Causes and Consequences of Magma Diversity in the Central Volcanic Zone in NW Argentina

Integrating petrology, geology, geophysics & modelling

Robert Trumbull
GFZ - Potsdam

SFB-267 DFG Collaborative Research Centre „Deformation Processes in the Andes“ 1993 - 2005

Geophysics, FUB, GFZ:
C. Haberland, F. Schilling, H. Brasse, B. Schurr, X. Yuan

Geodynamic modelling, GFZ:
S. Sobolev, A. Babeyko, I. Koulakov

Volcanology & petrology, TUB, GFZ:
J. Lindsay, A. Schmitt, W. Schnurr, A. Risse, W. Siebel

Geology, GFZ, UP, FUB, TUB:
O. Oncken, M. Strecker, F. Lucassen, U. Riller, E. Scheuber

Collaborations:
M. Gardeweg, J. Clavero: Chile
P. Caffe, B. Coira, J. Viramonte: Argentina
S. de Silva, S. Kay: USA

Central Andes Superlatives

- second-highest continental plateau on earth
- "type locality" for crustal delamination at Cordilleran margins
- among Earth's largest Neogene ignimbrite provinces
- largest crustal magma body ever detected geophysically

Does this all fit together (how) ?

Central Volcanic Zone magma diversity

<u>Stratovolcanoes (andesite-dacite):</u>

Oligo-Miocene to present-day

Arc and along transverse zones

<u>Ignimbrites (dacite-rhyolite):</u>

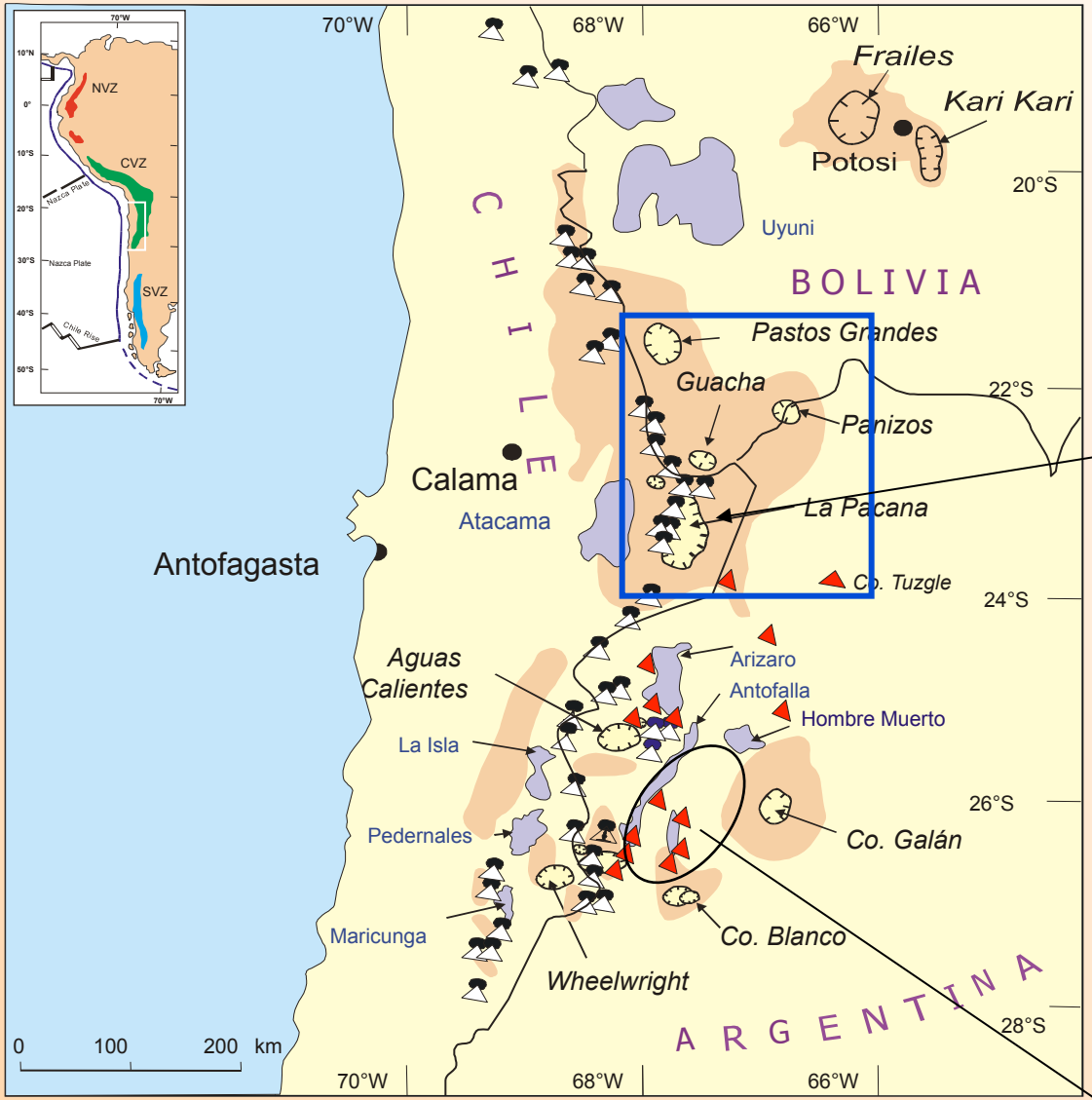
Oligo-Miocene to Pliocene

Patchy distribution, arc and back-arc

<u>Mafic monogenetic centers:</u>

Pliocene and younger

Mainly southern Puna back-arc

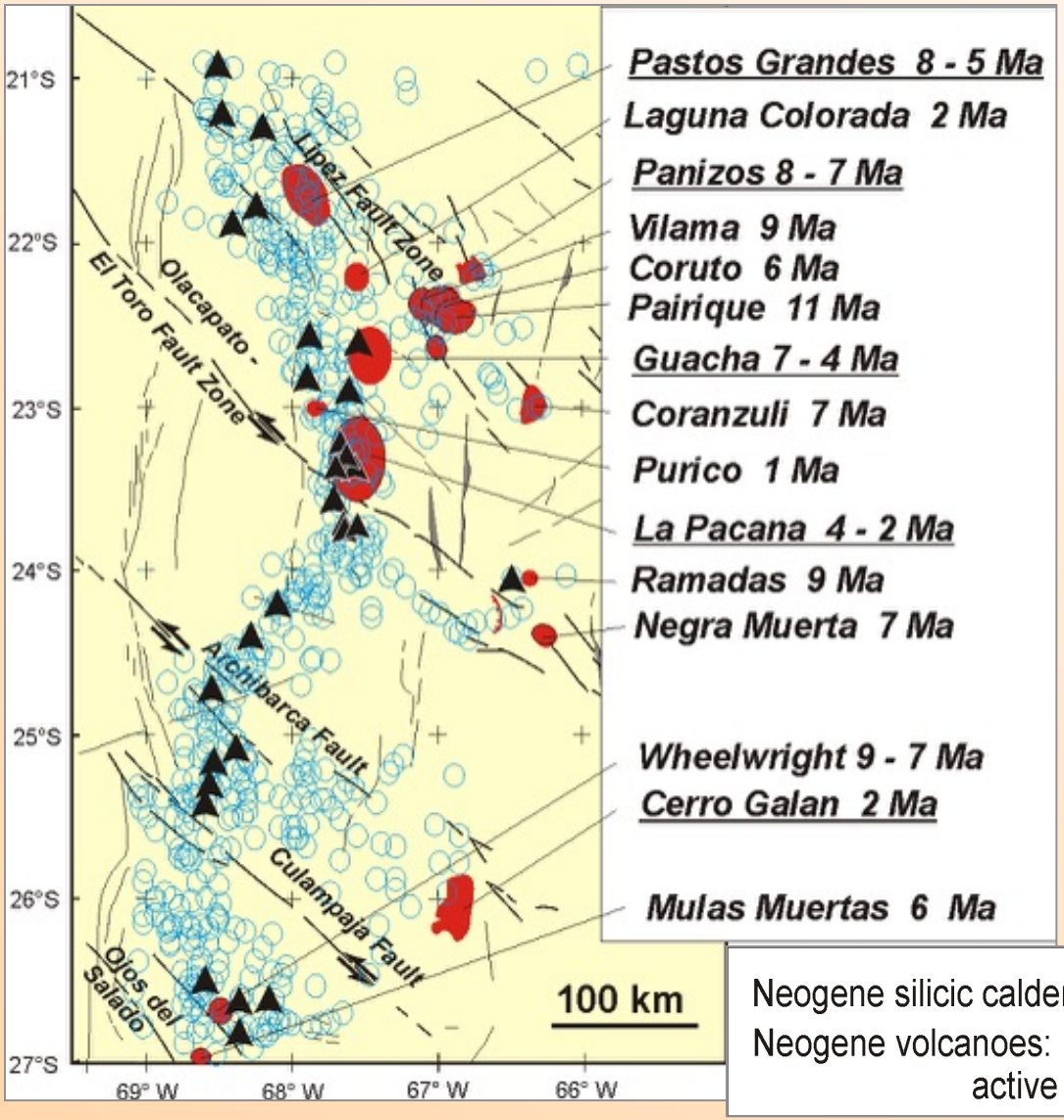


Altiplano-Puna Volcanic Complex

Case study La Pacana

- Neogene ignimbrites
- Calderas
- Quaternary arc volcanoes
- Mafic back-arc volcanoes

Case study S. Puna



Altiplano-Puna ignimbrite "flare-up" 9-4 Ma

APVC ignimbrites:
ca. 20 to 40 km^3 /Ma /km

All Neogene volcanoes together:
ca. 3 km^3 /Ma /km

Ignimbrite magma volumes:

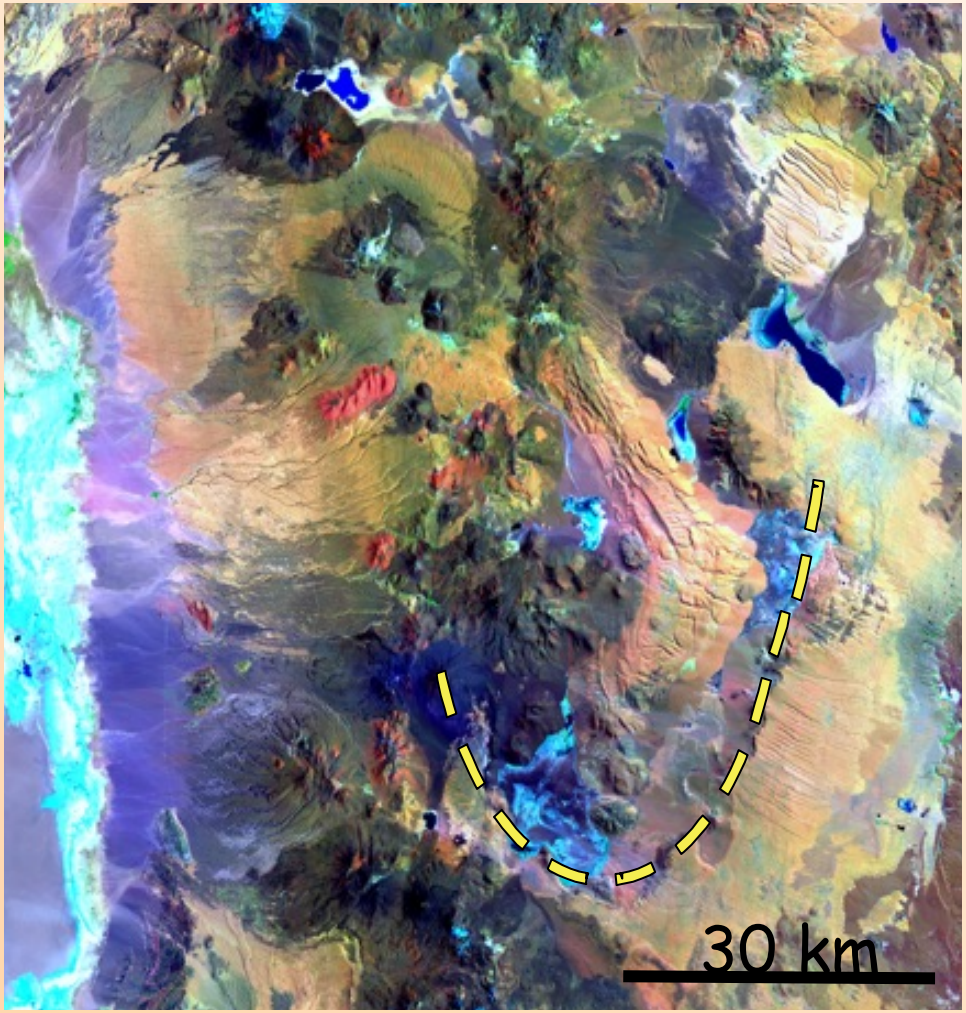
APVC total erupted volume
> 15,000 km^3 ignimbrites

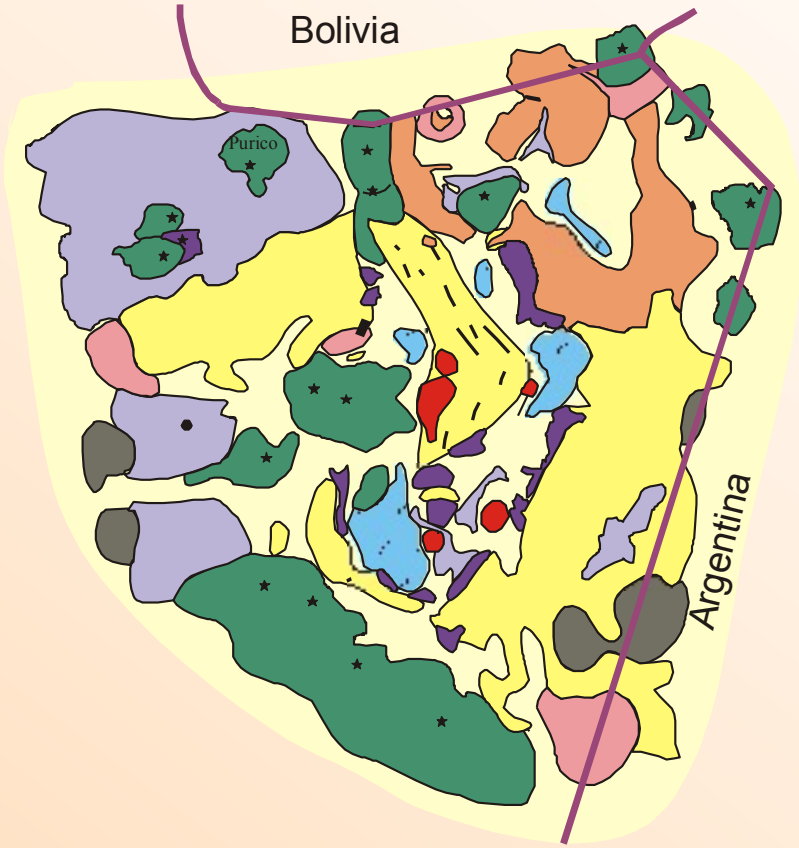
Mega-eruptions with single flow units of 100's to >1000 km^3

Pinatubo, 5 km^3

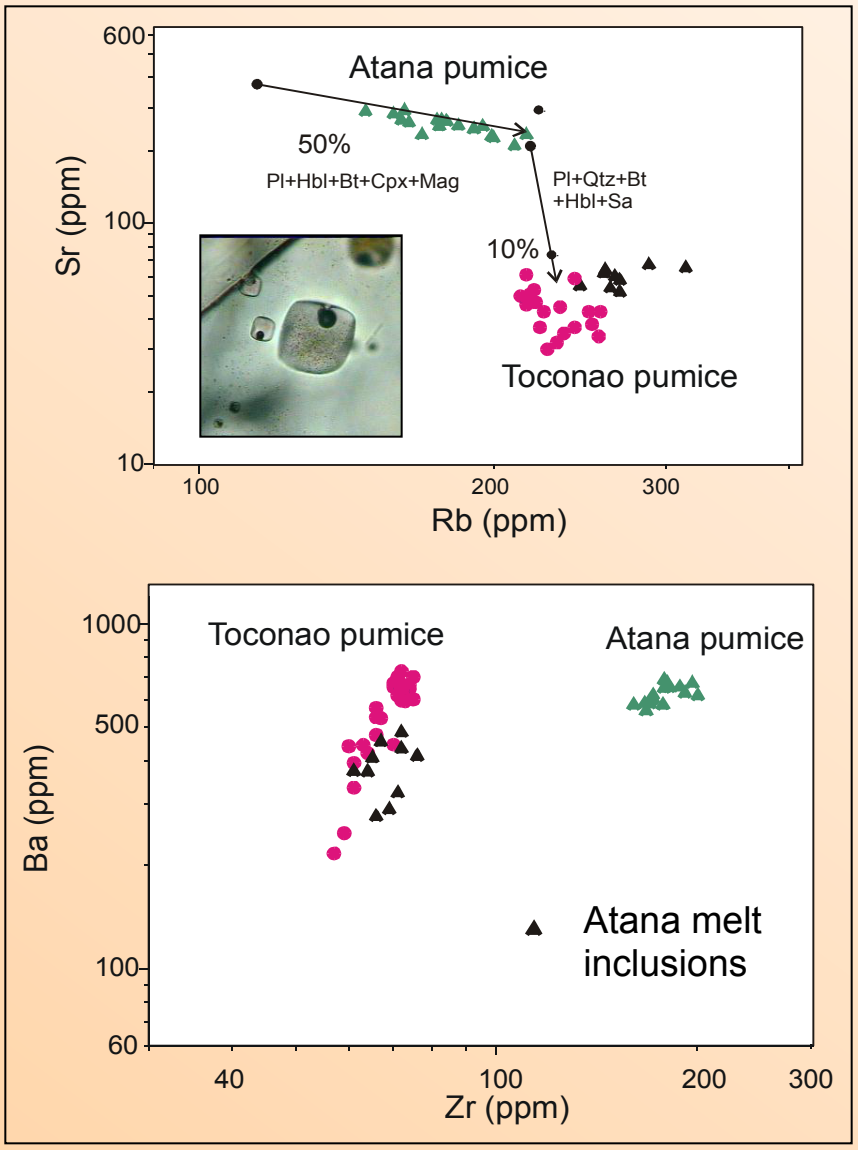
Mt. St. Helens, 1km^3

Case Study: La Pacana Caldera

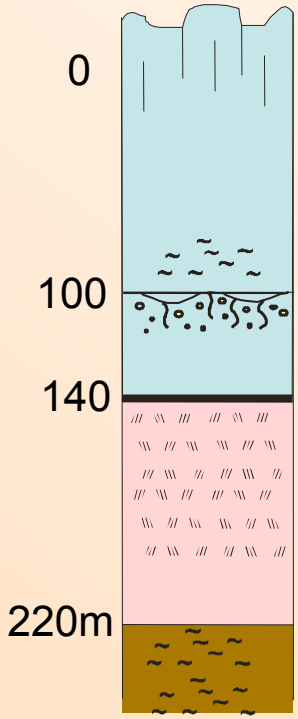




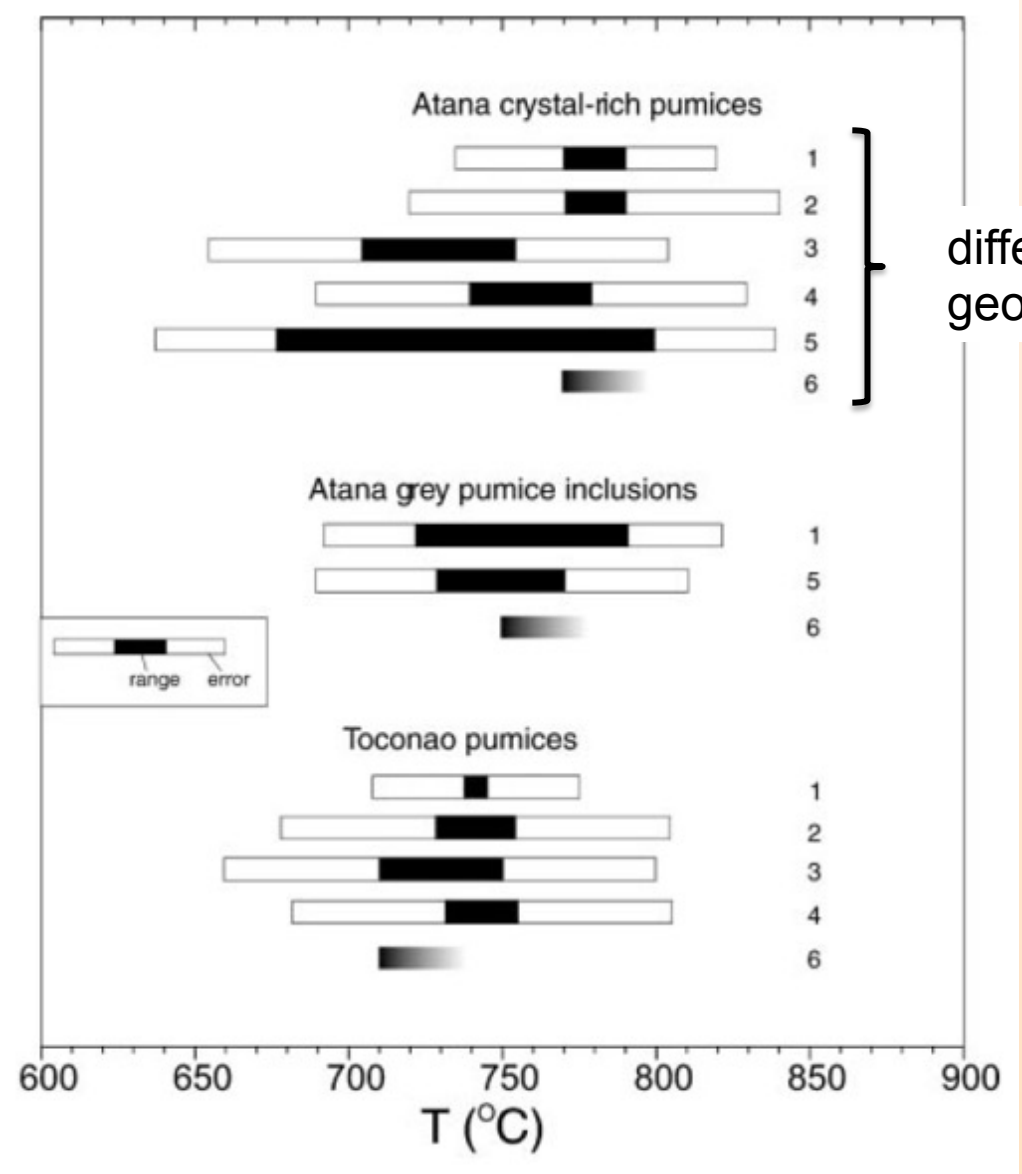
(Gardeweg & Ramierz, 1987; Lindsay et al., 2001)



Atana & Tononao Units: Zoned magma chamber ?



Lindsay et al. (2001) J. Petrology



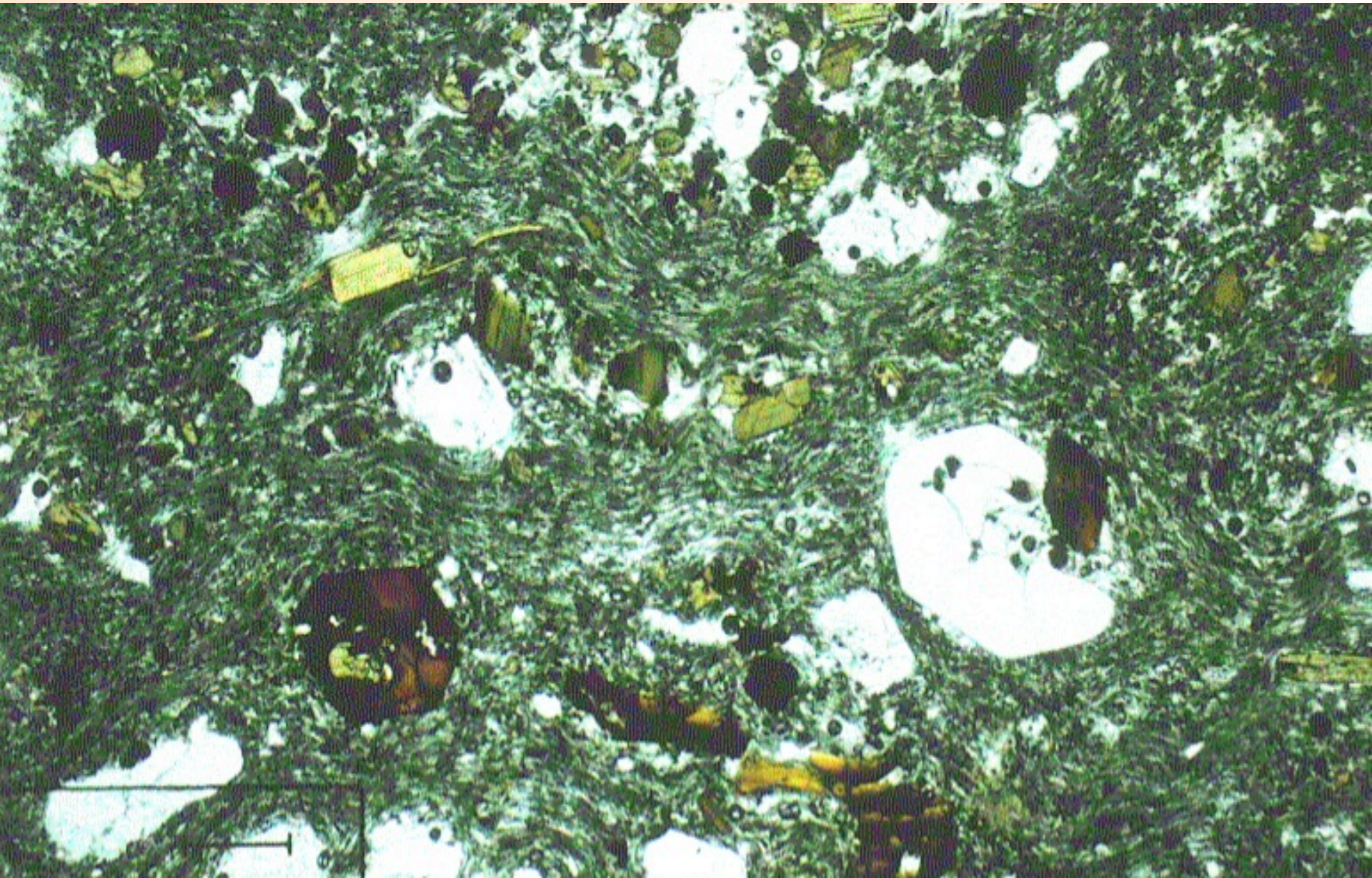
P - T conditions of magma storage

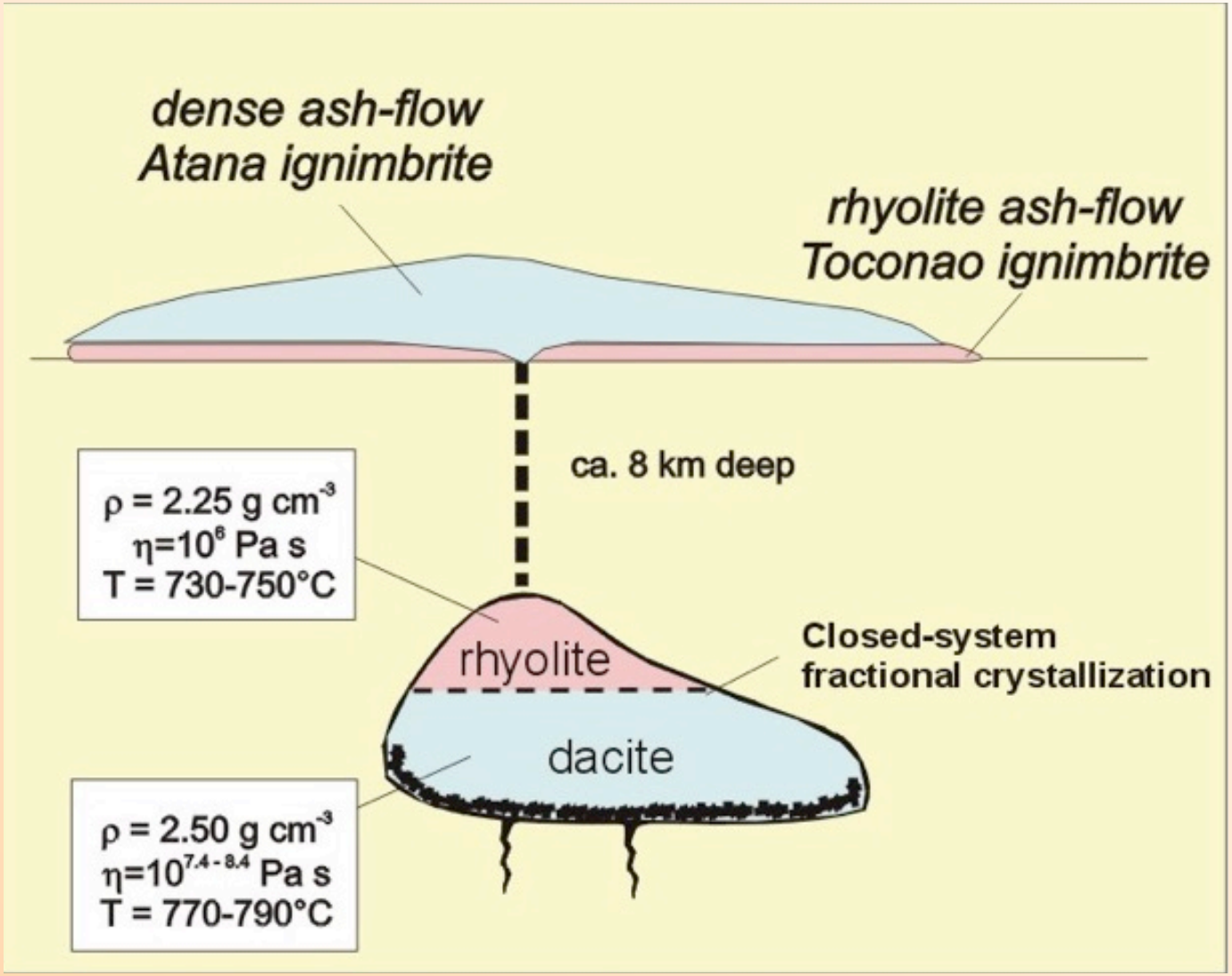
different geothermometers

Pressure:

150 - 200 ± 50 MPa
H_2O-CO_2 solubility in melt inclusions
Al-in hornblende

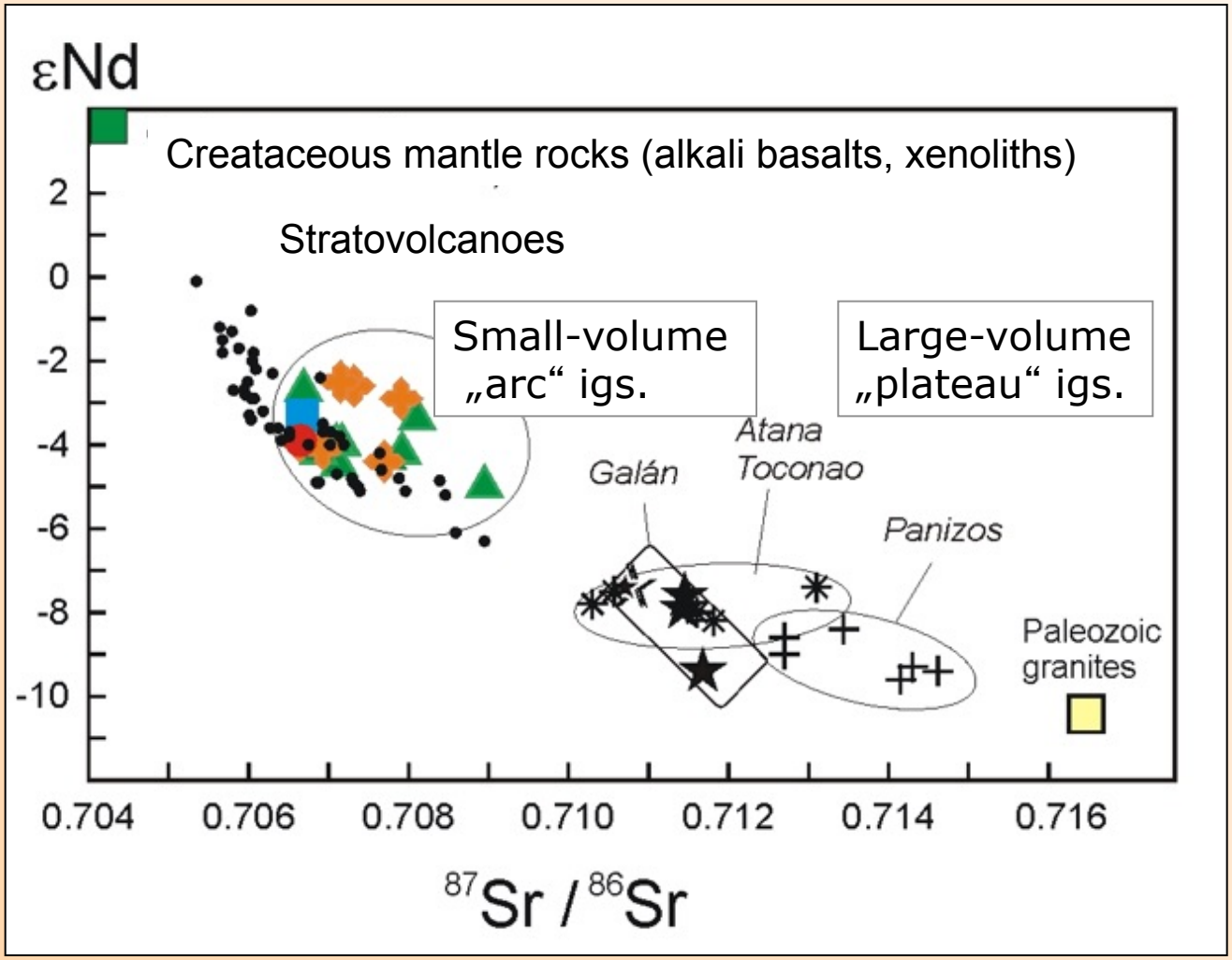
Lindsay et al. (2001) J. Petrology

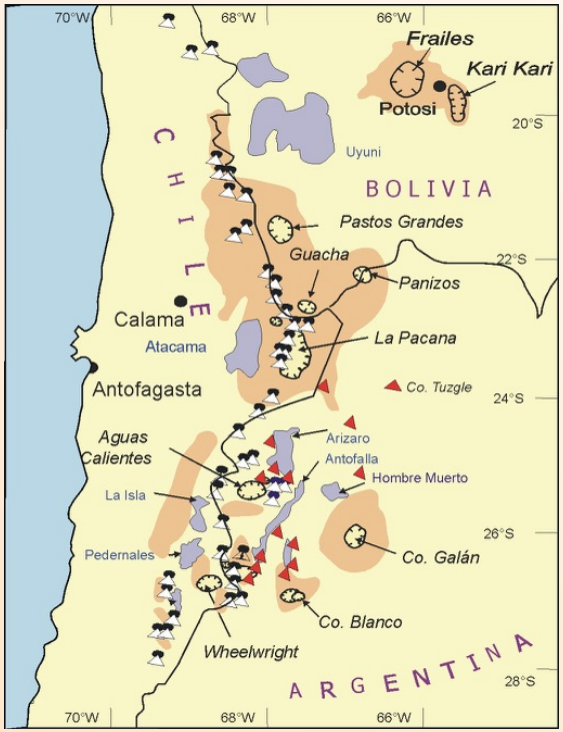




Lindsay et al. (2001) J. Petrology

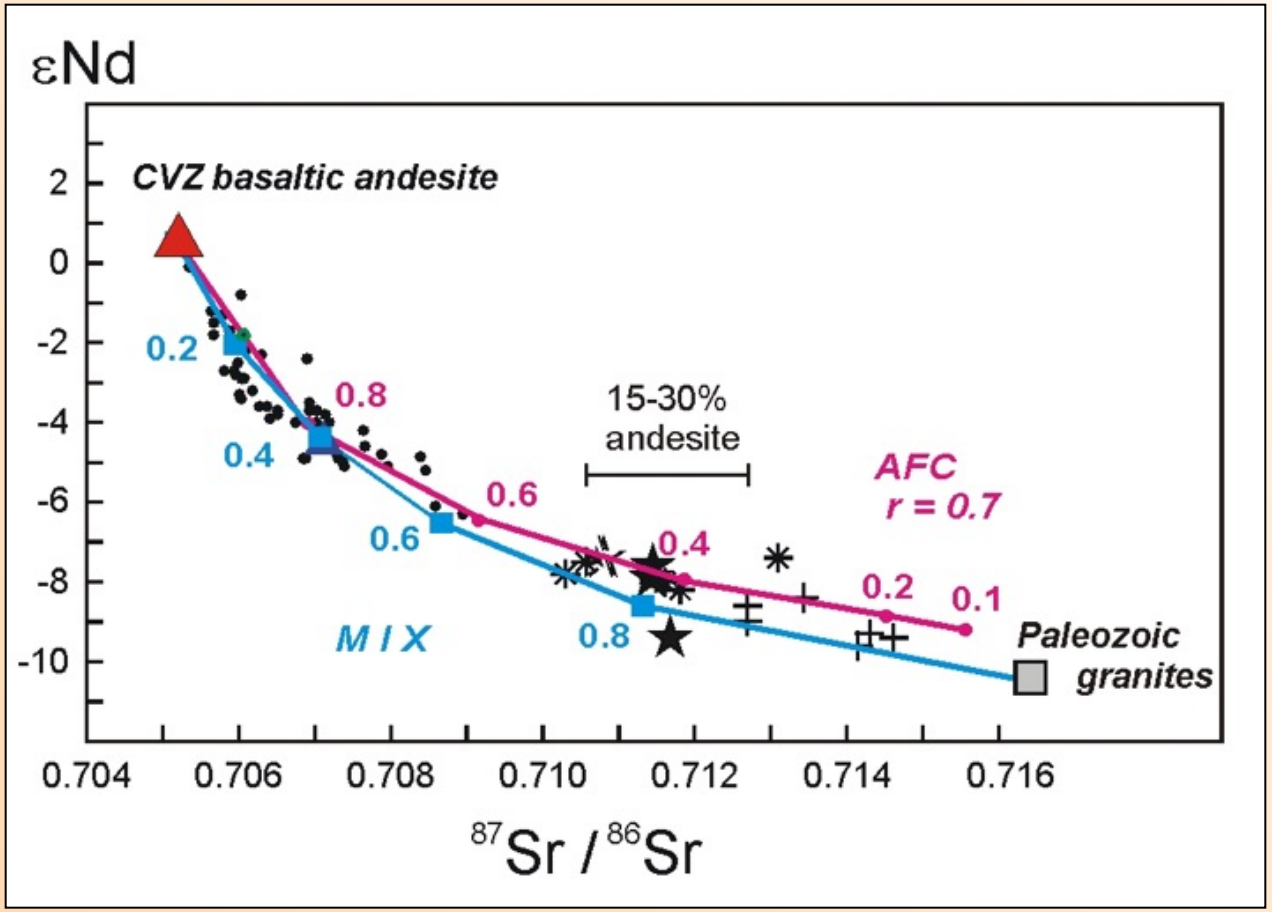
Magma diversity: Plateau vs. Arc ignimbrites



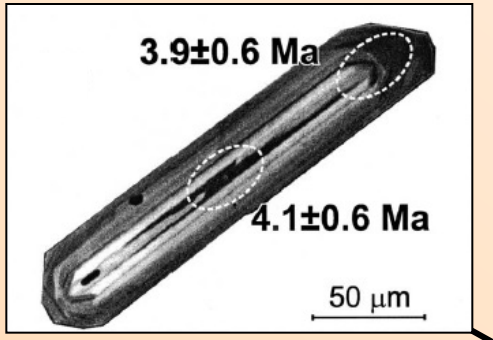


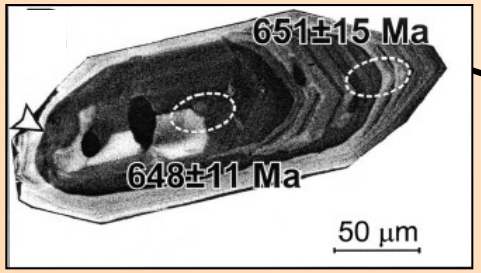
(Lindsay et al., 2001, J.Petrol. / Siebel et al., 2001, Chem. Geol.)

Crustal melts in the ignimbrite source



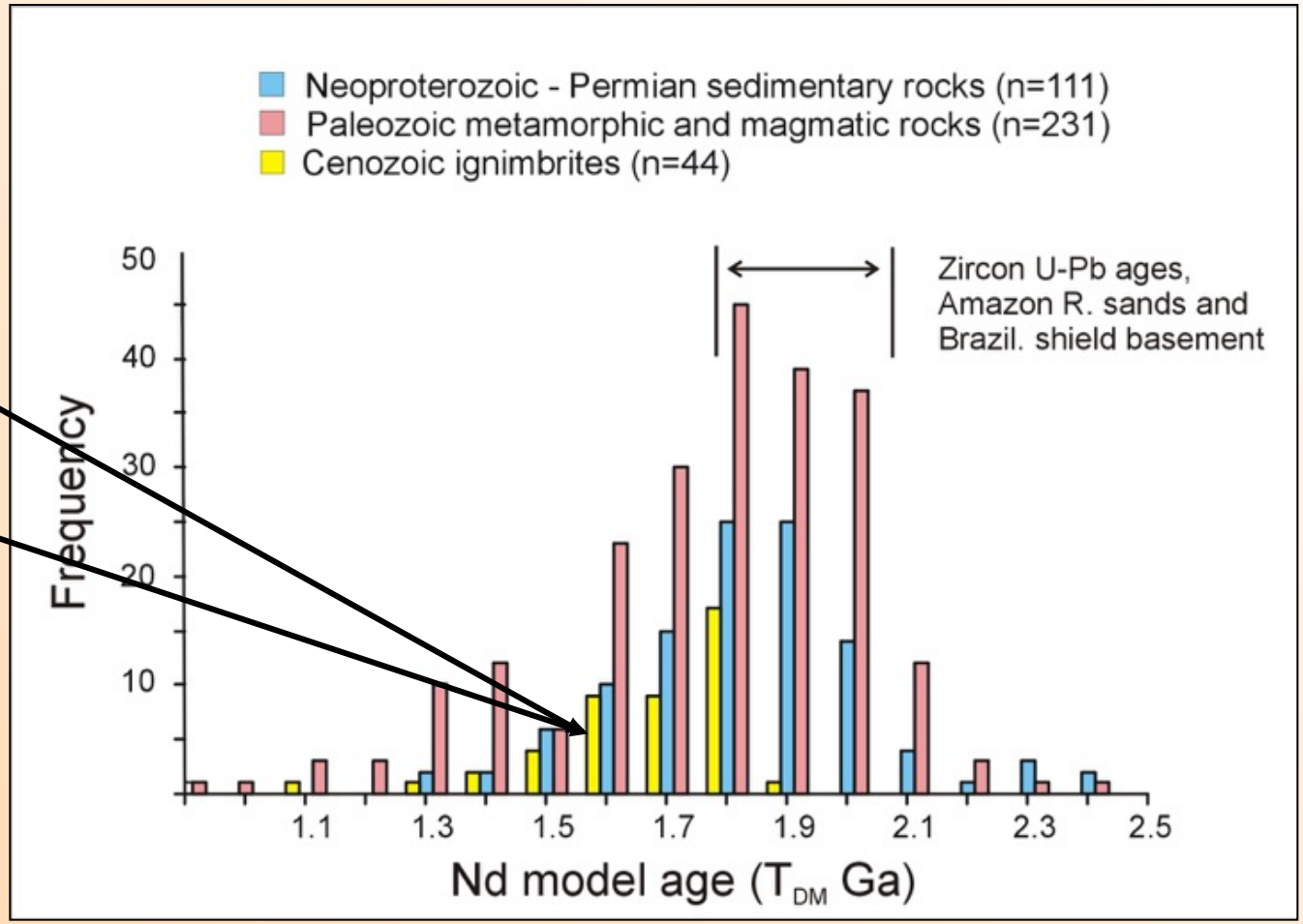
Crustal recycling: Pliocene U-Pb zircon age, Neoproterozoic T_{DM} age





Inherited zircons in Neogene lgs.

(Schmitt et al. 2002)



(Lucassen et al., 2001 Tectonophysics)

Crustal melt productivity and source depth: melt experiments of natural biotite gneiss at 5 to 10 kbar

low-P

1 Bt + 1 Qz + 0.5 Pl = 0.6 Opx + 1.8 melt

high-P

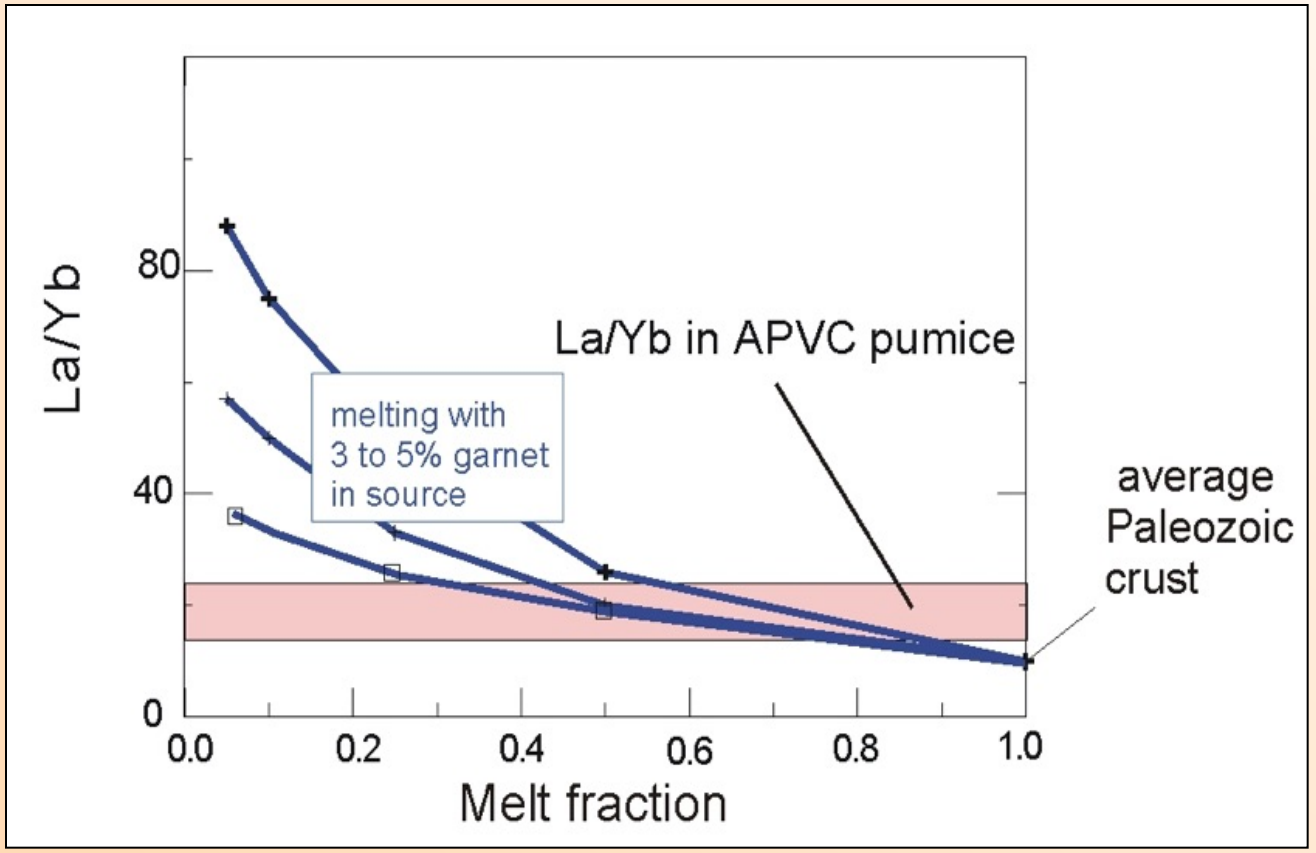
1 Bt + 0.8 Qz + 0.14 Sill = 0.7 Gt + 1.7 melt

(Patino-Douce & Beard, 1996, J. Petrol.)

Point 1: without external fluid, **maximum 20% melt production** for average basement gneiss with 10% biotite

Point 2: melting at >10 kbar should produce **garnet effect on REE patterns**

APVC ignimbrites lack garnet signature: source depth < 30 km



Large-volume plateau ignimbrites - main points

Eruptions: Huge - 1000 km^3 single flow units

- Homogeneous, crystal-rich dacite, viscous, water-poor (2-3 wt.%)

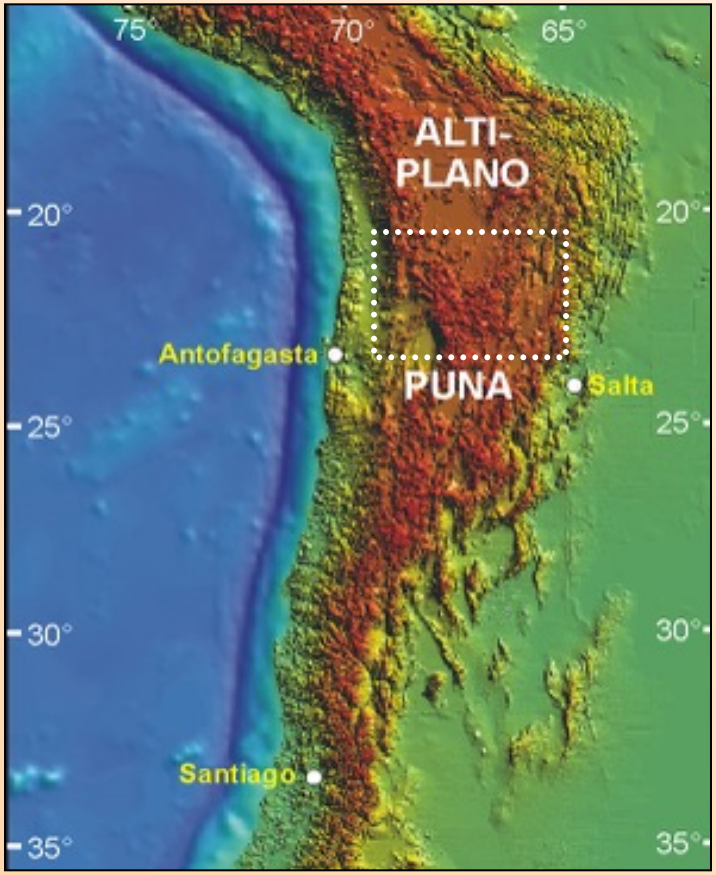
Magma storage: Shallow

- Pre-eruptive magma temperature 750-850°C
- Magma chamber depths ca. 5-8 km

Magma source: Crustal

- Sr-Nd-Pb isotopes overlap with Paleozoic basement
- Not pure crustal melts: 20-30% mafic magma (arc?) mixed in
- Not lower crust (no garnet signature, moderate T, dehydration melting

Geophysical evidence for partial melts



Gravity and Seismic velocity
Schmitz et al., 1996

Electrical conductivity
Schilling et al. 1997
Brasse et al. 2002

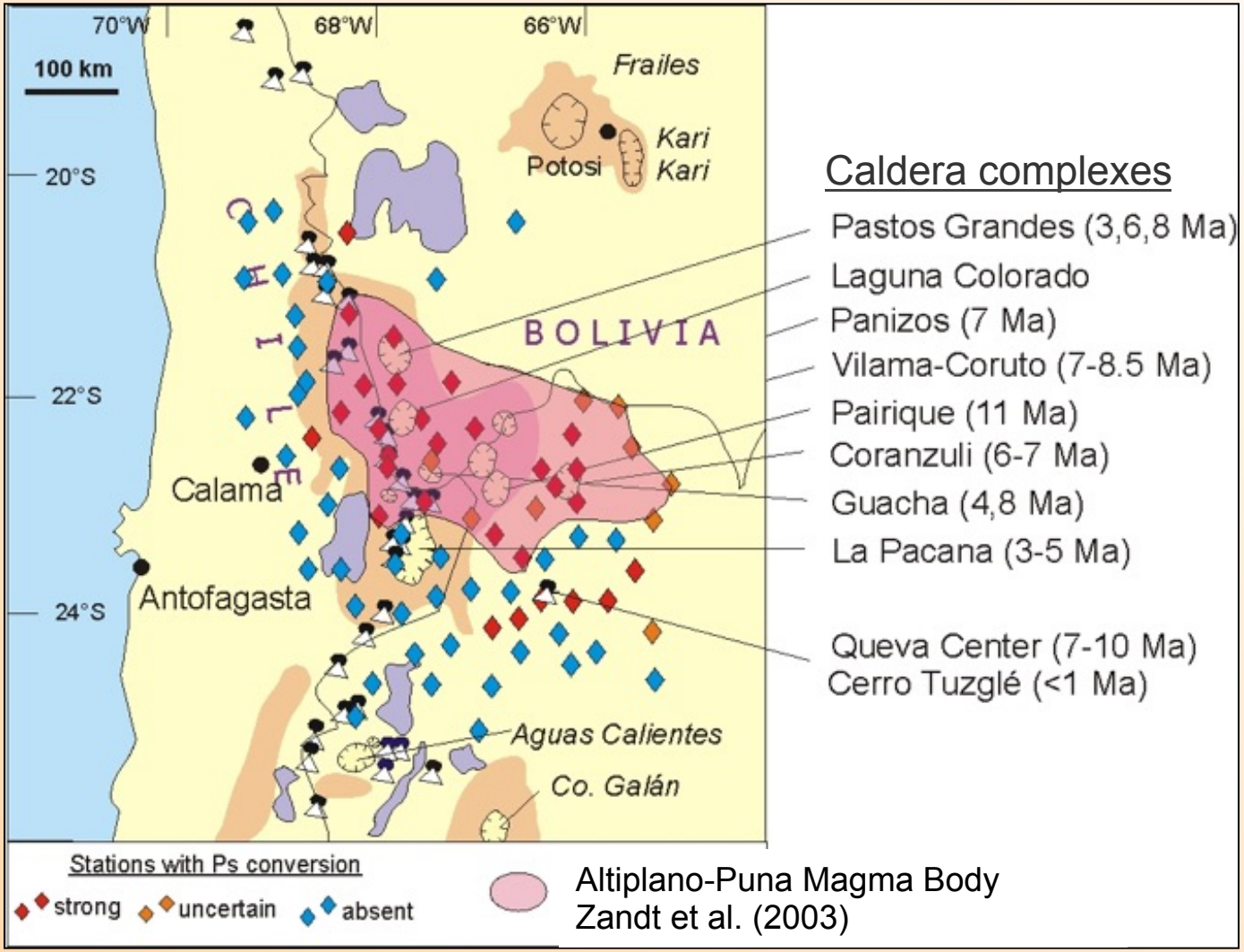
Seismic attenuation tomography
Haberland & Rietbrock, 2001
Schurr et al., 2002

Seismic receiver functions
Chmielowski, 1999
Yuan et al., 2000
Zandt et al., 2003

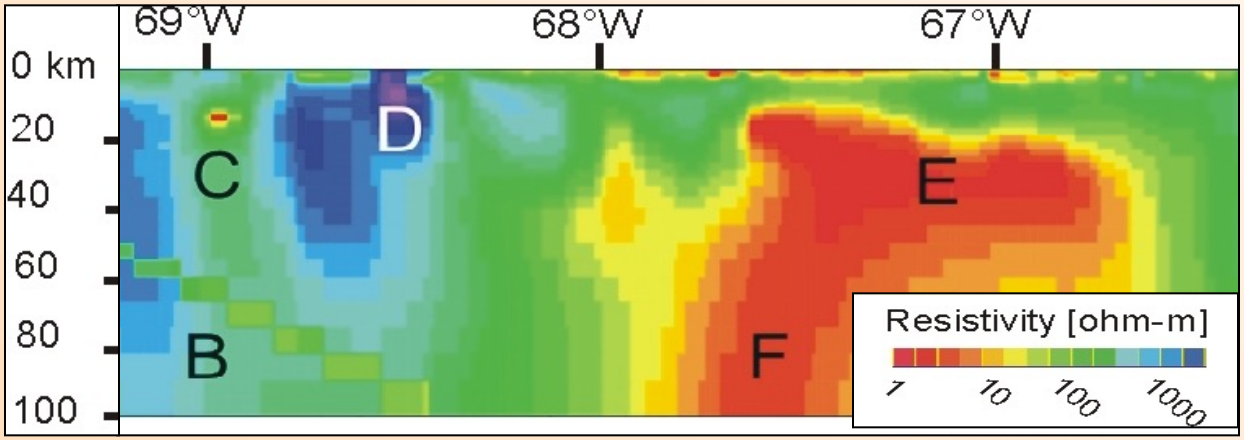
High surface heat-flow density
Springer, 1999

- Areal extent and depth of the partial-melt zone
- Proportion of melt present within it

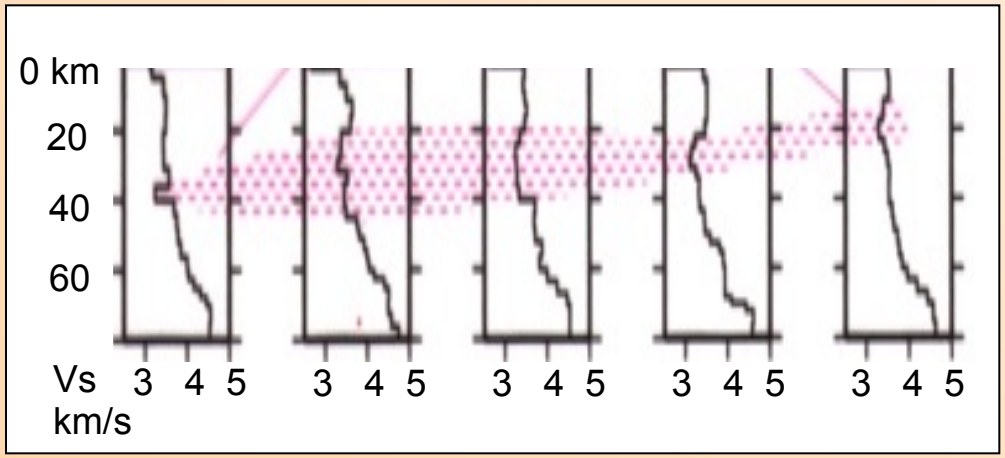
Area of geophysical anomaly coincides with caldera complexes



Depth to top of the anomaly is ca. 20 km, thickness is poorly defined

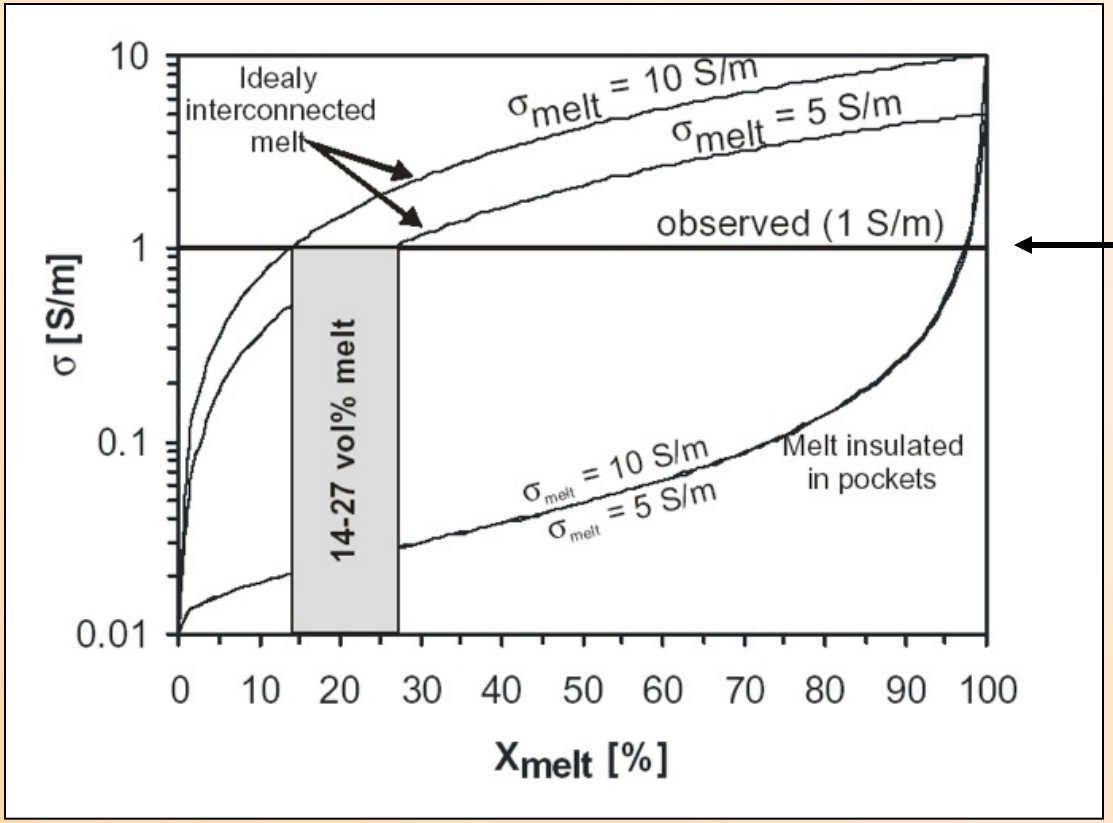


Electrical resistivity modified from Brasse et al. (2002)



S-wave velocity -depth profiles from receiver functions Yuan et al. (2000)

Melt proportion in the zone around 20% if connected



Electrical conductivity at 20 km depth

(Schilling & Partsch, 2001, PEPI)

The A-P Magma Body is a “live” regional migmatite

Thermo-mechanical modelling:

Can we explain formation of the APMB
in terms of crustal heat budget during deformation?

Model temperature development at 20-25 km depth with time for different heat sources:

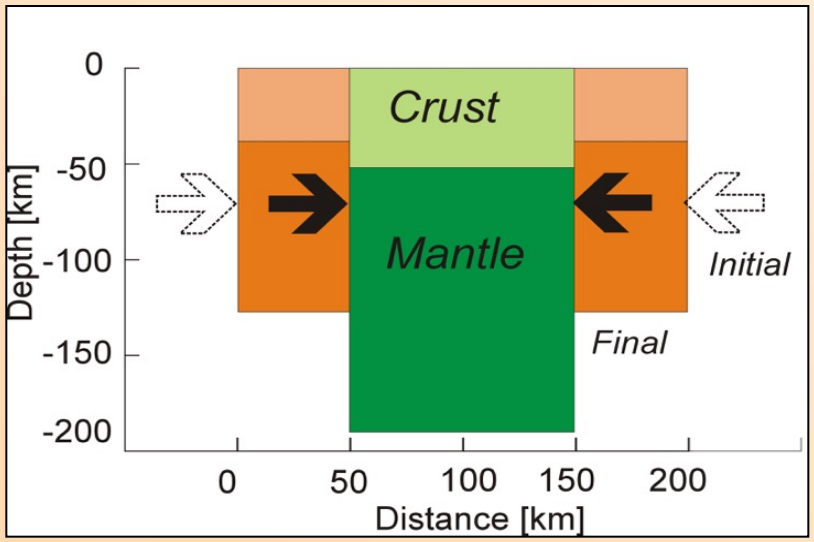
Internal crustal (radiogenic, frictional heat)

Active arc: random, pluton intrusions at 1200°C distributed in 5 km-thick layer for a total flux of 30km^3/km/My

Hot Mantle: heat flow 60mW/m^2 at Moho

Initial conditions: 35 km crust, 25°C/km geotherm

Required: > 800°C at 20 km
within 10-15 Ma after onset of shortening



Model lithosphere section, 200 km wide (APVC dimension):

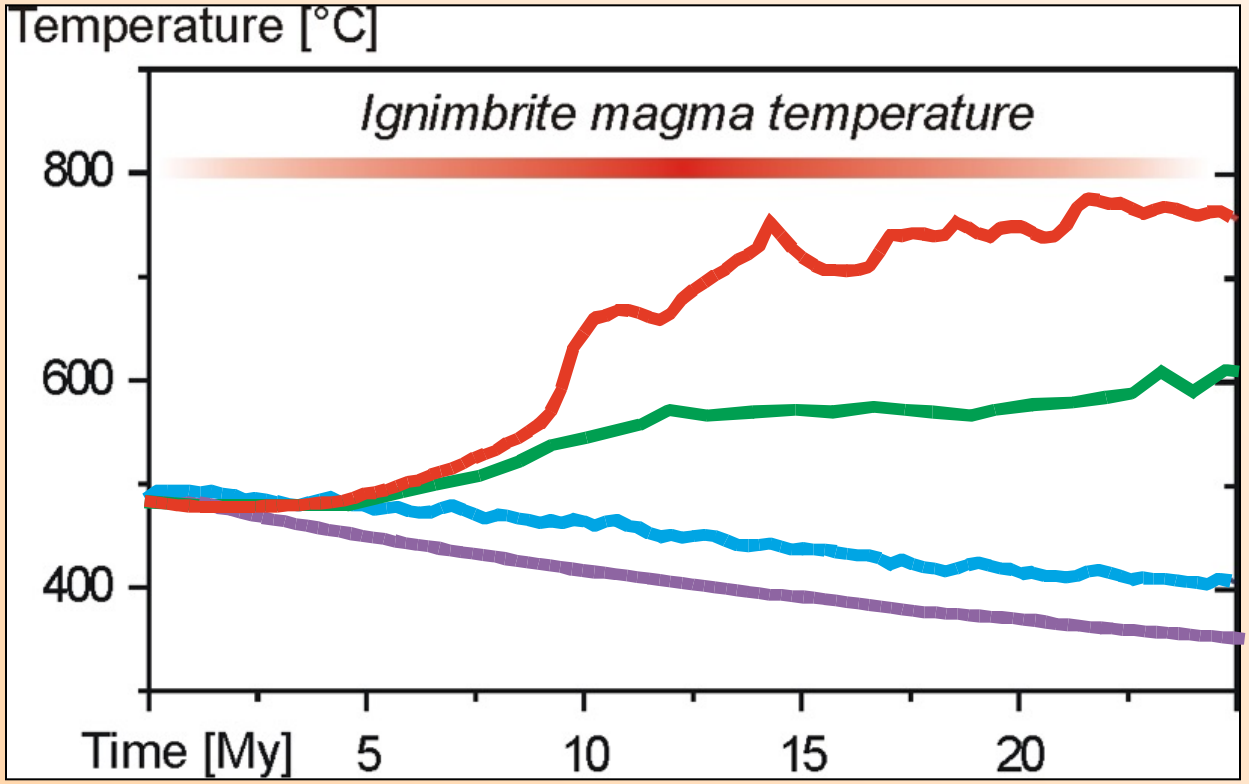
35 km crust (initially) quartz rheology
95 km mantle with olivine rheology

constant shortening by 100% for 30 My

(Babeyko et al. 2002, EPSL)

Result: average temperatures at 20-25 km depth during 30 my

Required: > 800°C at 20 km
within 10-15 Ma after onset of shortening



(Babeyko et al. 2002, EPSL)

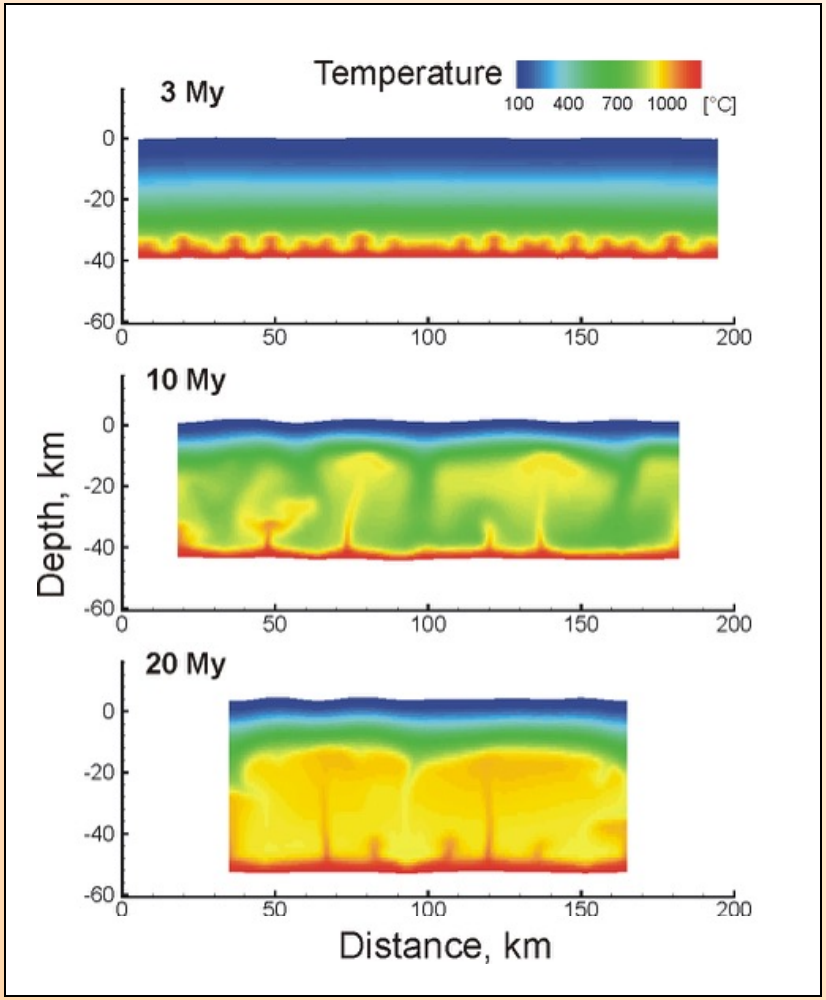
Hot mantle, convection

Hot mantle, conduction

Internal heat plus arc intrusions

Internal heat sources

Hot mantle, convection



Conclusions from modelling:

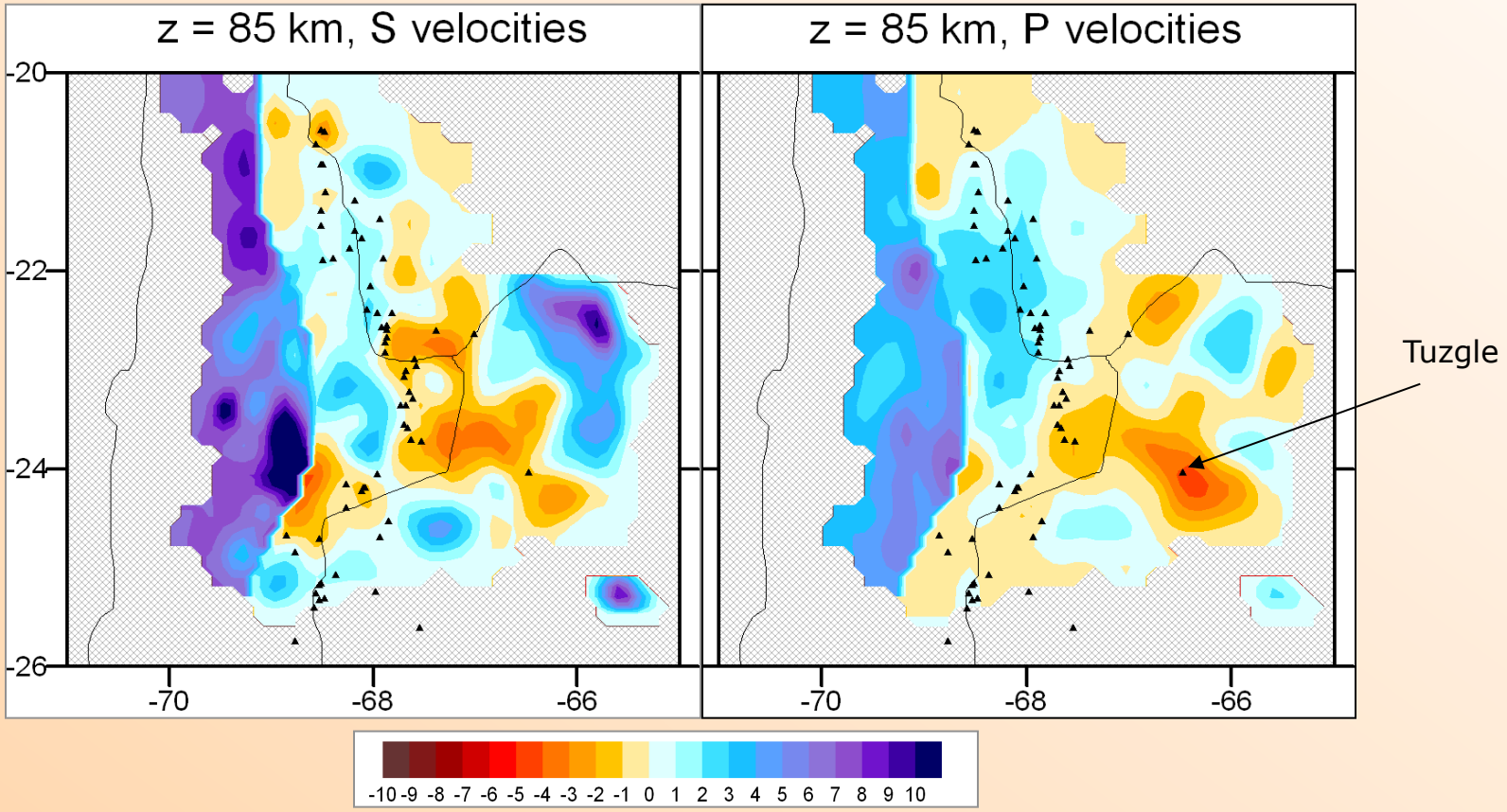
mid-crustal melt zone can be established if:

Mantle heat input is high

Heat is transported by crustal convection

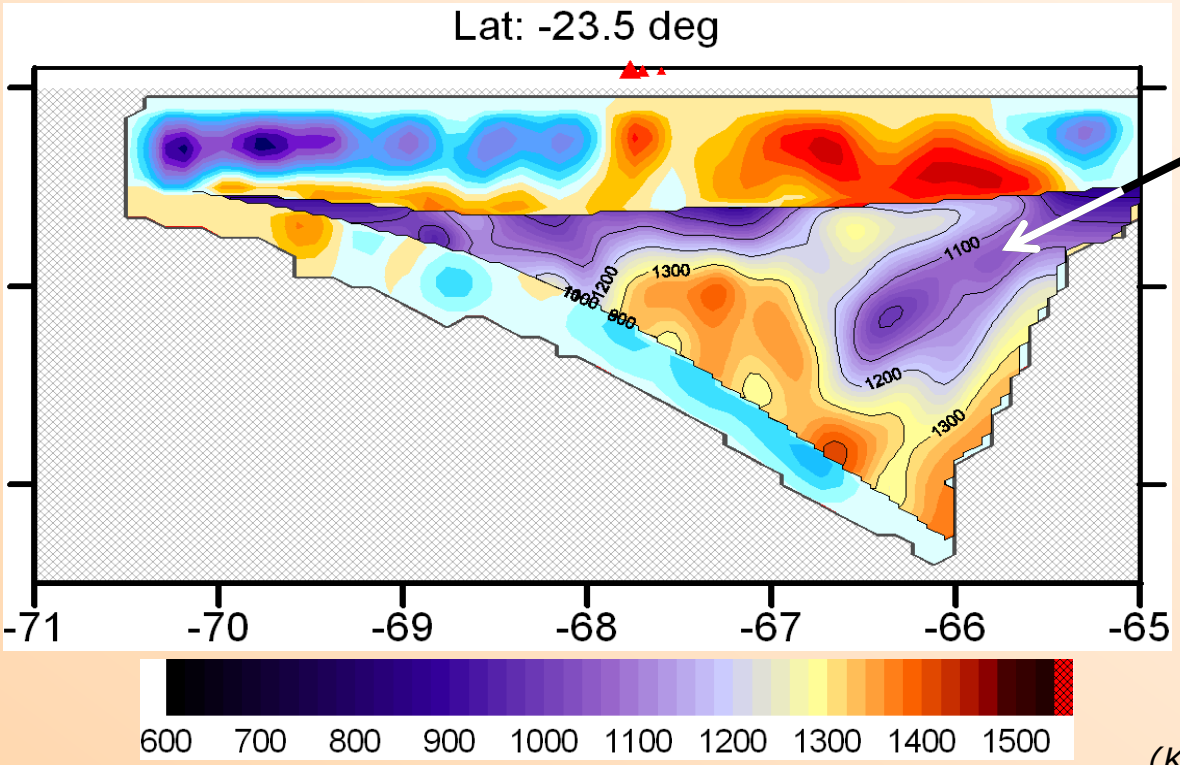
Convection (ductile flow) is possible for felsic crust with quartz rheology
and active shortening

Evidence for hot upper mantle: seismic tomography



(Koulakov et al., 2005)

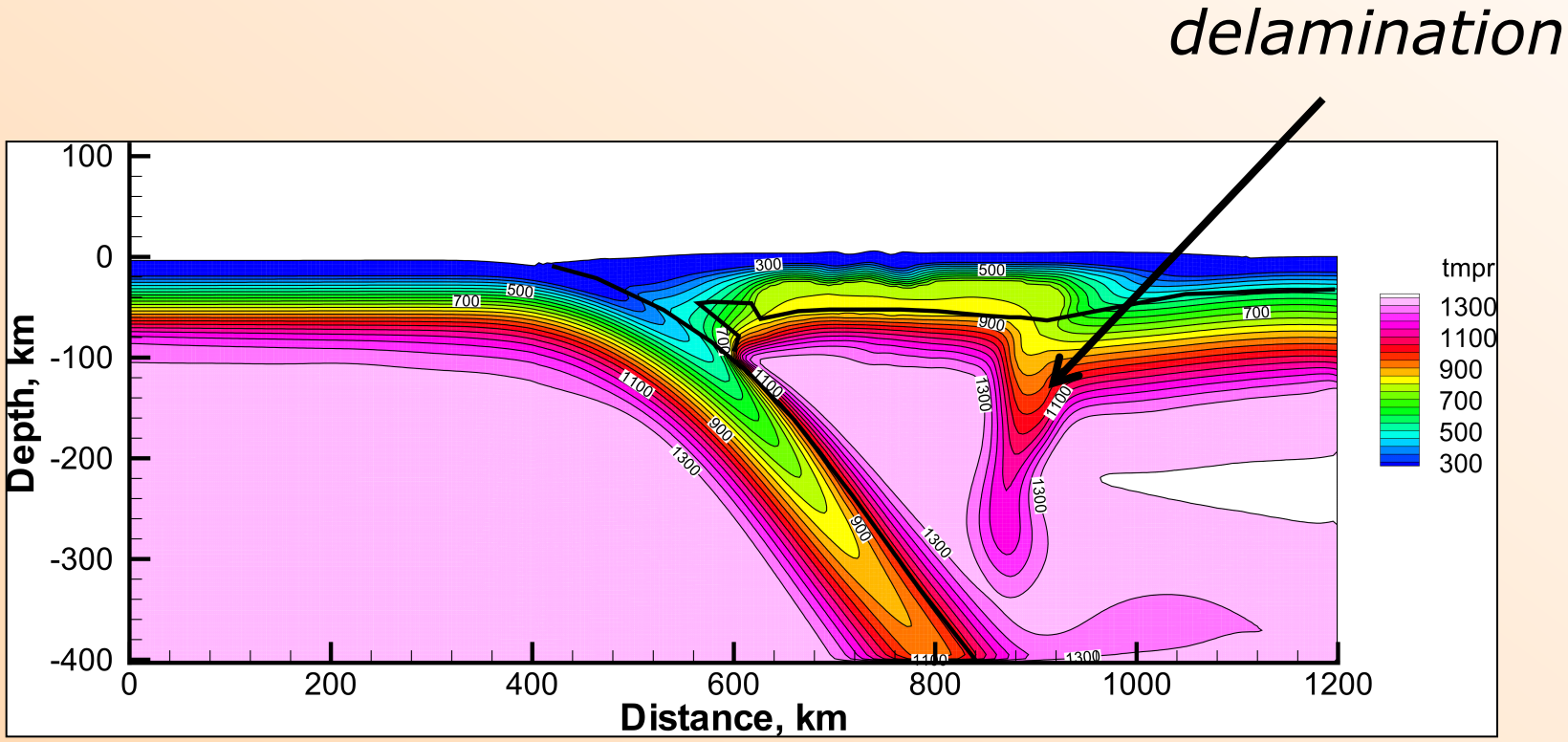
Temperature distribution in the mantle wedge from S-wave tomography inversion



Delamination ?

(Koulakov et al., 2005)

Thermo-mechanical model of the Andean Orogeny (temperature distribution)



Sobolev et al. (2006)

Conclusions

1. Information from APVC ignimbrites and various geophysical anomalies in the plateau region are entirely consistent and probably expressions of the same process.

2. The geophysical anomalies detect a „live“ migmatite zone in the mid-crust with an overall, average proportion of melt ca. 20%.

3. Crustal melting on a large scale is **not an arc process *per se*:**

Arc magmas are unimportant as a heat source; melting is not happening in the south; and „arc ignimbrites“ in the CVZ are quite different from the large, „plateau ignimbrites“.

4. Starting and maintaining the mid-crustal melt zone requires high mantle heat and intracrustal convection enhanced by deformation.

5. All available evidence supports the idea of lithospheric delamination under the Puna plateau with upwelling of hot asthenosphere in the gap.

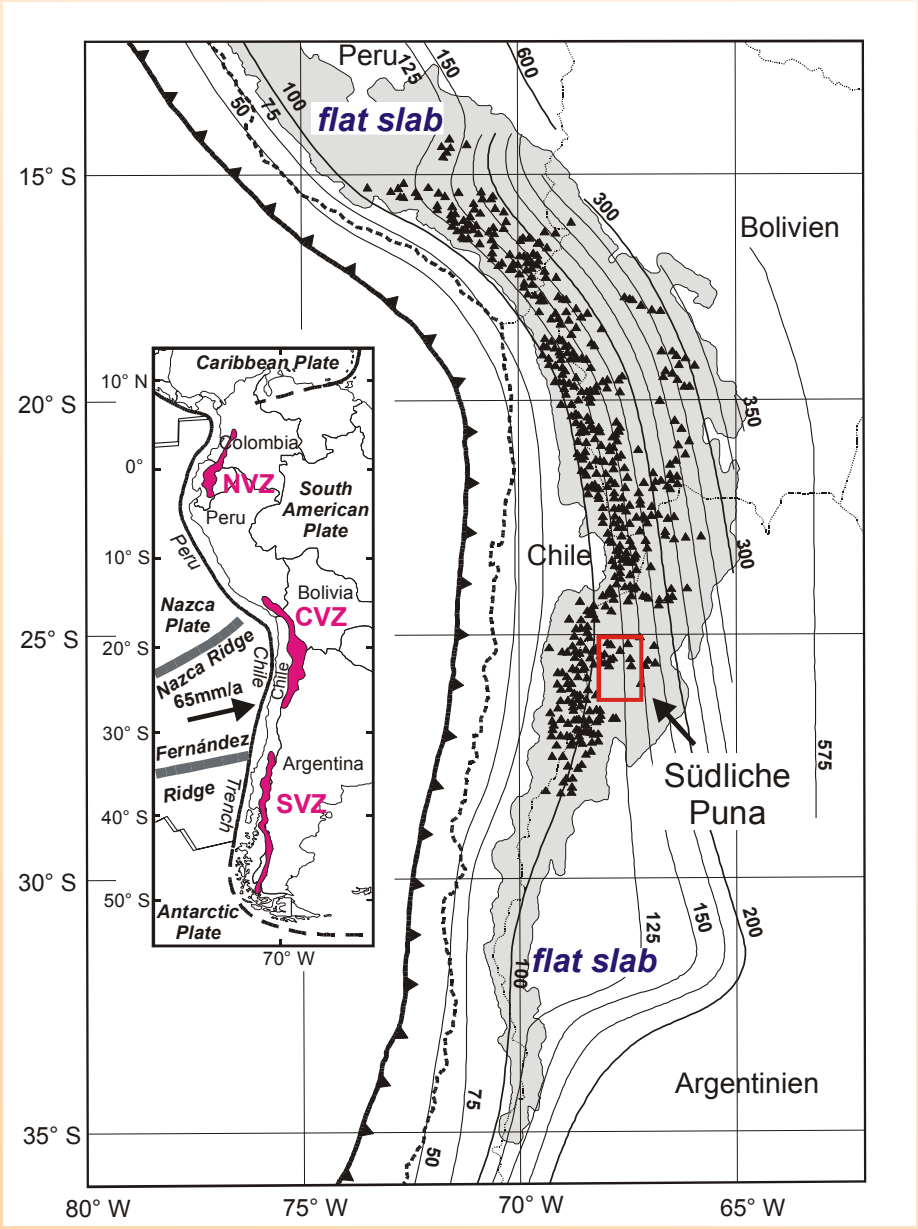
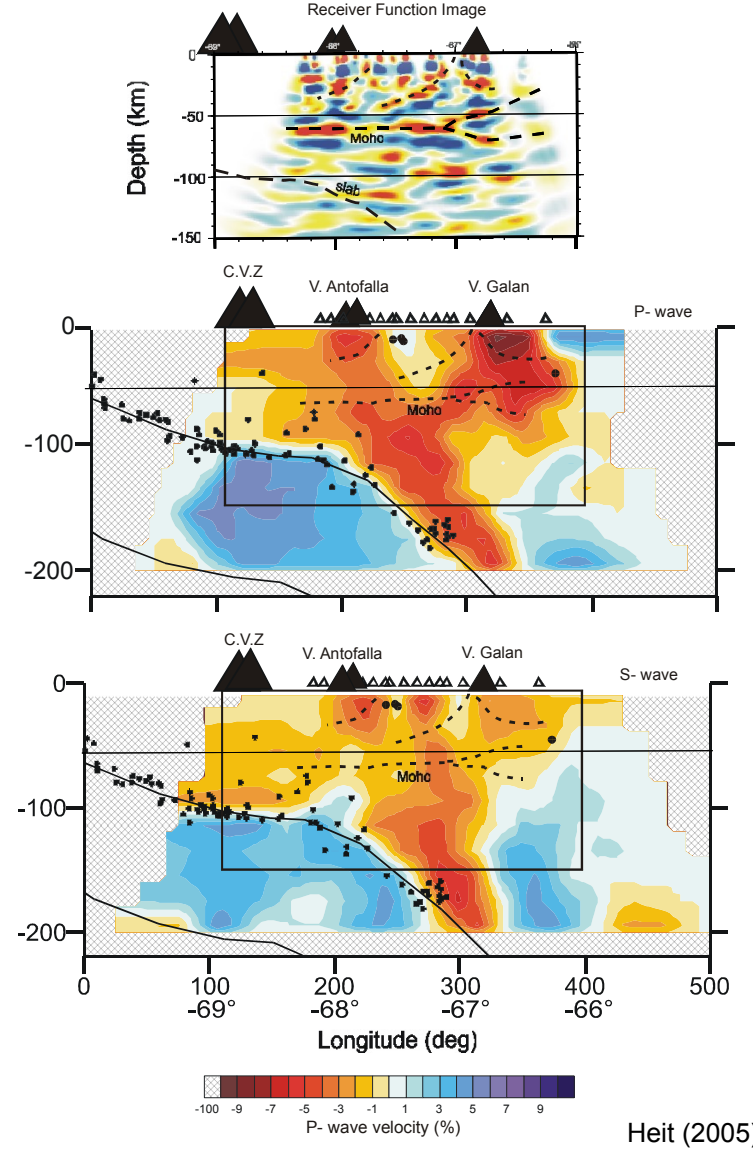
Causes and Consequences of Magma Diversity in the Central Volcanic Zone in NW Argentina

Integrating petrology, geology, geophysics & modelling

Thank you for listening!

Deutsche Forschungsgemeinschaft DFG
CONICET
LAND BRANDENBURG
Universität Potsdam
GFZ Helmholtz-Zentrum Potsdam
Universidad de Buenos Aires
Universidad Nacional de Salta
Universidad Nacional de Tucumán

Geodynamics



Geophysics