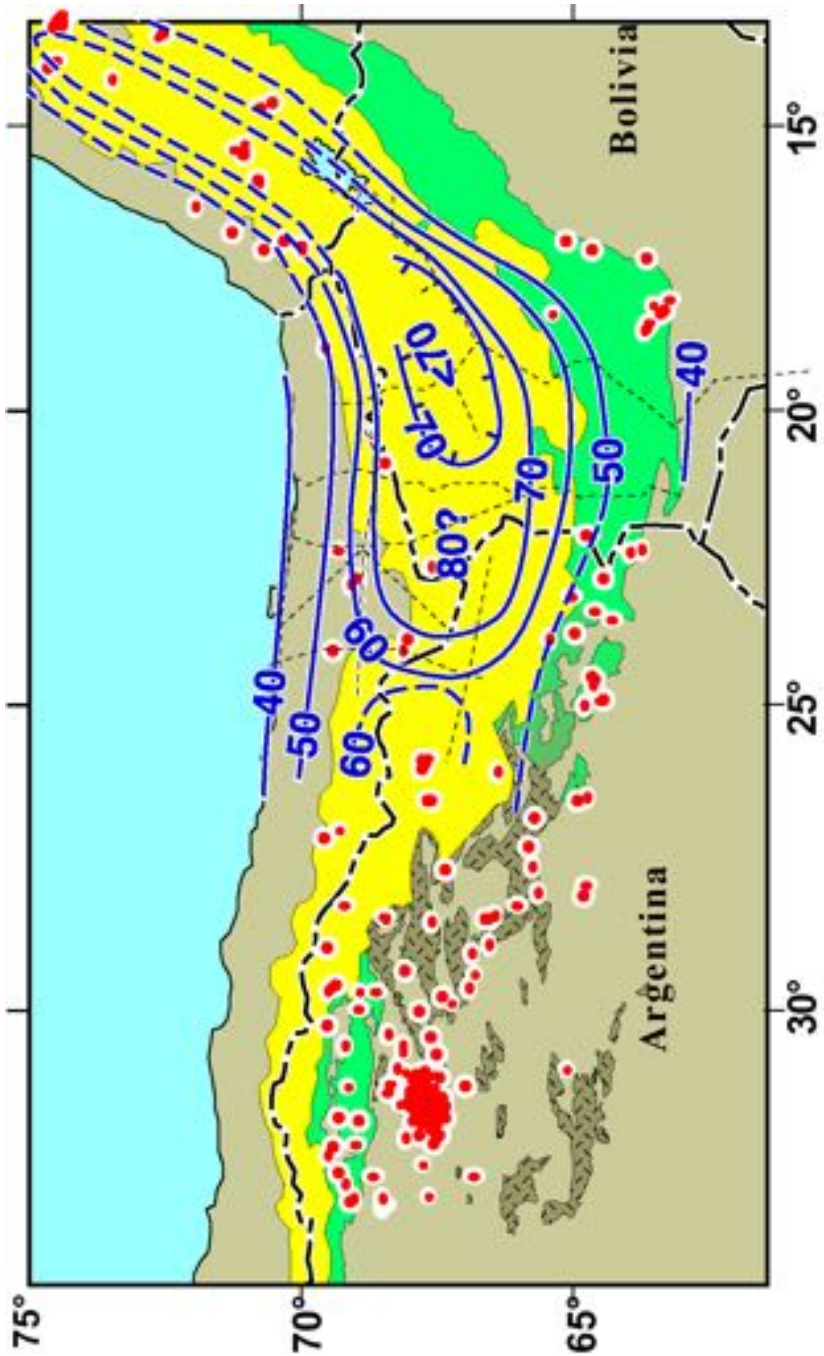
The “transition zone“ and the Santa Barbara System

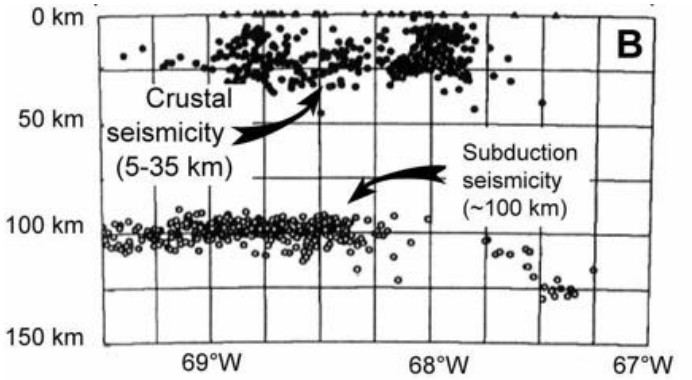
Steep-slab region: Sierras Subandinas

Plate geometry vs. inherited structures

Crustal thickness in the Central Andes: The Andean Plateau (Altiplano-Puna)

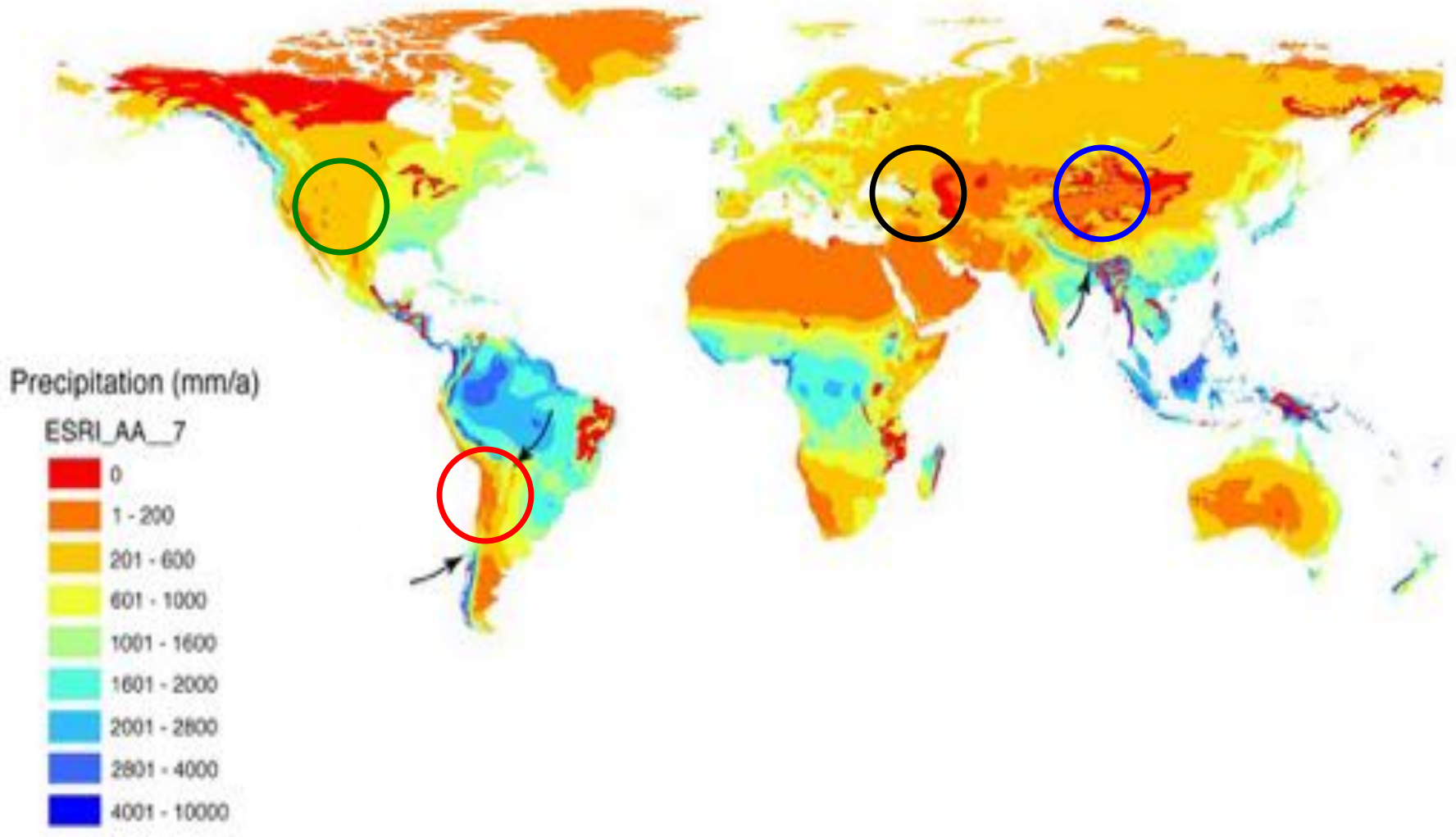
(blue contours depicts crustal thickness; red dots denote earthquake locations)

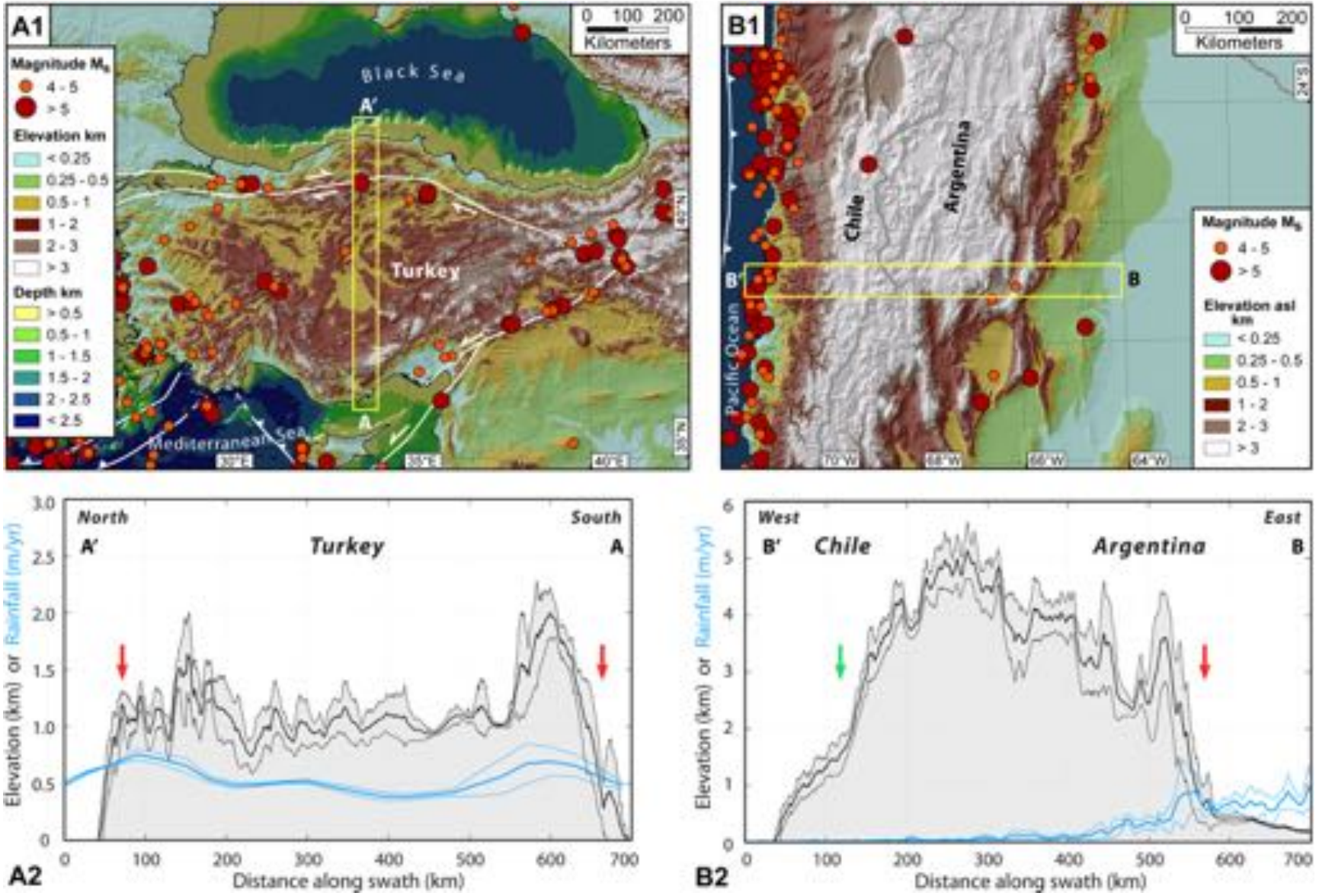




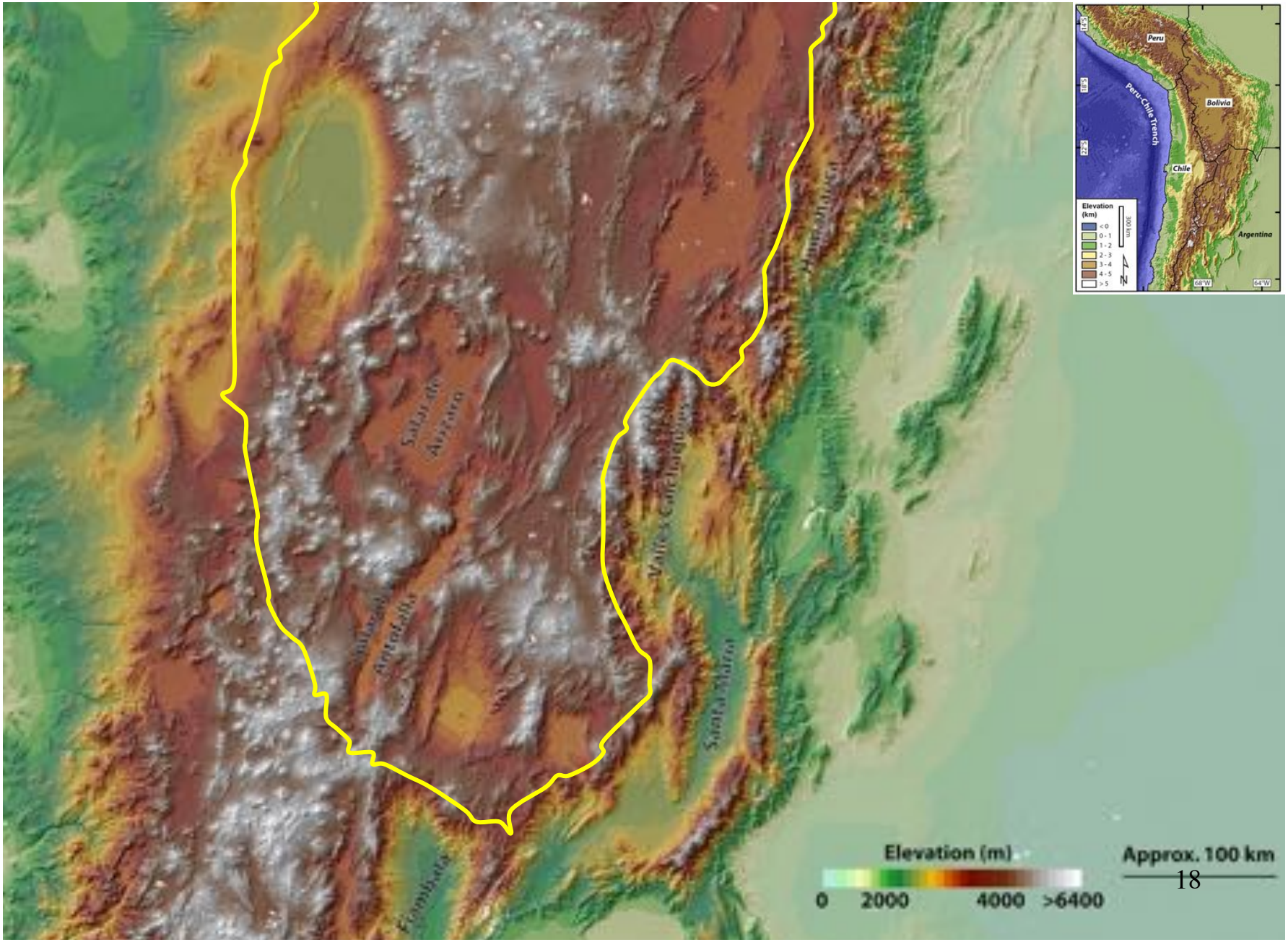
Allmendinger et al., 1997; Barazangi & Isacks, 1976

Orogenic plateaus – general characteristics: climate, topography, mantle anomalies

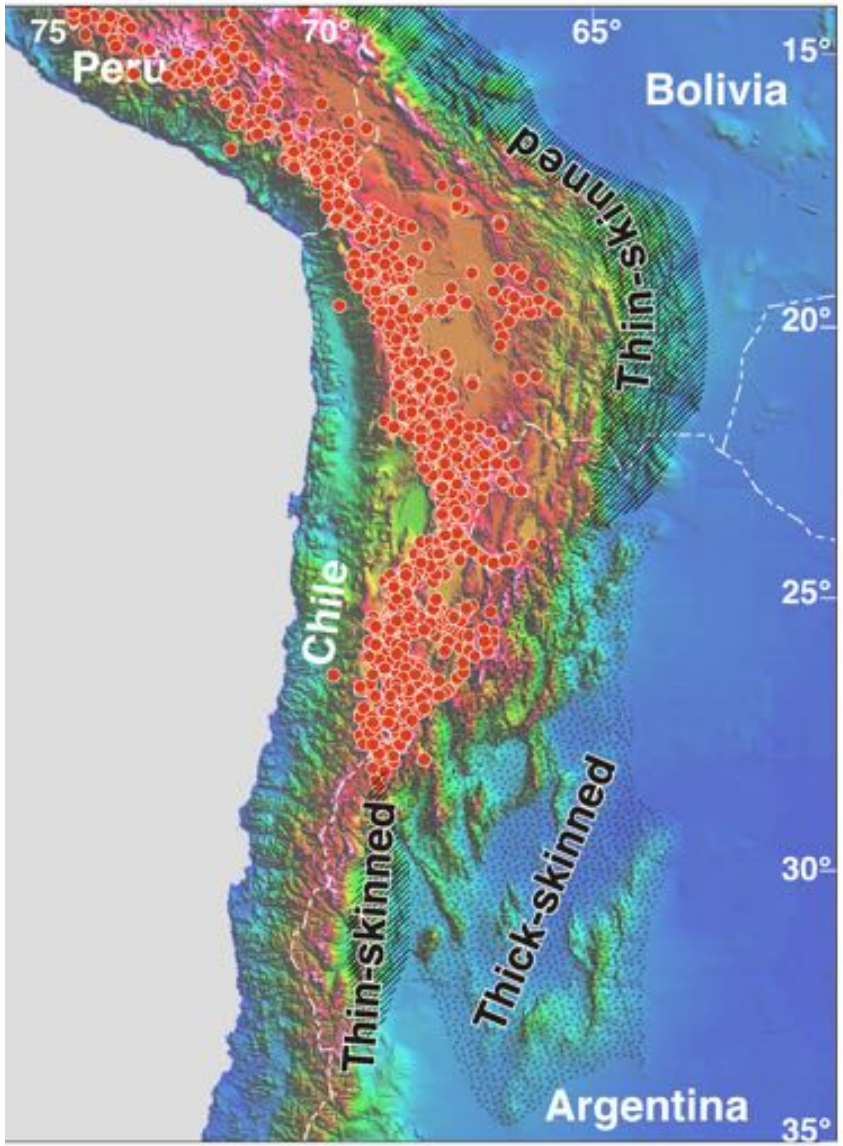


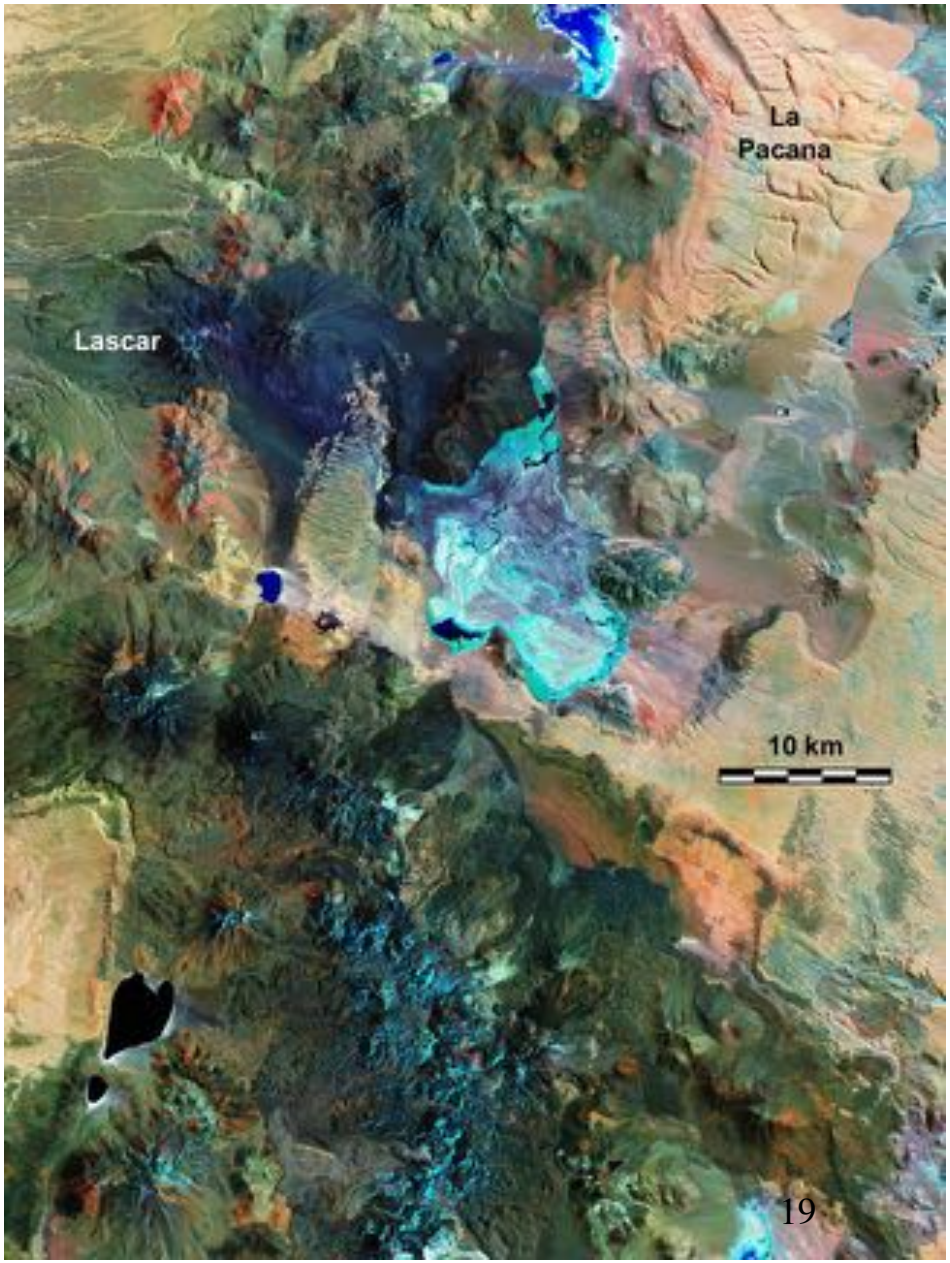

A1
Black Sea
A'
Turkey
A
Mediterranean Sea
Magnitude M_s
4 - 5
> 5
Elevation km
< 0.25
0.25 - 0.5
0.5 - 1
1 - 2
2 - 3
> 3
Depth km
> 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
< 2.5
0 100 200
Kilometers
B1
Chile
Argentina
Pacific Ocean
B'
B
Magnitude M_b
4 - 5
> 5
Elevation asl km
< 0.25
0.25 - 0.5
0.5 - 1
1 - 2
2 - 3
> 3
0 100 200
Kilometers
North
A'
Turkey
South
A
Elevation (km) or Rainfall (m/yr)
Distance along swath (km)
A2
West
B'
Chile
Argentina
East
B
Elevation (km) or Rainfall (m/yr)
Distance along swath (km)
B2

Closed Basins, arid interior of orogen

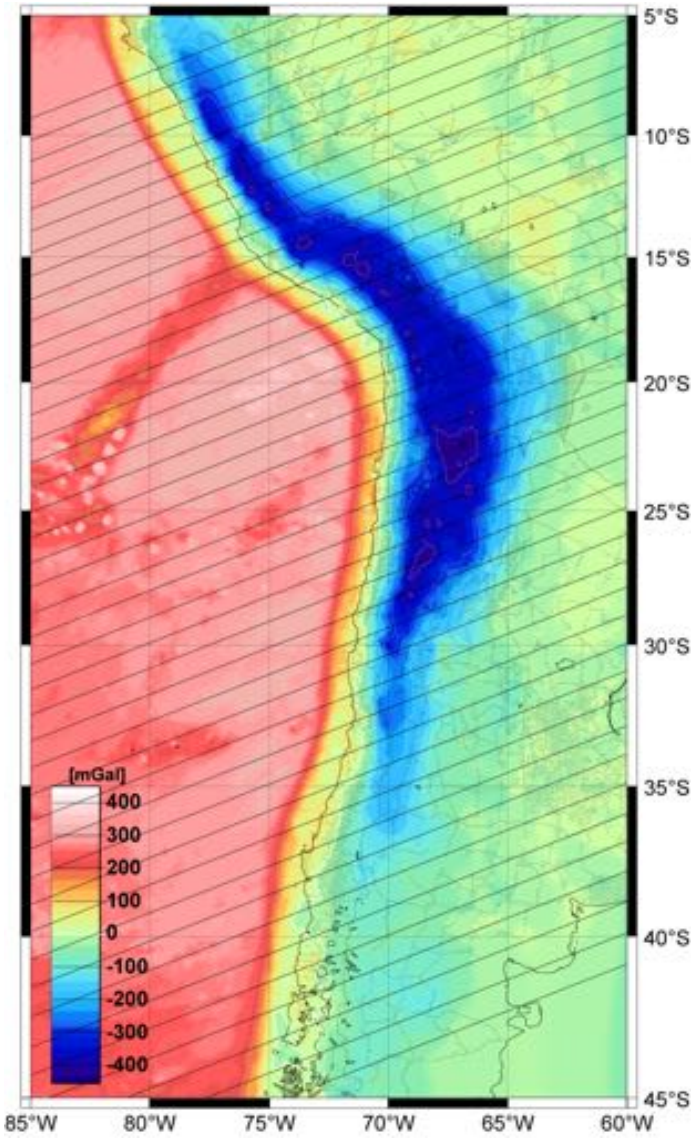


Volcanism

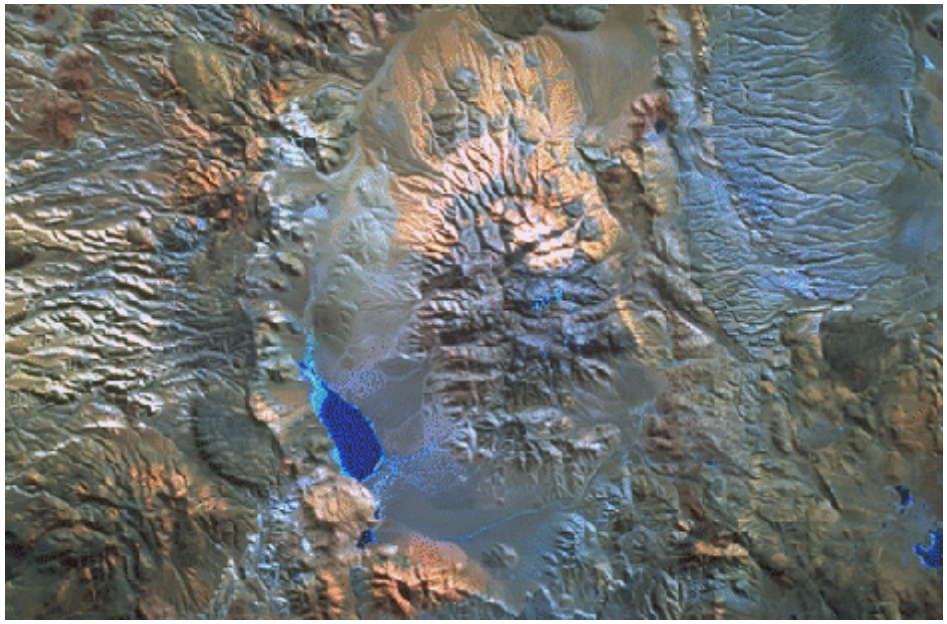

75°
70°
65°
15°
20°
25°
30°
35°
Peru
Bolivia
Chile
Argentina
Thin-skinned
Thick-skinned
Thin-skinned


La
Pacana
Lascar
10 km

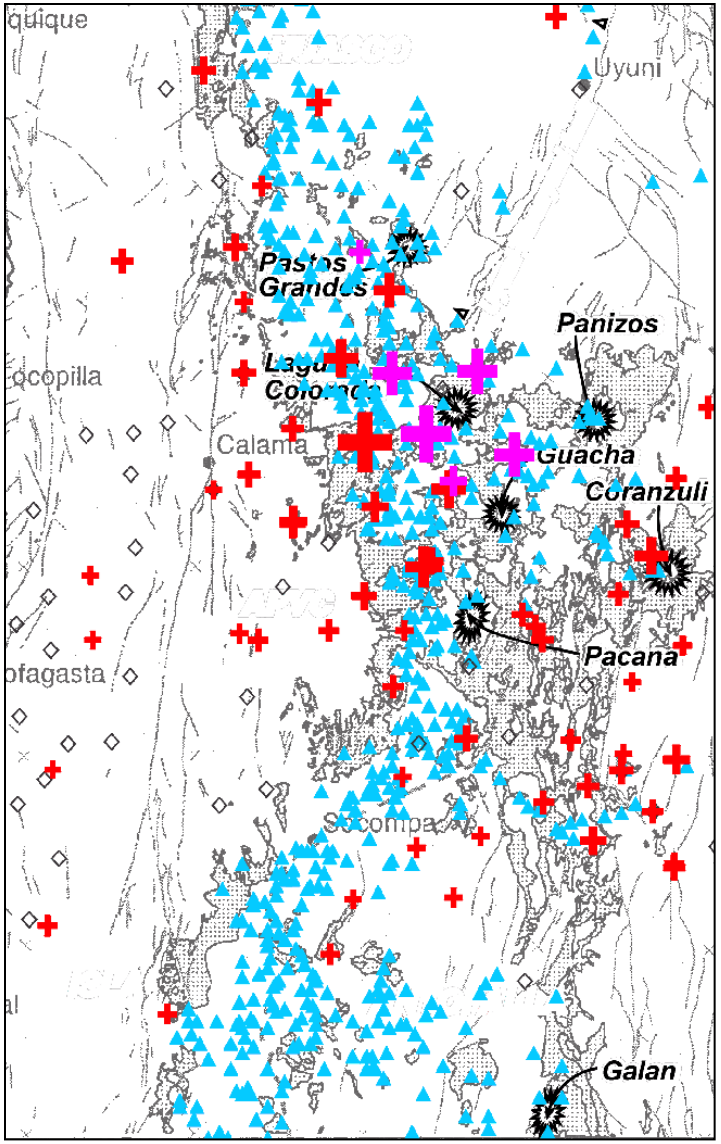
Plio-Pleistocene Volcanism



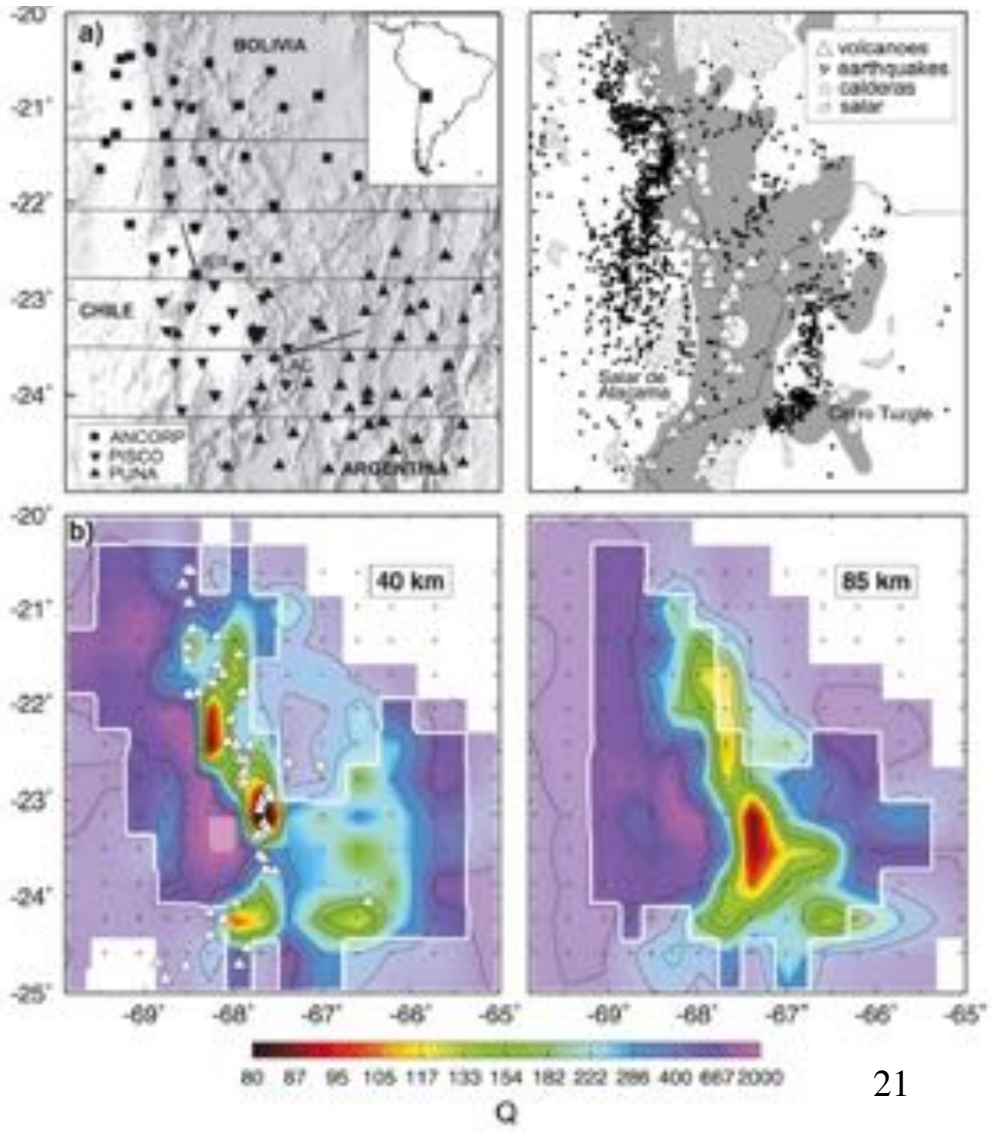
Tassara et al., 2006

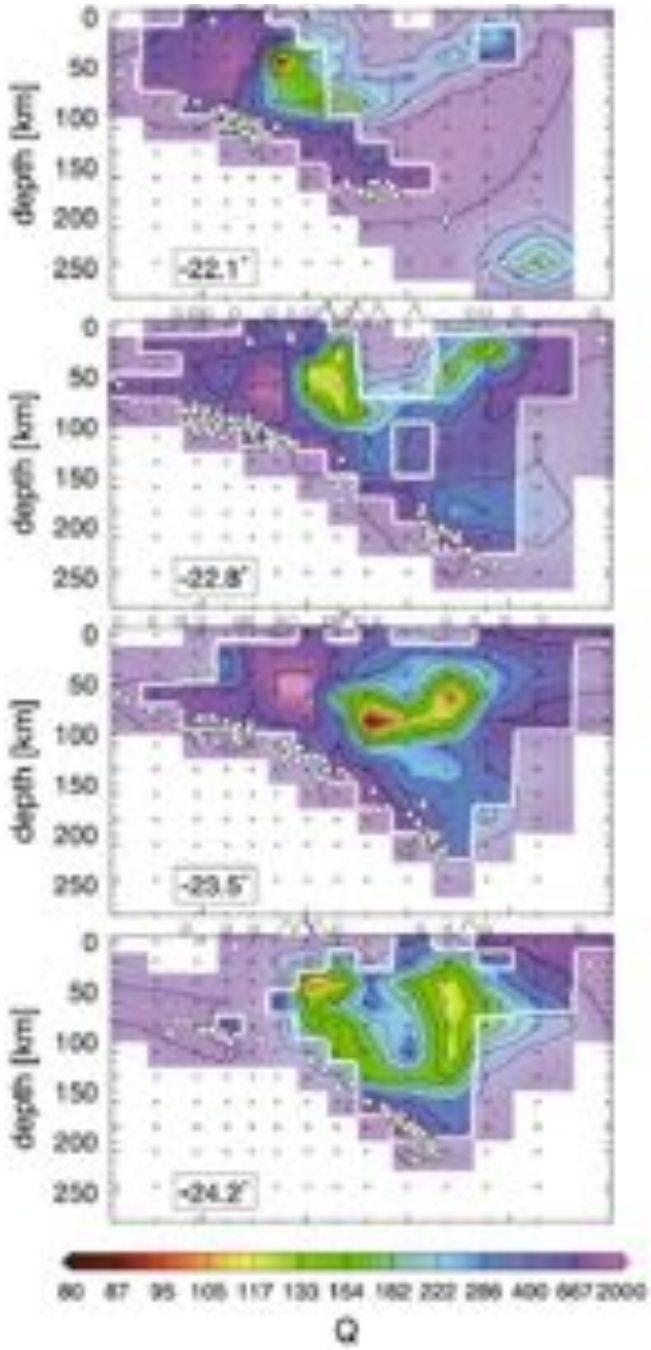


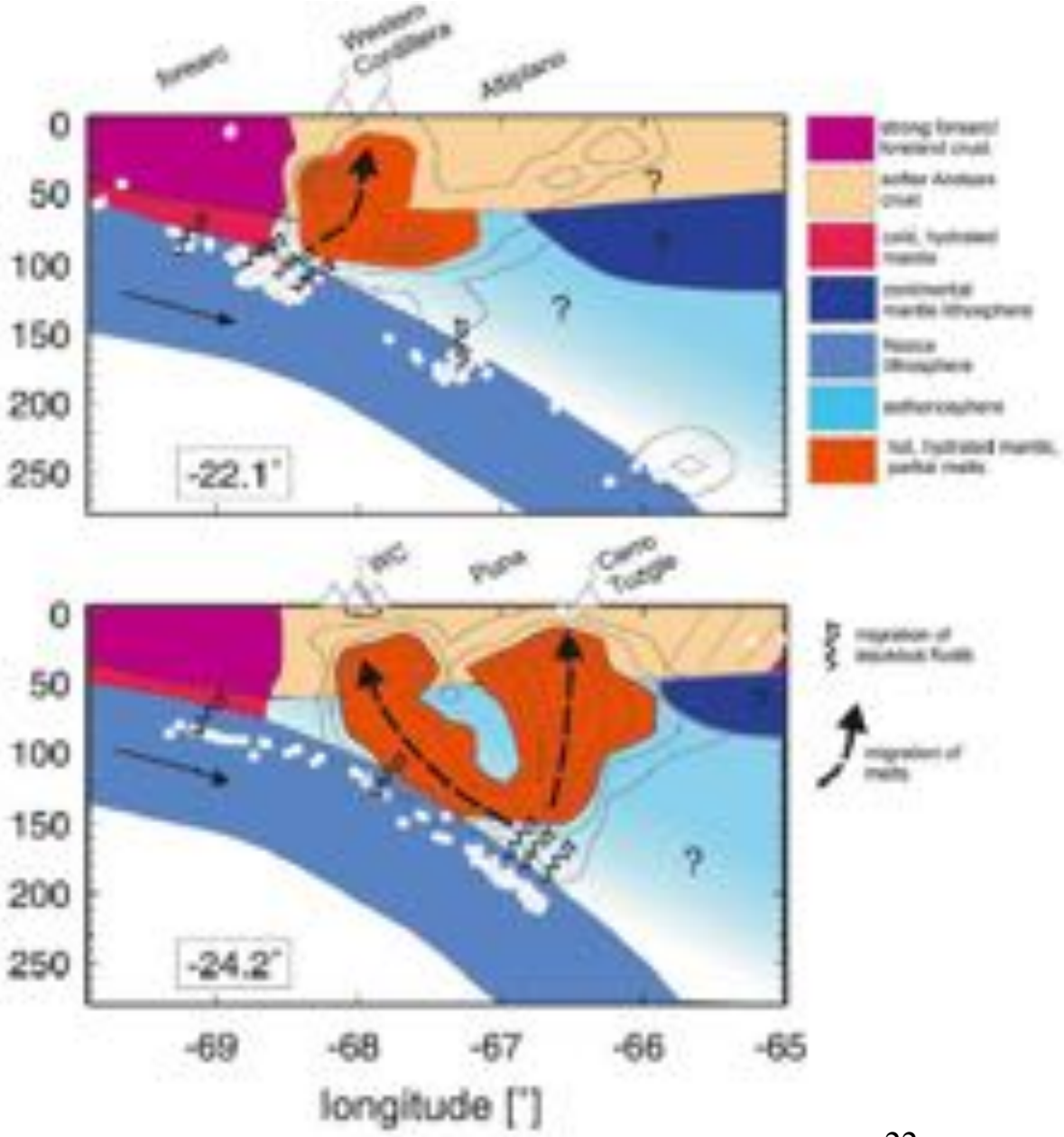
Attenuation tomography



Schurr et al., 2003; Haberland et al., 2004

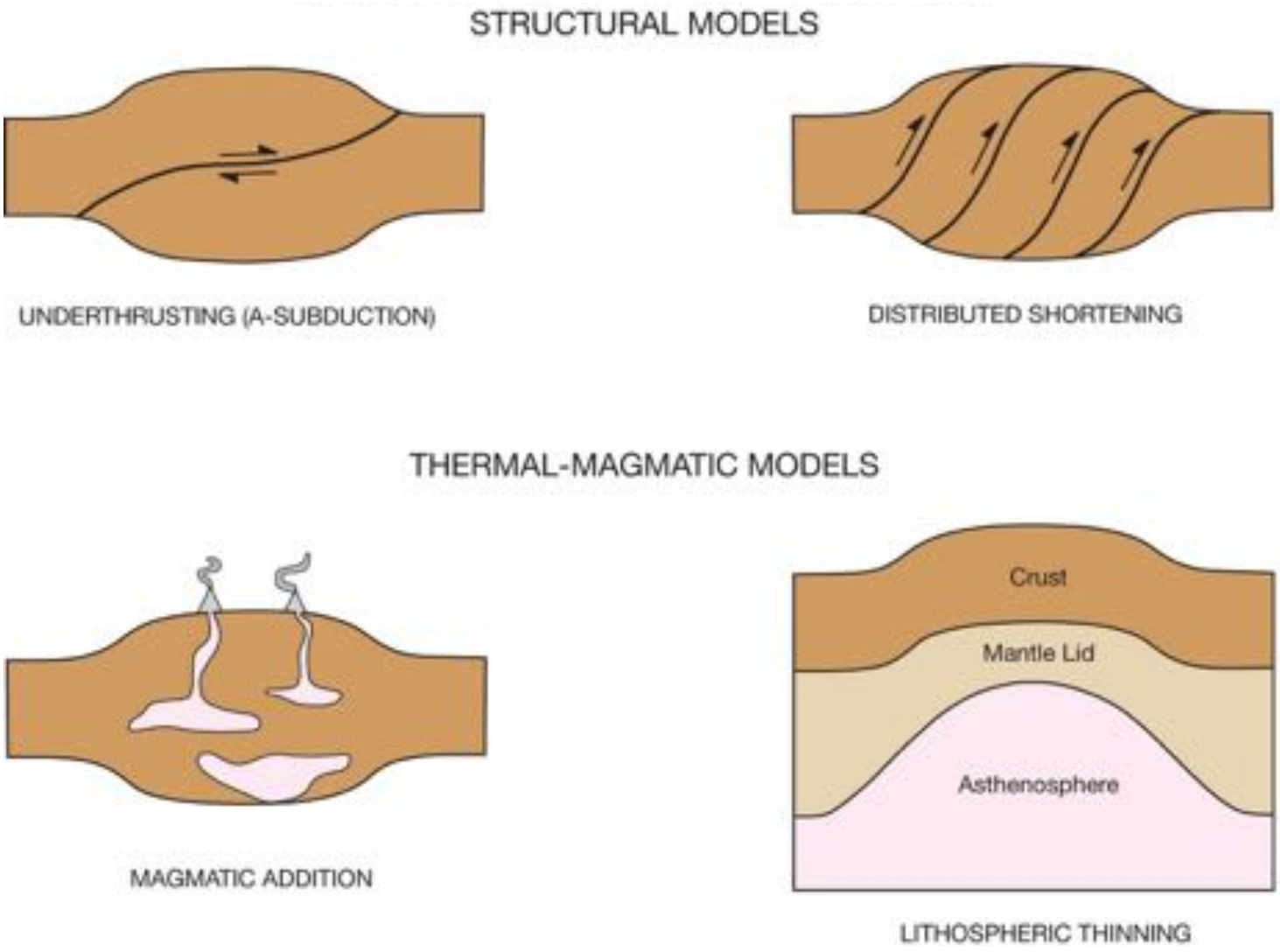






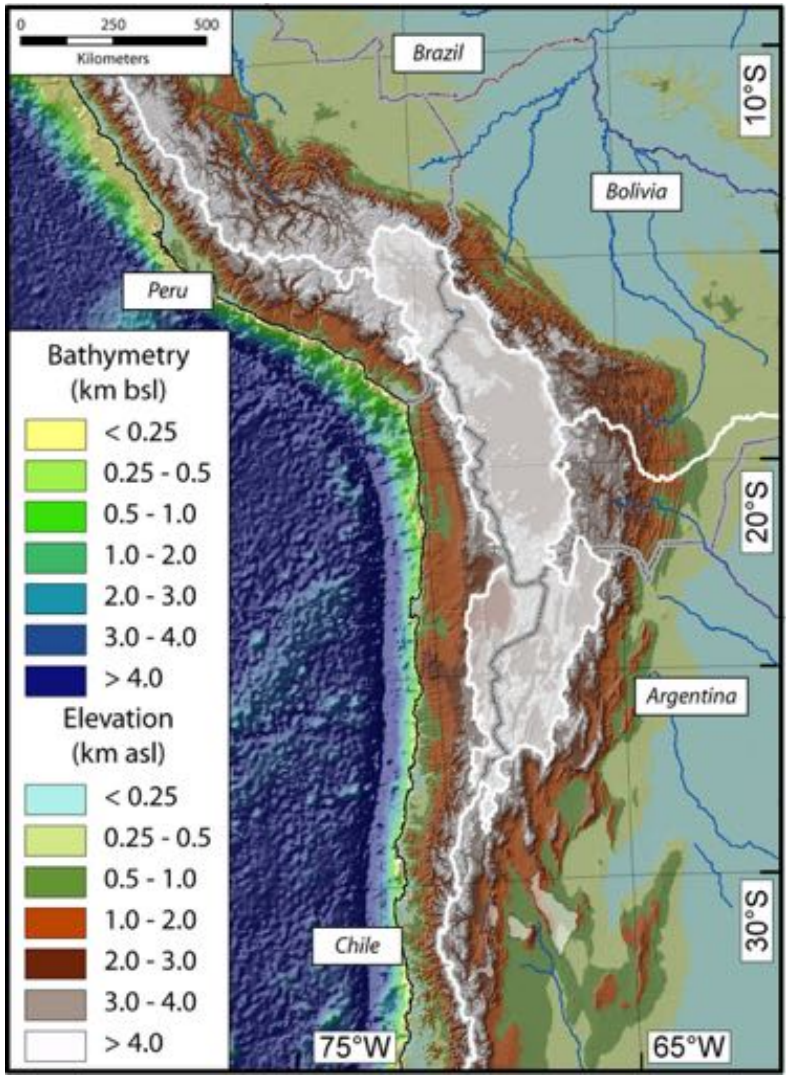
Schurr et al., 2003; Haberland et al., 2004

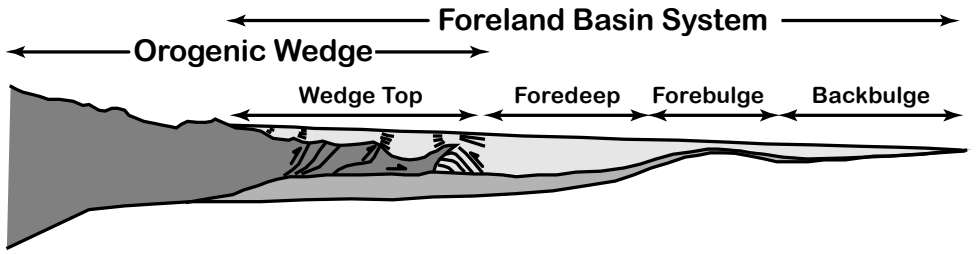
Mechanisms of plateau formation

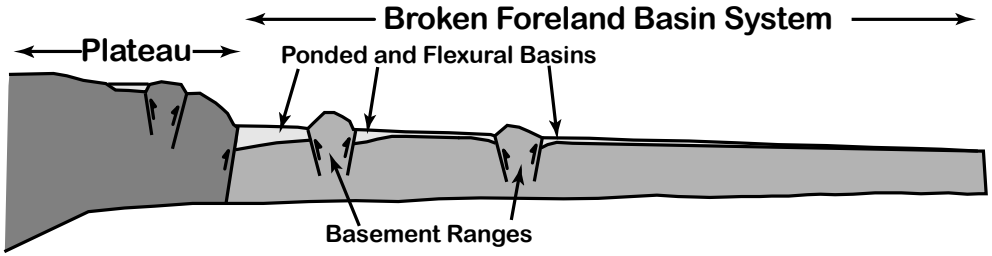


after Allmendinger (1986); Allmendinger et al., 1994

Different foreland deformation styles, plateau margins, sediment routing, and geomorphic evolution

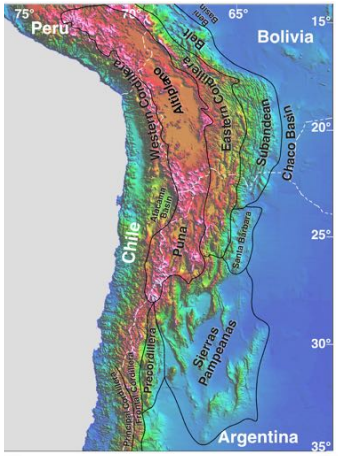






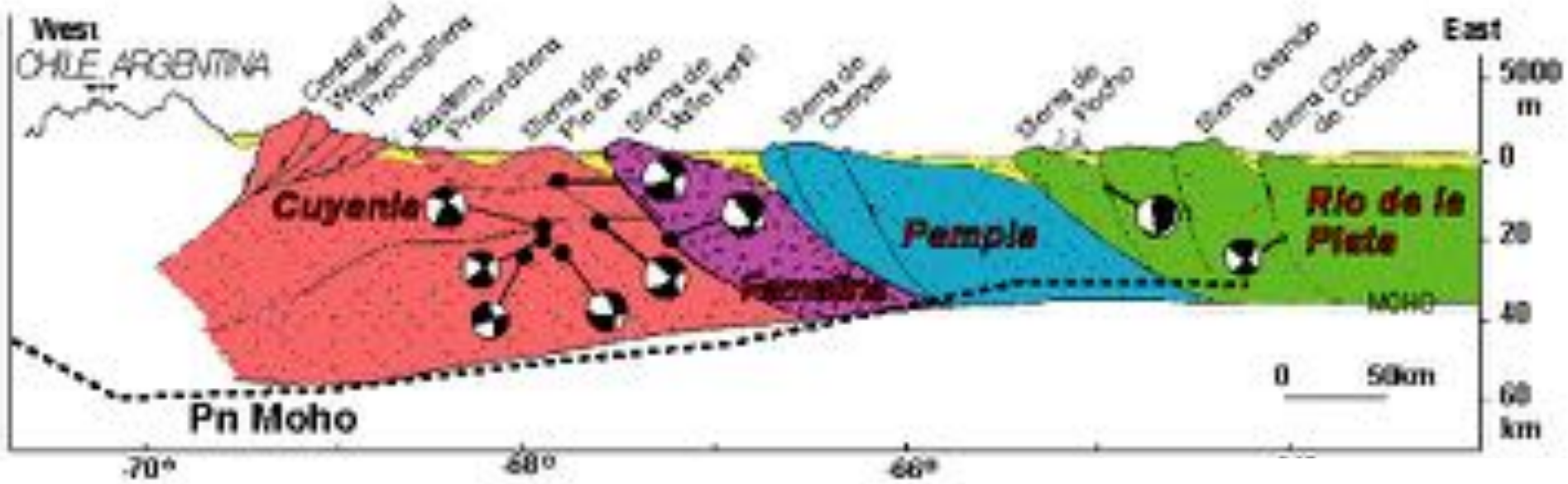
after DeCelles and Giles, 1996

Geologic cross-section at 31° S lat – flat-slab region



W

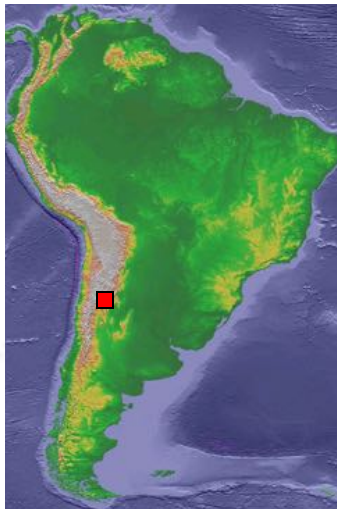
E

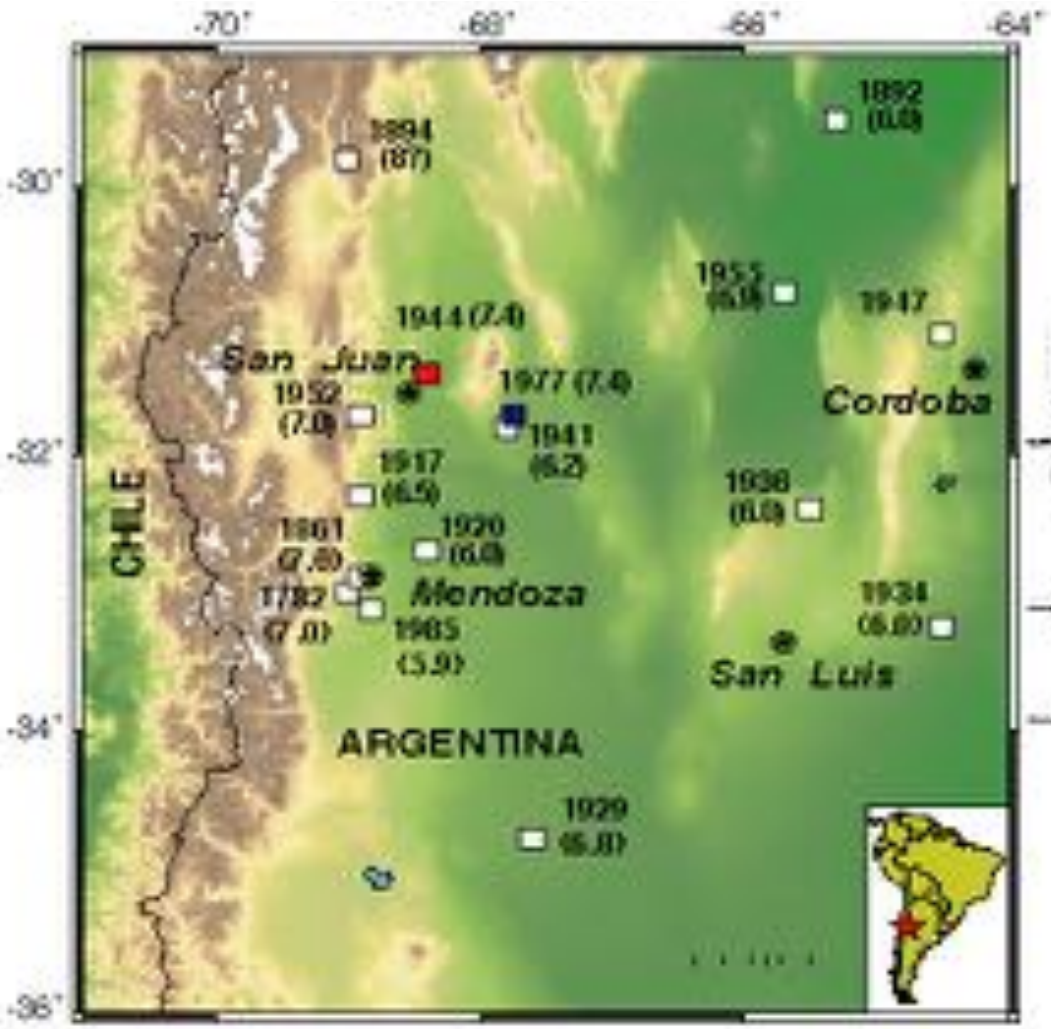


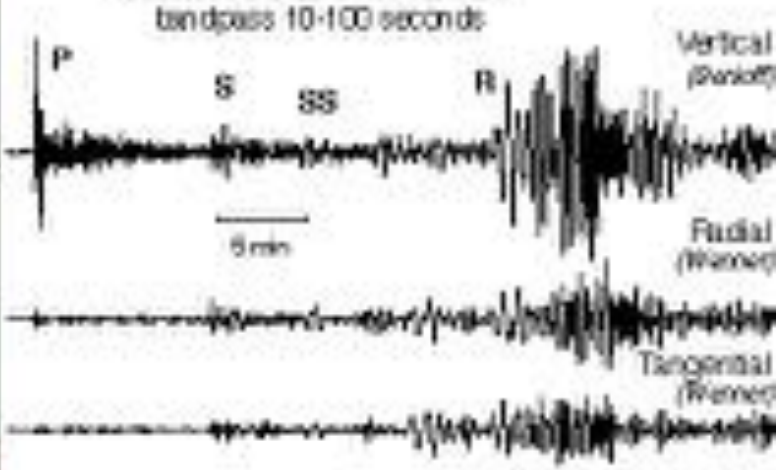
Modified from Ramos et al., 2002

Sierras Pampeanas

Historic seismicity

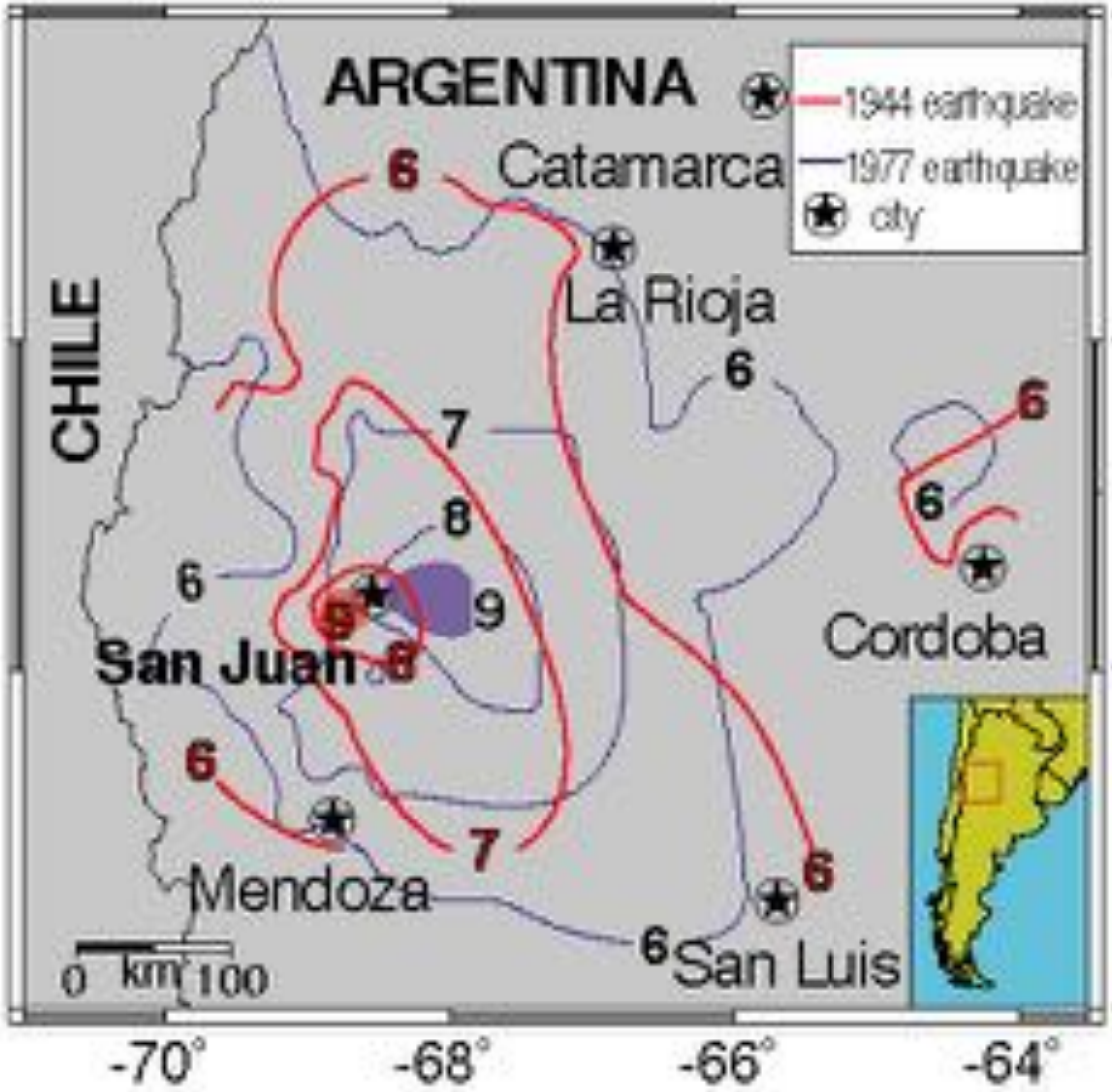






Courtesy of S. Beck, U Arizona

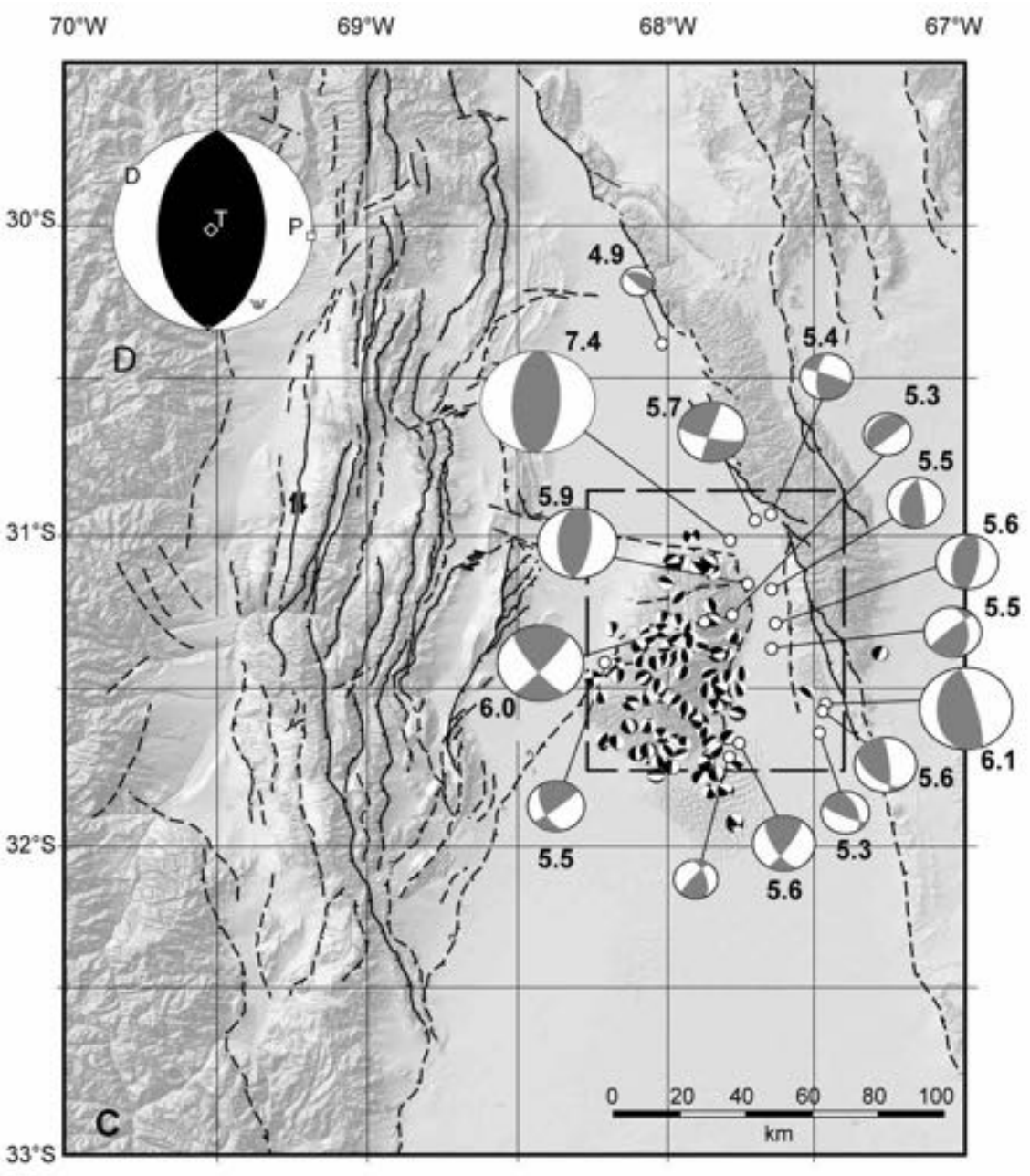
The 1944 San Juán earthquake



Damage around San Juan, Argentina after the 1944 (M=7.4) earthquake which killed 10,000 people and devastated 80% of the epicentral area. In 1977 another shallow earthquake (Ms=7.4) caused ~100 deaths. The 1944 event is considered the most destructive earthquake in Argentina history .

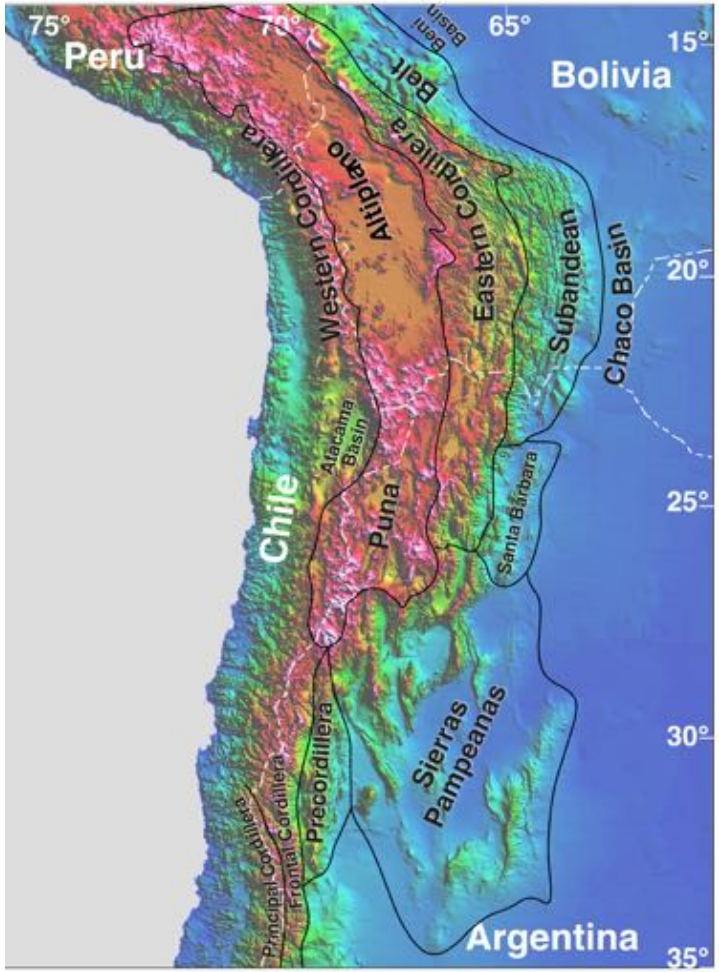
Courtesy of S. Beck, U Arizona

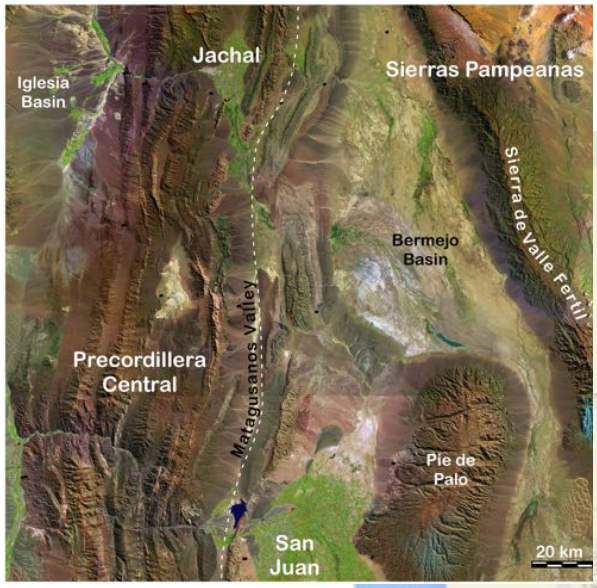
Depths & focal mechanisms of crustal earthquakes



Alvarado et al., 2004;
Siame et al., 2006

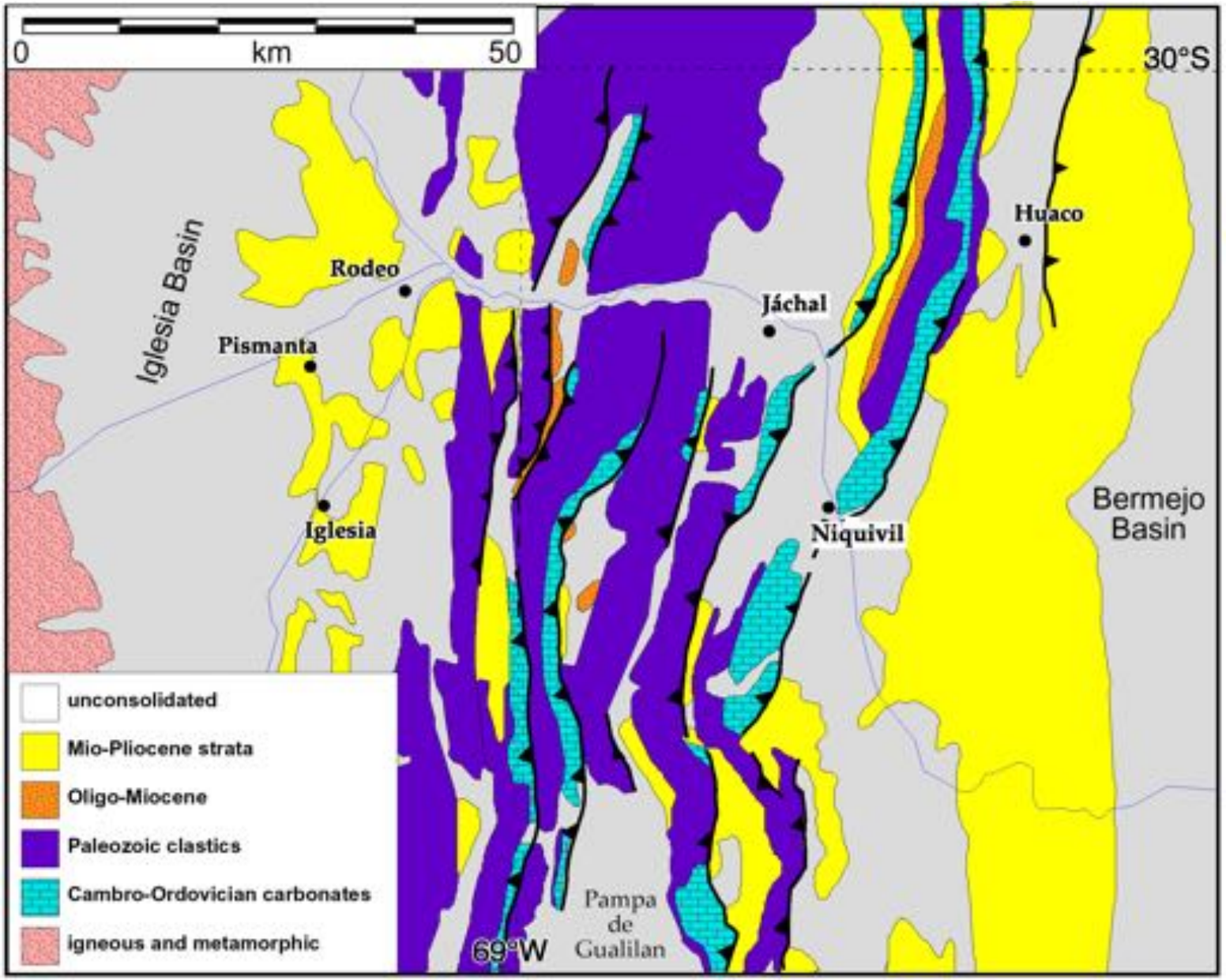
The flat-slab region: Precordillera & Sierras Pampeanas provinces



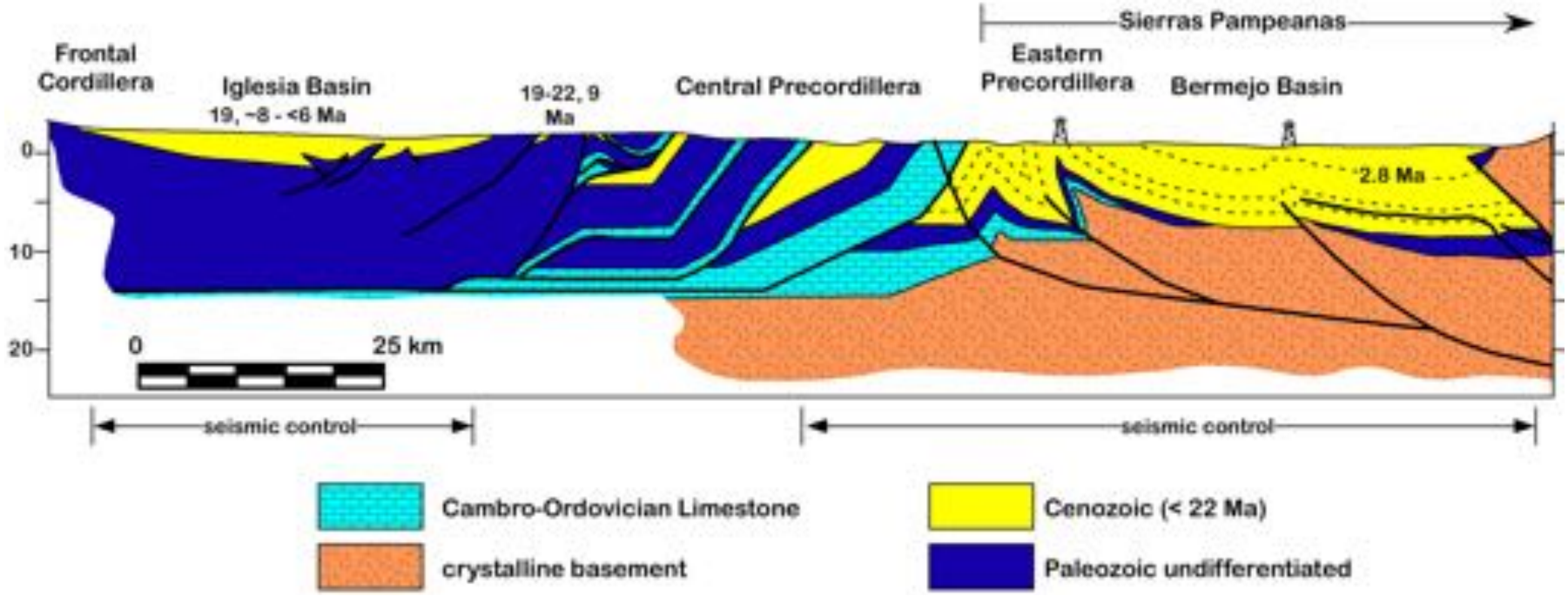


Modified after Jordan et al., 1983 and Cahill et al., 1988

Geologic map of the Precordillera along Río Jáchal

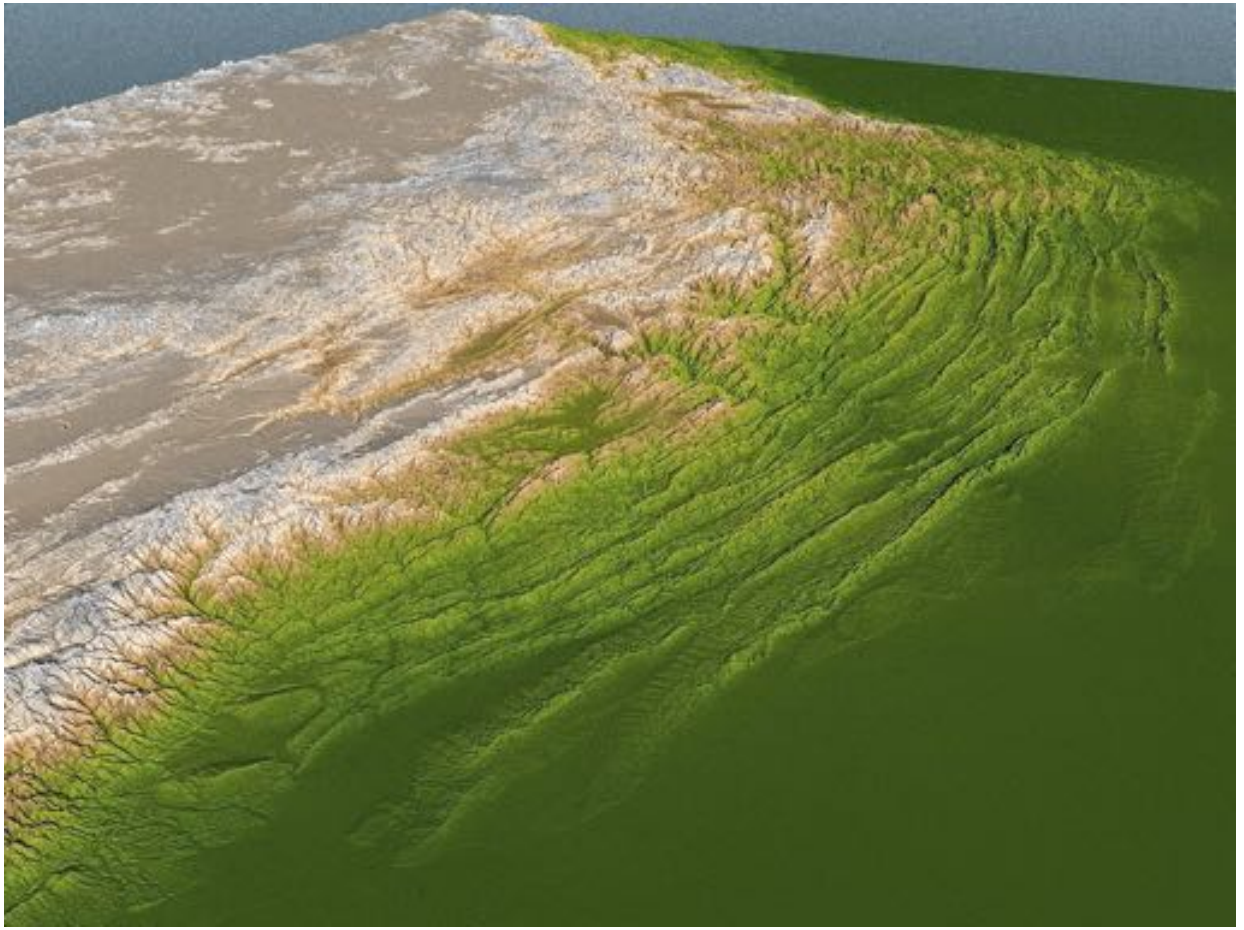


Structure section of the Precordillera at 30° S lat: thin-skinned vs. thick-skinned tectonics

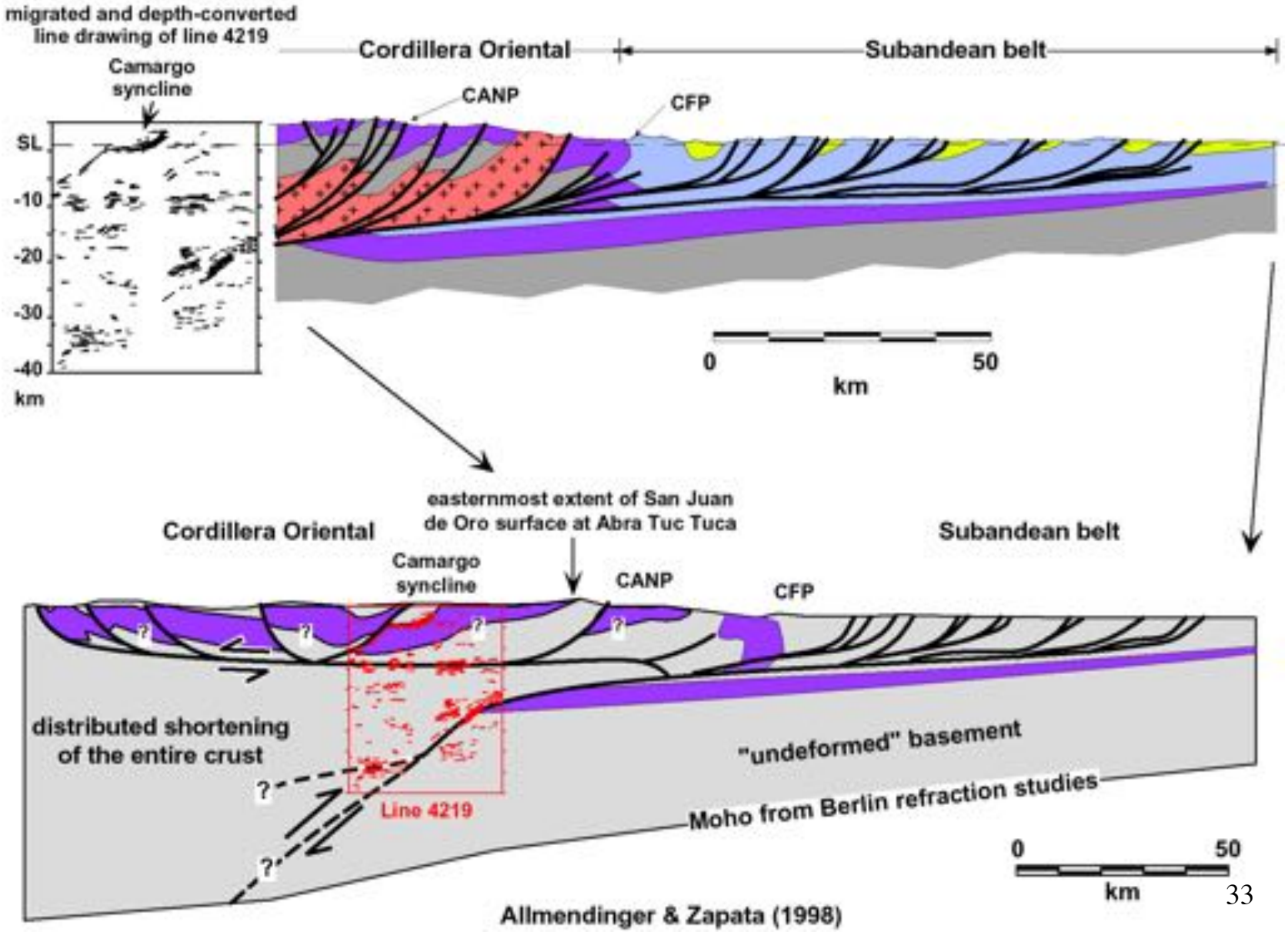


Allmendinger et al., 1990; Beer and Allmendinger, 1990; Zapata and Allmendinger, 1996
Figure courtesy of Rick Allmendinger

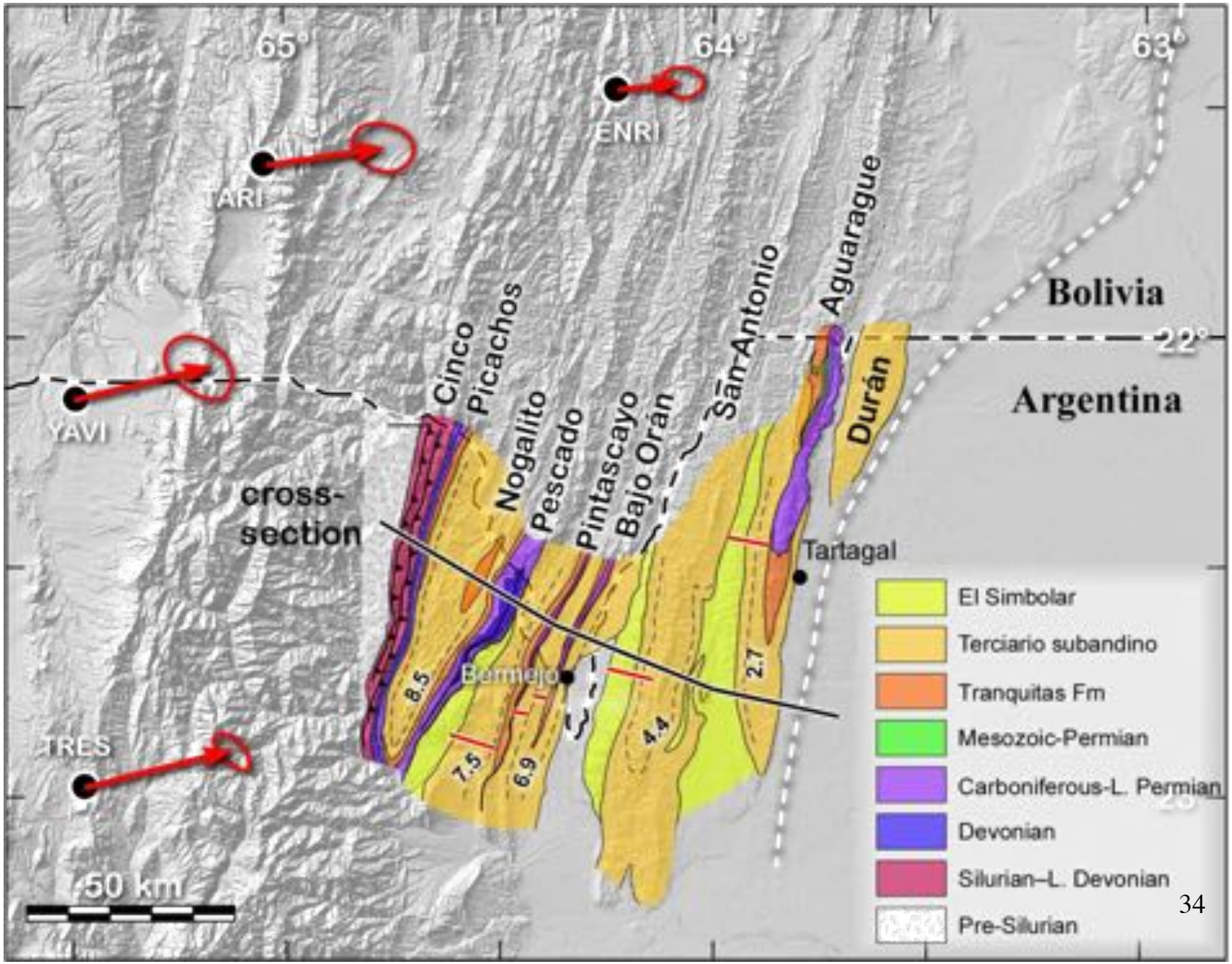
Subandes & Eastern Cordillera



Roots of the Southern Subandean Belt

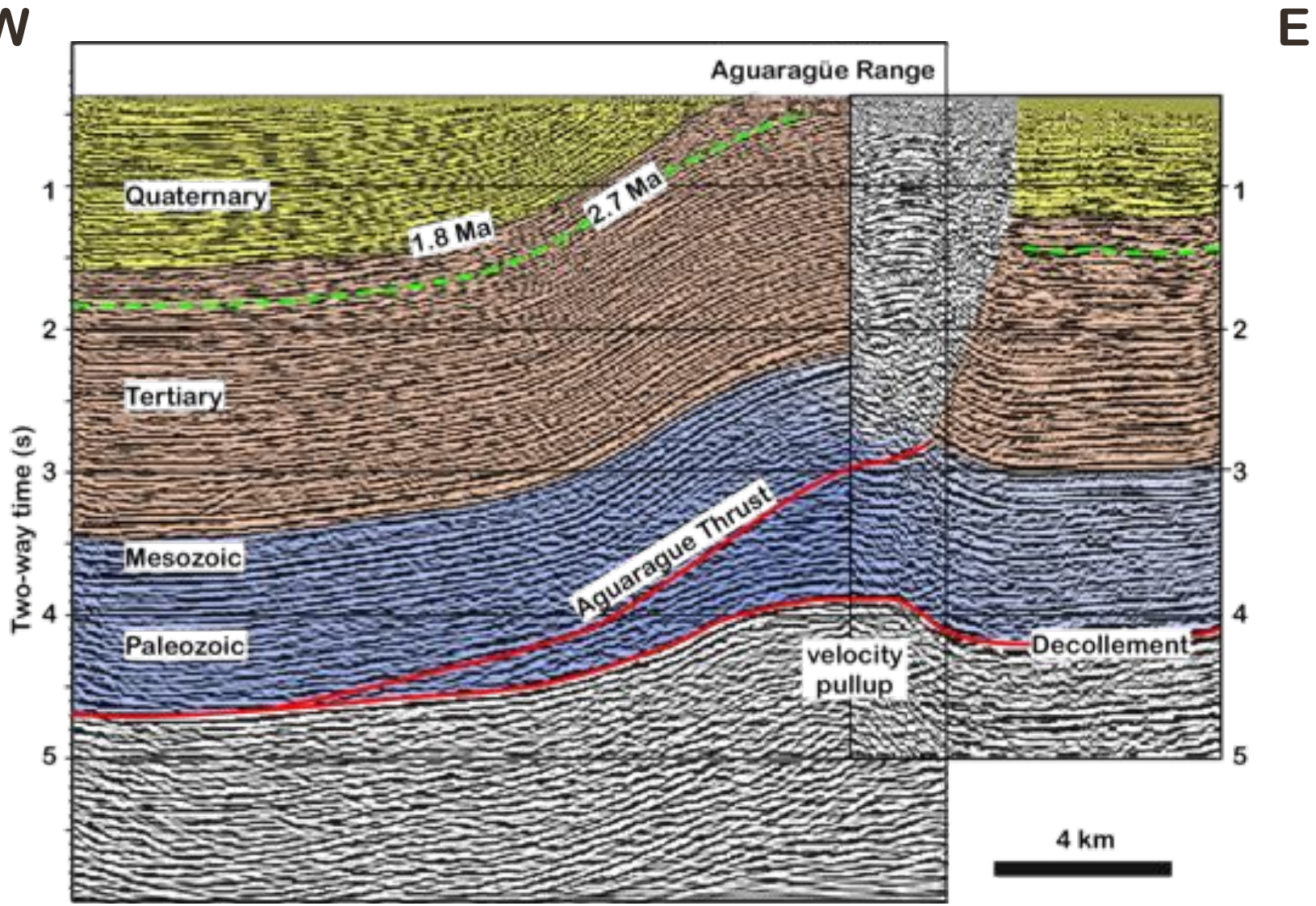


Geology of the Southern Subandean thrust belt



Echavarría et al. (2003), AAPG

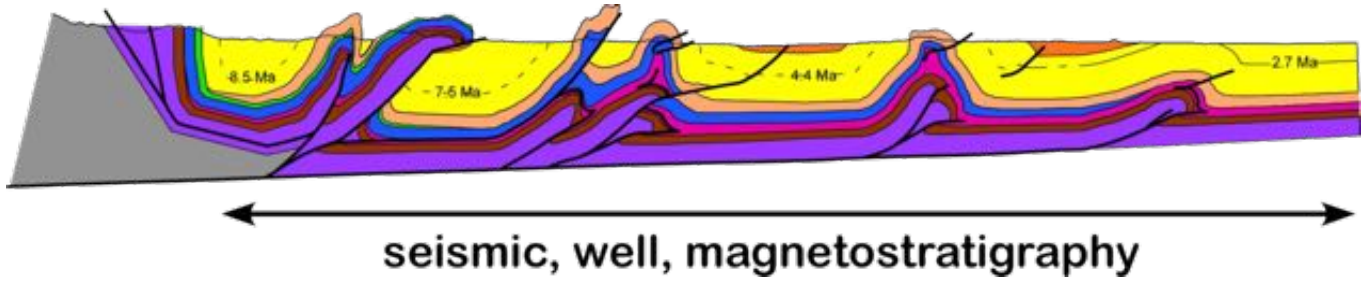
Subandean growth strata

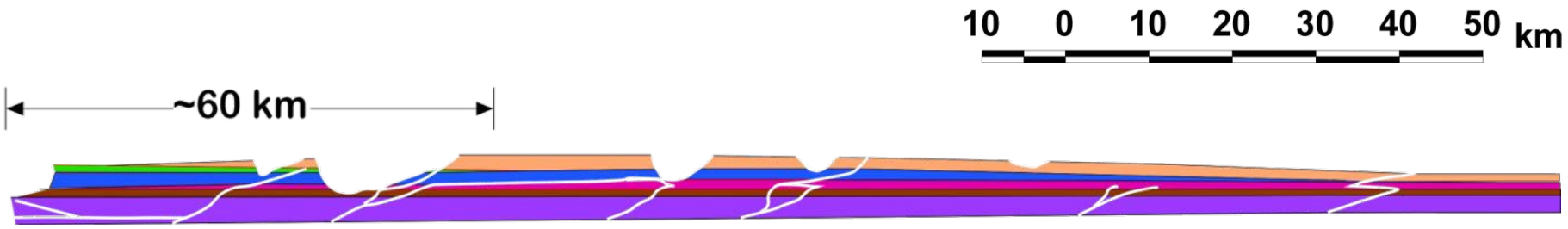


Echavarría et al. (2003), AAPG

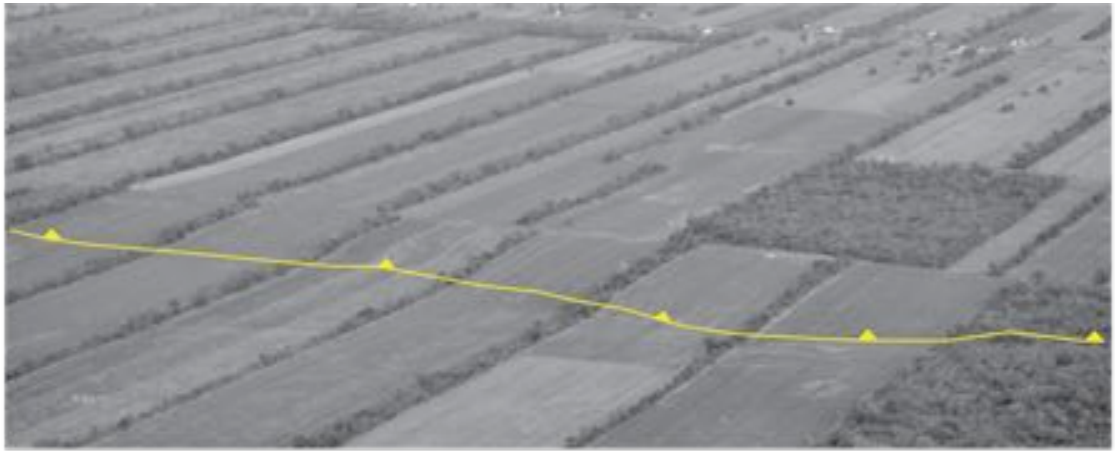
Systematic eastward-directed shortening in the Subandean Belt

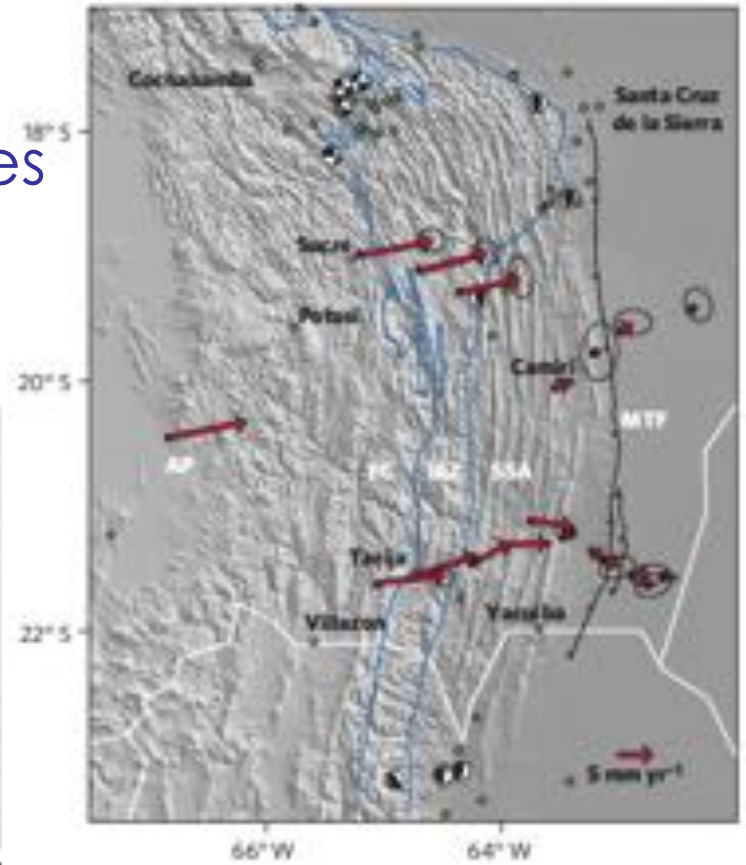
Echavarría et al. (2003, AAPGB)

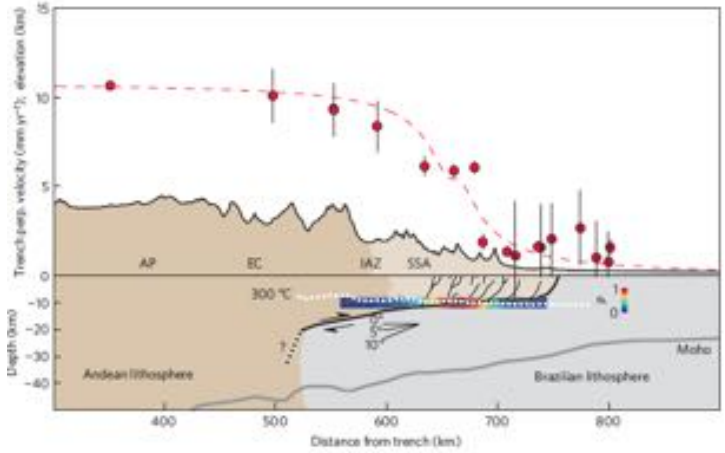




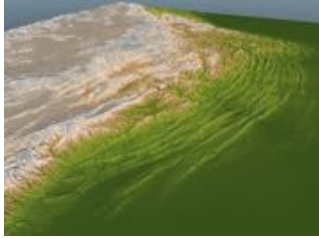
Freely moving fault in W, locked fault in the E – but large earthquakes may be generated on youngest faults in thrust belt



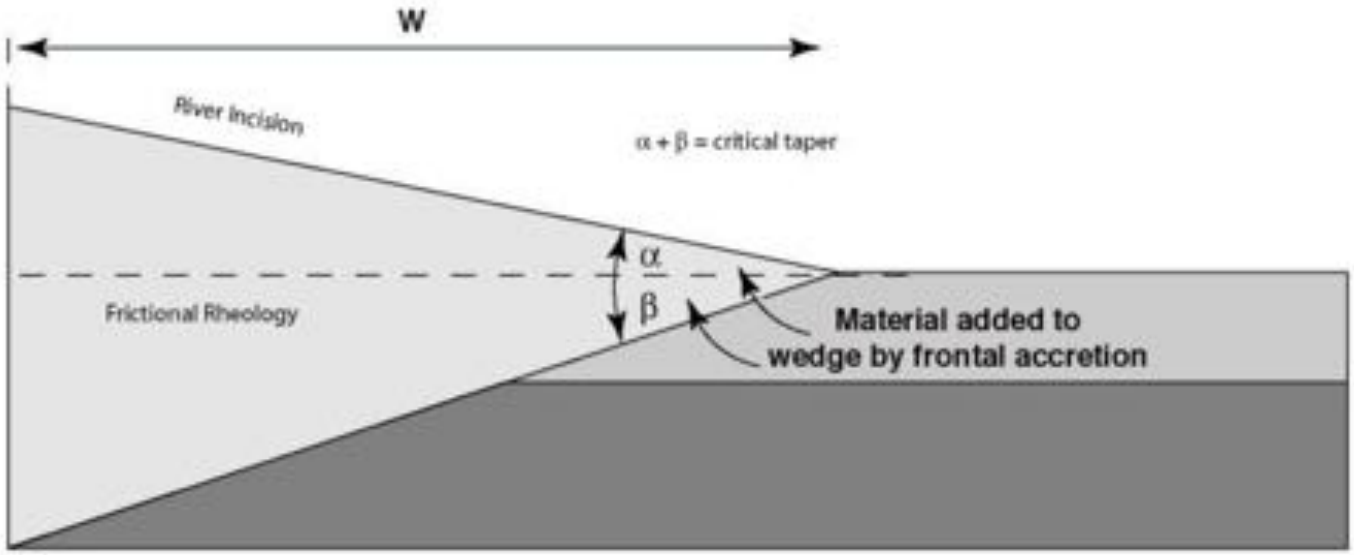


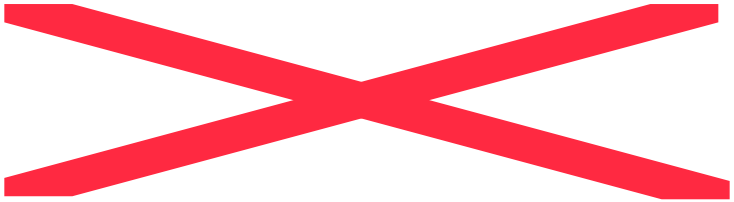


Brooks et al., Nature Geoscience, 2011

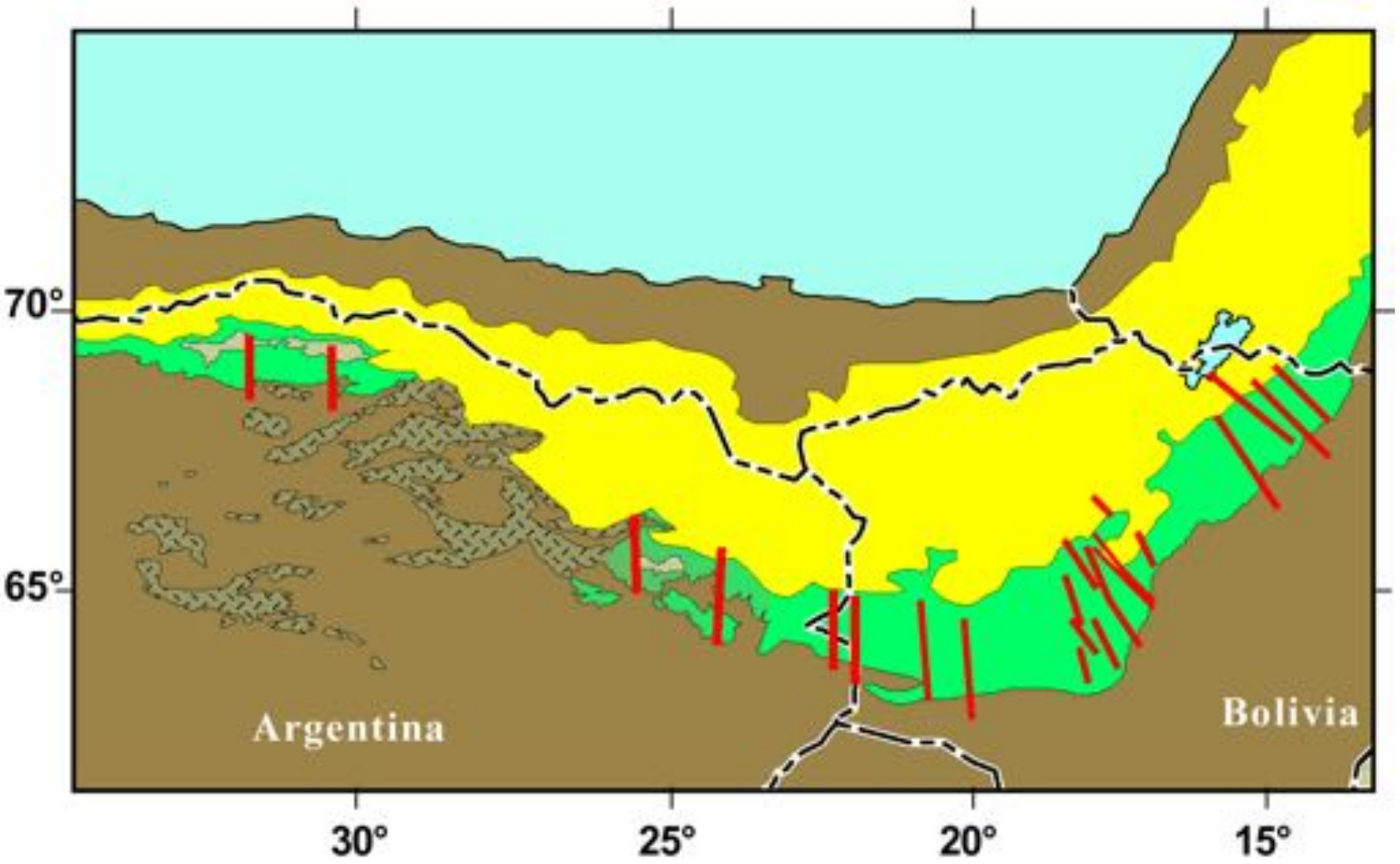


Orogenic wedges of the Eastern Andes

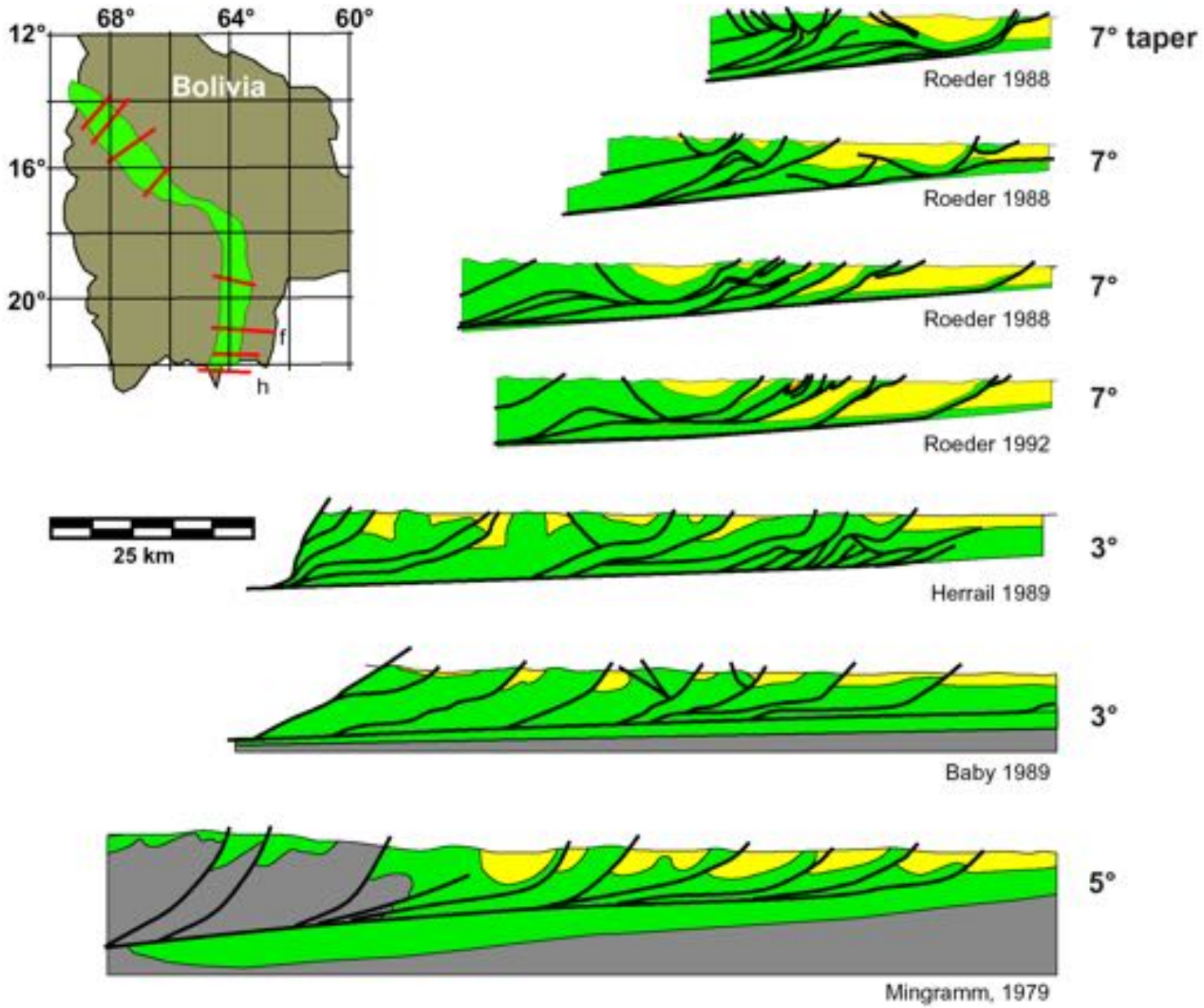




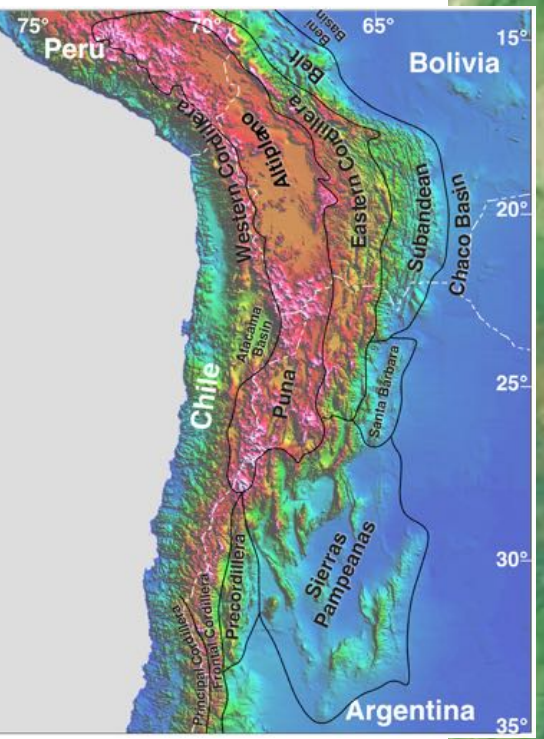
Locations of balanced cross-sections

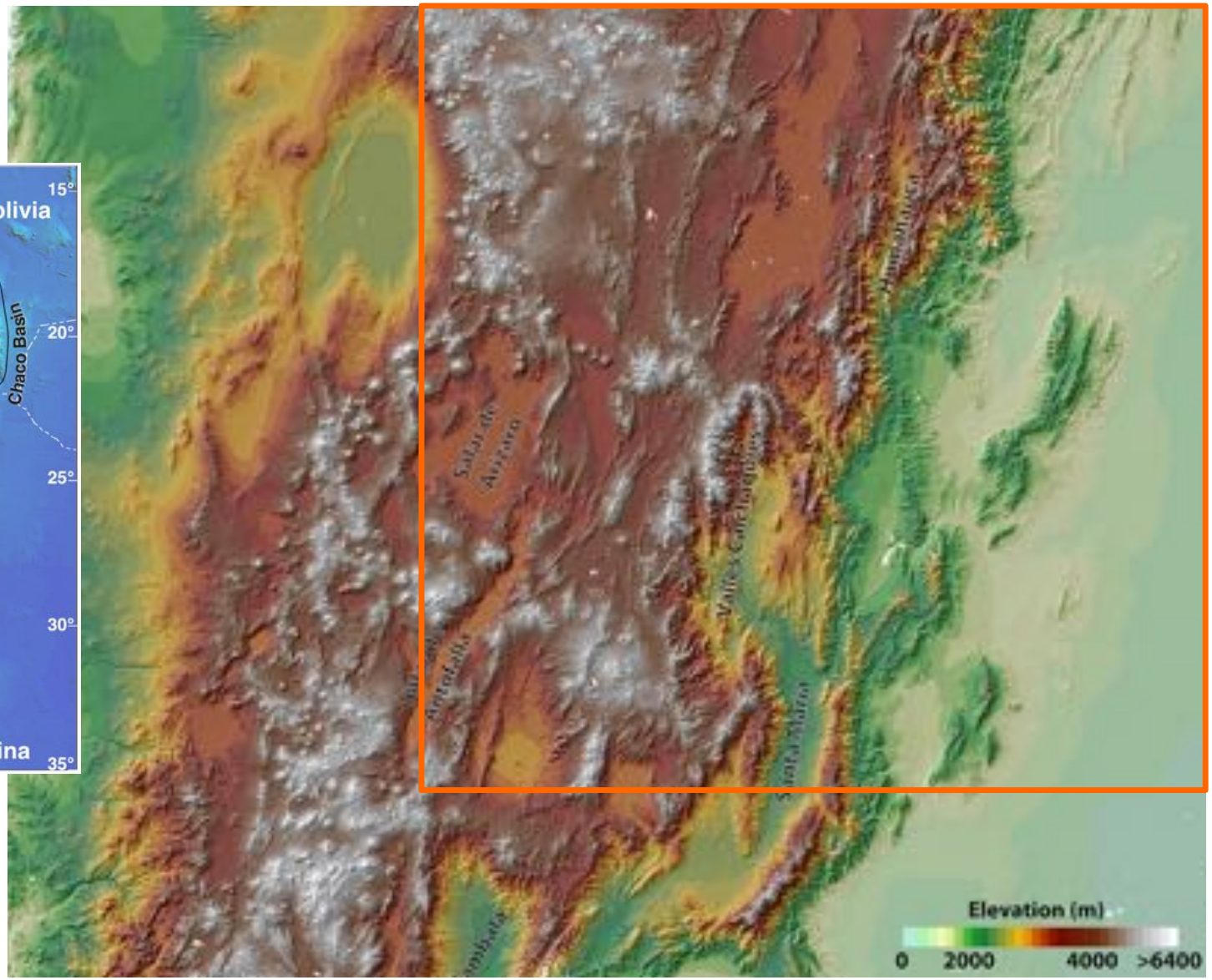


Subandean Belt in Bolivia

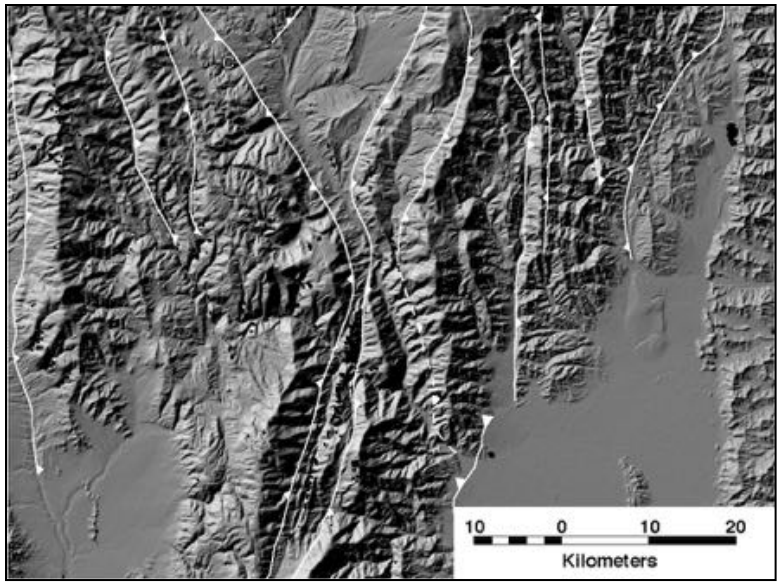


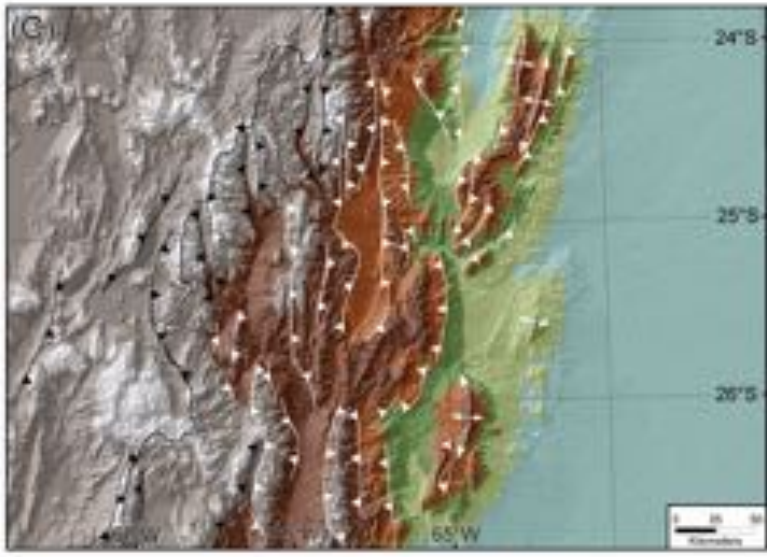
The Santa Barbara System – a region of unsystematic, disparate broken-foreland deformation

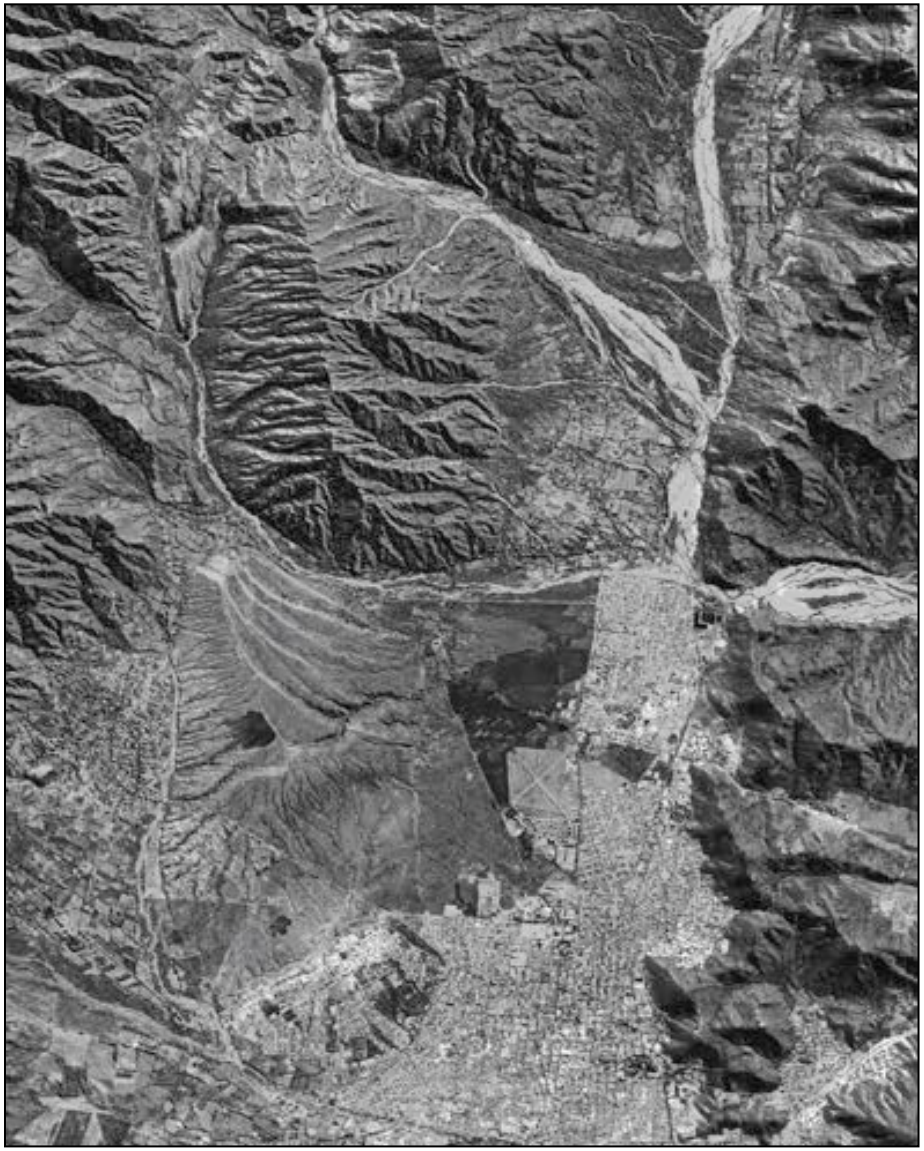




Inherited structure, basin geometry, fluvial networks and sediment dispersal

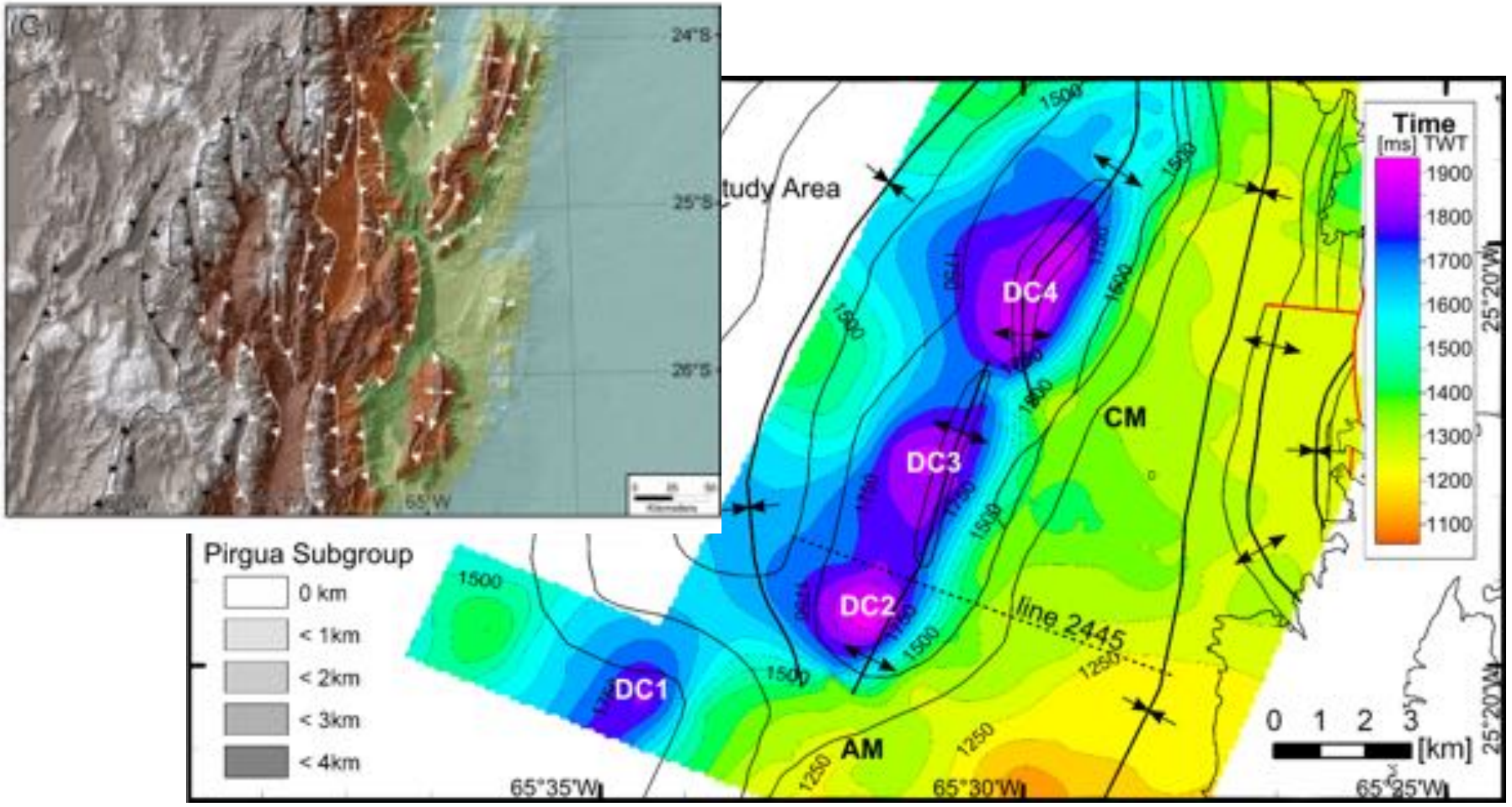






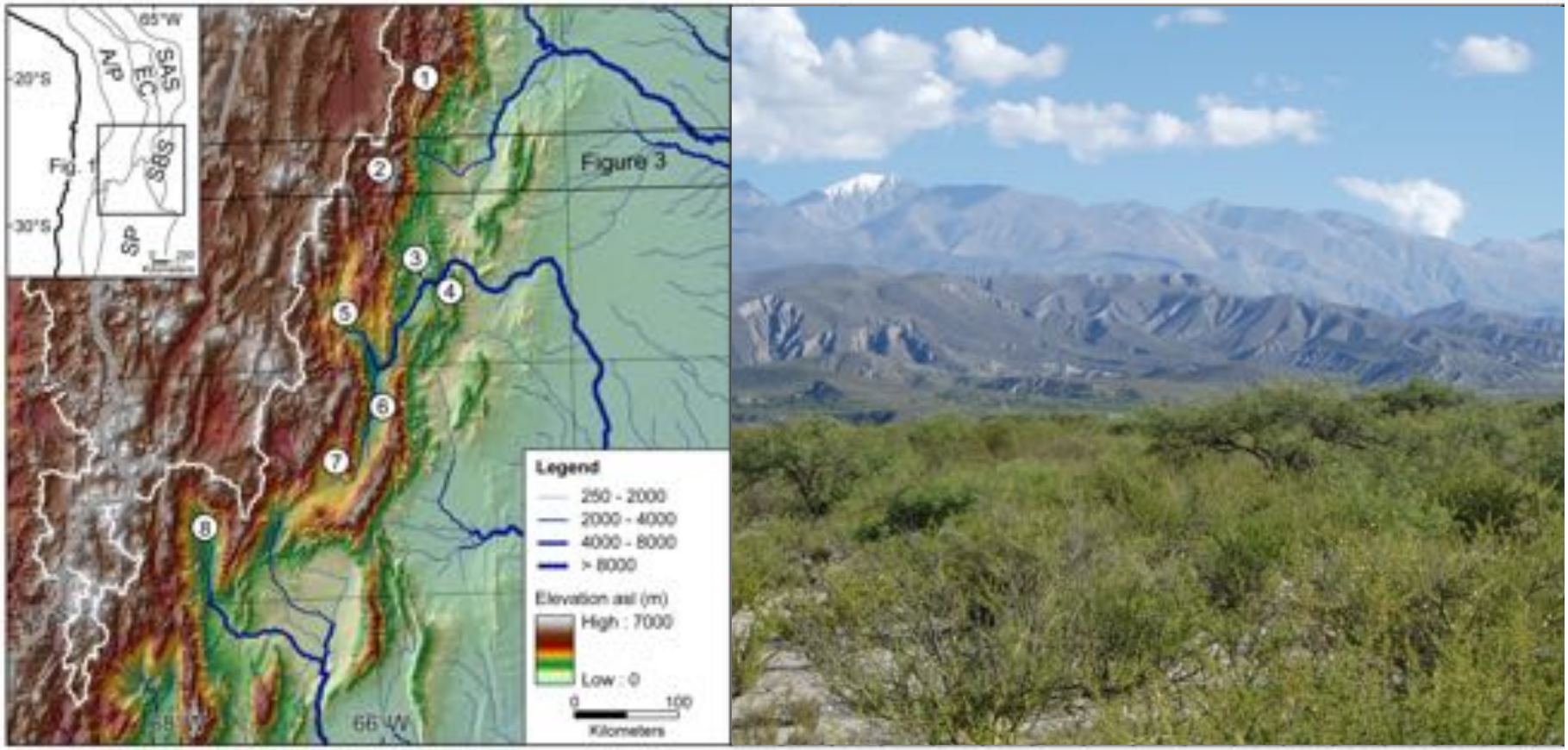
Hain et al., 2011, Tectonics

Contractile reactivation of rift structures and evolution of fluvial networks



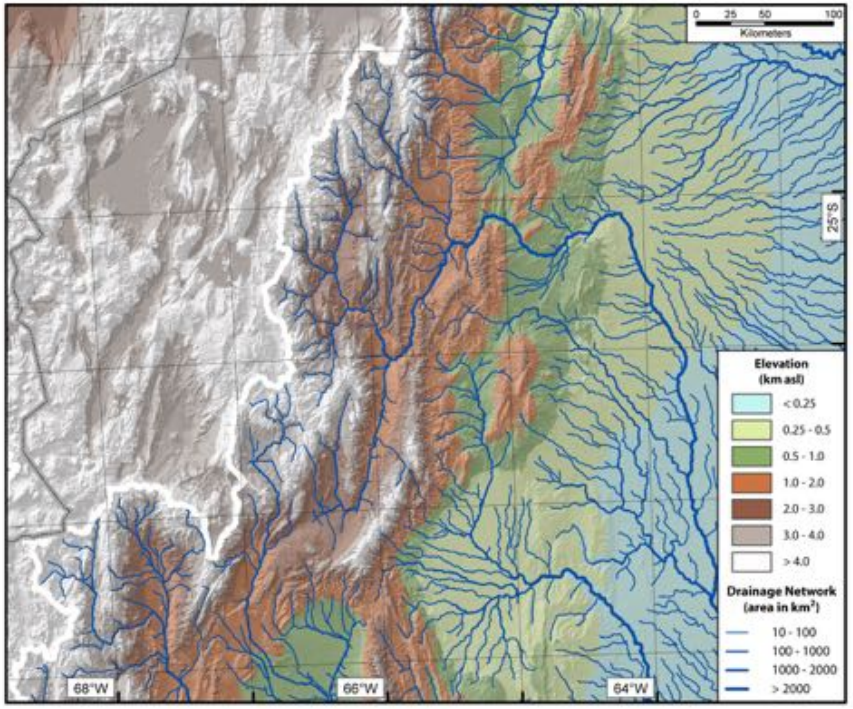
Based on seismic reflection data by YPF; Hain et al., 2010, Tectonics

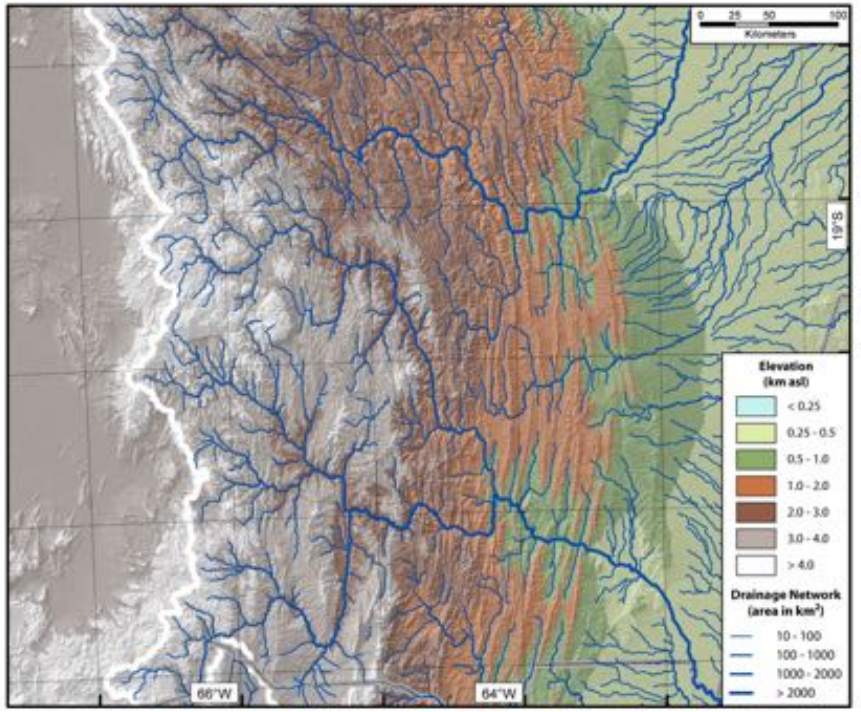
Spatiotemporal characteristics of broken-foreland deformation: the fate of sediments during alternating fluvial isolation and foreland connectivity



Bossi et al., 2001, JSAES; Strecker et al., 2009, Geology

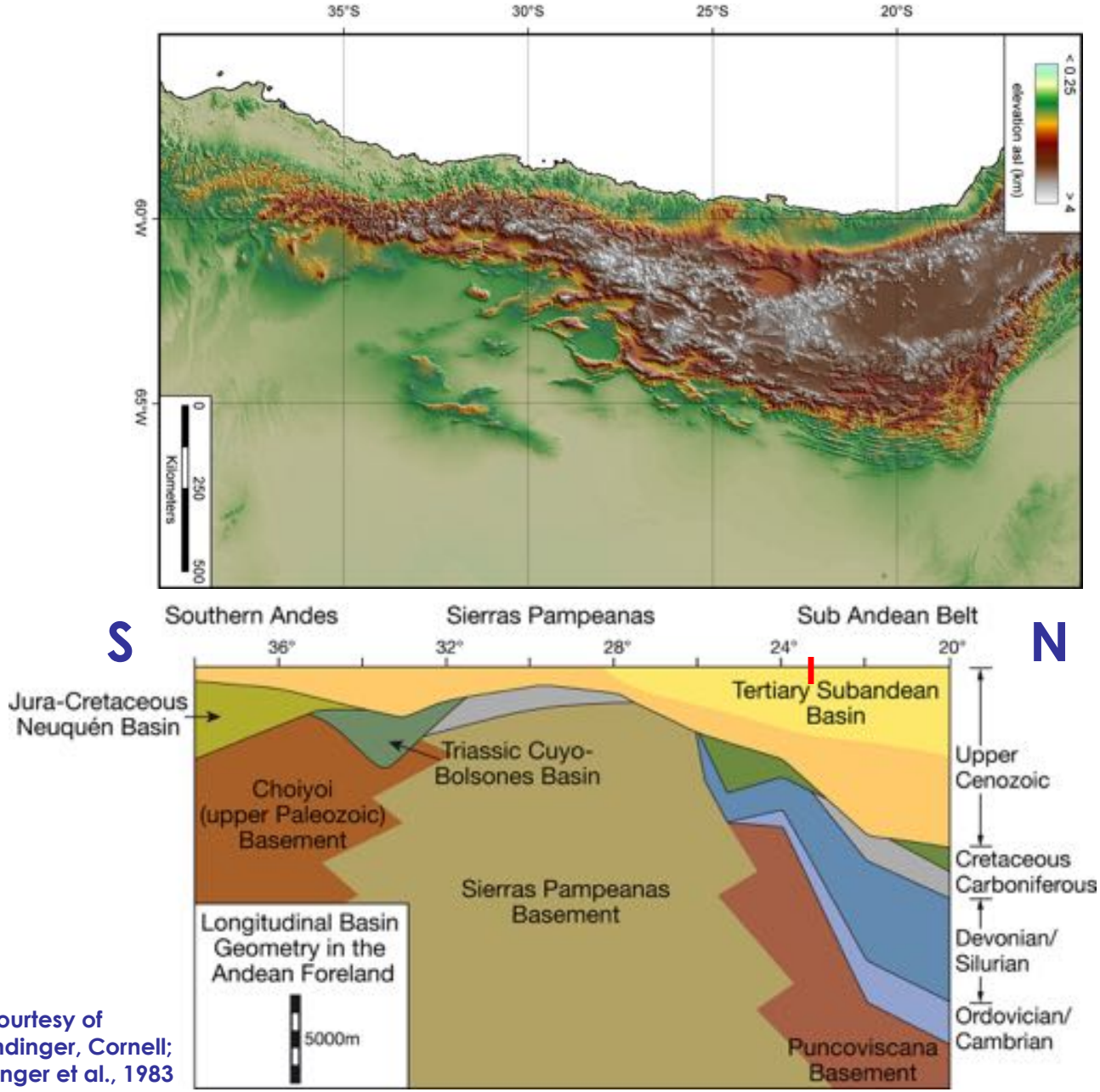
Structurally controlled drainage systems in the broken foreland and the Subandean fold-and-thrust belt: consequences for sediment storage and dispersal





Strecker et al., 2012; Tectonics of Sedimentary Basins, Wiley & Sons, London,

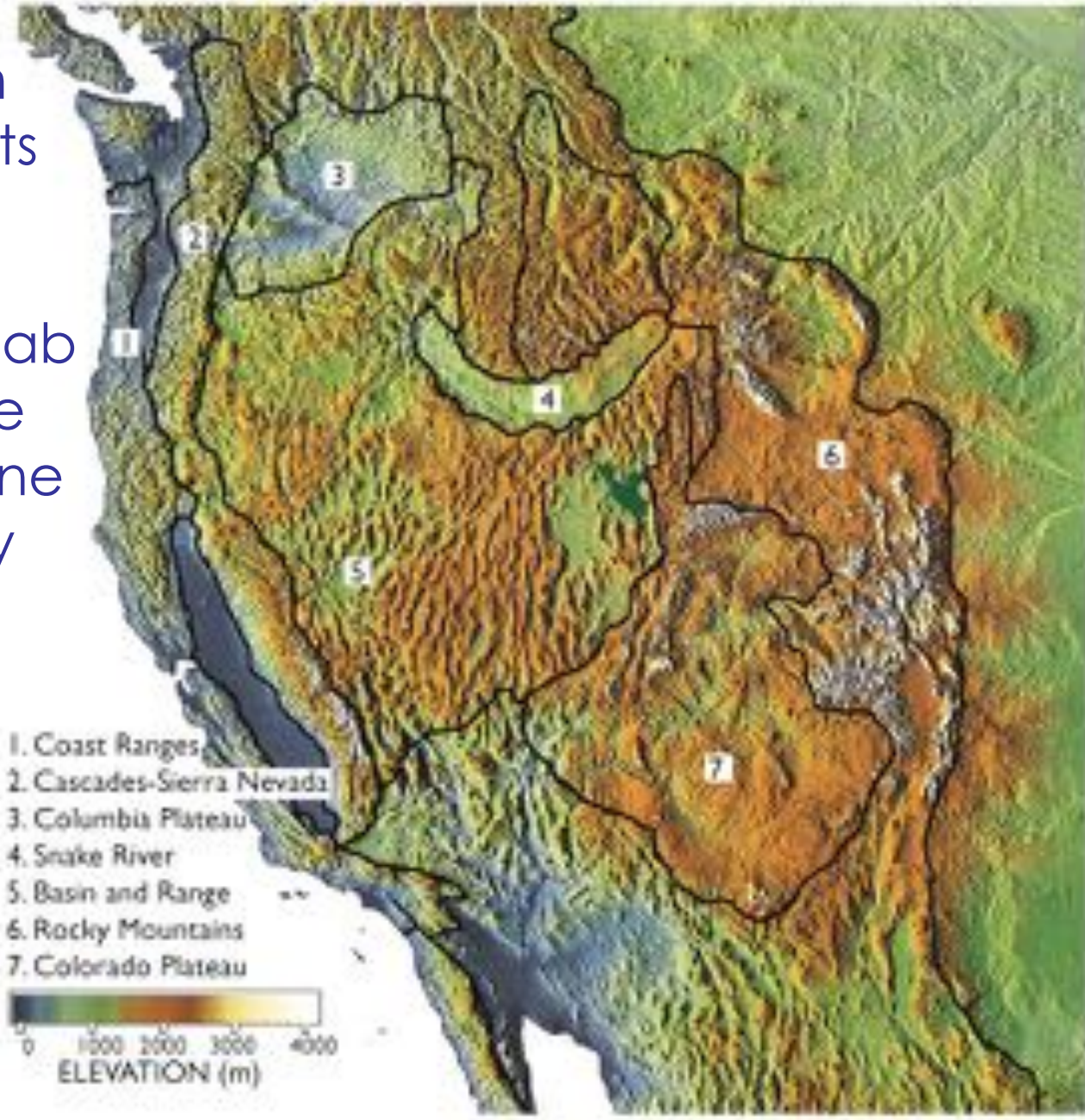
Reactivated basement anisotropies



Figure, courtesy of R. Allmendinger, Cornell; Allmendinger et al., 1983

Similar scenarios in other mountain belts

An example from N America: the flat-slab subduction and the **Cretaceous** to Eocene Laramide Orogeny



Spatiotemporally disparate basement uplifts in a broken foreland, no well-defined deformation front

All diagrams from Lillegraven et al., 2004; Rocky Mountain Geology

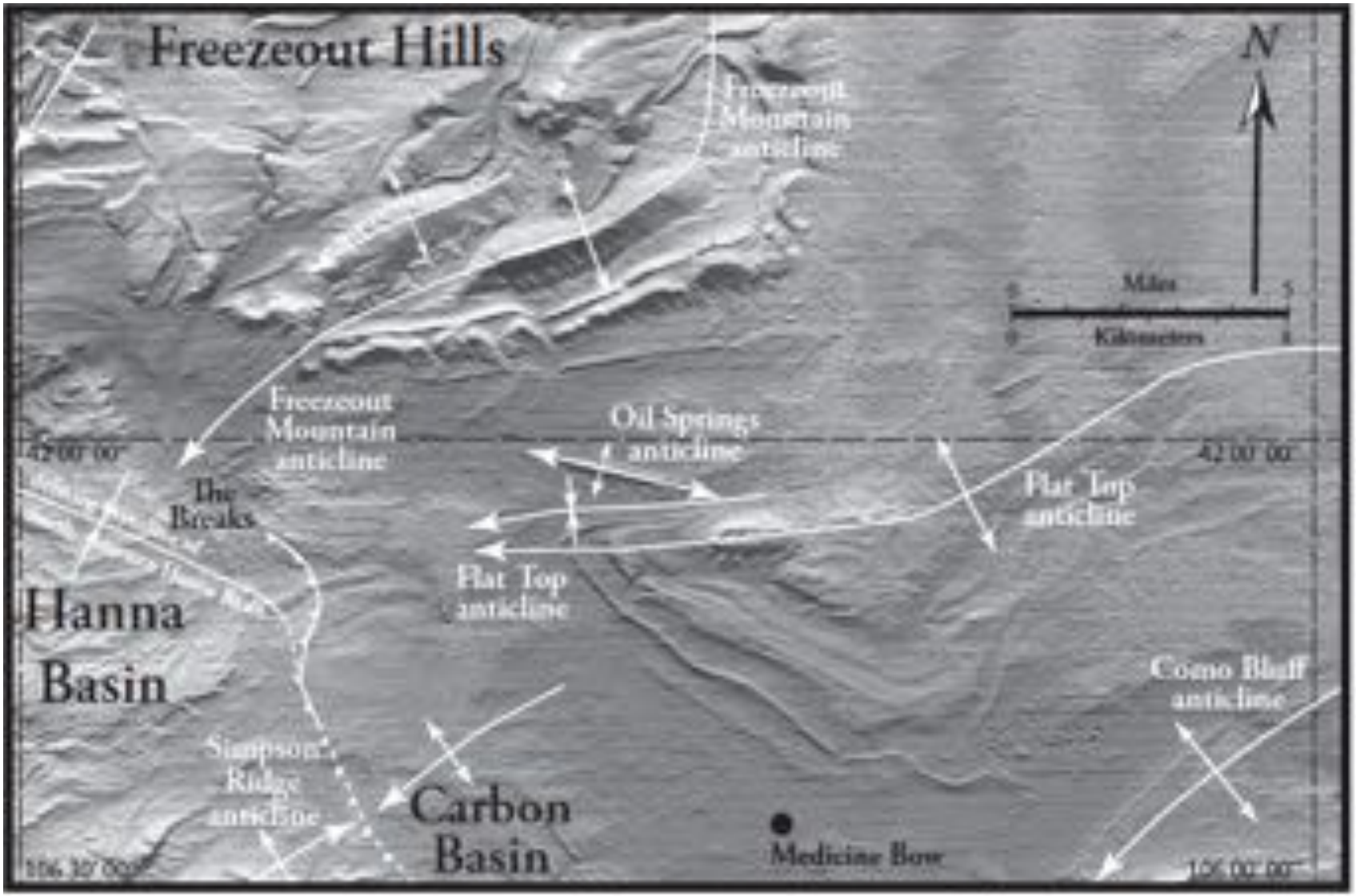
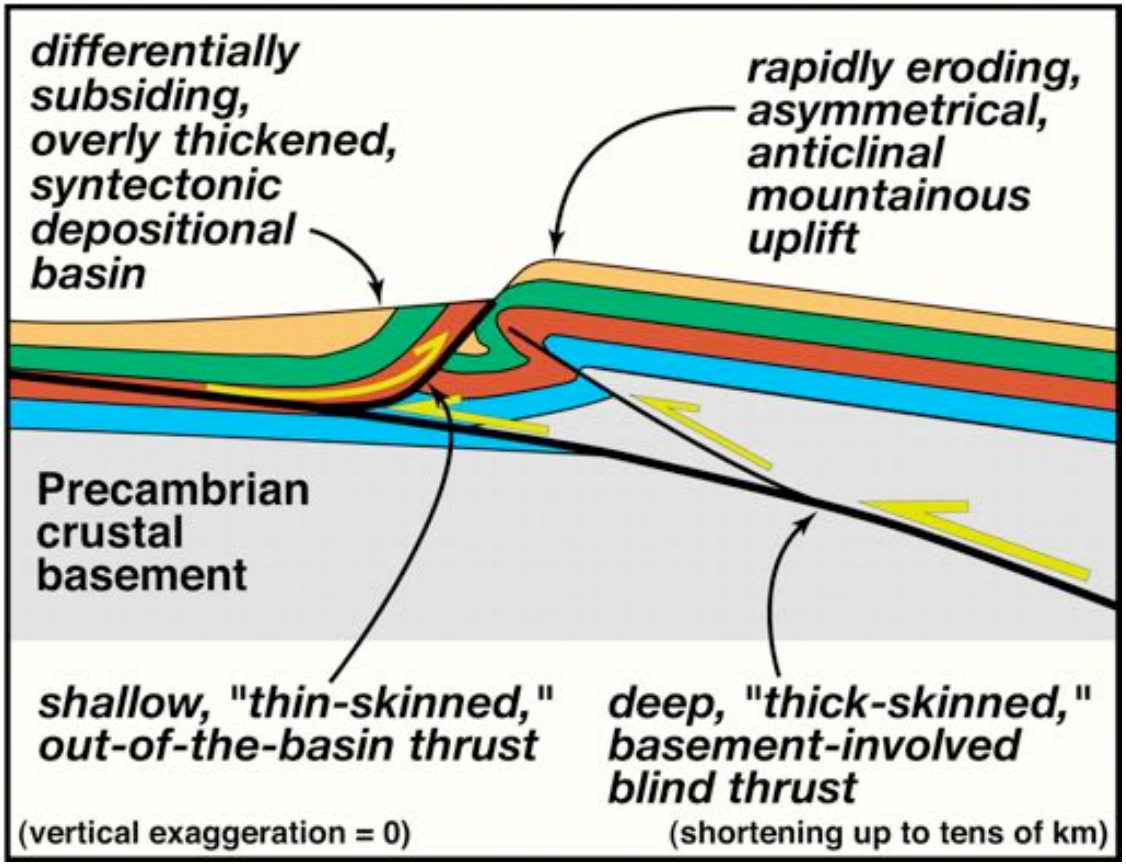
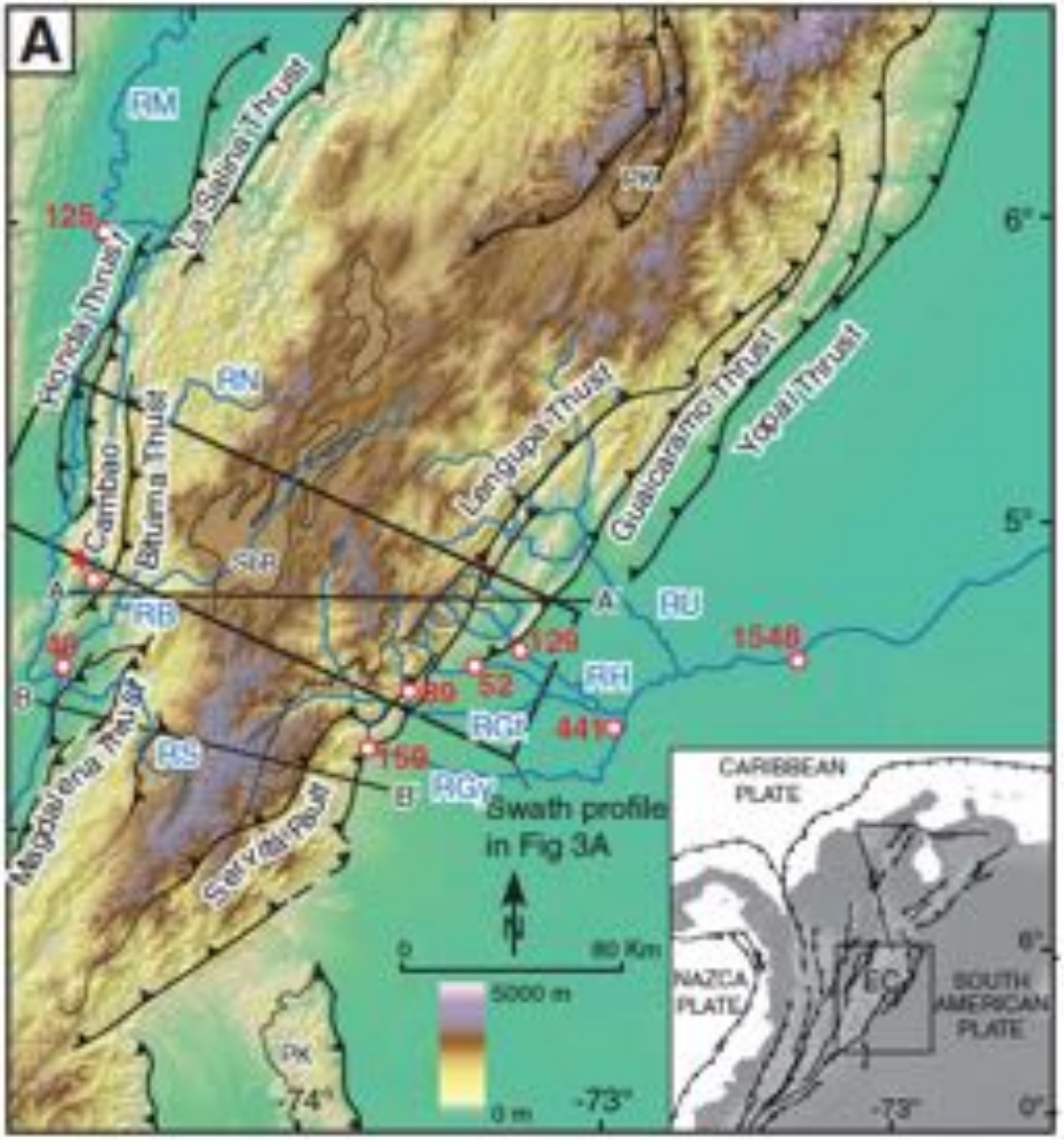


Figure 3. Map emphasizing most important structural features in vicinity of eastern part of Hanna Basin, southeastern Freezeout Hills, and northwestern part of landscape labelled "Area of northeast-trending folds" in Figure 1. Eastern margin of modern Hanna Basin is a complex zone of out-of-the-basin thrusts in lower parts of Hanna Formation (equivalent to legs 1–10 of measured section) that is faulted onto Upper Cretaceous strata on western nose of Flat Top anticline (thrusted zone is symbolized and simplified on map by a single fault trace). Vertical exaggeration in digital elevation model is X3.

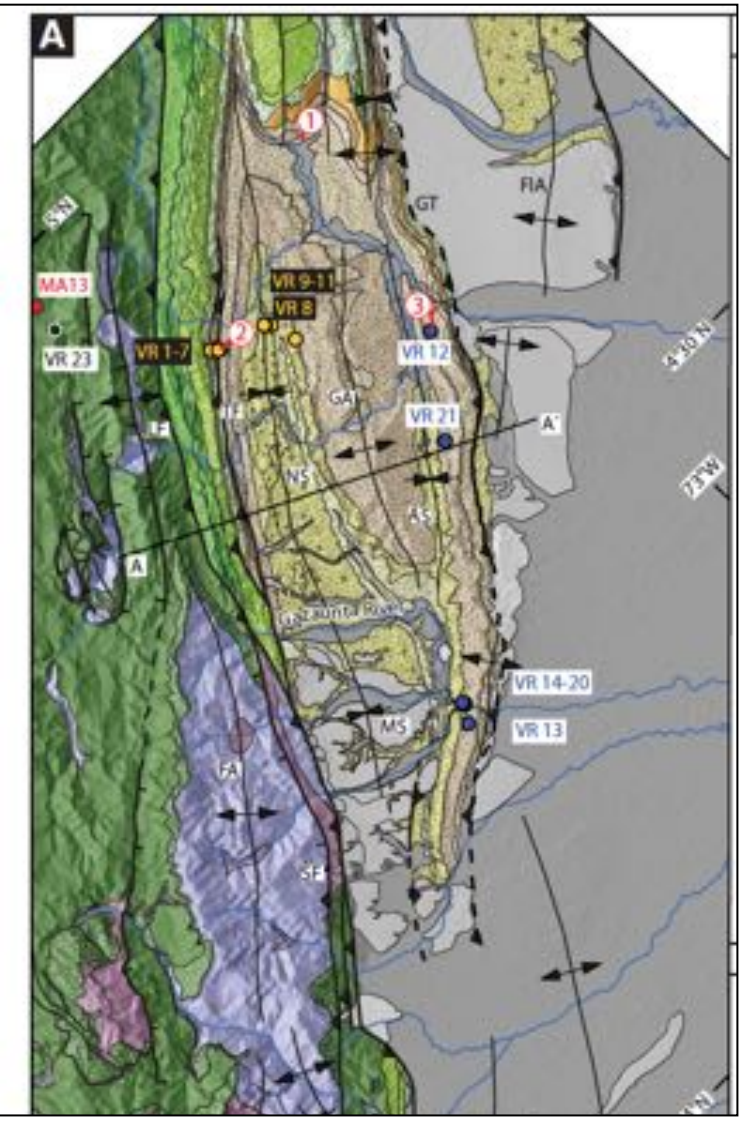
Basement Uplift and Folding of Sedimentary Cover Strata: Drape Folding – an ubiquitous Phenomenon

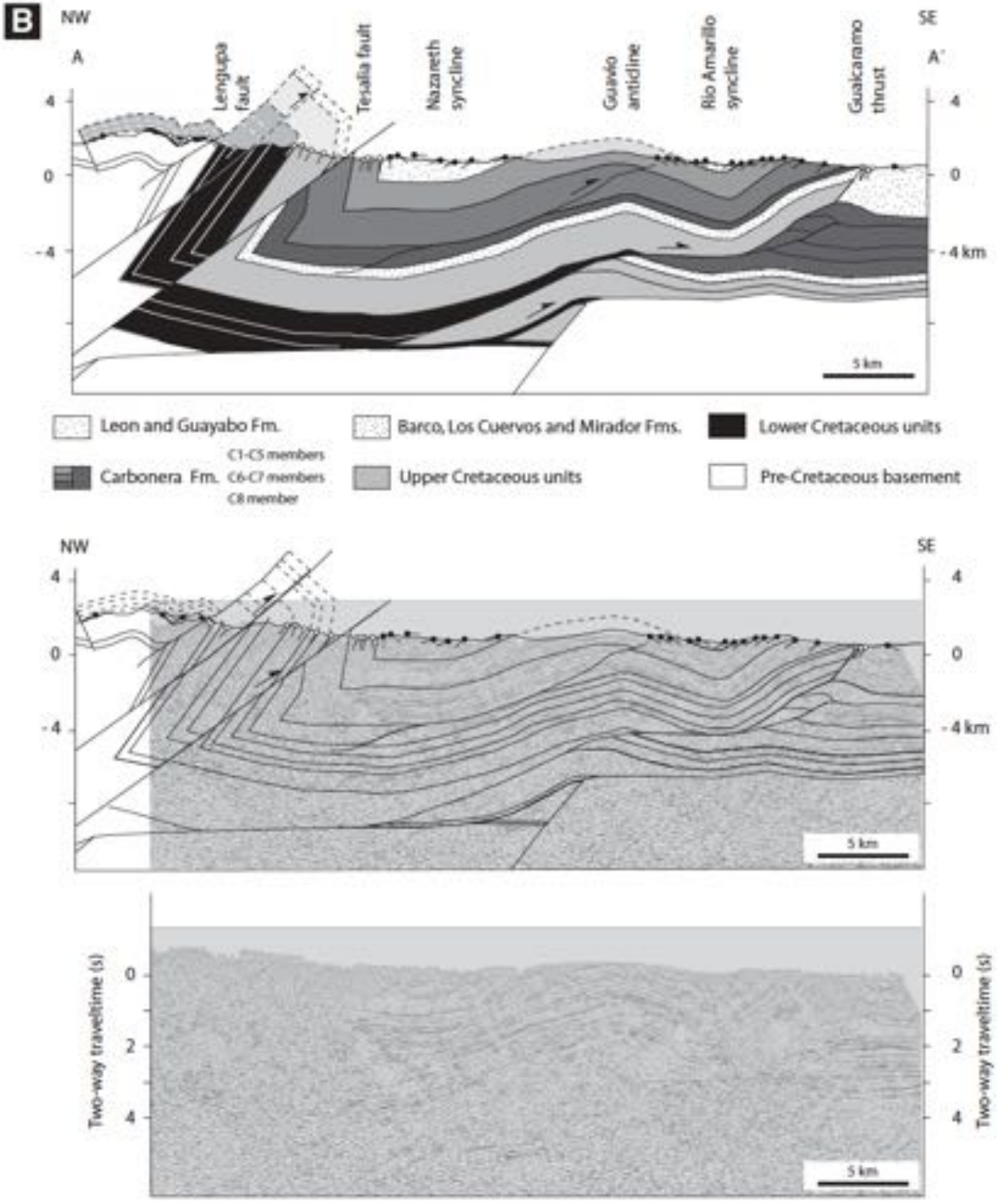


Schematic cross section of a basement-involved triangle zone inspired by the "trishear fault-propagation" model of Erslev (1991). "Thin-skinned," out-of-the basin faults form a roof fault system above an oppositely directed and dipping, "thick-skinned" basement-rooted fault system. Displacement along various faults of this triangle zone is inferred to be broadly synchronous but episodic. This triangular geometry of opposing fault systems can yield complex structural relationships such as a blind, basement-rooted master fault, high-angle "breakthrough" reverse faults, younger-on-older out-of-the-basin faults, and folded folds in the hanging wall of the basement-rooted system.

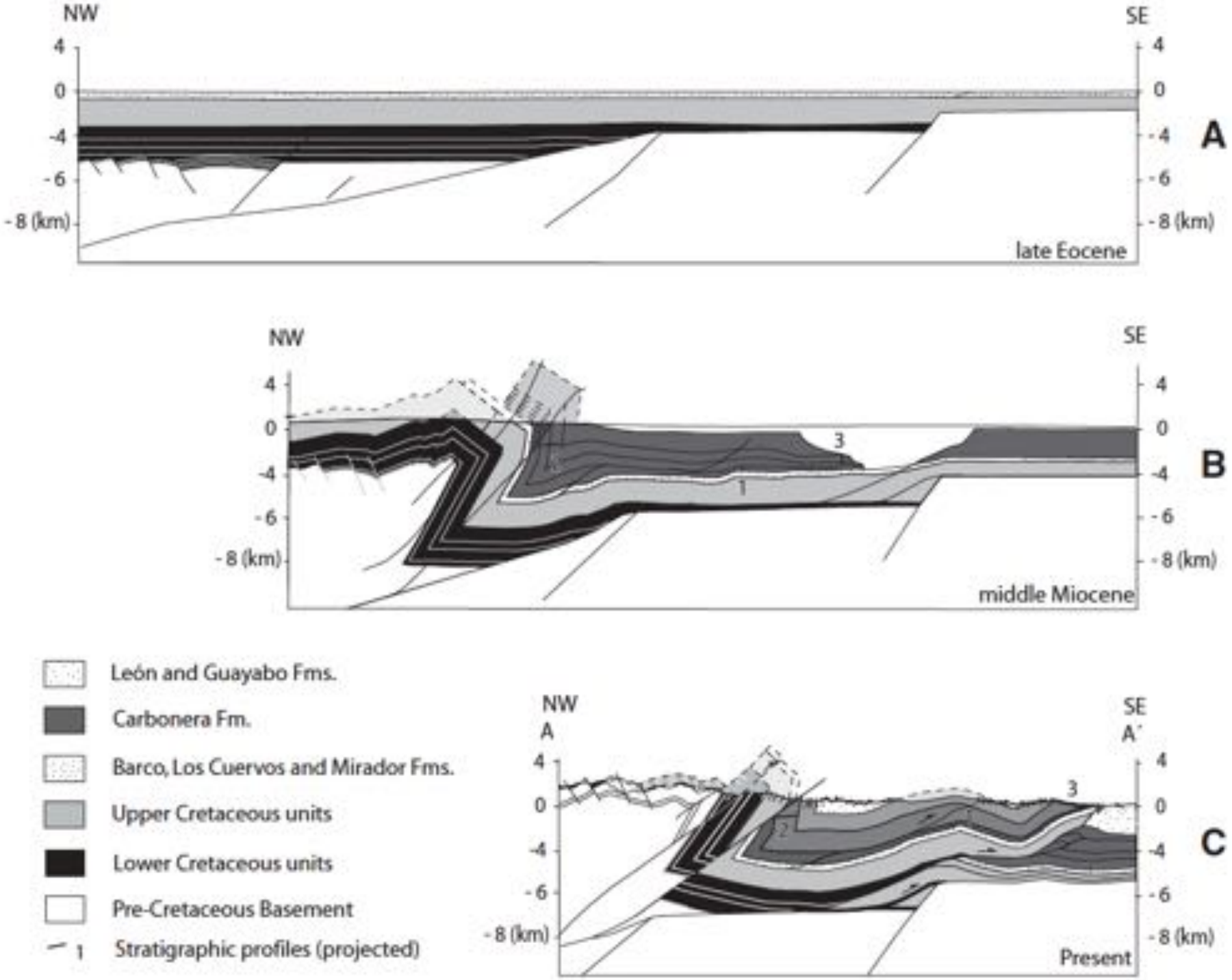


Similar styles of deformation in the Andes and other mountain belts with pronounced crustal anisotropies: The **Eastern Cordillera of Colombia** – compressional reactivation of Cretaceous extensional structures



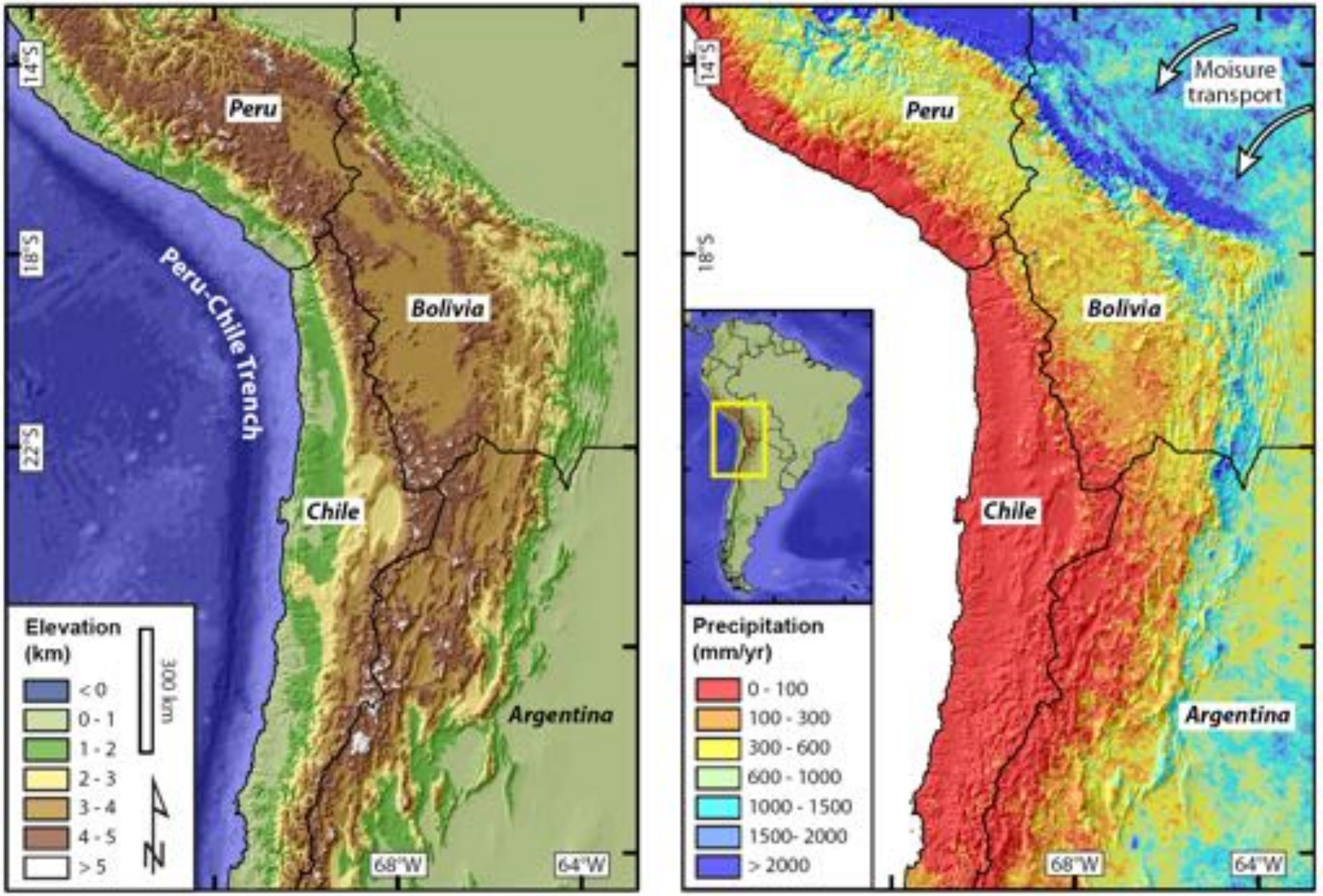


Parra et al., 2009; Geol. Soc. America Bulletin



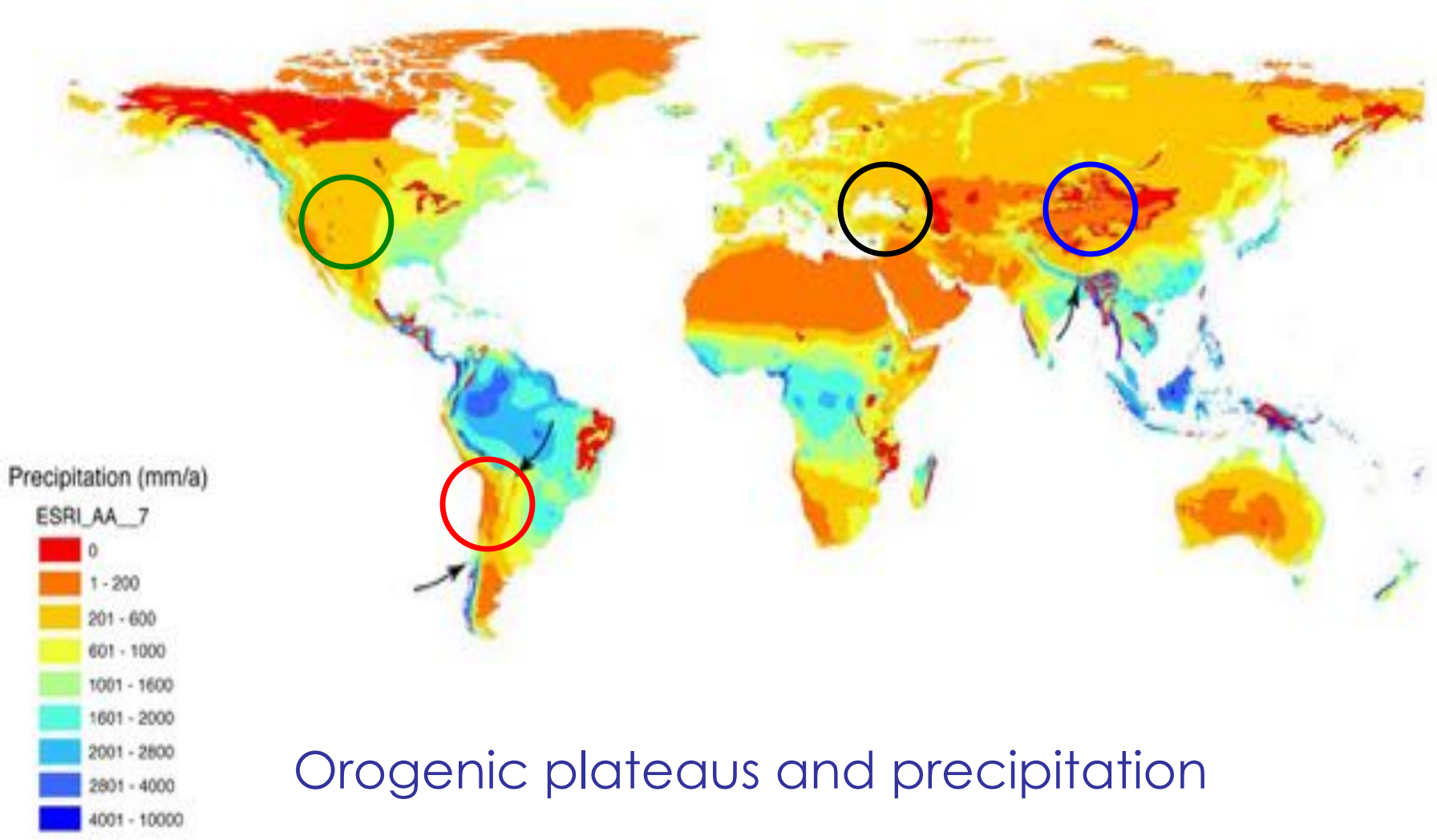
Parra et al., 2009; Geol. Soc. America Bulletin

(4) The Andes: a hemispheric-scale orographic barrier



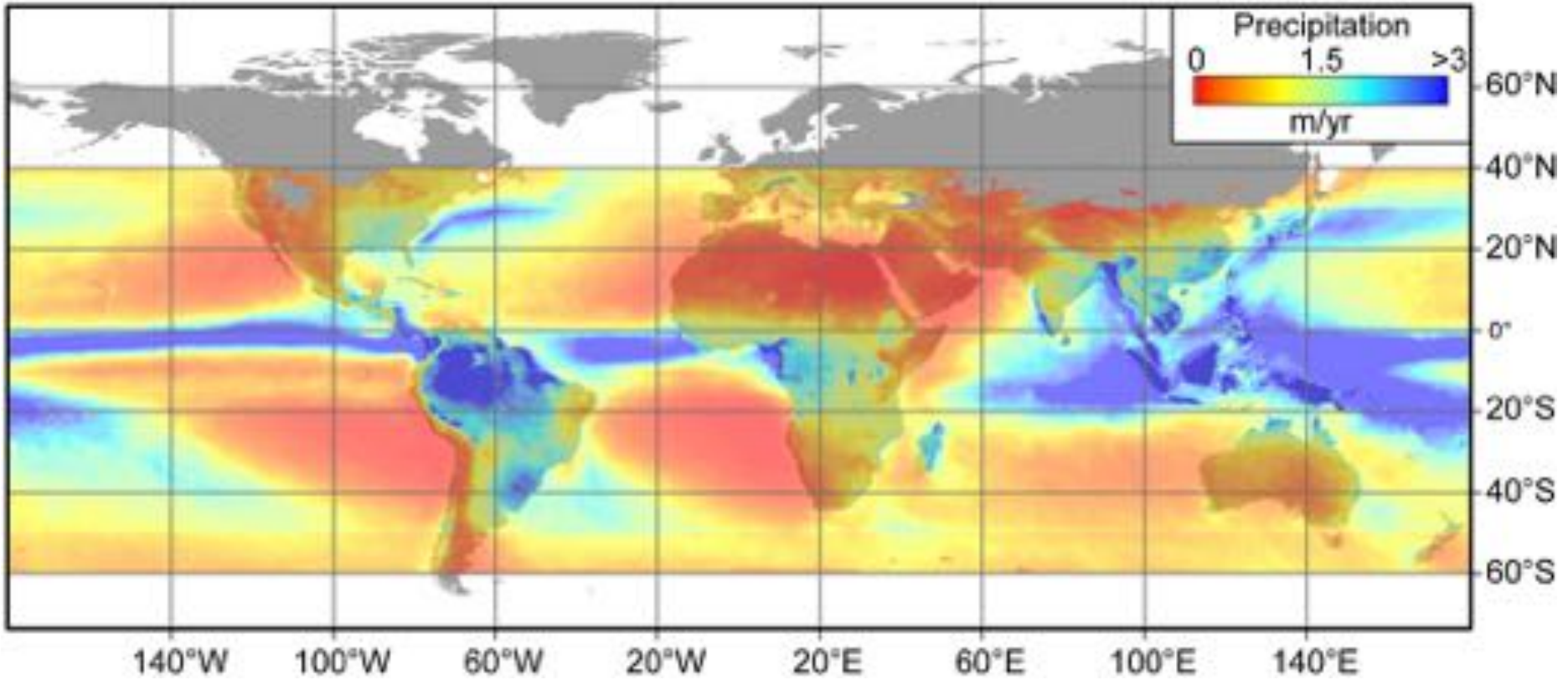
ETOPO1 dataset; Bookhagen & Strecker, 2008 GRL

The Andean Plateau: The world's second large orogenic plateau (Altiplano-Puna Plateau)

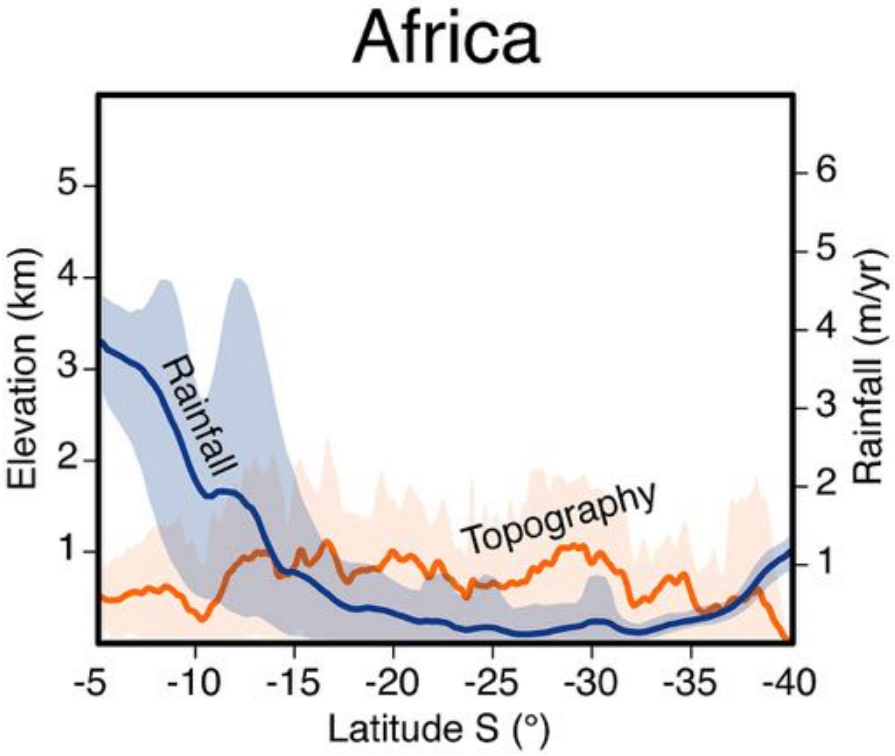


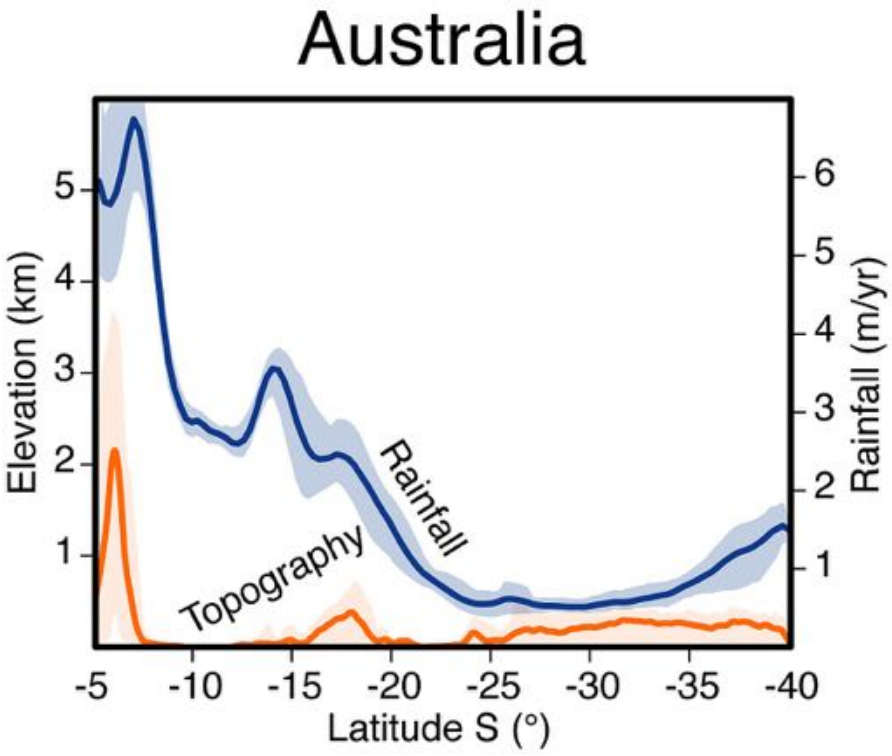
Orogenic plateaus and precipitation

Andean rainfall in light of global precipitation patterns: a paradox ?

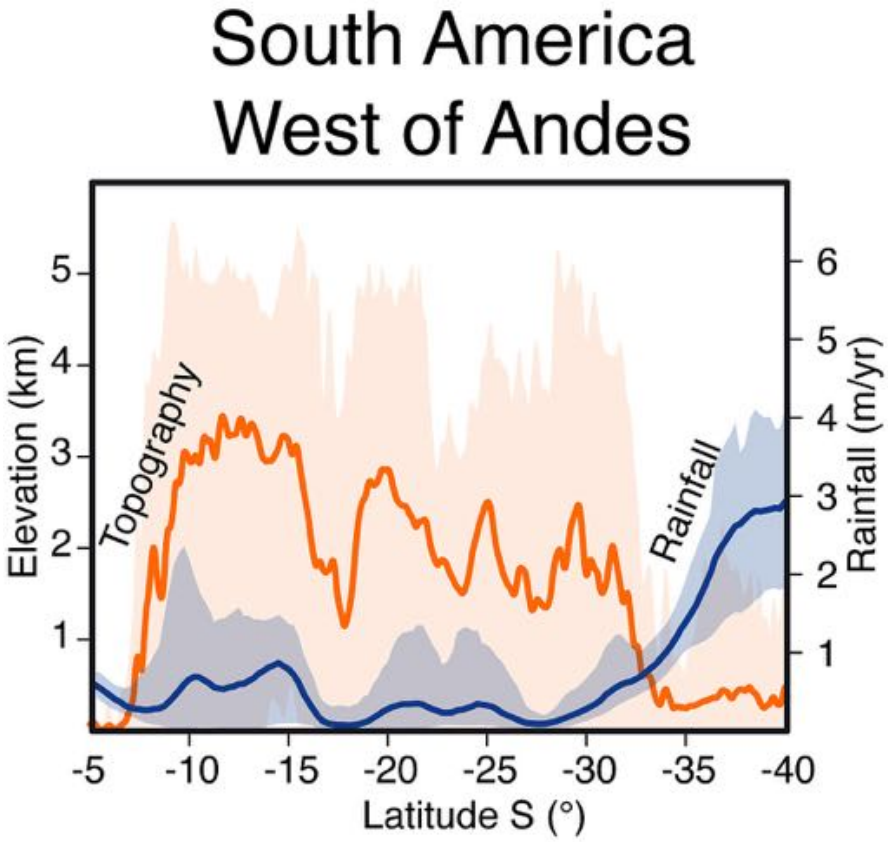


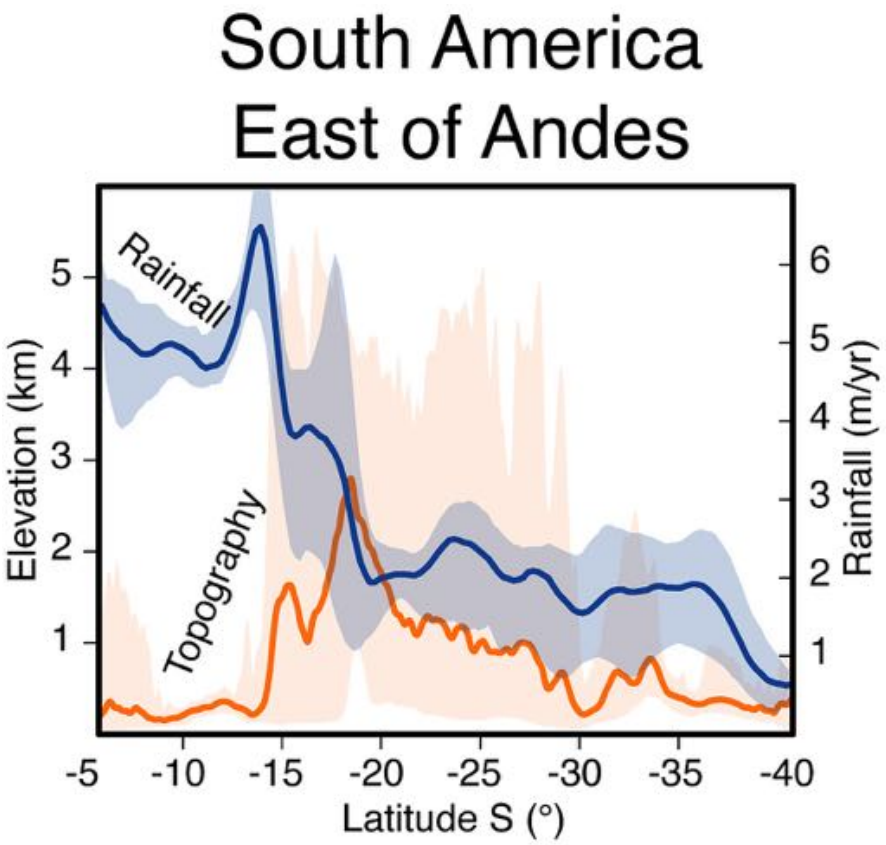
Let‘s have a look at precipitation and topography on other continents at a similar latitude: the W sides of Africa and Australia



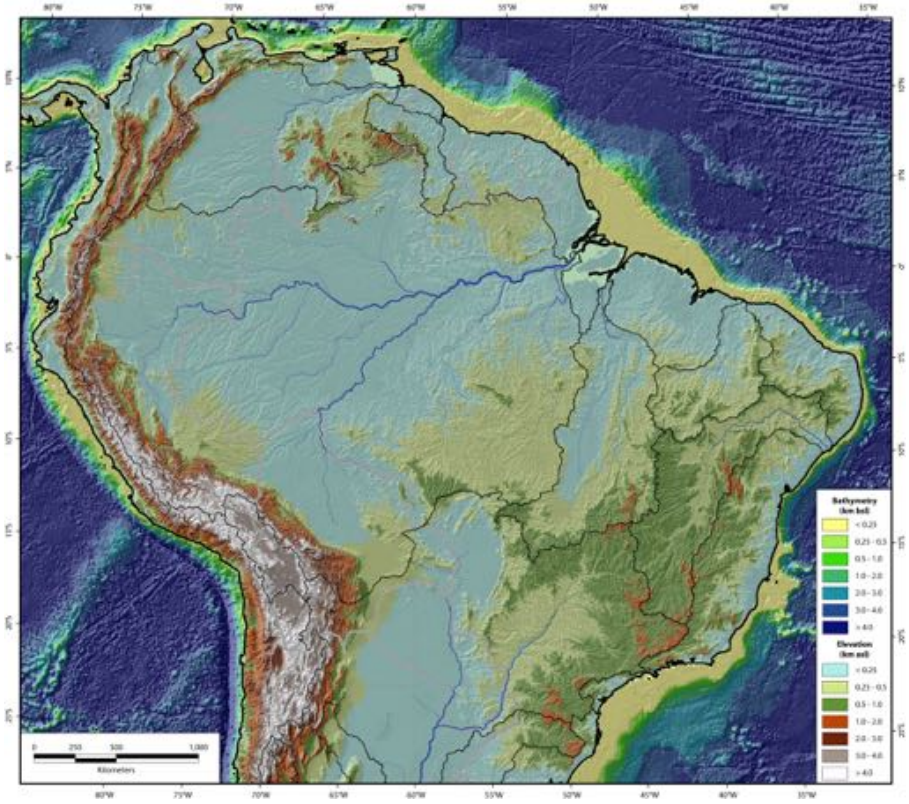


Andean precipitation: relationships between topography and atmospheric circulation

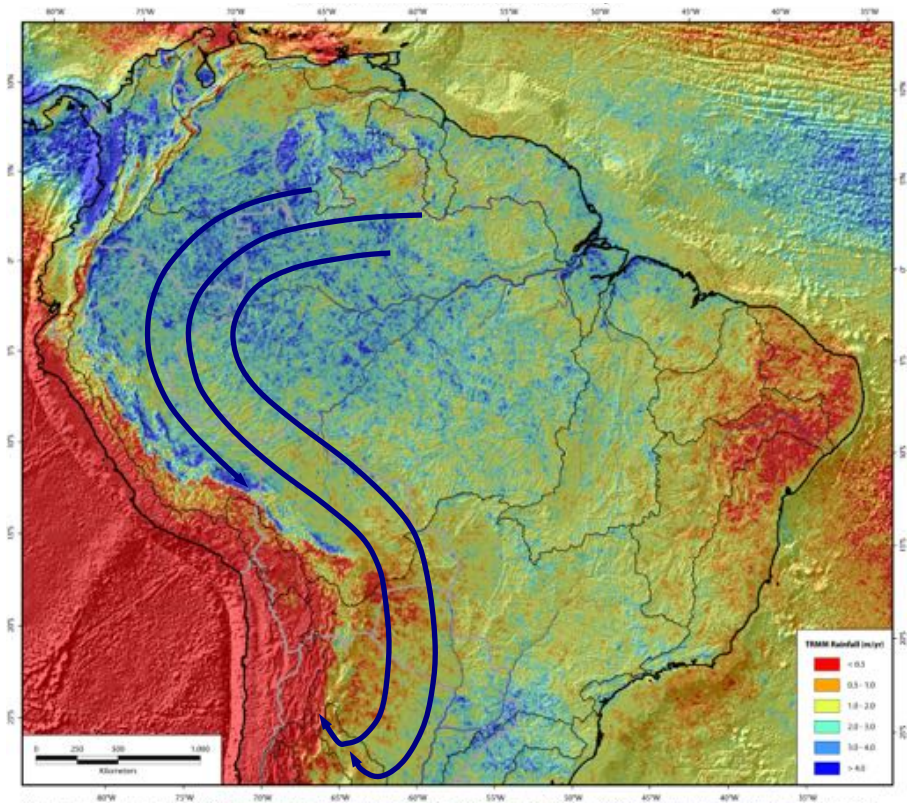




Topography, moisture transport and p: South American Monsoon and Low-Level Andean Jet



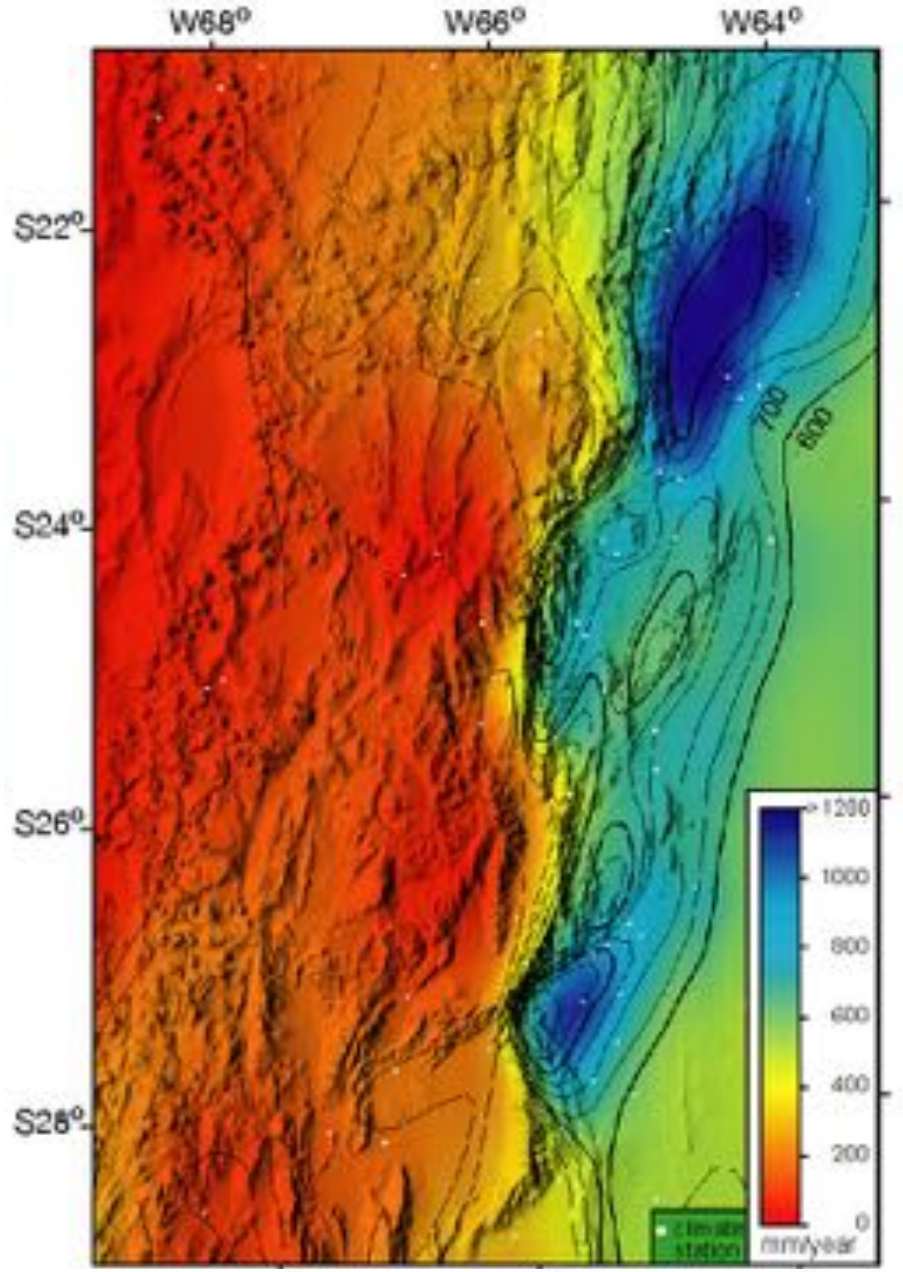
Topography (SRTM V3 - 90m) and Bathymetry (ETOPO - ~3000m)



TRMM (Tropical Rainfall Measurement Mission) Rainfall; mean annual rainfall from 1998 - 2006 in m/yr

Vera et al., 2007, J. Climate; Bookhagen & Strecker, GRL, 2008

Extreme E-W rainfall gradients



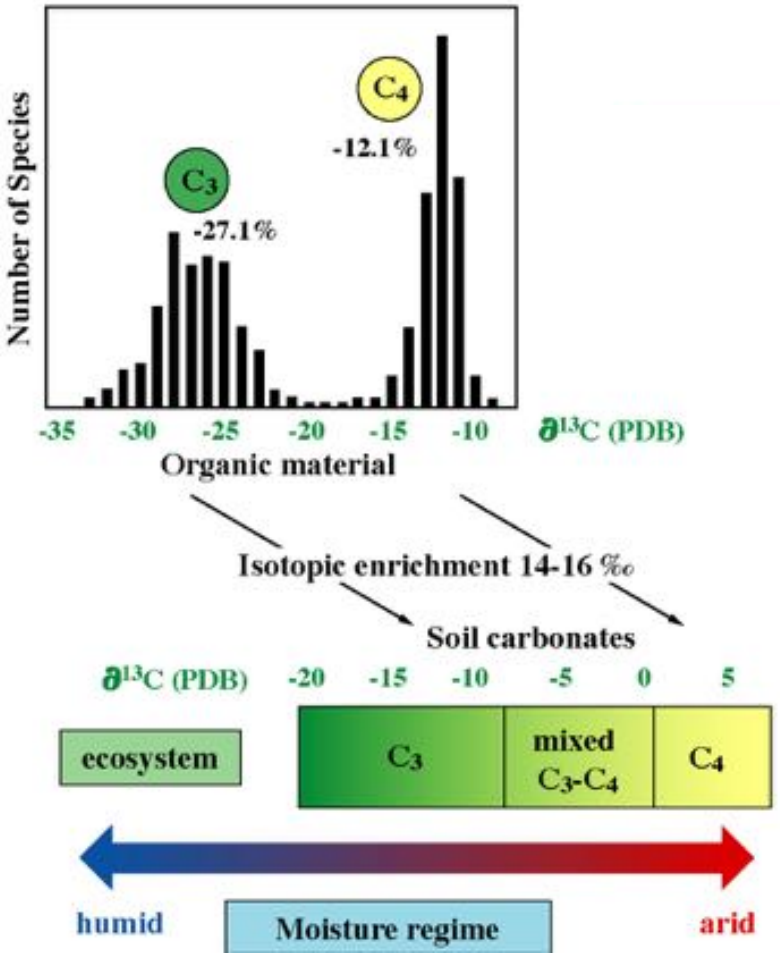
E-W rainfall distribution in the Central Andes – when did it all begin?

Modeled rainfall distribution in South America: the crucial role of topography

no mountains

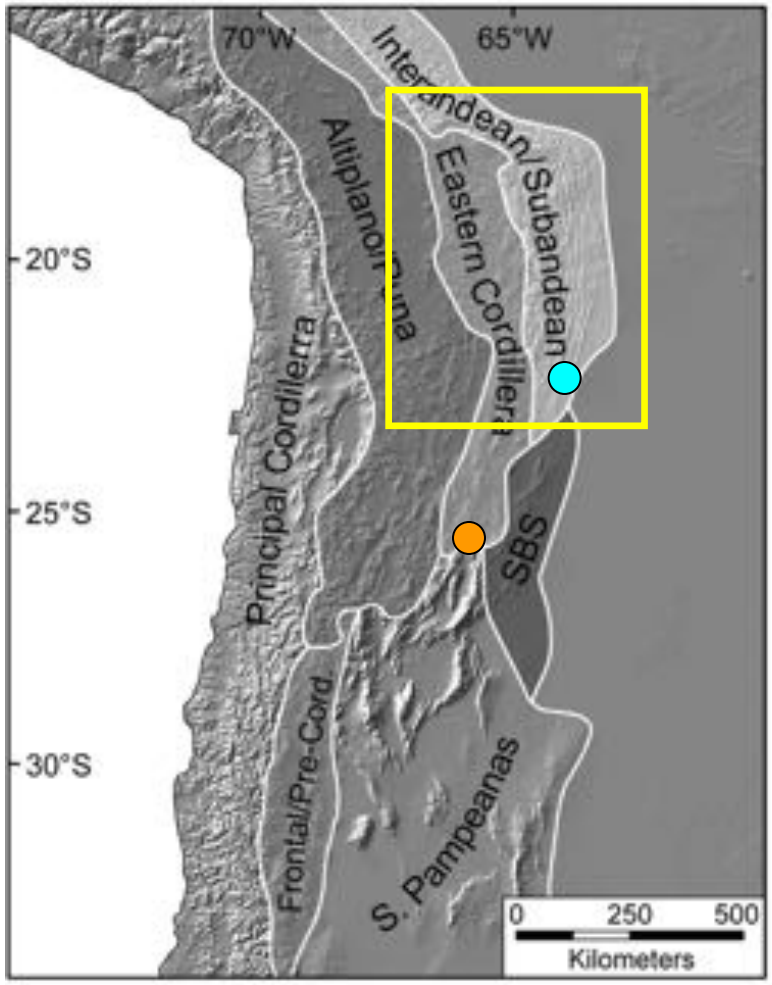
Lenters and Cook, 1997, J Climate

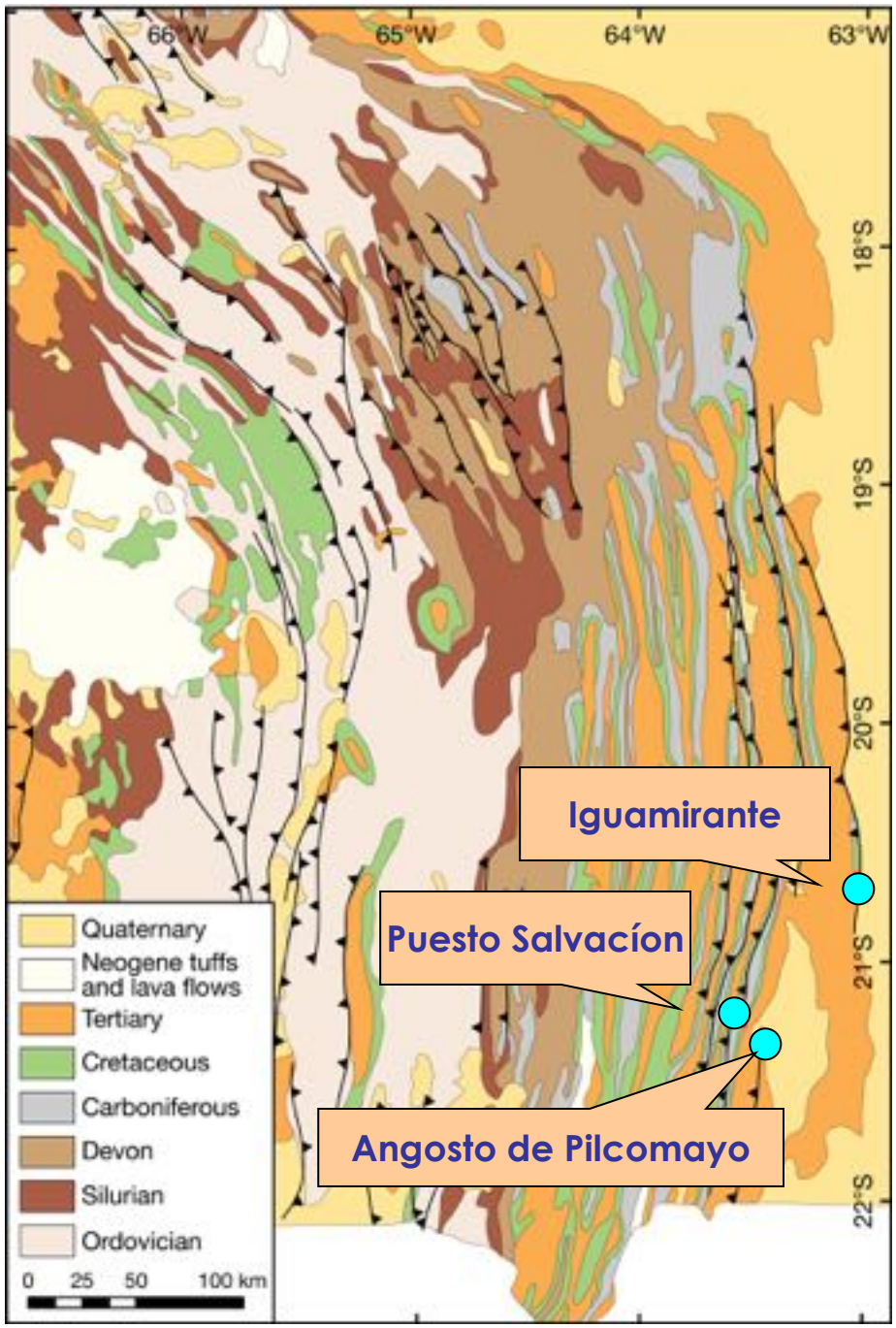
Assessing paleoclimate through stable C and O isotopes, vegetation & paleosols



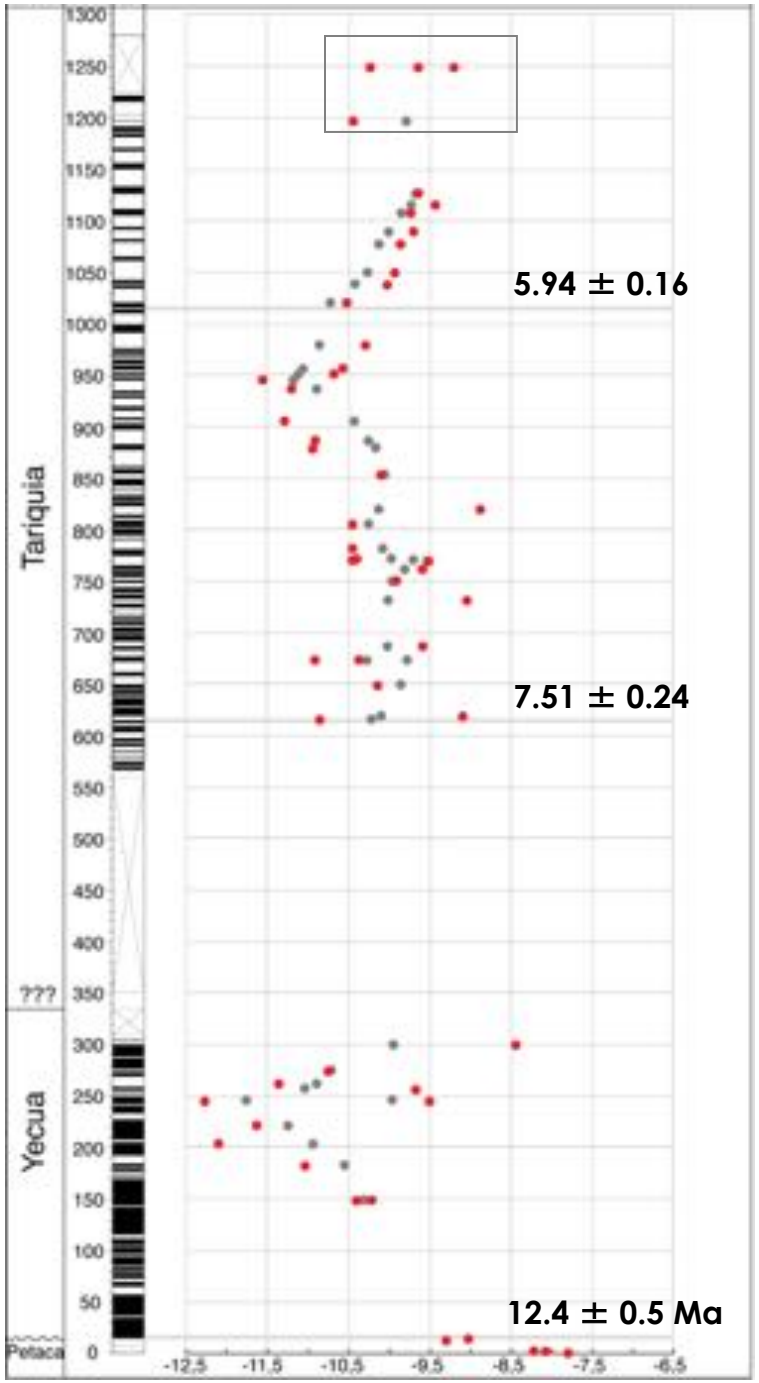
Cerling & Quade, 1993

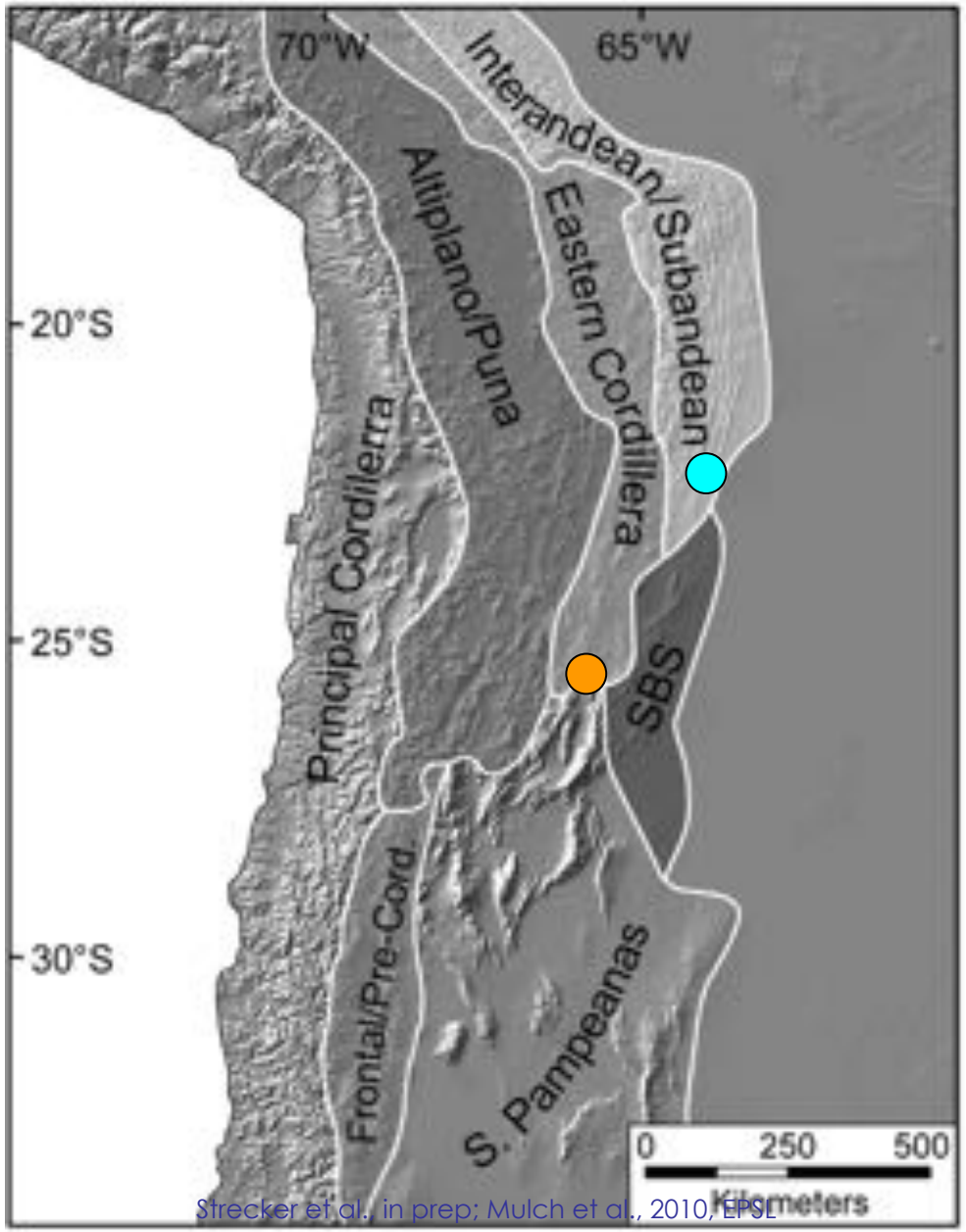
Geologic setting and location of sedimentary sections



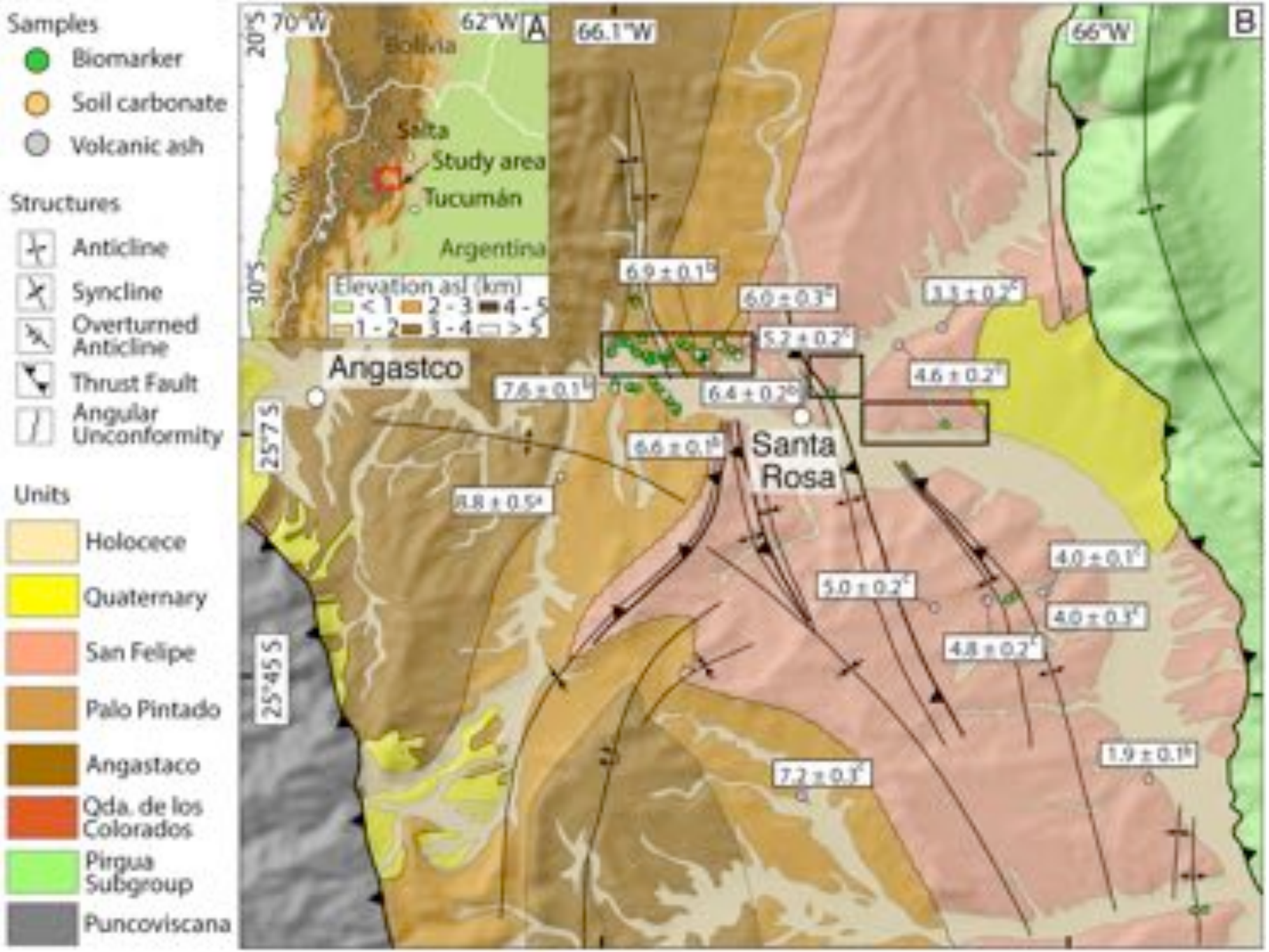


After Jordan et al., 1983, GSA Bulletin; Suarez Soruco, 2000, Geol. Map of Bolivia





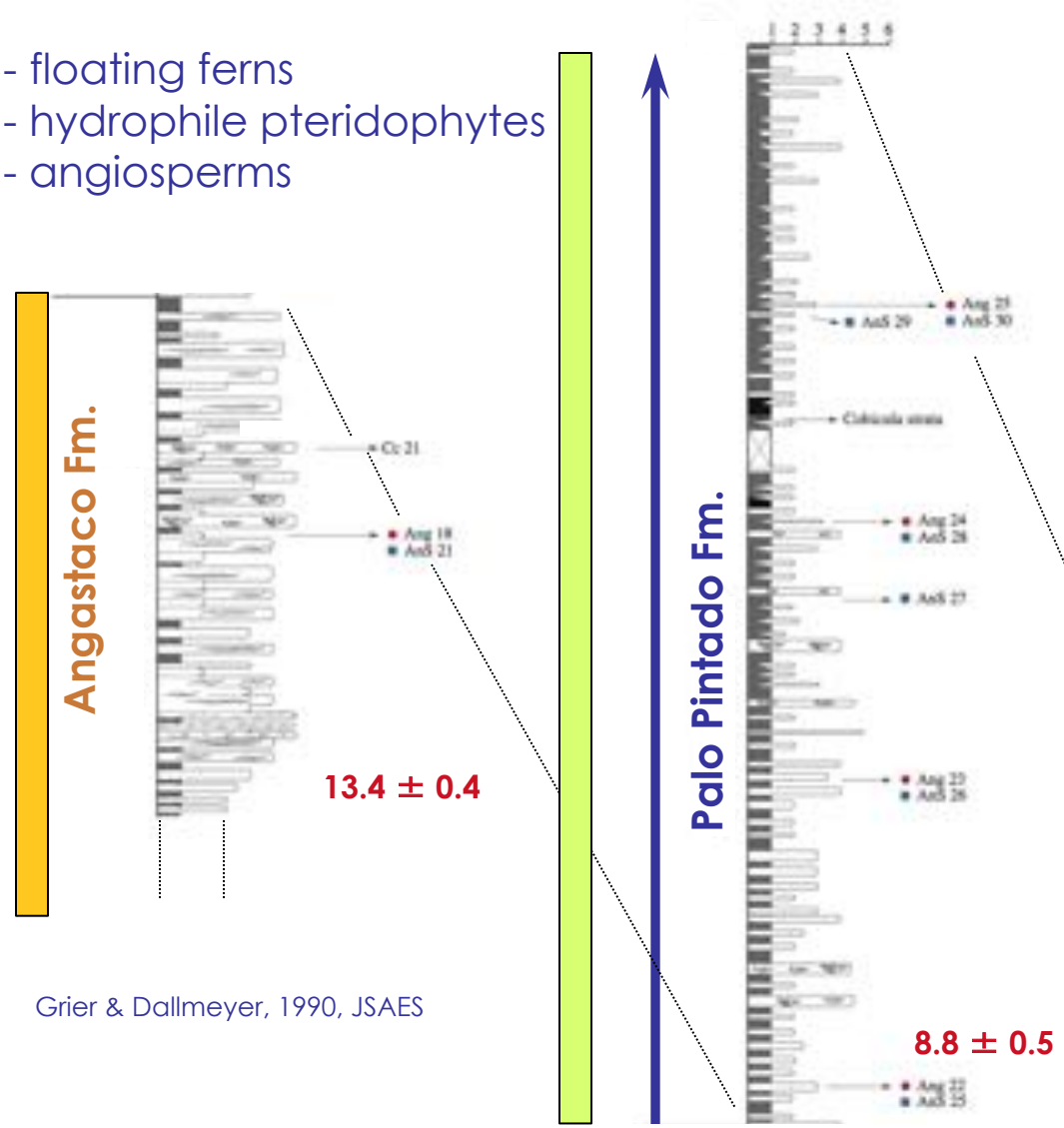
Strecker et al., in prep; Mulch et al., 2010, EPSL



Rohrmann et al., submitted

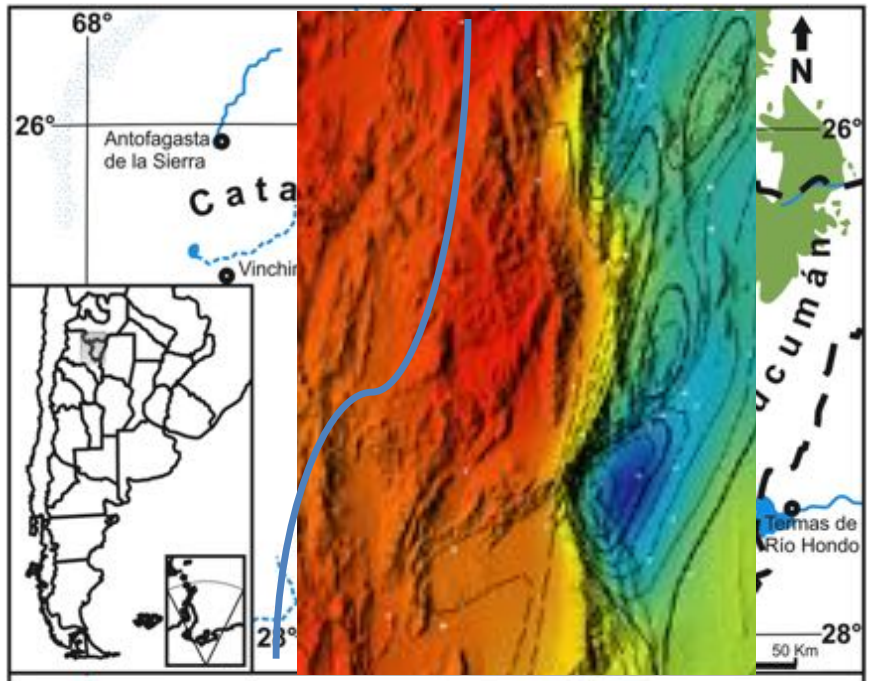
Paleontological & sedimentological data from Angastaco, Valle Calchaquí, Argentina

- floating ferns
- hydrophile pteridophytes
- angiosperms



Grier & Dallmeyer, 1990, JSAES

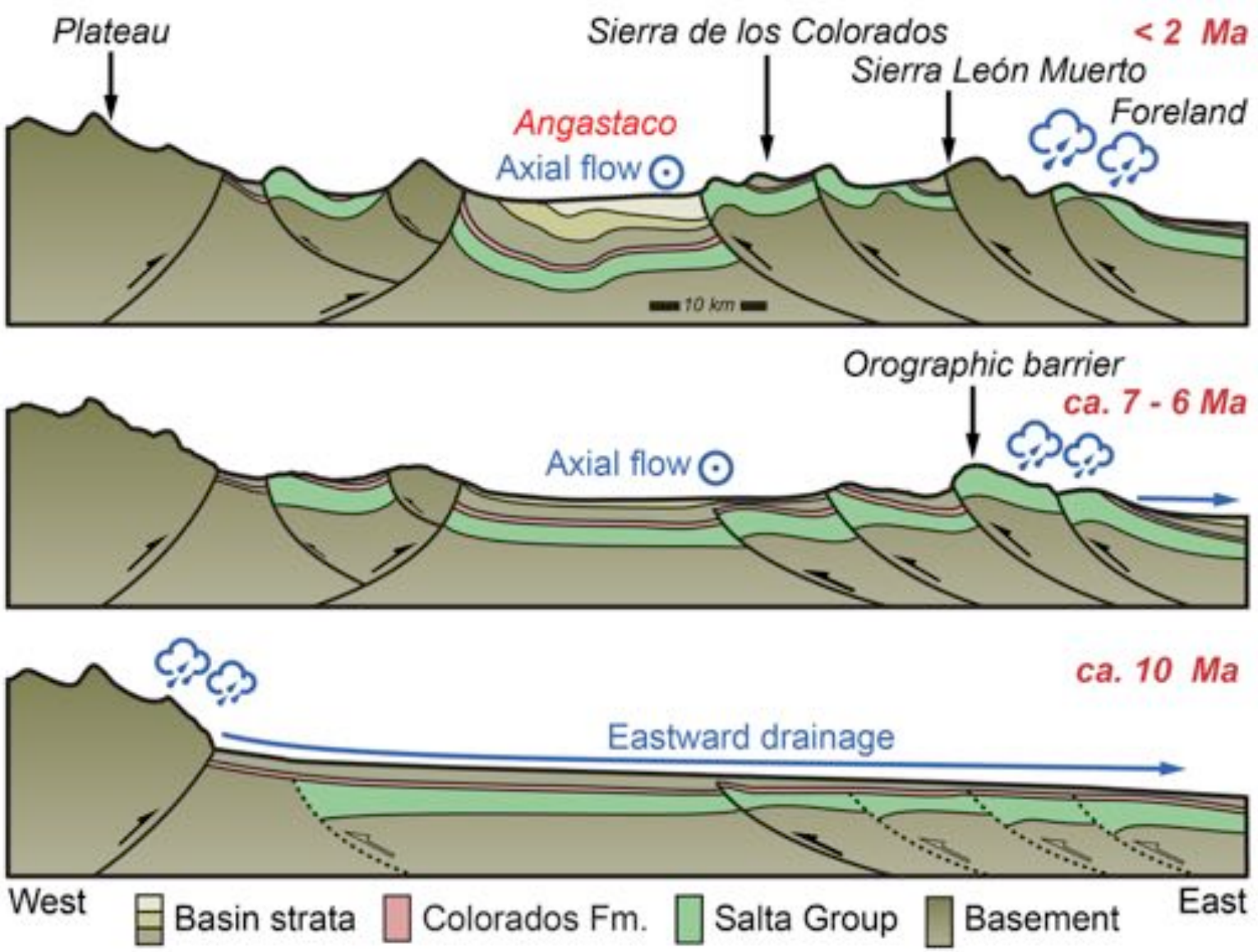
Anzóteguí, 1989; Anzóteguí, 2006, Ameghiana; Starck & Anzóteguí, 2001, JSAES; Coutand et al., 2006, Basin Research; Carrapa et al., 2012, Tectonics



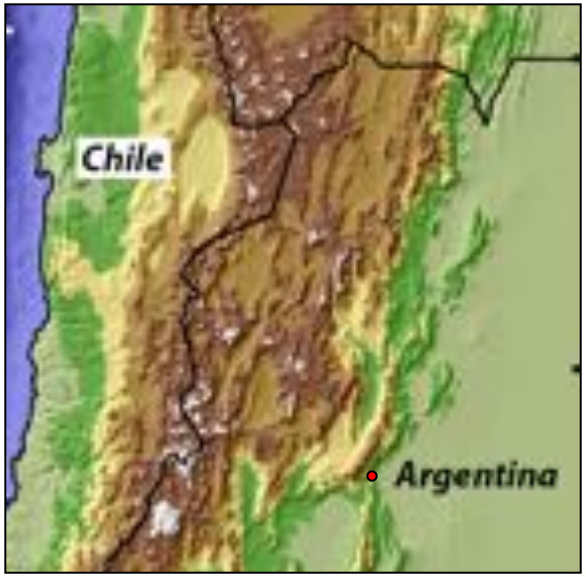
Fossiliferous localities Yungas forest

Anzóteguí, 2006, Ameghiana;
Martinez, Review of Paleobotany & Palynology, 2014

From foreland to intermontane basin setting

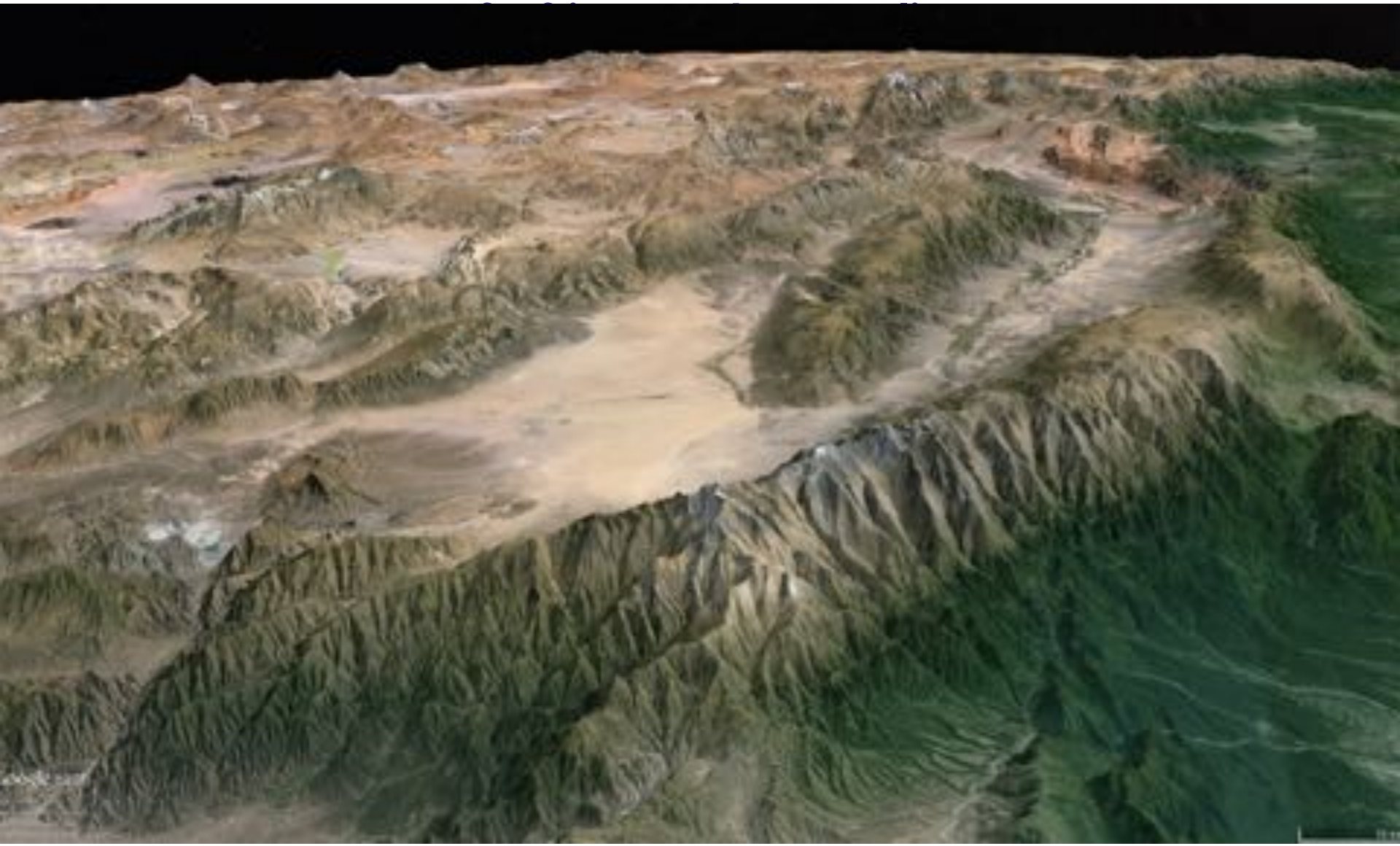


e.g. Carrera et al., 2006; Deeken et al., 2007; Hain et al., 2011; Galli et al., 2014; Rohrmann et al., 2017; Pingel et al., 2016



The red dot guides you in locating yourself!

Precipitation and topography from East to West



Eolian carbonate deposition

Soil-carbonate stage II

Soil-carbonate stage IV

THANK YOU!