Long-term and transient tectonic deformation of the Central Southern Andes (~36˚S) inferred with passive seismic methods.

Matteo Lupi*, Daniele Trippanera, Diego Gonzalez Vidal, Sebastiano D'Amico, Valerio Acocella

*Department of Earth Sciences, University of Geneva, Rue de Maraîchers 13, Geneva, CH

Matteo.Lupi@unige.ch

FNSNF
FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

Crustal Deformation & Fluid Flow
Geneva

UNIVERSITÉ
DE GENÈVE

The Group of Crustal Deformation and Fluid Flow at the University of Geneva since 2015

Group Website
https://www.unige.ch/sciences/terre/en/research/crustal-deformation-and-fluid-flow/

@GeoGeneva

Outline of the seminar

- Introduction
- Tomographic images
- The 2010 M8.8 Maule earthquake
- Earthquakes and geology
- Food for thoughts

Tectonophysics 744 (2018) 215–226

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Crustal model of the Southern Central Andes derived from ambient seismic noise Rayleigh-wave tomography

Diego González-Vidal[a,*], Anne Obermann[b], Andrés Tassara[a,c], Klaus Bataille[a], Matteo Lupi[d,*]

Tectonophysics 774 (2020) 228204

Contents lists available at ScienceDirect

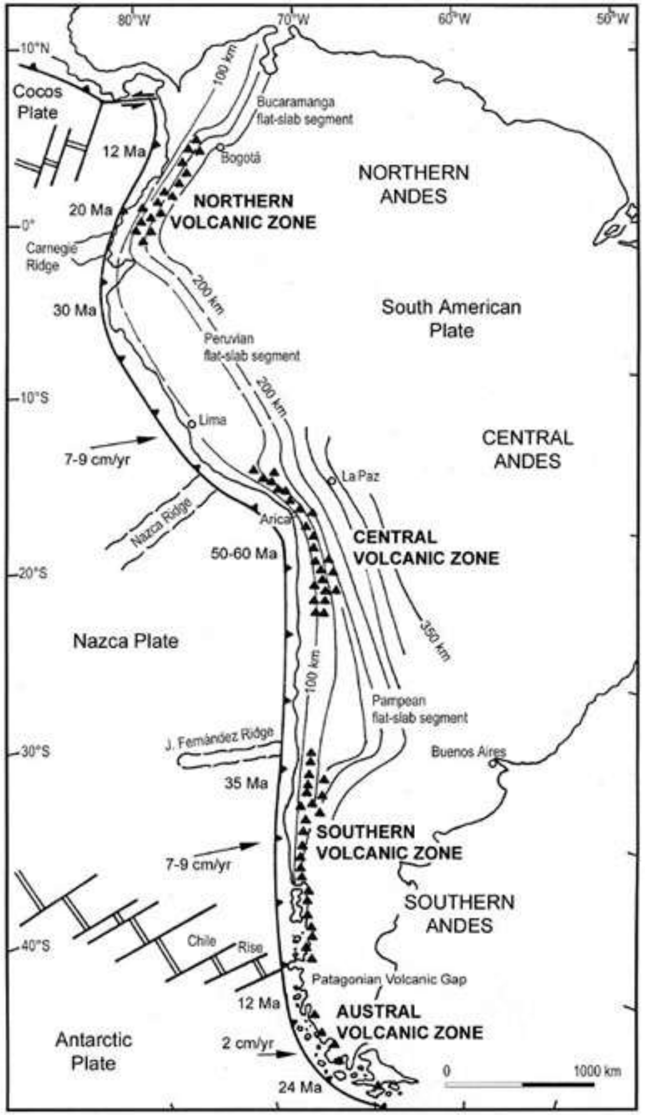
Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Transient tectonic regimes imposed by megathrust earthquakes and the growth of NW-trending volcanic systems in the Southern Andes

Matteo Lupi[a,*], Daniele Trippanera[b,c], Diego Gonzalez[d], Sebastiano D'amico[e], Valerio Acocella[c], Catalina Cabello[d], Marc Muelle Stef[d], Andres Tassara[d,f]

Introduction: The Southern Andes

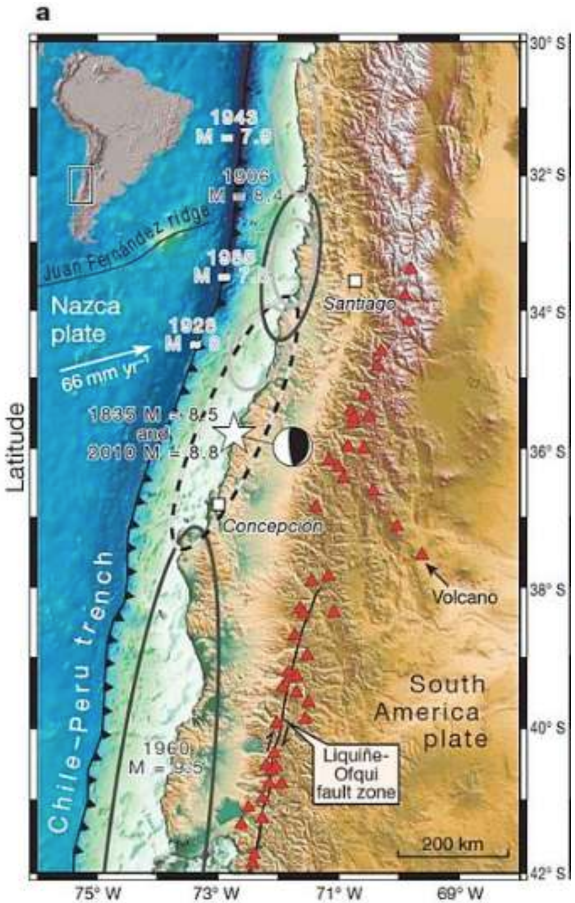


- Extends for about 7240 km crossing South America
- Formed after 120 Ma years of subduction
- The highest point is Monte Aconcagua (6960 m asl)

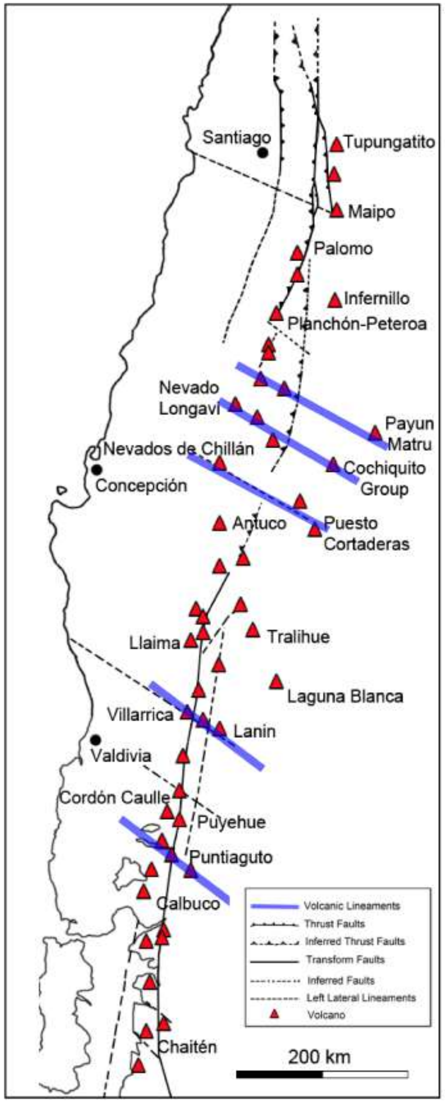
Charles R. Stern
Revista Geológica de Chile, Vol. 31, No. 2, p. 161-206, 11 Figs., December 2004

Few relevant aspects…

The M8.8 Maule earthquake in 2010



Moreno et al., 2012



LETTERS nature geoscience
PUBLISHED ONLINE: 1 JULY 2013 | DOI: 10.1038/NGEO1855

Subsidence at southern Andes volcanoes induced by the 2010 Maule, Chile earthquake

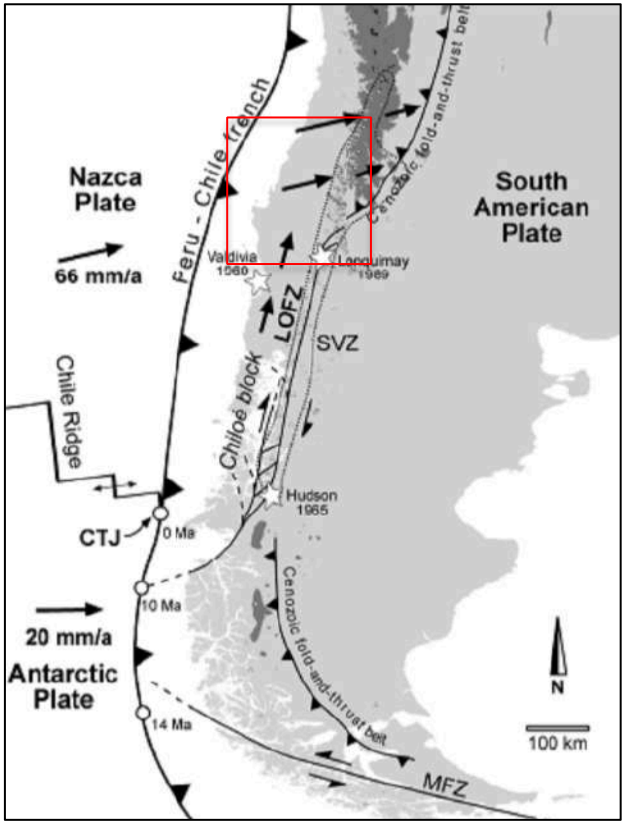
M. E. Pritchard[1]*, J. A. Jay[1], F. Aron[1], S. T. Henderson[1] and L. E. Lara[2]

nature geoscience LETTERS
PUBLISHED ONLINE: 1 JULY 2013 | DOI: 10.1038/NGEO1857

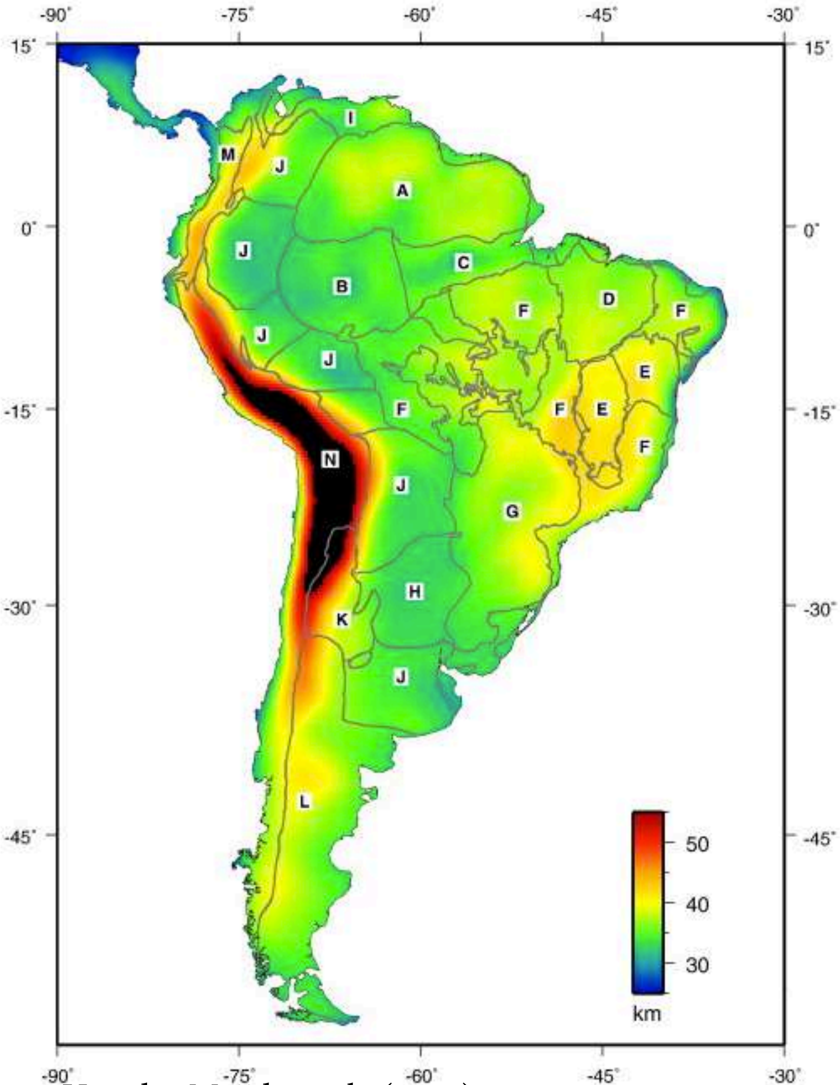
Volcanic subsidence triggered by the 2011 Tohoku earthquake in Japan

Youichiro Takada* and Yo Fukushima

A complex region in the Southern Central Andes

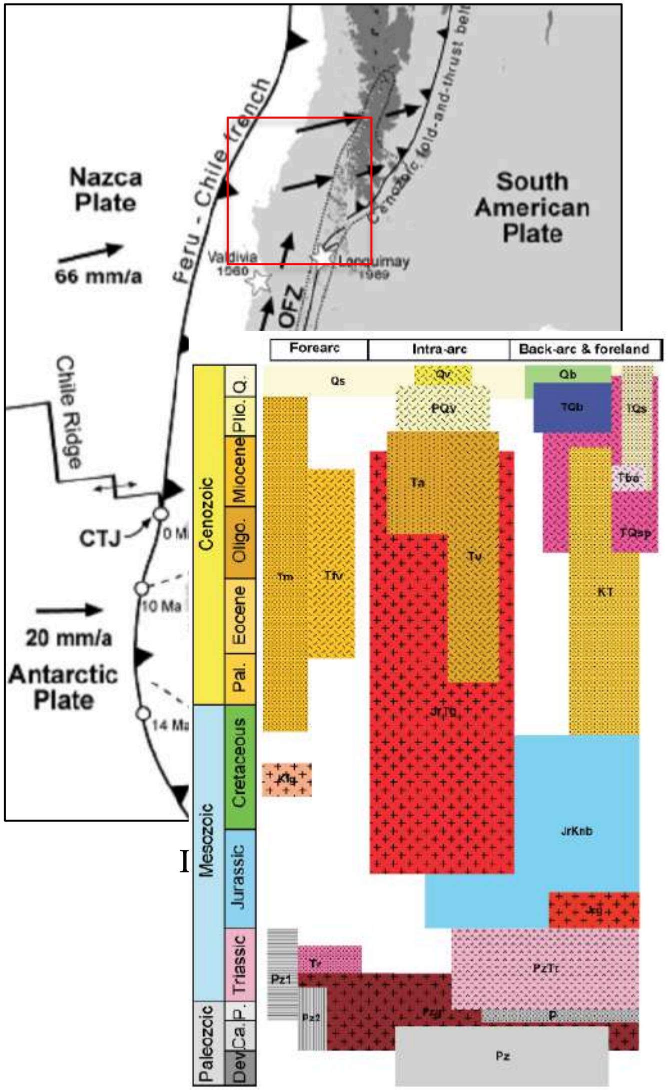


Lara et al., (2008)

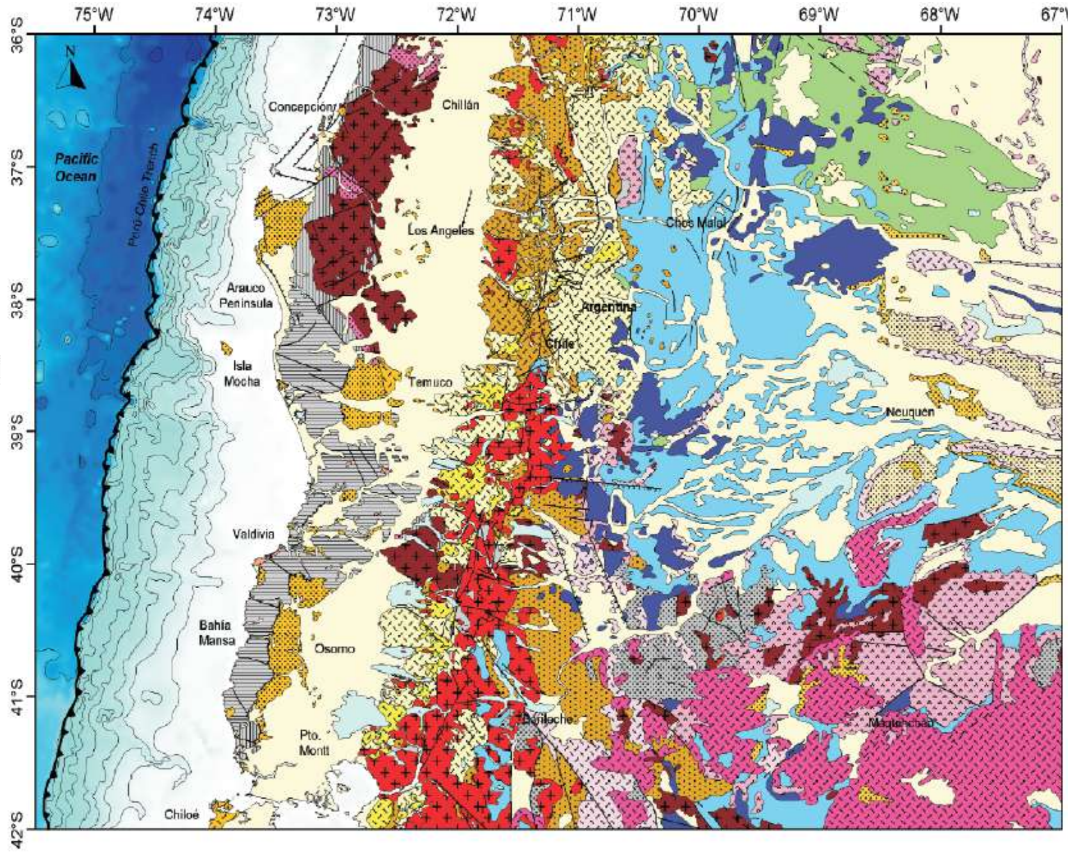


Van der Meijde et al., (2013)

A complex region in the Southern Central Andes



I

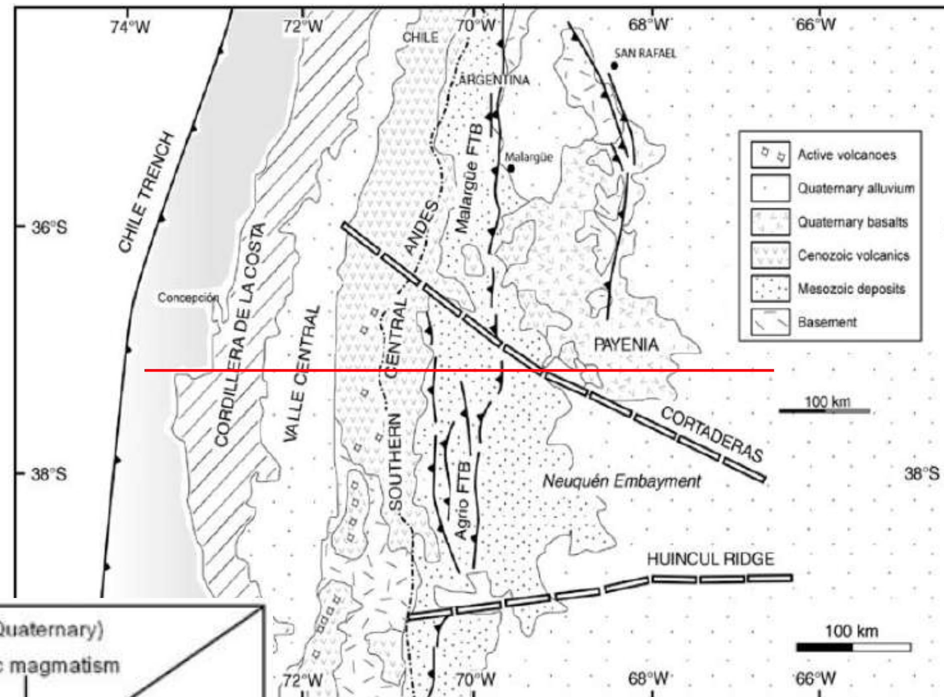


Melnick and Etchler, (2008). Morphotectonic and Geologic Digital Map Compilations of the South-Central Andes (36˚– 42˚S)

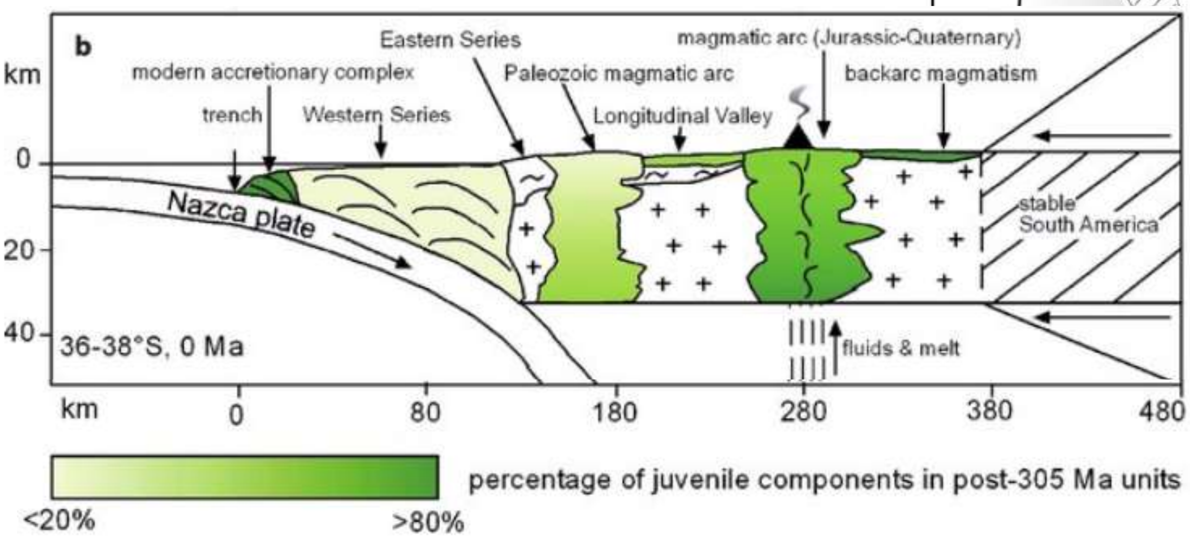
Introduction: The Cortaderas lineament (?)

Ramos (1981) and later Cembrano and Lara (2009) interpreted the Cortaderas lineament as a basement boundary reactivated during the Andean orogeny.

Cobbold and Rossello (2003) argue that it is a reactivated North-verging thrust system.



Victor Ramos and Suzanne Mahlburg Kay Geological Society of America Special Papers, 2006, 407, 1-17

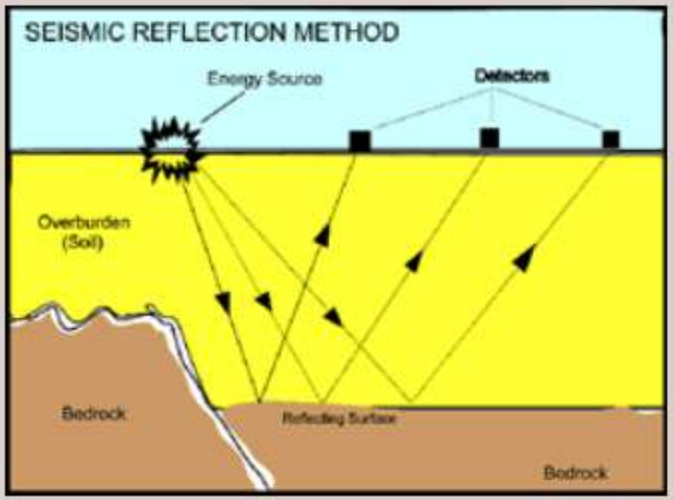


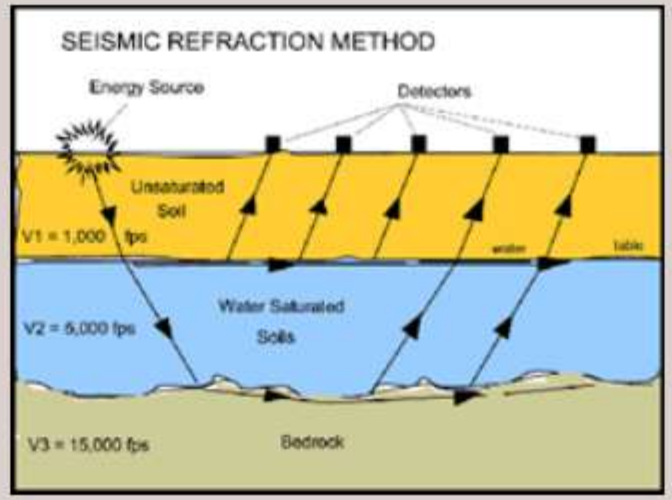
Glodny et al., 2005

What's below the Southern Central Andes?

How to image the subsurface with seismic methods?

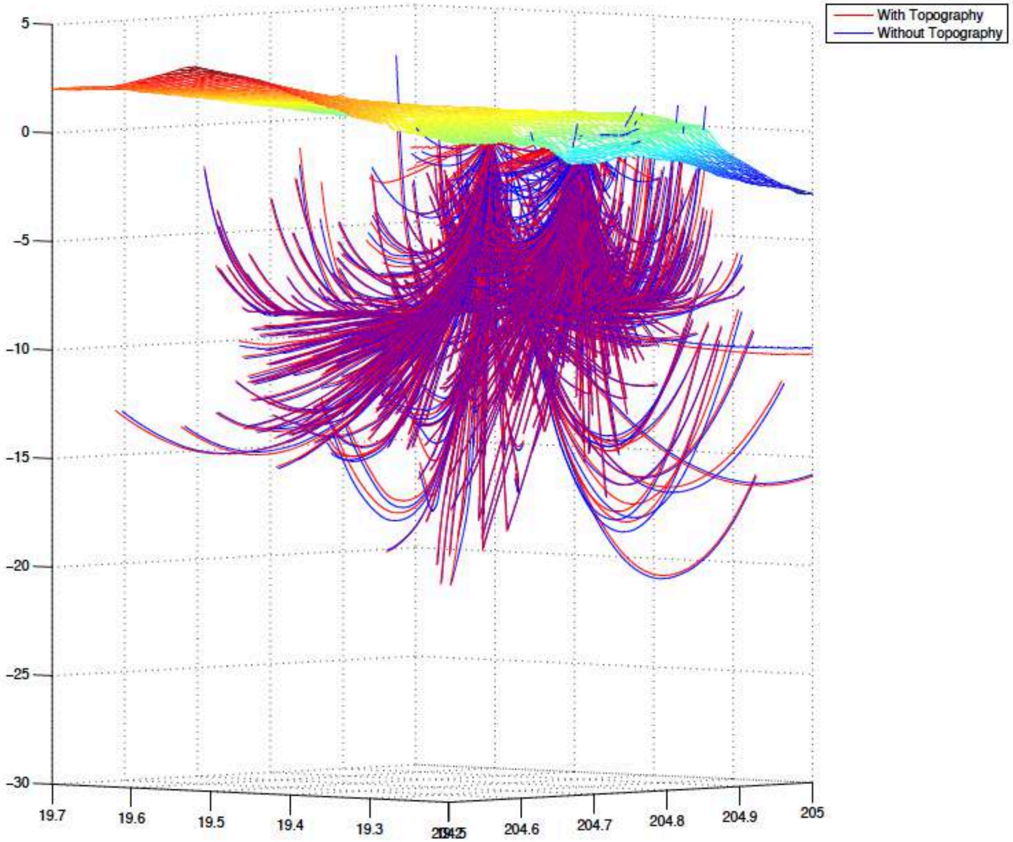
Reflection and Refraction seismic





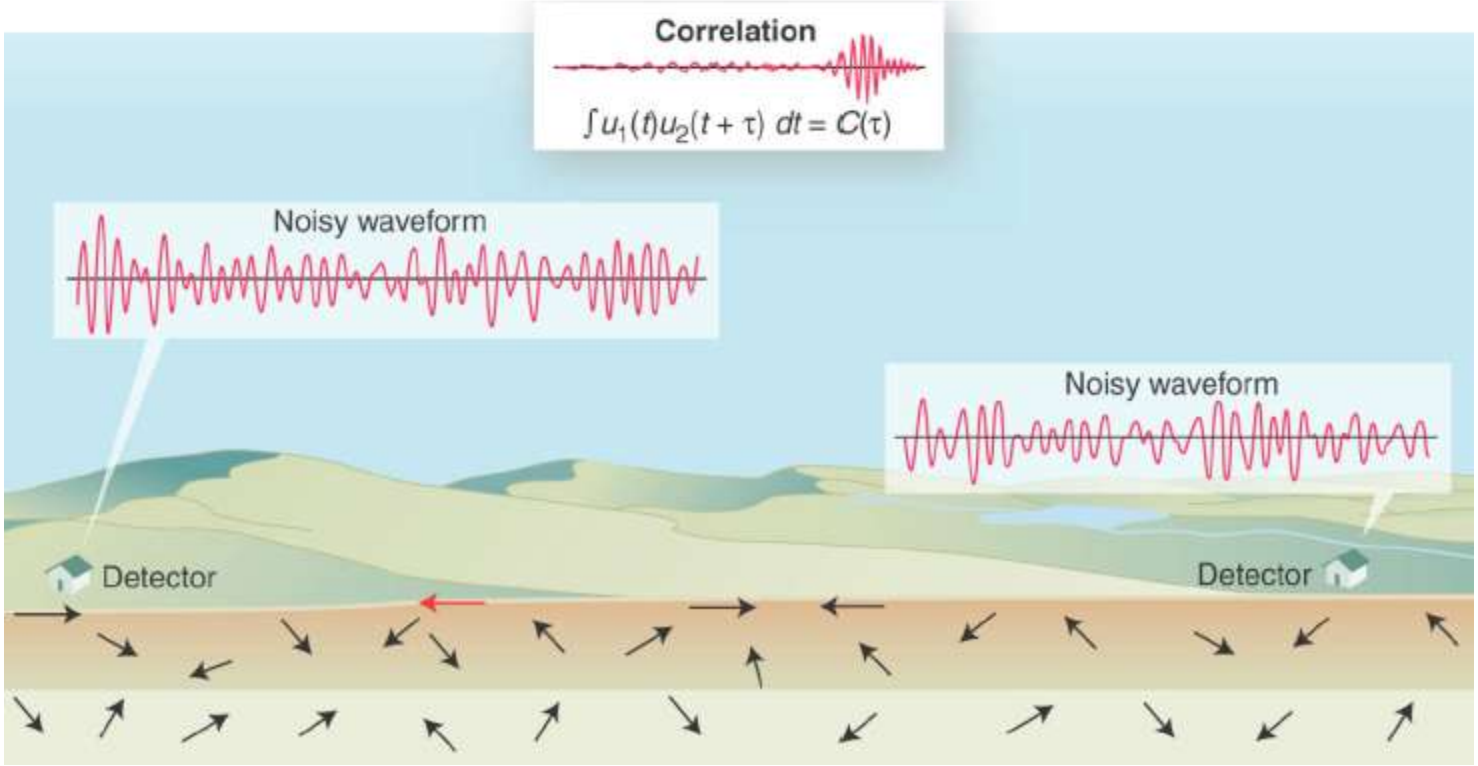
How to image the subsurface with seismic methods?

Local Earthquake Tomography



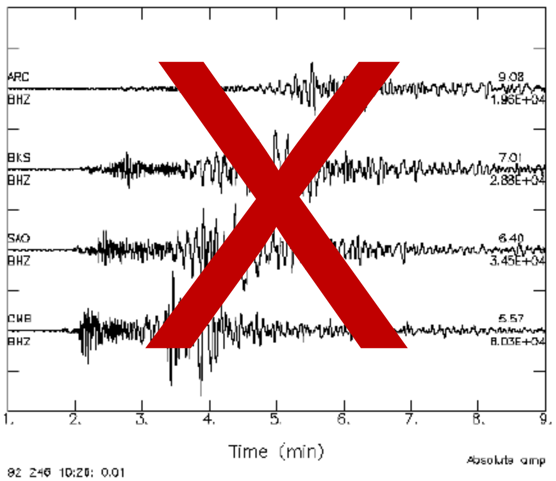
How to image the subsurface with seismic methods?

Ambient Noise Tomography



Ambient Noise Tomography

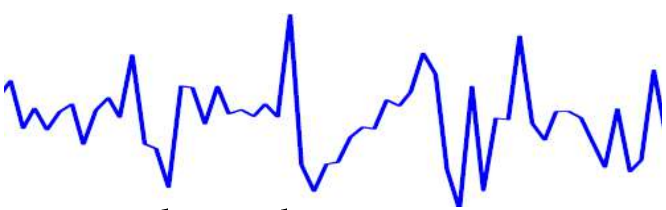
Earthquakes



Noise

- Use of coherent signals recorded at pairs of stations

- Low amplitude Ambient Noise at stations is generated from several sources (waves, winds along shorelines including anthropic sources)



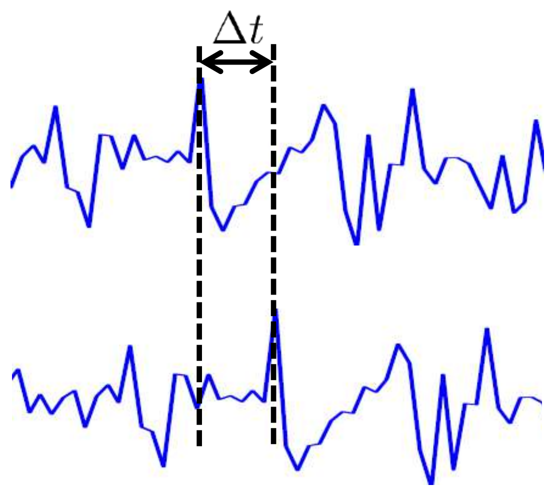
Incident ambient noise

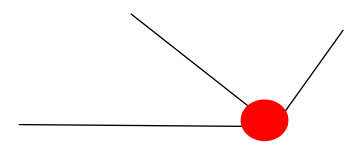
Ambient Noise Tomography

- By cross correlating long time series between stations, the common signal is retrieved while the incoherent energy cancels out. This leaves a signal that reveals information about seismic velocity between the two seismometers.

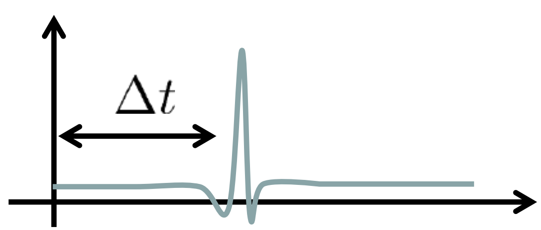
Noise recorded at receiver A $N_A =$

Noise recorded at receiver B $N_B =$





$$N_A(t) \star N_B(t) =$$



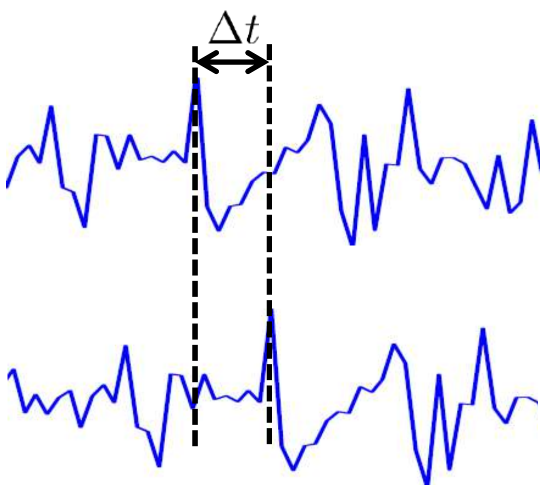
Lobkis & Weaver 2001, (JASA)

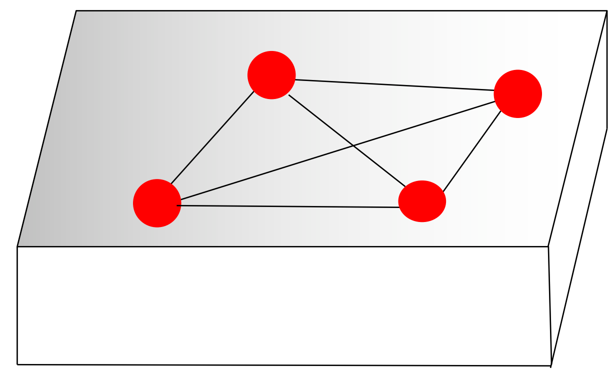
Ambient Noise Tomography

- By cross correlating long time series between stations, the common signal is retrieved while the incoherent energy cancels out. This leaves a signal that reveals information about seismic velocity between the two seismometers.

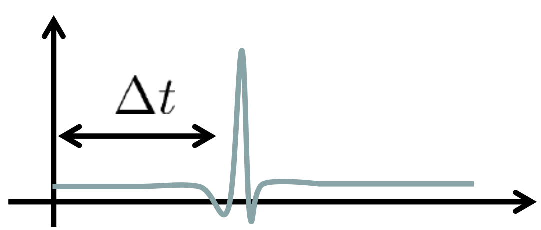
Noise recorded at receiver A $N_A =$

Noise recorded at receiver B $N_B =$





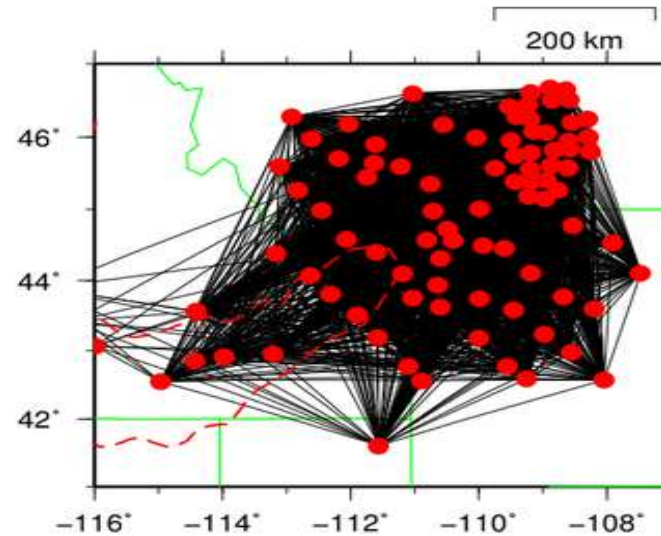
$$N_A(t) \star N_B(t) =$$



Lobkis & Weaver 2001, (JASA)

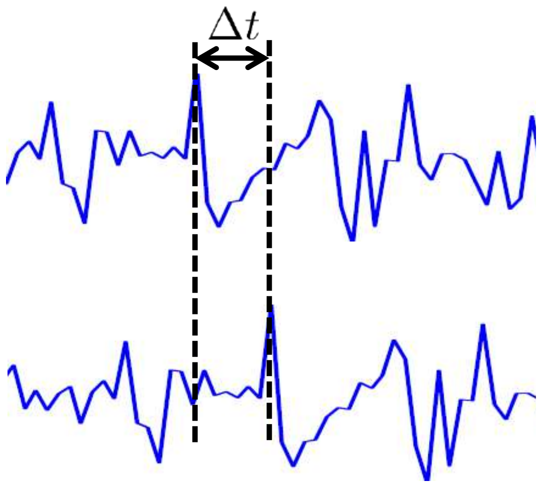
Ambient Noise Tomography

- By cross correlating long time series between stations, the common signal is retrieved while the incoherent energy cancels out. This leaves a signal that reveals information about seismic velocity between the two seismometers.

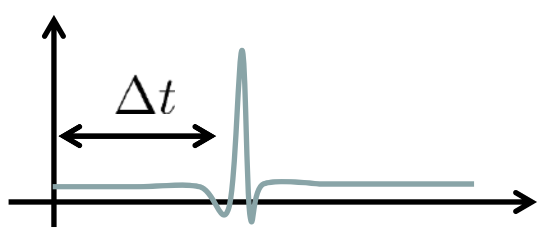


Noise recorded at receiver A $N_A =$

Noise recorded at receiver B $N_B =$



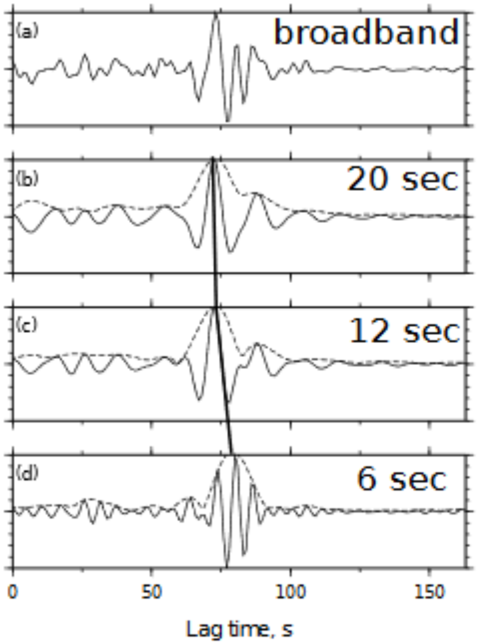
$$N_A(t) \star N_B(t) =$$

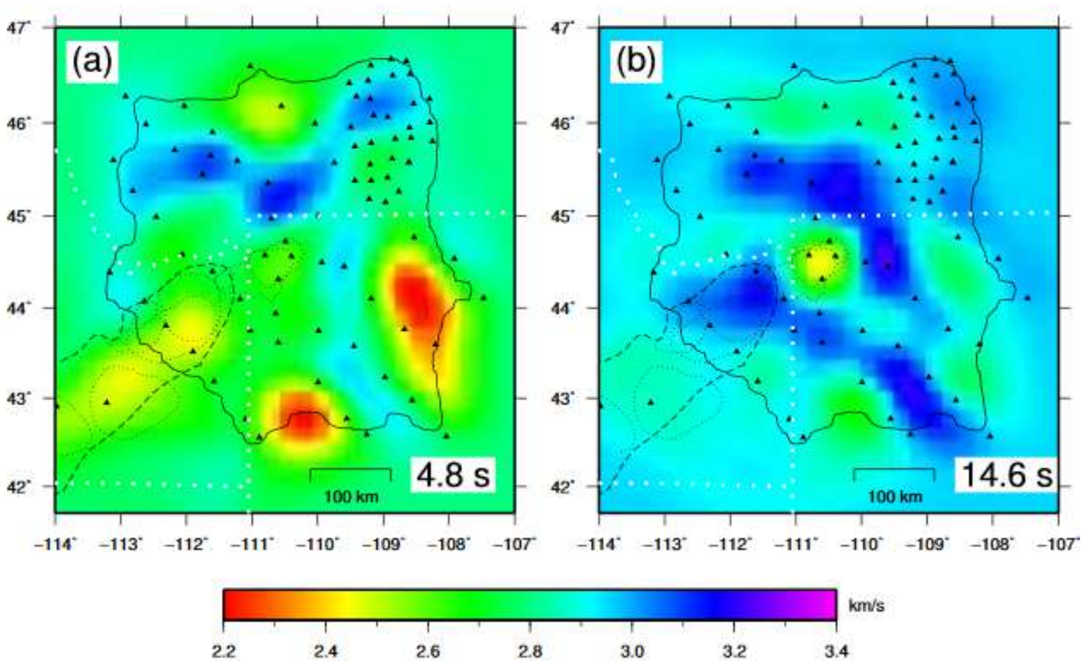


Lobkis & Weaver 2001, (JASA)

Ambient Noise Tomography

- Using filters to select given periods (proportional to the penetration depth of the surface waves) it is possible to investigate the upper crust.



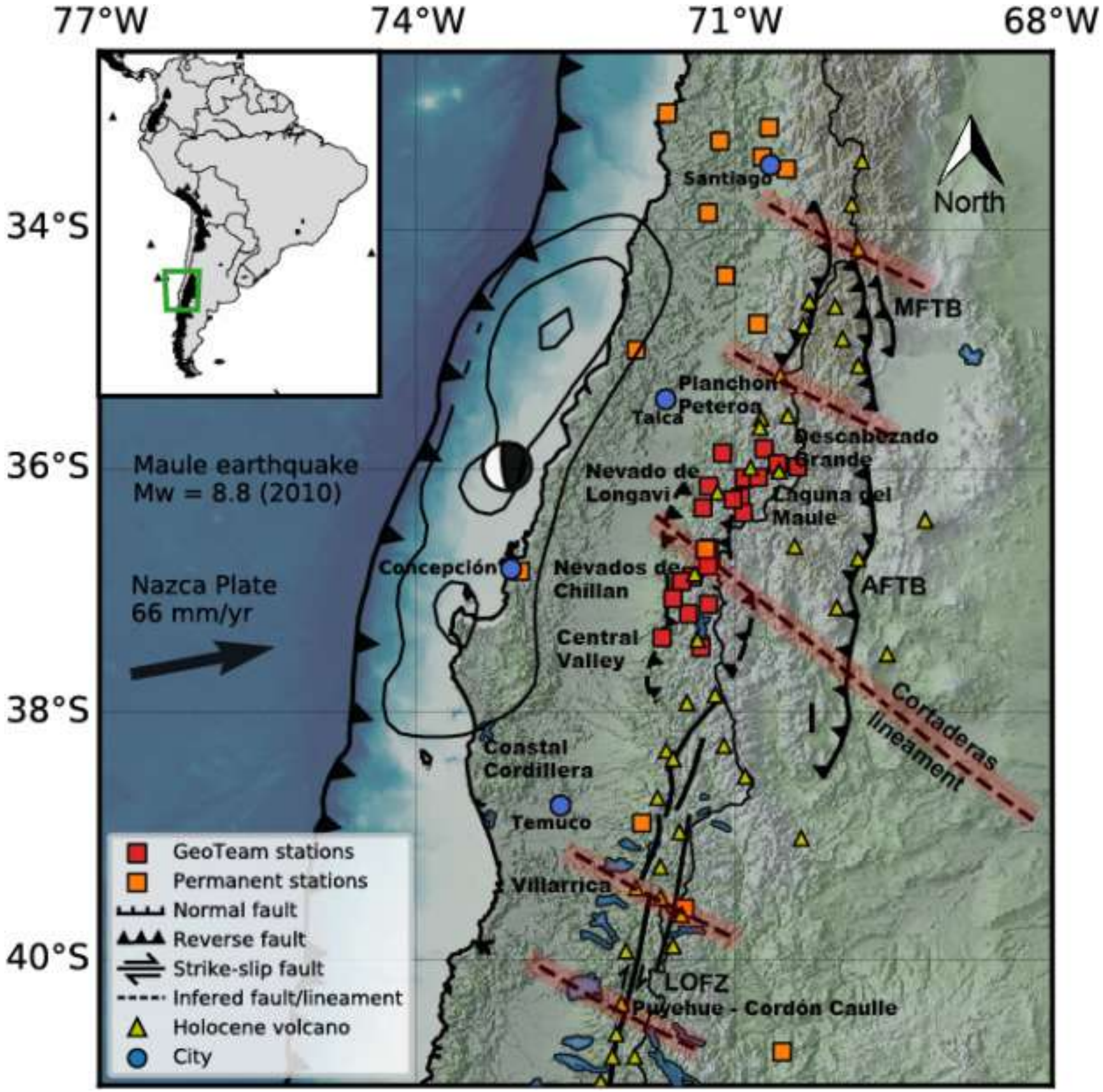


Example from: http://www.isti.com/wp-content/uploads/2015/02/ant-workflow-1.pdf

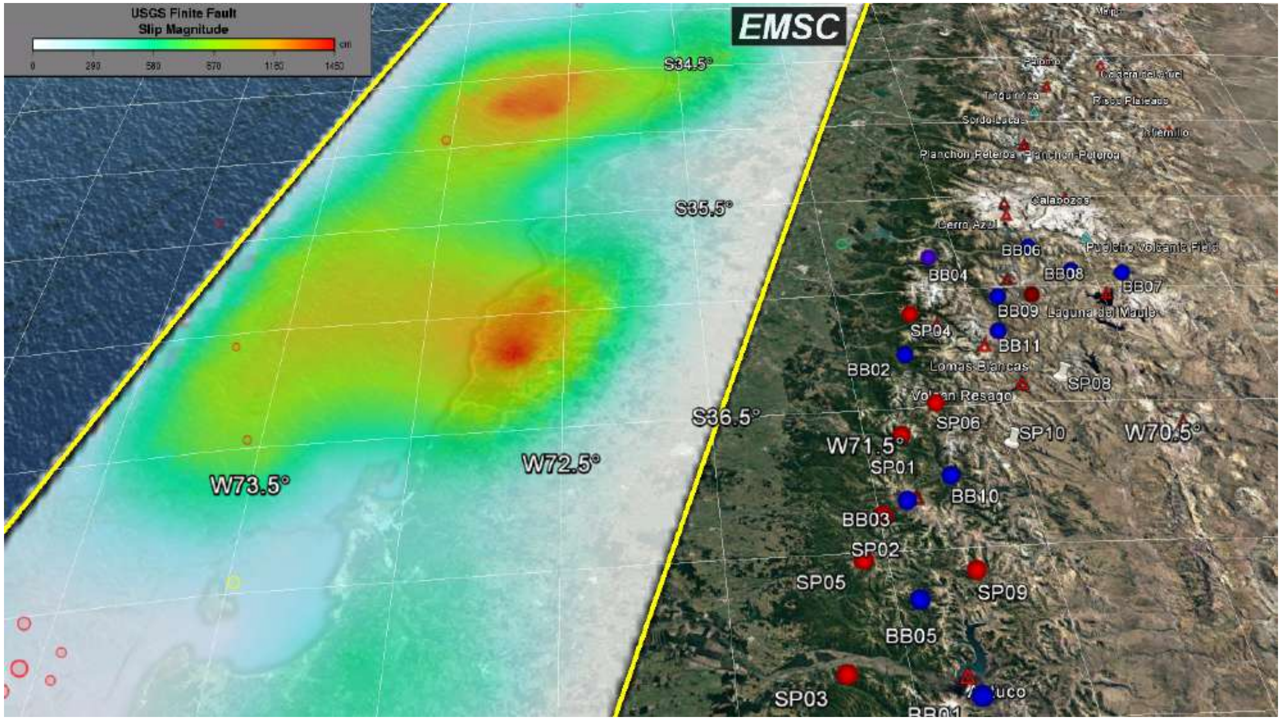
From Surface waves (group or phase velocities) it is possible to extract shear waves.

Shear wave velocities are affected by several factors such as (lithology, compaction, presence of fluids).

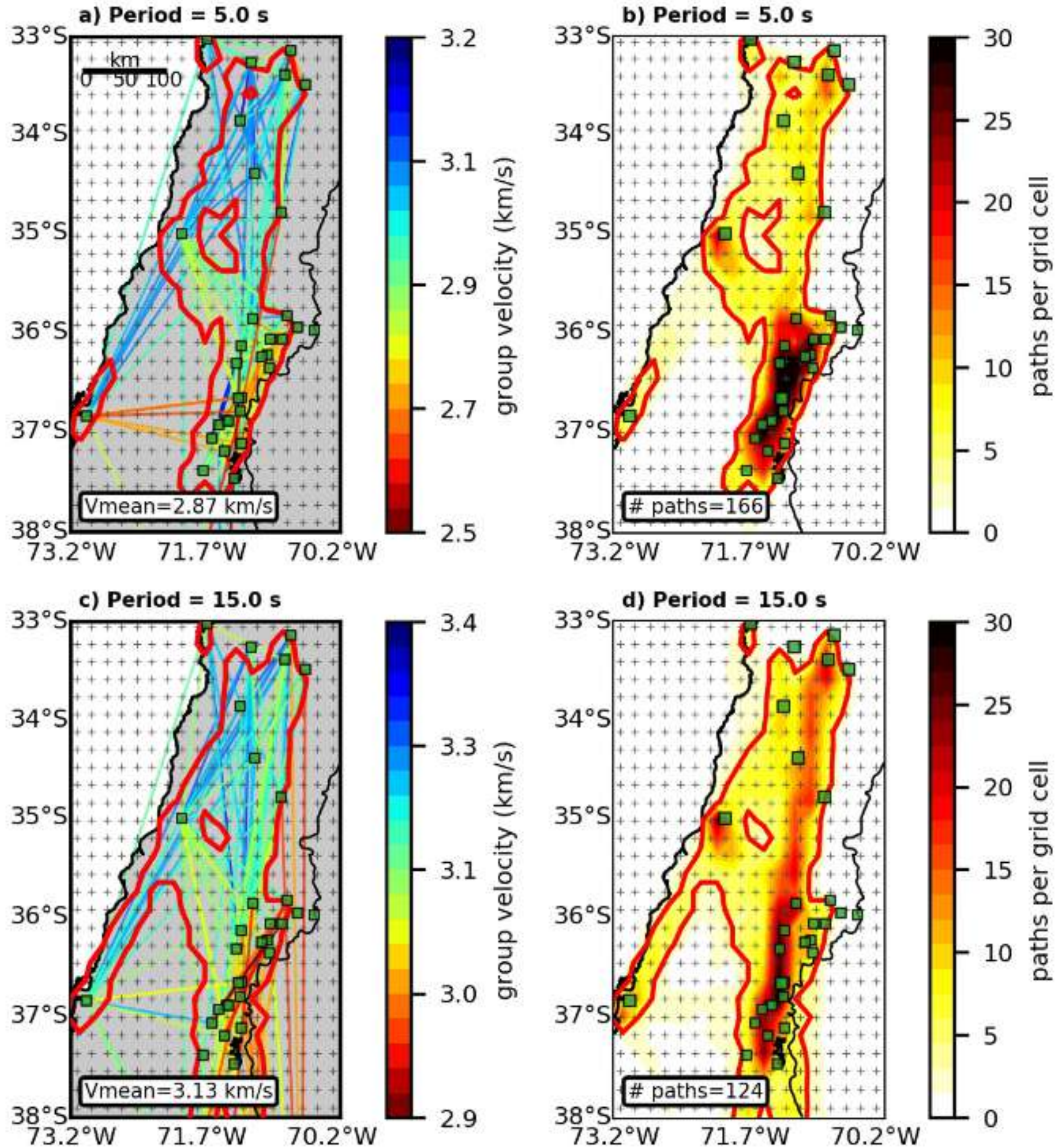
Ambient Noise Tomography

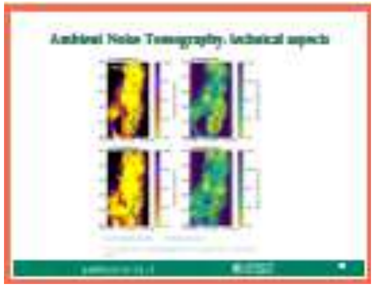


Ambient Noise Tomography



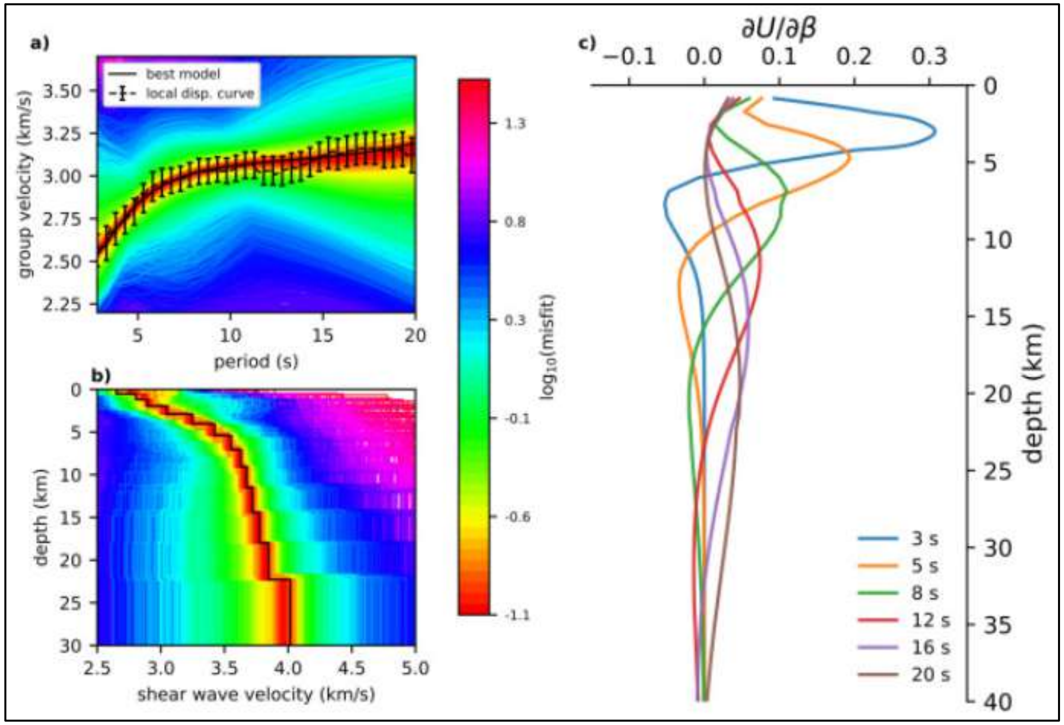
Ambient Noise Tomography

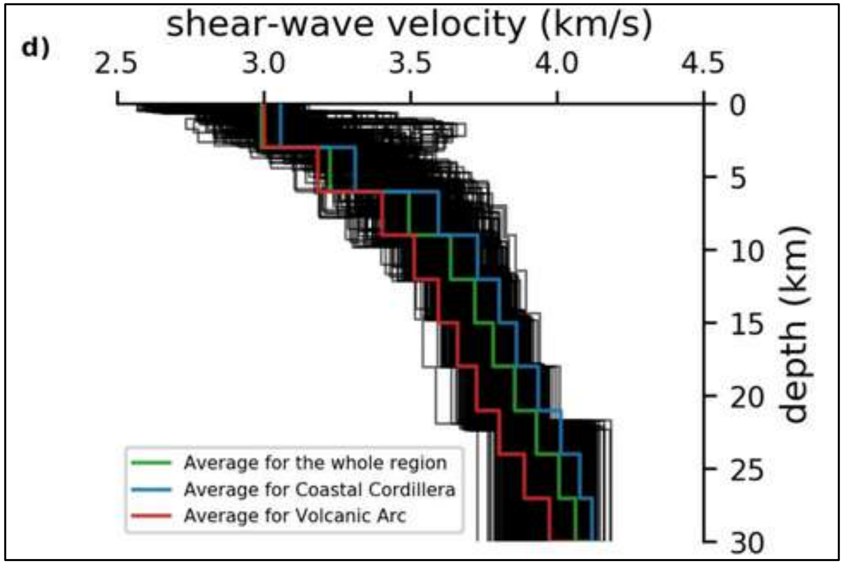


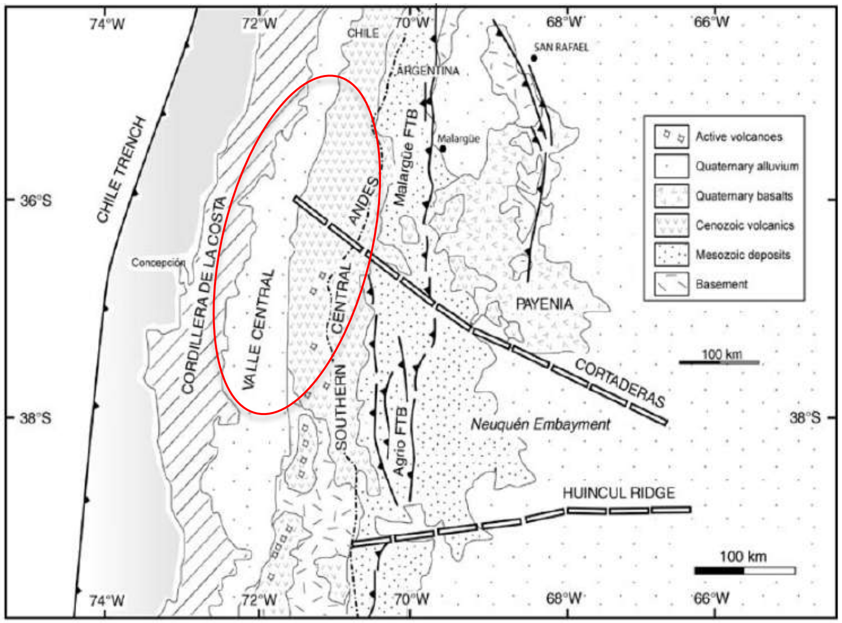


Spatial resolution and resolution shift in the backup slides

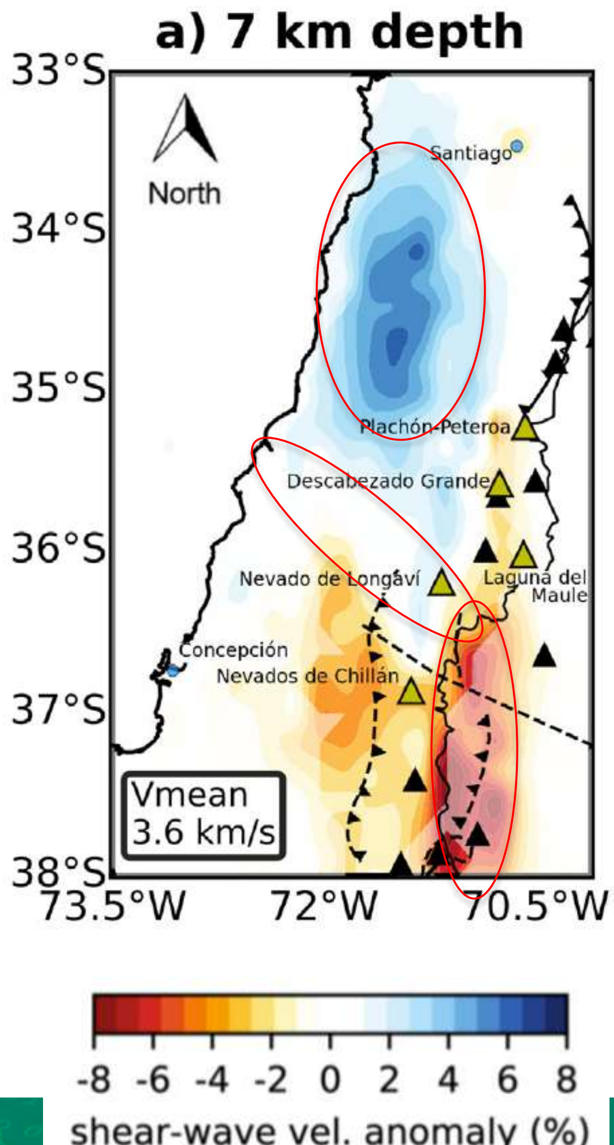
Ambient Noise Tomography

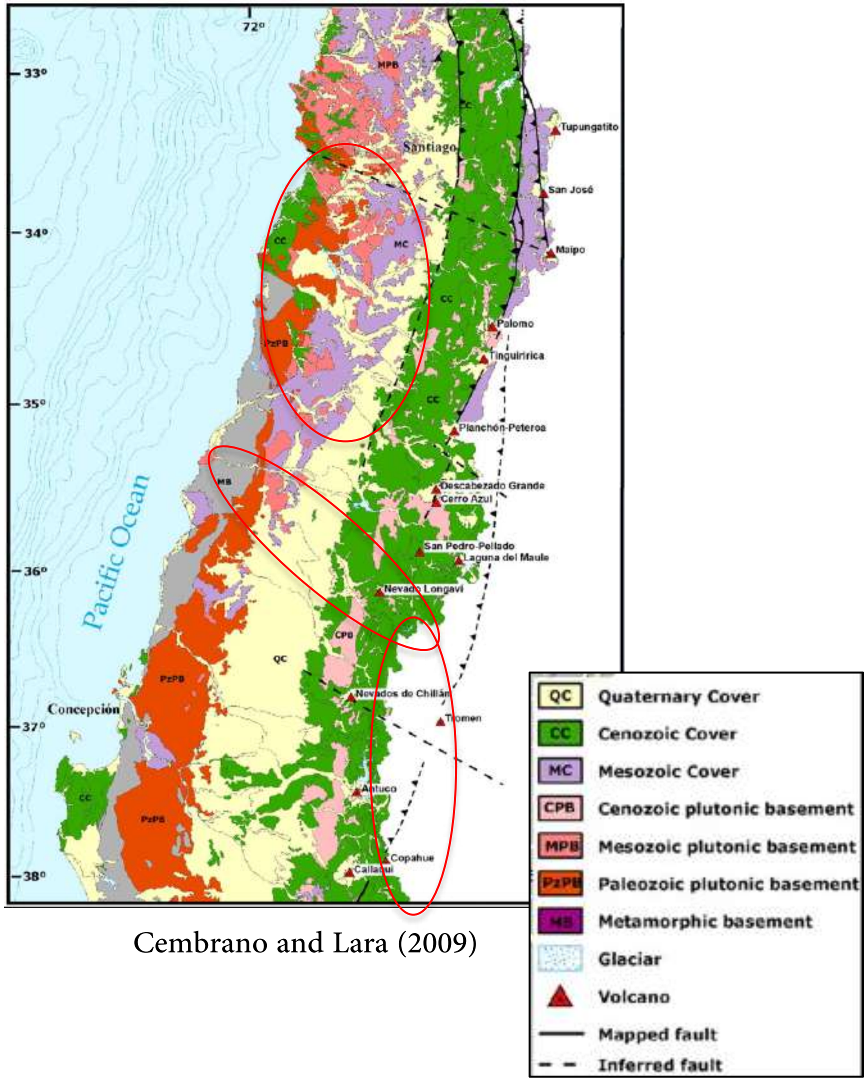






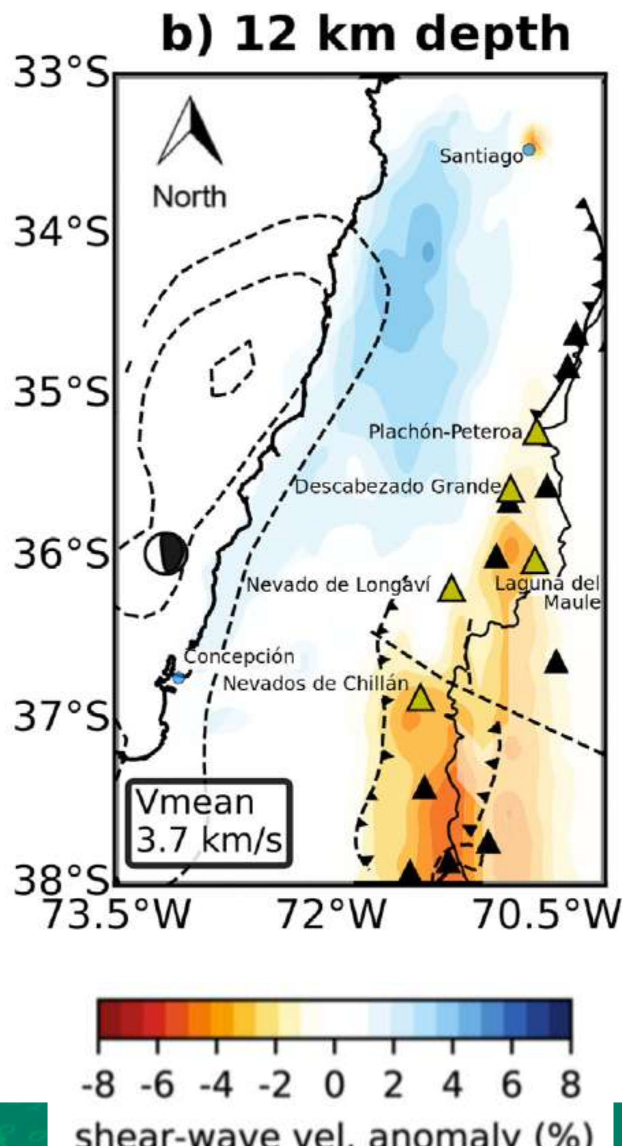
Ambient Noise Tomography

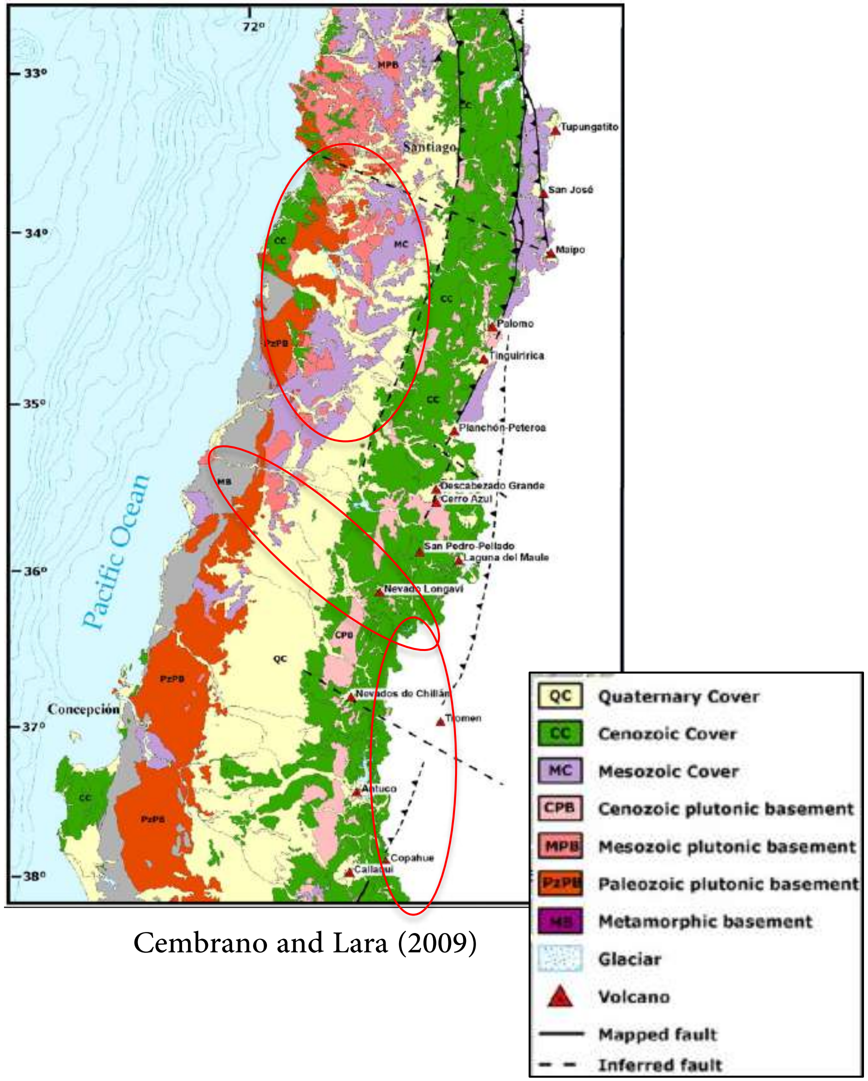




Cembrano and Lara (2009)

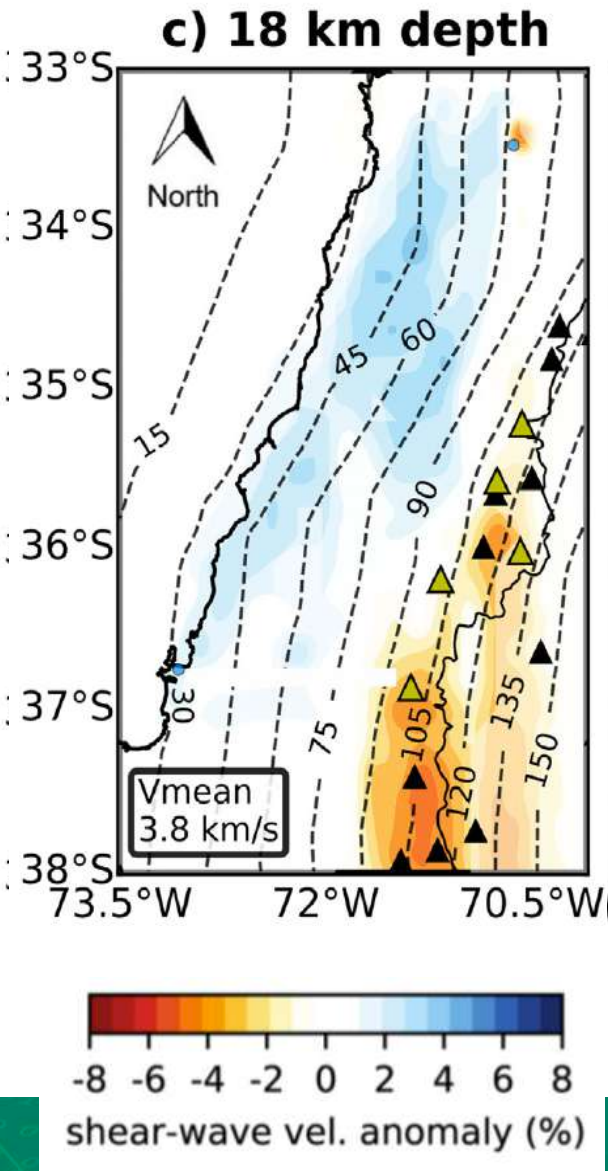
Ambient Noise Tomography

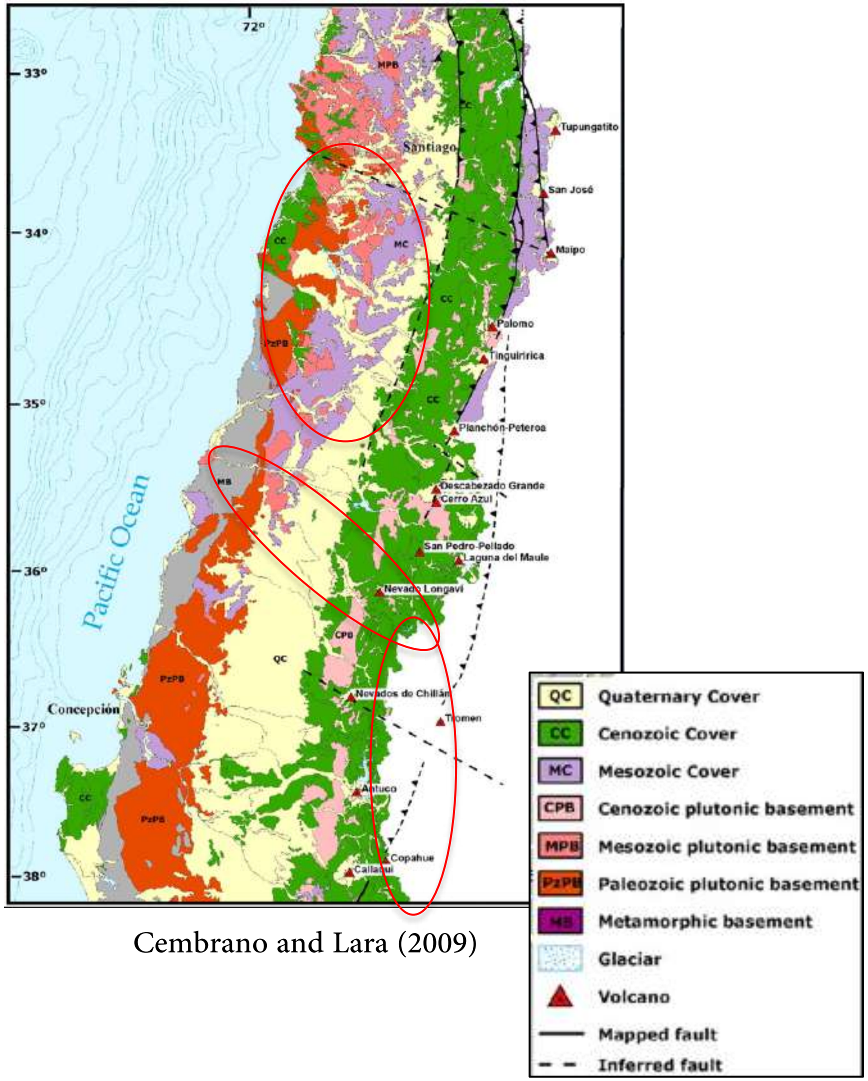




Cembrano and Lara (2009)

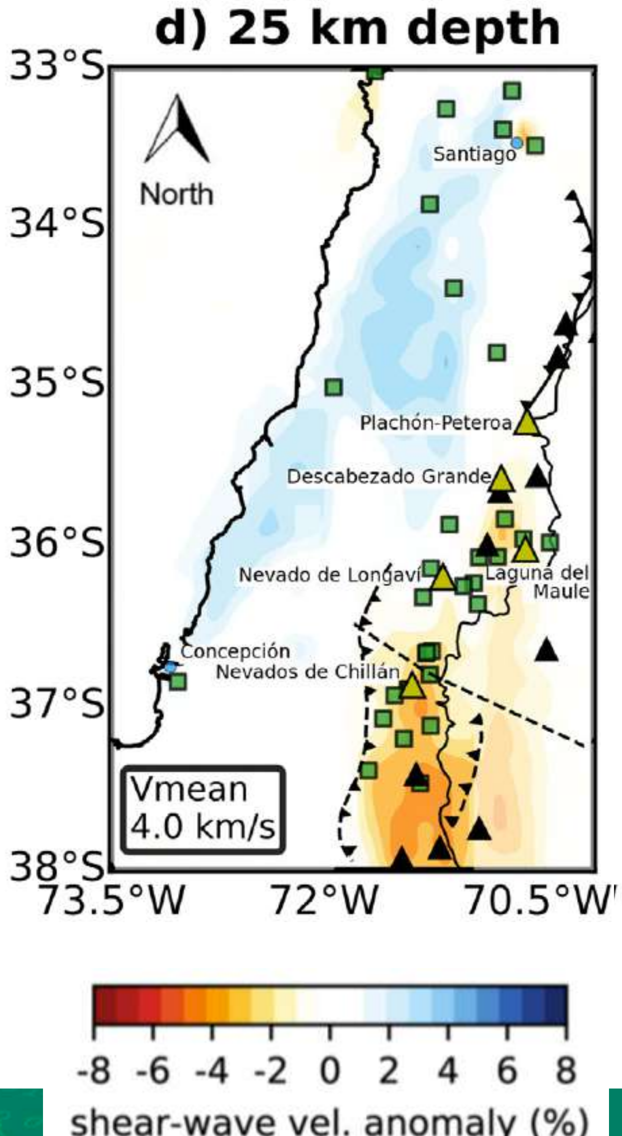
Ambient Noise Tomography

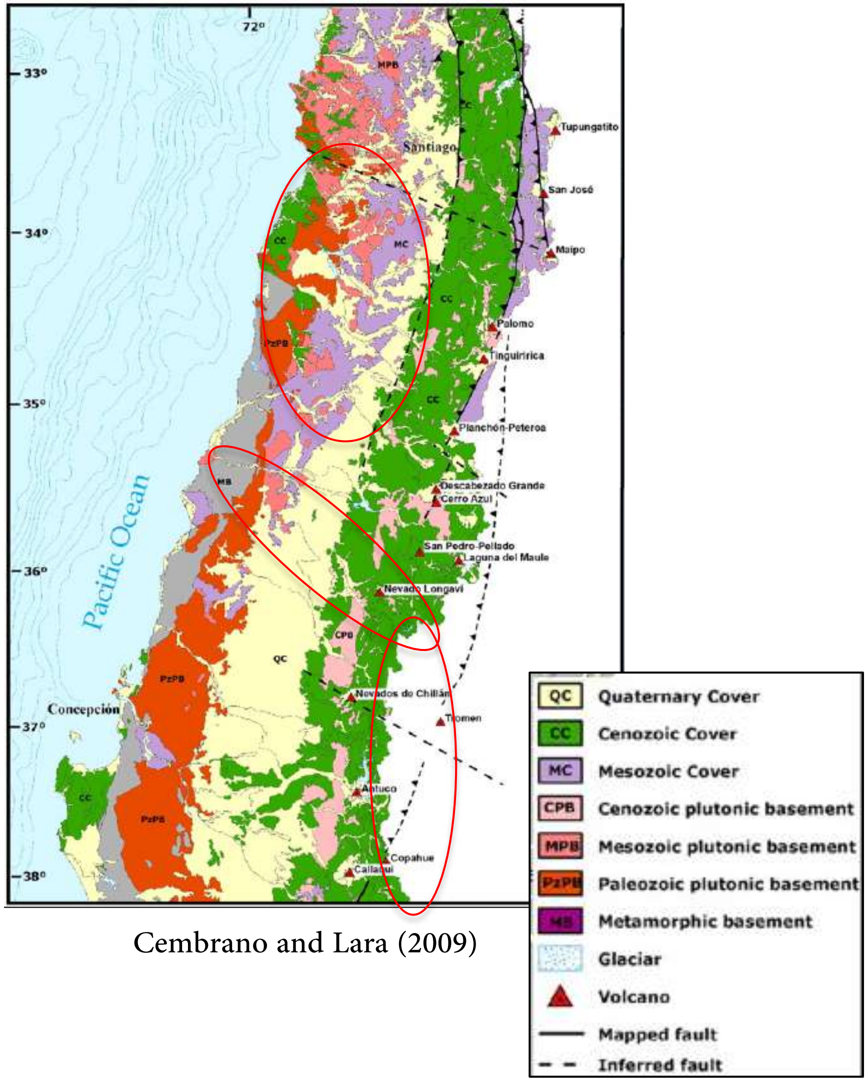




Cembrano and Lara (2009)

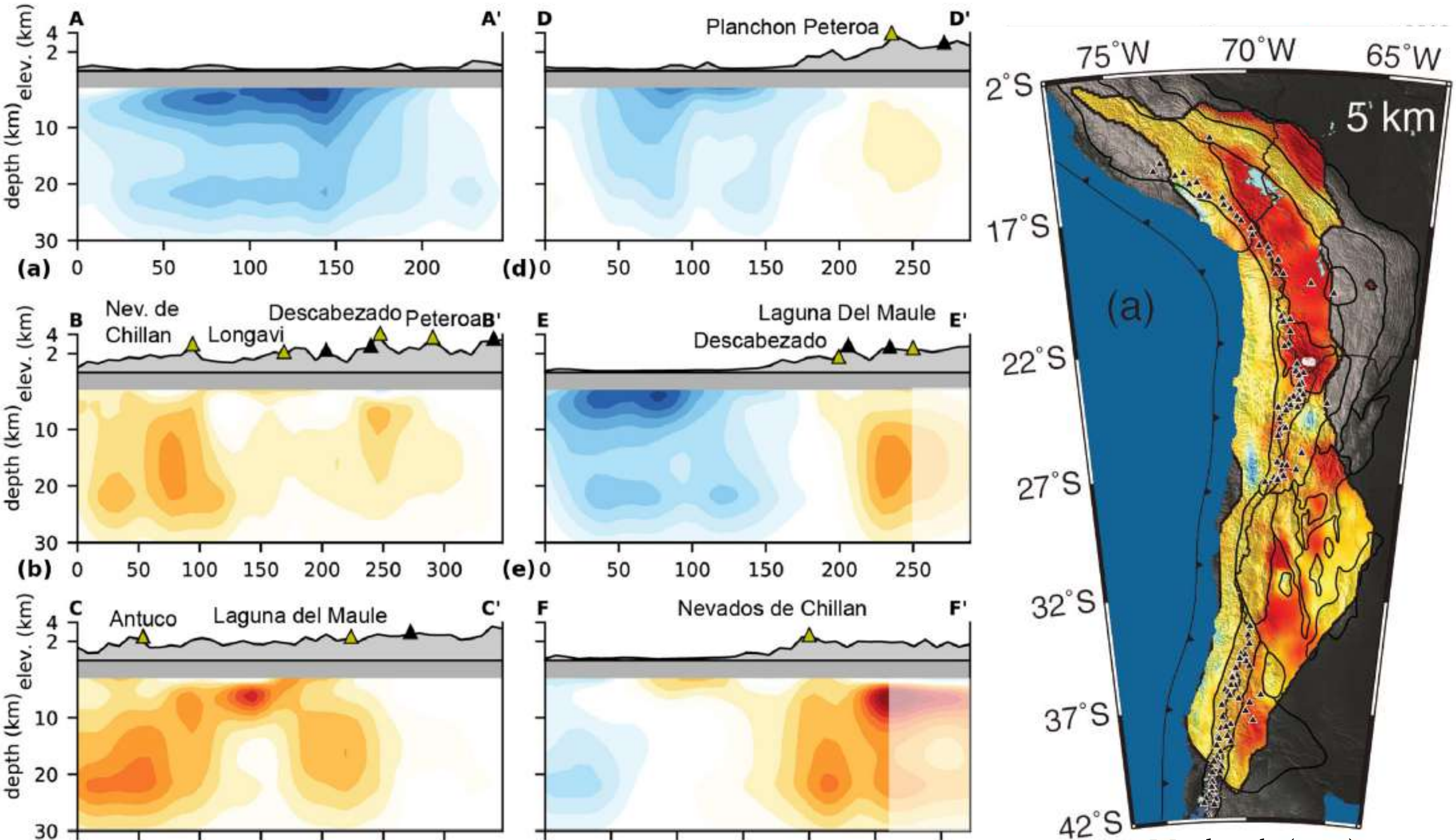
Ambient Noise Tomography





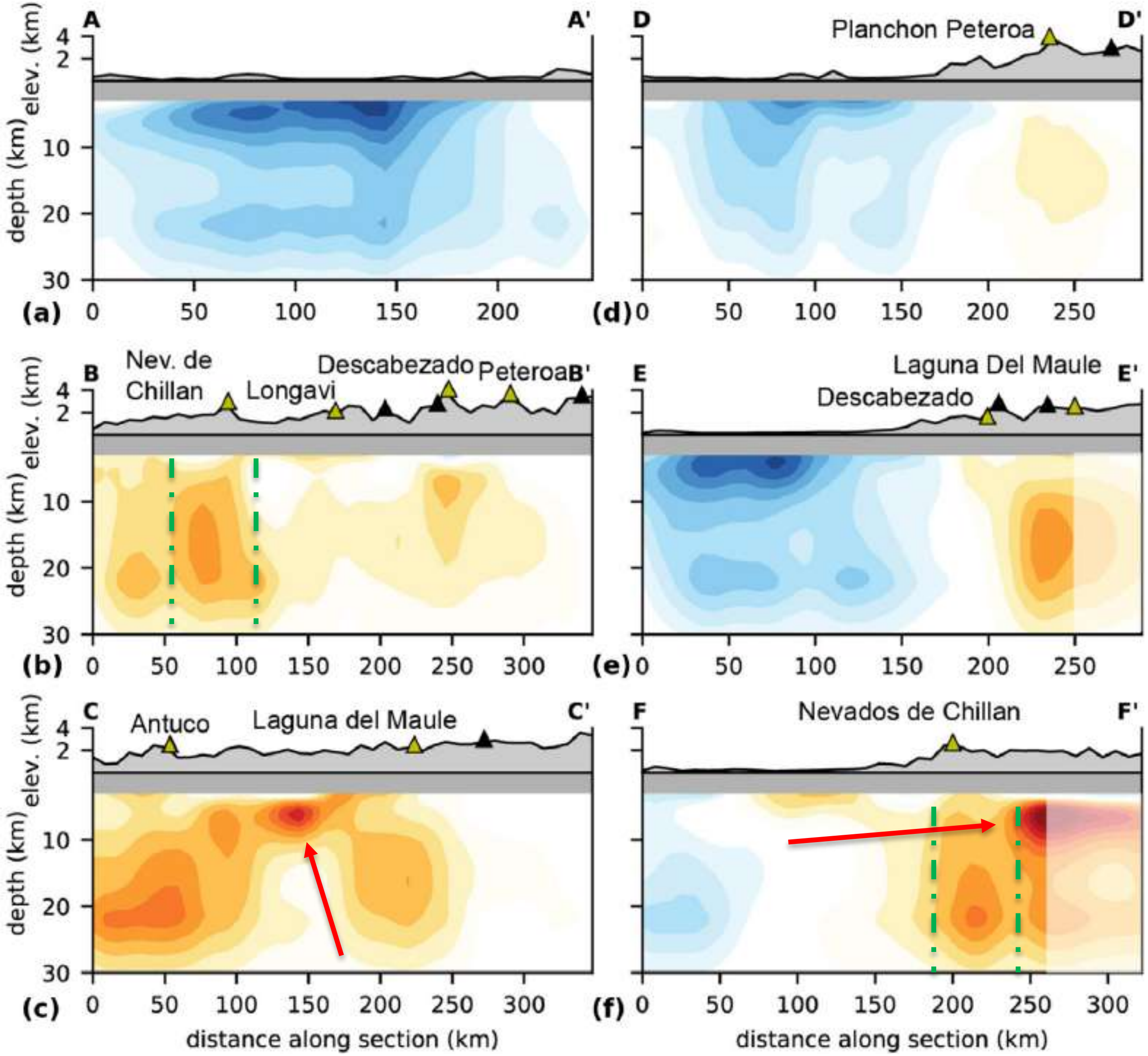
Cembrano and Lara (2009)

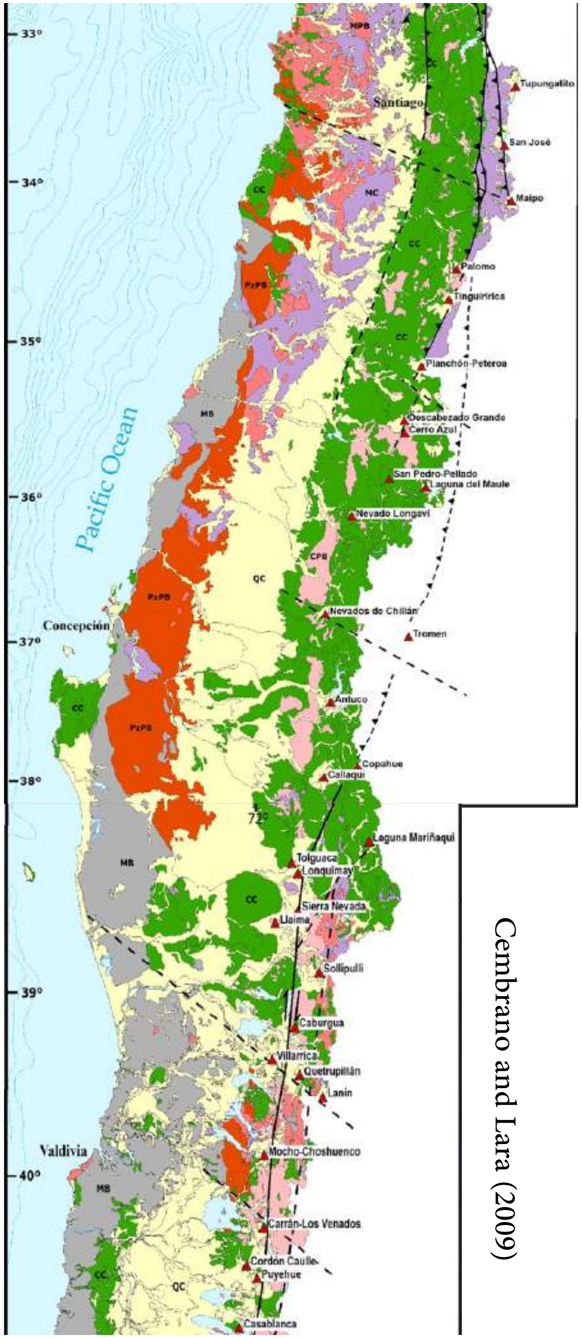
Ambient Noise Tomography



Ward et al., (2013)
shear-wave vel. anomaly (%)

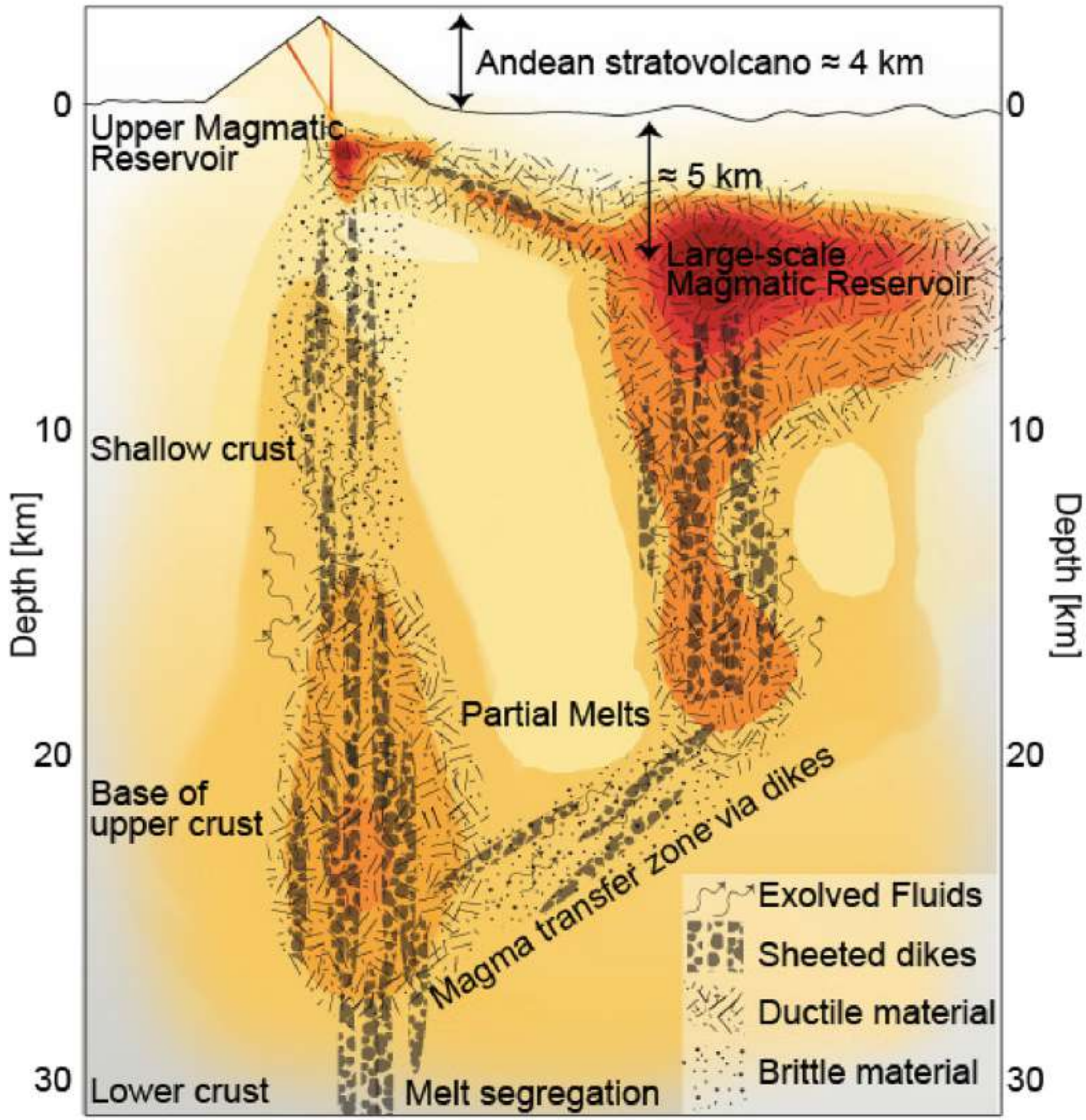
Ambient Noise Tomography Vs Tectonics



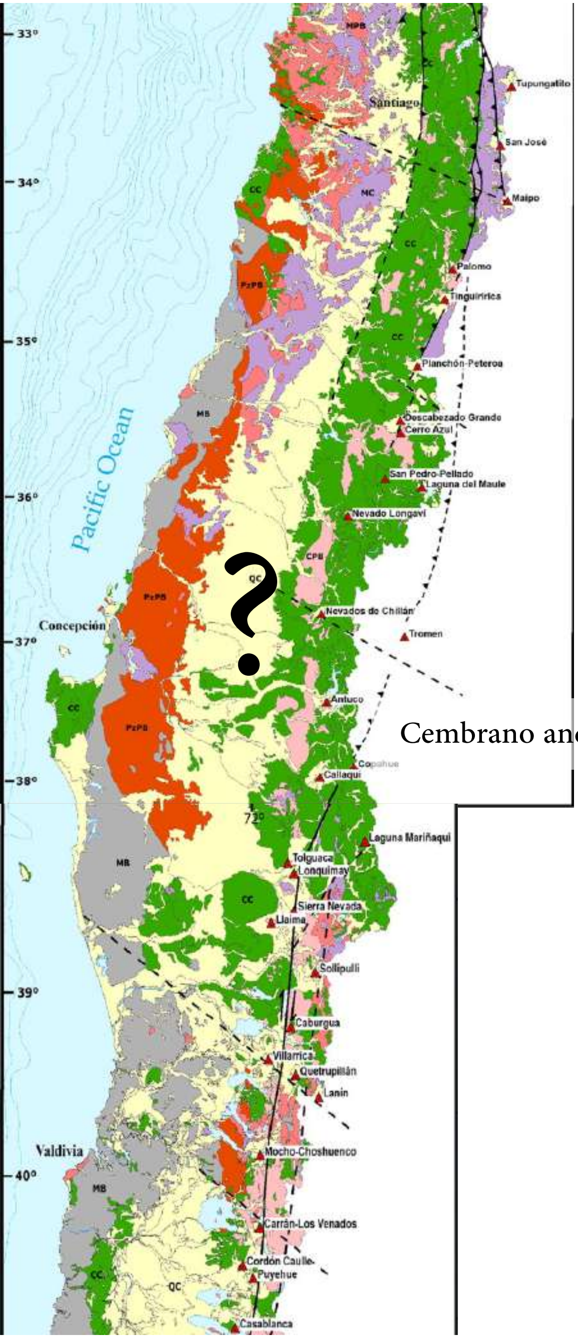


Cembrano and Lara (2009)

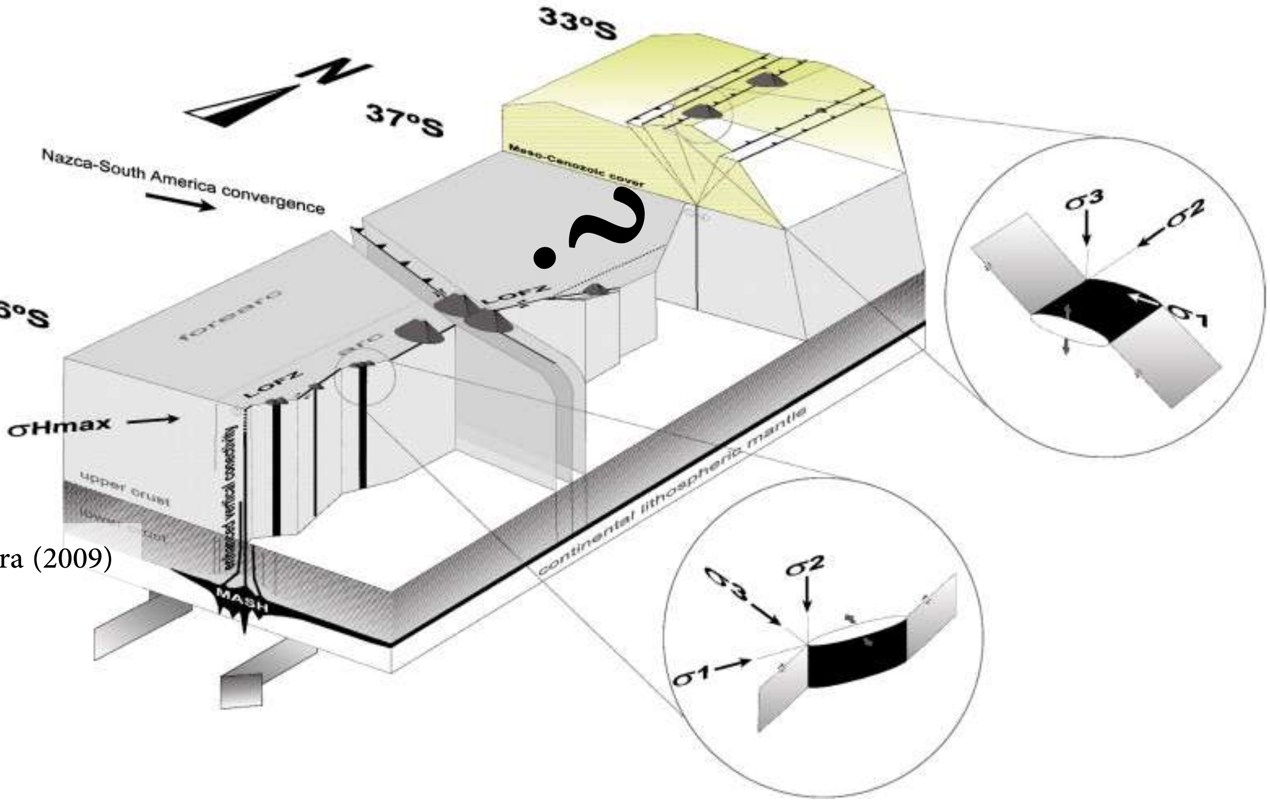
Conceptual model



Not an easy tectonics setting

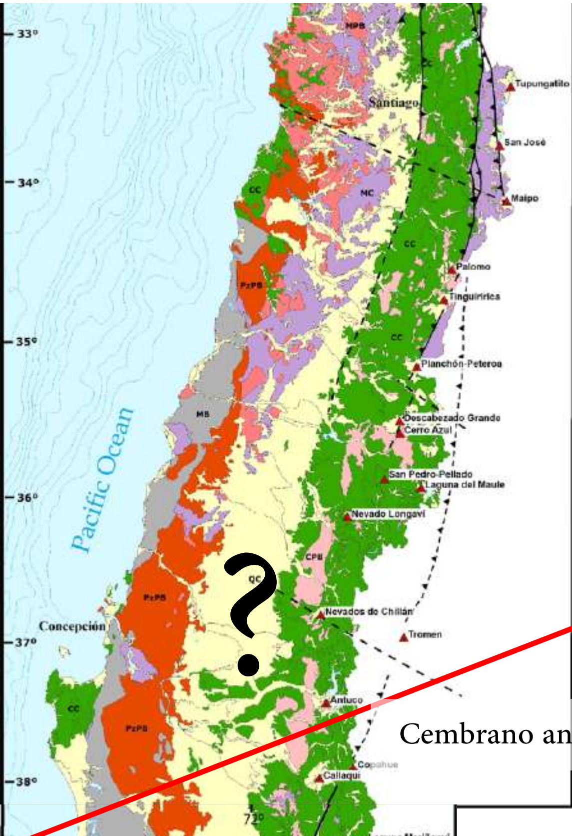


Cembrano and Lara (2009)

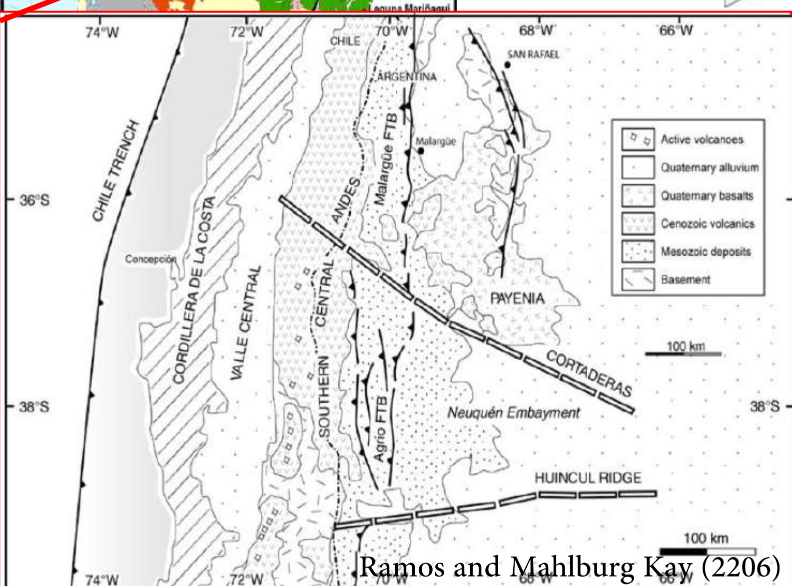


Ramos and Mahlburg-Kay (2206)

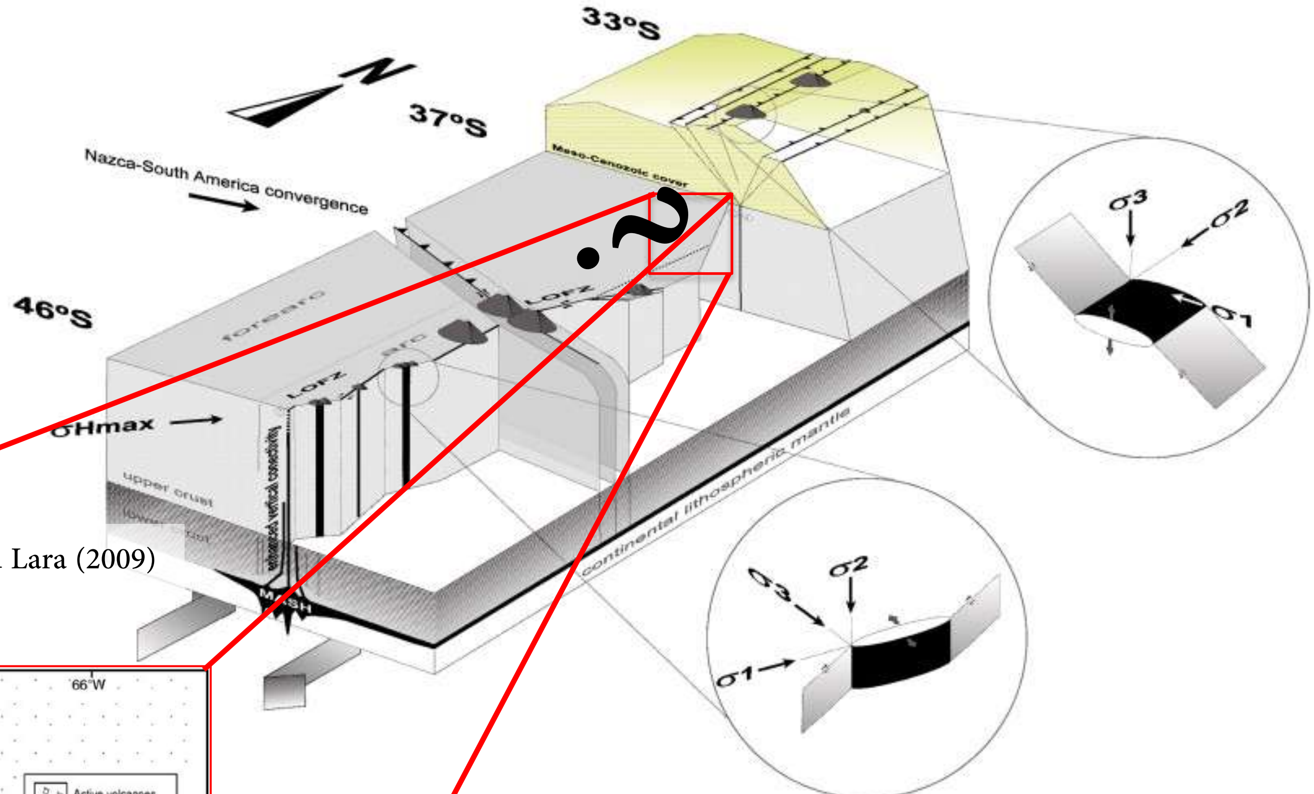
Not an easy tectonics setting



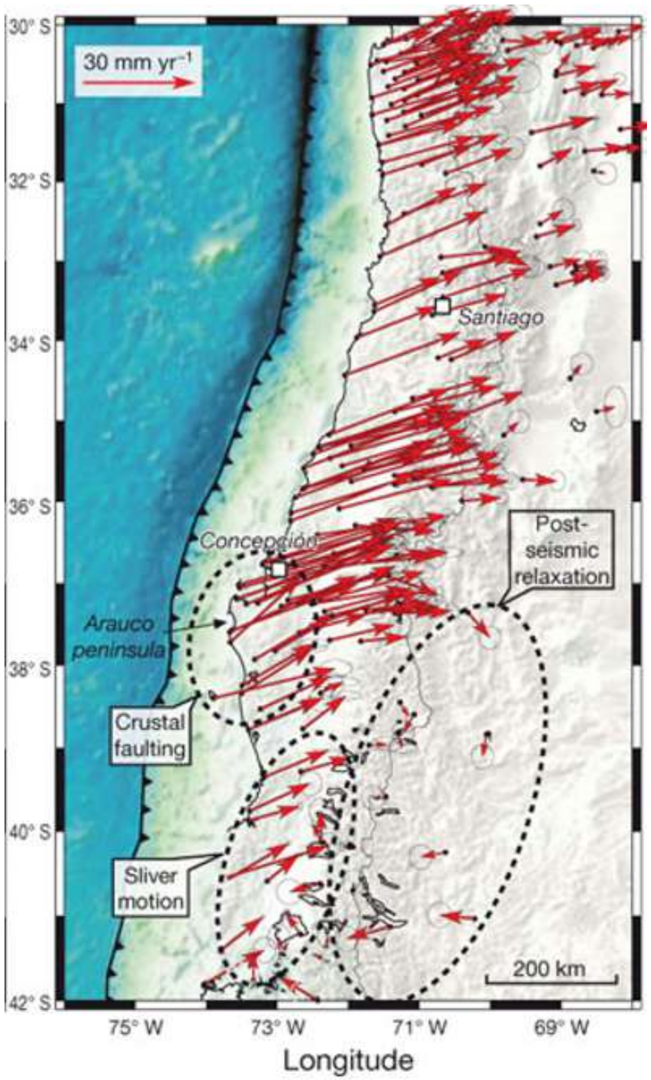
Cembrano and Lara (2009)



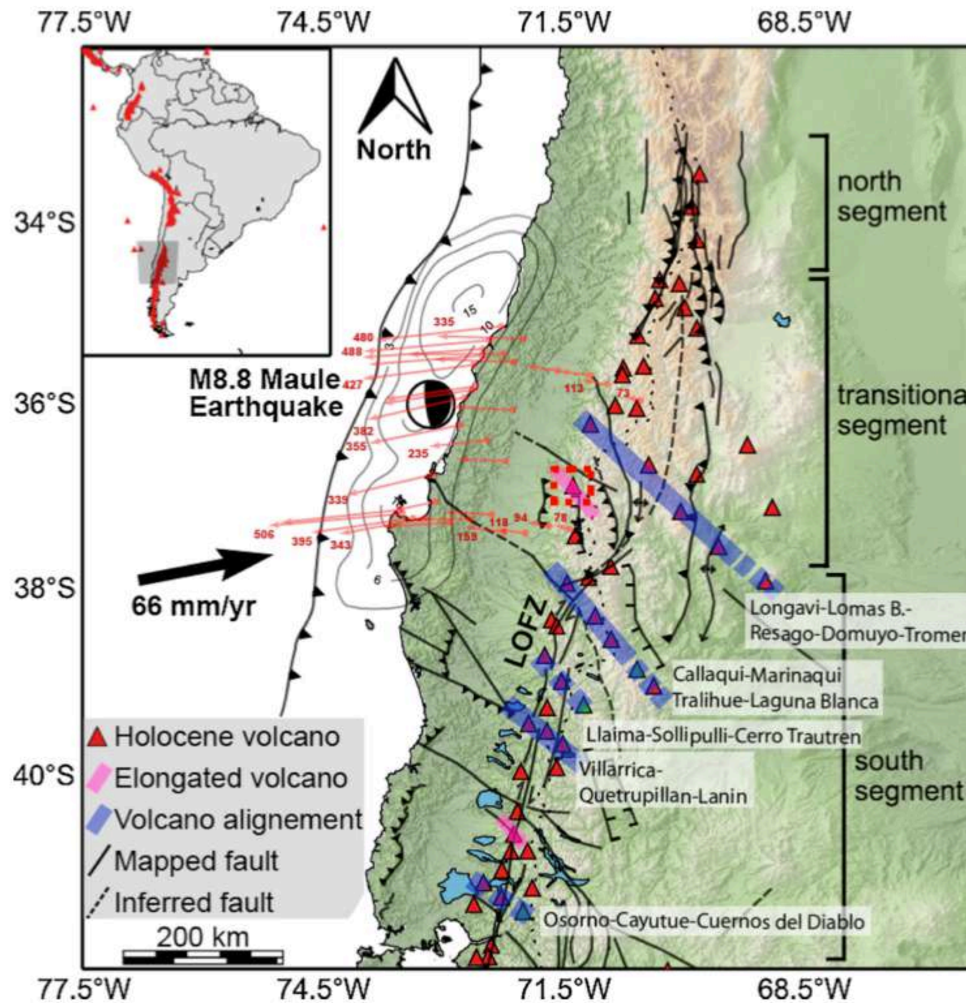
Ramos and Mahlburg Kay (2206)



Not an easy tectonic setting

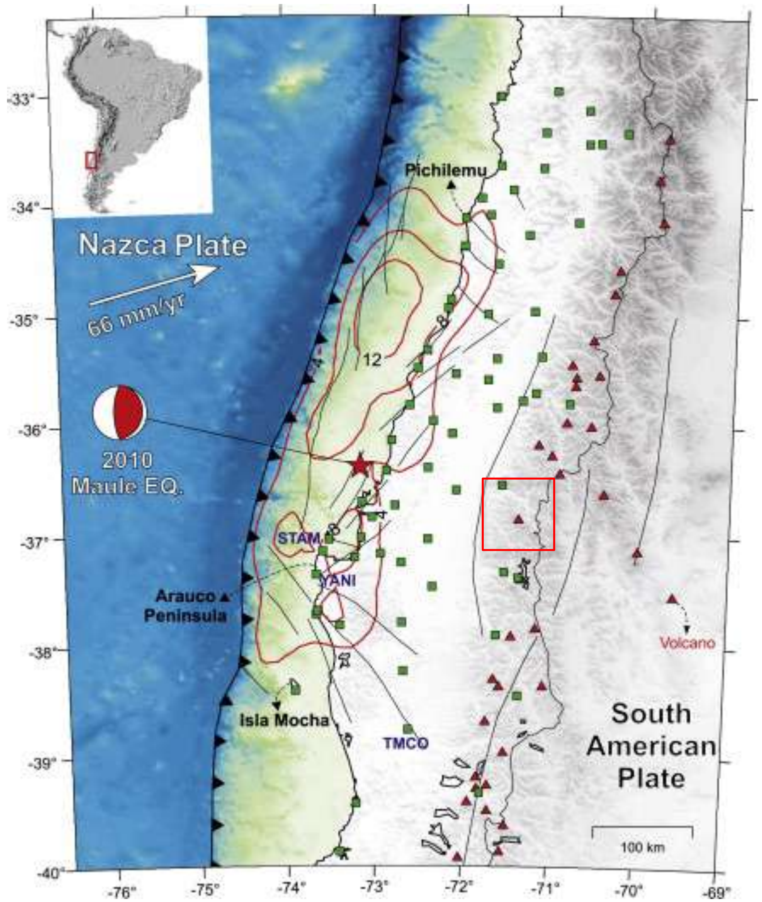


Moreno et al., 2010 (nature)

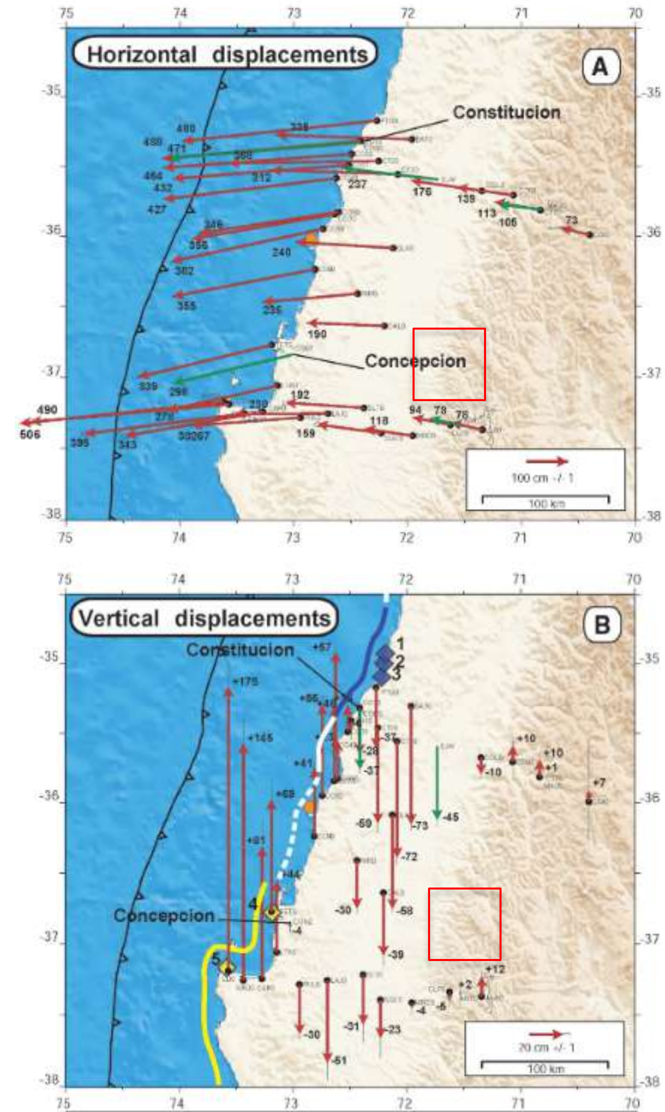


Lupi et al., (2020)

The 2010 M8.8 Maule earthquake

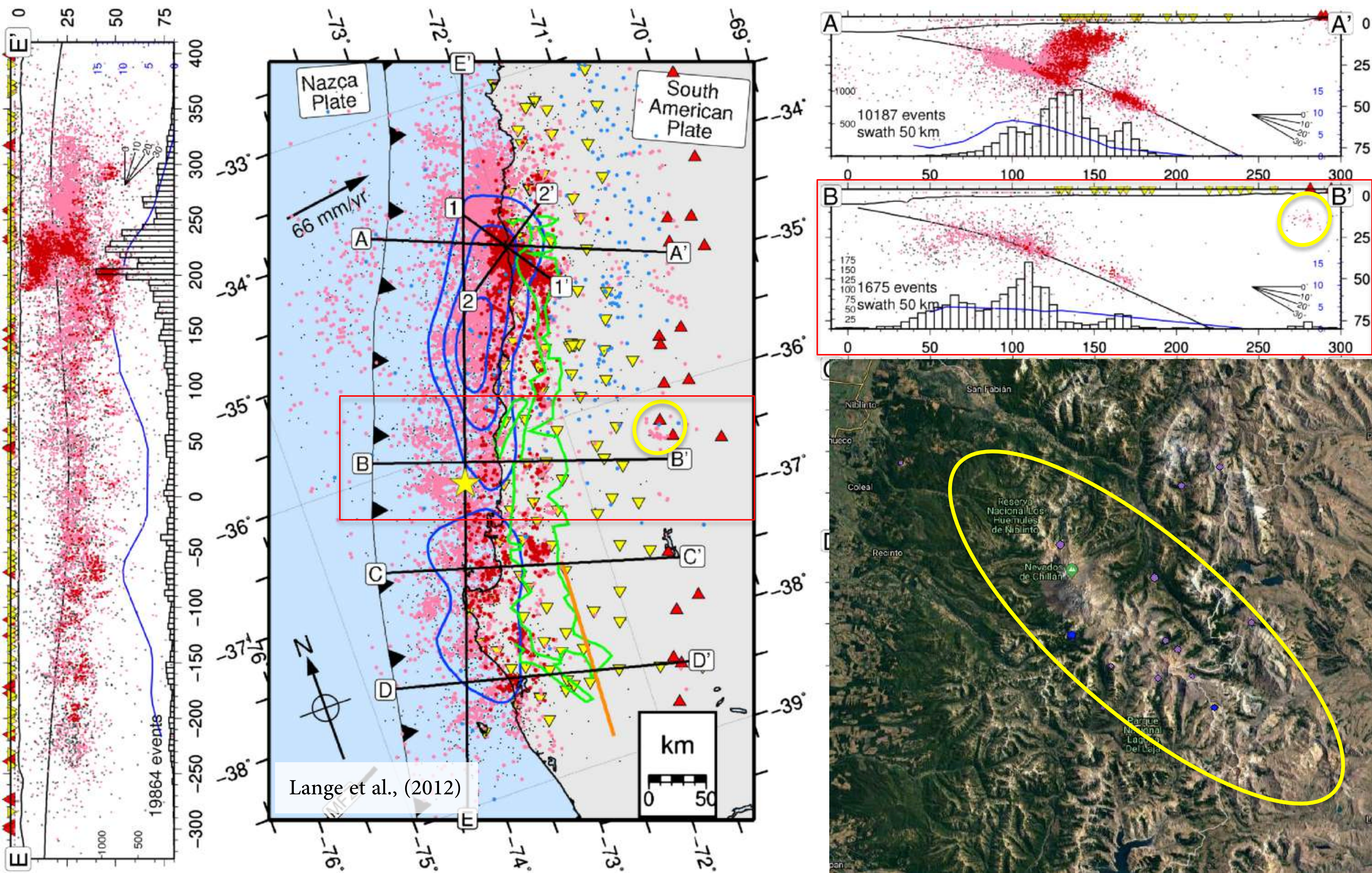


Bedford et al., (2013)

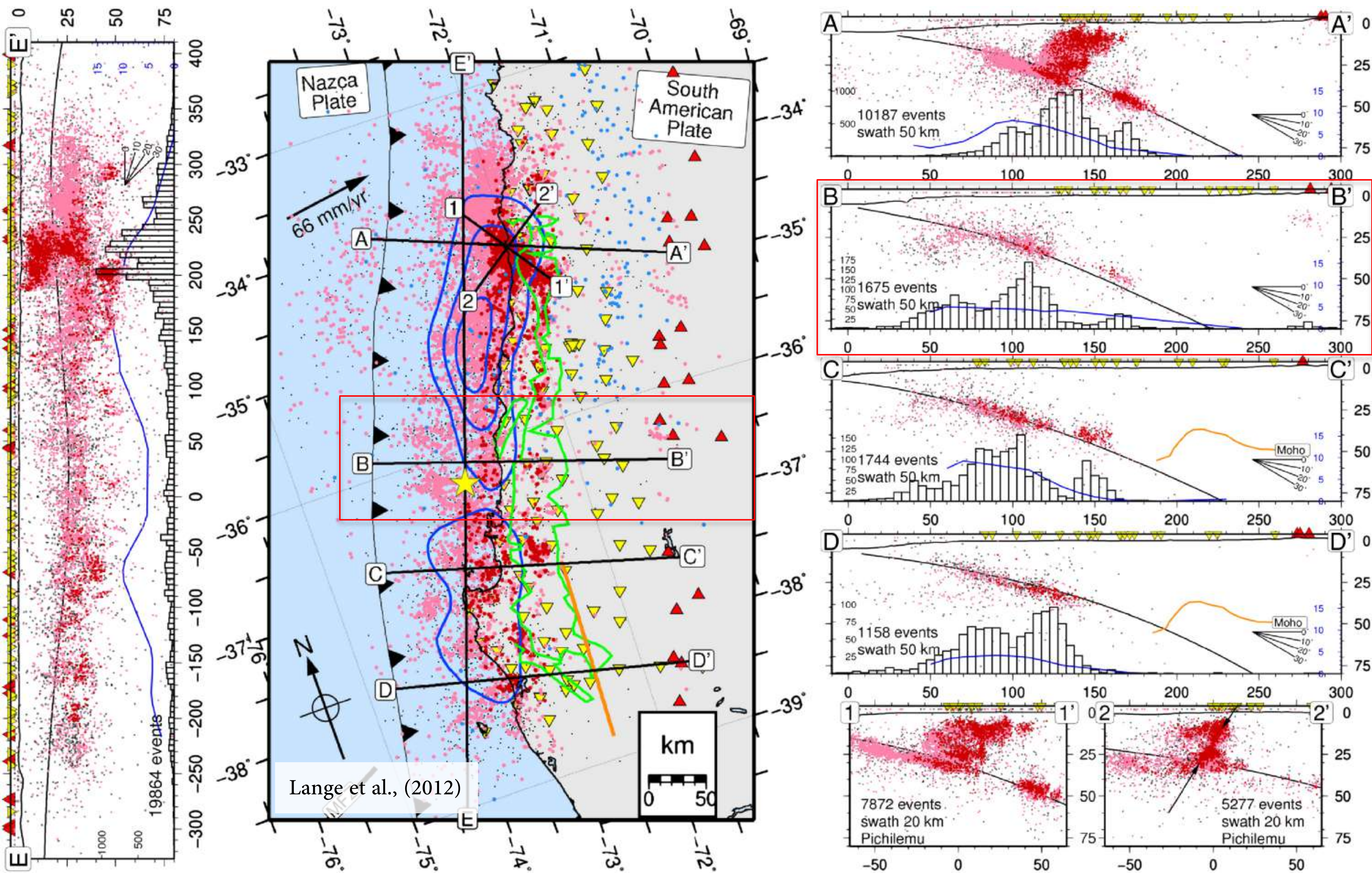


Vigny et al., 2011 (science)

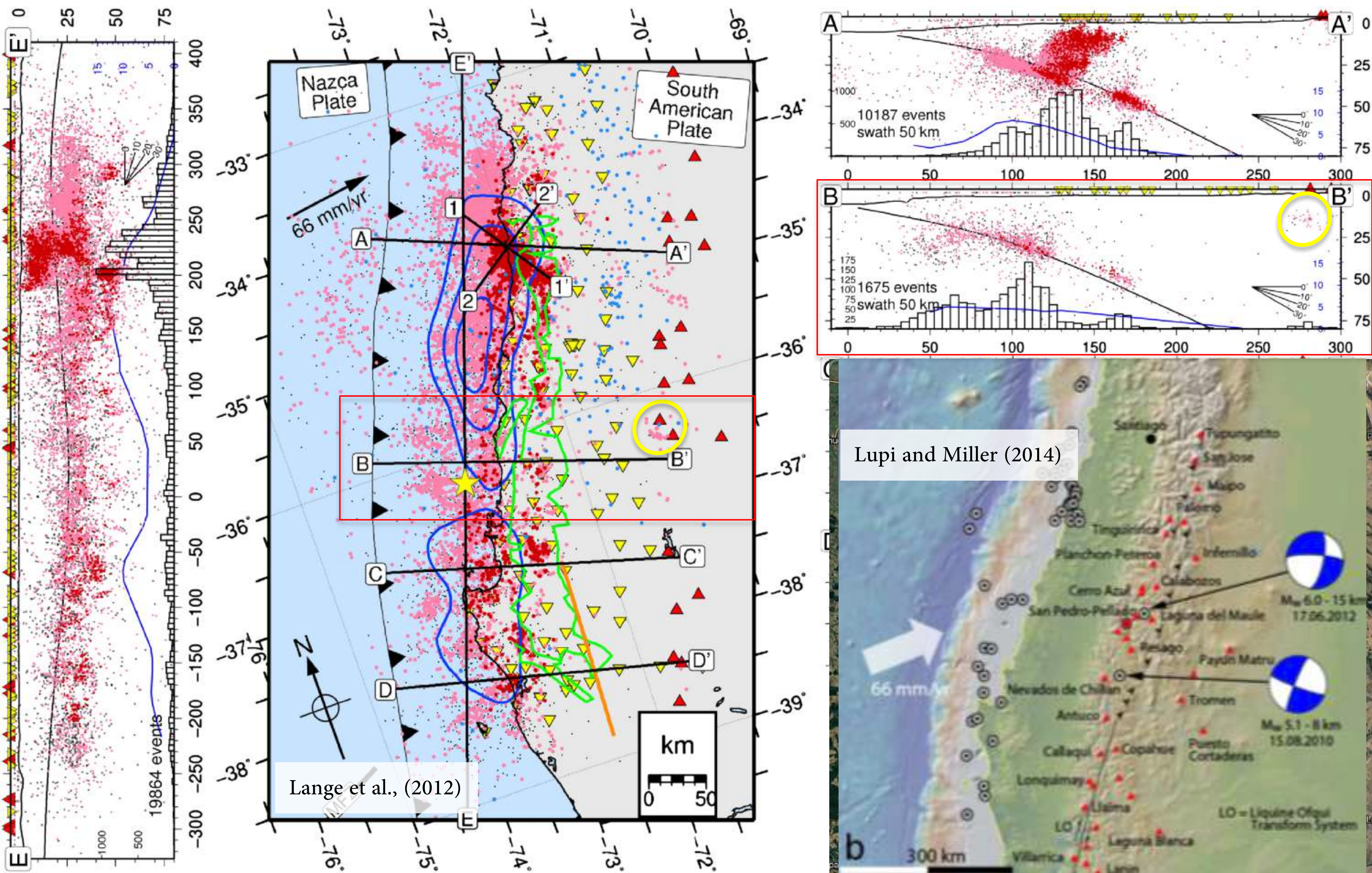
The seismicity after the 2010 M8.8 Maule earthquake (15.3 to 30.9.10)



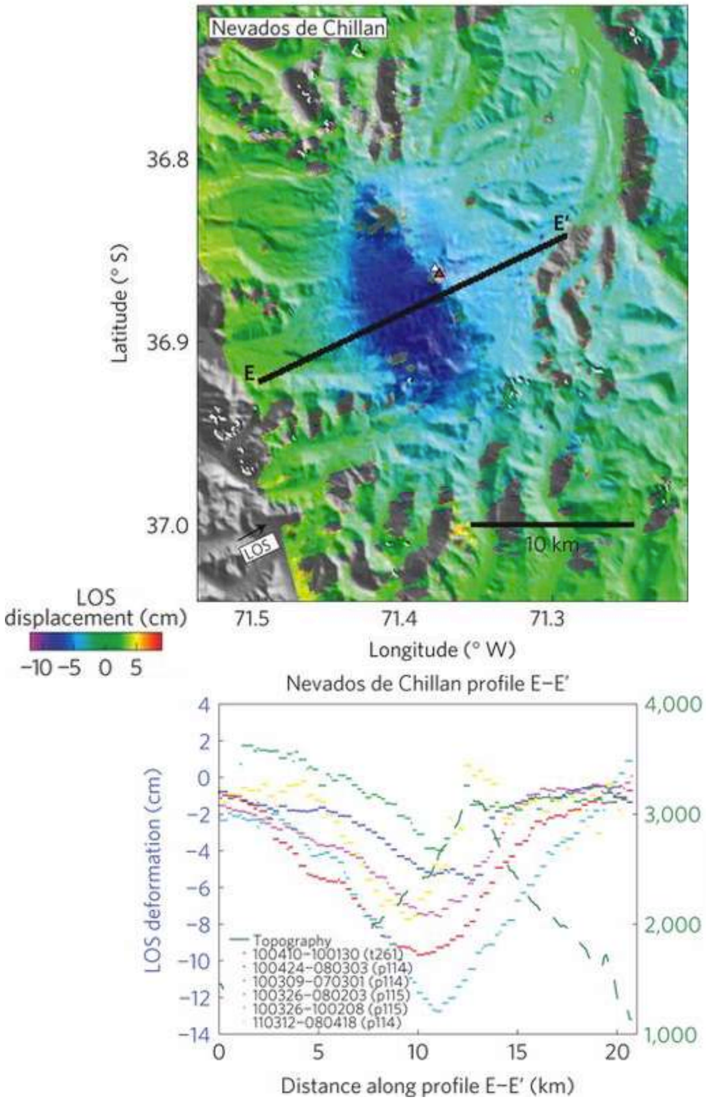
The seismicity after the 2010 M8.8 Maule earthquake (15.3 to 30.9.10)



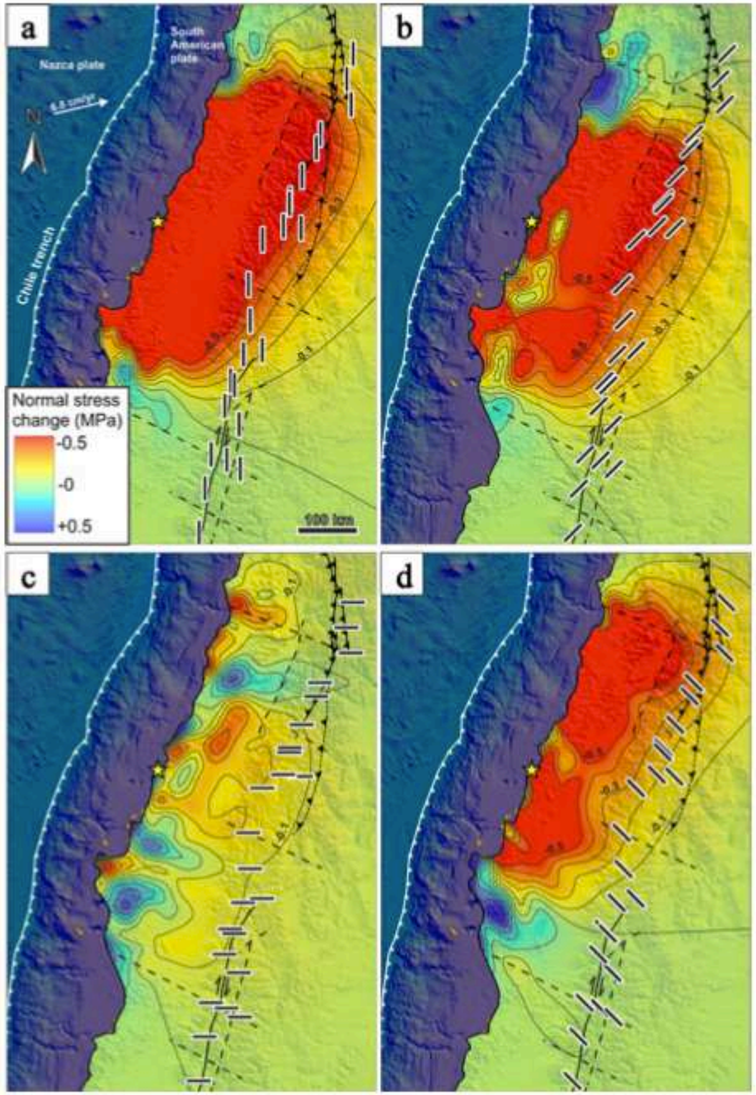
The seismicity after the 2010 M8.8 Maule earthquake (15.3 to 30.9.10)



Short- and long-term M8.8 Maule effects on the arc

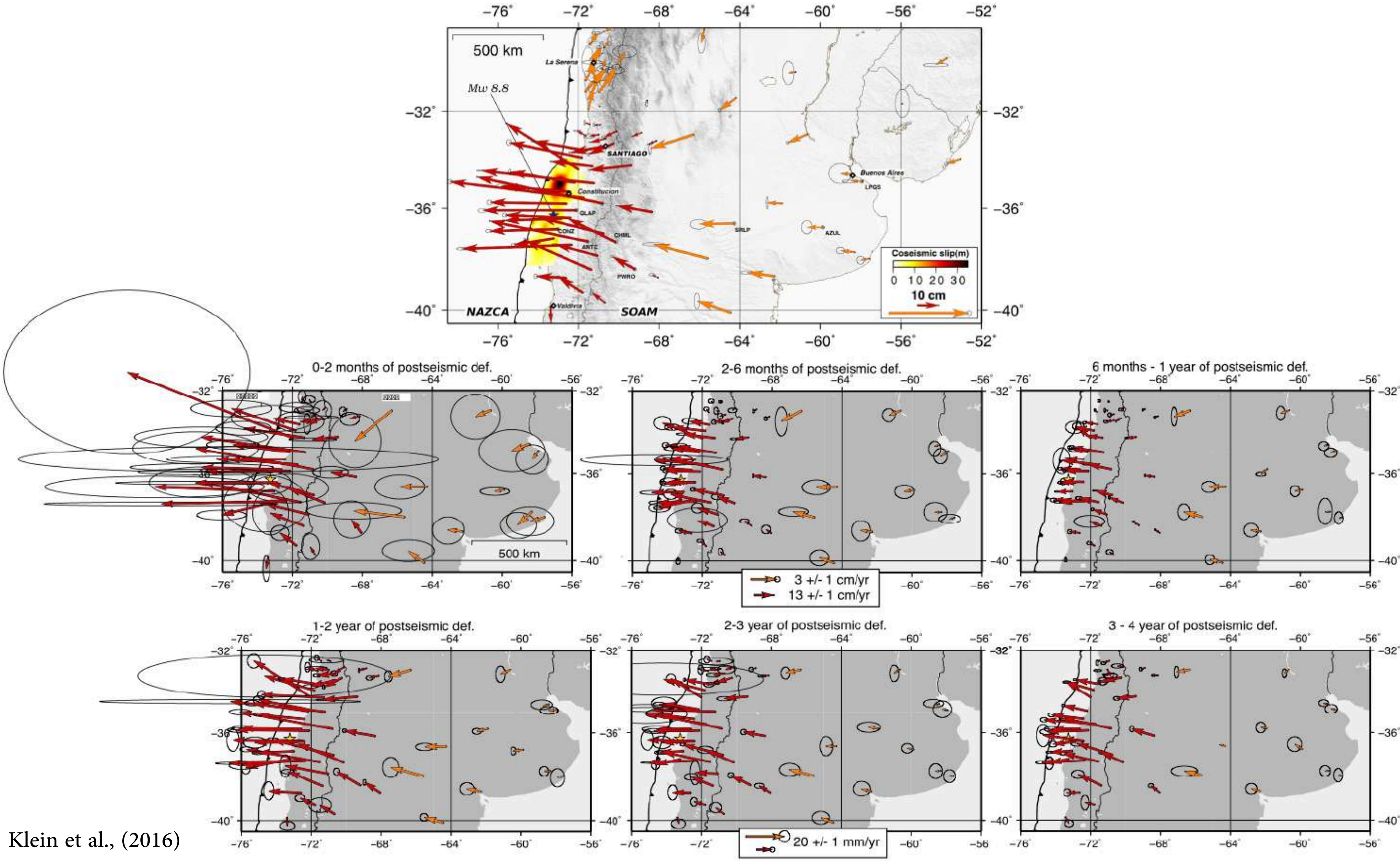


Pritchard et al., (2013)



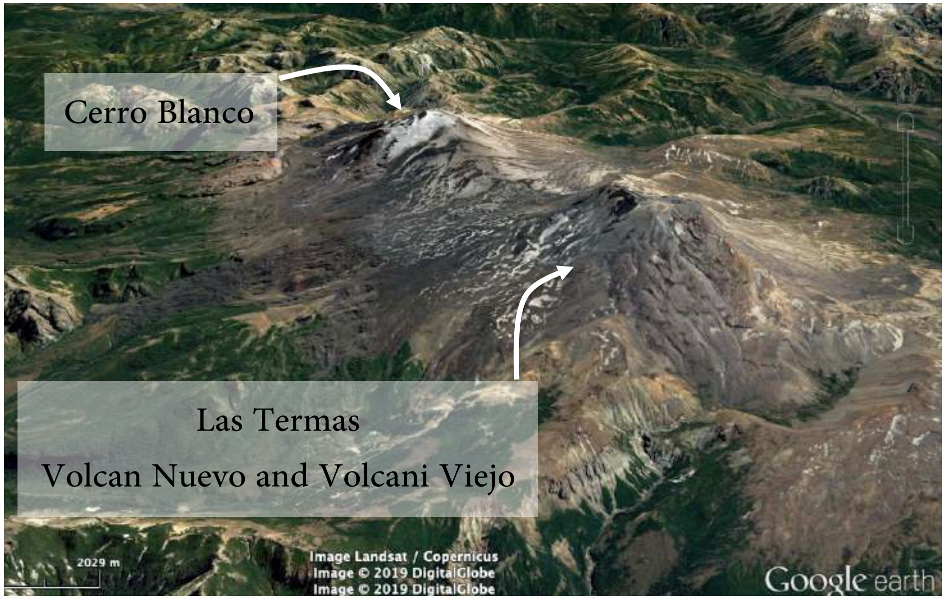
Bonali et al., (2015)

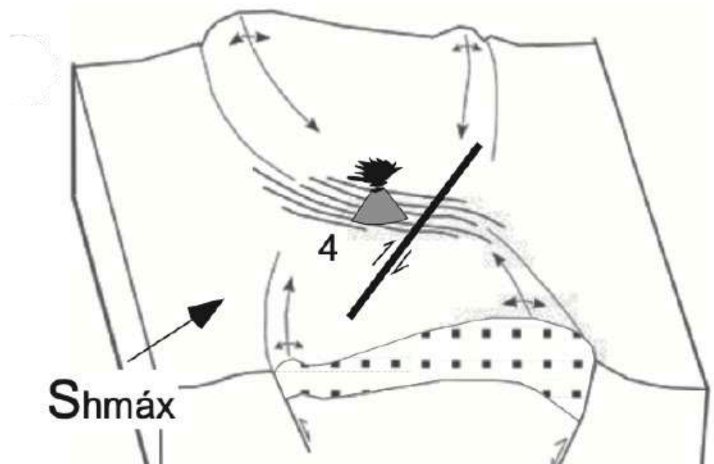
Prolonged deformation of the M8.8 Maule earthquake



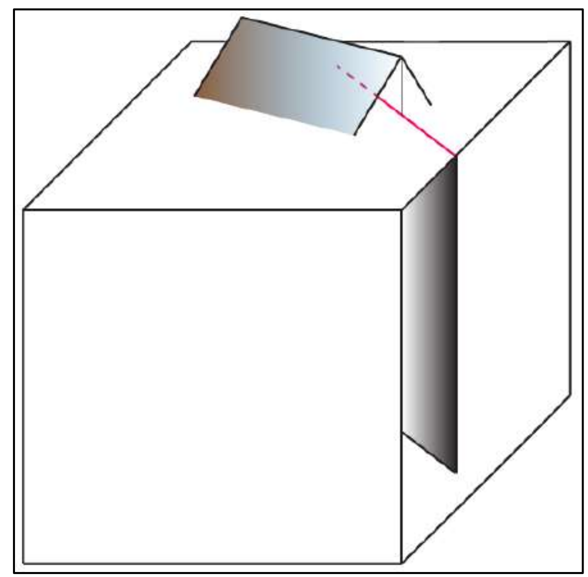
Klein et al., (2016)

The Nevados de Chillan



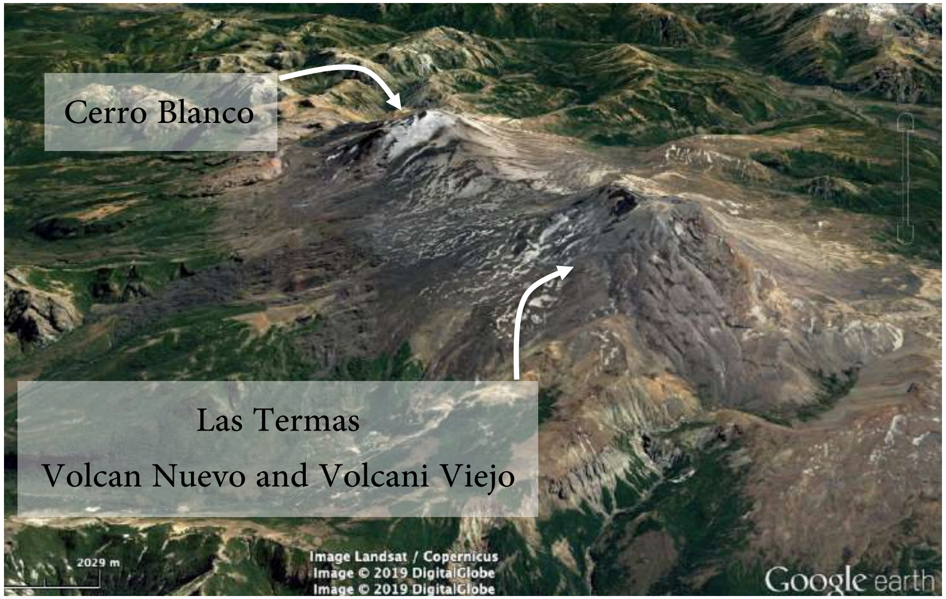


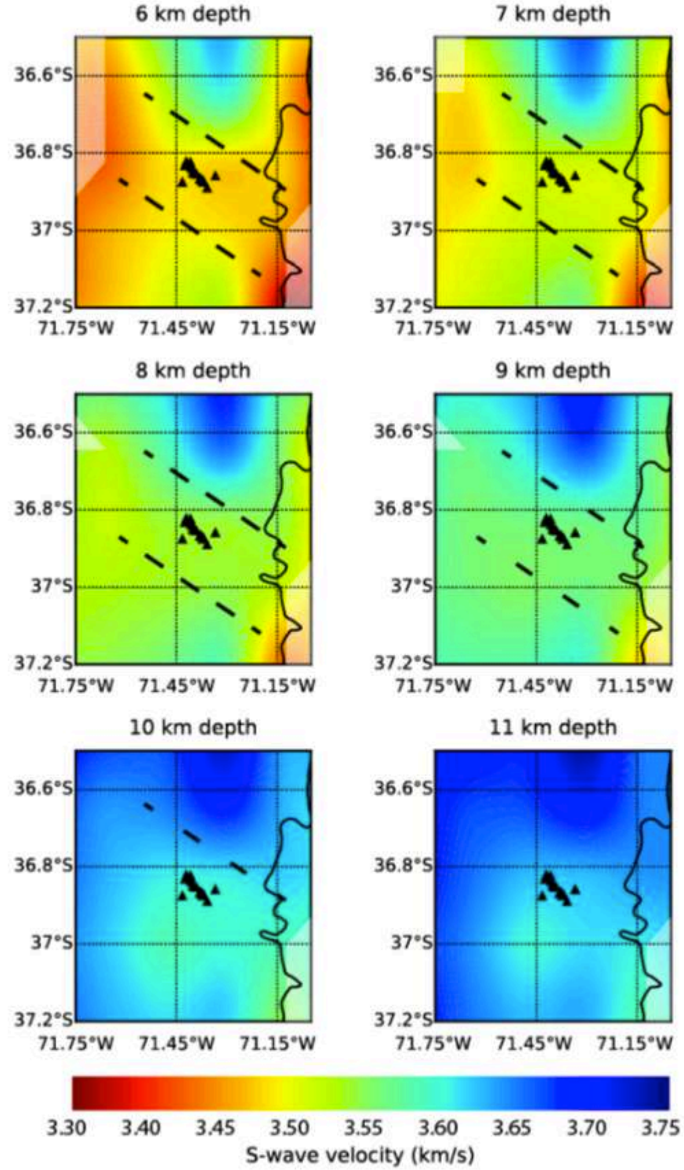
Radic (2006)



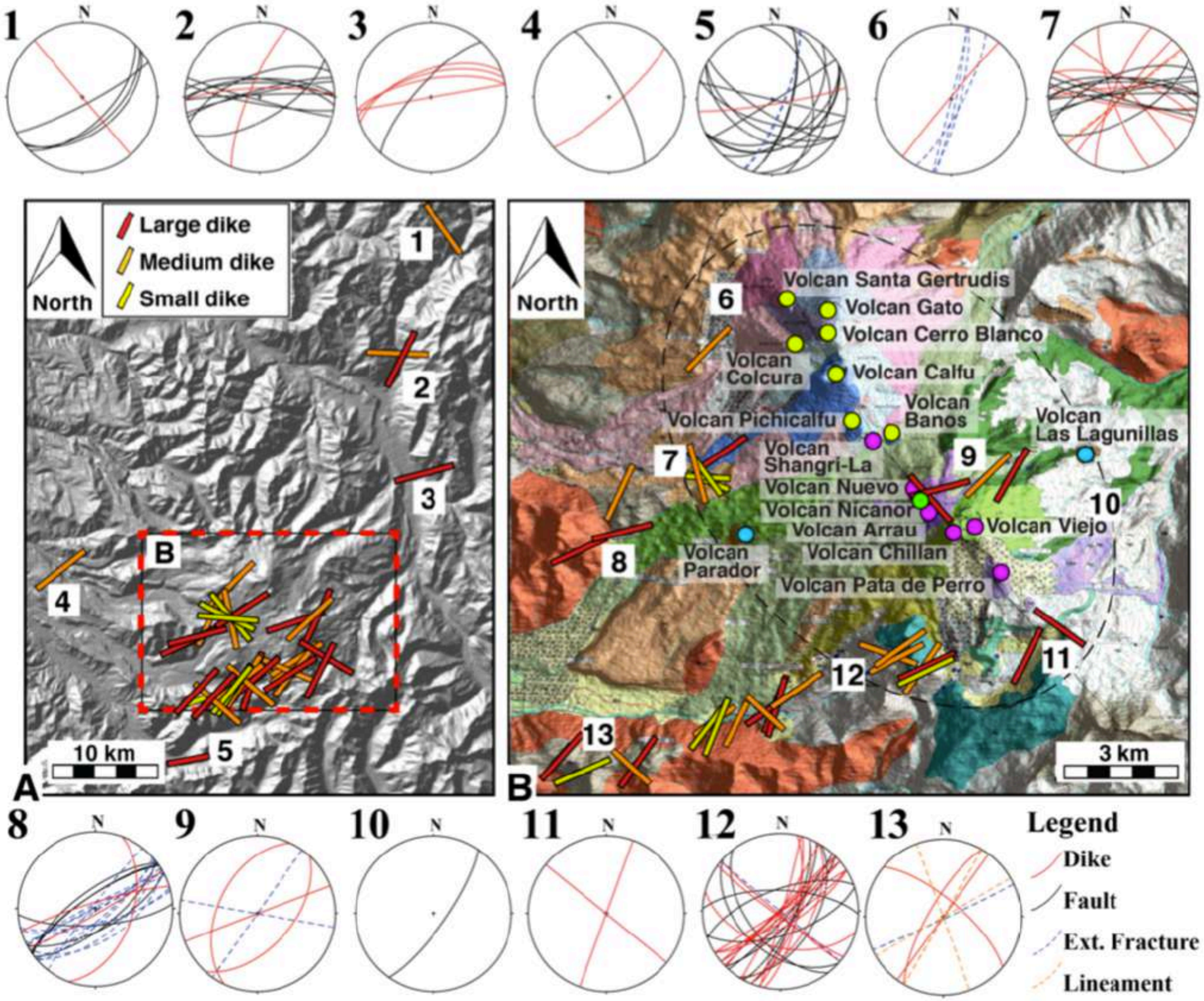
Ramos and Malbourgh Kay (2006)
Cembrano and Lara (2009)

The Nevados de Chillan



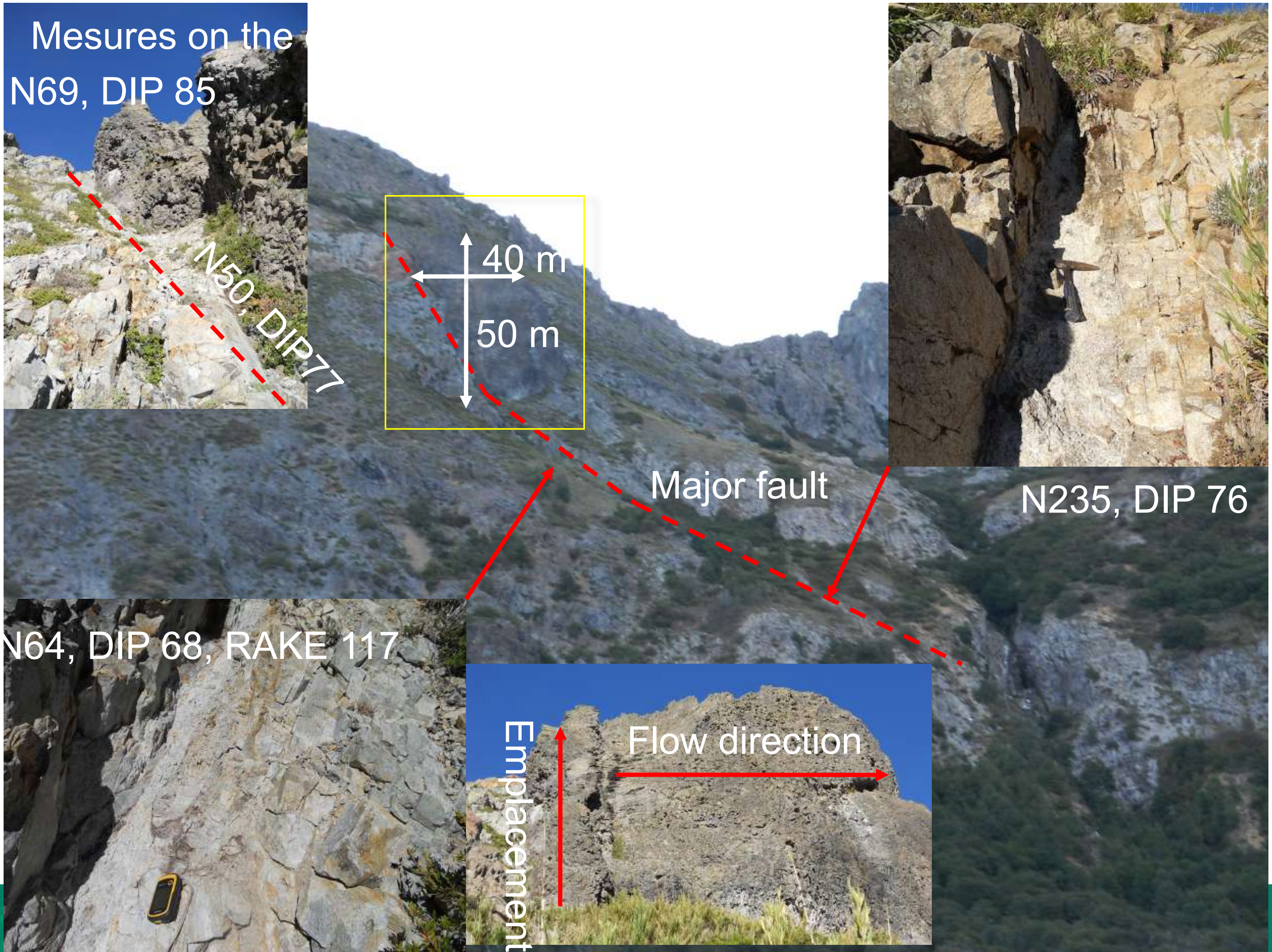


Faults and dikes



Faults, dikes and faults&dikes

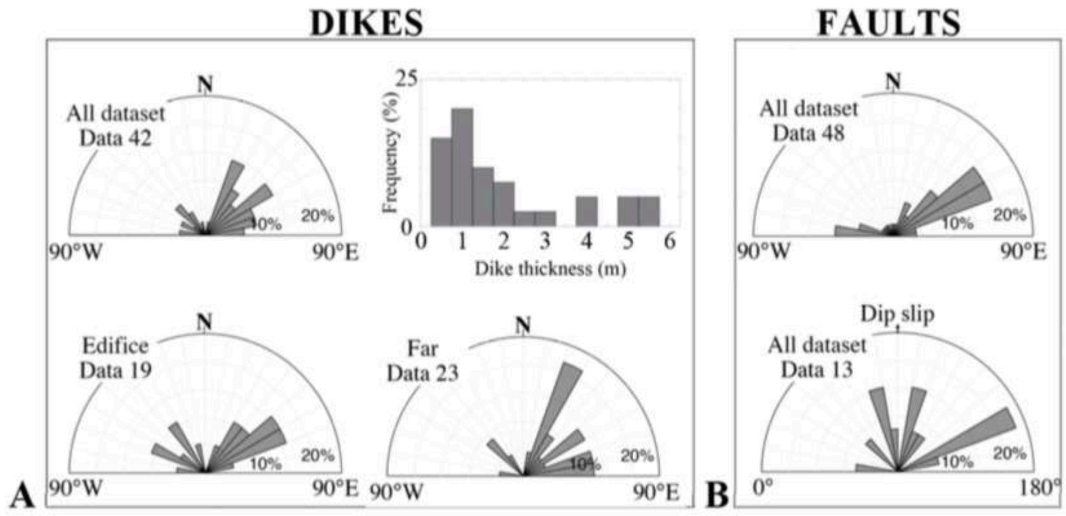
Faults, dikes and faults&dikes



Faults, dikes and faults&dikes

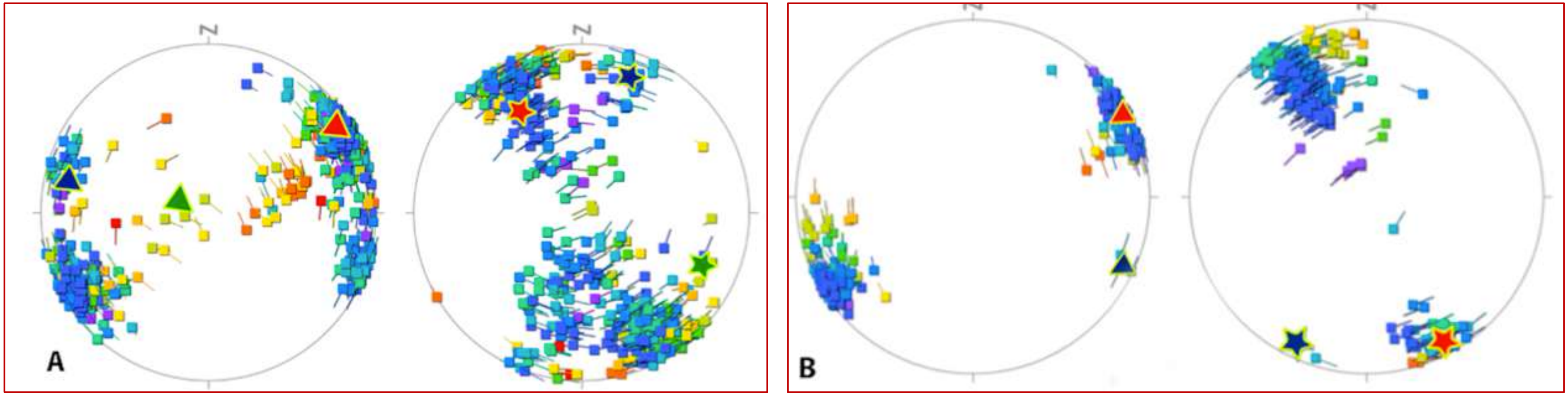
Faults, dikes and faults&dikes

Field data

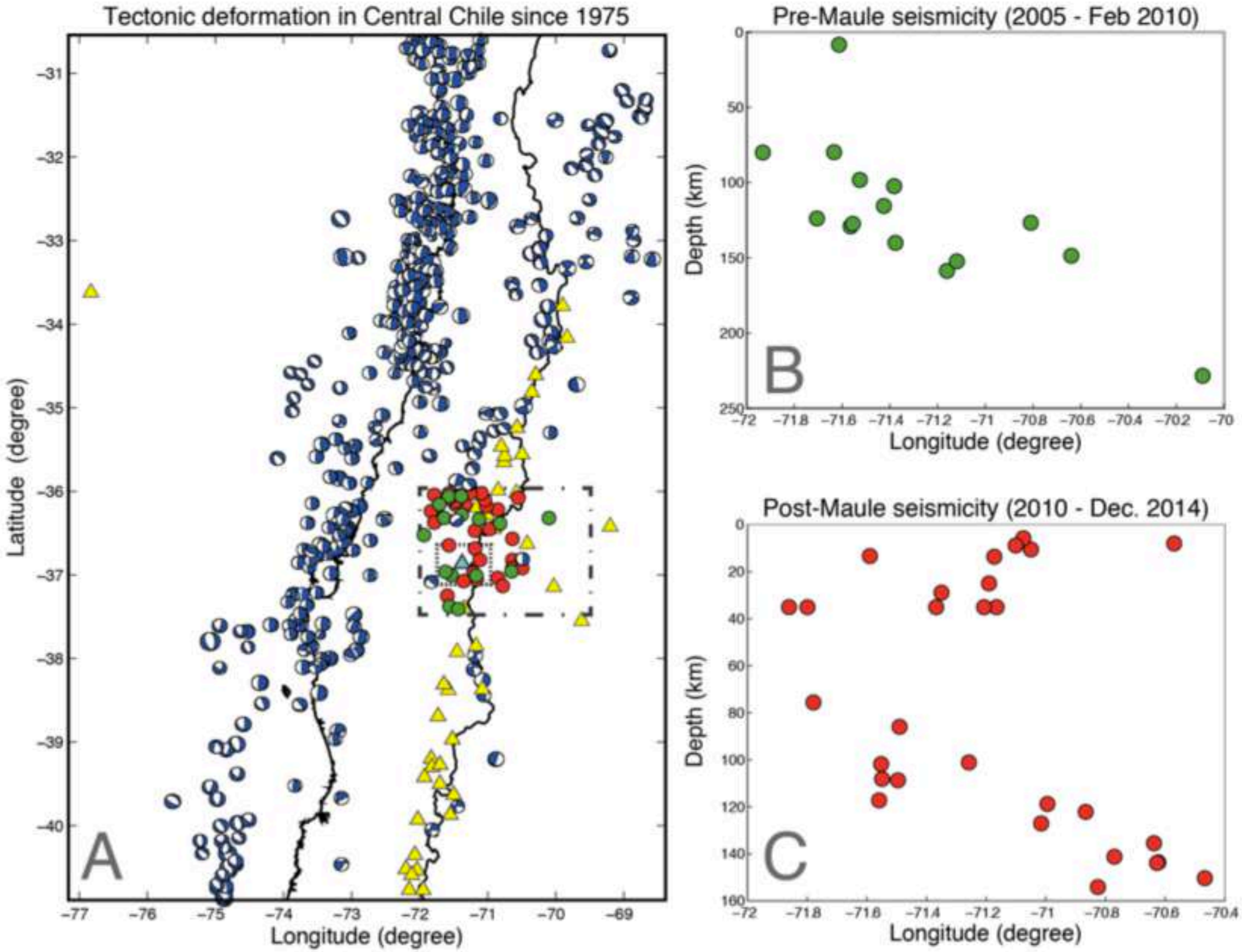


Farfield

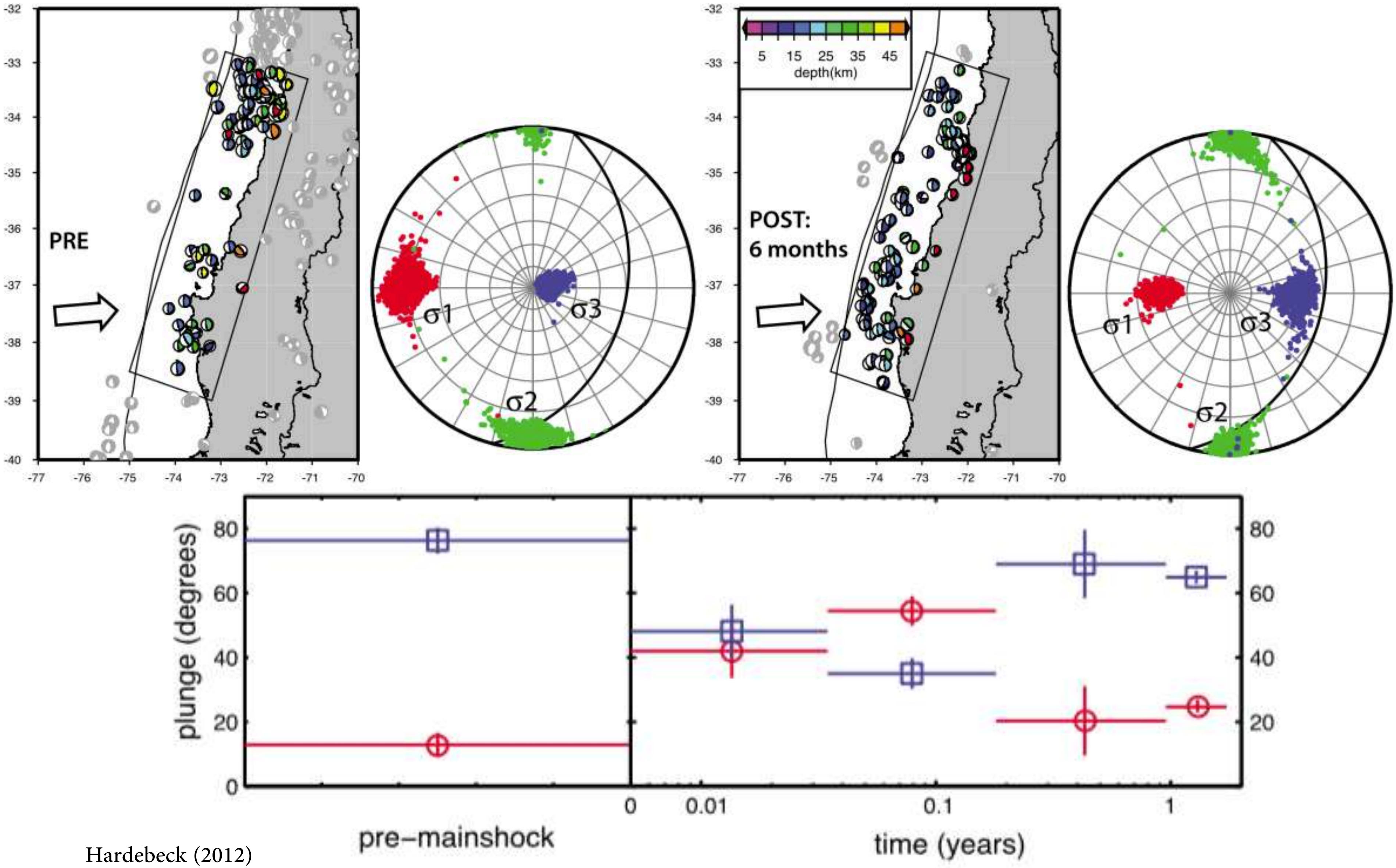
Nearfield



Seismic data (M≥M4.5, shallower than 35 km)



Post-Seismic tectonic deformation

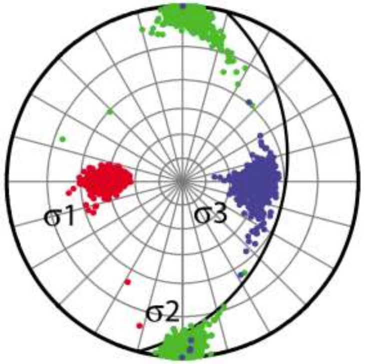


Hardebeck (2012)

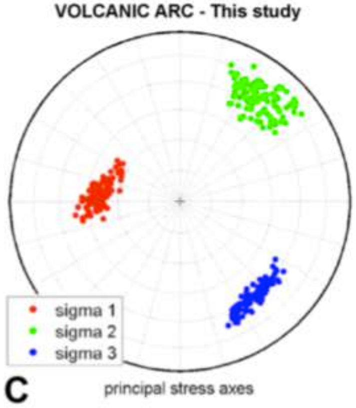
Post-Seismic tectonic deformation

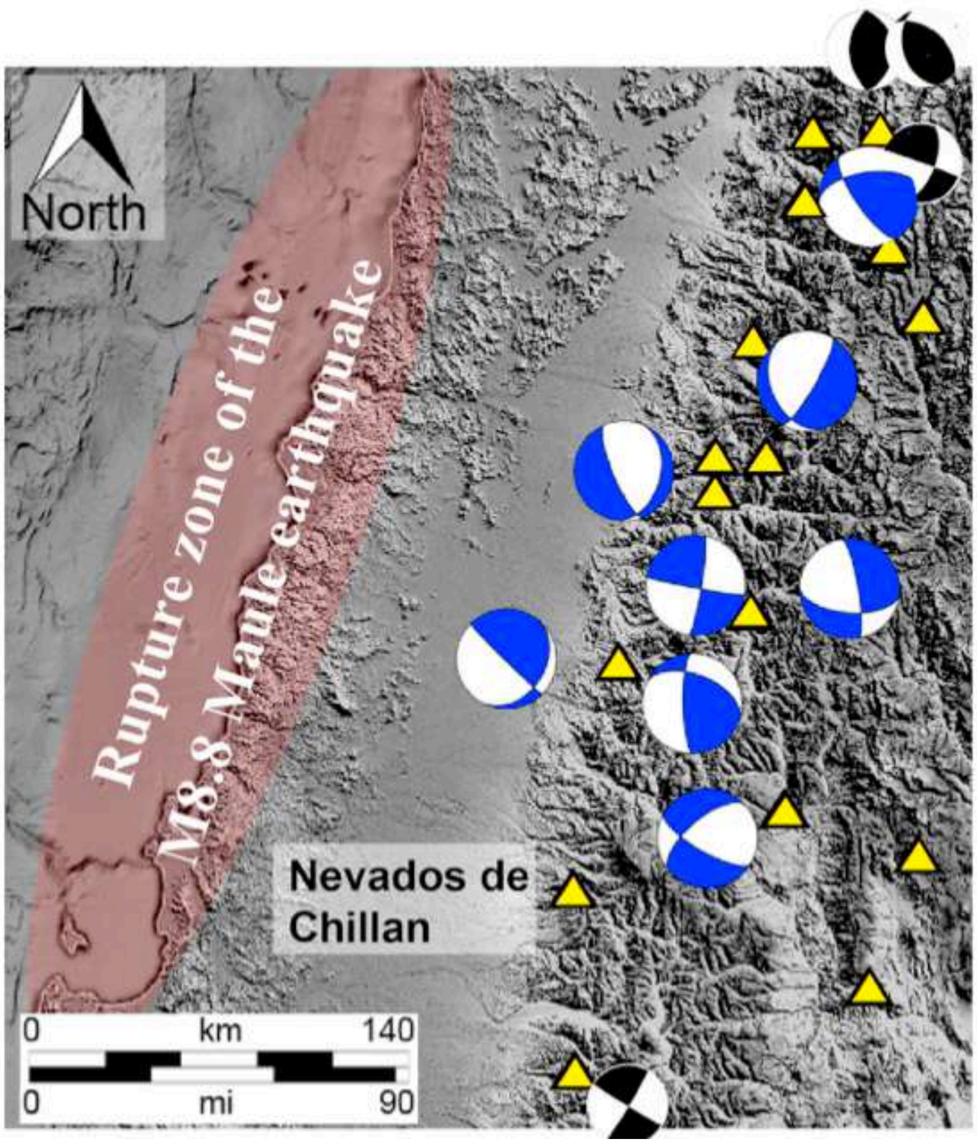
Table 1
List of M > M4.0 earthquakes shallower than 35 km occurred in the volcanic arc after the M8.8 Maule earthqual
In grey the focal mechanisms of the events shown in Fig. 8.

Date			Latitude	Longitude	Depth	M_ω
2010/02/27	9:25:18	UTC	37.701S	71.837W	35.00 km	4.9
2010/02/27	9:34:53	UTC	35.714S	71.105W	35.00 km	4.3
2010/02/27	14:18:40	UTC	35.786S	70.561W	35.00 km	4.0
2010/02/27	23:46:09	UTC	35.467S	70.285W	35.00 km	4.5
2010/02/28	1:52:00	UTC	36.177S	71.359W	35.00 km	4.2
2010/03/01	10:17:25	UTC	37.071S	71.367W	35.00 km	4.8
2010/03/05	8:15:53	UTC	36.990S	71.207W	35.00 km	4.4
2010/03/05	8:21:26	UTC	37.067S	71.165W	35.00 km	4.0
2010/03/20	1:41:07	UTC	37.825S	71.664W	35.00 km	4.5
2010/04/03	3:38:19	UTC	35.324S	70.339W	6.300 km	4.4
2010/05/29	17:15:11	UTC	35.454S	70.256W	10.00 km	4.1
2010/08/15	7:50:36	UTC	36.814S	71.101W	8.90 km	5.2
2010/08/15	7:50:36	UTC	36.820S	71.080W	10.00 km	5.2
2010/09/06	10:47:45	UTC	35.322S	70.491W	13.40 km	4.5
2011/01/21	10:25:22	UTC	37.692S	71.907W	17.50 km	4.8
2011/02/18	23:54:03	UTC	34.910S	70.390W	17.70 km	4.8
2012/06/07	19:25:25	UTC	36.036S	71.075W	5.80 km	5.0
2012/06/07	4:05:04	UTC	36.074S	70.570W	8.00 km	6.0
2012/07/14	22:34:40	UTC	36.077S	71.050W	10.50 km	4.8
2012/11/29	20:40:59	UTC	36.426S	71.082W	3.30 km	4.2
2013/11/14	4:20:57	UTC	36.700S	71.190W	25.00 km	4.0

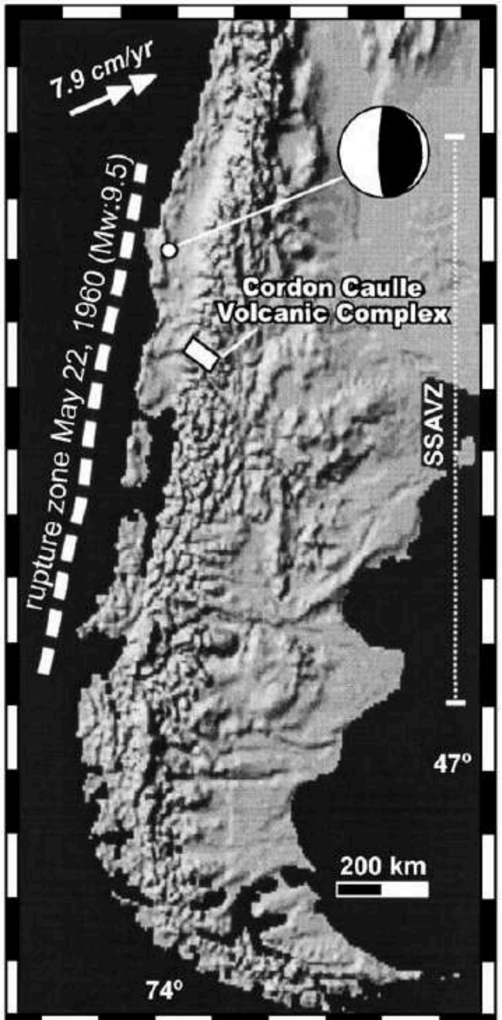


Hardebeck (2012)

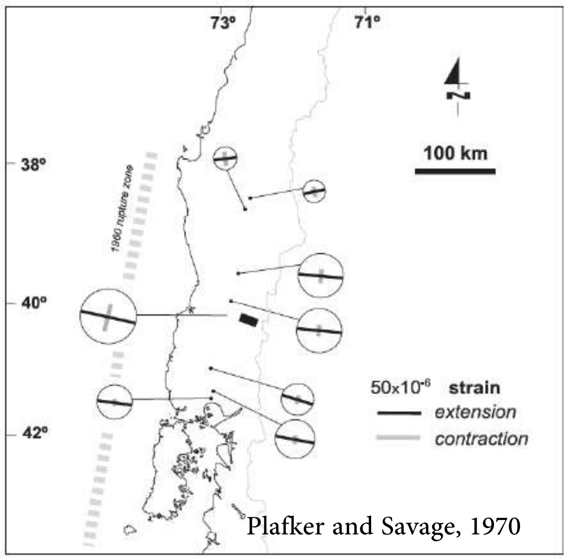




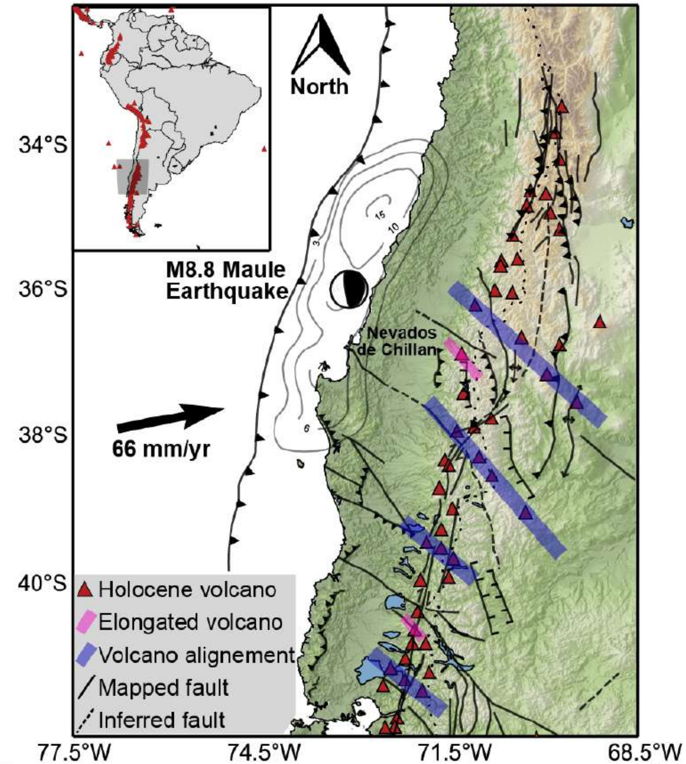
Something similar in 1960 after the M9.5 Valdivia earthquake

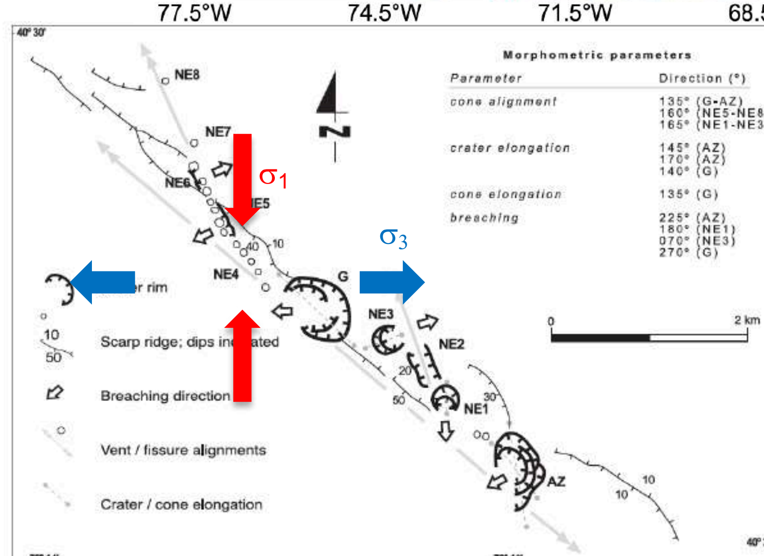


- 1000 km rupture length
- Cordon Caulle (CC): NW-SE, 240 km inland
- CC located on a regional NW fault (Rio Iculpe)
- CC activated 38 h after the 1960 earthquake
- E-W co-seismic extension
- NW-SE oriented eruptive fissure
- Temporary local right- lateral trans-tension



Plafker and Savage, 1970



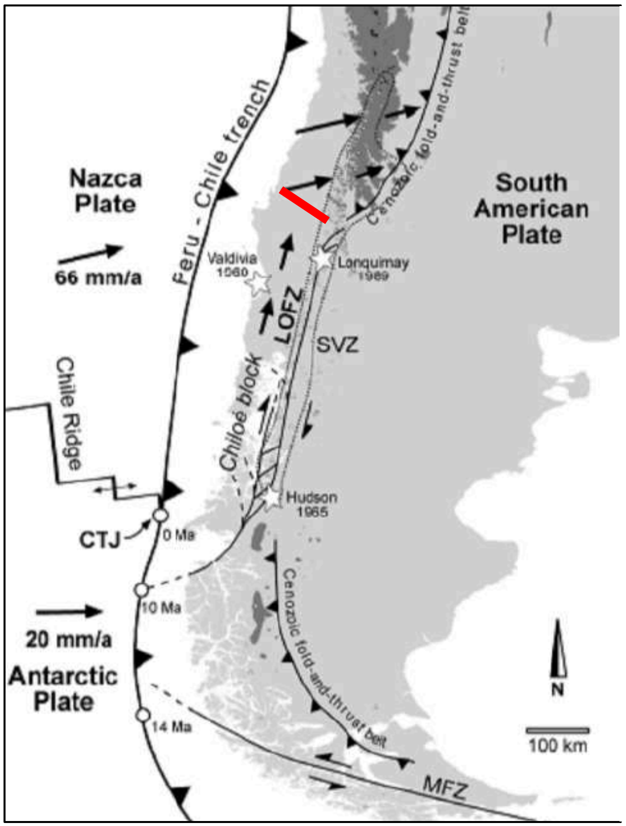


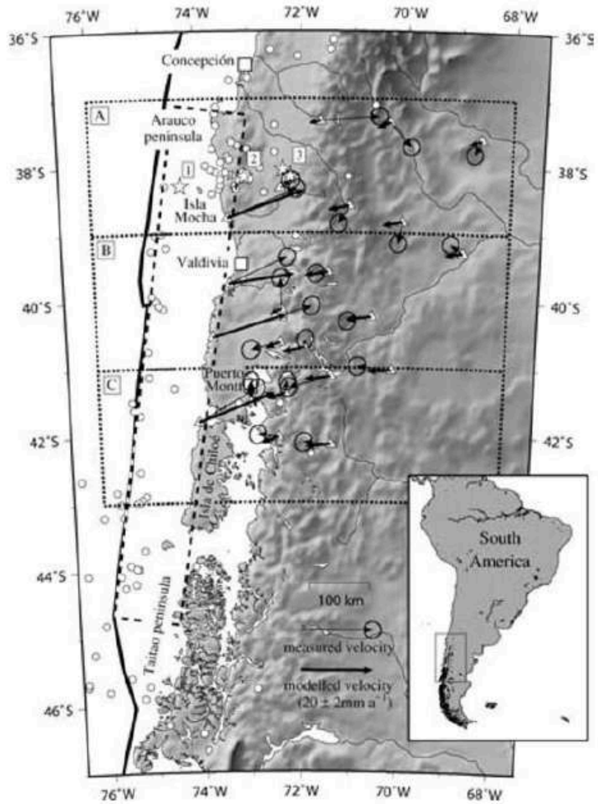
How to explain several NW-Striking systems?

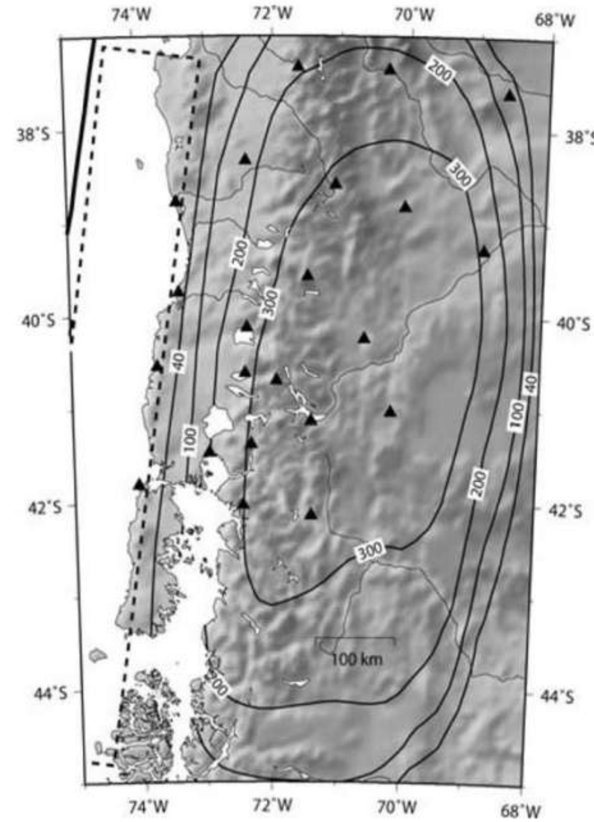
Inversion for rheological parameters from post-seismic surface deformation associated with the 1960 Valdivia earthquake, Chile FREE

Francisco Lorenzo-Martín, Frank Roth, Rongjiang Wang

Geophysical Journal International, Volume 164, Issue 1, January 2006, Pages 75–87,
https://doi.org/10.1111/j.1365-246X.2005.02803.x
Published: 01 January 2006 **Article history** ▾

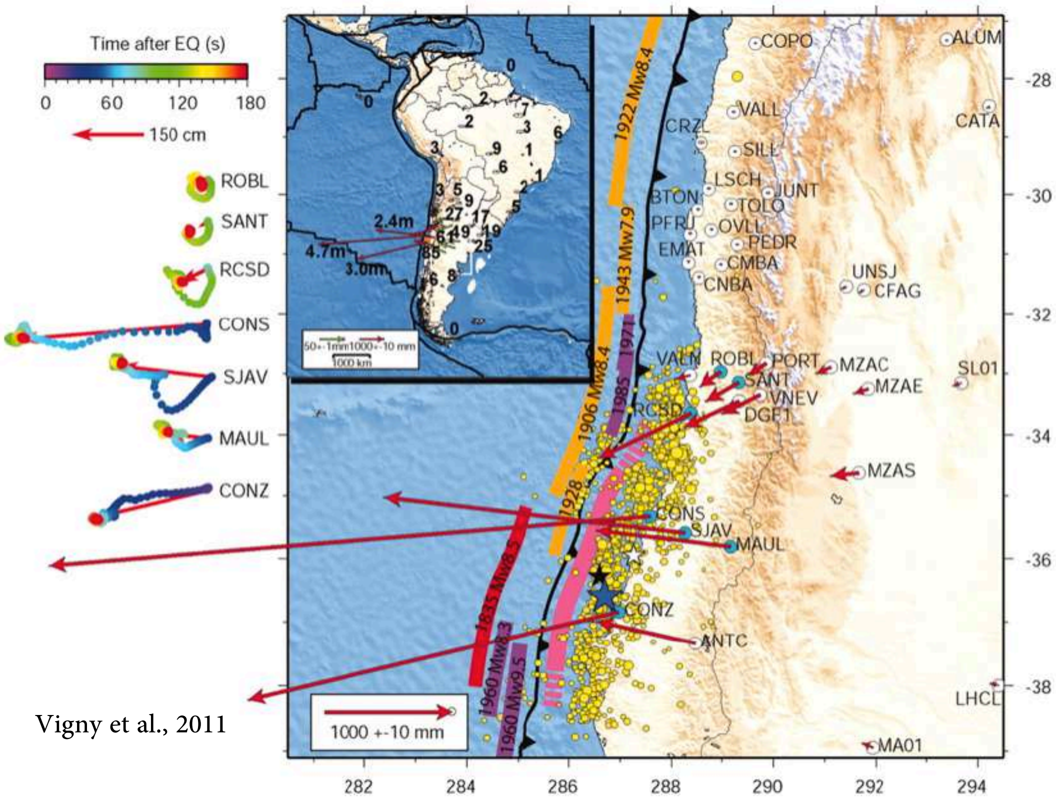




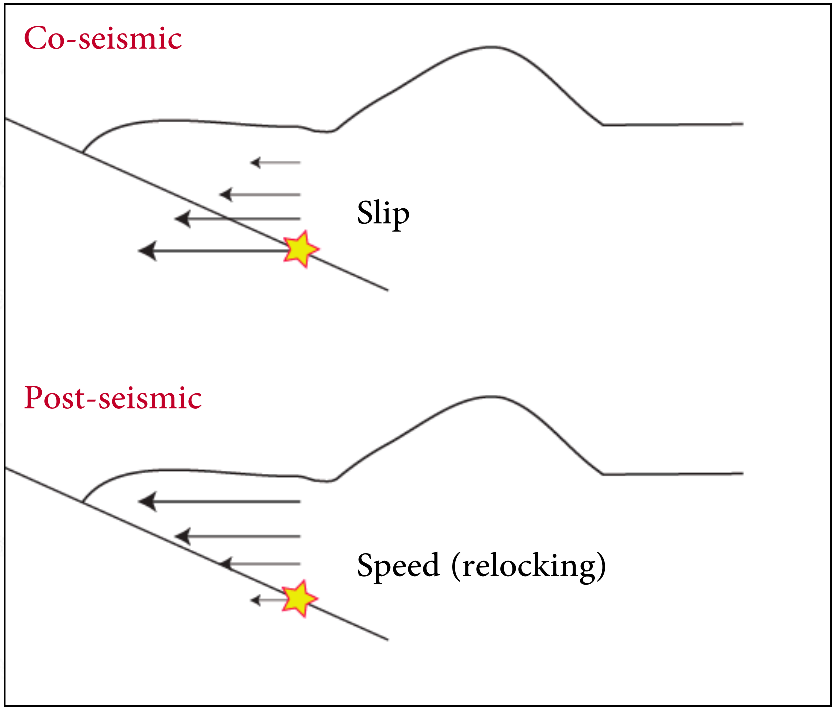


Number of years after the event during which the post-seismic relaxation produce velocities of at least 4 mm a^{-1}.

During and after the megathrust slip

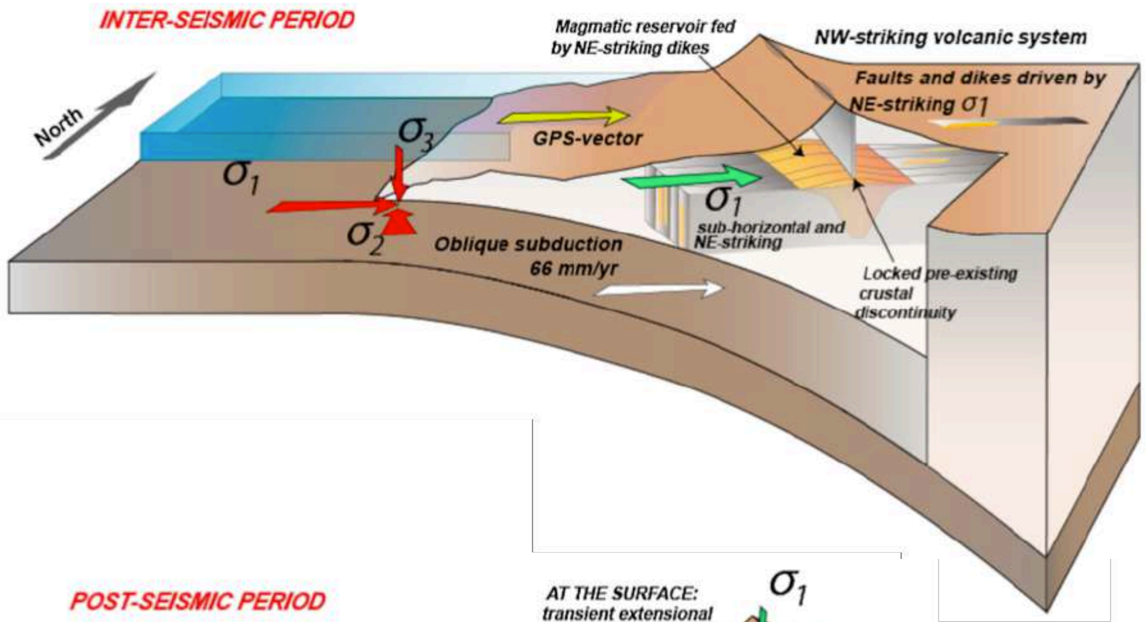


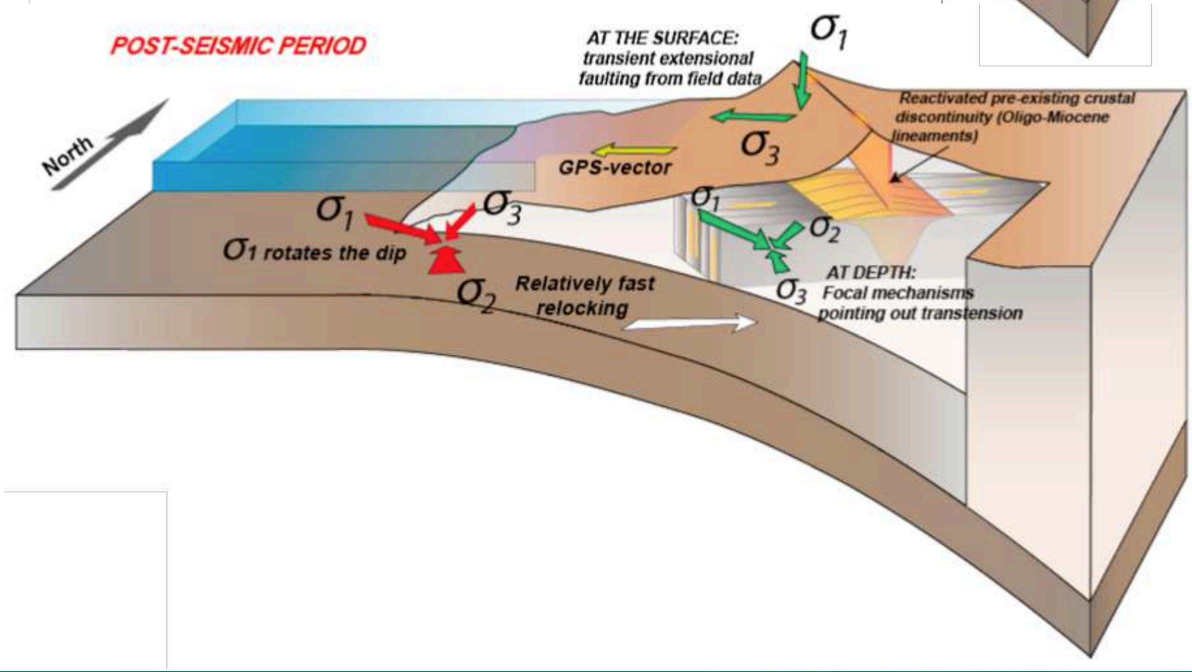
Vigny et al., 2011



- Coseismic stress drop of about 80% (Hardebeck, 2012)
- Subsidence (Pritchard et al., (2013)

Conceptual model

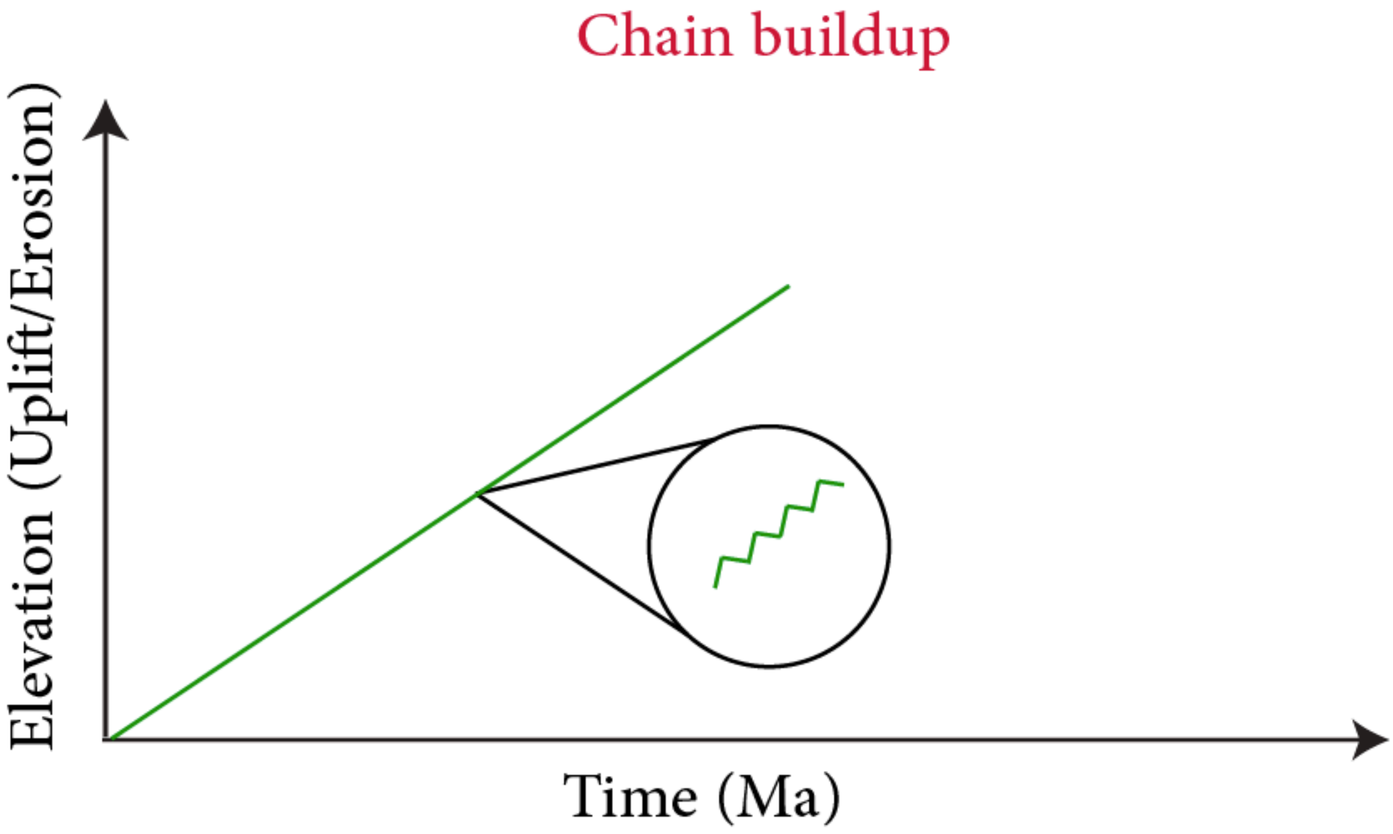




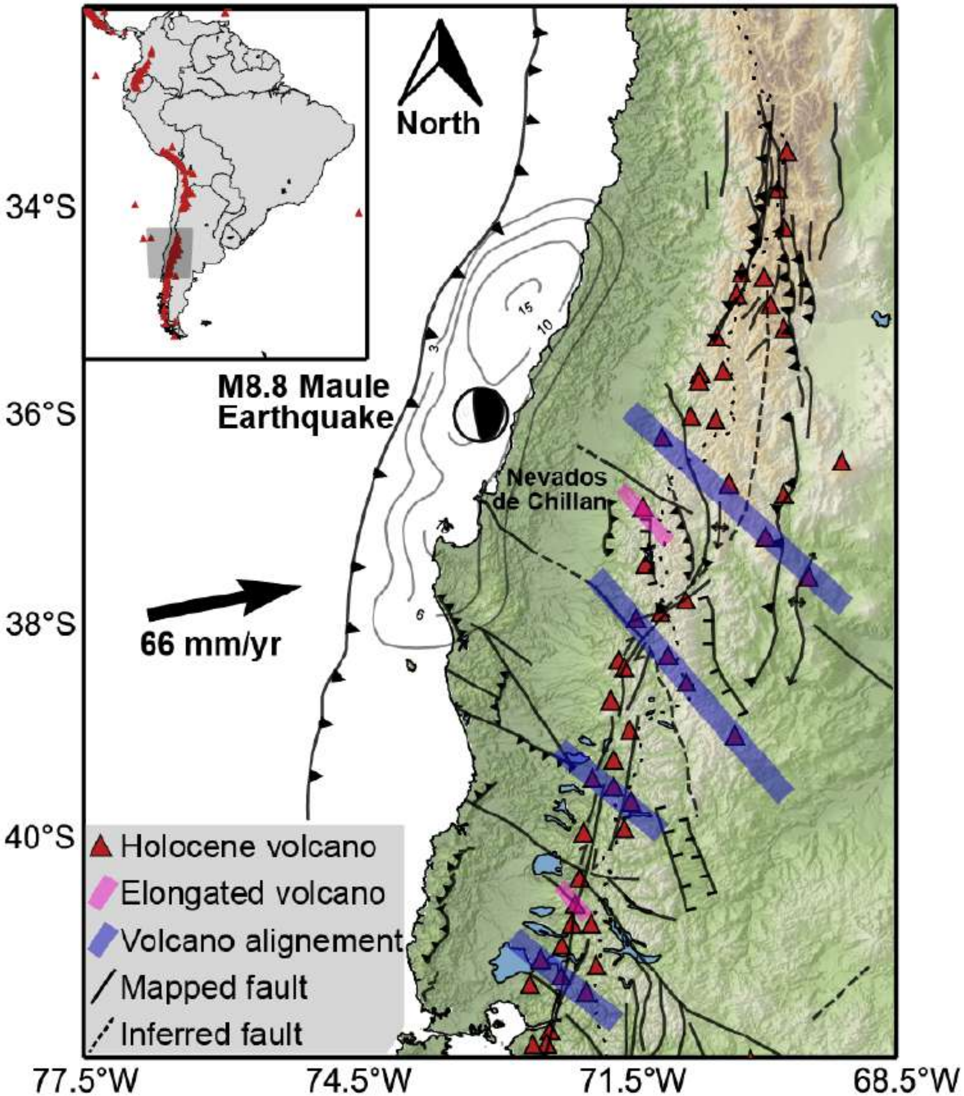
Take home messages

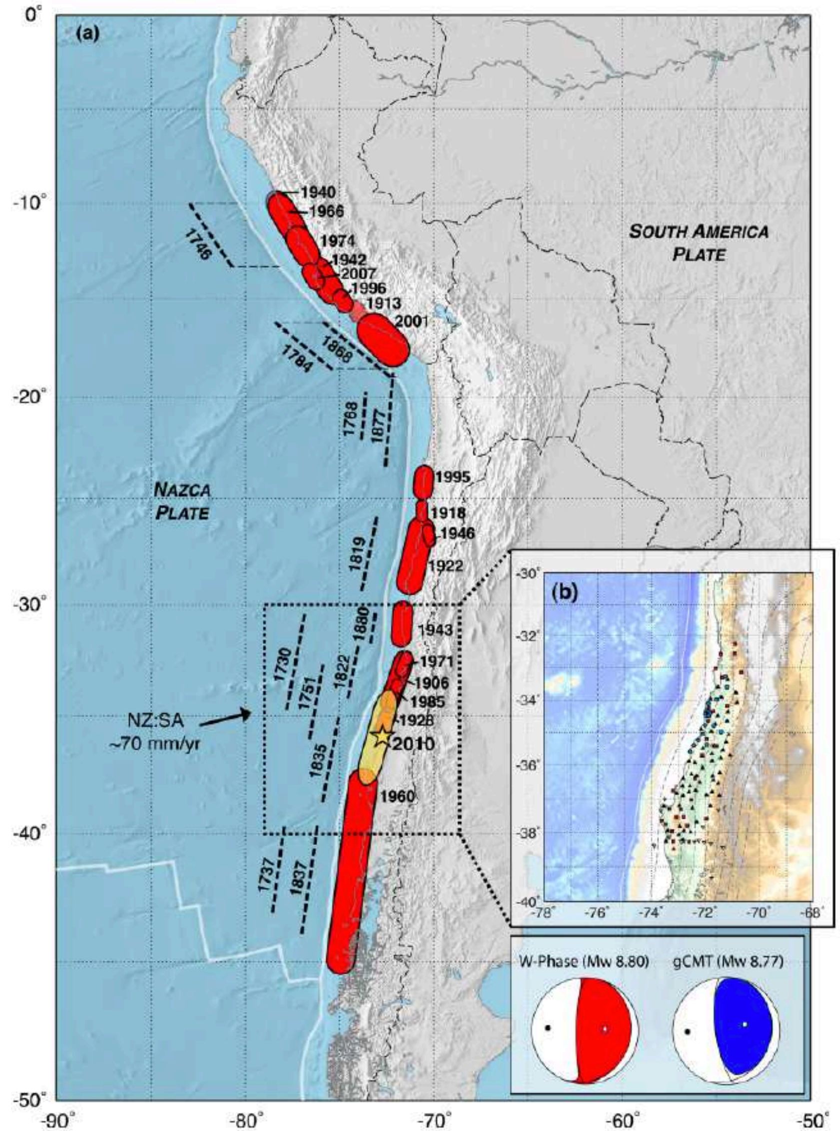
- Large magmatic reservoirs may not seat immediately below the volcanic edifice but they could be offset
- Strong tectonic control on the geometries of the magmatic reservoirs
- NW-striking volcanic complexes need some thoughts as they are antithetic/quasi-perpendicular to the direction of maximum compression
- Megathrust earthquakes may contribute to activate these structure strongly affecting the formation of volcanic arcs

Is chain buildup a steady state OR a transient geological process ???

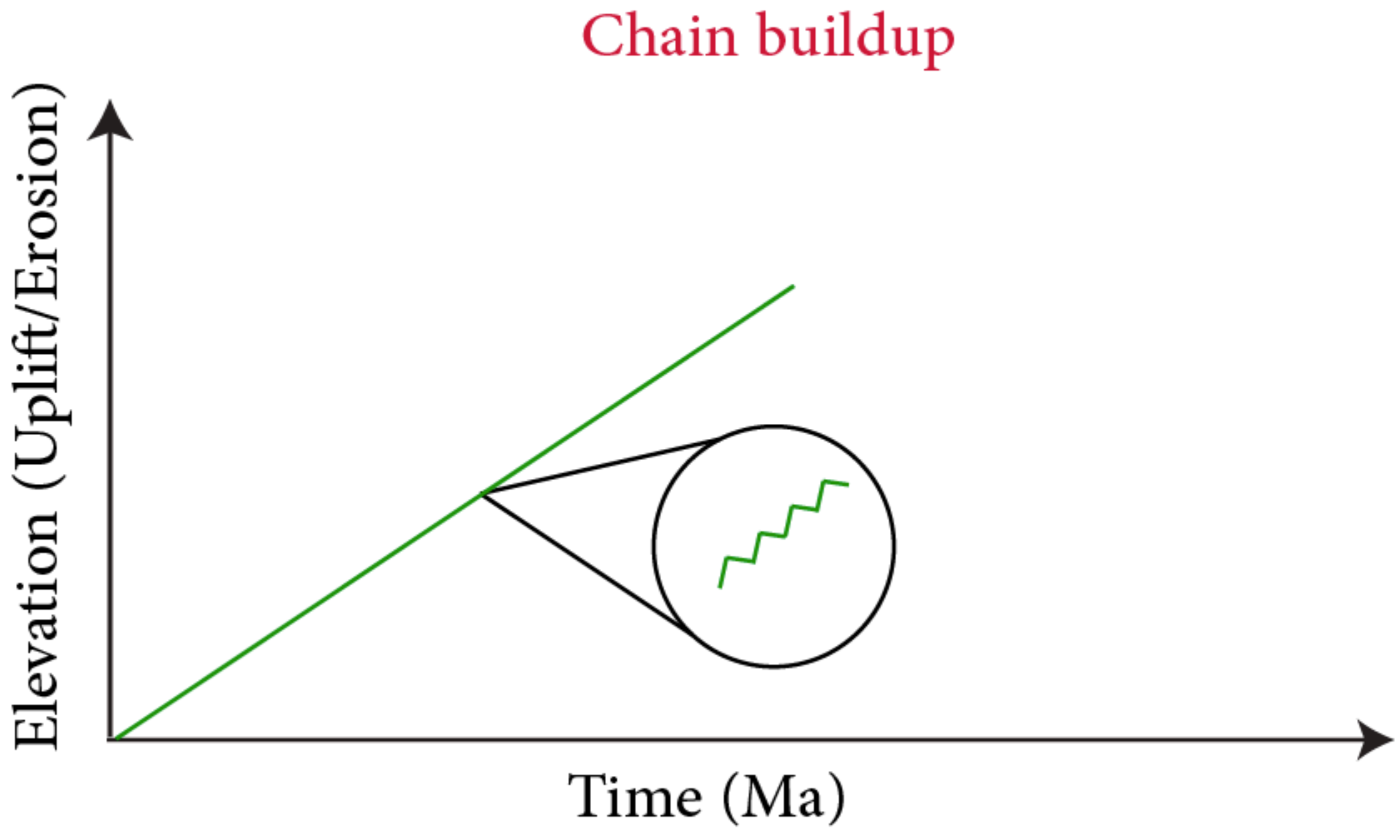


Is chain buildup a steady state OR a transient geological process ???





Is chain buildup a steady state OR a transient geological process ???



Grazie per la vostra attenzione!