



CRUSTAL DEFORMATION ASSOCIATED WITH THE 1960 EARTHQUAKE EVENTS IN THE SOUTH OF CHILE

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Outline

- Motivation
- 1960 earthquake general description
- Evidences of subsidence and uplift
- Possible reasons
- Subduction hypotheses
- Conclusions

Motivation

“Since tectonic subsidence and uplift is not taken into account in present design of coastal structures, 2 m subsidence will make, for example, sea walls meaningless against tsunami attack”

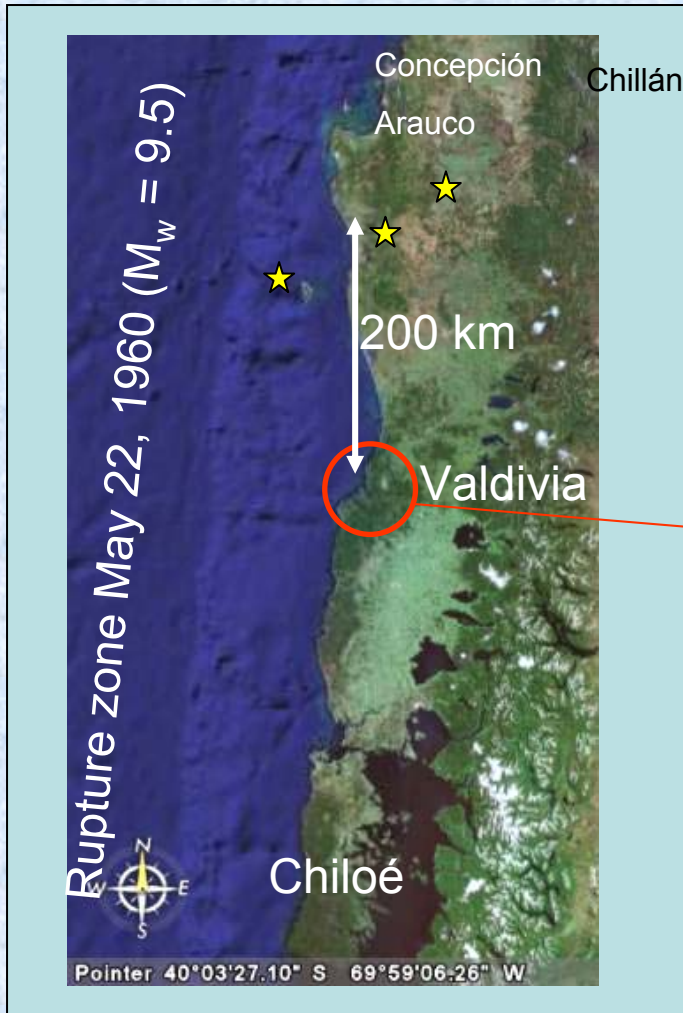


Several weeks
after 22/05/1960
Steinbrugge and
Flores (1963)

Despite the epicentre was in Arauco, Valdivia was the most affected area

South of Chile

Valdivia city and surroundings



★ Possible epicentre positions

In the aftermath of the earthquake

Sunday 22nd May 1960 15:12 (local time)

- Remains the largest seismic event ever recorded by seismological instruments, $M_w = 9.5$
- Tsunami reached Japan, Hawaii, Russia, New Zealand (15:30, first of five waves until 21:30)
- Tectonically depressed basin (Valdivia)
- Flooded meadows along the coast during the first hours equivalent to 2 m of subsidence
- Salty water flooding the meadows became sweet after some days
- Landslides and lake overflow (24th July 1960)
- Volcanic eruptions

Haverbeck small island and promenade



Steinbrugge and Flores (1963)

Subsidence along the Valdivia promenade



(Steinbrugge and Flores 1963)

Road along the promenade showing concrete pavement distorted, broken and tilted towards the river, (a) road going under the river passing the bridge in the upstream direction and (b) just before passing under the Pedro de Valdivia Bridge.

Waterfront dropped about 2 m due to regional subsidence.

Date: 19/06/1960

Facts and evidences

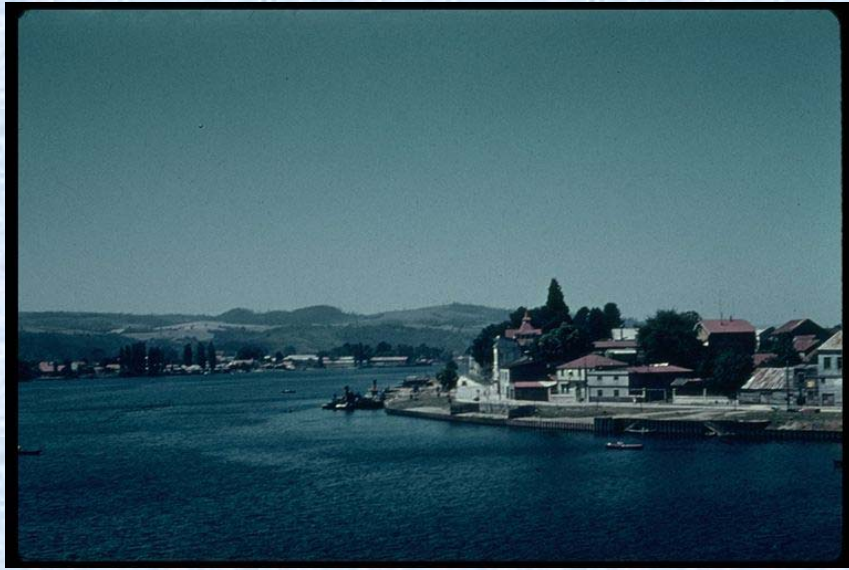
- 1 – 1.5 m depression of a land strip of about 30 km wide by 600 km long
- Uplifts of 1.2 m in the Arauco peninsula and 1 – 3 m in the Guafo island, almost connected to Chiloé island
- Horizontal displacements *ca.* 20 m in coastal areas and 2 m in the Andes
- Local compaction of alluvial sediments accounts for a few centimetres
- Bathymetry change (*e.g.* a bank sunk from 2 m to 4 m), plus erosion allowed vessels to reach more easily Valdivia

Questions and uncertainties

“What was the cause of Valdivia inundation and subsidence? and, why today Valdivia is again above the water?”

“The reason of the city subsidence because of subsoil seismic compaction can not explain the later on city uplift to almost the level previous to the earthquake”

Valdivia before, after and today



Possible reasons

- Seismic compaction of alluvial sandy and clayed sedimentary deposits (40 m thick overlying gravel before reaching the bedrock in Valdivia Basin)
- Crustal deformation as a result of the thrust in the subduction zone (Weishet 1963)
- Flooding was caused by: (a) sea water entering into the land and the subsequent tsunami, (b) overflow of the Riñihue Lake

Subduction in the southern Andes.

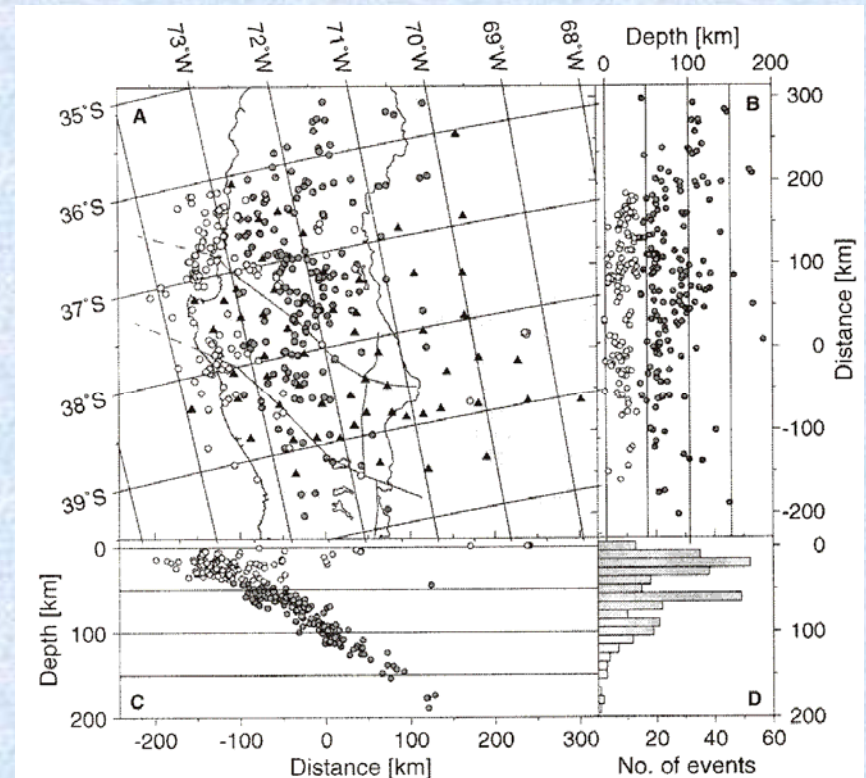
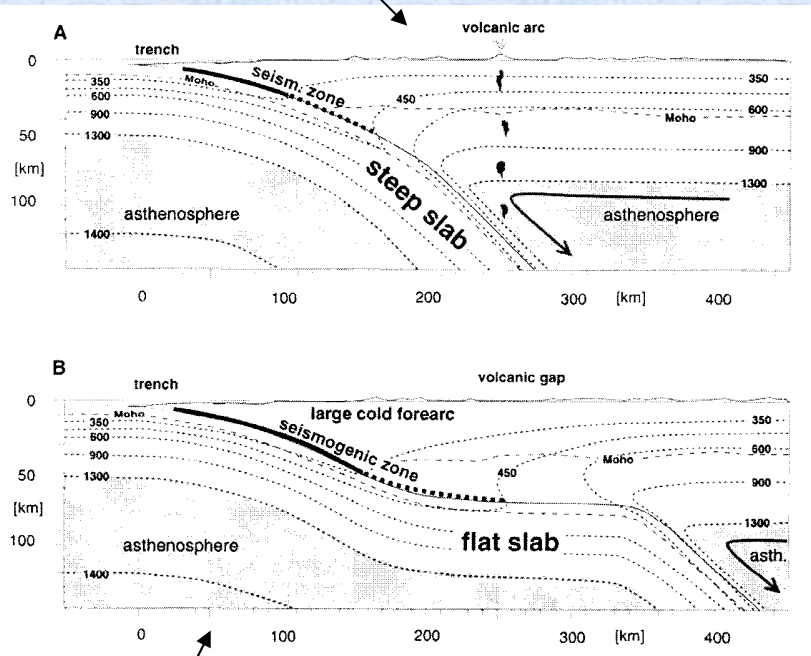
Hypotheses

- Decreasing mountain peaks towards the south for coastal and Andes chains
- Flat slab (north) versus deep subduction (south)
- Thickness of the continental crust >70 km in the north and ~ 35 km in the south
- Seismic cycle of subsidence and uplift in coastal areas

The complex geometry of the Watadi-Benioff zone

South (steep)

South



North (shallow plate dip)

Gutscher (2002). JSAES 15

Epicentres of 333 local seismic events in a three month period

Bohm *et al.* (2002) Tectonophysics 356

Long-term tectonic deformations

- GPS observations¹ revealed that post-seismic stress relaxation is still occurring in the region
- Elastic short-term effect and viscoelastic long-term effect
- Four stages seismic cycle²: subsidence due to a massive earthquake, fast post-seismic uplift, slower inter-seismic uplift and pre-seismic subsidence not yet well known

¹ Klotz *et al.* (2001). *Earth and planetary Science letters* **193**

² Bourgeois (2006). *Nature* **440**

Conclusions

- The 1960 M_w 9.5 Valdivia earthquake triggered crustal deformation along 1000 km causing subsidence and uplifts in the order of 1 to 3 m
- The subduction kinematics depends on the shape of the Wadati-Benioff zone
- The Nazca plate dip in the coast is $< 30^\circ\text{E}$, creating a shallow seismicity zone ~ 35 km deep
- Great advantage of GPS accurate horizontal displacement measurements (not yet vertical)
- Post-seismic relaxation could explain the recovery of the current level in Valdivia