Recurrence of 1960-like earthquake shaking in South-Central Chile revealed by lacustrine sedimentary records.


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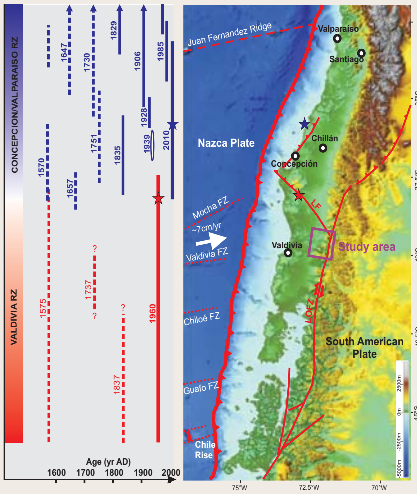
Introduction, setting & methods



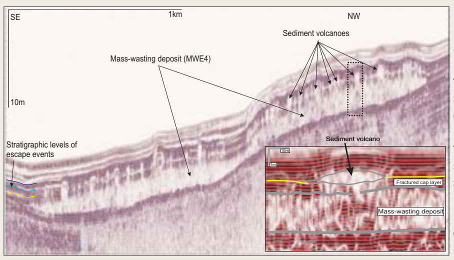
Megathrust ('giant') earthquakes in the South-Central Chilean subduction zone (e.g. 1960 earthquake; Mw: 9.5) pose a major threat to society. A reliable seismic hazard assessment requires establishing if such mega-events occurred in the past and determining their **recurrence pattern**.

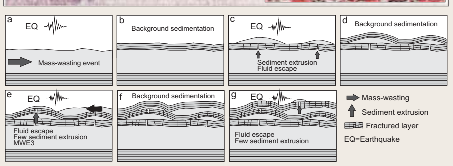
The Lake District (39-42°S), located in the northern half of the 1960 earthquake rupture zone, contains several large, steep-sloped glacigenic **lakes** with high sedimentation rates, and whose sedimentary deposits are highly susceptible to **earthquake-triggered slope instability**.

To establish the recurrence interval of earthquakes during the Late Holocene, we mapped the spatial distribution of seismically-induced sedimentary 'event' deposits and structures in each lake using very-high-resolution **reflection seismic data**, and collected a series of short gravity **cores** and long piston cores.

Fig.: Setting and historical earthquakes in South-Central Chile. Data derived from Barrientos (2007); Campos et al. (2002); Melnick et al.(2009)

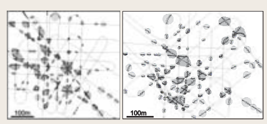
b) Sediment volcanoes





Lenses of low-amplitude reflections are interpreted as **sediment volcanoes**. Such sediment volcanoes can be produced by sudden liquefaction in a thick buried mass-wasting deposit and subsequent **sediment fluidization and extrusion** at the paleo-lake bottom (Moernaut et al., 2009). In this process, the mass-wasting deposit acted as a **source layer** and 0.5 m of background sediment drape as a sealing **cap layer**.

Locally, some of the sediment/fluid escape structures extend to a higher position in the stratigraphy, which points to a **polyphase escape** process associated with multiple multi-century spaced strong earthquakes. Thickness and morphology of the **source layer** seem to exert a dominant control in the production of sediment/fluid extrusions.



Upper Fig.: sediment vollcanoes above a thick MWD
Lower Fig.: Schematic illustration of the relation between earthquake-triggered mass-wasting deposits and sediment volcanoes.
Right Fig.: Spatial distribution of sediment volcanoes.

Preliminary comparison of paleoseismic records

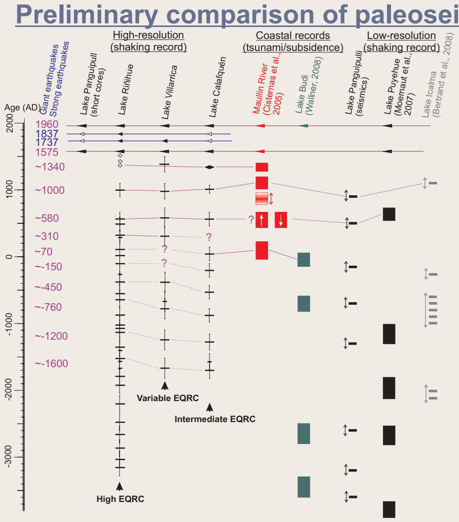
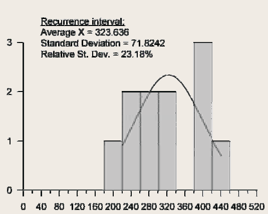


Fig.:Comparison between lacustrine records of earthquake shaking and coastal records of tsunami's and subsidence.

***triangles:** historical earthquake fingerprints **diamonds:** varve-dated prehistorical earthquakes. **narrow symbol:** smaller earthquake fingerprint. **Block or vertical line:** 2σ age error range.*

*We obtained a strong correlation for the last 1500 yrs. For older periods, **a better age-control is needed**. This can be obtained by extending the varve-counting, more and better 14C dating, tephra-stratigraphy, etc.*



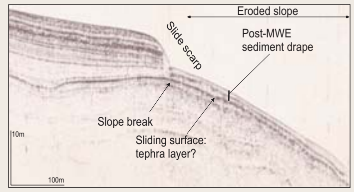
Conclusions

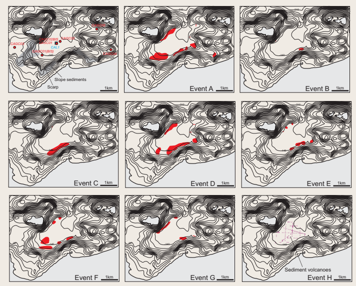
Our study confirms that -in our study area- shaking associated to the 1575 earthquake was similar than in 1960. Combining our data with historical and other paleoseismologic studies (Cisternas et al., 2005), we hypothesize that the 1837 earthquake took place along the southern segment of the Valdivia Rupture Zone. Thus, the Valdivia rupture zone seems to be characterized by a "**variable rupture model**".

Our results show that -over the last 4000 years- very strong **1960-like shaking events had a quasi-periodic recurrence (220-440 yrs) with a mean recurrence interval of 324 yrs**. Sites with an enhanced EQRC also included smaller shaking events which gives a mean recurrence rate of ~160 yrs and larger variance.

More records are needed to decipher if all paleoseismic events originated at the subduction thrust fault or that other earthquake types (upper crustal, intra-downgoing slab, etc.) were also recorded in the lake sediments.

a) Mass-wasting events





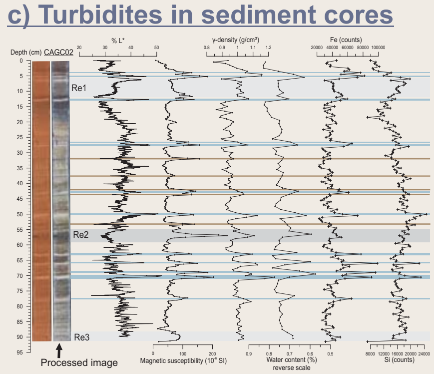
We revealed **mass-wasting deposits** (MWD's) resulting from translational sub-lacustrine slope failure. Multiple MWD's locate on a same stratigraphic level, pointing towards a **synchronicity** of failure (mass-wasting event: MWE). Such MWE's are most likely **earthquake-triggered** because:
-Linkage with historical earthquakes.
-Synchronicity of multiple slope failures in calm depositional areas.
-Other triggering mechanisms (lake level fluctuations, wave action, gas discharge, etc.) are unlikely.

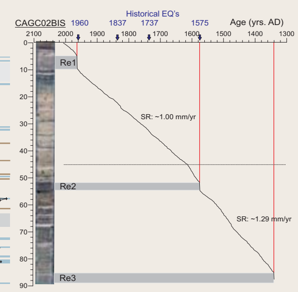
Our seismic and core data showed that **sandy tephra layers** acted as "**weak layer**" for slope failure as these might be highly susceptible to earthquake-induced liquefaction (see e.g. Harders et al., 2010). Thus, volcanic history strongly controls the magnitude and timing of extensive slope failures.

Upper left Fig: Prominent slide scarp in Lake Villarrica

Lower left Fig.: Spatial distribution of the uppermost 8 mass-wasting events (of 15) in Lake Calafquén. Isobaths every 10m.

c) Turbidites in sediment cores





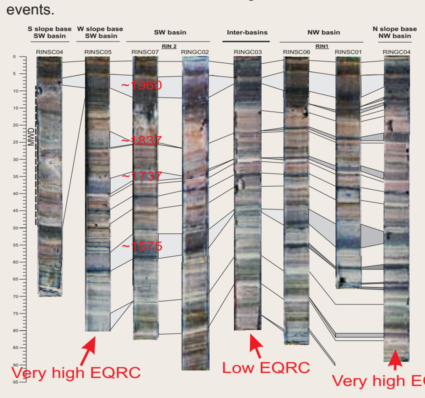
Left Fig: Multi-proxy study (blue: clay layer; brown: tephra). Re: Resedimentation event deposit (turbidite, sand flow, etc.). Right Fig.: Preliminary varve chronology

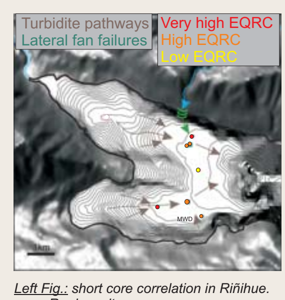
Resedimentation event deposits (Re: mostly turbidites) were characterized in **sediment cores** by their specific signature of color, grain-size, magnetic susceptibility, geochemistry, density, water content, etc. compared to laminated background sediments.

Varve-counting revealed that these event deposits correlate with **historical earthquakes**. The giant 1575 and 1960 earthquakes left a clear sedimentary fingerprint in most core sites, while only fragmentary evidence was found for the less strong 1837 and 1737 events.

Short cores revealed that the NW and SW basins in Riñihue are independent recorders of paleo-earthquake shaking. It seems that **earthquake-recording capacity (EQRC) is site-dependent**. I.e. sites with a very-high EQRC (proximity to sediment source, etc.) bear a clear fingerprint of 1837 and 1737 earthquakes, while sites with low EQRC only register giant earthquakes, such as those in 1960 and 1575.

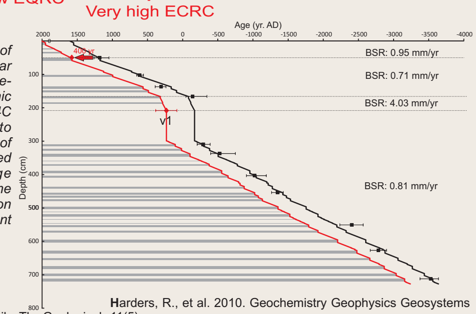
This variability in EQRC opens perspectives for **quantification** of earthquake shaking strength.





Left Fig.: short core correlation in Riñihue. grey: Re deposits.
Right Fig.: Model explaining the spatial distribution of EQRC.

Right Fig: Preliminary age-depth model of Lake Riñihue (RIN2) based on linear interpolation between 14C dates, varve-counting and a onshore dated volcanic deposit. In our lake records, AMS 14C dates on bulk sediment appear to underwent an aging effect in the order of 400-700 years by the input of aged terrestrial carbon. Therefore, age correction was executed based on the discrepancy between the radiocarbon age-depth model and historical event deposits (identified by varve-counting).



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