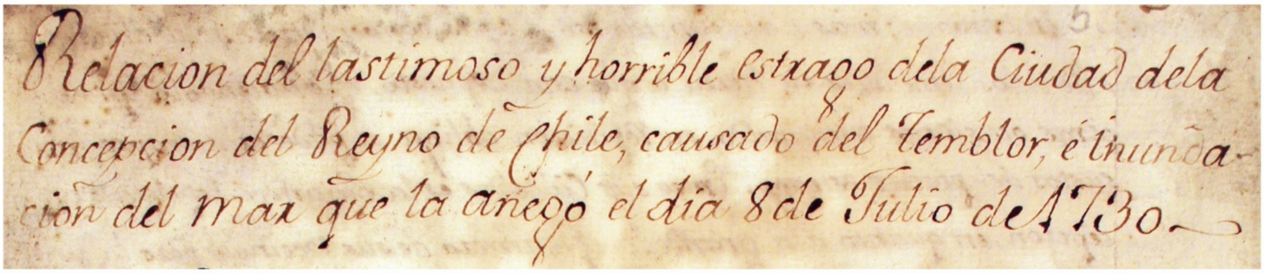
12th International INQUA Meeting on Paleoseismology, Active Tectonics and Archaeoseismology (PATA),
October 6th-11th, 2024, Los Andes, Chile

Conference-Intrameeting fiedtrip

Fieldtrip guide

Geologic record of historical earthquakes and tsunamis on Metropolitan Chile's coast

October 11th, 2024, Campiche, Quintero Bay, Chile


Relacion del lastimoso y horrible estrago dela Ciudad dela Concepcion del Reyno de Chile, causado del Temblor, é Inundacion del mar que la anegó el dia 8 de Julio de 1730.

Laboratorio GeoTsunami
Instituto de Geografía
Pontificia Universidad Católica de Valparaíso

Guide: Marco Cisternas
Collaborators: Bladimir Saldaña and Mario Guerra

- ## Introduction

We will visit the coast of Metropolitan Chile and work in a low area fringing Quintero Bay: the Campiche wetland (32.75º South; p. 3, 4). There, we will study an extensive, buried sand layer interpreted as left by a large, colonial Chilean tsunami.

Due to region`s recent seismic past (p.7), the community living along this coast shares a risky perception of tsunami immunity (Zamora et al., 2020). Although adjacent coasts, both to the south and to the north, have recently experienced major tsunamis triggered by large earthquakes, in 2010 and 2015, the sandwiched metropolitan coast has not in nearly three centuries. The last three big metropolitan earthquakes, in 1822, 1906 and 1985, although very destructive, triggered small tsunamis. However, the effects of a poorly attested and understood major tsunami in 1730, affecting what was then a sparsely populated area, challenge the immunity perception in what is now the country´s most populated coast.

In this context, determining recurrence of the 1730-type events is crucial to adequately assess tsunami hazard on Chile's metropolitan coast. However, it is not possible through written history, as it begun in Chile in 1541 and recorded the 1730 event as the only major tsunami on this coast. Alternatively, studying the geological record left by past tsunamis could provide a proxy if a modern analogue is available. The only such work for the metropolitan coast suggests large tsunamis recurred between ~200 and ~650 years, with an average interval of ~500 years, during a mid-Holocene, 2600-year time window (Dura et al., 2015). Evidence was found in another lowland also fringing Quintero Bay, but 5 km south of Campiche (p.4, 5). Because the sequence did not record later events, including the 1730 tsunami, no modern analogue is available for comparison with either the mid-Holocene sequence itself or with historical inundation reports.

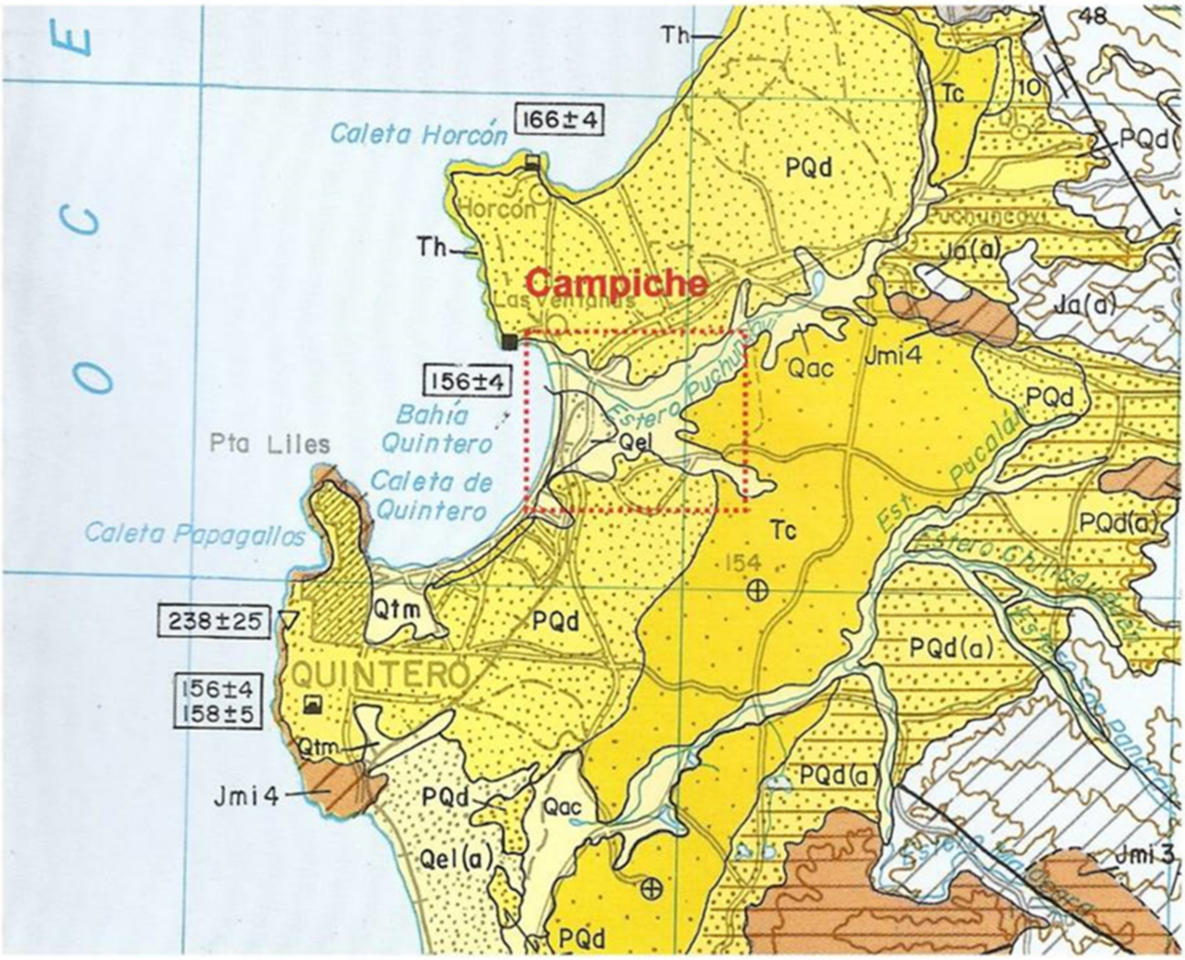
During our visit to Campiche we will see geologic evidence for the 1730 tsunami inundation and inconclusive evidence for associated coastal subsidence. It is a widespread, tabular, clean sand sheet, interbedded in the mud that filled in a former lagoon (p. 6, 9). The ~10 cm thick sand sheet sharply punctuates the mud and extends and pinches out 2 km inland from the coast. Locally, it overlies a strongly eroded mud horizon and contains abundant mud rip-up clasts. The sand of the sheet resembles that of the bay´s modern beach in texture, magnetic susceptibility, minerals, and grain size. Diatom assemblages preserved locally in the mud below and above the sand sheet changed after the tsunami. Freshwater diatoms were abruptly replaced by brackish and marine water diatoms (p. 11). This change, coupled with lithologic variations, suggest the lagoon level rose after the tsunami and remained there for decades, submerging previously emerged shorelines. Radiocarbon dates of plant remains from the mud immediately below and above the sand sheet constrains its deposition age to historical times (p. 10). Because the only large tsunami reported in historical times was that of 1730 (p. 7), we ascribe the widespread sand sheet and the evidence of strong erosion to this event. To produce this evidence, the 1730 tsunami had overrun both the landward inundation limit of the official tsunami inundation map and the area where large industrial and harbor infrastructure is founded today (p. 4).

Cited references

Dura, T., B. Horton, M. Cisternas, L. Ely, I. Hong, A. Nelson, R. Wesson, J. Pilarczyc, A. Parnell, N. Daria, 2017. Subduction zone slip variavility during the last millenium, south-central Chile. *Quaternary Science Reviews*, 175: 112-137.

Zamora, N., A. Gubler, V. Orellana, J. Leon, A. Urrutia, M. Carvajal, M. Cisternas, P. Catalán, P. Winckler, R. Cienfuegos, C. Karich, S. Vogel, J. Galaz, S. Pereira and C. Bertin, 2020. The 1730 Great Metropolitan Chile Earthquake and Tsunami Commemoration: Joint Efforts to Increase the Country's Awareness. *Geosciences*, 10, 246:10060246.

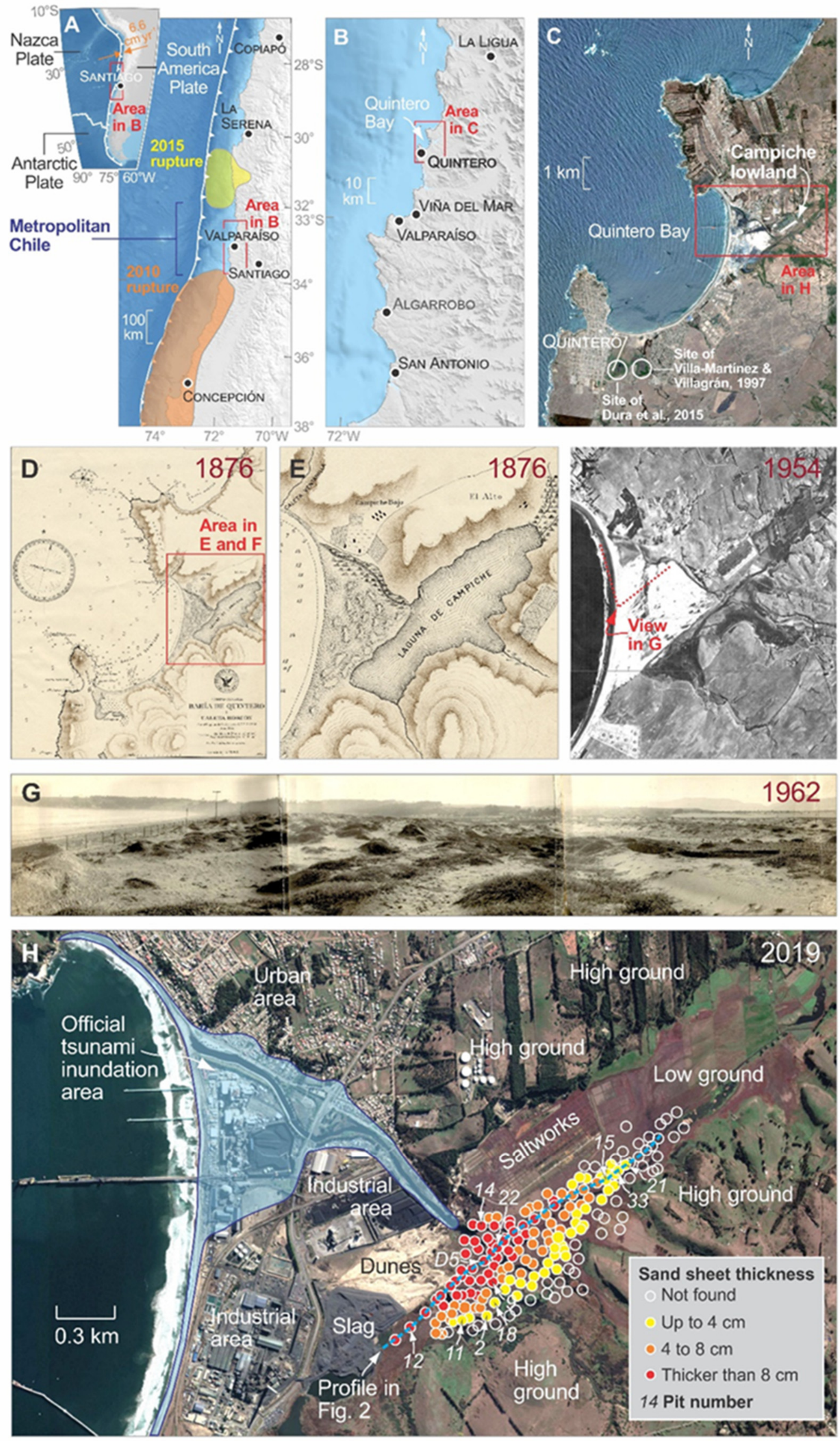
- Geology of the area to visit



KEY

Qel= Onshore and eolian sediments; beach deposits **Qtm**= Terraces of marine sediments **Qac**= Aluvian anc coluvial sediments; filled valleys **Pqd**= Old eolian sediments	QUATERNARY
Th= Caleta Horcón formation **Tc**= Confluencia formation	TERCIARY
Jmi4= Mincha supra-unit, Cavilolén unit **Ja**= Ajial formation, continental volcanoes	JURASSIC

- Campiche lowland setting

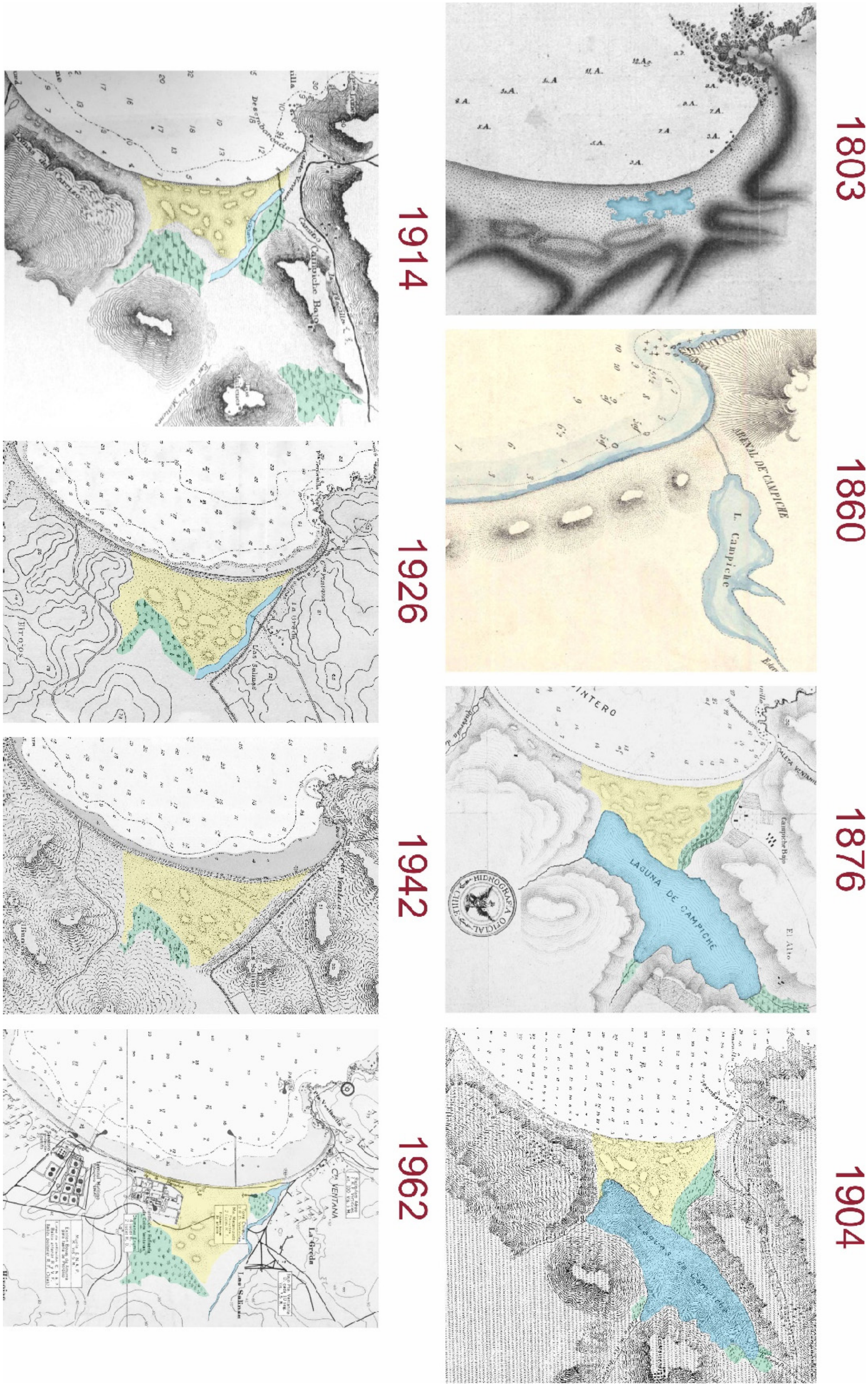


- Overview of Ventanas Beach

- Overview of Campiche lowland from East

- Overview of Campiche lowland from West

- Temporal evolution of Campiche lowland since 19th century



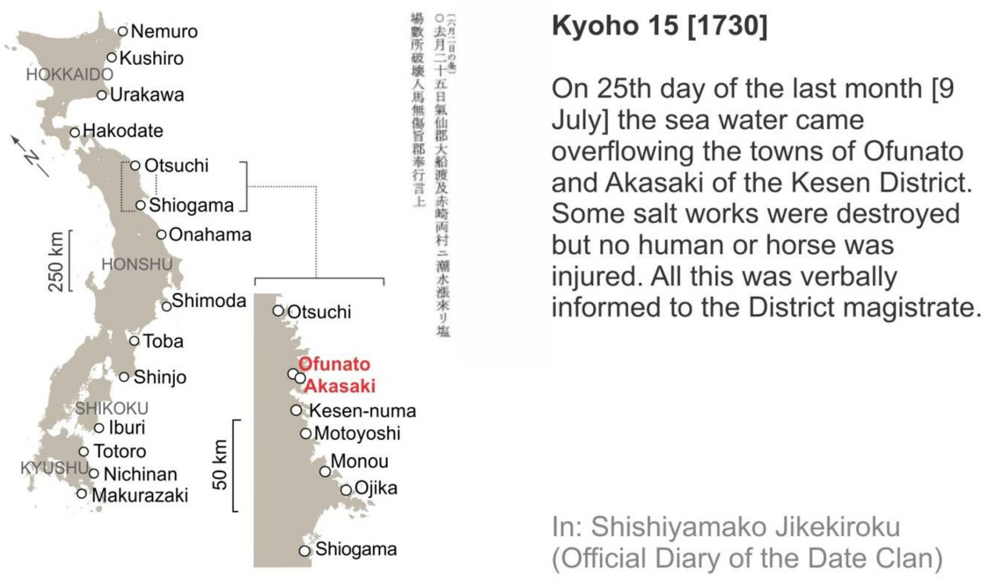
- ## Historical record of earthquakes and tsunamis on the coast of Metropolitan Chile

Owing to the early and continuous Spanish settlement in Metropolitan Chile since 1541, the region has a 483-year-long seismic historical record; the country´s longest. It has been struck by large earthquakes in 1575, 1580, 1647, 1730, 1822, 1906 and 1985. However, the 1575 and 1580 earthquakes may have been too small to be included in this list, and the 1647 event may differ from the rest in having an intraplate source. The last four of the sequence, although differing from one another in size, were certainly large interplate, underthrusting earthquakes as marked along the coast by strong shaking, land-level changes and tsunamis.

The July 8, 1730 earthquake has long been known as the largest event in Metropolitan Chile. It broke a quiescence period of at least 189 years without this kind of very large events, at least since 1541. The 1730 mainshock damaged buildings along 1,000 km, between northern Copiapó and southern Concepción, and as far east as Mendoza, in Argentina, beyond the Andes. The waves of the ensuing tsunami were very destructive in the two main coastal cities at that time in Chile, reaching heights of ~11 m in Valparaíso and ~9 m at Concepción. The tsunami also crossed the Pacific to Japan, being reported in six localities along northeast coast of Sendai, where it flooded rice fields and destroyed salt works, reaching a height of 2 m. These effects point to an earthquake of magnitude 9.1-9.3, with a rupture 600-800 km long, and up to 20 m of shallow slip offshore Metropolitan Chile.

The three events following the 1730 earthquake (1822, 1906, and 1985) share some common features, including a similar recurrence interval, averaging 85 years, strong shaking on the coast, coastal uplift, and moderate tsunamis. These effects, which suggest their ruptures took place deep in the megathrust, occurred mostly between, or with modest extension into, the rupture zones of the latest large earthquakes in 2010 and 2015. Yet, the 1822, 1906 and 1985 earthquakes differ from one another in the details of their latitudinal extent and the location of their results. The effects of the 1906 event, which of the four earthquakes seems to be second in size to the 1730 earthquake, extended southward through the northern third of the 2010 rupture area. In contrast, the 1822 and 1985 events were likely smaller, similar in size, and with effects centered in Metropolitan Chile, but with the effects extending slightly to the north in 1822 and to the south in 1985.

- ## Examples of Japanese chronicles

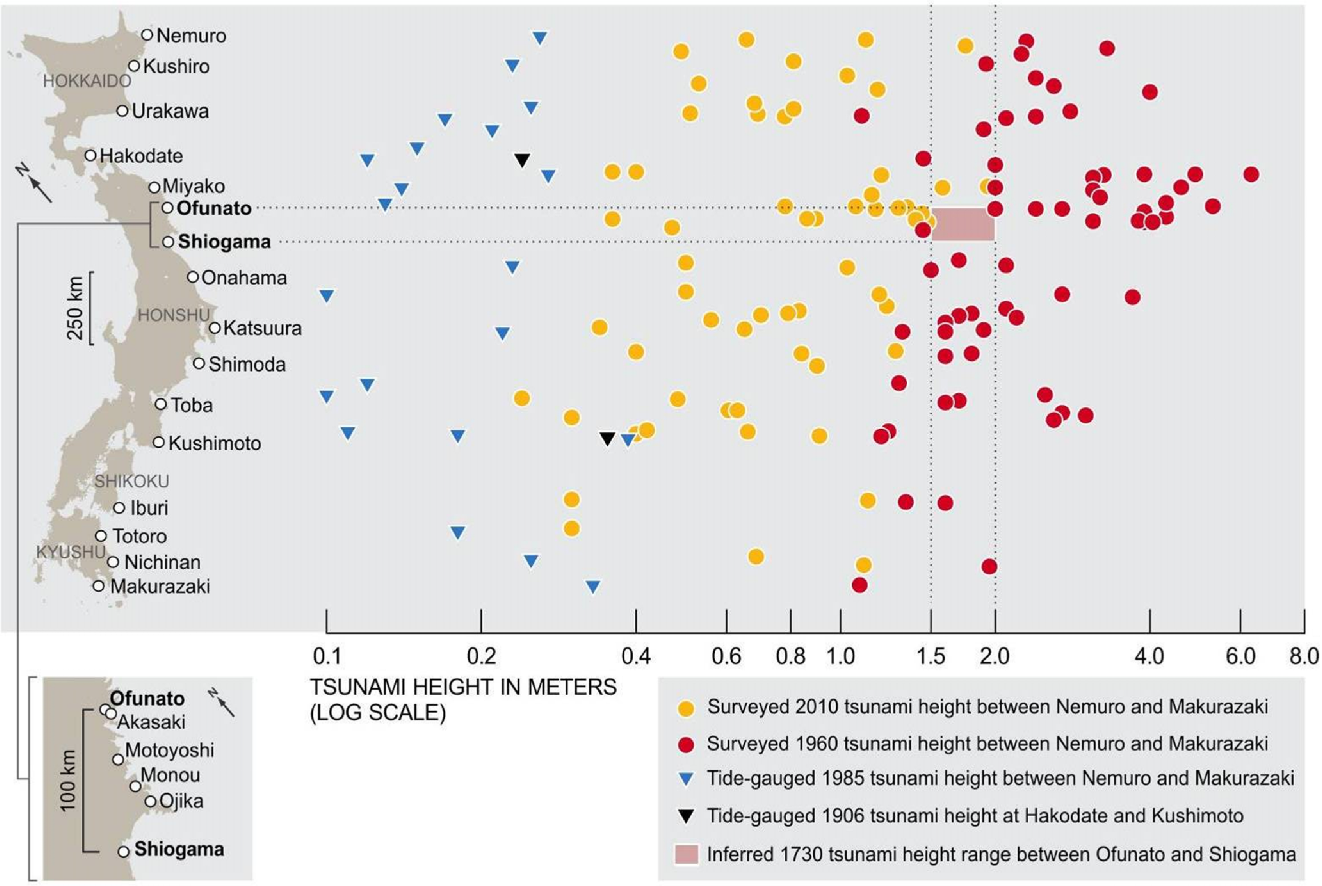


Kyoho 15 [1730]

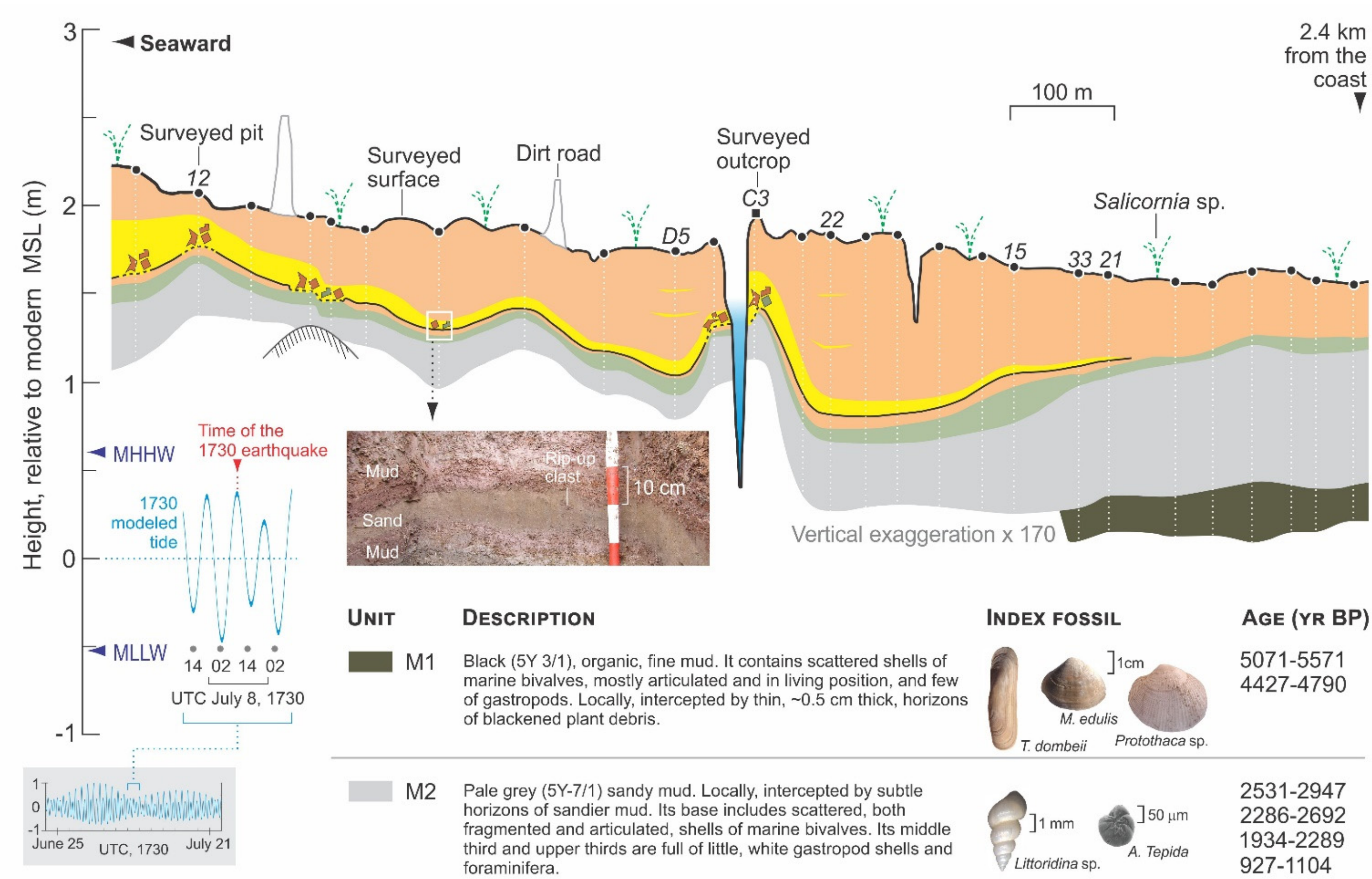
El día 25 del quinto mes [9 de Julio] hubo *kaisho* [tsunami] en los distritos de Miyagi, Ojika, Monou y Motoyoshi [todos en la actual prefectura de Miyagi]. Destruyó cercas y dañó arrozales y cultivos.

En: Tohan-shikou (Historia del Clan del Este)

- The 1730 tsunami compared with other Chilean tsunamis in Japan



- Geological record of the 1730 tsunami: an extensive and tabular sand sheet

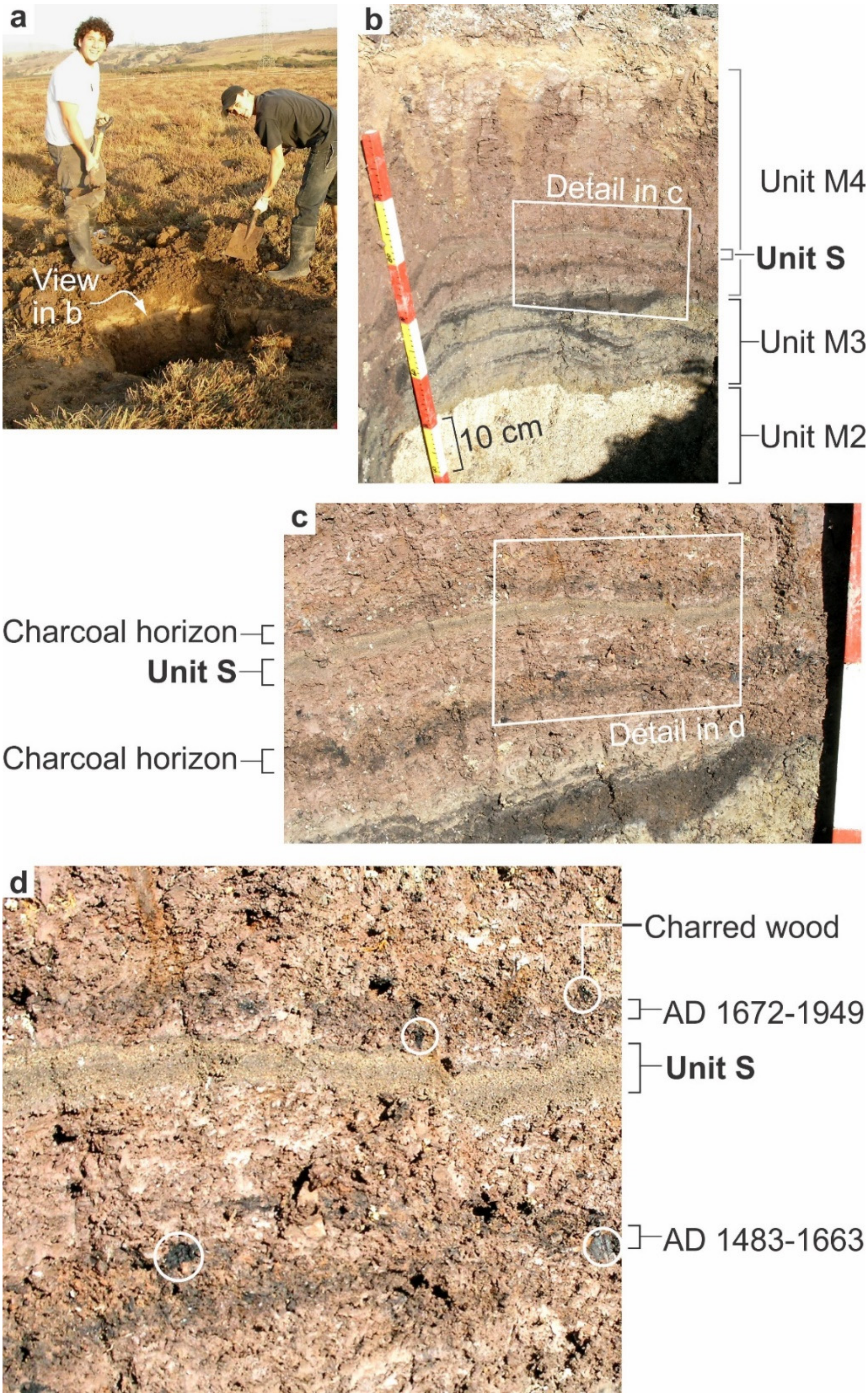


Unit	Description	Index fossil	Age (yr BP)
M1	Black (5Y 3/1), organic, fine mud. It contains scattered shells of marine bivalves, mostly articulated and in living position, and few of gastropods. Locally, intercepted by thin, ~0.5 cm thick, horizons of blackened plant debris.	*T. dombeii*, *M. edulis*, *Protothaca* sp. (1cm)	5071-5571 4427-4790
M2	Pale grey (5Y-7/1) sandy mud. Locally, intercepted by subtle horizons of sandier mud. Its base includes scattered, both fragmented and articulated, shells of marine bivalves. Its middle third and upper thirds are full of little, white gastropod shells and foraminifera.	*Littoridina* sp. (1 mm), *A. Tepida* (50 µm)	2531-2947 2286-2692 1934-2289 927-1104
M3	Olive gray (5Y-5/3) mud. At most pits it exhibits distinctive black, ~0.5 cm thick, organic horizons composed by blackened fibers and plant remains, likely algal mats. No fossil was found.		684-798
M4	Very sticky, brick red (2.5R 4/6), fine mud. Sharply punctuated by an extensive, tabular sand sheet (unit S) near its base. Where it also locally exhibits at least three ~0.5 cm thick, charcoal horizons. Although fossils were not found inside, shells of a freshwater snail are on surface.	*Planorbis* sp. (0.5 cm)	547-657
S	Tabular sand sheet disrupting M4, composed of very fine, yellowish-gray (5Y-6/4) sand. Contains mica and foraminifera. It is 1-30 cm thick and pinches out landward. Has a strongly erosive lower contact, and locally contains mud clasts and primary sedimentary structures.	*A. Tepida* (50 µm)	287-467 1-278 1-277 300-410*

Other features

- Sharp lower contact
- Erosive lower contact
- Rip-up mud clasts
- Outcrop of late-pliocene, marine sandstone

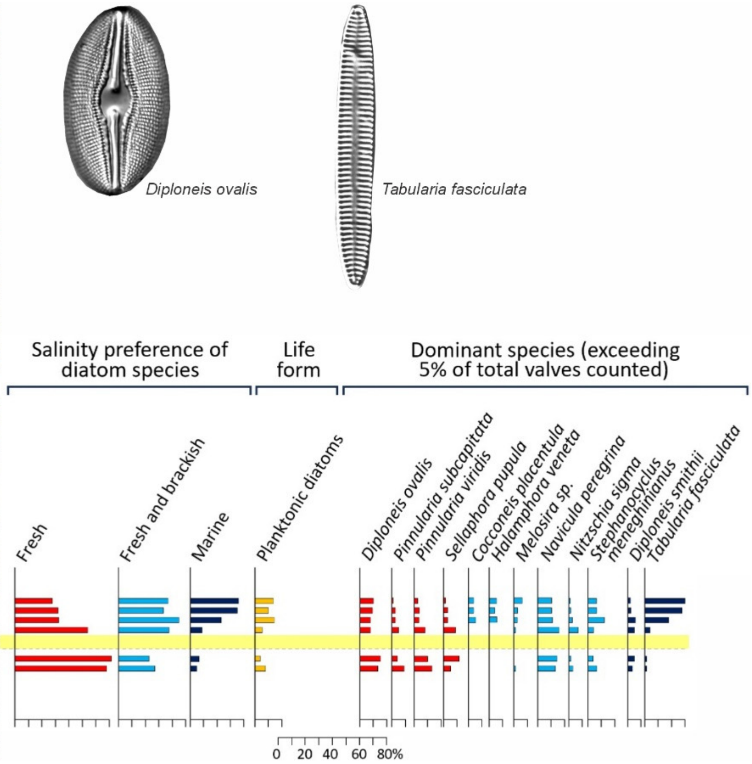
- Radiocarbon dating

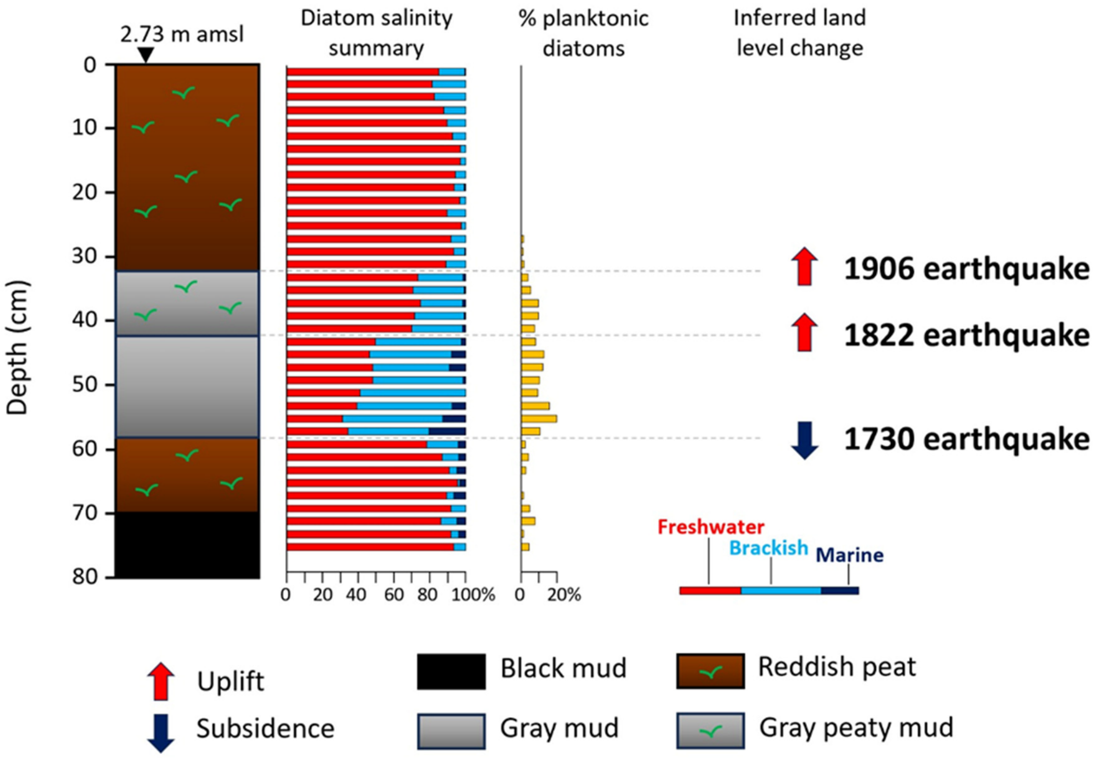


- Microfossils for dating and land level changes

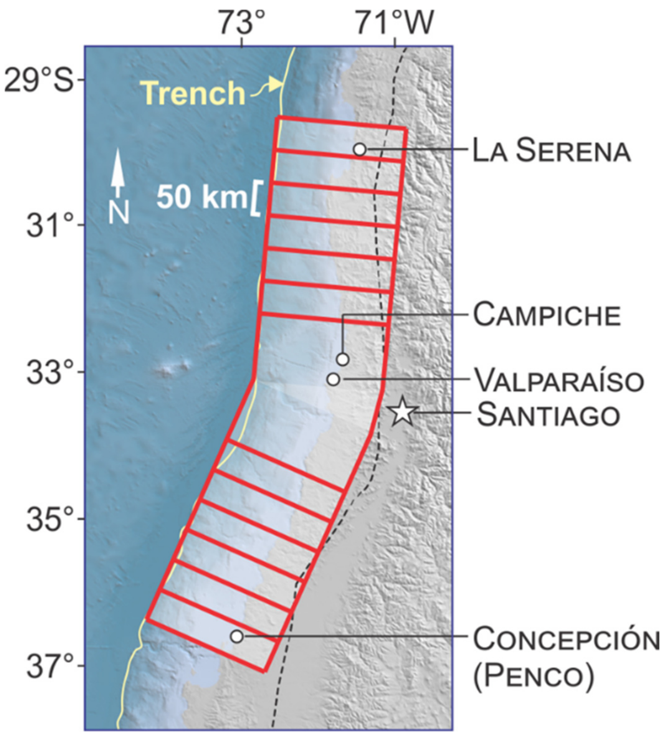
Pollen: *Pinus radiata*

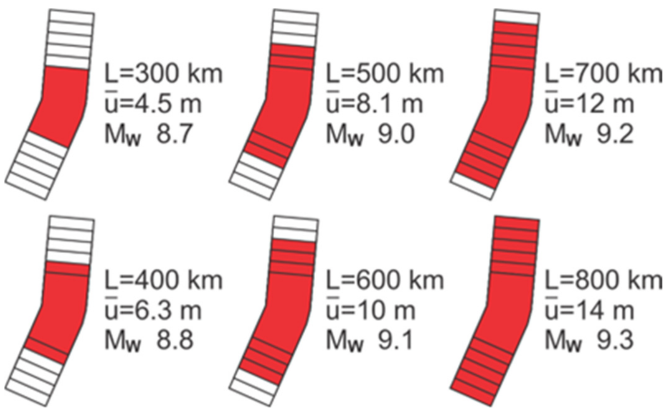
Diatoms: *Diploneis ovalis*

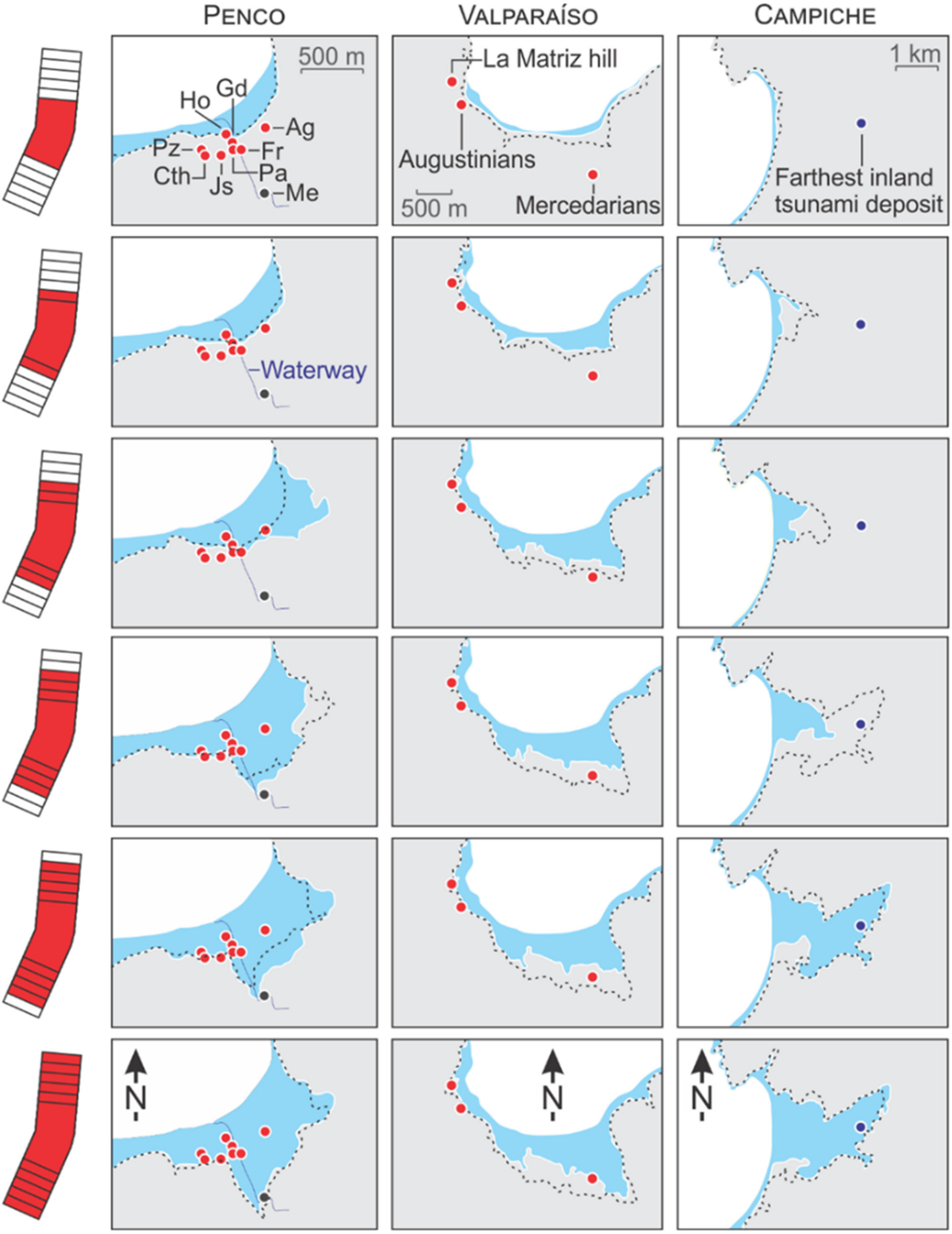



2.73 m amsl
Diatom salinity summary
% planktonic diatoms
Inferred land level change
Depth (cm)
1906 earthquake
1822 earthquake
1730 earthquake
Freshwater
Brackish
Marine
Uplift
Subsidence
Black mud
Gray mud
Reddish peat
Gray peaty mud

- Modeling


73°
71°W
29°S
31°
33°
35°
37°
Trench
N
50 km
LA SERENA
CAMPICHE
VALPARAÍSO
SANTIAGO
CONCEPCIÓN (PENCO)


L=300 km
$\bar{u}$=4.5 m
M_w 8.7
L=500 km
$\bar{u}$=8.1 m
M_w 9.0
L=700 km
$\bar{u}$=12 m
M_w 9.2
L=400 km
$\bar{u}$=6.3 m
M_w 8.8
L=600 km
$\bar{u}$=10 m
M_w 9.1
L=800 km
$\bar{u}$=14 m
M_w 9.3


Penco
Valparaíso
Campiche
500 m
Ho
Gd
Ag
Pz
Fr
Cth
Js
Pa
Me
La Matriz hill
Augustinians
500 m
Mercedarians
1 km
Farthest inland tsunami deposit
Waterway
N
N
N