

Tectonics, Relief Evolution & Climate : the case of the Andes

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Armijo R., Lacassin R., Coudurier-Curveur A., Carrizo D., *Coupled tectonic evolution of Andean orogeny and global climate*, Earth Science Reviews, 143, 1-35, 2015.

Coudurier-Curveur A., Lacassin R., Armijo R., *Andean growth and monsoon winds drive landscape evolution at SW margin of South America*, EPSL, 2015.



Funded by :



Project MegaChile

LabEx UnivEarthS

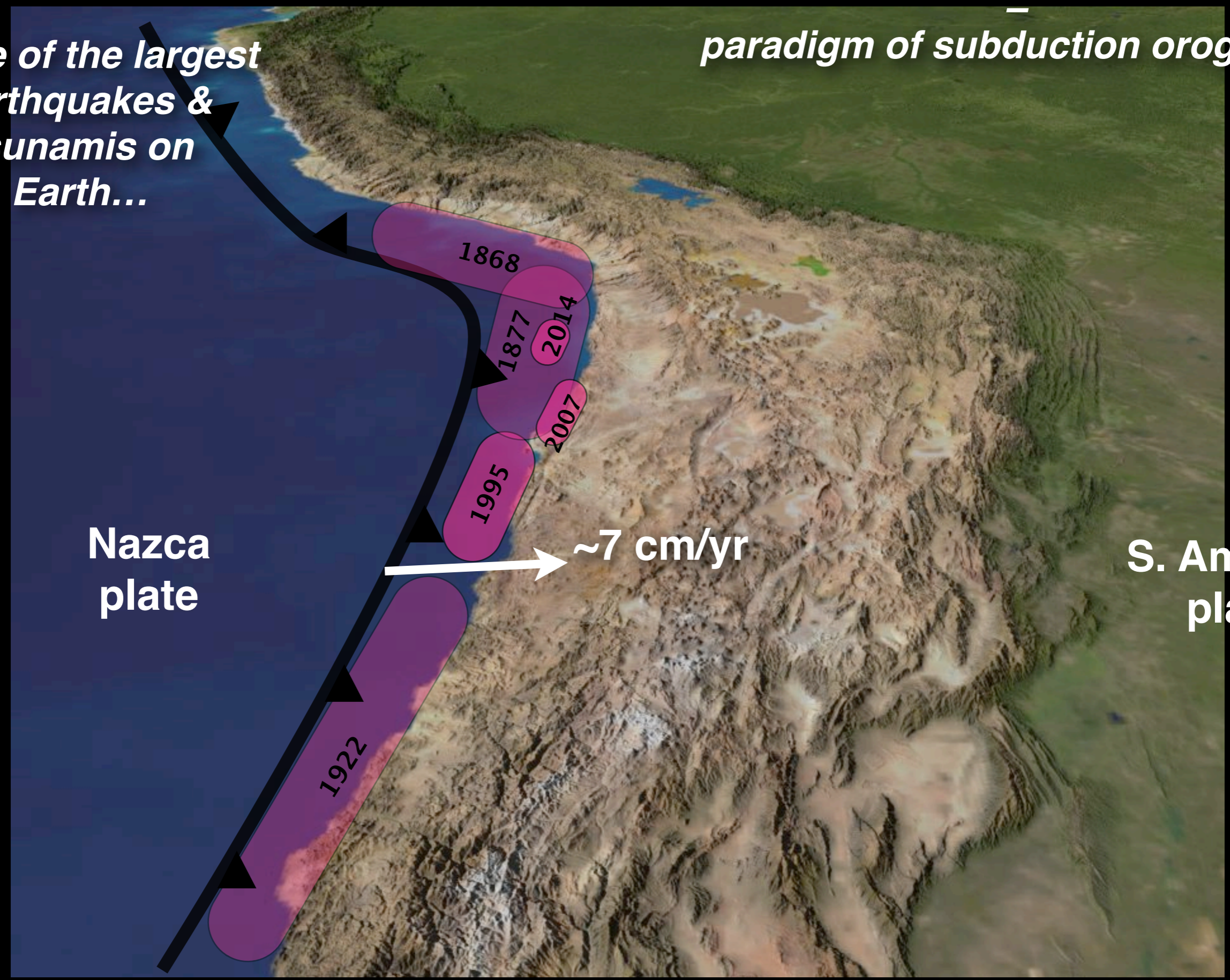


Labex UnivEarthS

Central Andes / Altiplano

paradigm of subduction orogeny...

Some of the largest earthquakes & tsunamis on Earth...



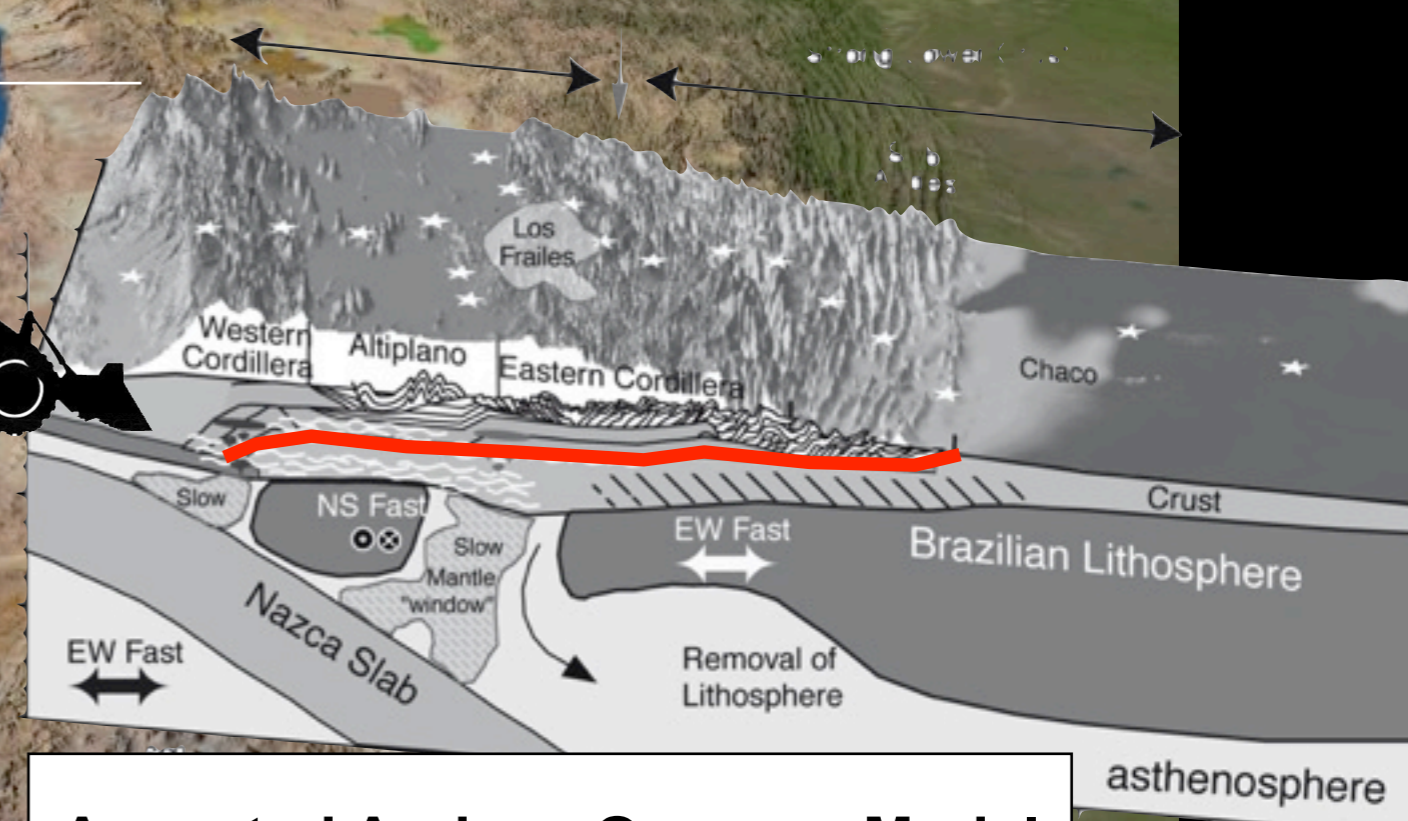
Central Andes / Altiplano

paradigm of subduction orogeny...

Some of the largest earthquakes & tsunamis on Earth...

largest relief on Earth ~13km

Tectonics of Andean W flank, facing the subduction : barely known / importance dismissed.
> Coupling processes that lead to both megathrust earthquakes & relief building ?



Accepted Andean Orogeny Model

Central Andes / Altiplano

orographic & climatic patterns

XX Wet

largest relief on Earth ~13km

**Cold
oceanic
current**

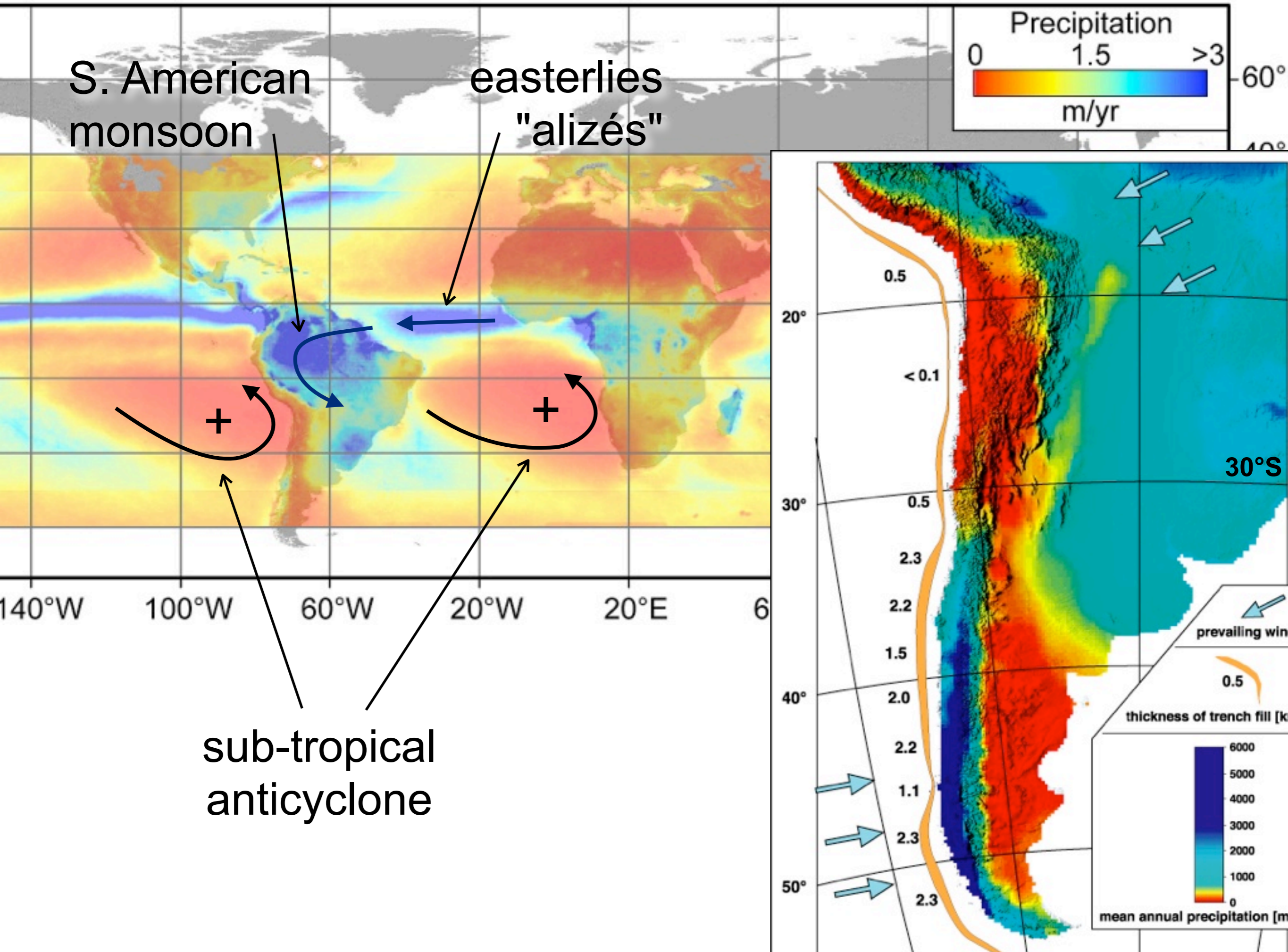
Altiplano

XX Arid

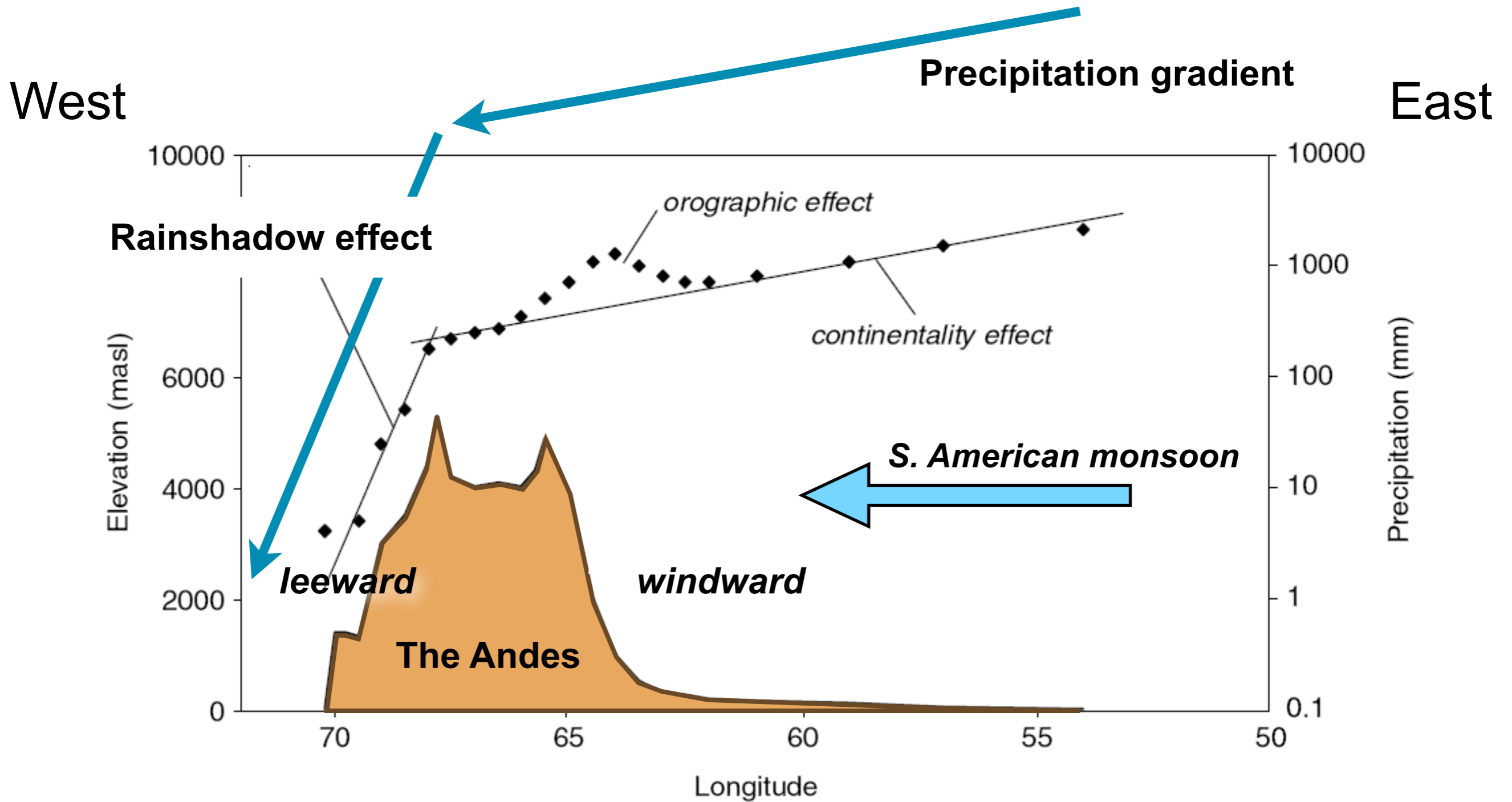
*Second
plateau on
Earth after
Tibet*

Puna

Wet



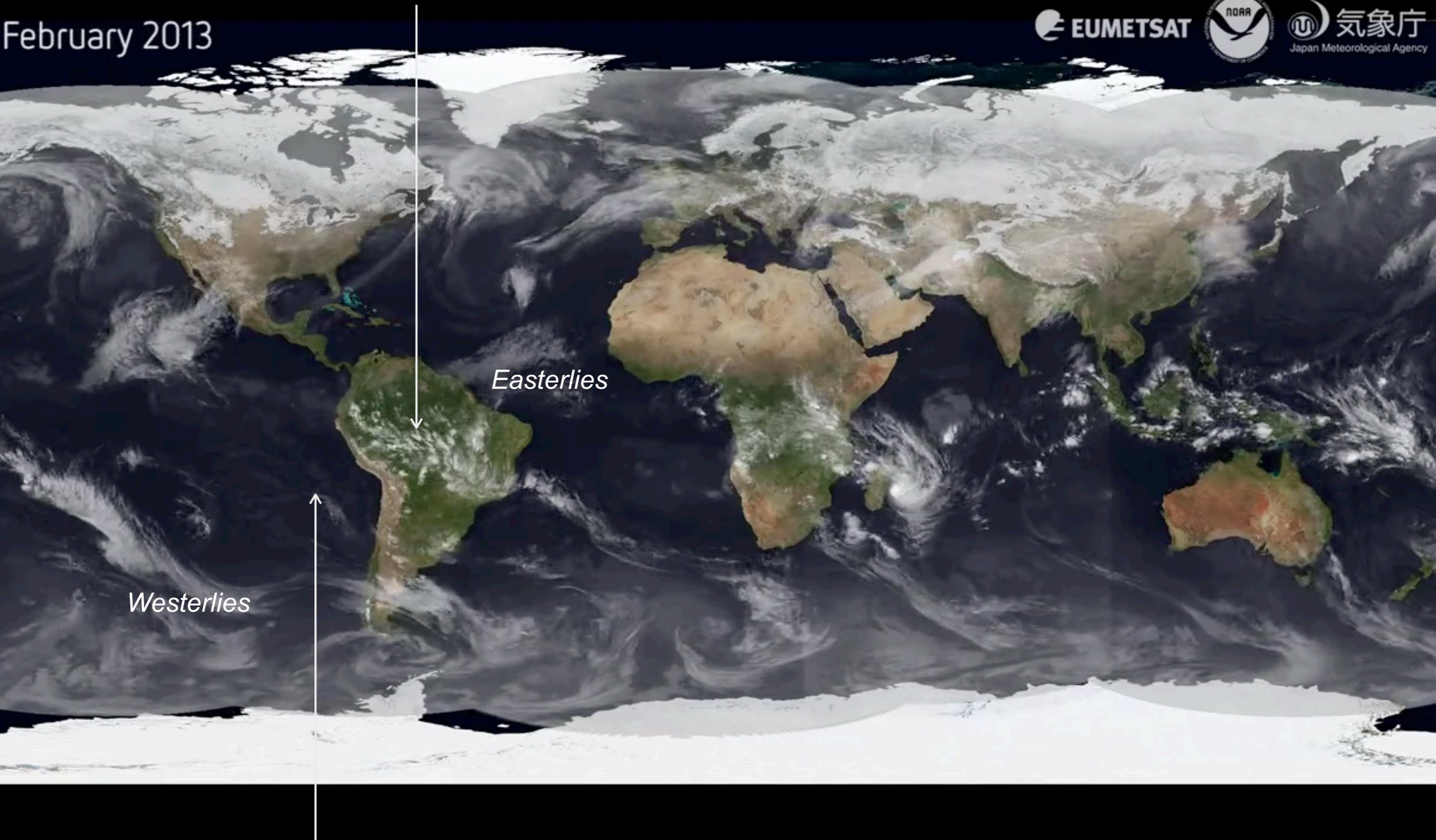
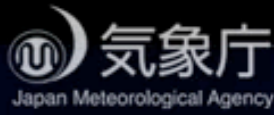
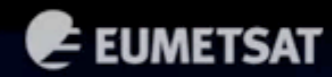
High Andes & dry Atacama Factor II: Rain shadow effect



Original figure courtesy R. Garreaud (U. Chile) and Hartley and Houston 2003

S American monsoon (coming from the Atlantic)

February 2013



Easterlies

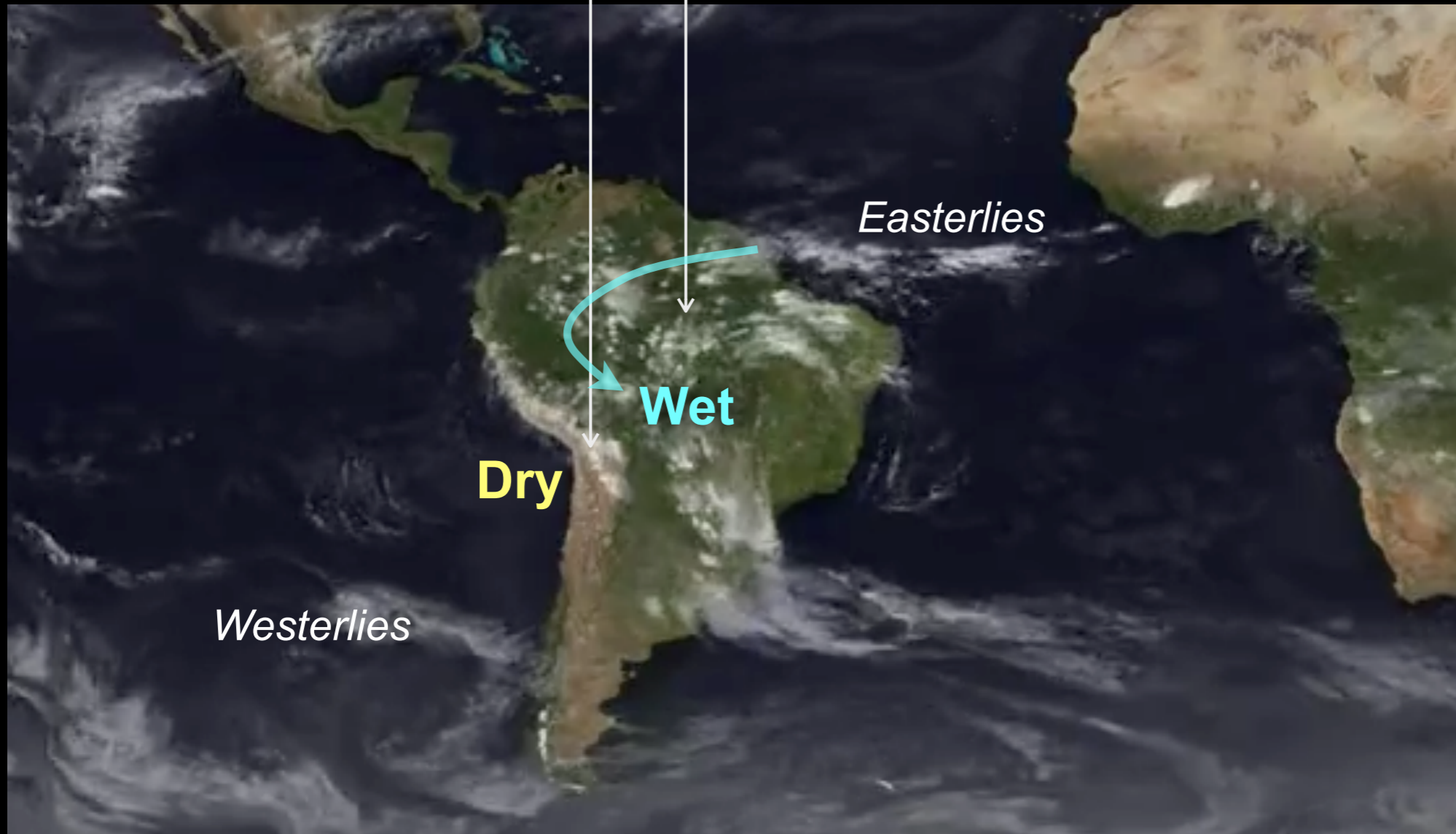
Westerlies

subtropical anticyclone

Central Andes / Altiplano
–
present-day climate

Precipitation front oblique to Altiplano

S American monsoon (from Atlantic)



mid-february 2013

Stability / evolution in the past ? time-scales of 1 to 10s of My – Effects ?

Feedbacks Tectonics / Climate on the long term ?

ISS flight over S America west margin (Peru / N Chile)

Altiplano

W Cordillera

Atacama Bench

Coastal scarp

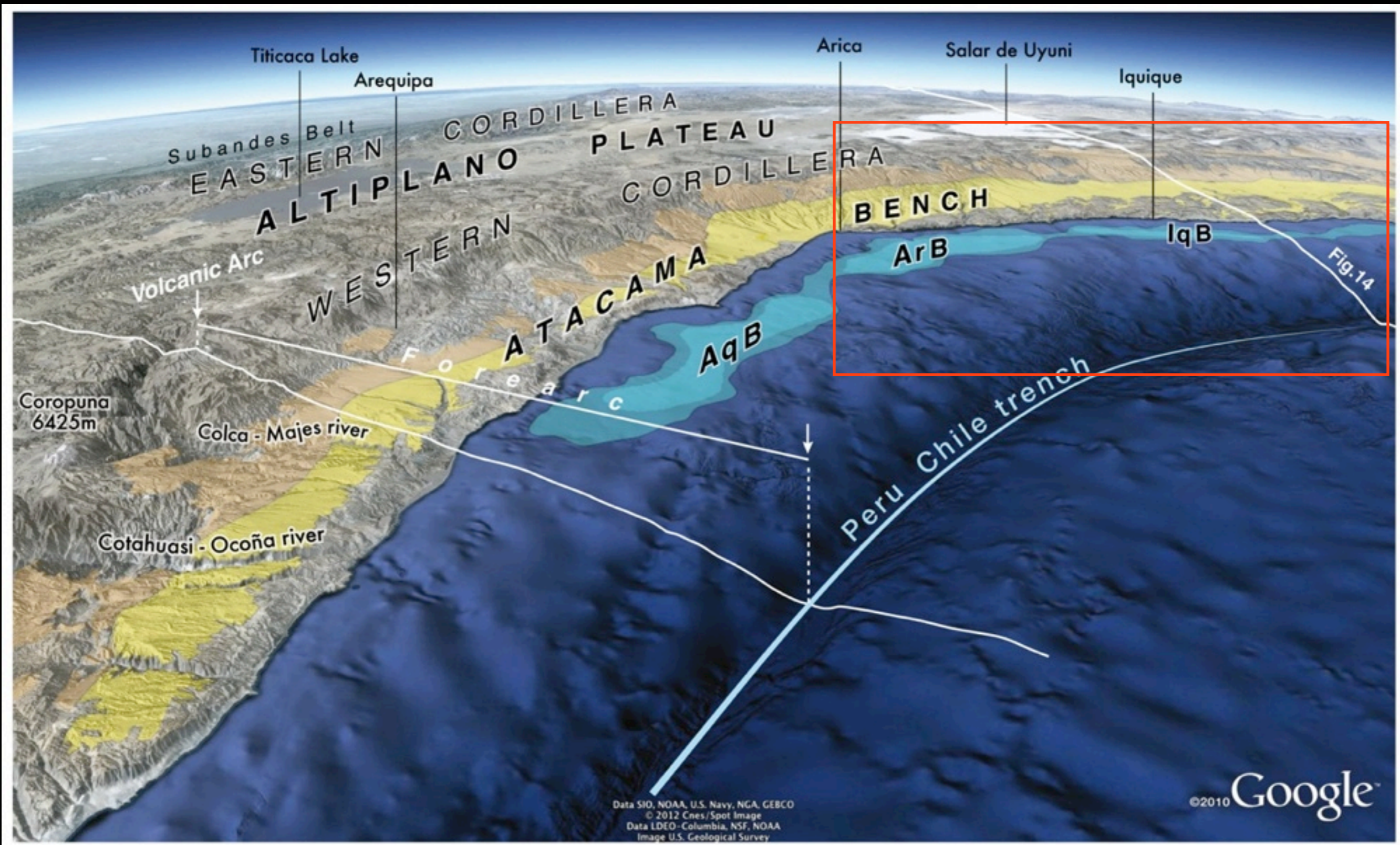
Desert

Atacama

endoreic drainage

geomorphic threshold

deep canyons - exoreic

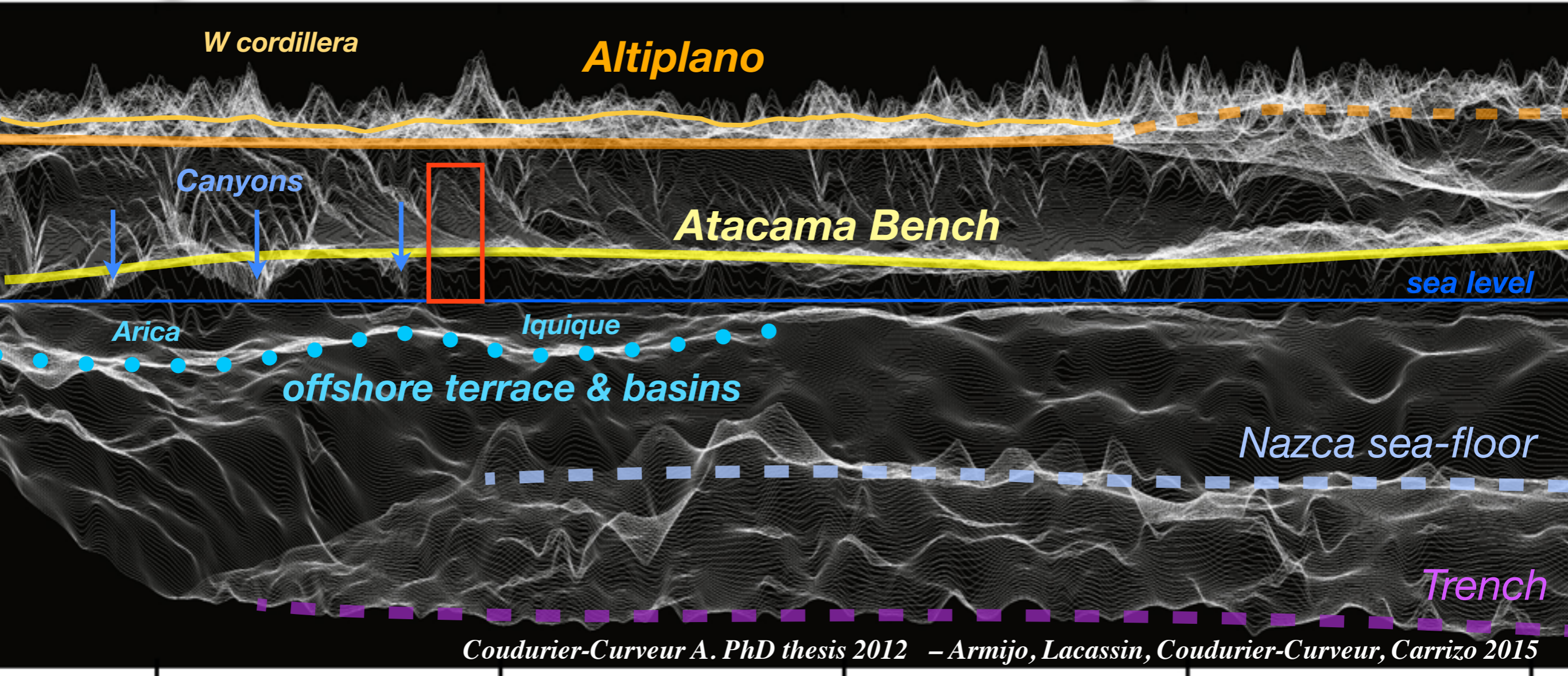
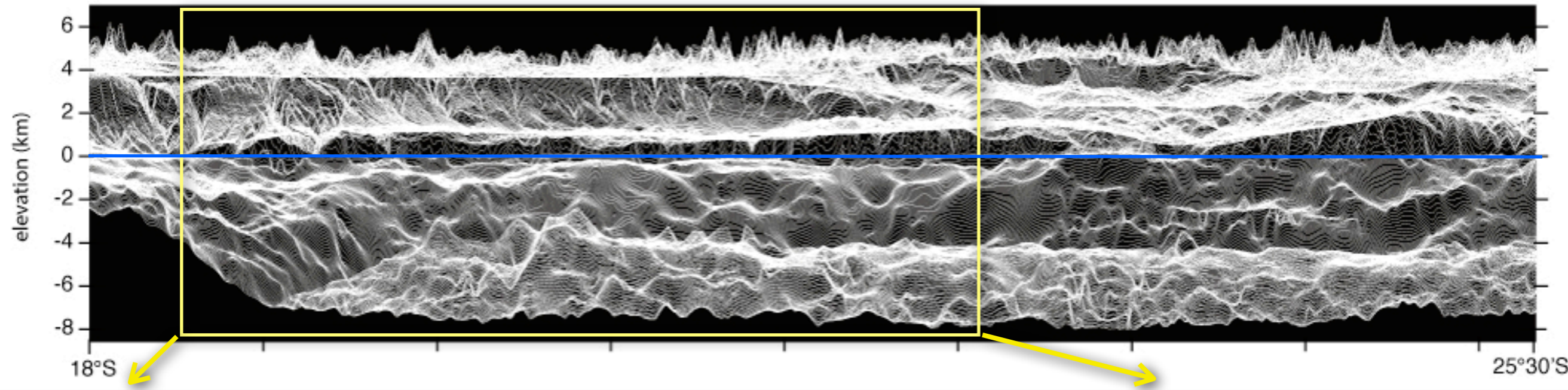


Armijo, Lacassin, Coudurier-Curveur, Carrizo 2015

N

Scan (wide-swath) of topography-bathymetry (SRTM30+)

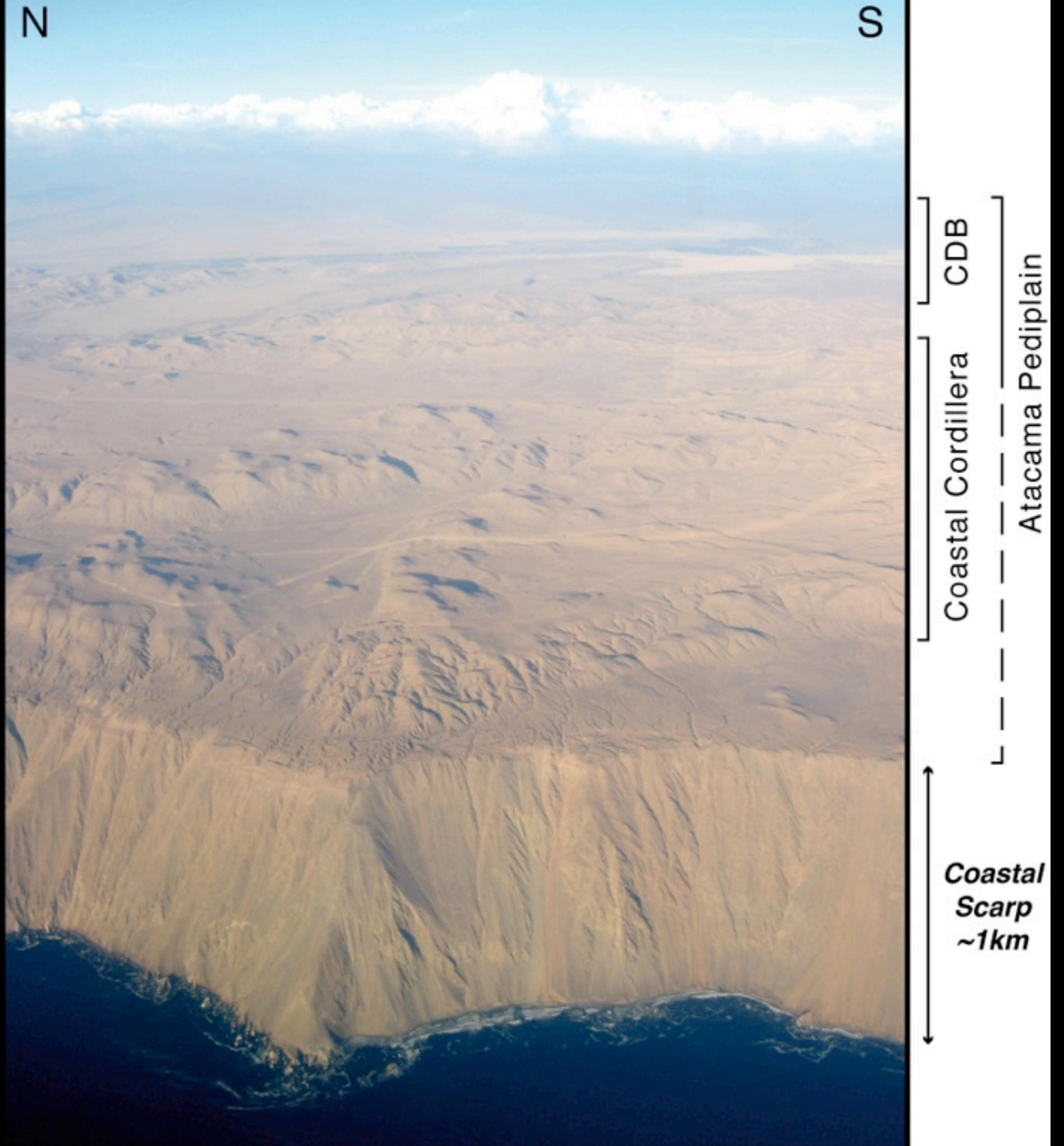
S



Coudurier-Curveur A. PhD thesis 2012 – Armijo, Lacassin, Coudurier-Curveur, Carrizo 2015

Atacama Bench =
plateau ~1km asl
with subdued relief,
long-standing evolution
at very low rate

Dramatic rejuvenation
at Coastal Scarp



E

W



W

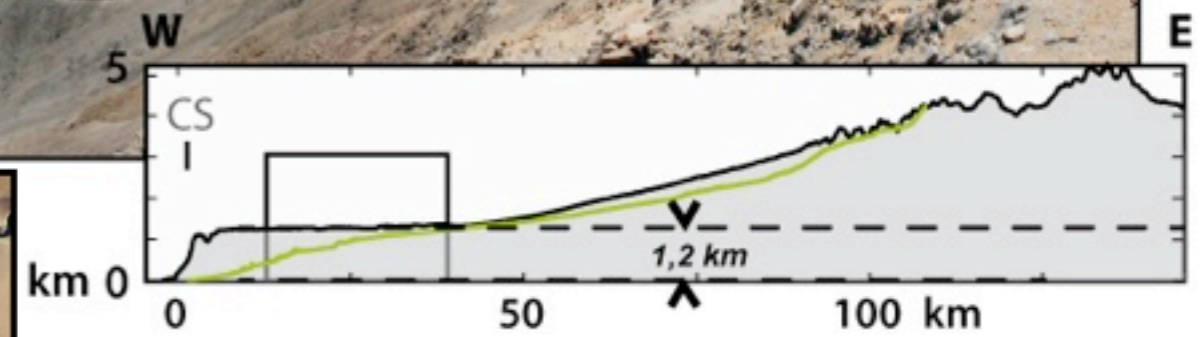
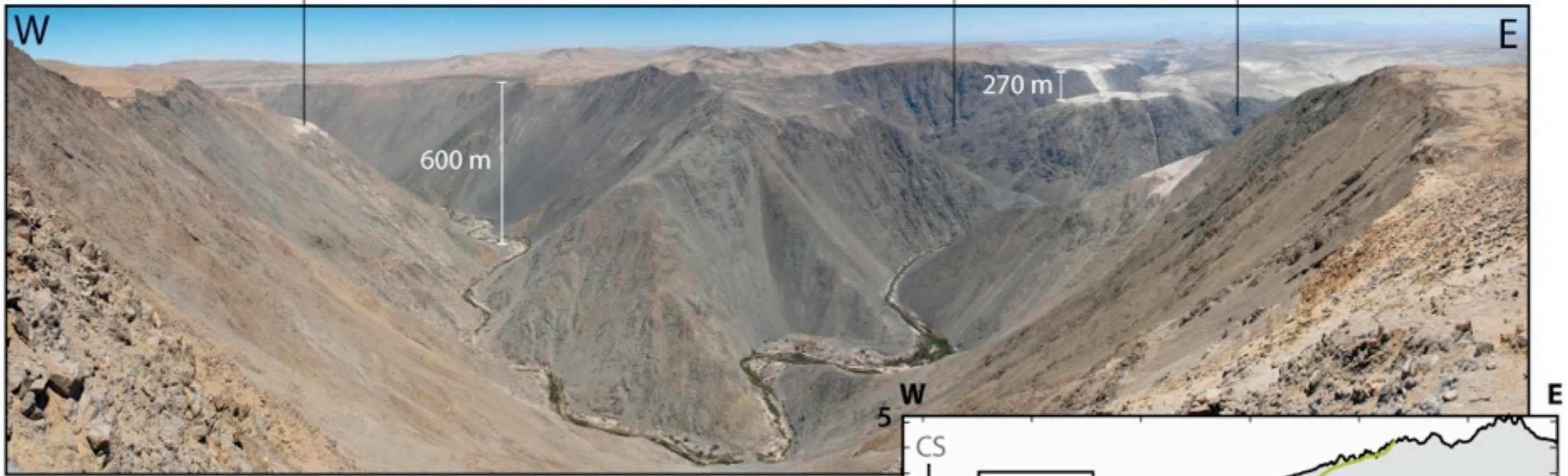
E



~6.4 Ma (Hoke et al., 2007)

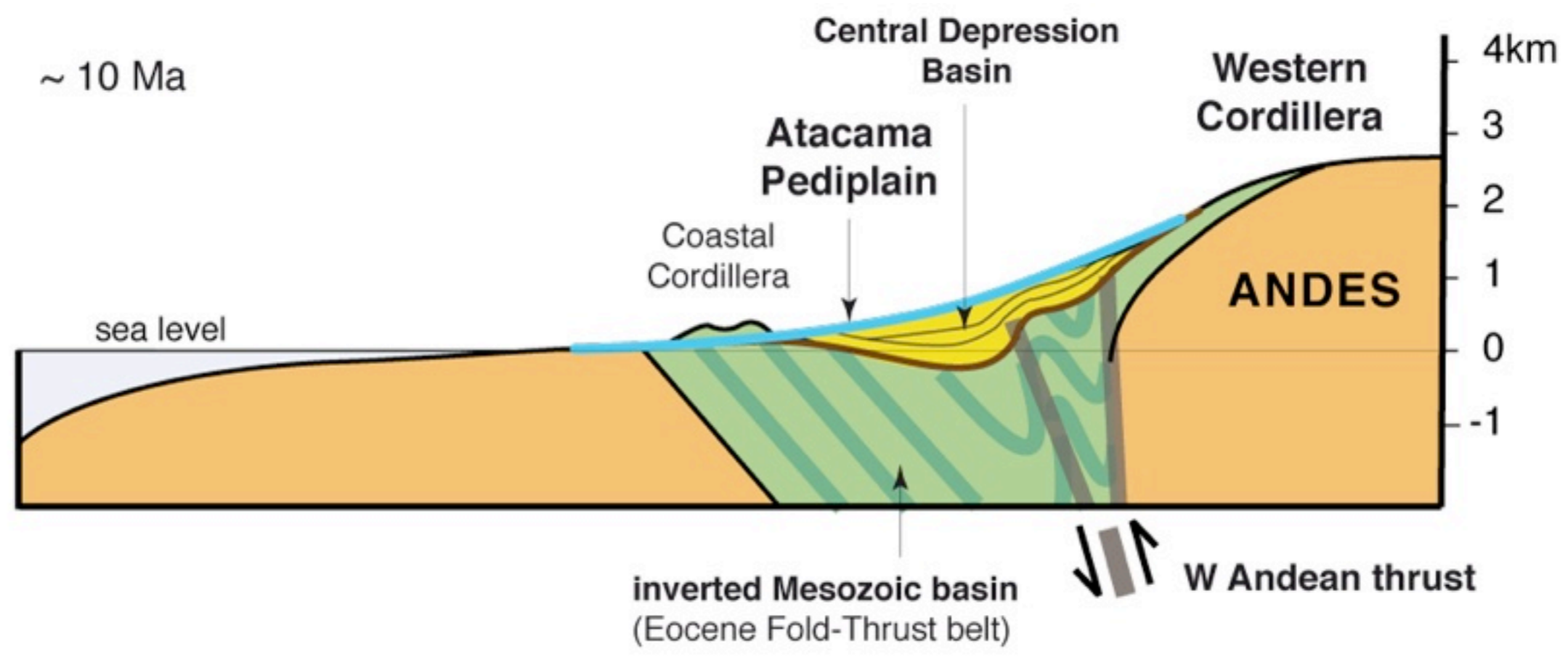
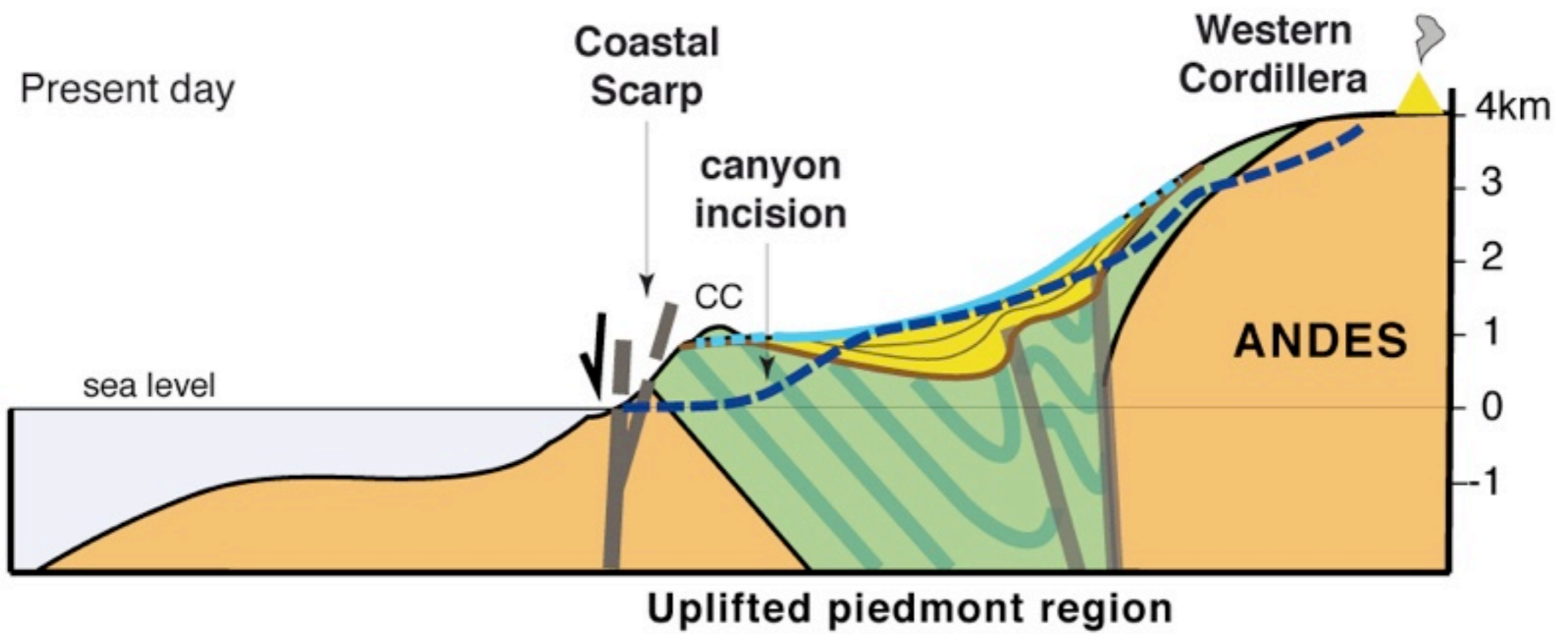
Tana canyon

Tiliviche canyon



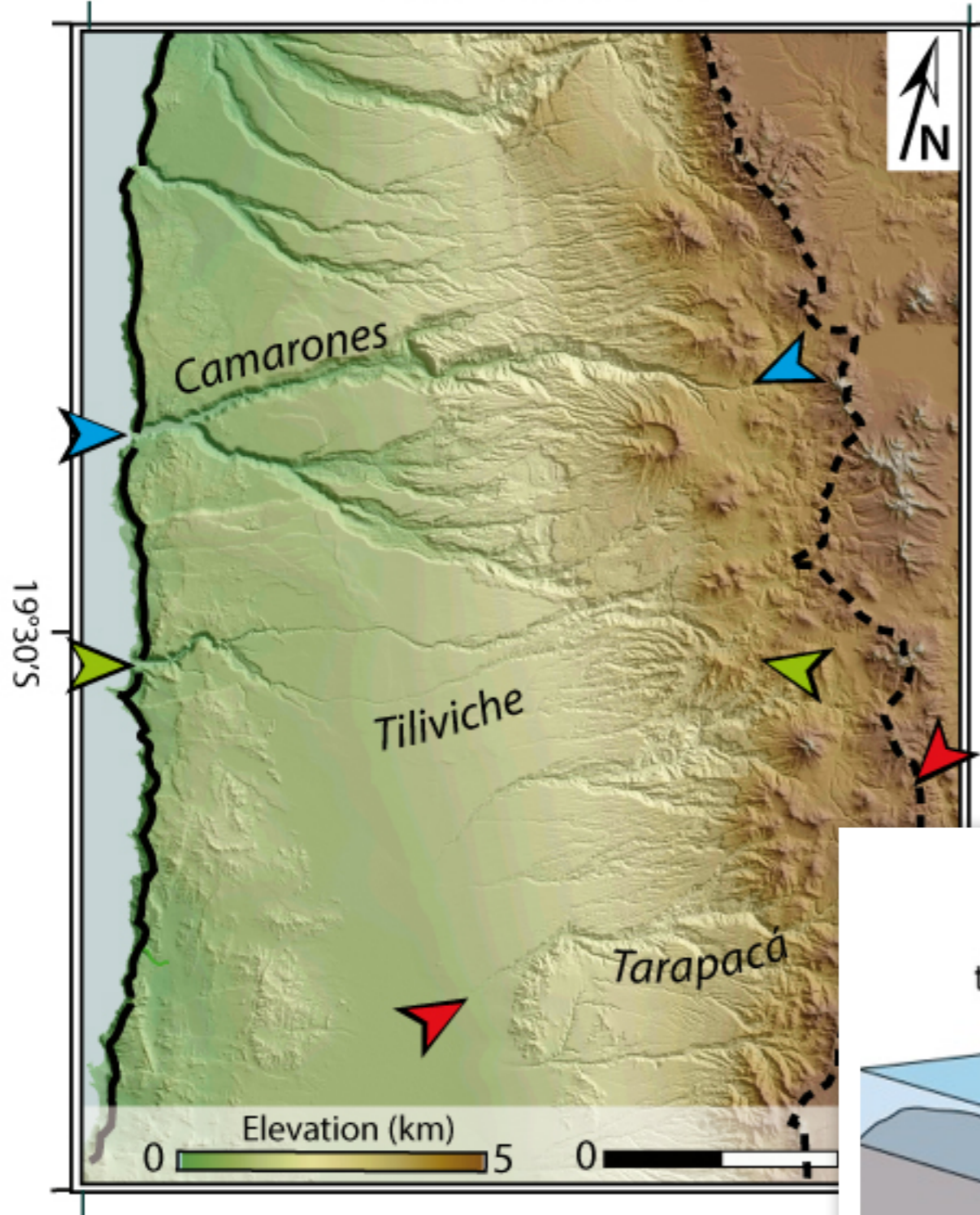
Drainage at geomorphic threshold

Coudurier-Curveur, Lacassin, Armijo EPSL 2015

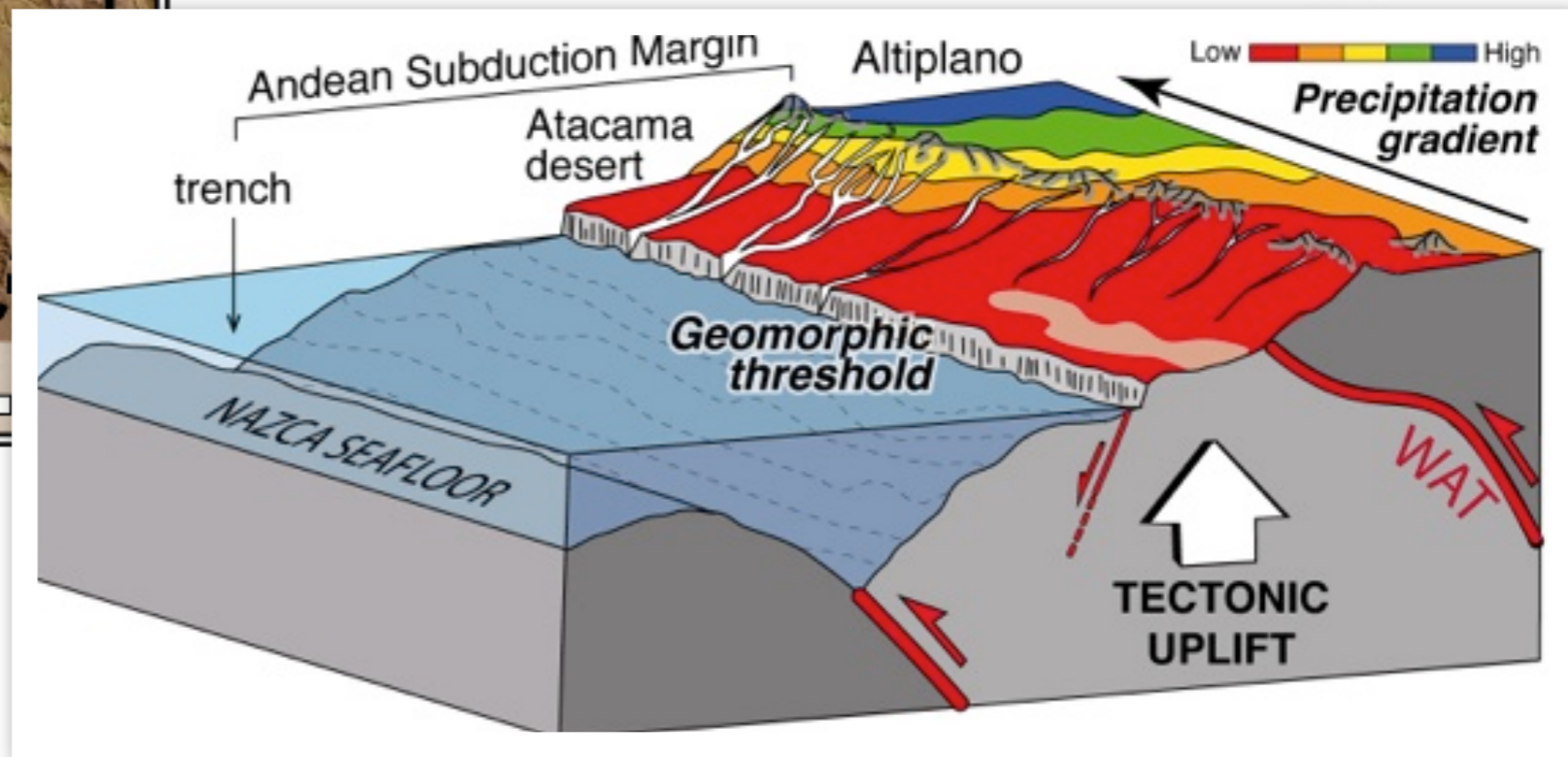
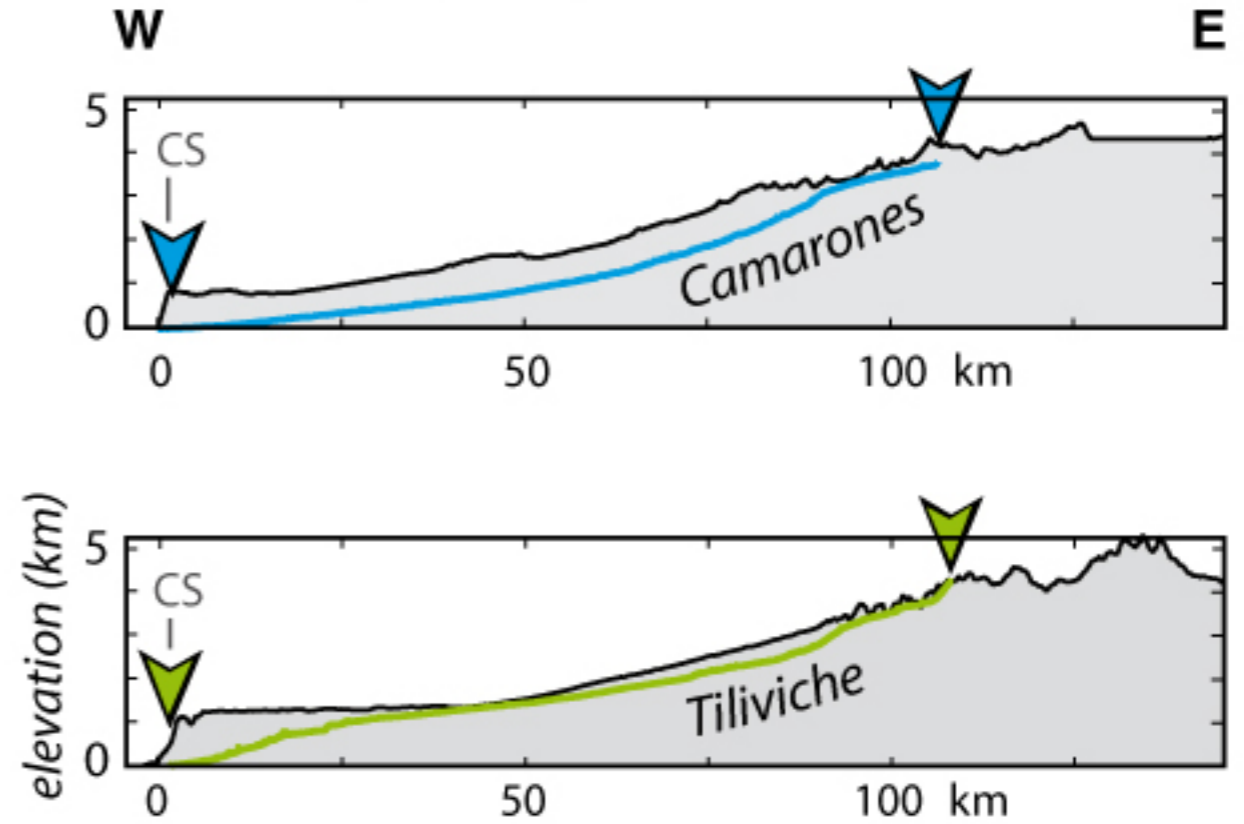


Coudurier-Curveur, Lacassin, Armijo EPSL 2015

Observations

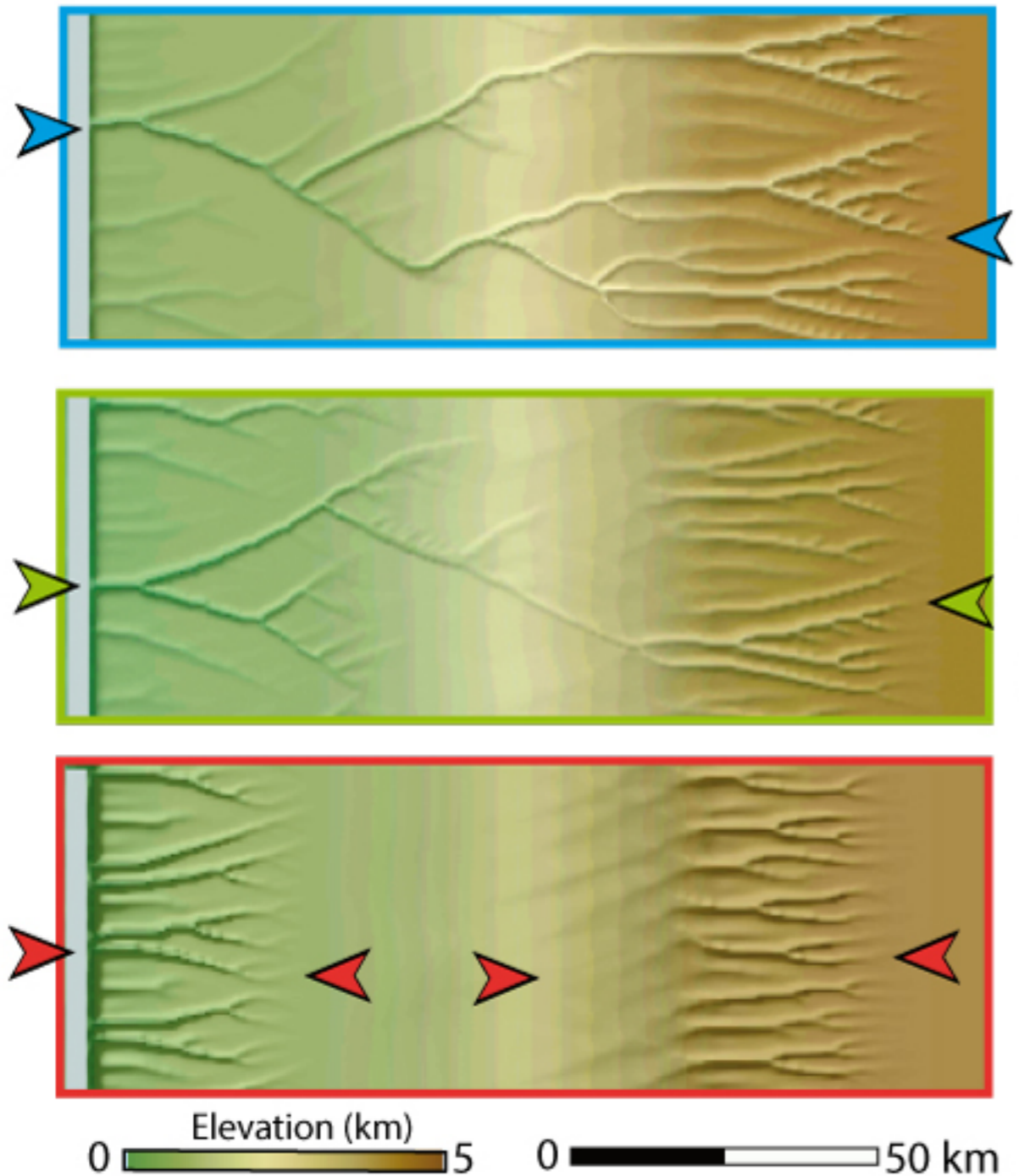


Topography and river profiles



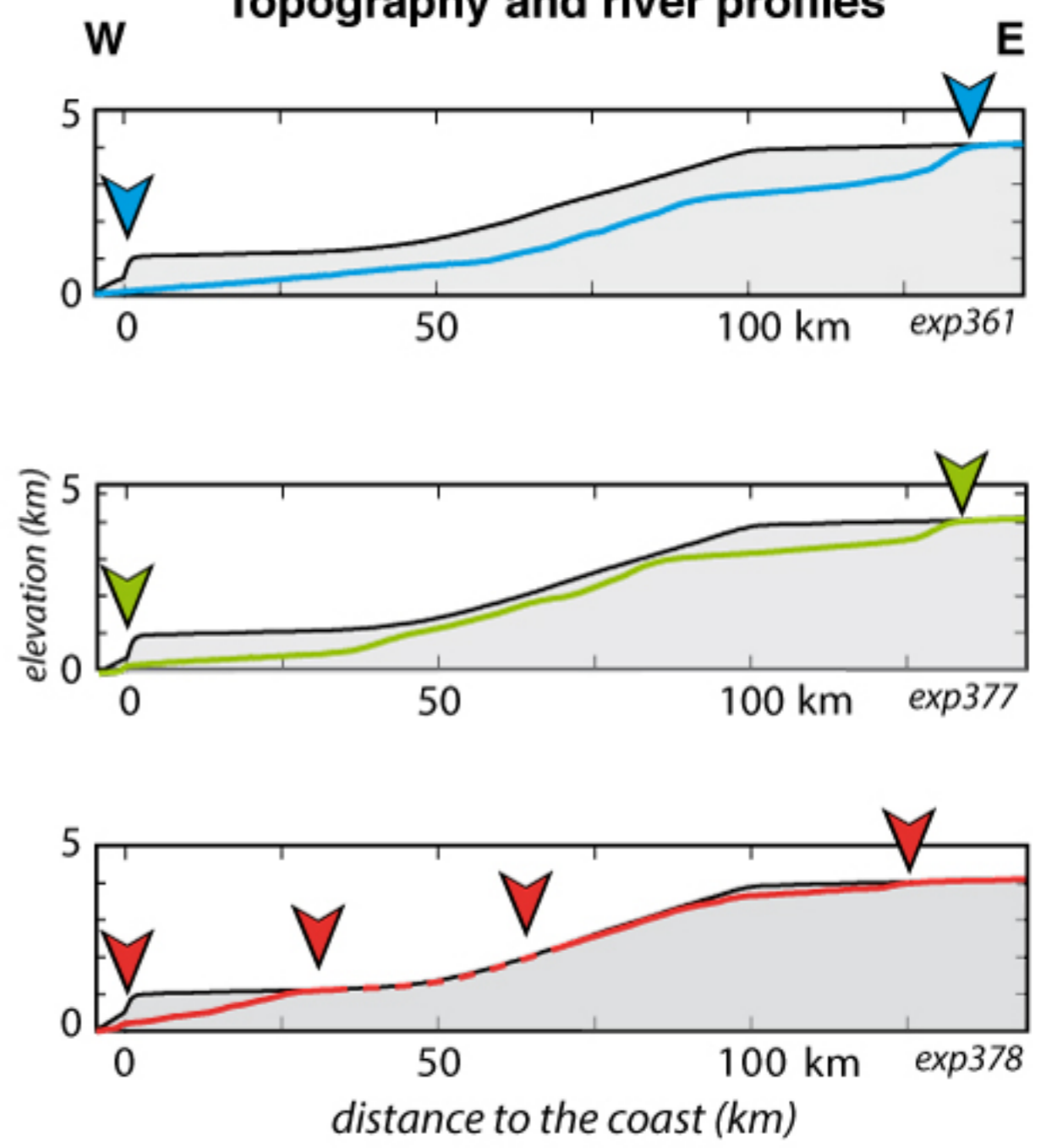
Coudurier-Curveur, Lacassin, Armijo EPSL 2015

Model



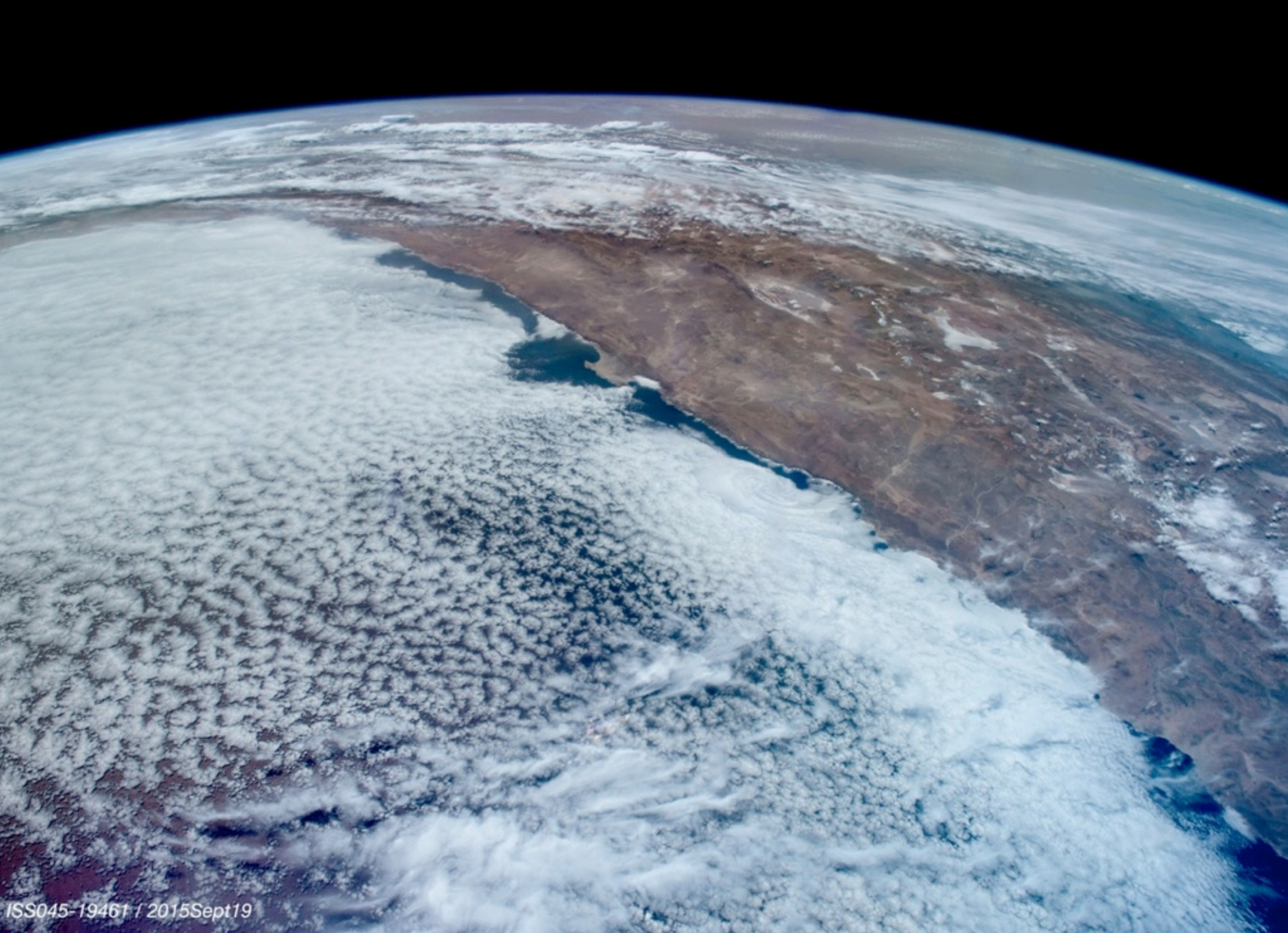
+
 higher
 intermediate
 precipitation rates
 lower
 -

Topography and river profiles



Landscape Evolution Model with Carretier and Lucazeau (2005) code

Coudurier-Curveur, Lacassin, Armijo EPSL 2015



ISS045-19461 / 2015Sept19



Image Landsat

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google earth

W

E



Armijo, Lacassin, Coudurier-Curveur, Carrizo 2015

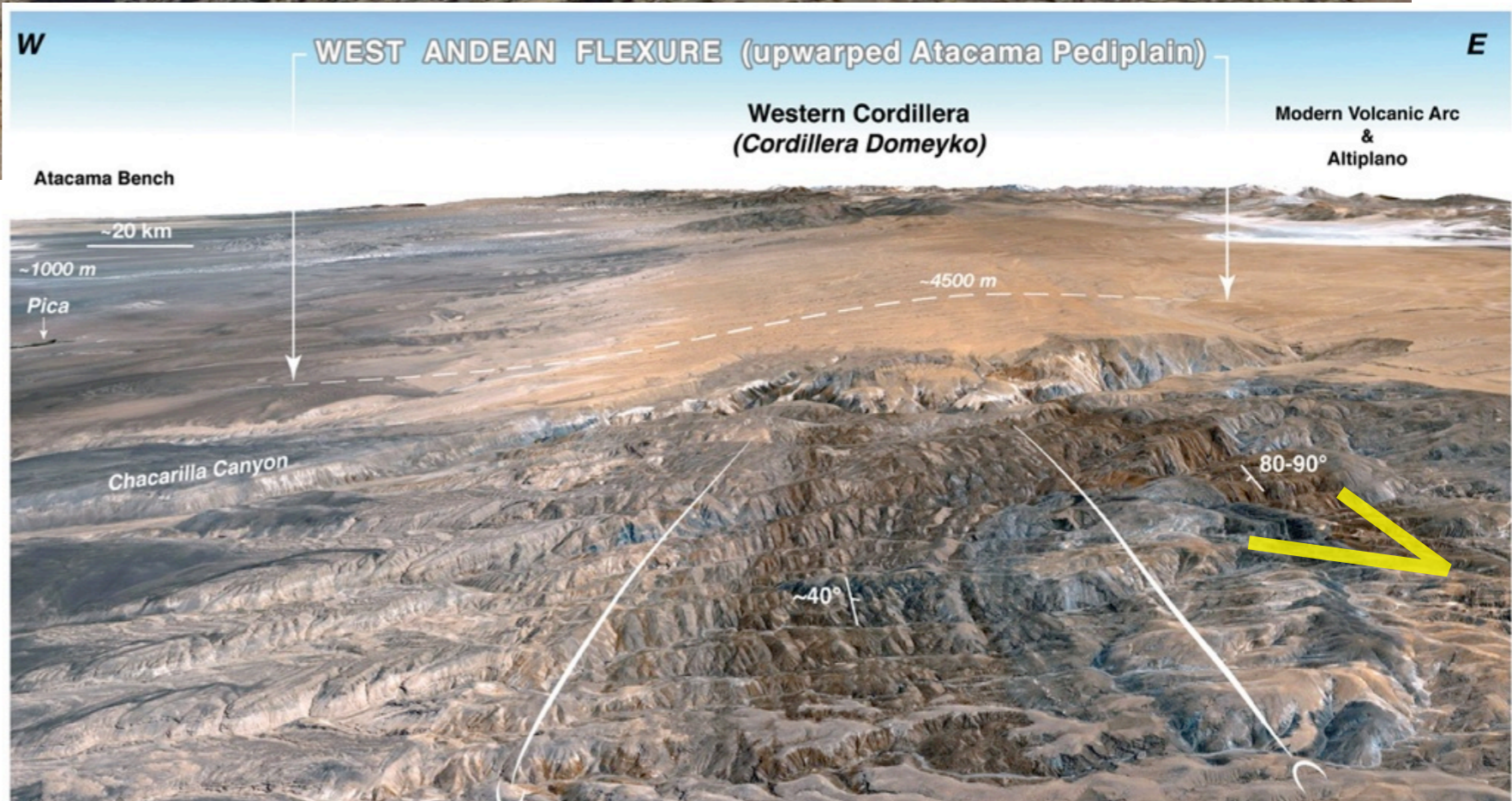
W

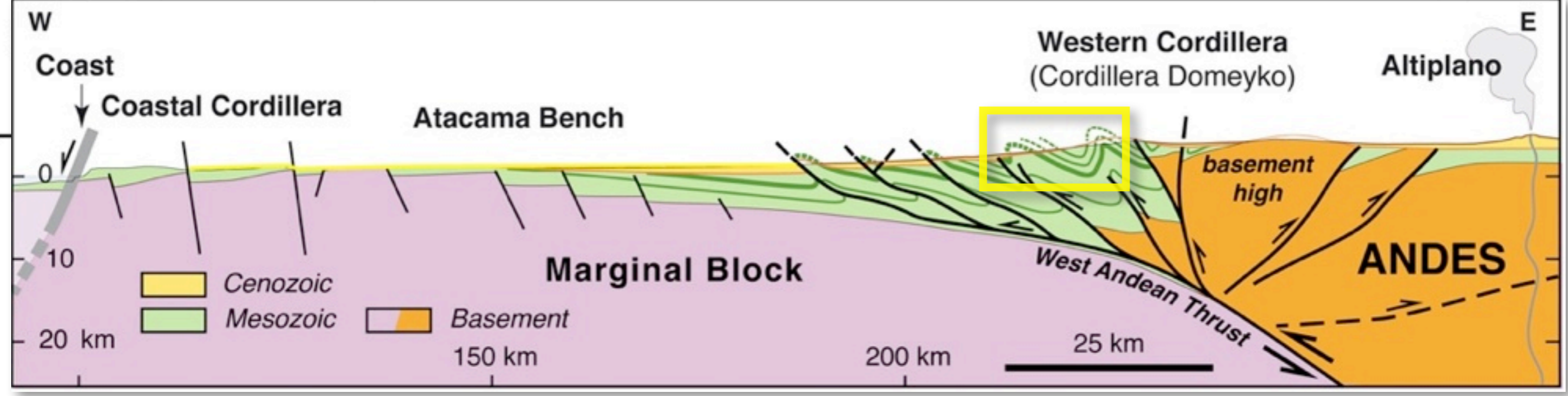
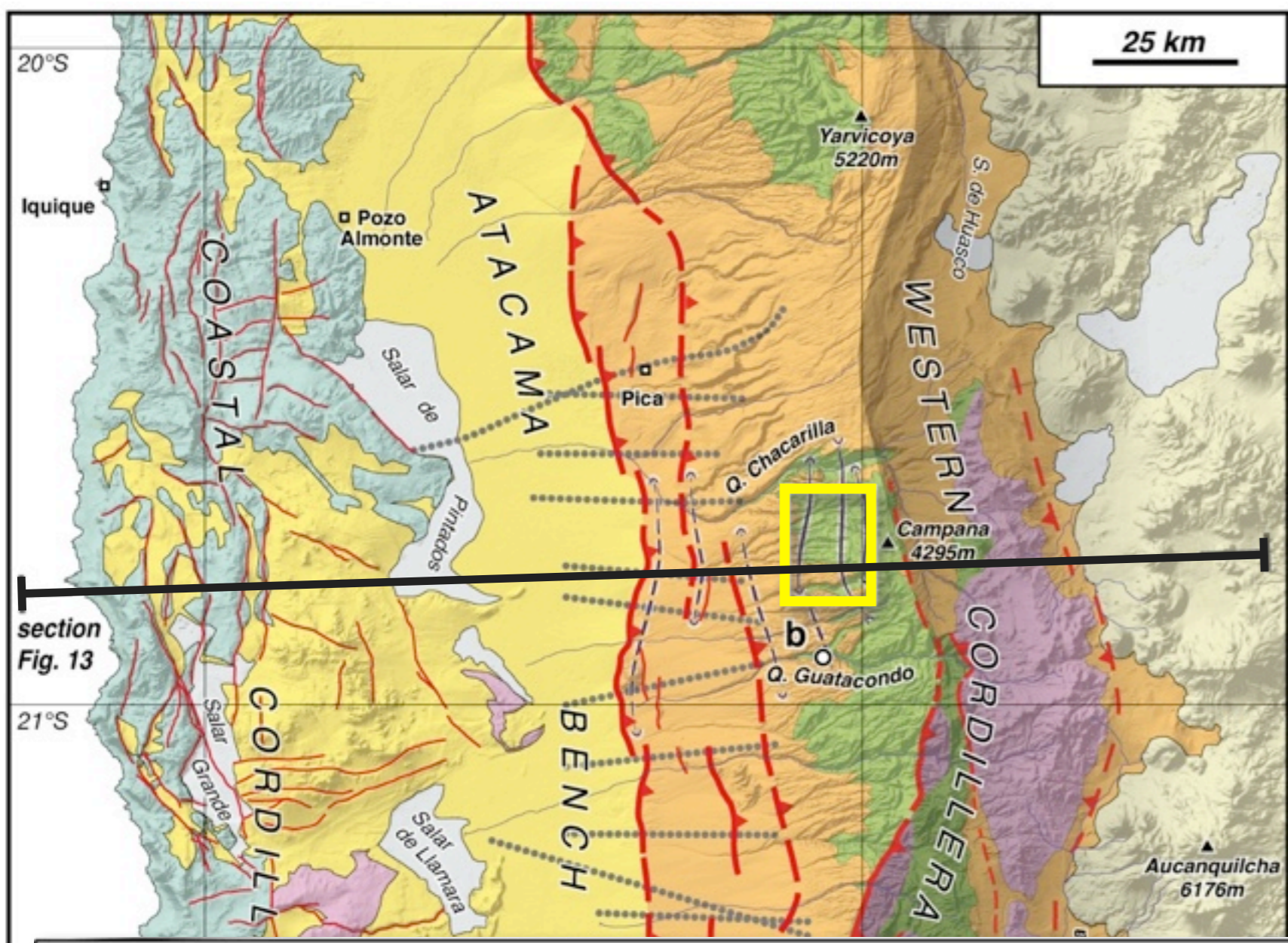
E



W

E

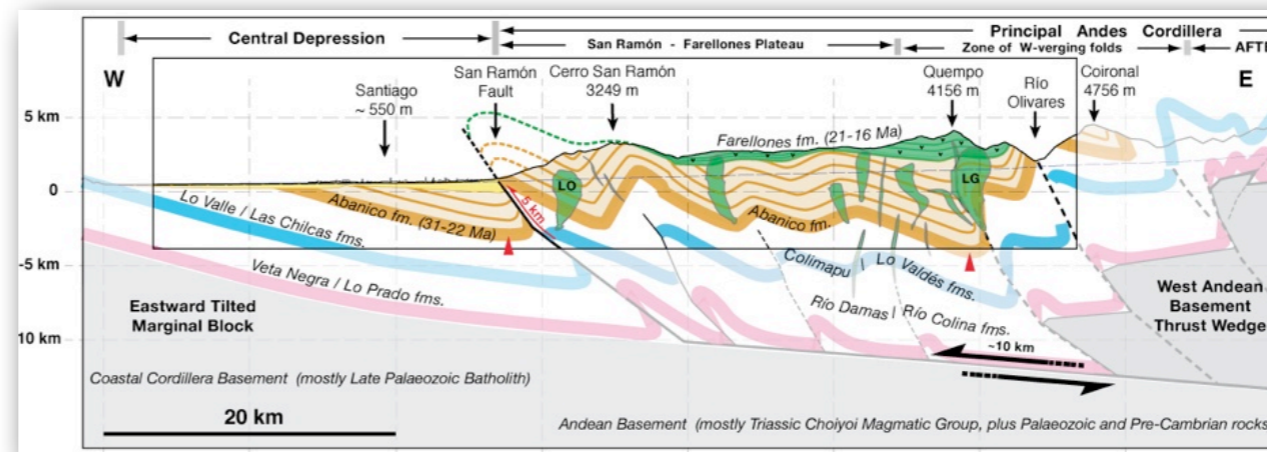
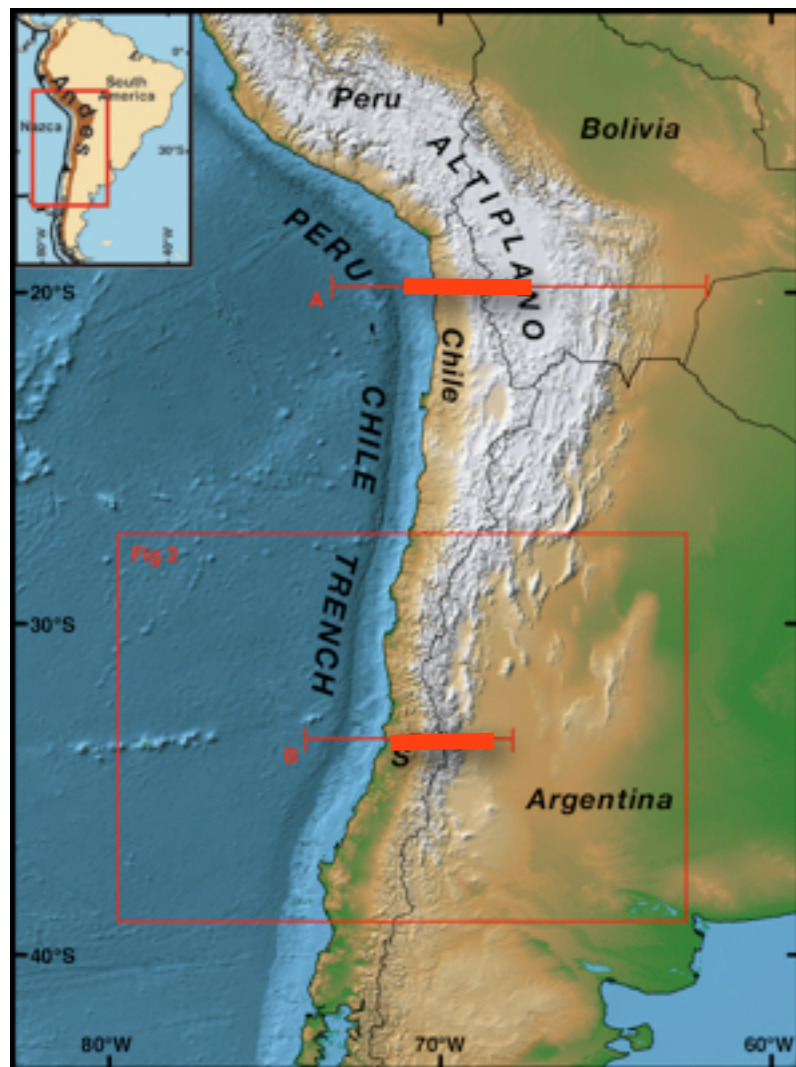
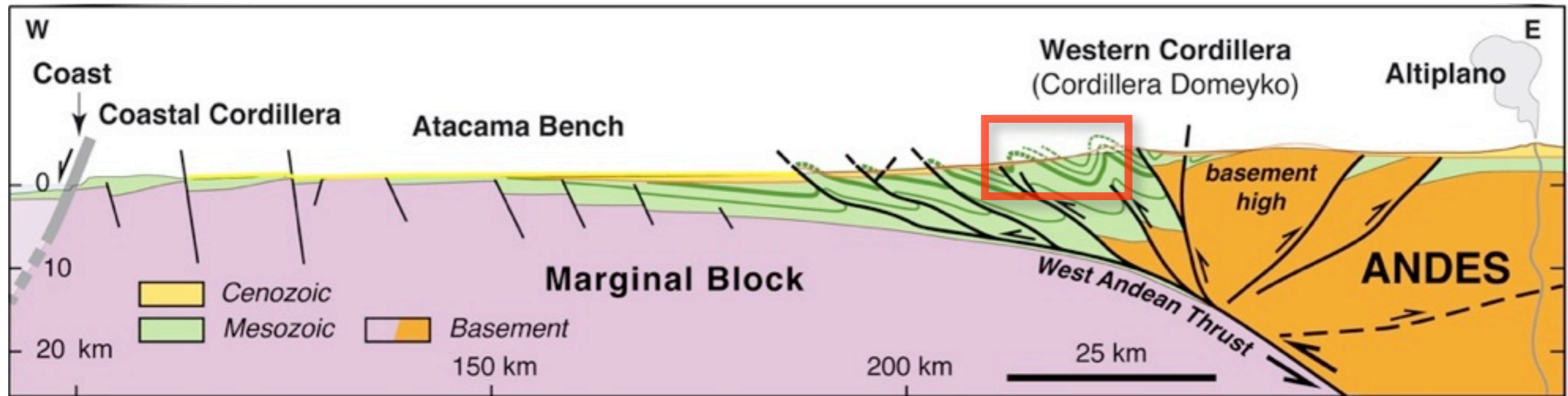




Armijo, Lacassin, Coudurier-Curveur, Carrizo 2015

North Chile Fold & Thrust Belt (~21°S)

Armijo, Lacassin, Coudurier-Curveur, Carrizo, 2015



same scale !

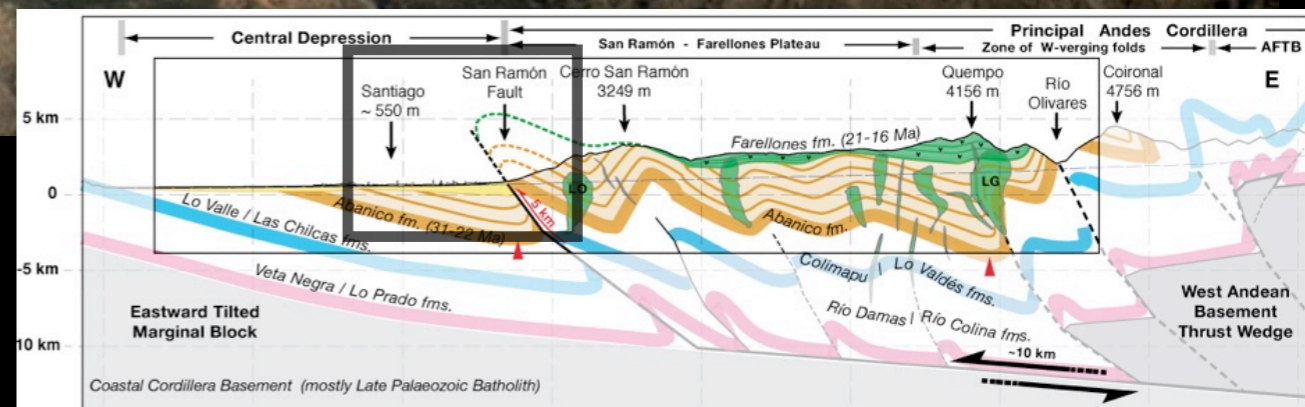
San Ramón Fold & Thrust Belt (~33°S)

Armijo et al. 2010

~1400 km southward

SW

NE



San Ramón Fault - Helicopter view - R. Lacassin

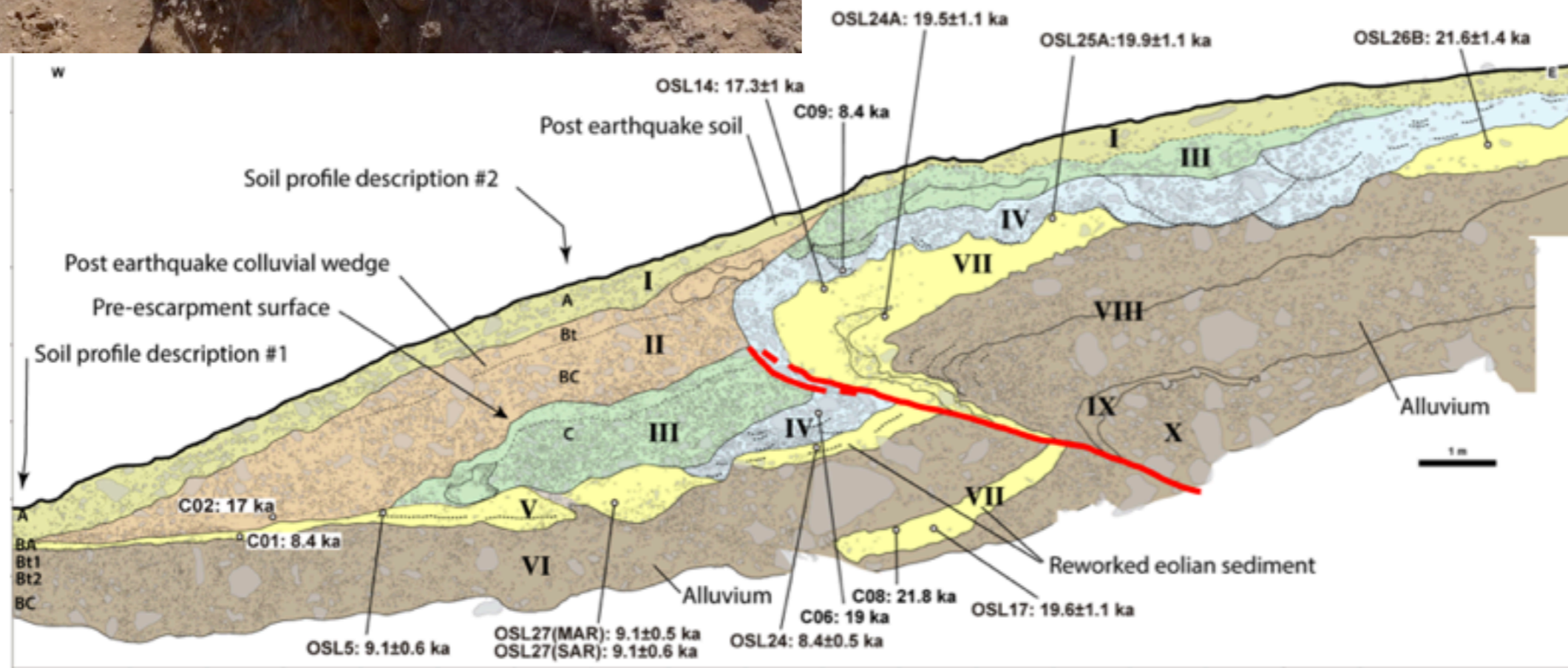


San Ramón Fault (WAT)

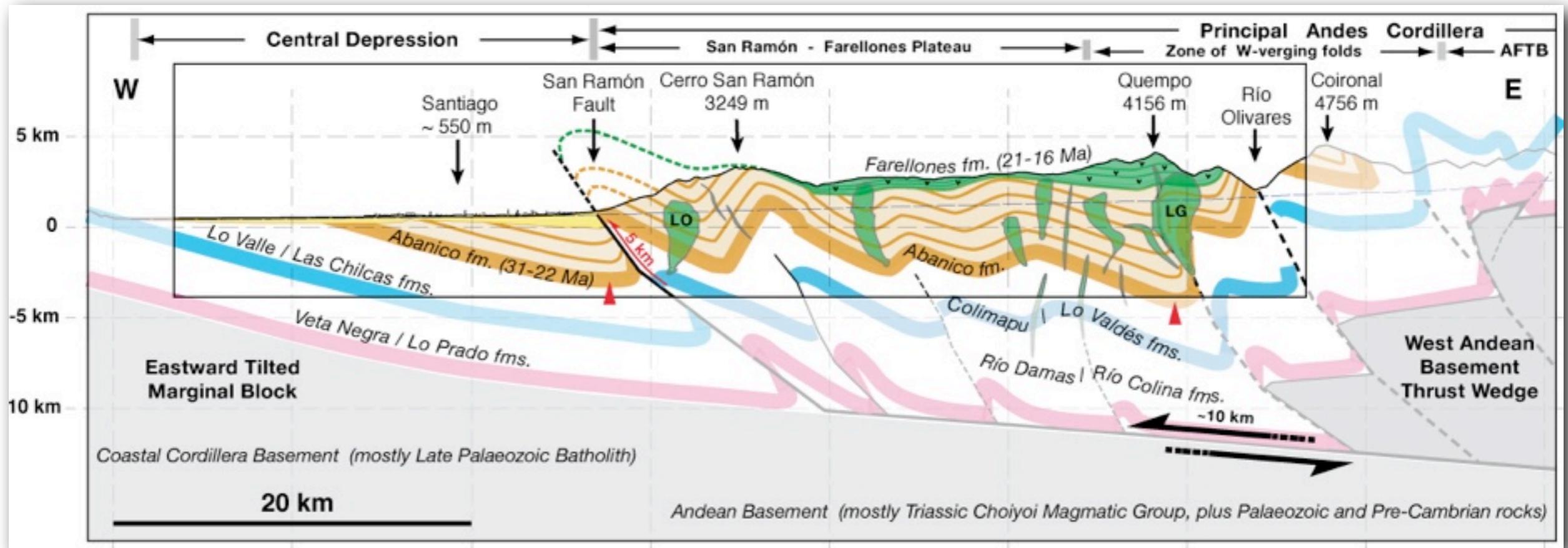
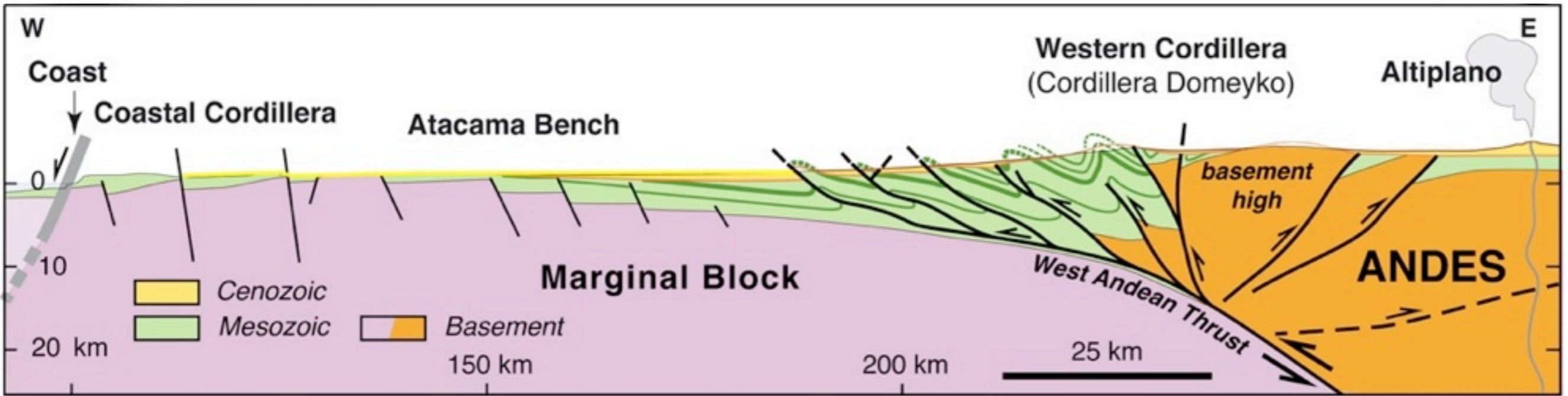
Two large $M_w \sim 7.5$ earthquakes in the past 17-19 kyr

Last event ~ 8 kyr

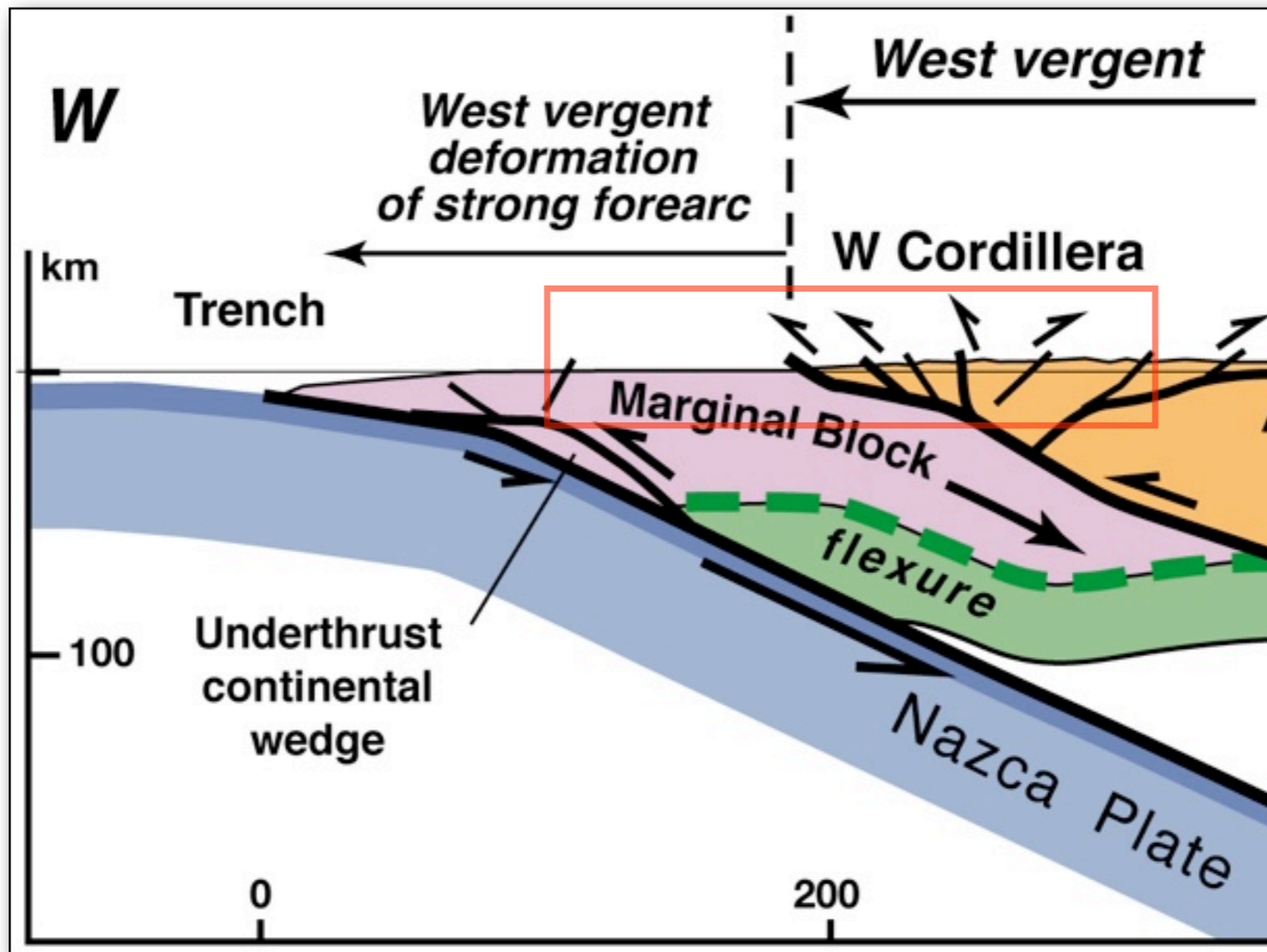
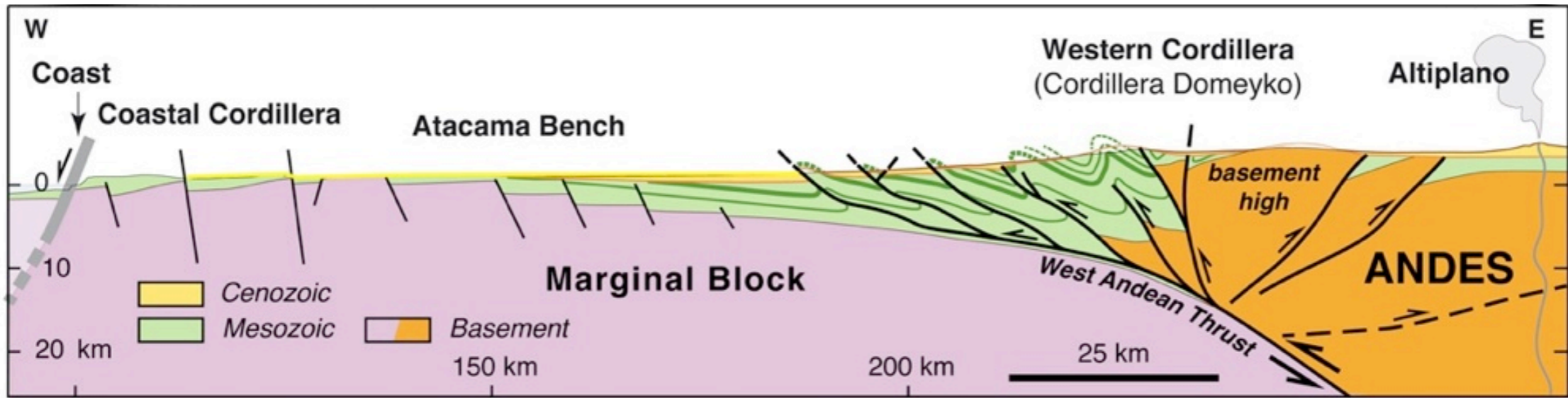
ripe for another large earthquake...

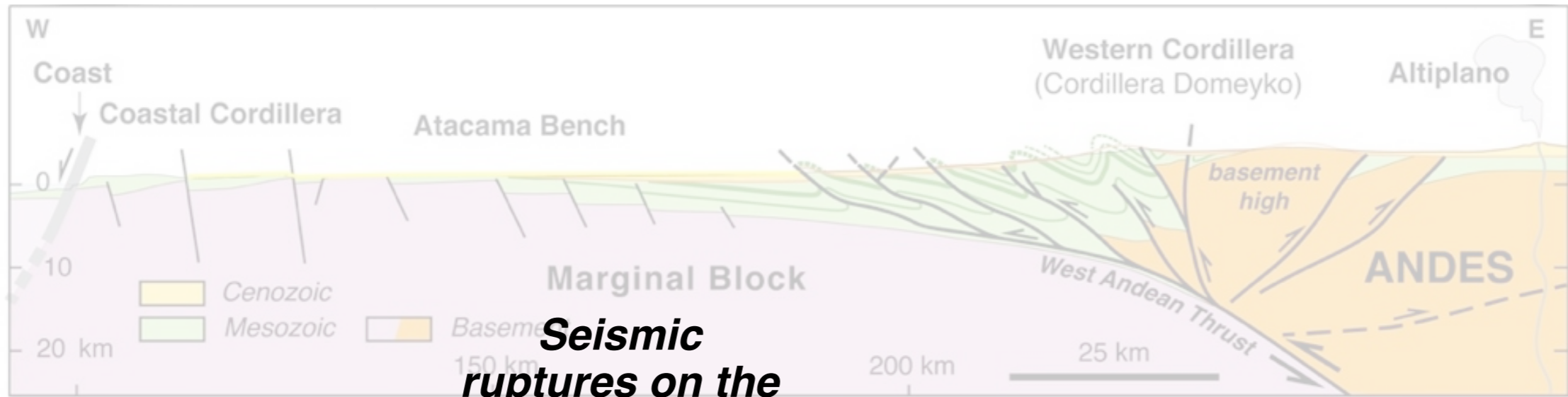


Vargas et al., Geology, 2014

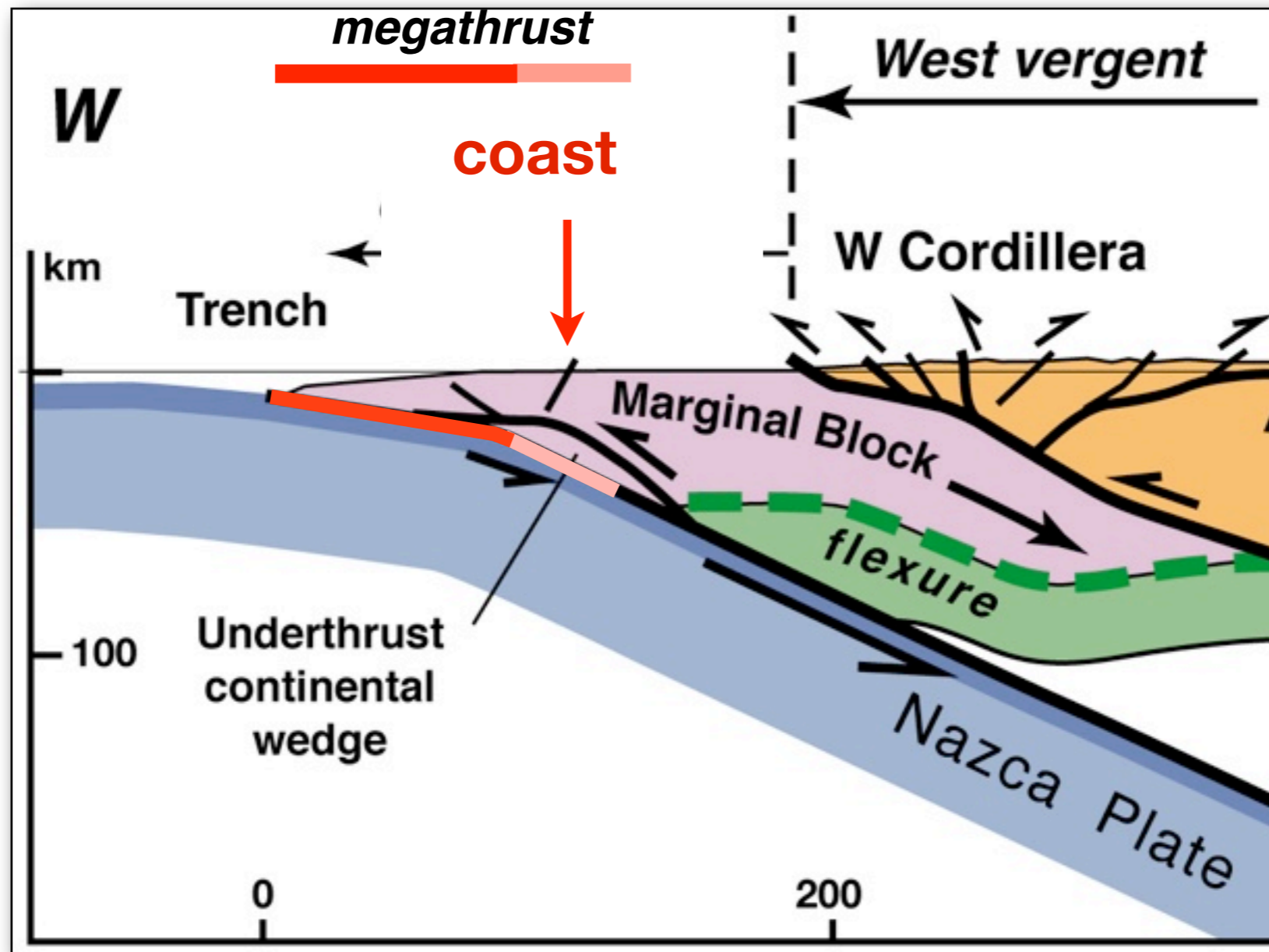


San Ramón Fold & Thrust Belt (~33°S)



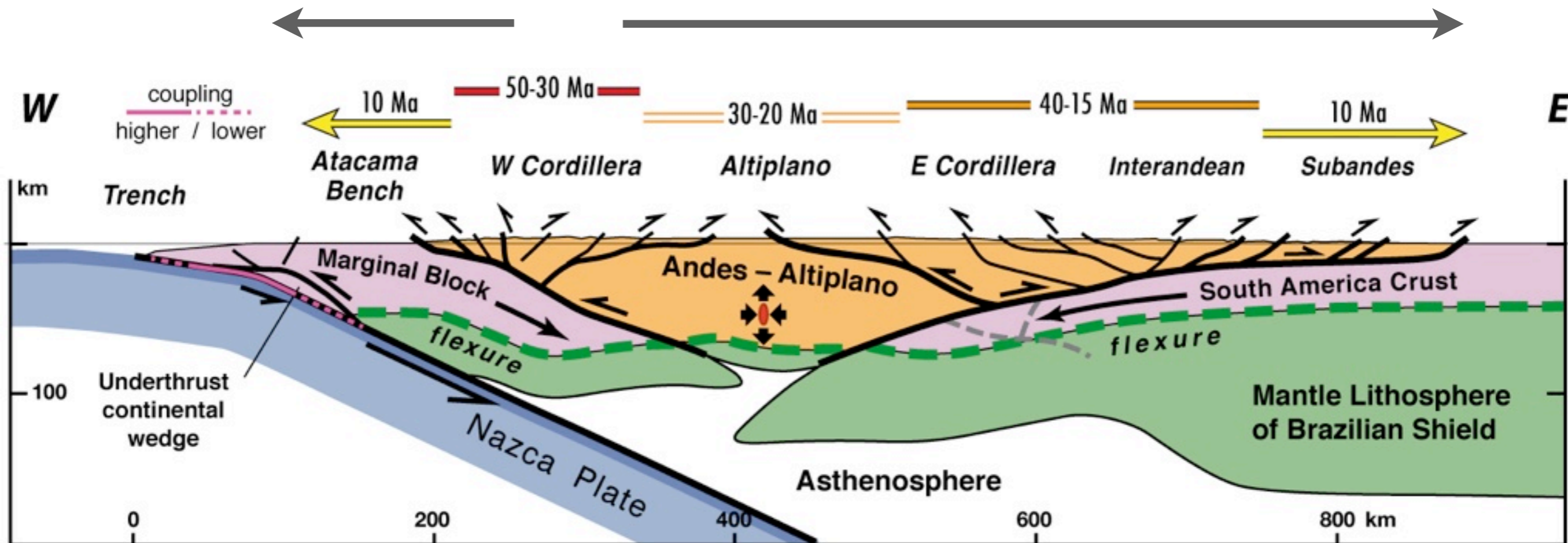


Seismic ruptures on the subduction megathrust



enlarging the view...

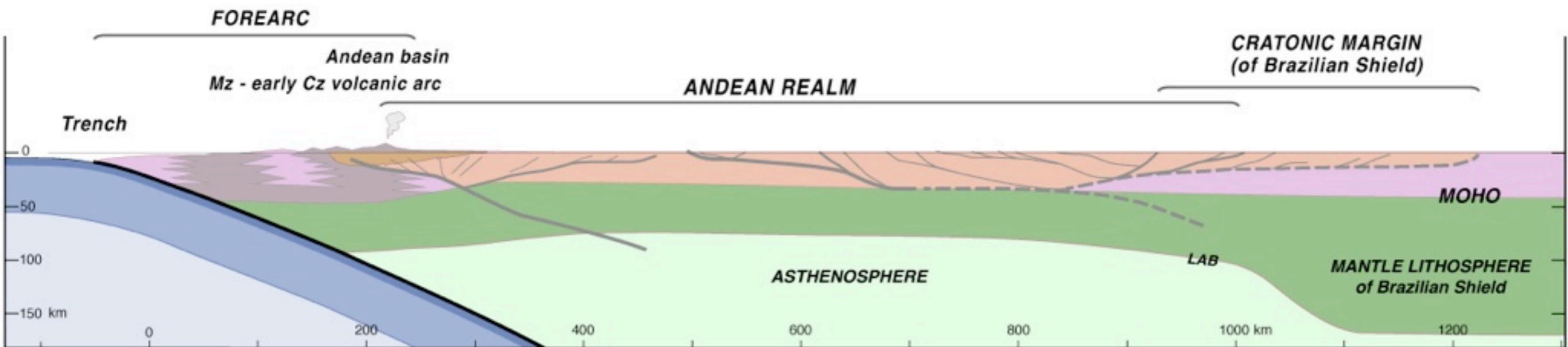
Bivergent diachronic growth



50 Ma [70-50]

W

E



40 Ma [45-35]

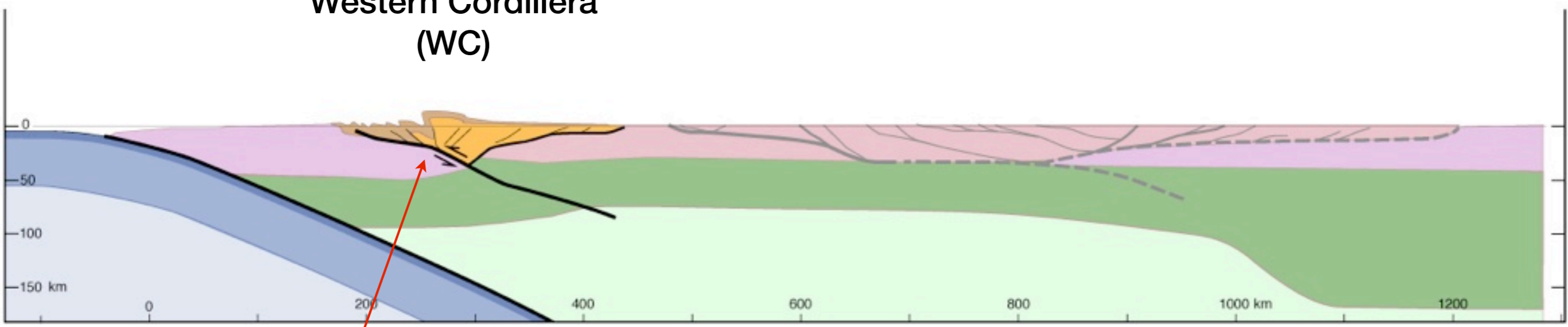
W

E

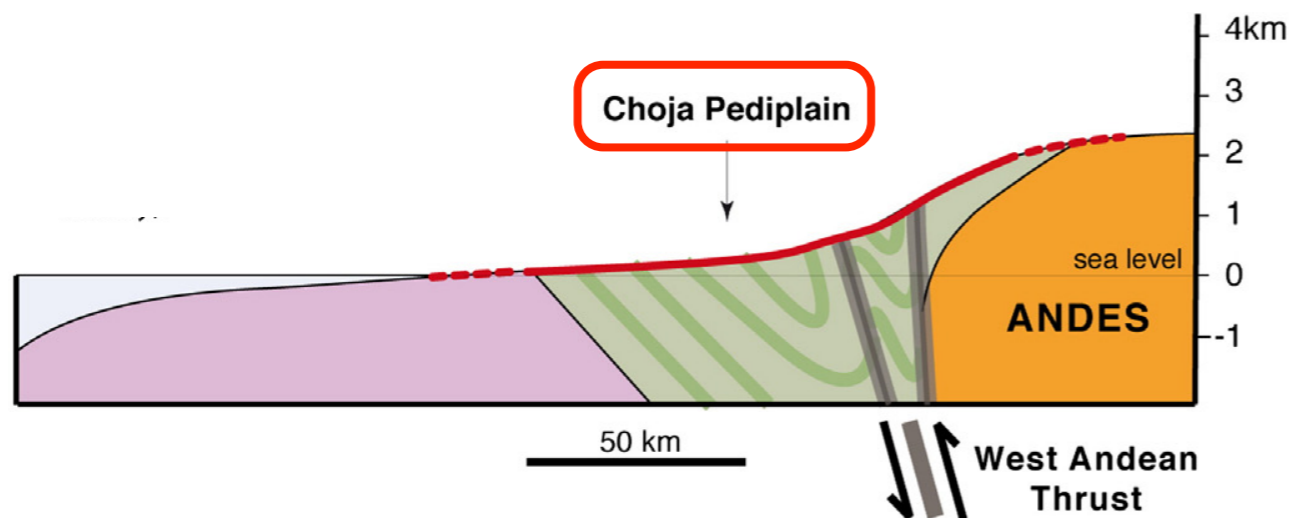


Semi-aridity / growing WC eroded

Western Cordillera
(WC)



West Andean Thrust (WAT)



End of erosion of WC
Formation of the Choja Pediplain

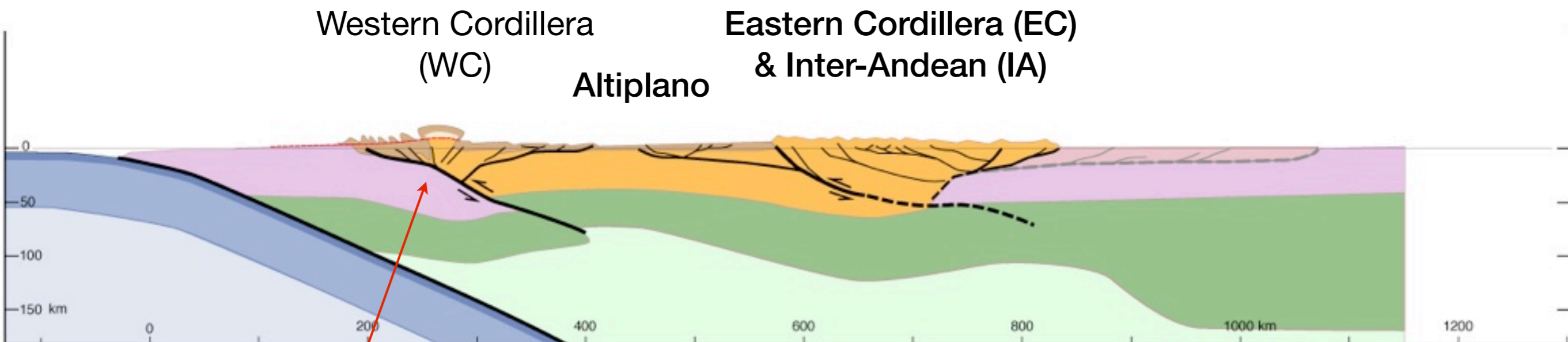
30 Ma [35-25]

W

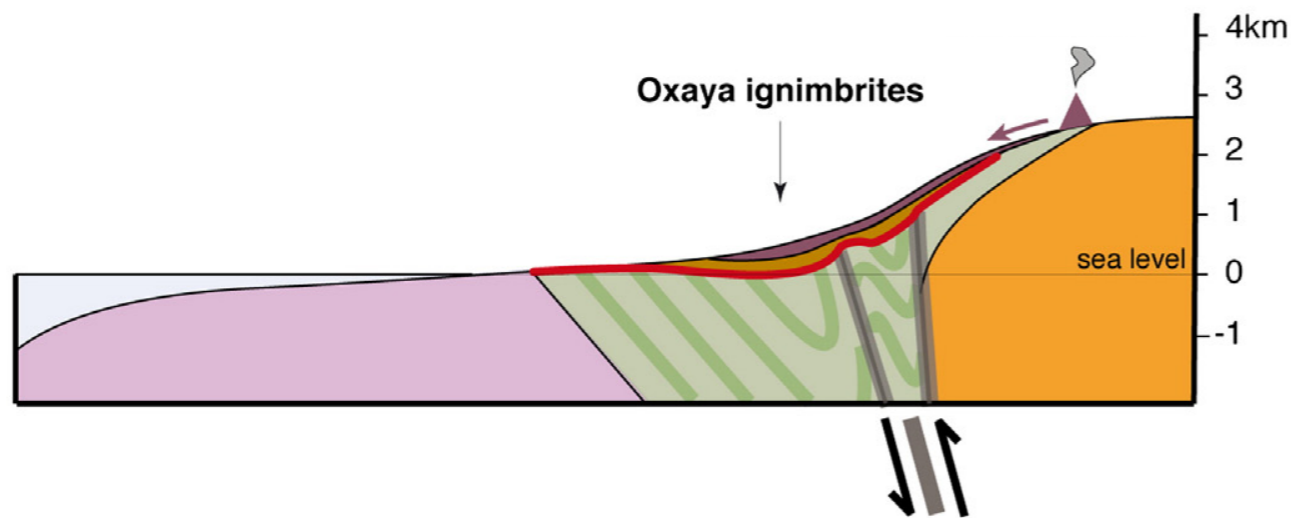


increased aridity: WC "frozen"

E



West Andean Thrust (WAT)



Deposition of Azapa fm. & Oxaya ignimbrite: starved Central Depression Basin (CDB)

20 Ma [25-15]

W

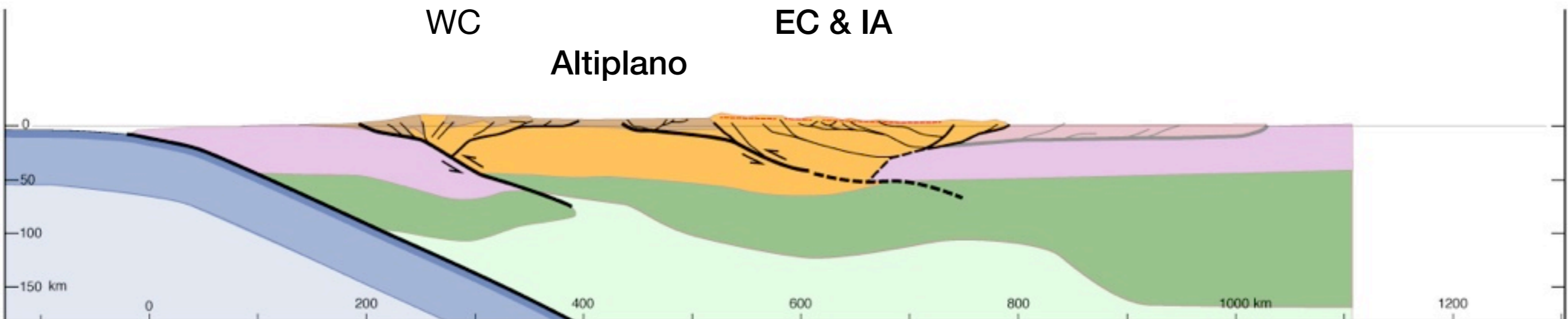
E

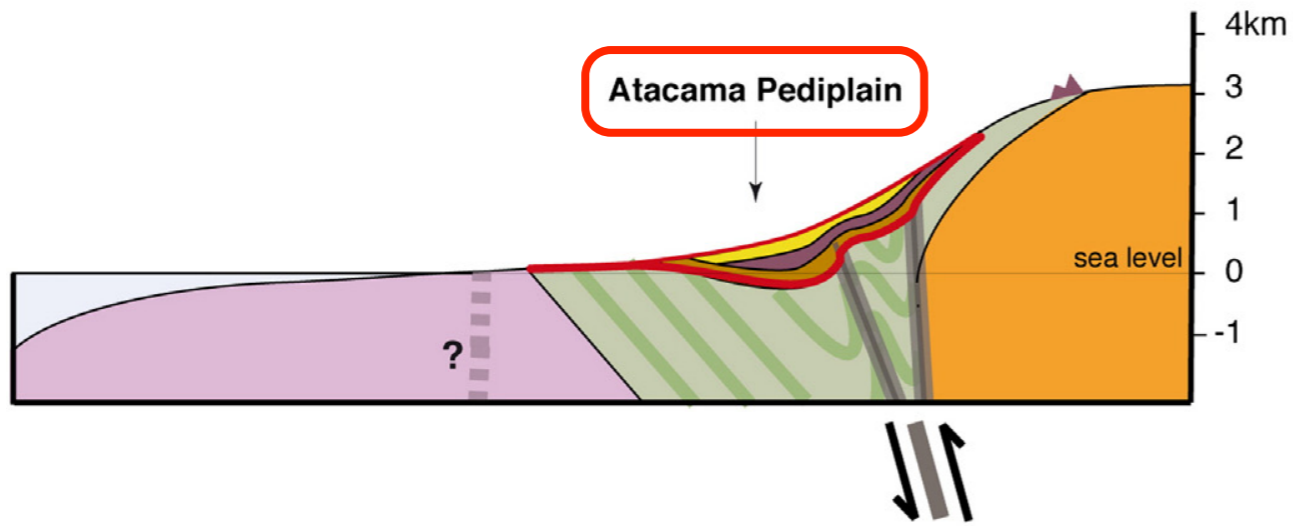


WC

EC & IA

Altiplano





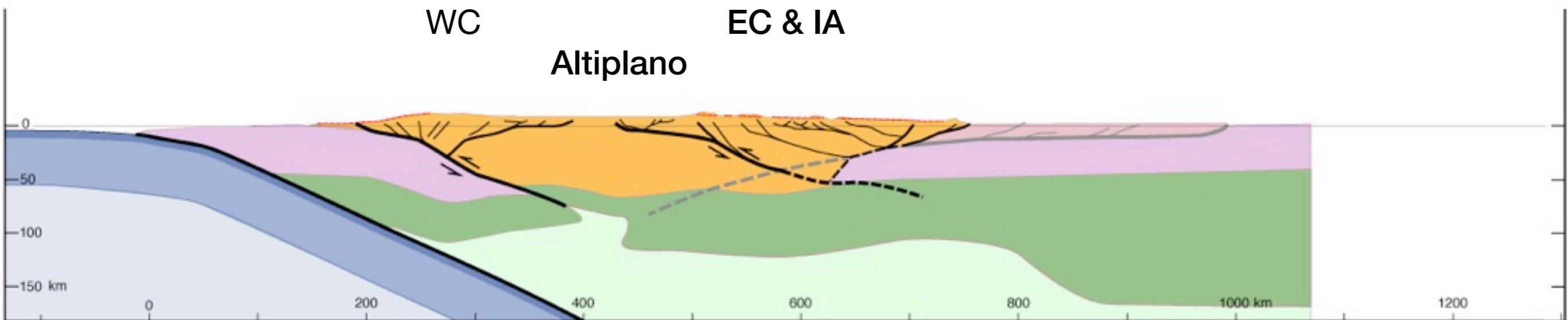
*End of deposition in CDB
Formation of the Atacama pediplain*

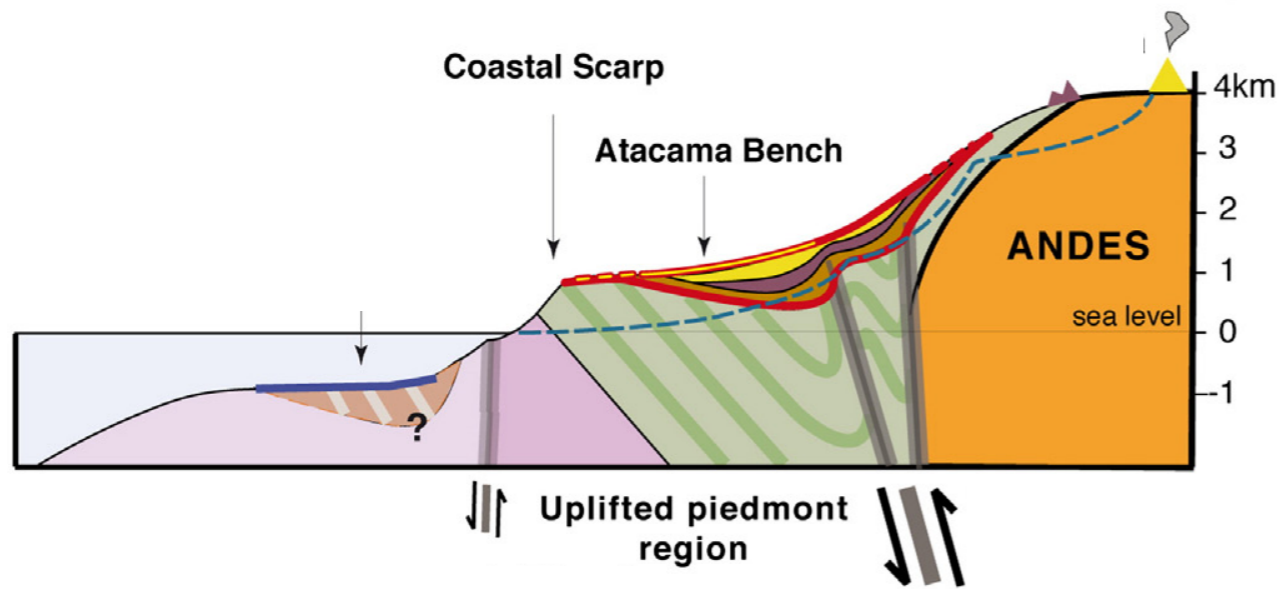
10 Ma [15-10]

W

 *hyper-aridity*

E





*Uplift of Atacama Bench:
canyons and coastal scarp*

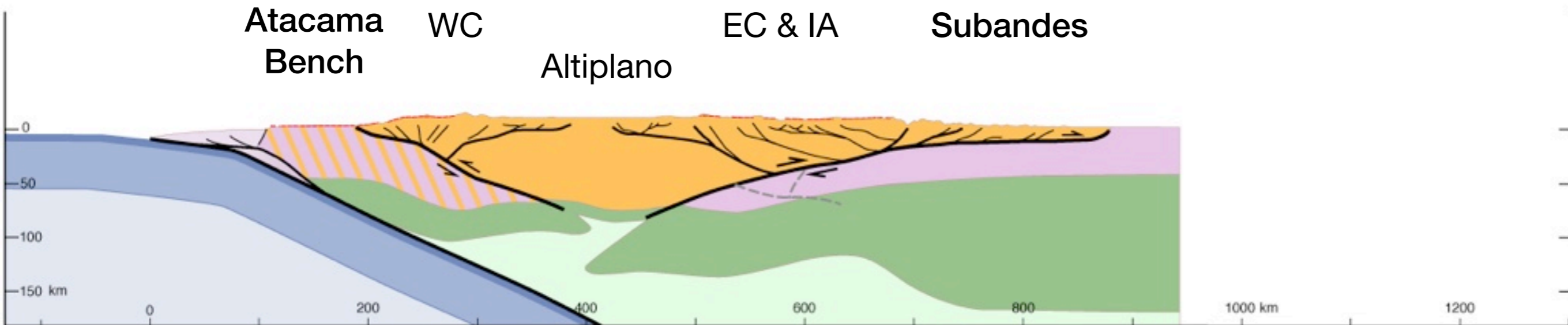
present

W



hyper-aridity

E



Onset of Andean Orogeny

Andean Orogeny

(km)

Andean shortening

SA⁺

EC-I⁺

WC

Exhumation / erosion W Cordillera

Increasing aridity in Atacama

“local” climatic evolution

Choja Pediplain

Atacama Pediplain

60 50 40 30 20 10 0 Age (My)

Armijo, Lacassin, Coudurier-Curveur, Carrizo 2015

Onset of Andean Orogeny



Andean shortening

Exhumation / erosion W Cordillera



Increasing aridity in Atacama



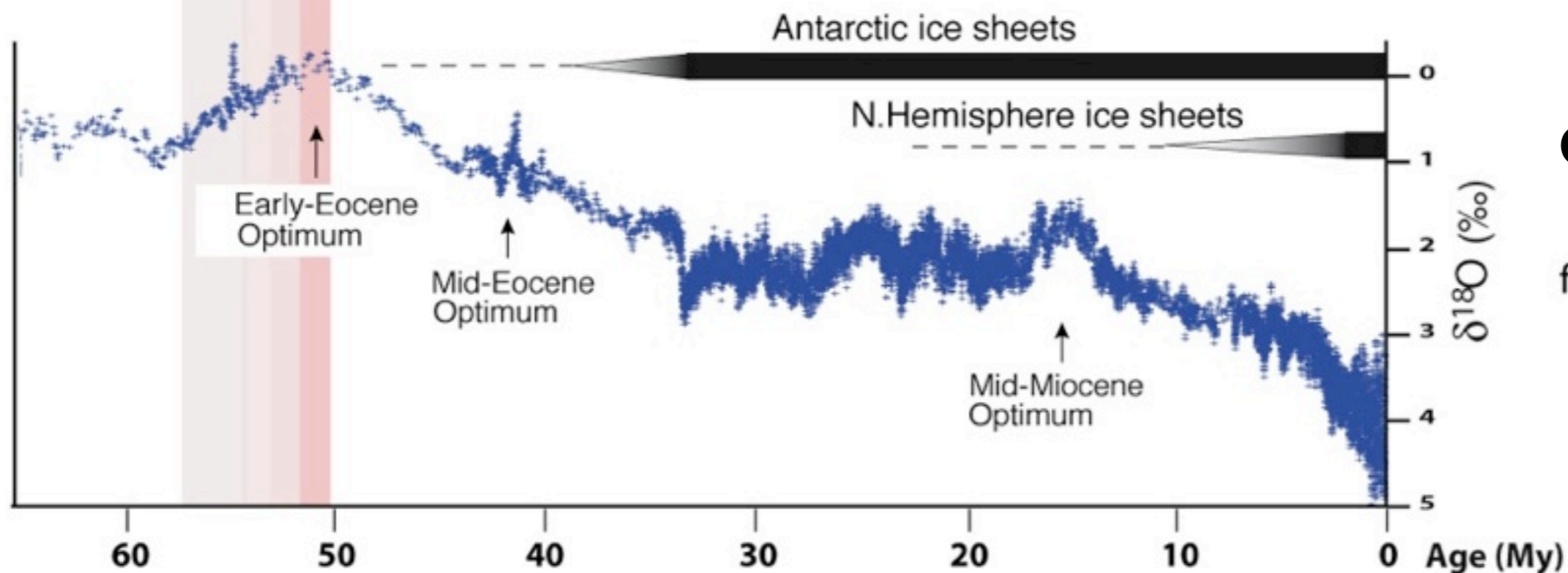
Choja Pediplain



Atacama Pediplain



“local” climatic evolution

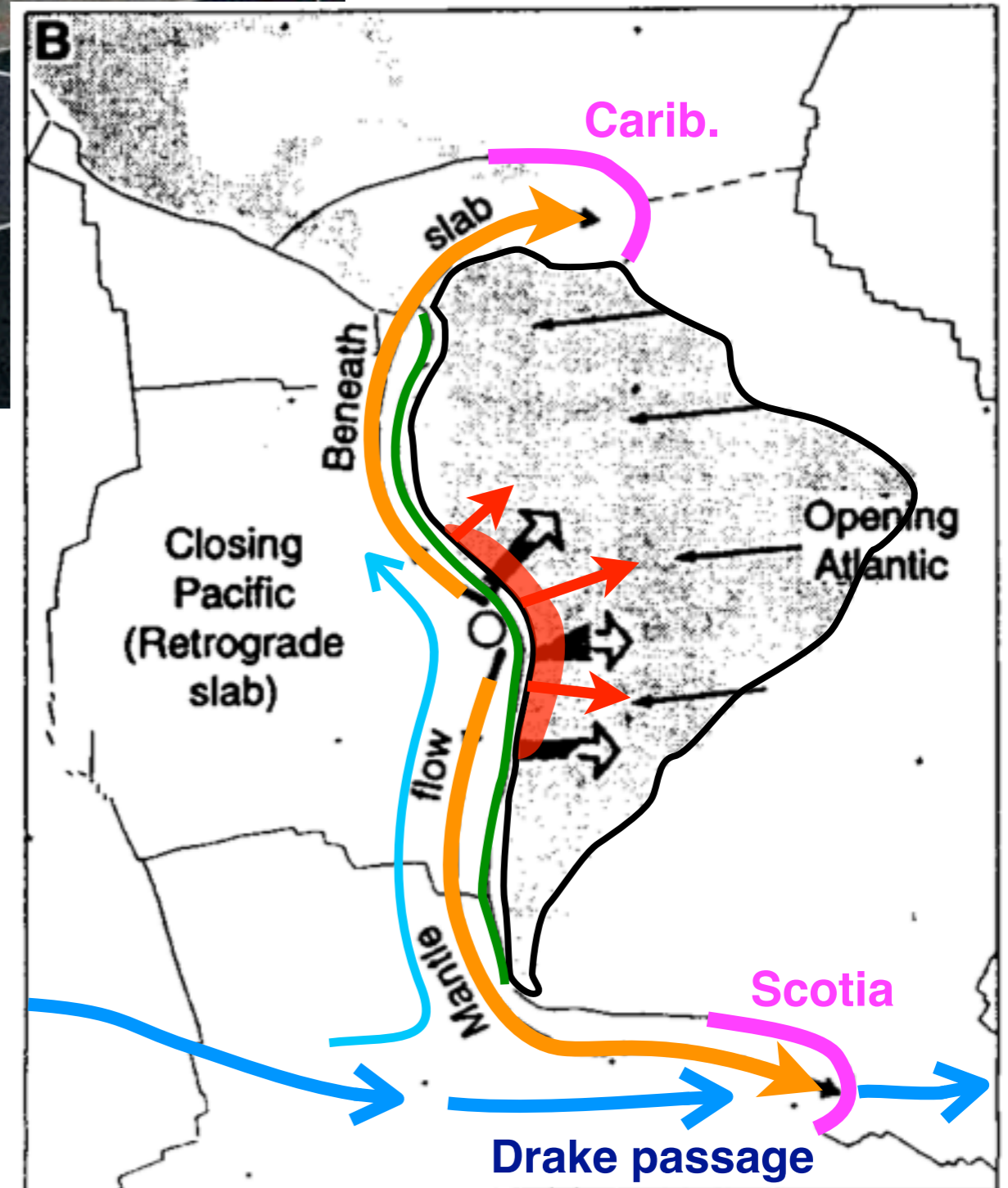
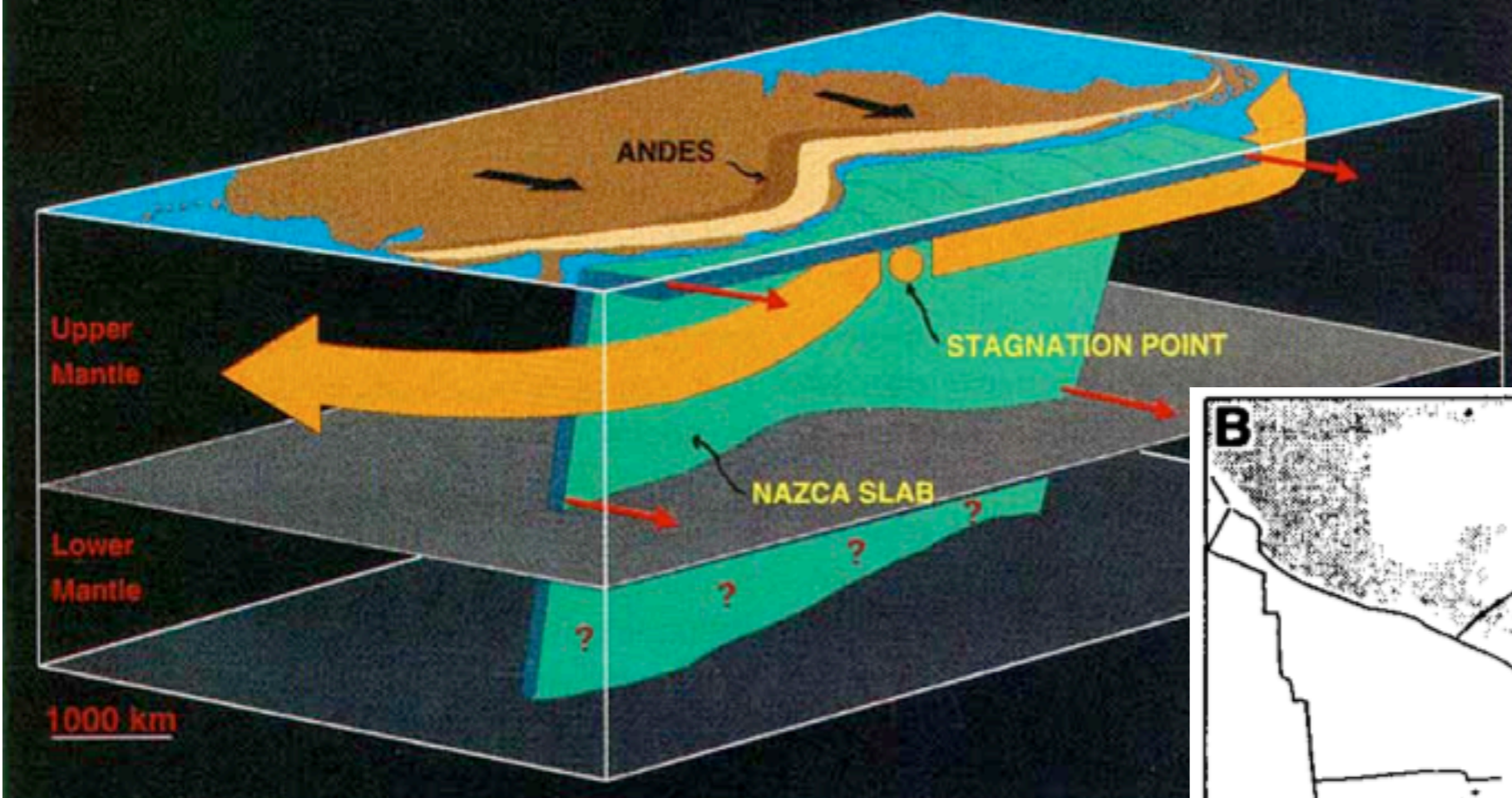


Global climatic evolution

from Zachos 2008

Armijo, Lacassin, Coudurier-Curveur, Carrizo 2015

Russo and Silver,
SCIENCE 1994,
1996



Mantle flow away from “stagnation” point

Formation of Caribbean / Scotia arcs

Diachronic growth of Andean orogen

Opening of Drake passage,
Antarctic Circumpolar Current,
& Peru-Chile Current

Also Schellart et al. 2007 & Schellart 2008

Onset of Andean Orogeny

Andean Orogeny

(km)
400
300
200
100
0

Andean shortening

Exhumation / erosion W Cordillera

Increasing aridity in Atacama

Choja Pediplain

Atacama Pediplain

Progressive opening of Drake passage

Antarctic ice sheets

N.Hemisphere ice sheets

Early-Eocene Optimum

Mid-Eocene Optimum

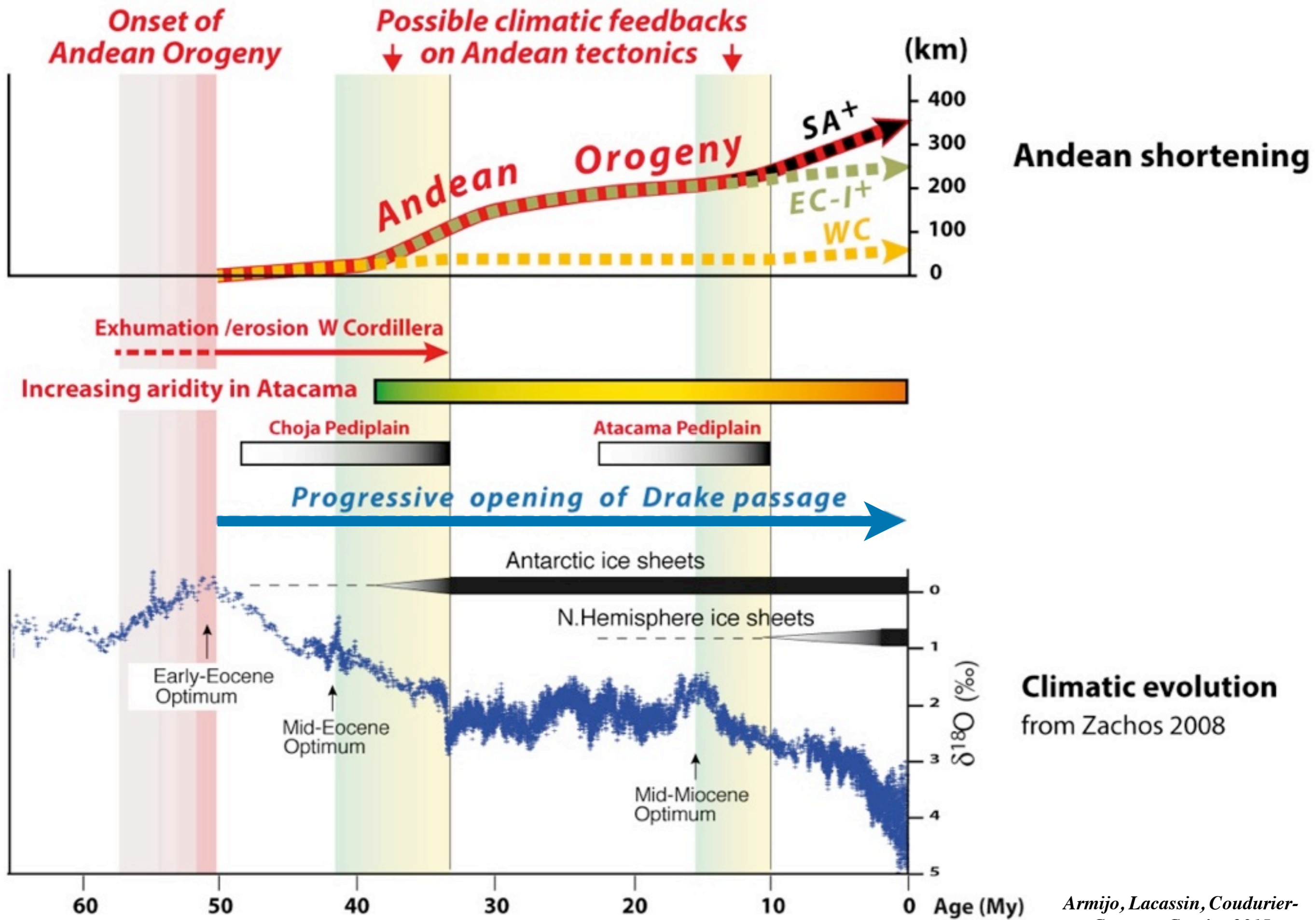
Mid-Miocene Optimum

Climatic evolution
from Zachos 2008

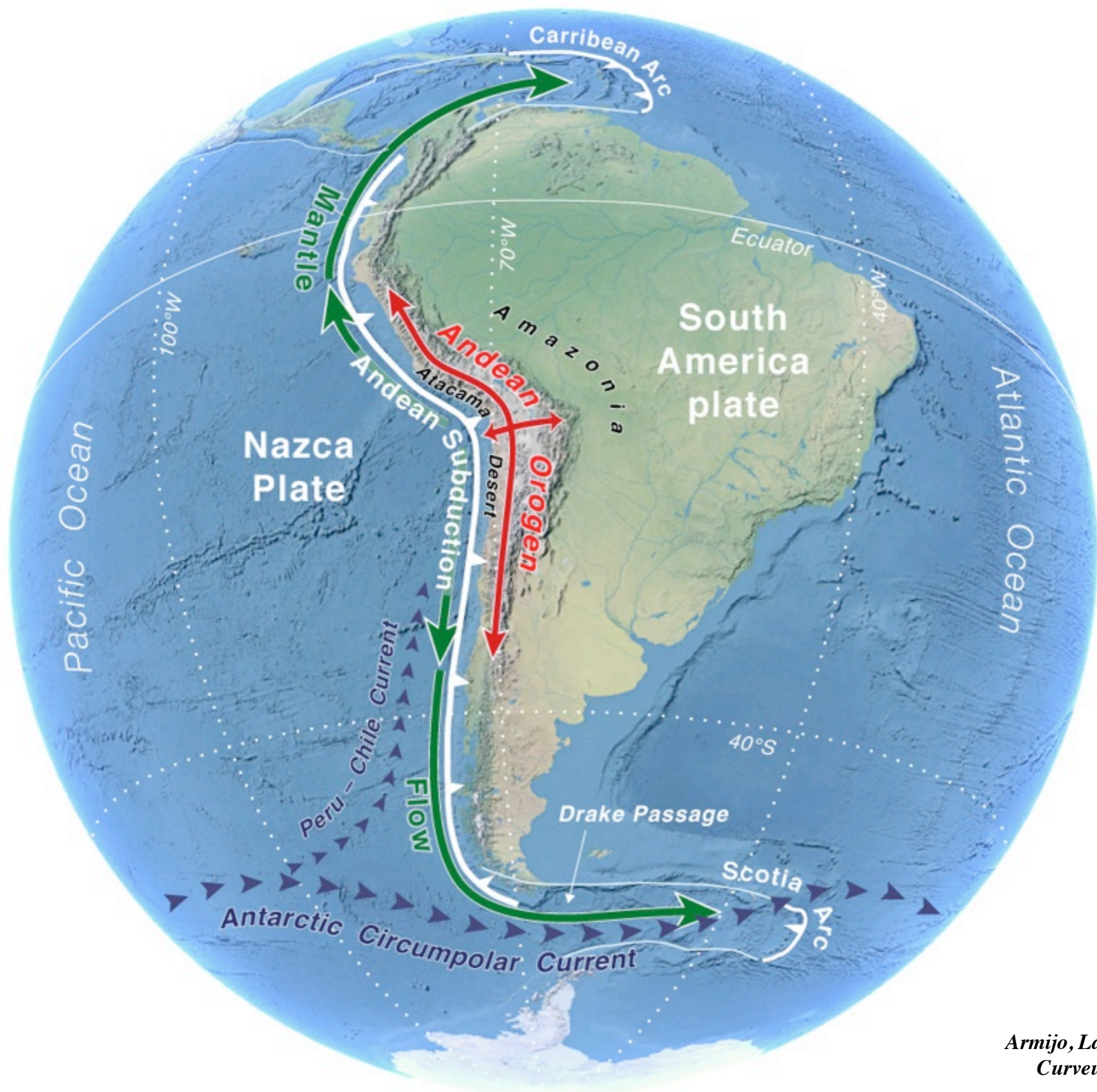
60 50 40 30 20 10 0 Age (My)

$\delta^{18}O$ (‰)

Armijo, Lacassin, Coudurier-Curveur, Carrizo 2015



Armijo, Lacassin, Coudurier-Curveur, Carrizo 2015



Armijo, Lacassin, Coudurier-Curveur, Carrizo 2015

People: Rolando Armijo, Robin Lacassin (IPG Paris), Aurélie Coudurier Curveur (now at EOS Singapore), Daniel Carrizo (U. Chile Santiago)

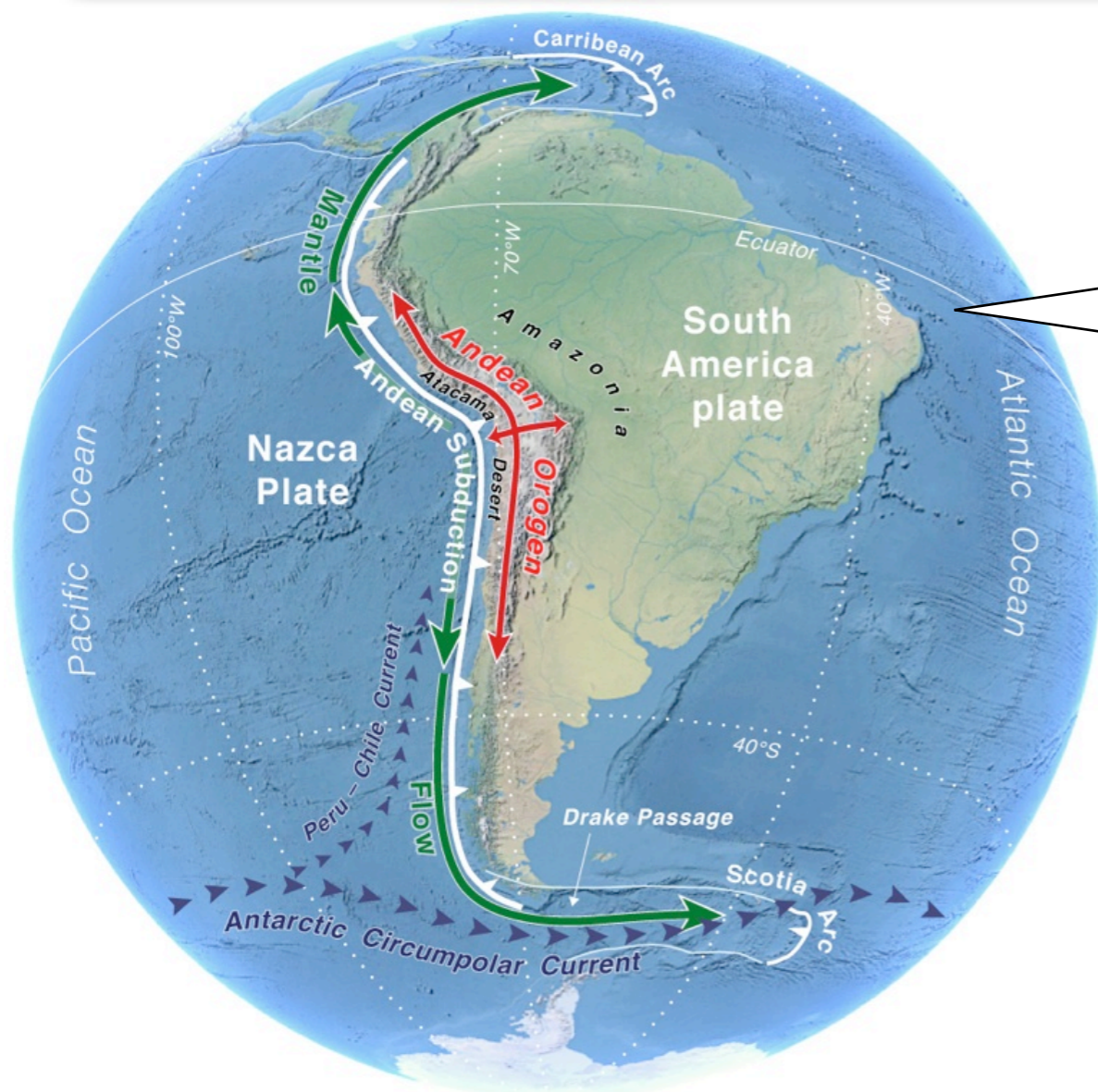
Thanks to G. Vargas, R. Thiele, J. Campos, R. Garreaud (U. Chile), G. Gonzalez (U. Antofagasta), F. Métivier (IPGP) - M. Riesner, G. Fuentes (both working on their PhD) - and many others for enlightening discussions.

Papers: Armijo R., Lacassin R., Coudurier-Curveur A., Carrizo D., *Coupled tectonic evolution of Andean orogeny and global climate*, Earth Science Reviews, 143, 1-35, **2015**.

Coudurier-Curveur A., Lacassin R., Armijo R., *Andean growth and monsoon winds drive landscape evolution at SW margin of South America*, EPSL, **2015**.

Vargas G., Klinger Y., Rockwell T., Forman S.L., Rebolledo S., Lacassin R., Armijo R., *Probing occurrence of large intra-plate earthquakes at the west flank of the Andes*, Geology, **2015**.

Armijo R., Rauld R., Thiele R., Vargas G., Campos J., Lacassin R., Kausel E., *The West Andean Thrust (WAT), the San Ramón Fault and the seismic hazard for Santiago (Chile)*, Tectonics, **2010**.



Few inspiring papers about large-scale kinematics and dynamics

Russo, R.M., Silver, P.G., 1994. Trench-parallel flow beneath the Nazca Plate from seismic anisotropy. *Science* 263 (5150), 1105–1111.

Russo, R.M., Silver, P.G., 1996. Cordillera formation, mantle dynamics, and the Wilson cycle. *Geology* 24 (6), 511–514.

Silver, P.G., Russo, R.M., Lithgow-Bertelloni, C., 1998. Coupling of South American and African Plate motion and Plate deformation. *Science* 279 (5347), 60–63.

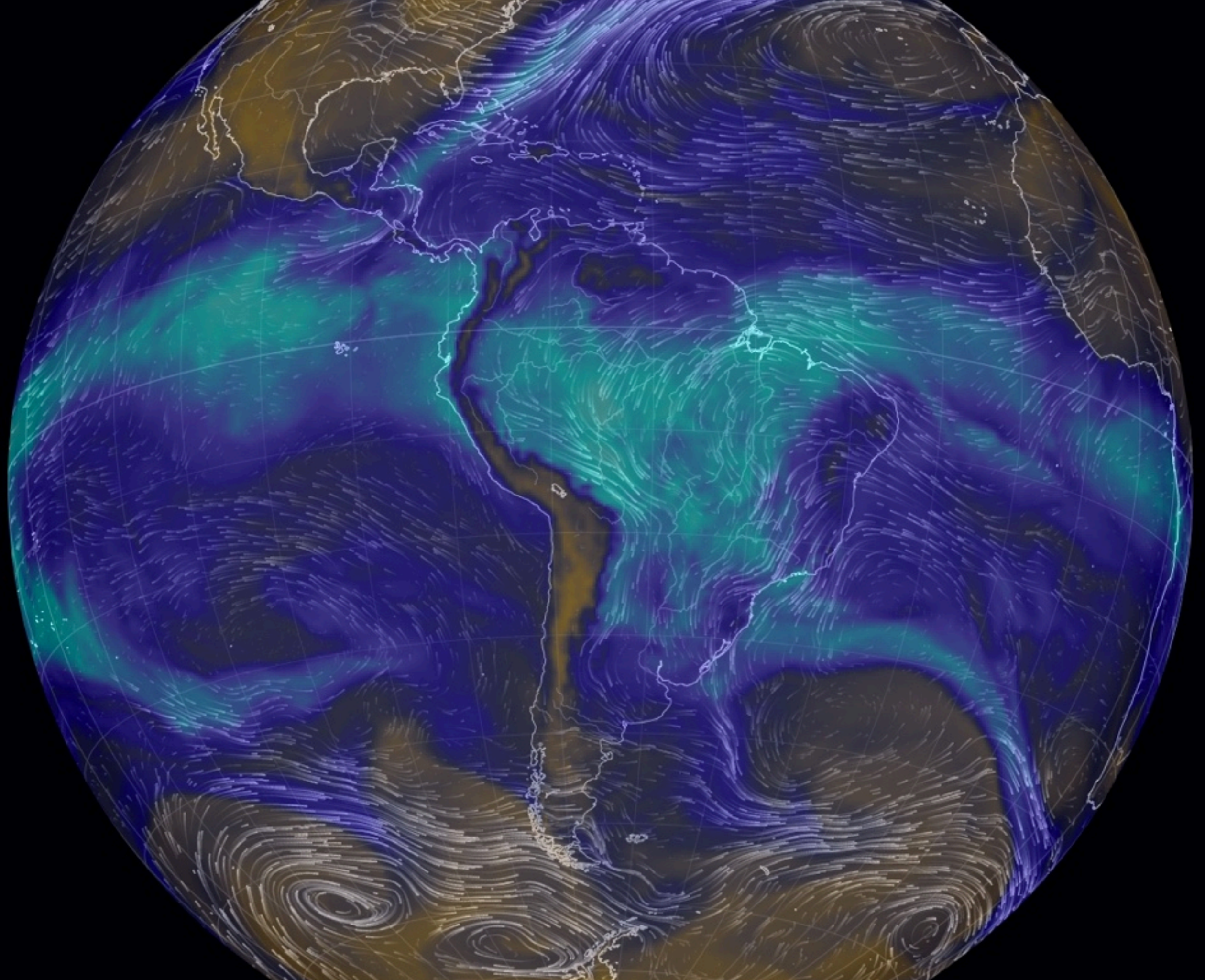
Schellart, W.P., Freeman, J., Stegman, D.R., Moresi, L., May, D., 2007. Evolution and diversity of subduction zones controlled by slab width. *Nature* 446, 308–311

Husson, L., Conrad, C.P., Faccenna, C., 2008. Tethyan closure, Andean orogeny, and west-ward drift of the Pacific Basin. *Earth Planet. Sci. Lett.* 271 (1), 303–310.

Faccenna, C., Becker, T.W., Conrad, C.P., Husson, L., 2013. Mountain building and mantle dynamics. *Tectonics* 32 (1), 80–93.

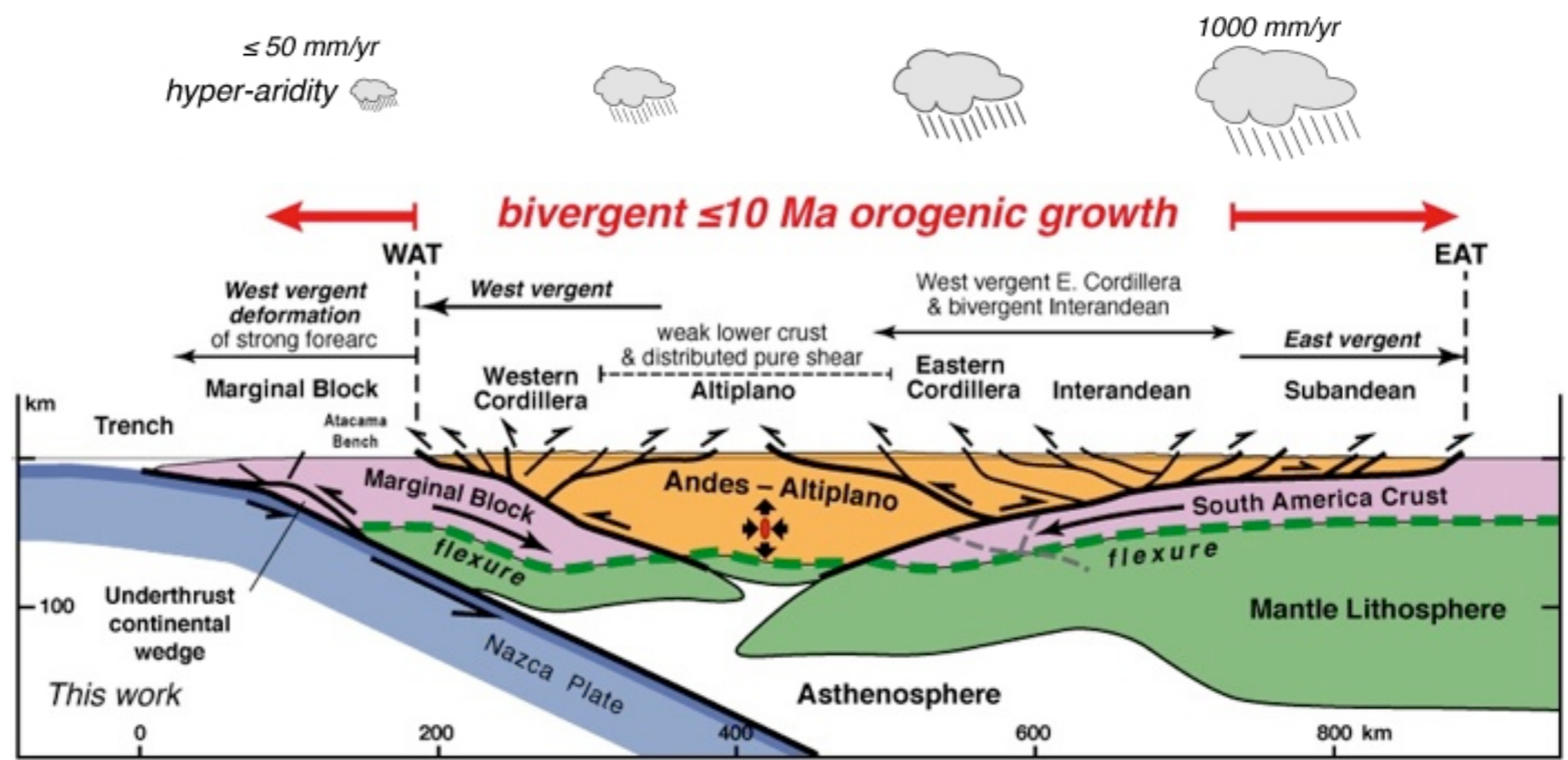
High-resolution versions of many figures as well as other infos at :

<http://www.ipgp.fr/~lacassin>

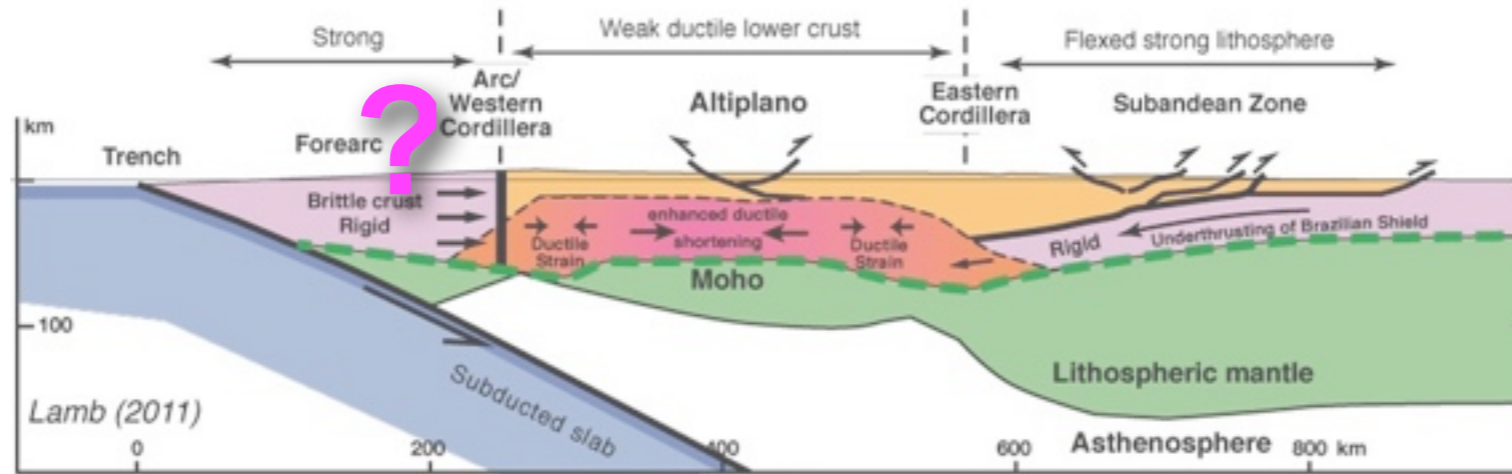


Our new model :

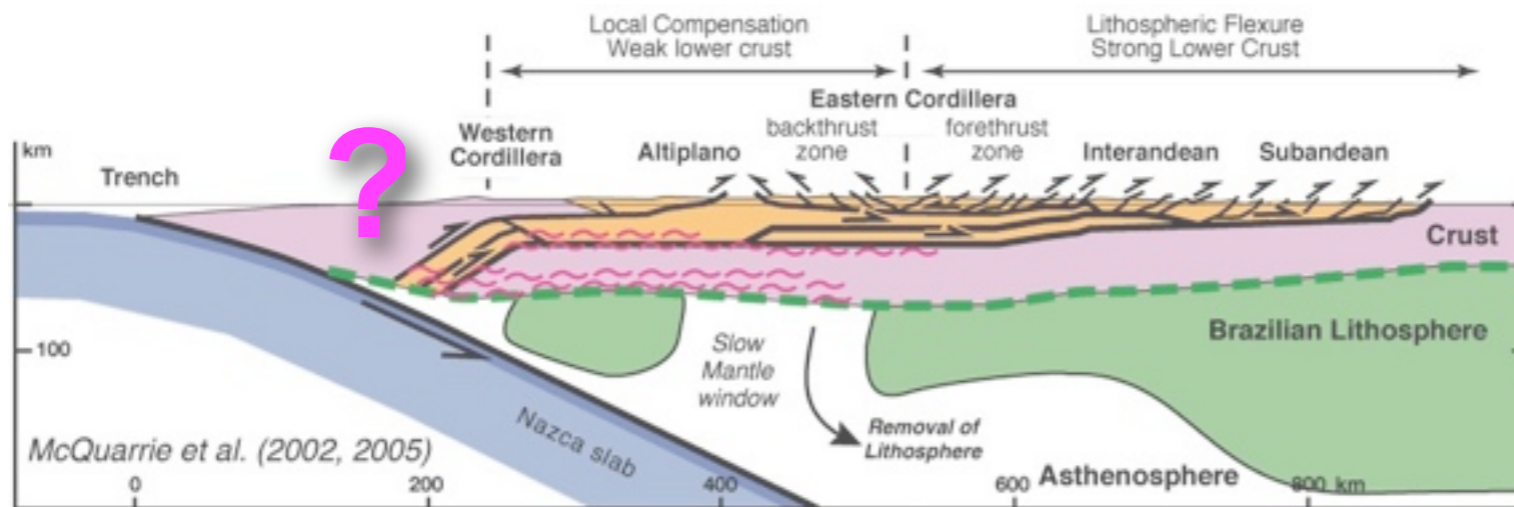
- elucidates structure of W andean flank & links with subduction
- suggests tectonic-climate interactions & feedbacks



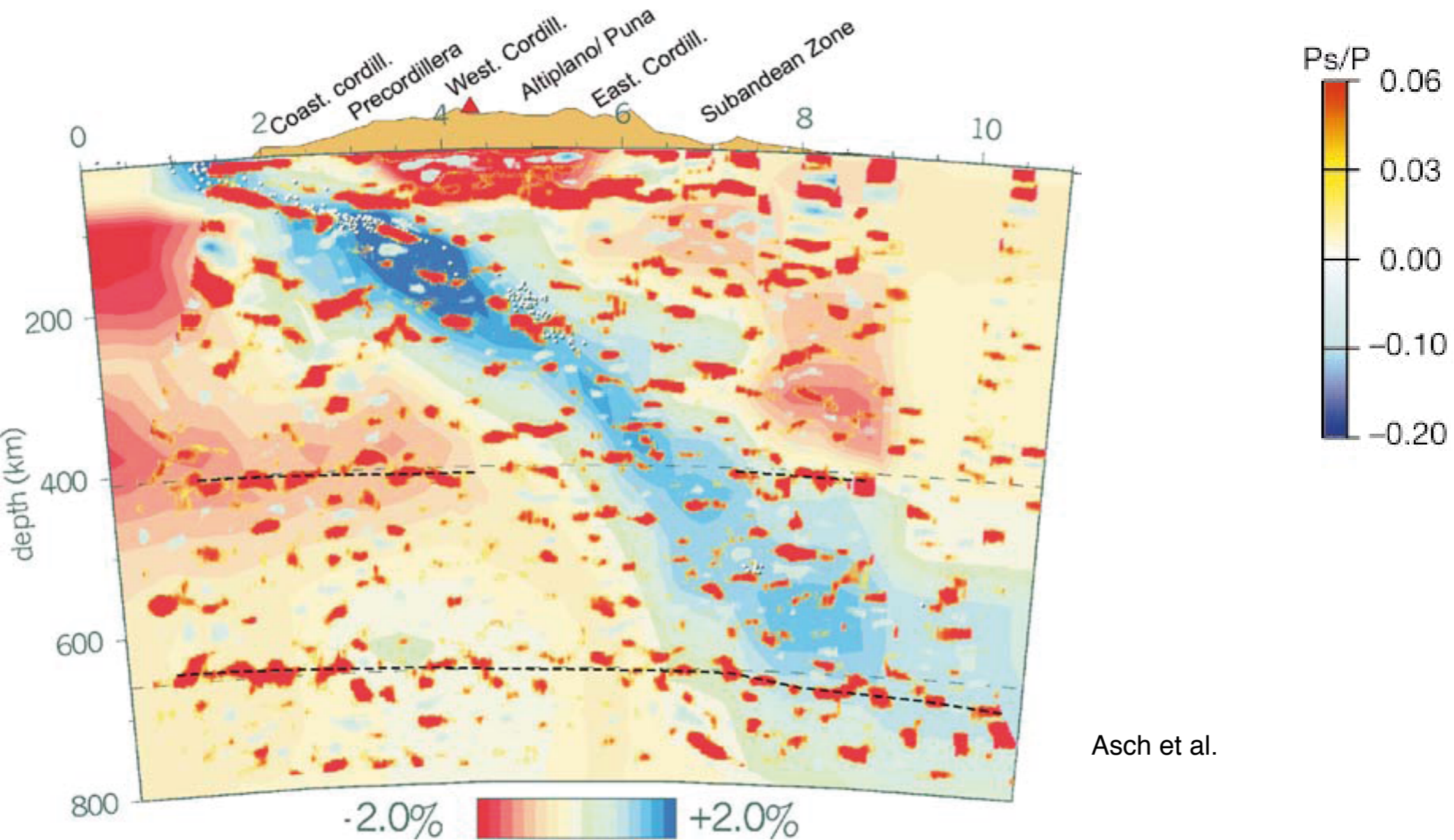
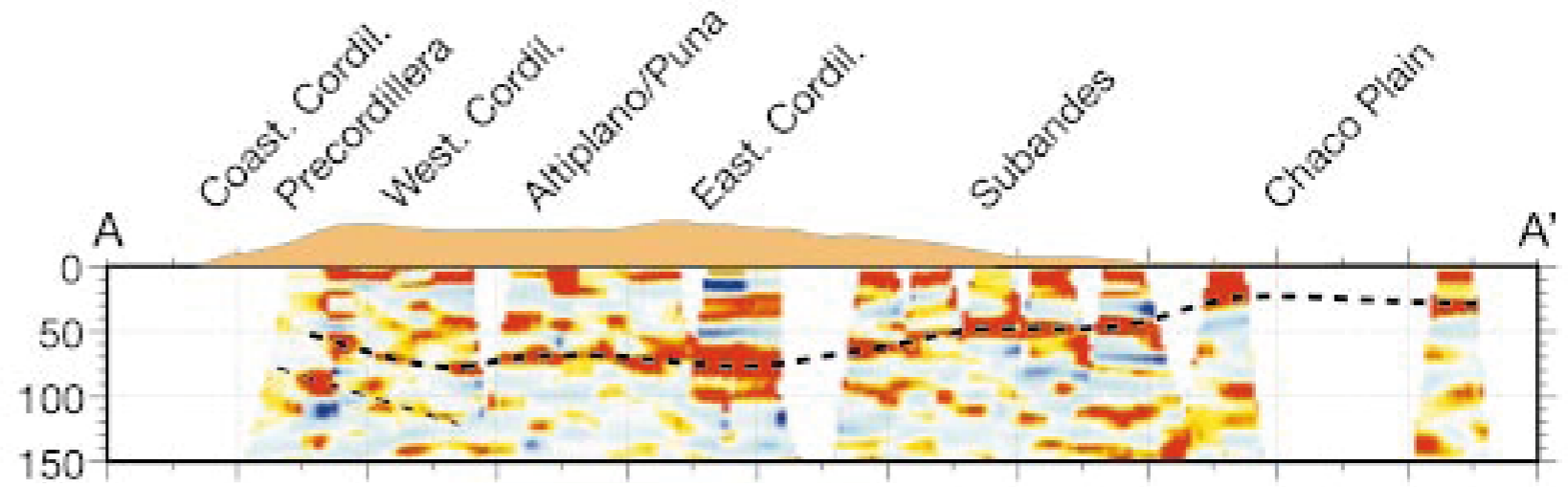
Lamb 2011



McQuarrie et al. 2002, 2005



Yuan et al.
2000



Asch et al.