LETTERS

Predecessors of the giant 1960 Chile earthquake

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It is commonly thought that the longer the time since last earthquake, the larger the next earthquake's slip will be. But this logical predictor of earthquake size[1], unsuccessful for large earthquakes on a strike-slip fault[2], fails also with the giant 1960 Chile earthquake of magnitude 9.5 (ref. 3). Although the time since the preceding earthquake spanned 123 years (refs 4, 5), the estimated slip in 1960, which occurred on a fault between the Nazca and South American tectonic plates, equalled 250–350 years' worth of the plate motion[3,6–10]. Thus the average interval between such giant earthquakes on this fault should span several centuries[3,9,10]. Here we present evidence that such long intervals were indeed typical of the last two millennia. We use buried soils and sand layers as records of tectonic subsidence and tsunami inundation at an estuary midway along the 1960 rupture. In these records, the 1960 earthquake ended a recurrence interval that had begun almost four centuries before, with an earthquake documented by Spanish conquistadors in 1575. Two later earthquakes, in 1737 and 1837, produced little if any subsidence or tsunami at the estuary and they therefore probably left the fault partly loaded with accumulated plate motion that the 1960 earthquake then expended.

The 1960 Chile mainshock resulted from a rupture nearly 1,000 km long on a north–south trending fault that conveys the subducting Nazca plate beneath South America at rates averaging 8 m per century[3]. Lurching westward above the rupture, the South America plate rose in a mostly offshore area while subsiding 1–2 m in a coastal downwarp[6] (Fig. 1b). The ensuing tsunami, with crests 10–15 m high in Chile[11], reached maximum heights of 10 m in Hawaii[12] and 6 m in Japan[13].

The 1960 earthquake was preceded historically by earthquakes in 1575, 1737 and 1837 (Fig. 1b; Supplementary Table S1). The reported effects from 1575 most nearly resemble those from 1960 (ref. 4). Conquistadors, at forts limited to the northern half of the 1960 rupture area, wrote of persistent marine inundation near Imperial, Valdivia and Castro that implies widespread tectonic subsidence. They also described a devastating tsunami near Valdivia (Supplementary Table S1, record 1). The 1737 earthquake, known only from secondary sources, damaged the few Spanish settlements then remaining south of Concepción. It lacks a reported tsunami, even though tsunamis from central Chile in 1730 and 1751 were noted locally[14] and in Japan[13,15]. The 1837 earthquake damaged towns along the central third of the 1960 rupture area and changed land levels along the southern half of that area. Its associated tsunami, by reportedly cresting 6 m high in Hawaii[12], provides evidence that the 1837 earthquake released almost half the seismic moment of the

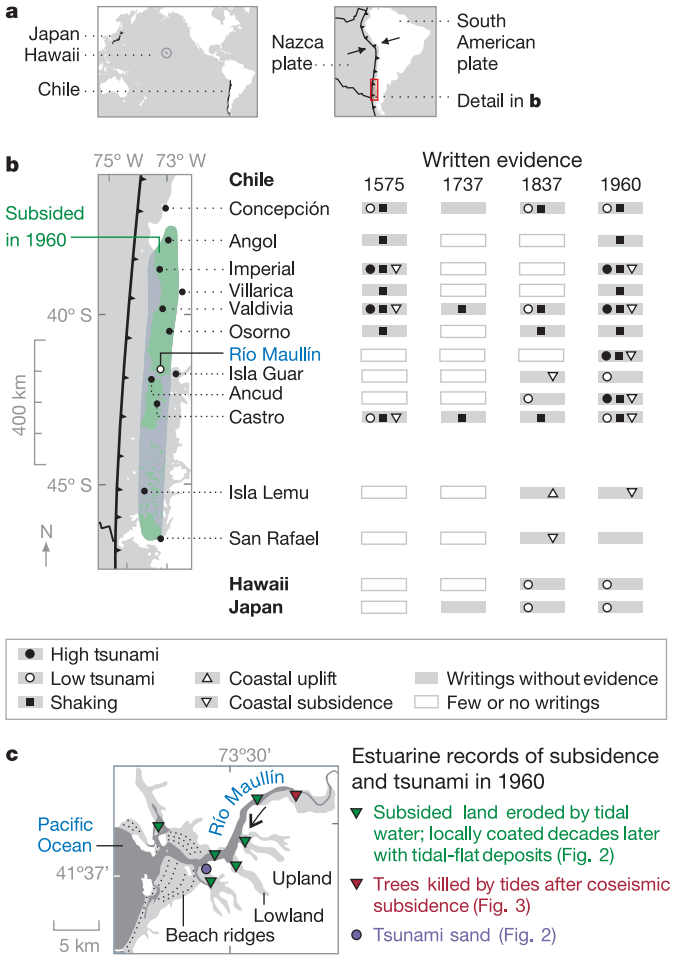

Figure 1 | Index maps. a, Plate-tectonic setting of south-central Chile. Paired arrows indicate plate convergence at 8.4 cm yr^{-1}. **b**, Documented effects of the 1960 earthquake and its historical predecessors. Compiled from refs 4, 5, 13 and 14, and from Supplementary Table S1. **c**, Study area along the Río Maullín. Barbed lines in **a** and **b** show seaward edges of subduction zones; teeth point down the plate boundary.

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1960 mainshock[16]. However, according to primary sources in Supplementary Table S1, the same tsunami caused little if any flooding at Valdivia and no reported damage anywhere in Chile or Ancud.

To further compare the 1960 earthquake with these historical earthquakes, and to gain perspective from earlier earthquakes as well, we reconstructed a 2,000-yr history of repeated subsidence and tsunamis at the Río Maullín estuary (Fig. 1b, c). Because of the estuary's central location, this history probably includes earthquakes from full-length breaks of the 1960 rupture area, while perhaps excluding earthquakes from partial ruptures to the north or south.

Our stratigraphic records are tied to modern analogues from 1960 along a nearly marine reach of the Río Maullín. There, 8 km inland from the sea (Fig. 1c, purple dot), markers of the 1960 earthquake extend across faint terraces and beach ridges stranded by net late Holocene emergence[17]. Eyewitnesses recall that the 1960 tsunami coated upper terraces with sand[18]. We traced the sand, up to 15 cm thick, more than 1 km inland across the buried 1960 soil in areas covered only by the highest post-earthquake tides (Figs 2a, b). In this same area, the sandy record of post-1960 storms extends just a few metres inland from the shore. On lower terraces, now covered routinely by tides, a 1960 pasture soil has been eroded and bioturbated on post-earthquake tidal flats. Waves and currents are now

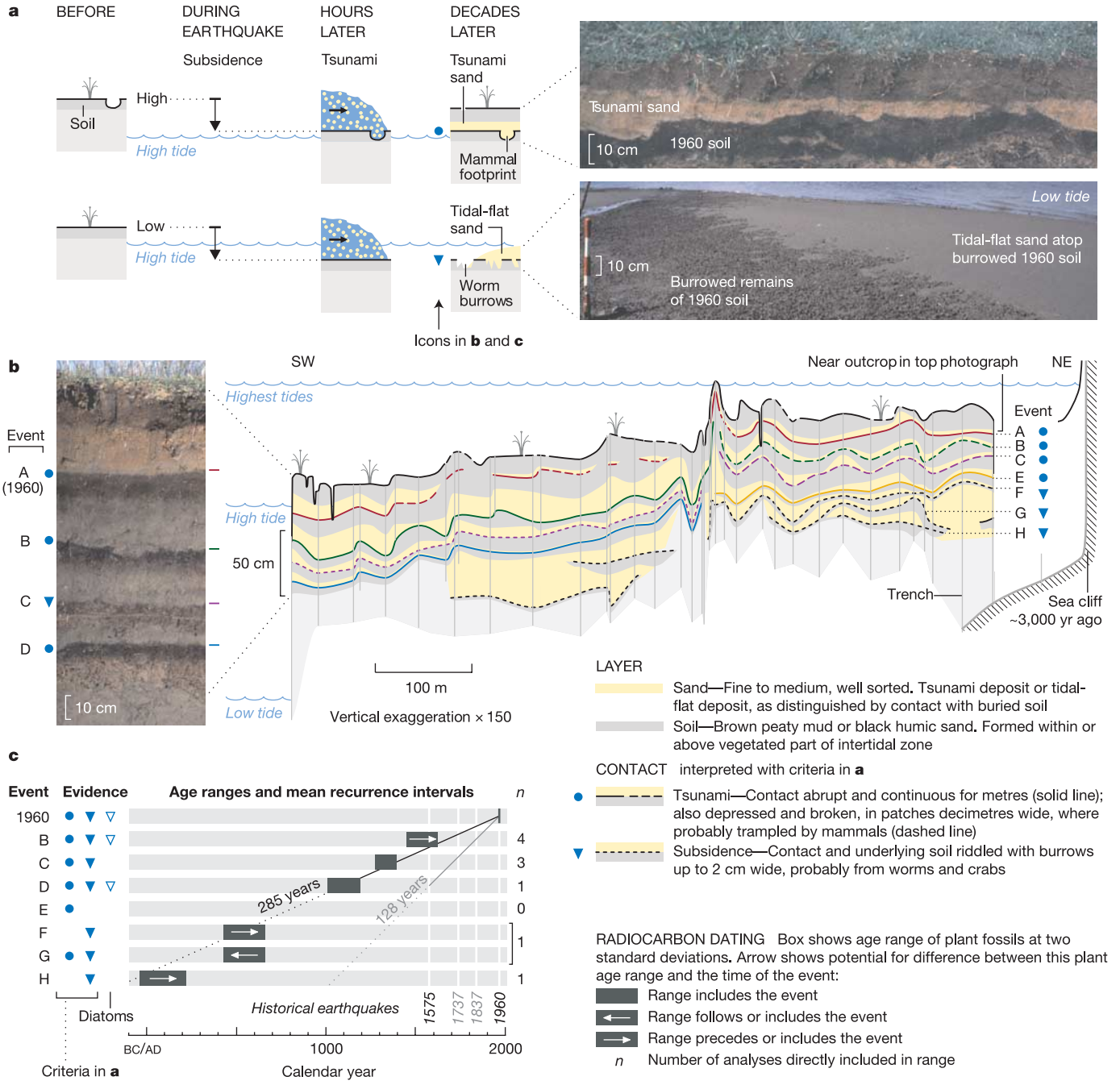

Figure 2 | Stratigraphic evidence for 1960 earthquake and its ancestors in area shown by purple dot in Fig. 1c. Supporting data in Supplementary Figs S1–S4 and Supplementary Tables S2–S4. **a**, Records of the 1960 earthquake that serve as modern analogues for inferring past occurrence of a tsunami and of coseismic subsidence. **b**, Sequences of such records correlated among trenches. Tides measured 1989, 2003, and 2004. **c**, Chronology of the inferred events compared with the historical sequence in Fig. 1b. Field evidence for subsidence and tsunami (solid blue circles and triangles at left) comes from all transects (Supplementary Figs S2 and S3). The average of the historical recurrence intervals, 128 yr, contrasts with the longer average intervals between the events recorded stratigraphically.

burying the remains of this soil with sand as much as 1 m thick (Fig. 2a), and with mud in sheltered areas.

Additional sand sheets mantle buried marsh and meadow soils beneath the 1960 soil. Using criteria from the 1960 examples, we interpret some of these sand sheets as tsunami deposits (blue dots in Fig. 2) and others as indicators of subsided, post-earthquake tidal flats (blue triangles). We traced these event records, which probably represent eight earthquakes in all (events A–H), among 60 trenches scattered along 2 km of transects (example, Fig. 2b). Like the 1960 earthquake (event A), four earlier events (B–D, G) produced tsunami deposits on meadows that post-earthquake tides rarely reached and correlative tidal-flat deposits on lower ground. Such evidence, assembled from all transects, is summarized by solid blue symbols in Fig. 2c. Some events are recorded less widely than the 1960 earthquake. The D sand sheet tapers landward without crossing a former beach ridge. The E sand sheet, found entirely inland from that ridge, may have been removed by erosion on the seaward side.

Diatom assemblages from soils that shortly predate and postdate tsunami deposition provide further evidence for subsidence during events A, B and D. In all three cases the assemblages above the tsunami sand are more nearly marine than those in the soil below (summary, Fig. 2c). The difference is clearest for the 1960 event. An attempted comparison for event C failed because the upper part of the buried soil is probably missing from erosion on a post-C tidal flat, and because the remnant soil is contaminated with burrow-filling tidal-flat sand.

In sum, our stratigraphy and paleoecology provide evidence for seven inferred pre-1960 earthquakes from the past 2,000 years (Fig. 2c). The youngest three (B–D), each marked by evidence for both subsidence and tsunami, occurred within the past 1,000 years. Event D dates to the two-sigma range AD 1020–1180—the age of growth-position stem bases of a rush (*Juncus procerus*) that tsunami sand surrounded. The event C tsunami similarly left sand around *Juncus balticus* and *Scirpus americanus* culms in a swale along a spur transect (Supplementary Fig. S3b); below-ground stems (rhizomes) that probably belonged to such plants yielded three statistically indistinguishable ages pooled as AD 1280–1390.

The tsunami deposit from event B probably exceeds the one from 1960 in thickness and landward extent. Because the 1837 tsunami was large in Hawaii[12,16], we expected this penultimate sand sheet to date from the early nineteenth century. Instead, a burned horizon mostly 2 cm below the sand dates to AD 1450–1510 or 1590–1620, as judged from four statistically equivalent ages on charred twigs. Because it followed the fire, probably by a century at most, we correlate event B with the extensive subsidence and devastating tsunami of 1575 (Fig. 1b).

We checked additional estuarine records in a further, futile search for signs of the 1837 earthquake. These records include trees that the 1960 earthquake lowered into tidal freshwater farther up the Río Maullín (red triangle, Fig. 1c). Residents on hand for the 1960 earthquake testify that a forest, green and emergent before the earthquake, lost its foliage from routine tidal submergence in the first few years thereafter. Several decades later, defoliated trunks dominated an area of 10 km^2. But several decades after the 1837 earthquake, a nautical chart[19] depicted all trees in this area as leafy (Fig. 3a). In an accompanying report[20], the expedition botanist does not mention dead or dying trees among the forest's riparian plants and animals, which he studied for four days. We cut slabs of 15 dead standing trees in 2003 to estimate their lifespans by counting annual rings. We assume these trees died in 1960. In that case, ten of them were alive in 1837 and two in 1737 (Fig. 3b). This finding suggests that the forest failed to subside in 1837 as much as it did in 1960, in agreement with the nautical survey and the botanist's report.

Shoreline changes provide additional evidence that the 1837 earthquake did not produce 1960-size subsidence along the Río Maullín. Some of the islands and pastures that subsided in 1960 into the middle or lower part of the intertidal zone are barren intertidal or subtidal flats (Fig. 1c, green triangles). At a similar time after the 1837 earthquake, these areas were charted[19] as emergent and vegetated (Supplementary Fig. S1b).

Earthquakes evident in these various estuarine records thus recurred less often than did earthquakes in the historical sequence: 1575, 1737, 1837, 1960 (Fig. 2c). The best-defined of the earthquake intervals recorded geologically, which together span most of the past millenium, average nearly 300 yr—more than double the historical average of 128 years. The 1960 earthquake ended a 385-year interval that includes the years 1737 and 1837. The poorly understood earthquakes of 1737 and 1837 probably released too little seismic moment midway along the 1960 rupture to leave tsunami deposits or subsidence stratigraphy at the Río Maullín.

Where size varies markedly among successive earthquakes on the same part of a fault, much of the fault slip during the largest earthquakes may have thus accumulated before earlier earthquakes of smaller size. Such storage through multiple recurrence intervals probably helps to explain the enormity of the 2004 Sumatra–Andaman earthquake. The fault slip in 2004 near the Nicobar Islands amounted to 10 m (ref. 21) in an area where the fault had last ruptured in 1881 during an earthquake of estimated magnitude 7.9 (ref. 22). By contrast, the fault loading between 1881 and 2004 amounted to less than 4 m at plate-convergence rates recently estimated from satellite geodesy[22] and less than 7 m at rates inferred from long-term plate motions[3]. As in the 1960 Chilean case, the 2004 earthquake may thus have used accumulated plate motion that a previous earthquake left unspent.

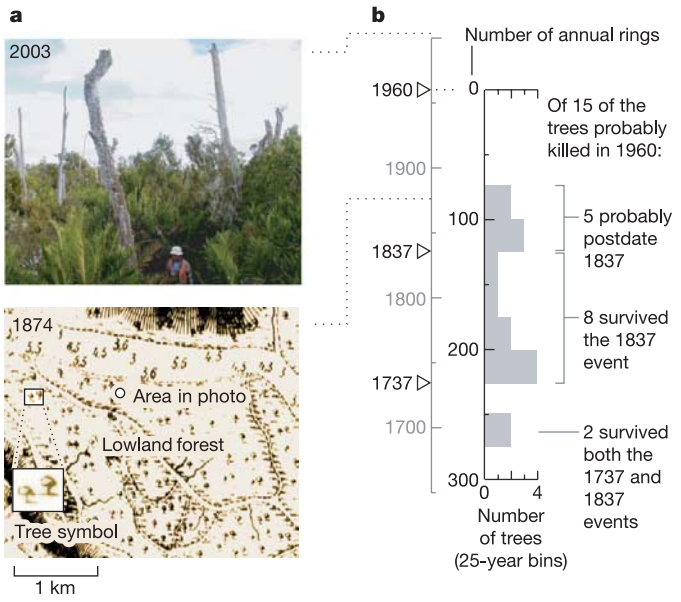

Figure 3 | Arboreal evidence for difference between the 1960 and 1837 earthquakes, in area shown by red triangle in Fig. 1c. (See Supplementary Fig. S1d, e). **a**, Views of riparian forest several decades after each earthquake (1874 image from ref. 19). **b**, Counts of annual rings in trees probably killed in 1960 (species, Supplementary Table S4).

Received 9 March; accepted 15 June 2005.

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Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

Acknowledgements This work was supported by Chile's Fondo Nacional de Desarrollo Científico y Tecnológico (Fondecyt) and by the US Geological Survey. Logistical help came from the Municipality of Maullín and its people (M. I. Silva, P. Soto, R. Vergara, J. Gallardo, G. Andrade, J. Soarzo and C. Ruiz), and from the Servicio Hidrológico y Oceanográfico of the Armada de Chile. The manuscript incorporates suggestions from S. Barrientos, S. Bondevik, C. Lomnitz, A. Nelson, K. Wang, J. Clague and E. Geist.

Author Contributions M.C. and B.A. led the fieldwork and writing. F.T. studied documents; Y.S. studied diatoms; G.M. studied tree slabs. M.L. and I.S. contributed to three seasons of fieldwork, G.M. and C.Y. to two, and A.E., M.H., T.K., J.K.M., C.P.R., Y.R. and M.S. to one.

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Figure S1 Maps and airphotos

a Map of Río Maullín estuary by Francisco Vidal Gormaz, 1874

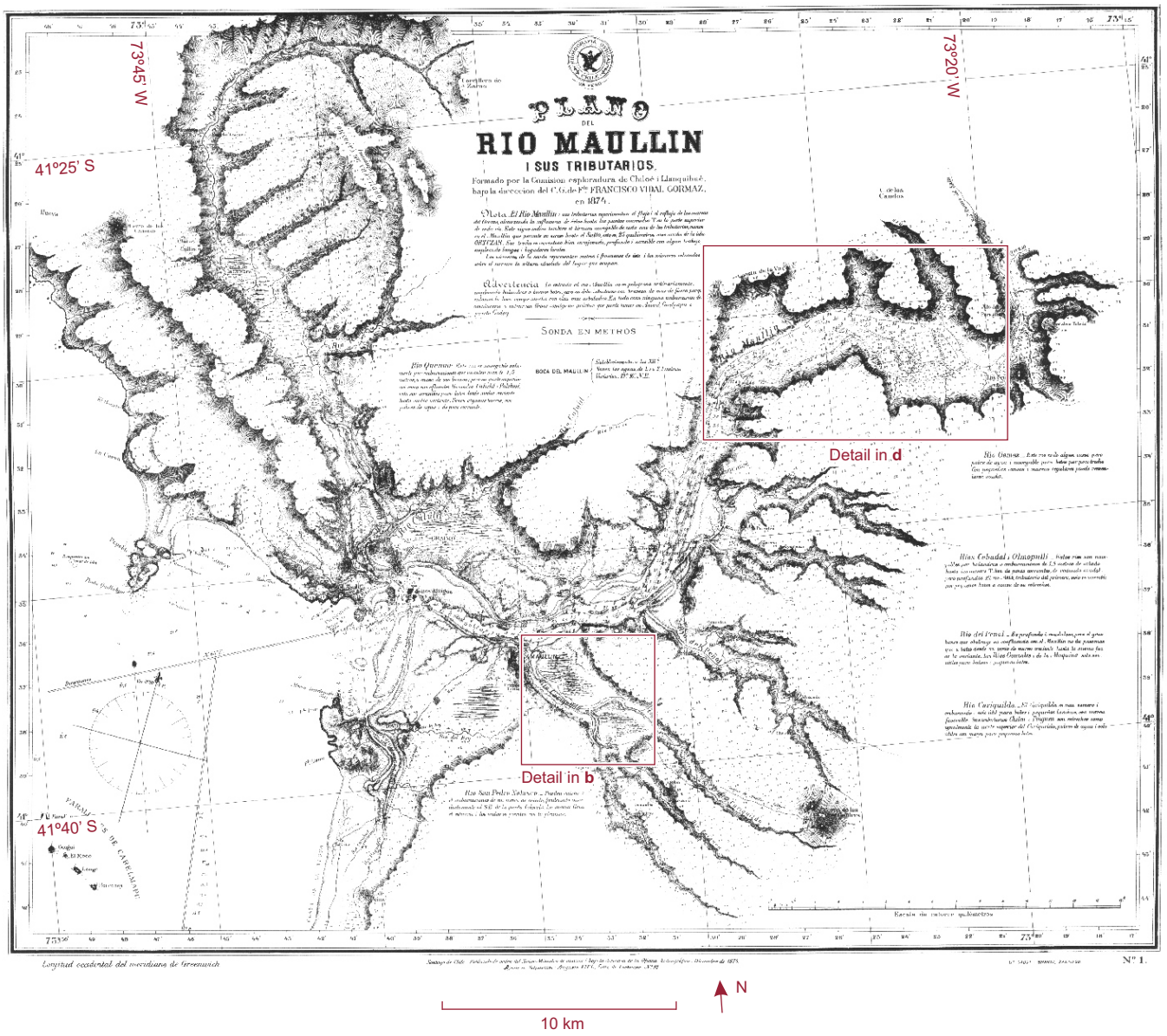
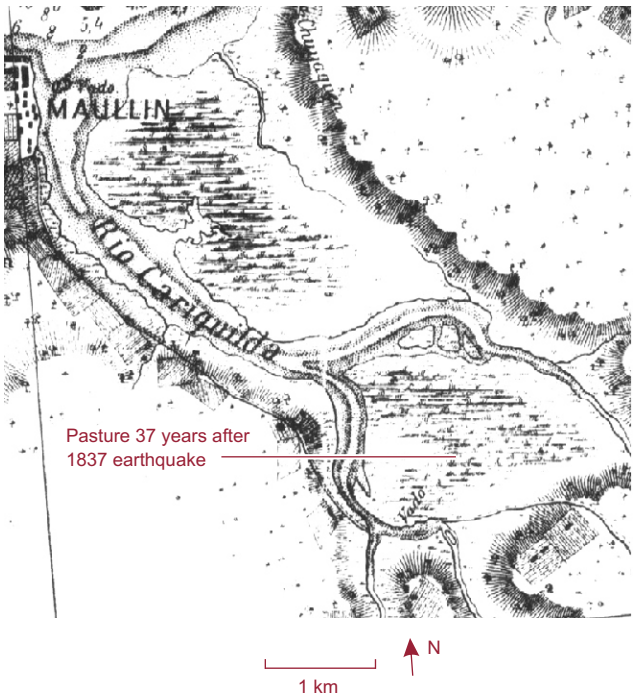
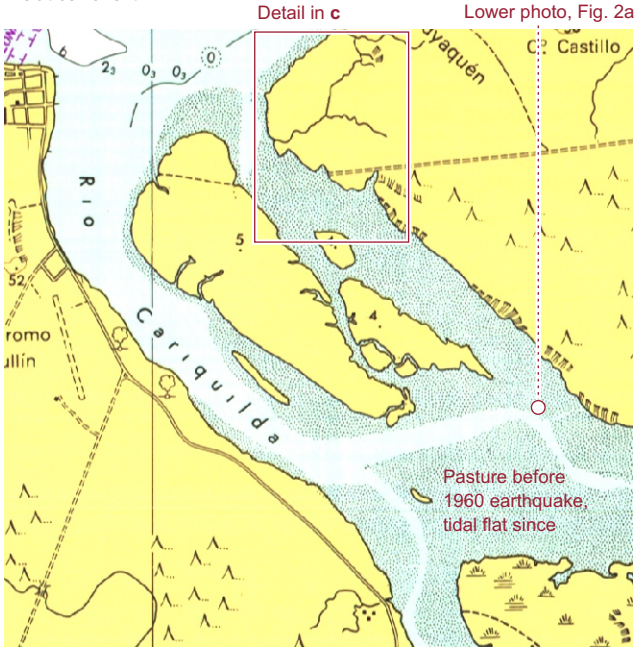


Figure S1, *continued*

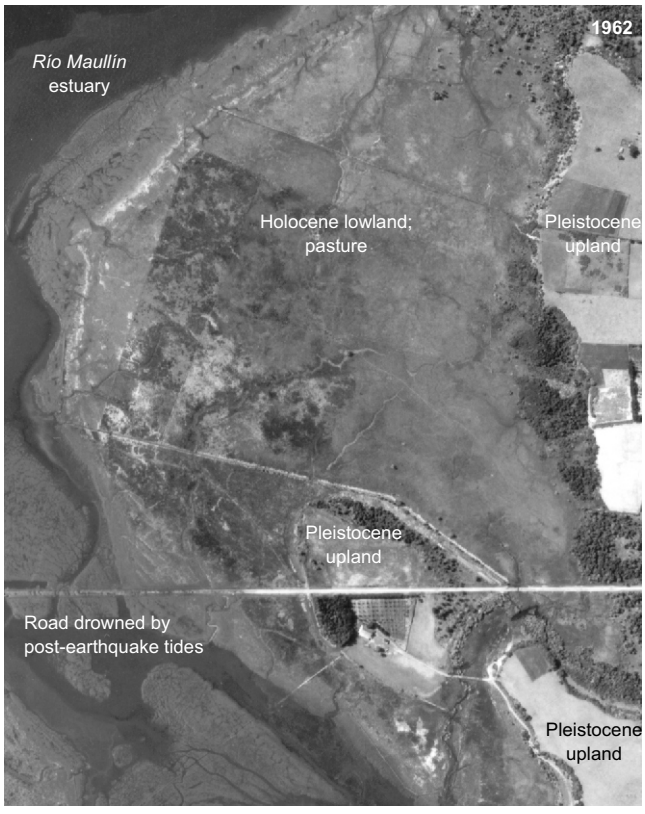
b Vidal Gormaz map of lower Chuyaquen, 1874, compared with a post-1960 nautical chart

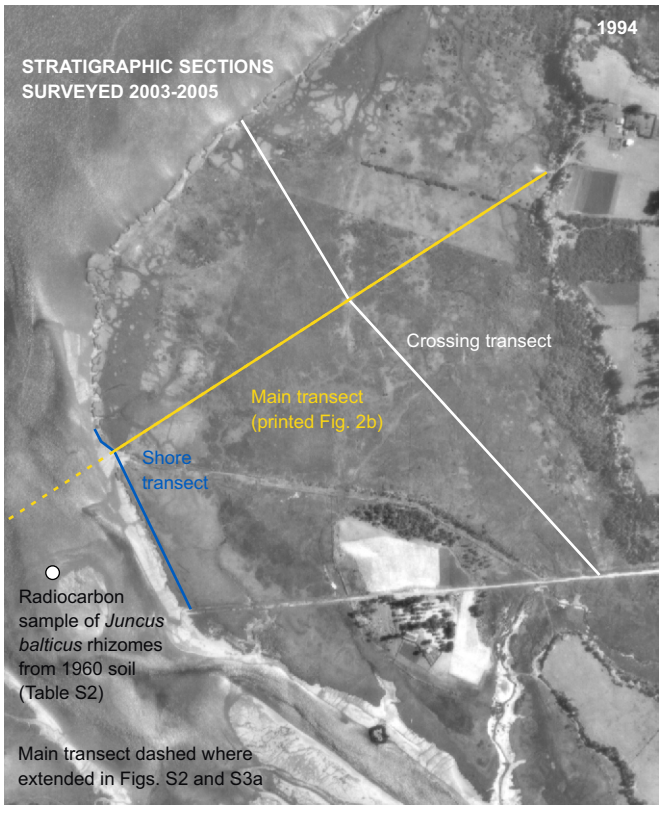




From "Canal Chacao," by Servicio Hidrográfico y Oceanográfico de la Armada de Chile, scale 1:50,000, published 1993. Planimetry from aerial photographs taken 1987. Bathymetry measured in or before 1986.

c Vertical airphotos showing setting of stratigraphic cross sections in printed Fig. 2b and in supplementary Figs. S2 and S3



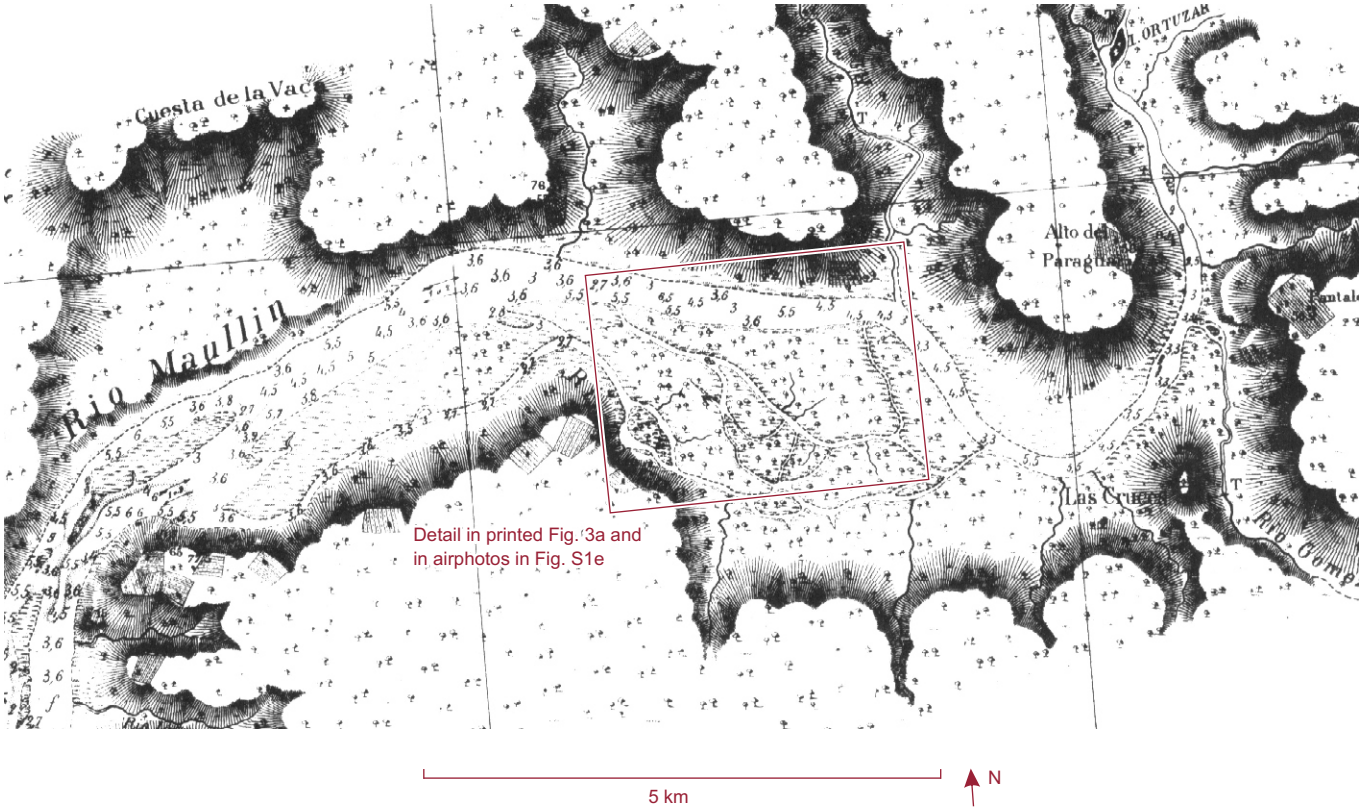


0 1 km N

Approximate scale

Figure S1, *continued*

d Vidal Gormaz map of Misquihué and vicinity



e Vertical airphotos of area outlined in d. The tree lifespans in printed Fig. 3b were measured on samples cut from trees dead in this area.

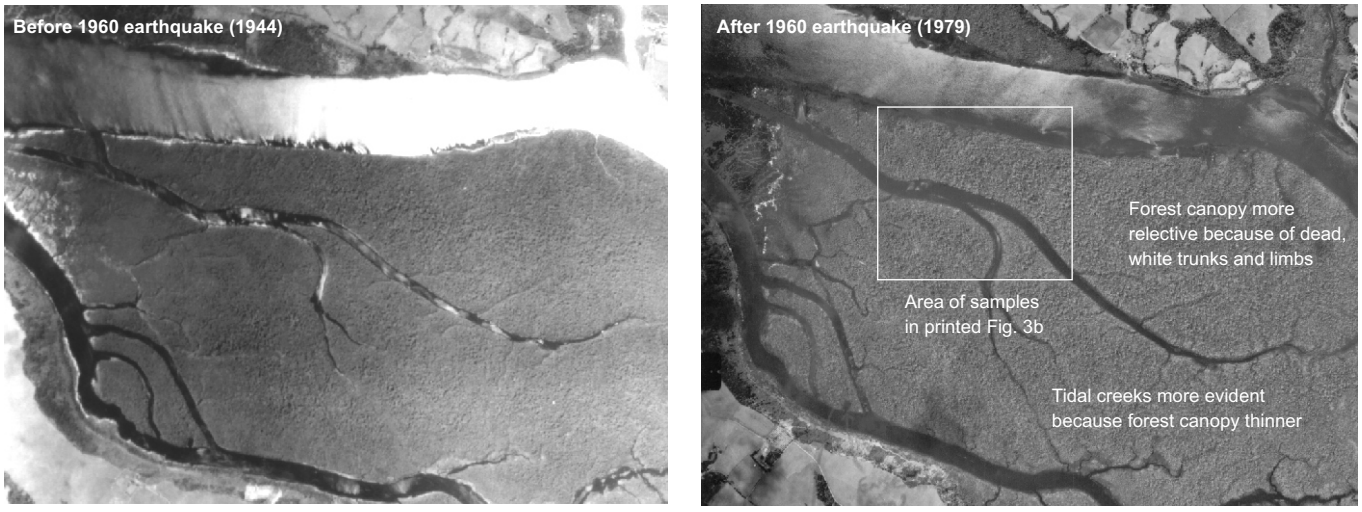


Figure S2 Stratigraphic units (location of transects shown in Fig. S1c)

a Events recorded beneath pasture on seaward parts of the transect plotted below and of the additional transect plotted in **d**

EVENT AND ITS DISTINGUISHING STRATIGRAPHIC FEATURES

A (1960) **Sand sheet** widespread, tabular, less than 15 cm thick, interrupted mainly by post-1960 hoofprints. Sand tapers at ridges, as at long trench in Fig. S3b. **Buried soil** dark brown, sandy. Commonly contains rhizomes of *Juncus balticus* from 1960; these are difficult to break because they retain strong vascular bundles. **Contact** with overlying sand sheet abrupt. The sand surrounds decayed stems of herbaceous plants from 1960, in growth position.

B **Sand sheet** widespread, tabular, commonly thicker than that from 1960. **Buried soil** black, sandy. Lacks fossil rhizomes but contains angular charcoal, probably from herbs or small shrubs, in a burned horizon a few centimeters below the soil top. **Contact** with overlying sand sheet abrupt. The sand surrounds carbonized stems of herbaceous plants, in growth position.

C Detail below

D **Sand sheet** less than 10 cm thick, tapering inland. Field evidence for event D not recognized in NE part of main transect, where the buried soils of events D and C probably merge. **Buried soil** distinctly black and humic in upper part, brown and muddy below. At radiocarbon locality for event D at seaward (SW) end of main transect (Fig. S3a), soil divided by a sand layer a few millimeters thick. **Contact** with overlying sand sheet is typically abrupt, except at low altitude near SW end of crossing transect, where locally diffuse from filled burrows a few millimeters wide.

C **Sand sheet** varies in thickness more than does the sand from events B and 1960. The C sand, though commonly less than 10 cm thick, locally thickens to 0.5 m, as in the long trench in Fig. S3b. Such thickening is common on modern tidal flats where bars and megaripples of sand now migrate across bioturbated remains of the 1960 soil (seen near site in lower photo, printed Fig. 2a). **Buried soil** black and humic in upper part, brown and muddy below. Contains sand layer <1 cm thick at seaward (SW) end of main transect and transect, and along shore transect. The layer lacks buried-soil evidence for more than about 0.5 m of associated subsidence. **Contact** with overlying sand sheet diffuse from filled burrows a few millimeters wide.

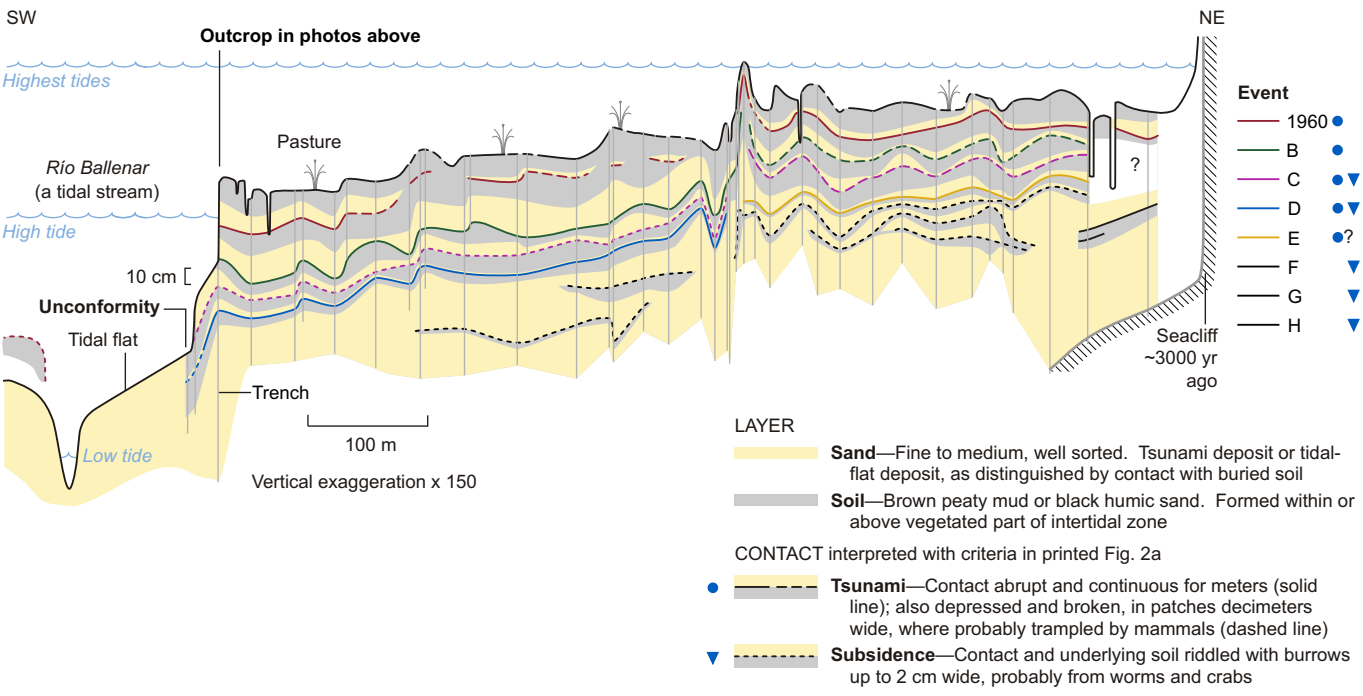
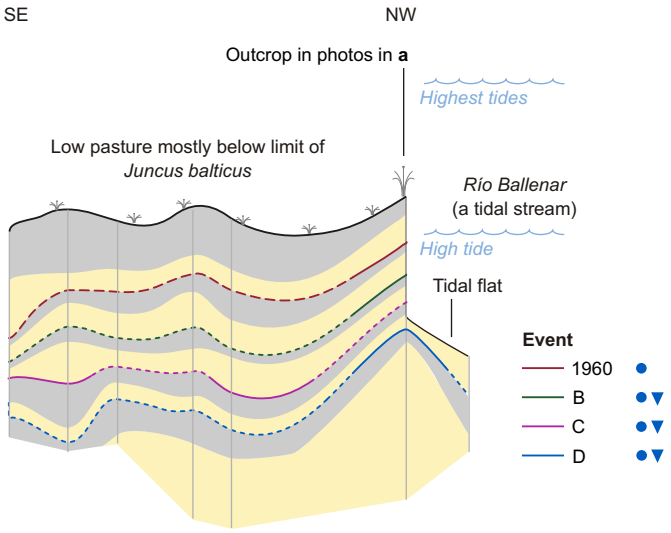


Figure S2 Stratigraphic units, continued

b Beneath pasture on shore transect



LAYER

Sand—Fine to medium, well sorted. Tsunami deposit or tidal-flat deposit, as distinguished by contact with buried soil

Soil—Brown peaty mud or black humic sand. Formed within or above vegetated part of intertidal zone

CONTACT interpreted with criteria in printed Fig. 2a

● **Tsunami**—Contact abrupt and continuous for meters (solid line); also depressed and broken, in patches decimeters wide, where probably trampled by mammals (dashed line)

▼ **Subsidence**—Contact and underlying soil riddled with burrows up to 2 cm wide, probably from worms and crabs

EVENT AND ITS DISTINGUISHING STRATIGRAPHIC FEATURES

1960 **Sand sheet** mostly discontinuous, filling animal hoofprints. commonly 10 cm thick. **Buried soil** dark brown, sandy. Commonly contains rhizomes of *Juncus balticus* from 1960; these are difficult to break because they retain strong vascular bundles. **Contact** with overlying sand sheet abrupt but undulatory and locally near vertical, where depressed by hoofprints that probably predate the 1960 tsunami. The tsunami sand fills these depressions.

B **Sand sheet** widespread, tabular, 10-20 cm thick. **Buried soil** black, sandy. **Contact** with overlying sand sheet diffuse from filled burrows a few millimeters wide. This bioturbation not seen on other transects, probably because the contact there is at higher elevation, too high to have become a tidal flat after the land subsided during the B (1575) earthquake.

C **Sand sheet** 15-25 cm thick. **Buried soil** black and humic in upper part, brown and muddy below. Contains sand layer 1-2 cm thick. **Contact** with overlying sand sheet ranges from abrupt and scarcely bioturbated to diffuse and abundantly burrowed; burrows a few millimeters wide.

D **Sand sheet** less than 10 cm thick. **Buried soil** distinctly black and humic in upper part, brown and muddy below. Soil divided by a sand layer a few millimeters thick. **Contact** with overlying sand sheet is typically abrupt, lightly bioturbated from filled burrows a few millimeters wide.

Figure S2 Stratigraphic units, continued

c Beneath pasture on landward parts of main transect (plotted below)

Bank of shallow creek. Shovel handle 0.5 m, divisions 0.1 m

Trench wall. Rule 1.0 m; divisions 0.1 m

	EVENT AND ITS DISTINGUISHING STRATIGRAPHIC FEATURES
1960	**Sand sheet** <10 cm thick. Thickest in depressions on 1960 surface. Locally interrupted by post-1960 hoofprints. **Buried soil** dark brown, sandy. **Contact** with overlying sand sheet abrupt to diffuse, from rootlets.
1960	Detail above
B	**Sand sheet** <10 cm thick, typically broken (by hoofprints?). **Buried soil** black, sandy. **Contact** with overlying sand sheet abrupt to diffuse.
C	**Buried soil** black, sandy. Lower part probably contains soil that marks event D to the SW. **Sand sheet <**10 cm thick but too thick to correlate with the sand sheet from event D. The sand is typically broken (by hoofprints?). **Contact** with overlying sand sheet abrupt.
E	**Sand sheet** mostly <10 cm thick. **Buried soil** brown, muddy. **Contact** with overlying sand sheet abrupt, smooth, continuous. This distinctive combination of field evidence for event E not recognized to the SW.*
F	**Sand sheet** <10 cm thick. **Buried soil** distinctly black in uppermost centimeter and brown and muddy below. Charcoal locally common. **Contact** with overlying sand sheet is diffuse from filled burrows a few millimeters wide.
G	
H	**Sand sheet** <10 cm thick. The sand sheet between the G and H soils may be absent near NE end of main transect, where a muddy tidal-marsh soil rests directly on the buried A horizon of another such soil.**Buried soil** brown, muddy. **Contact** with overlying sand sheet abrupt, smooth, continuous.

*In the seaward (SW) part of the main transect, the buried soil that marks event E was probably destroyed by bioturbation and erosion on a post-E tidal flat. Such erosion is likely because the soil itself, being muddy, probably formed in the intertidal zone. We infer that an earthquake, represented by a tsunami sand sheet atop the E soil, lowered this already intertidal soil to the level of a tidal flat, where postearthquake worms, crabs, wind waves, and currents removed it.

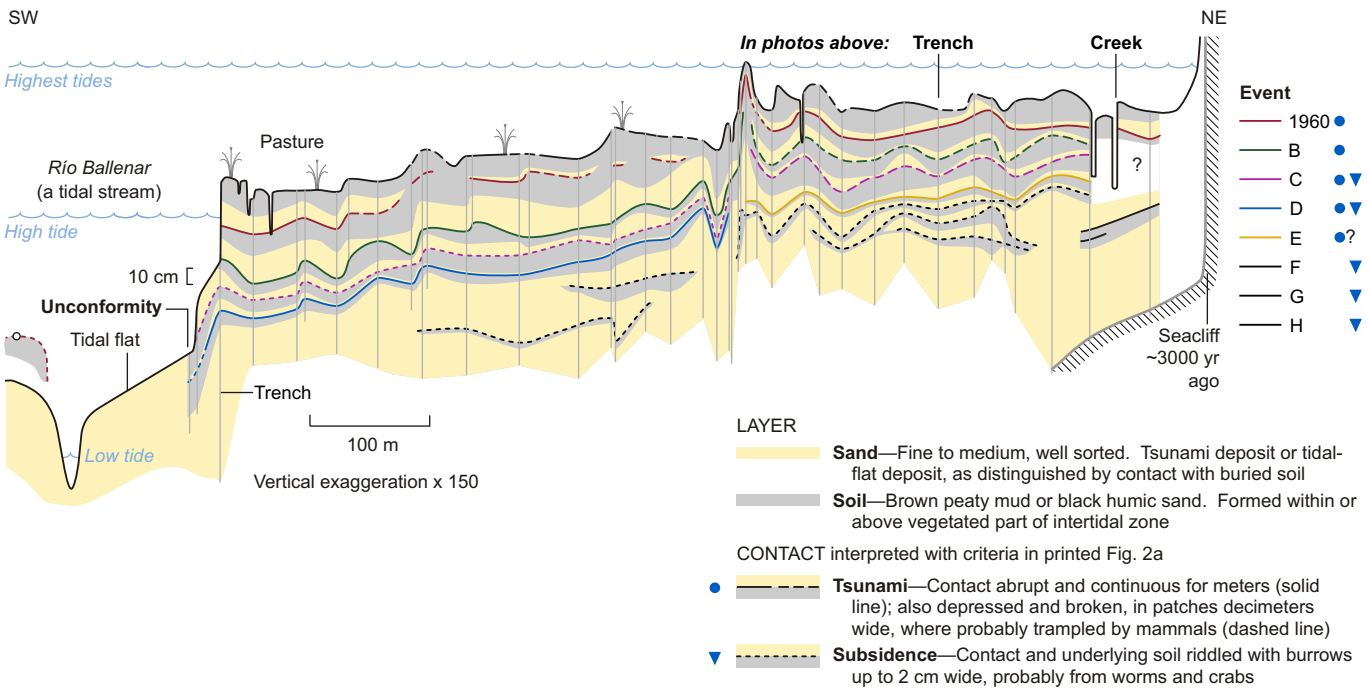


Figure S2 Stratigraphic units, continued

d Beneath pasture on landward (ESE) part of crossing transect (plotted below)

Trench walls. Rules 1.0 m; main divisions 0.1 m

EVENT AND ITS DISTINGUISHING STRATIGRAPHIC FEATURES

1960 **Sand sheet** <10 cm thick. Thickest in depressions on 1960 surface. Locally interrupted by post-1960 hoofprints. **Buried soil** dark brown, sandy. **Contact** with overlying sand sheet abrupt to diffuse, from rootlets.

B **Sand sheet** <10 cm thick, typically broken (by hoofprints?). **Buried soil** black, sandy. **Contact** with overlying sand sheet abrupt to diffuse.

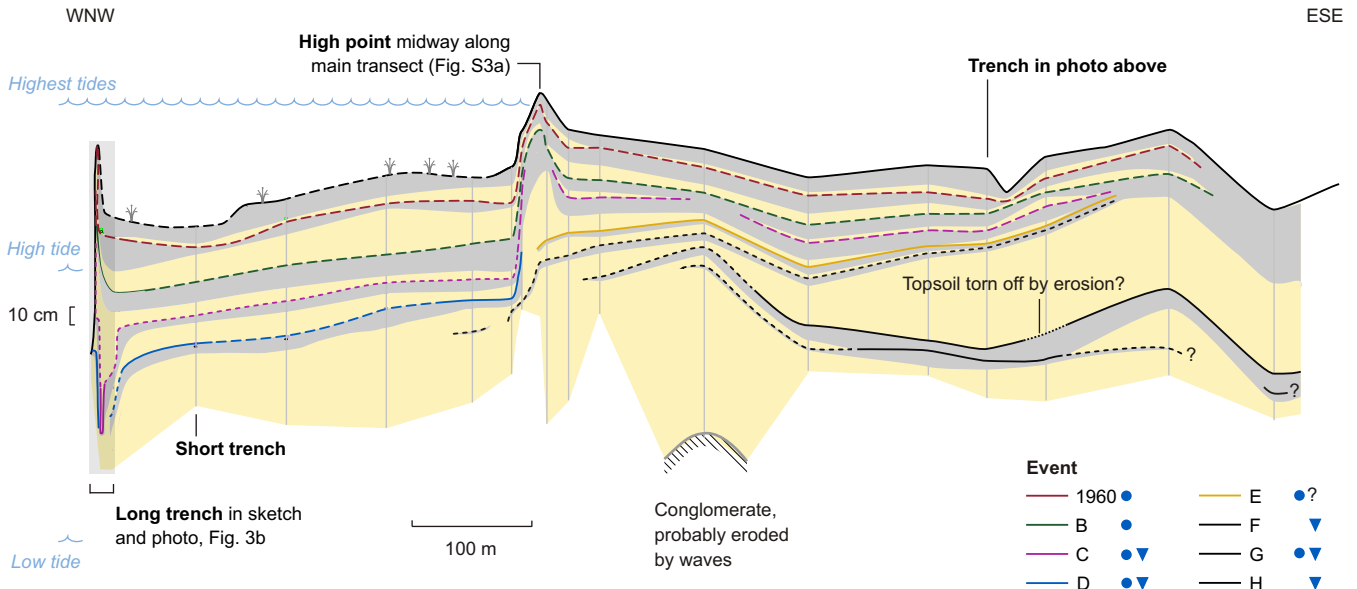
C **Sand sheet <**10 cm thick, commonly broken (by hoofprints?).**Buried soil** black, sandy. Lower part probably contains soil that marks event D to the SW. **Contact** with overlying sand sheet abrupt.

E **Sand sheet** <10 cm thick except beneath former beach ridge (at "high point"), where nearly 40 cm thick and probably eolian. Sand probably not deposited on tidal flat because underlying contact lacks burrrows; therefore not deposited soon after subsidence of salt-marsh soil. Sand perhaps entirely eolian.**Buried soil** brown, muddy; probably a salt-marsh soil whose plant remains have been lost to oxidation. **Contact** with overlying sand sheet abrupt, smooth, continuous.

F **Sand sheet** <10 cm thick. **Buried soil** distinctly black in uppermost centimeter and brown and muddy below. Charcoal locally common. **Contact** with overlying sand sheet is diffuse from filled burrows a few millimeters wide.

G **Sand sheet** above soil is 5-60 cm thick, probably of compound origin: lowest part deposited by tsunami where underlying soil is at low altitude, otherwise deposited on tidal flat after subsidence of soil. **Buried soil** brown, muddy. **Contact** with overlying sand sheet abrupt, smooth, continuous where soil is at low altitude, burrowed at higher altitude.

H **Sand sheet** above soil is <5 cm thick, probably deposited on tidal flat. **Buried soil** brown, muddy. **Contact** abrupt and smooth where overlain directly by G soil, bioturbated where overlain by sand sheet.



Vertical exaggeration x 150
Same scale as in Fig. S3a

LAYER

Sand—Fine to medium, well sorted. Tsunami deposit or tidal-flat deposit, as distinguished by contact with buried soil

Soil—Brown peaty mud or black humic sand. Formed within or above vegetated part of intertidal zone

CONTACT interpreted with criteria in printed Fig. 2a

Tsunami—Contact abrupt and continuous for meters (solid line); also depressed and broken, in patches decimeters wide, where probably trampled by mammals (dashed line)

Subsidence—Contact and underlying soil riddled with burrows up to 2 cm wide, probably from worms and crabs

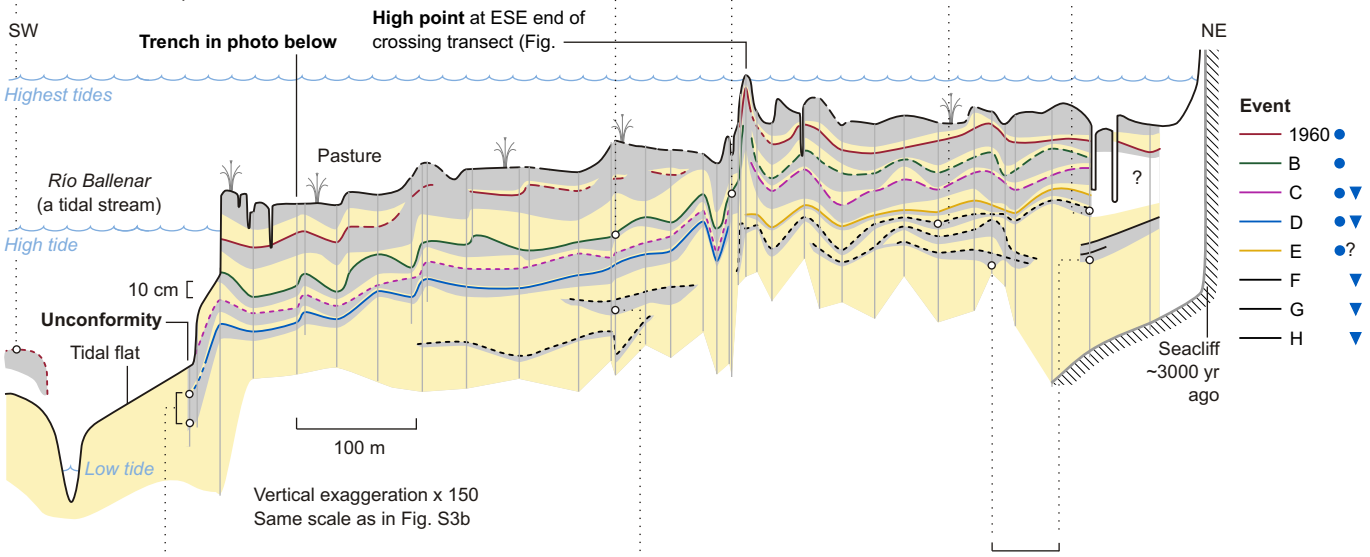
Figure S3 Setting of radiocarbon samples

a Main transect (location, Fig. S1c)

Test of 1960 date Rhizomes of *Juncus balticus* rooted in an erosional remnant of the 1960 soil, gave an age in the range A.D. 1668-1953 (sample 1, Table S2). The remnant, 125 m SE of the cross section (Fig. S1c, right photo), looks like the one in printed Fig. 2a. The dated rhizomes are typical of those in no buried soil other than the 1960 soil: fibrous, difficult to break. They probably contain carbon taken from the atmosphere in the 1940s and 1950s.

Dating of event B Charcoal from two trenches, collected from a widely preserved burned horizon a few centimeters below to top of the buried soil, gave concordant ages (samples 2 and 4, left; samples 3 and 5, right). Their pooled mean corresponds mainly to AD 1450-1505, which we interpret as a limiting-maximum age for the B event.

Dating of event F Charcoal (left) and carbonized *Scirpus americanus* rhizomes (right) provide limiting-maximum ages for event F (samples 14-16). The ages range from AD 30-530 to AD 440-650.



Dating of event D

THE UPPER DOT locates *Juncus procerus* stems that tsunami sand of event D surrounded. The stems gave an event age of AD 1020-1180 (sample 10). This age is supported by a close limiting-maximum event age of AD 890-1130 that was obtained on a rhizome of *Juncus balticus* 2 cm below the top of the D soil in another trench (Fig. 2b, sample 11).

THE LOWER DOT denotes *Spartina densiflora* rhizomes 11 cm below the top of the soil. These rhizomes gave an age of 1130-390 BC (sample 12). We don't understand this result, because farther inland (to the NE) along the cross section, several sand sheets of marine origin formed between 300 BC and AD 1000 (events E through H).

Dating of event F? *Spartina densiflora* rhizomes 6-7 cm below the bioturbated top of the soil gave an age of AD 570-760 (sample 13). The age supports correlation with the F event, which extends widely in the NE part of this cross section.

Dating of events H and G A bark-bearing twig low in a bioturbated soil sets a limiting-maximum age range of 20 BC to AD 220 for event H (left; sample 18). A similar bark-bearing stick similarly limits event G, event H, or both to being younger than AD 80-330 (right; sample 17).

LAYER

Sand—Fine to medium, well sorted. Tsunami deposit or tidal-flat deposit, as distinguished by contact with buried soil

Soil—Brown peaty mud or black humic sand. Formed within or above vegetated part of intertidal zone

CONTACT interpreted with criteria in printed Fig. 2a

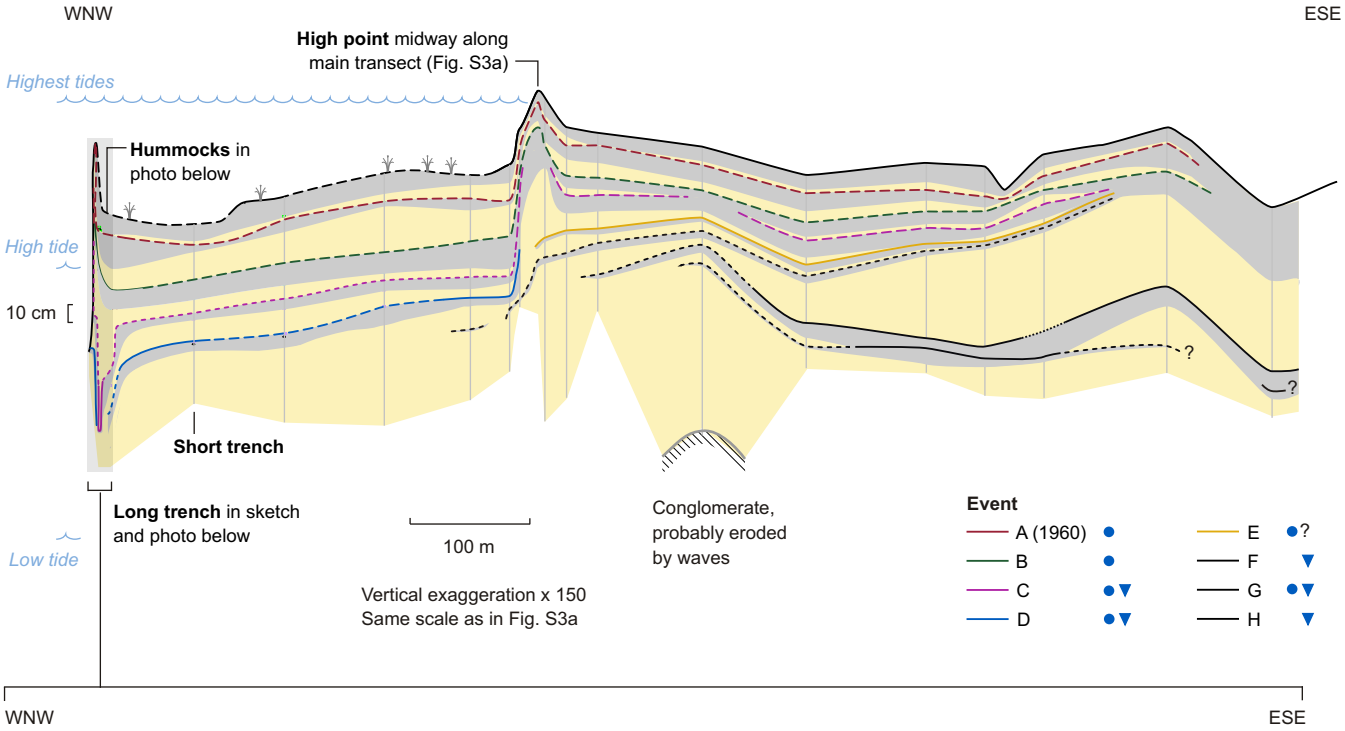
● **Tsunami**—Contact abrupt and continuous for meters (solid line); also depressed and broken, in patches decimeters wide, where probably trampled by mammals (dashed line)

▼ **Subsidence**—Contact and underlying soil riddled with burrows up to 2 cm wide, probably from worms and crabs

Trench of typical size View to NE along SW part of main stratigraphic transect. Trench location plotted on this transect, above. Gray spoils from additional trenches in background; Pleistocene upland (Fig. S1c) on skyline. Ruler, 1 m.

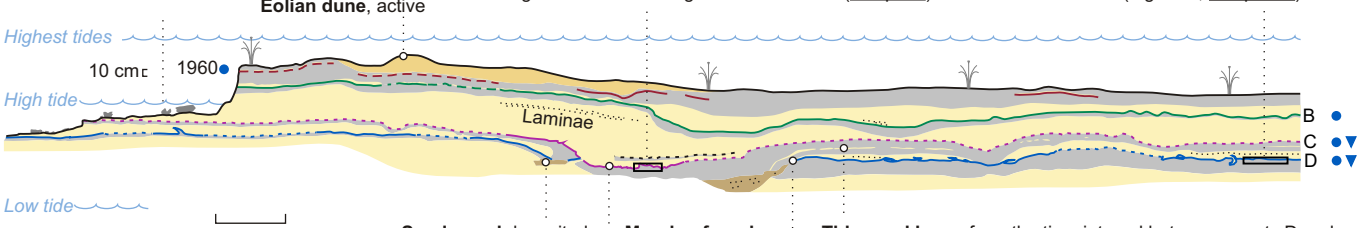
Figure S3, *continued*

b Crossing transect (location, Fig. S1c)



Dating of event C Rhizomes of *Juncus balticus* and *Scirpus americanus* are preserved in growth position 1-4 cm beneath the floor of a swale that event-C tsunami coated with sand. Three of them yielded concordant ages pooled as AD 1280-1390 (samples 6-8 in Table S2). We interpret this range as the time of event C. A fourth rhizome gave a discordant age of AD 990-1160 (sample 9).

Dating of event D A rhizome of *Juncus balticus* 2 cm below the top of the soil gave an age of AD 890-1130 (sample 11). This close limiting-maximum event age accords with AD 1020-1180, the D event age measured more exactly with a sample from another trench (Fig. S3a, sample 10).

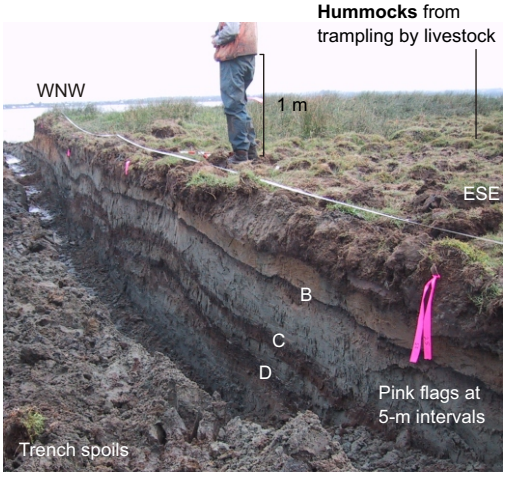


Sandy mud deposited under overhang in slumping bank of swale

Margin of swale truncates contact marking event D.

Thin sand layer, from the time interval between events D and C, is limited to the seawardmost trench in each cross section (on the main transect, it crops out in the site in the photo in printed Fig. 2b). It may represent a minor tsunami generated off Chile or a tsunami of remote origin.

Floor of swale, after being covered by tsunami sand during event C, escaped bioturbation and erosion evidenced elsewhere by filled burrows.



LAYER

Sand—Fine to medium, well sorted. Tsunami deposit or tidal-flat deposit, as distinguished by contact with buried soil

Soil—Brown peaty mud or black humic sand. Formed within or above vegetated part of intertidal zone

CONTACT interpreted with criteria in printed Fig. 2a

● **Tsunami**—Contact abrupt and continuous for meters (solid line); also depressed and broken, in patches decimeters wide, where probably trampled by mammals (dashed line)

▼ **Subsidence**—Contact and underlying soil riddled with burrows up to 2 cm wide, probably from worms and crabs

Figure S4 Diatom assemblages from outcrop 3 m from that of photo in printed Fig. 2b and photos in supplementary Fig. S2a

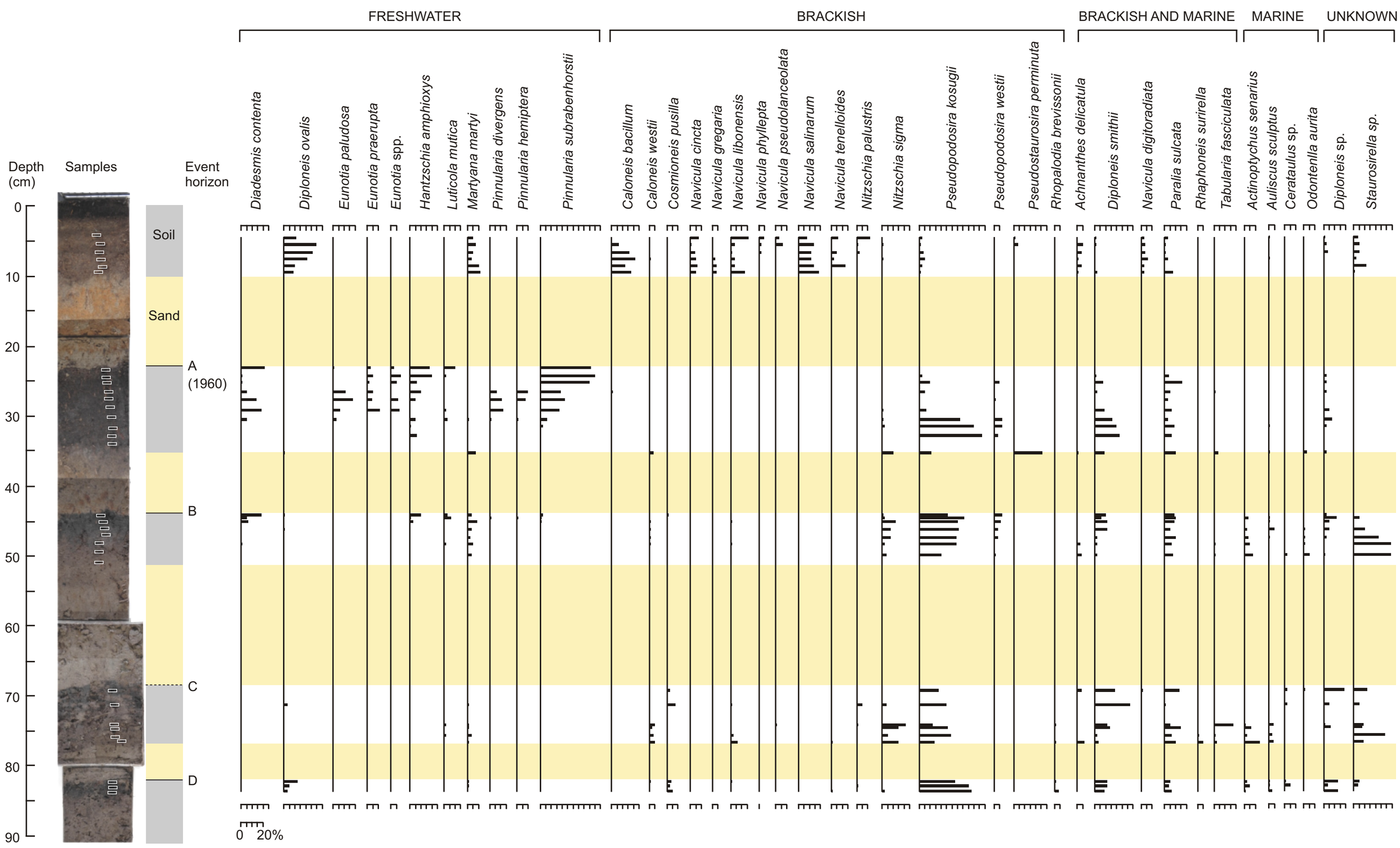


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes

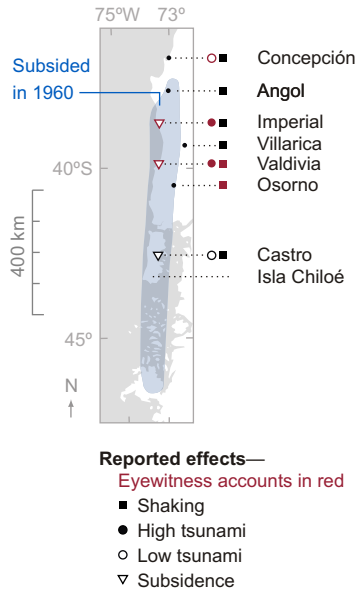
THIS SUPPLEMENT presents written descriptions of historical predecessors to the giant 1960 earthquake—the south-central Chile earthquakes of 1575, 1737, and 1837. Many of the accounts were previously summarized by Lomnitz (1970). We complement Lomnitz's summary by presenting twenty one accounts from the 16th to 19th centuries. Six pertain to the 1575 event (records 1-6; pp. 3-9), two to 1737 (7, 8; pp. 11, 12), and thirteen to 1837 (9-21; pp. 15-27). With one exception the originals were written in Spanish, which we reproduce beside a fairly literal translation into English (prepared by Cisternas, Atwater, and Eipert, with editing by Cinna Lomnitz).

We preface each earthquake with an overview of the event and of the accounts themselves (pp. 2, 10, and 13-14). We then introduce each account with additional background material and conclude each account by giving its bibliographic source. References cited elsewhere in the supplement are on page 28.

Details of the historical accounts support Lomnitz's (1970, p. 943) inference that the earthquake of 1575 resembled the 1960 mainshock. The effects of the 1737 earthquake appear modest by comparison, even after allowing for a dearth of 18th-century historical records from south-central Chile. At least along the northern half of the 1960 rupture, the 1837 earthquake probably lacked associated tsunami waves, river-blocking landslides, and casualties as grand as those from the 1575 and 1960 events.

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Earthquake and tsunami of December 16, 1575



AN EARTHQUAKE in December 1575 leveled all of Spain's main outposts south of Concepción—Angol, Imperial, Villarica, Valdivia, Osorno, and Castro. The day was Friday the 16th in the Julian calendar; the hour, 3 or 4 p.m. (records 1-5).

In Imperial the shaking brought down buildings in a minute and a half—in the time needed for *tres credos*, three recitations of the credo (2). This estimate can also be interpreted as the shaking's total duration. By contrast in Valdivia, the shaking is reported to have lasted a quarter hour (6). However, that estimate may extend into a time of aftershocks (Lomnitz, 1970, p. 942).

The shaking was accompanied or shortly followed by unusual currents and seas. These exposed the bed of a river in Valdivia, reversed that river's flow, claimed two ships then moored in the city's port, erased Indian villages, and cut a new outlet for the river at Imperial (the Río Imperial). Near Valdivia, surging up a river channel at speeds greater than those seen previously in downriver floods, a tsunami stranded great quantities of fish more than 15 km inland. The tsunami of May 22, 1960 did the same (Weischet, 1963, p. 1240).

Marine incursions apparently persisted near Imperial (2) and Valdivia (5) and perhaps also at Castro (4). These imply coseismic subsidence like that documented from 1960 by Weischet (1963), Plafker and Savage (1970), and Galli and Sanchez (1963, p. 1267-1268).

Casualties were reported from Imperial, Villarica, Valdivia, and Osorno; by one estimate, the dead included 23 Spaniards and as many as 1000 Indians (4). Concepción, then at a seaside place now called Penco, suffered comparatively minor damage from the shaking and the subsequent tsunami (3).

A landslide, caused by the shaking, blocked a tributary of the Río Valdivia near the outlet of Lago Renihua (Riñihue). By one account the damming raised the lake 40 cm a day (5). After four months the outflow breached the dam (6). The ensuing flood, long feared in Valdivia, lasted three days, killed more than 1200 Indians and great numbers of cattle, and destroyed houses and crops. Similar damming and flooding were repeated in 1960 (Davis and Karzulovíc, 1963, p. 1403).

THE MAIN ACCOUNTS of the 1575 earthquake and tsunami contain vivid detail set down by probably traumatized conquistadors during the first weeks after the disaster. The writers came from comparatively aseismic Spain; they were among the few thousand Spanish men and women in Chile at the time (Villalobos, 1995, p. 130, Bengoa, 2003). Their accounts survive in official reports from Imperial, Valdivia, and Concepción, and in additional writings by persons on hand in Valdivia. No such primary sources are known to survive from Osorno and Isla Chiloé, nor from military posts established in 1567 on the southern mainland along Canal Chacao.

The excerpts on the next six pages describe the 1575 earthquake and tsunami in order of their recorded or estimated dates of composition.

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 1

On December 28, 1575, twelve days after the earthquake and tsunami, from his base in Valdivia, a civilian official of the colonial government describes them in a report to his superior in Concepción. The official, Pedro Feyjó, is reporting to Chile's lieutenant governor (Lugar-teniente de Capitán General)*, M. Calderón.*

Doña Esperanza's lands adjoined the coast near Toltén, according to record 2.

Illustrious Sir. This past Friday that was the 16th of this [month], two hours before nightfall the earth in this city trembled and there was an earthquake that I believe has never been seen before, such that no house, church, or monastery remained standing but within a quarter hour all was razed to the ground, some people died, though as it was I thought all of us would, because there was no man who could remain standing, the earth opened in such a way that it seemed about to swallow us, the large river of this city instead of running to the sea ran up[stream] with such impetus that I have never seen its running down [stream] anywhere, was Our Lord willed that the lake from which it used to spring a hill fell down on its outlet and closed it in a way that no water runs through […]. Two ships that were in this port bound for Peru and almost dispatched, though being loaded with wood by many sailors, couldn't be saved, both were lost [...]. The Indians […] have not wanted to come to serve at the harbor for fear of the sea, they say it will eat them all and here it is believed certain that in Doña Esperanza's allotment, which was by the sea, more than a thousand souls have drowned […] and in this city we keep vigil […] that the lake doesn't release suddenly all water and drown all of us here […]. What I say of this city must be said also of La Imperial, La [Villa]Rica and Osorno, that all of them were left without any building.

Ilustre Señor. El viernes pasado que fueron 16 de éste, dos horas antes que anocheciese tembló la tierra en esta ciudad y hubo un terremoto que creo yo jamas tal se ha visto, fue de suerte que ninguna casa, iglesia ni monasterio quedó en pie que dentro de un cuarto de hora no se arrasase todo por el suelo, algunas gentes murieron, aunque según ello fué yo pensé que todos íbamos, porque no hubo hombre que se pudiera tener en pie, abriose la tierra en tanta manera que parecía que a todos nos quería tragar, el río grande de esta ciudad en lugar de correr hacia la mar corría hacia arriba con tanto ímpetu que no he visto yo correrle hacia abajo por ninguna parte tan recio, fué Nuestro Señor servido que la laguna donde manaba cayese un cerro sobre la boca del desaguadero y lo tapó de tal suerte que no corre agua por el [...]. Dos navíos que estaban en este puerto para el Perú casi despachados, aunque se halló en ellos mucha gente de marineros que los cargaban de madera, no pudieron remediarlos, que entrambos se perdieron […]. Los indios […] no han querido venir a servir al puerto por miedo de la mar, que dicen los ha de comer a todos y aquí se ha hecho por cierto que el repartimiento de doña Esperanza, que estaba junto a la mar, se le han ahogado mas de mil ánimas [...] y en esta ciudad nos velamos [...] no se suelte la laguna toda la agua de golpe y nos ahogue aquí a todos [...]. Lo mismo que digo de esta ciudad hay que decir de la Imperial, la Rica y Osorno, que todas quedaron sin ningún edificio.

Source: "Carta de Pedro Feyjó al licenciado M. Calderón relatándole un temblor que asoló a Valdivia y demás pormenores". *Dated December 28, 1575 at Valdivia. Included in:* Colección de Documentos Inéditos para la Historia de Chile, Segunda Serie, vol. II 1573-1580, Fondo Histórico y Bibliográfico J.T. Medina, Santiago, 1957, pp. 212-214.

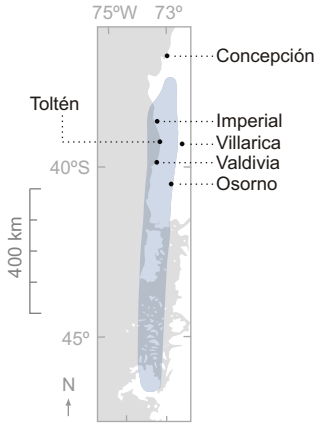


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

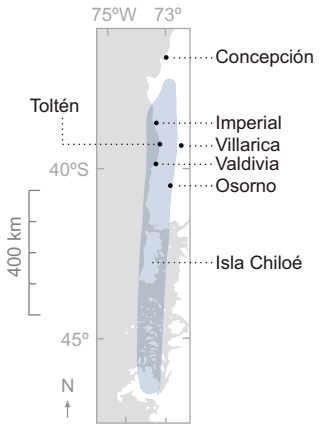
Record 2

Imperial's town council, or cabildo, submits its report to M. Calderón on January 8, 1576, a little more than three weeks after the disaster. The report contains information scarce or absent in other sources: an estimate of the earthquake's duration, certain details about the destruction of two ships near Valdivia, evidence for coseismic subsidence (lasting submergence by postearthquake tides), and the opening of a river mouth at Imperial.

The writer gives the earthquake's duration as within the time needed to recite the credo thrice. Recited rapidly a credo lasts nearly 30 seconds.

In the account of the ships near Valdivia, Tenguelén (also spelled Tenquelén) probably refers to a place about 10 km upriver from the port, which was then within a few kilometers of Niebla. The 1960 tsunami moved ships several kilometers upstream from their anchorage near Niebla (Sievers and others, 1963).

Names associated with the ships may include those of their owners. The names follow the preposition de*, which connotes either ownership or place of origin.*



Illustrious Sir […], and as God was pleased that on the sixteenth of December, two hours before sun down[,] within the time of three credos with a tremble and earthquake, all this city fell down, without leaving any house where one could dwell or dare to enter and thinking that only here had been the damage, we have heard[,] and it is true[,] that in the cities of Valdivia, Osorno, Villarrica, no house or foundation remains, with enormous damage to haciendas in addition to the persons who died. In Valdivia twenty-two [Spanish] persons [died…]; also dead were more than a hundred *piezas de servicio* [pieces of service; Indians] and furthermore the sea went out with such fierceness and force, that flooding of the city seemed certain. Two ships in the harbor [of Valdivia] were lost, neither can be used [any more]. The ship of San Joan de Fontaso was thrown ashore at Tenguelén and [that] of Santiago de Uriona sank; there was no more. [Upstream from Valdivia] two hills fell on the lake outlet at the Indian village of [belonging to] Arias Pardo, [and the fallen hills] clogged the outlet so extremely that the river Delame [now San Pedro] dried up […]. In Osorno the wife of Diego de Rojas died and another young woman and some piezas [Indians]. At Villa[rica] three piezas died; from Chiloé nothing has been heard […].
In this city [Imperial][…] only an Indian woman died,

Ilustre Señor [...], y por causa que Dios fué servido que a diez y seis de diciembre, dos horas antes de que se pusiese el sol en espacio de tres credos con un temblor y terremoto, se cayó toda esta ciudad, sin quedar casa que se pueda vivir ni osar entrar dentro y creyendo que aquí había sido solo el daño, hemos sabido como es verdad que las ciudades de Valdivia, Osorno, Villarrica, no quedó casa ni cimiento de todas ellas, con grandísimo daño de las haciendas y más de las personas que murieron. En Valdivia veintidós personas [...]; murieron también más de cien piezas de servicios y sobre todo salió la mar con tanta braveza y pujanza, que se tuvo por cierto se anegara la ciudad. Perdiéndose dos navíos que estaban en el puerto, sin poderse aprovechar de ninguno. El navío de San Joan de Fontaso le echó la mar en Tenguelén y de Santiago de Uriona se hundió; no había más. Cayéronse dos cerros en la boca de la laguna de la villa en los indios de Arias Pardo, que taparon tan en extremo el Desaguadero que se secó el río Delame [sic] [...]. En Osorno murió la mujer de Diego de Rojas y otra moza y algunas piezas. En la Villa [Rica] murieron tres piezas; de Chiloé no se sabe nada hasta ahora [...].

The account concludes on the next page.

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 2, *continued*

the sea caused enormous damage, on the Toltén coast many piezas [Indians] died in doña Esperanza's allotment, the sea did not spare any crops, it rose through the valley up[stream] more than two leagues [over 10 km] left the fields full of many fish, the tide rose in this river [Imperial] up to Maquehua island and still does even after the sea has returned to its course [...], the sea opened a harbor-mouth two cuadras [250 m] wide[,] deep and clean and in the place where the people of this city [had] wanted to open […].

En esta ciudad [Imperial] [...] no murió más que una india, hizo la mar grandisímo daño, en la costa murió de Toltén del repartimiento de doña Esperanza muchas piezas, no les dejó la mar ninguna sementera, salió por el valle arriba más de dos leguas dejó los campos llenos de mucho pescado, subió la marea por este río [Imperial] hasta la isla de Maquehua y así sube hasta y después que la mar ha vuelto a su curso [...], abrió la mar una boca de puerto de más de dos cuadras de ancho hondable e limpio y ésto fué por la parte que los de esta ciudad le querían abrir [...].

Source: "Carta del cabildo de la Imperial al licenciado M. Calderón sobre el estado de la ciudad después del terremoto que la asoló". *Dated January 8, 1576 at Imperial. Included in:* Colección de Documentos Inéditos para la Historia de Chile, Segunda Serie, vol. II 1573-1580, Fondo Histórico y Bibliográfico J.T. Medina, Santiago, 1957, pp. 217-219.

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 3

M. Calderón in Concepción, no doubt having received the reports from Valdivia and Imperial (records 1 and 2), briefly summarizes the earthquake and tsunami in a letter to the King of Spain five weeks after the disaster, on January 22, 1576. The Lugar-teniente de Capitán General describes the effects on Concepción as relatively benign.

[…] an earthquake in this realm on the last December sixteen ruined most of it, [and] with [this earthquake] the sea rose so much from its bed that it seems a matter of great marvel: this city was the one that suffered the least damage and it was all flooded […].

[…] un terremoto que hubo en este reino a diez y seis de diciembre pasado que arruinó la mayor parte del, con el cual salió la mar tanto de su curso que parece cosa de gran admiración: esta ciudad fué la que menos daño recibió y se anegó toda […].

Source: "Carta del licenciado M. Calderón a Su Majestad informando del envío de la residencia de los oidores de la Audiencia". *Dated January 22, 1576 at Concepción. Included in:* Colección de Documentos Inéditos para la Historia de Chile, Segunda Serie, vol. II 1573-1580, Fondo Histórico y Bibliográfico J.T. Medina, Santiago, 1957, p. 219.

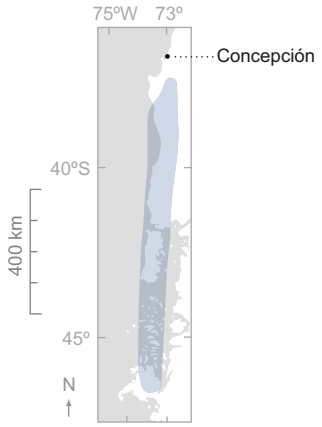


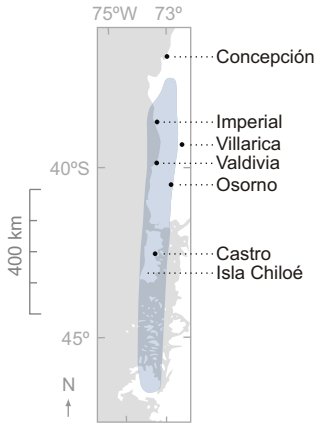
Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 4

Writing in Concepción two months after the catastrophe, on February 12, 1576, Martín Ruiz de Gamboa gives the King a fuller description than Calderón's (record 3). Ruiz de Gamboa was then serving as lieutenant general and chief justice (Teniente General y Justicia Mayor) *of the provinces Arauco and Tucapel, which together encompassed the earthquake's colonized region. His is the earliest surviving report that mentions damage and flooding in far-off Castro.*

Ruiz de Gamboa quantifies flooding in units of length that probably refer to horizontal distances. His verb for the flooding is subir, which literally means to rise. But at least for Valdivia, where the water "rose" by "more than four leagues"—over 20 km—the water's rise must refer instead to the inland distance reached either by the tsunami (implied by the dead fish cited in record 6) or by postearthquake tides.

Though the "rise" reported from Castro may represent the horizontal distance overrun by tsunami, it probably instead shows that land subsided there during the earthquake. Castro's flooding in 1960 resulted less from the tsunami, which crested 1 m above the level of post-earthquake high tides, than from coseismic subsidence, which amounted to 1.5-2.0 m (Galli and Sanchez, 1963, p. 1267-1268; Plafker and Savage, 1970, their Fig. 3).



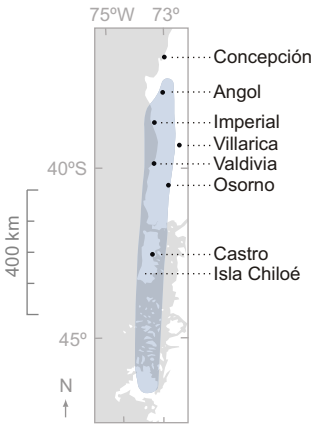
On last December sixteen of [the year fifteen] seventy-five at four o'clock in the afternoon, Friday, there was widespread temblor in this realm, […], and its force reached up to this city, in a way that caused little damage here [while] the other cities from here upward [southward] the cities of Valdivia, la Imperial, Villarrica, Osorno and Castro were razed, even foundations leapt away from their houses, killed were twenty-three persons women and men [Spaniards] and had it been at night nobody would have escaped. [Among the] native Indians around eight hundred or a thousand souls died. One hill joined another at the outlet of a lake where the main river that passes through Valdivia flows out, so that the river was left dry. The sea left its limits and rose at Valdivia more than four leagues [22 km] upstream than usual and in the provinces of Chiloé, where is inhabited the city of Castro, they write it rose ten estadales [30 m], though it didn't get as far as the city […].

A diez y seis de diciembre de setenta y cinco pasado a las cuatro de la tarde, viernes, hubo un temblor general en este reino, […], y su fortaleza llegó hasta esta ciudad, de suerte que en ella hizo poco daño y de las demás ciudades de aquí para arriba que son las de Valdivia, la Imperial, Villarrica, Osorno y la de Castro se asolaron, hasta los cimientos saltaron de las casas, murieron veintitrés personas mujeres y hombres y al ser de noche no escapara ninguno. Naturales indios murieron como ochocientas o mil ánimas. Juntose un cerro con otro en la boca del Desaguadero de la laguna donde salía el río principal que pasa por Valdivia, de suerte que quedó seco. Salió la mar de sus límites y subió en la Valdivia más de cuatro leguas del río arriba de los que solía y en las provincias de Chiloé, donde está poblada la ciudad de Castro, escriben subió diez estadales, aunque no llegó con mucho a la ciudad, […].

Source: "Carta de Martín Ruiz de Gamboa a su Majestad dando cuenta de diversos asuntos del reino". *Dated February 12, 1576 at Concepción. Included in:* Colección de Documentos Inéditos para la Historia de Chile, Segunda Serie, vol. II 1573-1580, Fondo Histórico y Bibliográfico J.T. Medina, Santiago, 1957, pp. 223-224.

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 5



An anonymous letter from Valdivia, included in a collection of Chilean documents from the year 1576, provides details unavailable elsewhere concerning the tsunami at Valdivia, incursion of salt water up the river, damming of the river farther upstream, and the growth of the lake behind the dam. As in record 1, the writer expresses fear of flooding from dam failure. His letter therefore probably predates the outburst of April 1576, described in record 6.

The writer estimates a lake-level rise of almost 80 m. By comparison, behind three landslide dams of similar location in 1960, Lago Riñihue rose 26.5 m in the first two months after the May 22 earthquake. The additional water in 1960 amounted to 2.5 billion cubic meters (Davis and Karzulovíc, 1963, p. 1403).

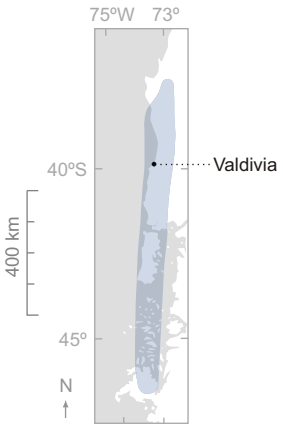
At three o'clock in the afternoon more or less came a great tremble and earthquake from the sea […]. And then incontinent the sea went out and the ships that were ready to set sail in the harbor mouth, the sea comes over the high hills such that it covered them with so much impetus that it unmoored the ships as if they were tied with a thread and carried them up the river from place to place and broke them into pieces […], the seawater arrived with so much pride and force that it carried trees and sticks and boards and the river ran faster upstream than it does in flood downstream […] and ever since the river has remained salty because of a great marvel that was to see that such a mighty river as it used to be that issued from a big lake and where the lake drained were narrows and in the middle of them a big hill fell and blocked it and it has been more than forty days that the river carries no water but from the sea, which has seized the river […] and the lake rises one codo [40 cm in height] every day and they say it has risen more than forty *estados* [~78 m, also in height] and it is frightening to see it because as this city is fourteen leagues [~80 km] from it they say if the dam suddenly lets loose the city will be carried away, said lake is big as a sea. From the rest of the cities came the same news that nothing had been left standing. Angol, Imperial, Villarrica, Osorno, Chiloé [probably Castro] are fallen to the ground. God help us, that from Concepción and Santiago no news are heard in this city.

A las tres horas de la tarde poco más o menos vino un gran temblor y terremoto de hacia la mar […]. Y luego incontinente sale la mar y los navíos que estaban de partida ala boca del puerto, viene la mar por los altos montes que los cubría con tanto ímpetu que los navíos los desamarró como si estuviera atados con un hilo y los llevó por el río arriba a una parte y a otra y los hizo pedazos […], llegó el agua de la mar con tan orgullo y fuerza que traía los árboles y palos y tablas y más recio corría hacia arriba que el río de avenida hacia abajo […] y hasta hoy se ha quedado el río salado a causa de una gran maravilla que fué ver un río tan caudaloso como era éste que salía de una gran laguna y por donde desaguaba era una angostura y en medio de esta angostura cayó un muy grande cerro y la tapó y ha ya más de cuarenta días que el río no trae agua sino es la de la mar, que quedó apoderada del río […] y va creciendo la laguna cada día un codo y dicen ha crecido más de cuarenta estados y es cosa verla da espanto que como estar esta ciudad catorce leguas de ella dicen que si la presa suelta de golpe se la llevará, está la dicha laguna hecha una mar. De las demás ciudades vinieron las nuevas era lo mismo que no había quedado cosa en pie. Angol, Imperial, Villarrica, Osorno, Chiloé están caídas por el suelo. Dios lo remedie, que de la Concepción y Santiago no se sabe en esta ciudad nuevas ningunas.

Source: "Relación anónima de un terremoto acaecido en Chile el 16 de diciembre de 1575". *Dated 1575. Included in:* Colección de Documentos Inéditos para la Historia de Chile, Segunda Serie, vol. II 1573-1580, Fondo Histórico y Bibliográfico J. T. Medina, Santiago, 1957, pp. 209-210.

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 6



Pedro Mariño de Lobera witnessed the 1575 earthquake and tsunami while serving as chief magistrate (Corregidor) *of Valdivia. Here, writing as a colonial historian, he recalls the disaster in a chronicle set down in Lima, Peru, sometime before his death, which came in 1584.*

Like the writers of records 1, 2, and 5, Mariño de Lobera recounts the destruction of ships that had been at anchor in Valdivia's port. But whereas those other writers refer to the ships with the general term navío, the former Corregidor uses nao—a specific term for a ship larger than a caravel but smaller than the subsequent galleon. (Columbus's flagship Santa María was a nao, while the swifter Niña and Pinta were caravels.) The naos destroyed at Valdivia by the 1575 tsunami were being loaded with wood for Peru (1). In return for such materials they supplied Chile's conquistadors with sugar, flour, and textiles.

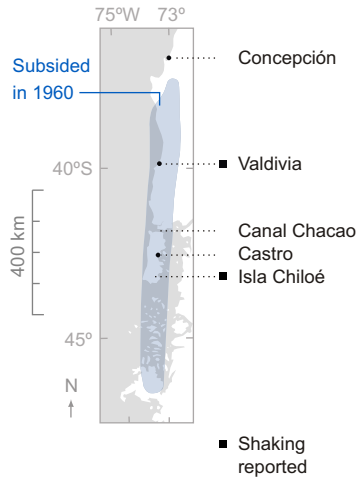
It happened that on December 16 Friday […], the ground began to quake […] unceasingly causing damage […], not only the buildings fell, but also the people […] the ground frequently opened […]. Besides this while the ground was shaking for a quarter of an hour it was seen in the mighty river, where the naos used to go up without risk[,] a most notable thing, was that at a certain place the river divided the water running one part to the sea, and the other part upstream leaving in that place the ground exposed in a way, that the stones were seen. Moreover the sea left its boundaries and borders running with great speed inland […]. And so great was its fury and fierceness, that it entered three leagues [17 km] inland, where it left large numbers of dead fish, […]. And among those storms and whirlpools two naos were lost, which were in the harbor […]. In this juncture fell a very high hill 14 leagues [~80 km] from the city […], it crossed the great river of Valdivia at its birthplace from the deep lake of Anigua [Riñihue], closing its channel […] leaving the riverbed dry […]. The outlet having remained thus closed for a period of four months and a half […]; it happened that at the end of the month of April of the following year of [15]76 it came to blow out with great fury […]. Finally the water [the flood] was receding at the end of three days, having killed more than 1200 Indians, and great numbers of cattle without counting here the destruction of houses, fields, orchards, which was difficult to reckon.

Sucedió pues en 16 de diciembre viernes […], comenzó a temblar la tierra […] sin cesar de hacer daño […], no solamente caian los edificios, sino tambien las personas […] se abría la tierra frecuentemente […]. Demas desto mientras la tierra estaba temblando por espacio de un cuarto de hora se vió en el caudaloso rio, por donde las naos suelen subir sin riesgo una cosa notibilísima, y fué que en cierta parte del se dividió el agua corriendo la una parte de ella hácia la mar, y la otra parte rio arriba quedando en aquel lugar el suelo descubierto de suerte, que se vian las piedras. Ultra desto salió la mar de sus límites y linderos corriendo con tanta velocidad por la tierra adentro […]. Y fué tanto su furor y braveza, que entró tres leguas por la tierra adentro, donde dejó gran suma de peces muertos, […]. Y entre estas borrascas y remolinos se perdieron dos naos, que estaban en el puerto […]. Cayó a esta coyuntura un altísimo cerro que estaba catorce leguas de la ciudad […], se atravesó en el gran rio de Valdivia por la parte que nace de la profunda laguna de Anigua, cerrando su canal […] quedándose la madre seca […]. Habiendo pues durado por espacio de cuatro meses y medio por tener cerrado el desaguadero […]; sucedió que al fin del mes de abril del año siguiente de 76 vino a reventar con tanta furia […]. Finalmente fué bajando el agua al cabo de tres dias, habiendo muerto mas de mil y doscientos indios, y gran numero de reses sin contarse aquí la destruccion de casas, chacaras y huertas, que fue cosa inaccesible.

Source: "Crónica del Reino de Chile". Pedro Mariño de Lobera. *First published before 1584. Included in:* Colección de Historiadores de Chile, Imprenta del Ferrocarril, Santiago, 1865, tomo VI, pp. 335-336, 344-345.

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Earthquake of December 24, 1737



TWO SECONDARY SOURCES—a pair of history books published in the last decade of the 18th century—provide the earliest known accounts of the 1737 earthquake. One, a history of the entire Spanish colony of Chile, describes damage from shaking in Valdivia (record 7); the other, a history of Chiloé and its archipelago, tells of such damage in that region (8).

The shaking in Valdivia, on December 24, reportedly lasted a quarter of an hour. People couldn't keep their balance. In many areas the ground cracked. Buildings and fortifications were destroyed. In Chiloé the shaking was said to have ruined most of the island's towns. A historian gives the likely date as a plural, December 23 and 24.

There are no known reports of shaking or tsunami in 1737 at Concepción. This negative evidence is significant for the earthquake because the city remained important, and under Spanish control, in 1737.

Farther south, by contrast, Spaniards had abandoned former outposts lost to an Indian uprising in 1598. Those outposts include Angol, Imperial, and Villarica, all of which provided reports of damage in 1575. The few southern outposts still under Spanish control in 1737 were Valdivia, including rivermouth fortresses at Corral and Niebla; forts along the shores of Canal Chacao at Carelmapu (established in 1603 as San Antonio de la Rivera de Carelmapu), Calbuco (1602, as San Miguel de Calbuco, later San Rafael), and Chacao (1567, San Antonio de Chacao); and settlements on Isla Chiloé, particularly at the island's colonial headquarters, Castro (1567, Santiago de Castro).

AS FOR A TSUNAMI associated with the 1737 earthquake, neither of the above history books mentions one. For Valdivia this implies that no large tsunami took place there, because the historian focuses on damage close to the sea, in the city's fortresses (record 7). In Chiloé, however, accounts of a 1737 tsunami would not be expected because most or all of its towns then faced inland waters.

A Chilean tsunami in 1737 is unknown from written records in Japan, even though 1737 is part of an era when tsunamis of American origin were being recorded in Japan. Those tsunamis came from Peru in 1687, Cascadia in 1700, Valparaíso in 1730, and Concepción in 1751 (Ninomiya, 1960; Watanabe, 1998; Atwater and others, 2005, p. 54). The 1837 and 1960 tsunamis from south-central Chile also registered in Japan—the 1960 event notorious for having taken 130 Japanese lives. The lack of Japanese accounts of a 1737 Chilean tsunami thus provides independent evidence that any such tsunami was modest in size.

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 7

Pedro González de Agüeros, a priest, wrote a history of Chiloé and its archipelago. The book was first published in 1791.

About another earthquake that was experienced in Chiloé, with the ruin of most of its settlements, I heard often mentioned there, and I have also seen it quoted on prints and manuscripts, but without stating the year […], I take it that the year was 1737, on the days December 23 and 24.

De otro terremoto que se experimentó en Chiloé, con ruina de las mas de sus poblaciones, oí hablar allí en repetidas ocasiones, y tambien lo he visto citado en impresos, y manuscritos, pero sin expresion del año […], y hallo que fué el año de 1737, en los dias 23 y 24 de Diciembre.

Source: "Descripción historial de Chiloé". Pedro González de Agüeros. *First published in 1791. Facsimile in:* Instituto de Investigaciones del Patrimonio Territorial de Chile, Universidad de Santiago. Editorial Universitaria, Santiago, 1988, pp. 104-105.

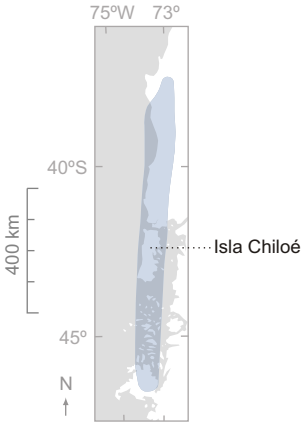


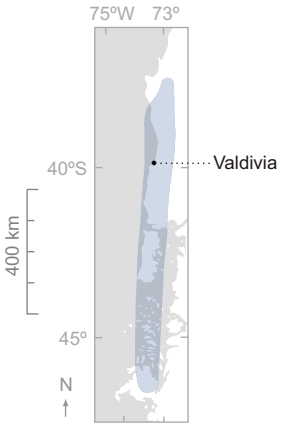
Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 8

A colonial history published 1796 includes an account of the 1737 earthquake as felt at Valdivia. The historian, Vicente Carvallo y Goyeneche, was born in Valdivia five years after the earthquake. Because his family had been living in Valdivia for several generations, he may have learned of the earthquake through family records and lore.

Carvallo y Goyeneche refers to the plaza de Valdivia, and to its castles (castillos). *The plaza was situated in the town itself, while the castles stood 20 km downstream, where they protected the harbor near present Niebla.*

The antiquity of these fortifications made them vulnerable to the shaking in 1737. Valdivia itself, then nearly two centuries old, was surrounded by walls that protected a population of 2000 Spaniards. The walls were made of stone but cemented with mud. A Valdivia governor, Moreno y Pérez, described them as irregular in plan, made of sandstone and slate, without foundation or moat or stakes, just high enough to ward off the Indians ("sin reglas de matemática, las murallas de piedras cancagua y laja, sin cimientos y sencilla; su alto de tres a cuatro varas poco más […]; no tiene foso estacado ni más defensa que la dicha, lo que basta para los indios […] la formación es un cuadrangulo y ocupa el terreno de un tiro de fusil, en cuadro"). *The damage wrought by the earthquake thus compelled Spanish officials to refortify the old city (Guarda, 1990, p. 100). The two defensive towers now standing in Valdivia, city icons known as Los Canelos and Del Barro, were built in 1774.*



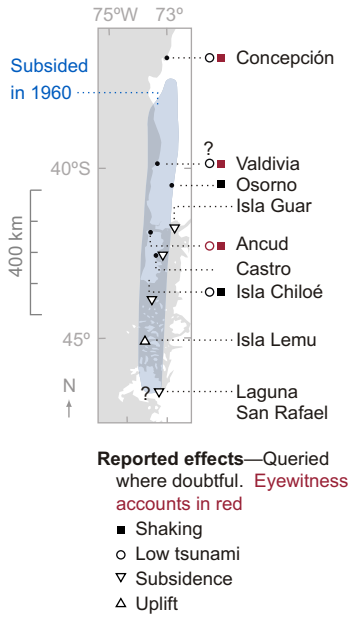
The city of Valdivia was afflicted last year by a formidable earthquake of three successive tremors (December 24, 1737), so continuous, that its pauses were almost imperceptible, and lasting around a quarter of an hour, with [such] violent undulations that the people couldn't remain standing, and in many places the ground opened. It uprooted the buildings and the fortifications, both interior and exterior of the city and its castles. The governor of the city proposed to move it to isla del Rei, or to the castle of Niebla, but the knight Manso, doing justice to its antiquity was persuaded that the great Pedro de Valdivia, its conqueror and founder, knew to establish it on a convenient location, and disapproved this thinking, he ordered to raise the walls of the castles that defend the harbour, and a *rebellín* fort for the defense of the city, against the attacks of the domestic enemies that until today don't know the use of the firearms.

La plaza de Valdivia fue asolada de año anterior con un formidable terremoto de tres estremecimientos (24 de diciembre de 1737), tan seguidos, que casi fueron imperceptibles sus interrupciones, i de cerca de cuarto de hora de duracion, con tan violentas ondulaciones que las gentes no se podian mantener a pié firme, i en muchas partes se abrió la tierra. Arrancó los edificios i las obras de fortificacion, tanto interiores como esteriores de la plaza, i sus castillos. El gobernador de ella propuso su traslacion a la isla del Rei, o al castillo de Niebla, pero el caballero Manso, haciendo justicia a la antigüedad se persuadió de que el gran Pedro de Valdivia, su conquistador i fundador, supo establecerla en ubicación conveniente, i desaprobado el pensamiento, le mandó levantar las murallas de los castillos que defienden el puerto, i un fuerte de rebellín para la defensa de la plaza, contra los ataques de enemigos domesticos que hasta hoy no conocen el uso de armas de fuego.

Source: "Descripción histórico-jeográfica del Reino de Chile". Vicente Carvallo y Goyeneche. *First published in 1796. Included in:* Colección de Historiadores de Chile, Imprenta de la Librería del Mercurio, Santiago, 1875, Tomo IX, p. 264.

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Earthquake and tsunami of November 7, 1837



COMPARED WITH the 1737 earthquake, the Chilean earthquake and tsunami of November 7, 1837 are well-documented events. By then, Valdivia, Osorno, Ancud, and Castro had become administrative centers of the republic of Chile, independent of Spain since 1810. In Valdivia and Ancud, *intendentes* (provincial governors) set down eyewitness accounts of the earthquake and, in Ancud, of the ensuing tsunami. Additional information came to light later, in the middle of the 19th century. At that time the Chilean Navy was preparing the first modern nautical charts of the southern part of the 1837 earthquake area. With a mandate that extended beyond hydrography into natural history, the surveyors linked the 1837 earthquake to some of what they saw and heard.

We found only one record of shaking in Concepción, then Chile's second-most important city. It is a cover note from the Intendente of Concepción, who forwarded the earthquake's news, from his counterpart of Valdivia, to the central government. This report also tells about puzzling sea movements.

THE ACCOUNTS BELOW are organized from north to south. They begin with descriptions of the earthquake's effects in Concepción (record 9), where shaking lasted four or five minutes and the sea moved strangely.

In Valdivia, the shaking threw people off balance, according to a pair of reports from the provincial intendente (records 10, 11). Buildings made of stone collapsed but those made of wood remained standing. One of Valdivia's forts, 20 km downstream at Niebla, was destroyed; another was damaged. The collapse of a house in Niebla killed one person. Osorno suffered cracks on the roads, fallen trees, and landslides. The Valdivia intendente's second report mentions damage to fortresses near the coast but does not mention any tsunami. His testimony casts doubt on tsunami effects that modern tsunami catalogs ascribe to an 1837 tsunami at Valdivia.

Three writers describe both shaking and a tsunami at Isla Chiloé: the intendente of Chiloé province, in a report from Ancud two weeks after the disaster (12); a French naturalist, in a letter dated another five weeks later, at a town almost 1000 km north of the earthquake's focal region (13); and a priest, writing in 1894 (15). The intendente's report may be the source for some of what the naturalist and priest described. Both the intendente and the naturalist state that wood houses helped Chilotes survive the shaking. The three writers concur that ground cracked and land slid. With regard to the tsunami, the intendente and the naturalist report that the sea surged in and out three times, and that it stayed within the usual range of tides in some areas while running inland nearly a kilometer in others. They state that the flooding caused no damage. The priest tells of algae and shellfish stranded beside the Río Pudeto and Canal Chacao.

The 1837 earthquake was probably accompanied by land-level changes along the southern half of the 1960 rupture, from the latitude of Ancud southward to Laguna San Rafael. Subsidence ascribed to the earthquake submerged shores of Isla Guar (14) and, near Castro, Isla Tac (15). Farther south, in an archipelago south of Chiloé, a local pilot on hand in 1837 recalled decades later that some islands vanished while others emerged (16). A French captain reported in 1838 that the earthquake had raised Isla Lemu, in a western part of the archipelago, by 2.5 m (17). Additional evidence for land-level change in 1837 was noted in the last half of the 19th century by Chilean Navy surveyors of Laguna San Rafael. They found drowned forests of dead or dying trees and interpreted them as signs

of subsidence from 1837 (18, 19). However, a priest's diary from 1766 describes these same trees or ones like them (20). After reading this diary, one of the Navy surveyors reinterpreted the subsidence as having repeated over time (21).

SOME MODERN TSUNAMI CATALOGS state that the 1837 tsunami destroyed Valdivia (Heck, 1947, p. 276; <http://www.ngdc.noaa.gov/seg/hazard/tsrnsrch_idb.shtml>, Valdivia entry for tsunami of November 7, 1837). The Valdivia Intendente's reports do not imply, however, that water caused any of the damage.

The NOAA online catalog, along with the printed catalog by Lockridge (1985), states that the 1837 tsunami was 2 m high at Mancera Island. Though the Intendente does not mention Mancera by name in the report below, he does mention the fortresses at Valdivia's harbor, and one of these (called San Pedro de Alcántara) was situated at Mancera.

According to the catalog by Soloviev and Go (1984, p. 66), "There is a report that the sea at Valdivia after rushing back, again rushed onshore, rising to an appreciable height."

Urrutia and Lanza (1993), without citing their source, state that the 1837 earthquake was associated with tidal anomalies at Concepción's port, Talcahuano. They probably used the Concepción Intendente's report (record 9).

Paradoxically, the 1837 tsunami is known as much from its effects in Hawaii and Japan as from those in Chile. In Hilo it reportedly reached heights of 5-6 m—about half the maximum height attained there by the 1960 Chilean tsunami (Lander and Lockridge, 1989). In Japan the 1837 tsunami flooded salt-evaporation works and farmland in areas damaged more heavily by the 1960 Chilean tsunami, which crested as much as 6 m high in Japan (The Committee for Field Investigation of the Chilean Tsunami of 1960, 1961; Watanabe, 1998).

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 9

Manuel Bulnes, who would become President of Chile four years later, served as Intendente of Concepción in 1837. In that capacity he forwarded a message from the Intendente of the neighbouring province of Valdivia to the central government (record 10). His cover note, transcribed below, provides unique information on the 1837 earthquake effects on Concepción. It is probably the sole extant account from an eyewitness to the shaking in Concepción and to its puzzling effects on the sea. Robert Fitzroy, in his "Voyages of the Adventure and Beagle" (Fitzroy, 1839), cites Bulnes's account and uses his expression bastante recio *(literally,* bastante*, enough;* recio*, strong) to describe the earthquake's effects in Concepción.*

With strong sentiment I have just received the attached communication [record 10] from the Intendente of Valdivia through which was announced the horrible earthquake suffered by that province on the day 7 of the current [month]. The duration and destruction described give an accurate sense of the earthquake, whose influence was felt also in this city [Concepción] on the same day and at the same time, in a ground movement that although without causing damage, was rather strong and lasted around four or five minutes, with the striking peculiarity of a slight observed withdrawal of the sea toward the center of Talcahuano [bay], and an interruption for some days of the flow and ebb of its waters.

Con el mayor sentimiento acabo de recibir la comunicación adjunta del Intendente de Valdivia por la que se anuncia el horrible terremoto que ha sufrido aquella provincia el dia 7 del presente. La descripción que se hace de la duración del temblor y sus estragos, manifiestan bien su intensidad; cuya influencia se dejó conocer también en esta ciudad en el mismo dia y a las mismas horas, en un movimiento de tierra que aunque no causo daño alguno, fue bastante recio y duró como cuatro o cinco minutos, con la particularidad notable de haberse advertido un pequeño retroceso de la mar ácia su centro en Talcahuano, y haber dejado interrumpido por algunos dias el flujo y reflujo de sus aguas.

Source: "Carta del Intendente de Concepción, Sr. Manuel Bulnes, al Sr. Ministro de Estado en el Departamento del Interior". *Dated December 2, 1837 at Concepción*. *Collected in:* Periódico El Araucano del 8 de Diciembre de 1837.

Manuel Bulnes (1799-1866) witnessed the 1837 earthquake's shaking in Concepción. As president of Chile, he later founded the University of Chile, the Academy of Fine Arts, the Conservatory of Music, the Astronomic Observatory, and supported the publication of the Claudio Gay's complete work (record 13).

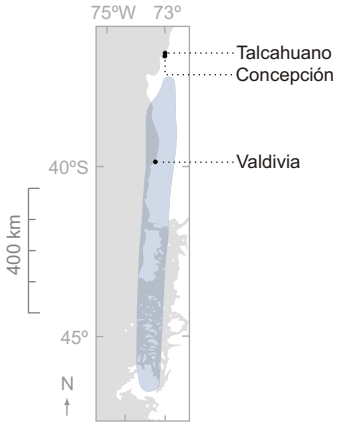


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 10

On November 7, the day of the 1837 earthquake, the Intendente of Valdivia province tells of the earthquake in a report to the central government via his counterpart, the Intendente of the neighboring province of Concepción (record 9).

The great earthquake this town has experienced in the morning of today, […] can be certainly taken as the largest ever to occur here […] [only] with difficulty could a man stay on his feet. […] The only two churches there were in this town, and all the governmental buildings have been completely ruined; and if the rest of the houses of this town didn't share the same fate it helped no doubt that they were made of wood […] it is known that nobody has perished.

El gran terremoto que ha esperimentado en este pueblo en la mañana de este día, […] se puede asegurar que sea el mayor de los hasta aquí acontecidos […] con dificultad podía un hombre sostenerse en pié. […] Las dos únicas iglesias que había en este pueblo, y todos los edificios fiscales se han arruinado completamente; y si no les han cabido igual suerte á las demás casas de esta población ha contribuído sin duda la circunstancia de ser ellas de madera […] al saber que no ha perecido una sola persona.

Source: "Carta del Intendente de Valdivia, Sr. Isidro Vergara, dirigida al Intendente de Concepción, Sr. Manuel Bulnes". *Dated November 7, 1837 at Valdivia. Collected in:* Periódico El Araucano del 8 de Diciembre de 1837.

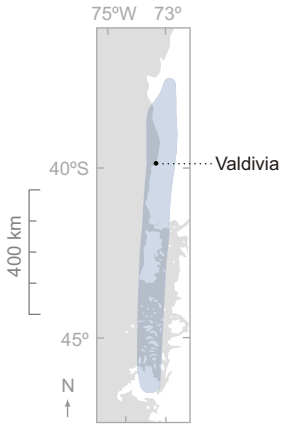


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 11

Two and a half weeks after the 1837 earthquake, on November 24, the Intendente in Valdivia describes the earthquake in a more detailed report to the national government in Santiago. Notably absent in this report, and in its predecessor (record 10), is any mention of flooding from the sea.

The parish church, the Government house, barracks and Hospitals were completely ruined […]. It is also distressing for me to inform you of notable damage to the fortresses of this harbor; the principal ones being Corral and Niebla, the houses of the first have been left completely uninhabitable, and the second reduced to debris, beneath which a twelve-year-old girl died […]. According to the news I have received from the departments, the parish church of Osorno and its Town Council's House have been left on the ground, […]. The roads have been made almost impassable, both for the large openings of the ground and for the fall of enormous trees and the landslides from nearby hills.

La iglesia parroquial, la casa de Gobierno, cuarteles y Hospitales se arruinaron completamente [...]. Me es igualmente sensible comunicar á Ud. notables perjuicios que han esperimentado las fortalezas de este puerto; pués siendo las principales las de Corral y Niebla, han quedado las casas de la primera enteramente inhabitables, y las segundas reducidas á escombros, bajo las cuales pereció una muchacha de doce año [...]. Según la noticia que hé recibido de los departamentos, la iglesia Parroquial de Osorno y su Casa de Cabildo han quedado por los suelos, […]. Los caminos han quedado casi intrancitables, tanto por las grandes aberturas de tierra como por la caída de árboles enormes y derrumbes de cerros inmediatos.

Source: "Carta del Intendente de Valdivia, Sr. Isidro Vergara, al Sr. Ministro de Estado en el Departamento del Interior". *Dated November 24, 1837 at Valdivia. Collected in:* Periódico El Araucano del 12 de Enero de 1838.

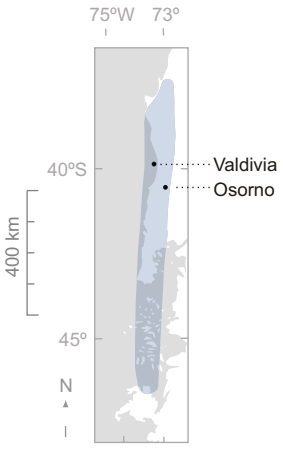


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 12

To the south on November 21, the Intendente of Chiloé, at Ancud, writes his report to the national government. His is probably the sole eyewitness account of the 1837 tsunami in Chile.

The day 7 of the current [month] […] an earthquake has been suffered in this province, which if it were not for the circumstance that all buildings here are made of wood, the inhabitants would have been completely ruined […]. In the sea some movement was felt, […] it flooded and ebbed three times with much speed, but without surpassing its natural boundaries; however on flat areas of some points in the archipelago the sea went onto the land as far as six *cuadras* [~700 m], but without causing any damage. Over the whole province one finds great cracks up to two cuadras [~250 m] long and three *cuartos* [1 m] wide, great landslides from hills and an infinity of massive uprooted trees […]. The damage received from this earthquake consists only of some houses that have fallen in the interior [of the province], and some crops that have been completely ruined by the shaking and landslides […]. In this city the government house made of stone fell completely […]. In the island of Quenac is where only two casualties have been suffered.

El día 7 del presente […] se ha sufrido en esta provincia un terremoto, el cual á no ser la circunstancia de estar construidos todos los edificios de madera, hubiera sido completamente arruinada su población […]. En la mar se sintió algún movimiento, […] hizo por tres veces el flujo y reflujo con mucha rapidez, pero sin pasar sus límites naturales; sin embargo en algunos puntos del archipiélago de terreno llano salió hasta seis cuadras, pero sin causar el menor daño. Por toda la provincia se descubren grandes grietas hasta de dos cuadras de largo y tres cuartos de ancho, grandes derrumbes de cerros é infinidad de árboles de mucho volúmen arrancados de raiz [...]. Los daños recibidos con el referido temblor consisten únicamente en algunas casas que se han caído en el interior, y algunas sementeras que han sido completamente arruinadas por la agitación y derrumbes […]. En esta ciudad cayó completamente la casa fiscal construida de piedra […]. En la isla de Quenac es donde se ha sufrido únicamente dos desgracias.

Source: "Carta del Intendente de Chiloé, Sr. Juan Vives, al Departamento del Interior". *Dated November 21, 1837 at Ancud. Collected in:* Periódico El Araucano del 22 de Diciembre de 1837.

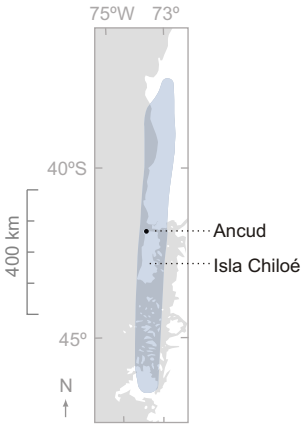


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 13

The French naturalist Claudio Gay, who worked in Chile from 1828 to 1841, witnessed the 1835 and 1837 earthquakes. In the letter below, addressed to the Secretary of the Académie des Sciences, *he compares the two shocks by location, size, and damage. Three months later, Charles Darwin would refer to this comparison in a talk before the Geological Society of London (Darwin, 1840).*

Gay's letter, like the Intendente's report from Ancud (record 12), tells of the 1837 tsunami in Chiloé. However, this part of Gay's letter may rely on the Intendente's sources, because both accounts describe the earthquake's effects in the same order.

Sir: In the time of my stay in Valdivia I had the honor of giving you some information on the earthquake that happened […] on February 20 of 1835 and which produced frightening devastation in the provinces of Concepción, Talca, etc. Today I am in the case of announcing you another even much stronger, although the damage has been considerably lesser. Here is that I have seen or known by my correspondents from Valdivia and Chiloé. On November 7 at 8 o'clock in the morning, a temblor was felt in most of the Republic. In the north it was rather weak, but in the south, and over all in Valdivia and Chiloé, it was so intense that according with the inhabitants it cannot be compared in any way to the one of 1835; people hardly could keep their balance, most of them fell. […]. The houses of Valdivia, Osorno, San Carlos [Ancud], etc., were left more or less deteriorated, but not destroyed; they owed their salvation to the flexibility of the wood they are made of and to their low height, […]; but the churches, hospitals, barracks, and other government buildings, made of stone, were left completely toppled and destroyed. In Chiloé […]; the sea was rough, and in the time of an half hour it flooded and ebbed three times with violent speed. The sea couldn't penetrate inland because the cliffs that border San Carlos' surroundings, but in the interior, where the beach is extensive, it covered the ground by a quarter of league [~1.1 km]. […] An infinity of big cracks were found to have reached sometimes 300 *pies* [~91 m] in length and 50 [~15 m] in width. Also observed were landslides and even rocks that covered a large areas of cultivated fields. […].

Señor: En la época de mi permanencia en Valdivia tuve el honor de darle algunas informaciones acerca del terremoto que ocurrió […] el 20 de febrero de 1835 y que produjo tan espantosos estragos en las provincias de Concepción, Talca, etc. Hoy me hallo en el caso de anunciarle otro todavía mucho más fuerte, aunque las pérdidas ocasionadas han sido considerablemente menores. He aquí lo que he visto o sabido por mis corresponsales de Valdivia y Chiloé. El 7 de Noviembre a las 8 horas de la mañana, un temblor se hizo sentir en una gran parte de la República. En el norte fue bastante débil, pero en el sur, y sobre todo en Valdivia y en Chiloé, fue de tal manera intenso que al decir de los habitantes no puede comparársele de ninguna manera al de 1835; las personas apenas podían mantenerse en pie; la mayoría cayó. […]. Las casas de Valdivia, Osorno, San Carlos, etc., quedaron más o menos deterioradas, pero no destruidas; debieron su salvación a la flexibilidad de la madera de que están construidas y a su poca altura, […]; pero las iglesias, hospitales, cuarteles y otros edificios fiscales, edificados con piedra, quedaron enteramente derribados y destruidos. En Chiloé […]; el mar estuvo muy agitado, y en el espacio de media hora experimentó tres especies de flujo y reflujo con violenta rapidez. No pudo penetrar en tierra a causa de los acantilados que bordean los alrededores de San Carlos, pero en el interior, donde la playa era bastante extensa, cubrió la tierra cerca de un cuarto de legua. […] se hallaron infinidad de grandes grietas que alcanzaron a veces 300 pies de largo por 50 de ancho. […].

Source: "Carta de C. Gay al Sr. François Arago, Secretario de la Academia de Ciencias, París". *Dated December 18, 1837 at Los Andes (near Santiago). Collected in:* Feliú, G. and C. Stuardo. Correspondencia de Claudio Gay. Eds. Biblioteca Nacional, Santiago, 1962, pp. 21-22.

Claudio Gay (1800-1873), French naturalist who studied Chile's natural history for more than a decade.

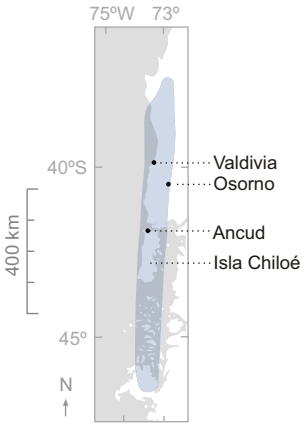


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 14

Francisco Vidal Gormaz, born four months before the 1837 earthquake, founded modern hydrography in Chile. In 1871, he learned of subsidence that his informants, on Isla Guar, blamed on the 1837 earthquake. Here he tells of their accounts, in a Navy report published the year of the survey.

At two o'clock in the afternoon we anchored north of this island and in the bay called Quetrulauquén, beginning immediately our survey […]. As we were working in the lagoon, many people told us that the terrains we were seeing flooded by the sea, had been arable not many years before, at present they are found useless for agriculture. This phenomenon of a modern sinking, on the basis we could get clear, owes its origin to the 1837 temblor that produced so much destruction in the archipelago, phenomenon that agrees with many of similar kind that we had had occasion to notice before in more southerly regions.

A las dos de la tarde fondeamos al norte de esta isla i en la rada denominada Quetrulauquén, dando inmediatamente principio al estudio de ésta […]. Cuando trabajábamos en la laguna, muchas personas nos hicieron notar que los terrenos que veíamos inundados por el mar, habian sido cultivables en años no mui remotos, encontrándose al presente inutilizados para la agricultura. Este fenómeno de un moderno hundimiento, a juzgar por lo que nos fué posible sacar en limpio, debe su orijen al temblor de 1837 que tantos estragos hizo en el archipiélago, fenómeno que concuerda con muchos de igual jénero que antes habíamos tenido ocasion de notar en rejiones mas australes.

Source: "Esploración de la costa de Llanquihue i archipiélago de Chiloé practicada por órden del supremo Gobierno por el capitán graduado de corbeta don Francisco Vidal Gormaz". Francisco Vidal Gormaz. *First published by the Chilean Navy in 1871. Soon reprinted in:* Anales de la Universidad de Chile, tomo XXXIX, 2º semestre, 1871, Santiago, pp. 5-80; pp. 62-63.

Francisco Vidal Gormaz (1837-1907), father of Chilean hydrography. Below, in 1874, he surveys at Carelmapu.

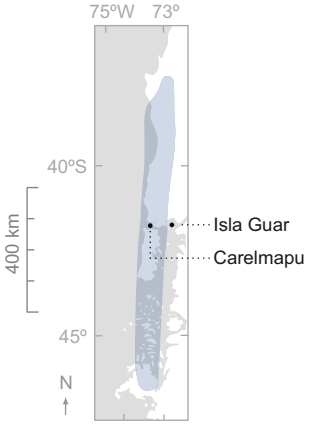


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 15

The reverend father Carlos Miller wrote in 1894 to the Chilean seismological agency concerning the 1837 earthquake on the island of Chiloé. The priest uses eyewitness testimony and his own late-19th-century observations to reconstruct the earthquake's effects. Some of the changes in land level that he ascribes to the earthquake may date from other times, like the submergence discussed in records 20 and 21.

The earthquake began, more or less, at seven o'clock in the morning of November seventh of 1837. […]. The destruction was considerable […]. Millstones jumped off their seats and the turned-down grass in plowed potato fields flopped back to its original position: there were large landslides, the ground was cracked all over and floods from the sea were big and repetitive. […]. Don José Santos Villar, resident of Ancud […], witnessed such events as a youngster some years old, told me that in the river of Pudeto and Chacabuco channel, there were extraordinary in and out sea surges, produced so violently that huge quantities of algae and shellfish went out and remained on the beaches […]. I think that the seismic disturbance I have referred to has caused many drops and rises of the coasts of Chiloé. In Isla Tac, Chauques archipelago, I have found trunks from centennial trees, which still are rooted and are found below high tides. Likewise I have observed in Tenaún that the sea has receded, because at present there are houses below where the sea used to be.

El terremoto comenzó, más o menos, a las siete de la mañana del siete de Noviembre de 1837 […]. Los destrozos fueron de mucha consideración [...]. Las piedras de los molinos saltaron de su sitio, los céspedes de los papales volteados volvieron a su primitivo lugar: hubo grandes derrumbes, la tierra se agrietó por todas partes y las salidas de mar fueron grandes y repetidas [...]. Don José Santos Villar, vecino de Ancud [...], presenció aquel suceso siendo ya joven de algunos años, me ha dicho que en la ría de Pudeto y canal de Chacabuco, hubo extraordinarias salidas y retiradas de mar, producidas con tal violencia que a las playas salieron y quedaron ahí enormes cantidades de algas y mariscos […]. Creo que la conmoción sísmica a que vengo refiriendome ha ocasionado muchos hundimientos y solevantamientos en las costas de Chiloé. En la isla de Tac, archipiélago de Chauques, he encontrado troncos de árboles centenarios, que están todavía arraigados y que se hayan más abajo de las altas mareas. Asimismo he observado en Tenaún que el mar ha retrocedido, porque actualmente hay casas más abajo de lo que antes el mar ocupaba.

Source: "Extracto de una carta dirigida el 18 de Julio de 1894 por R. P. Carlos E. Miller al Director del Servicio Sismológico." *Dated July 18, 1894. Published in:* Fernando Montessus de Ballore. Historia Sísmica de los Andes meridionales al sur del paralelo XVI. Anales de la Universidad de Chile, Tomo CXXXVIII, 1er Semestre, Santiago, 1916, pp. 12-14.

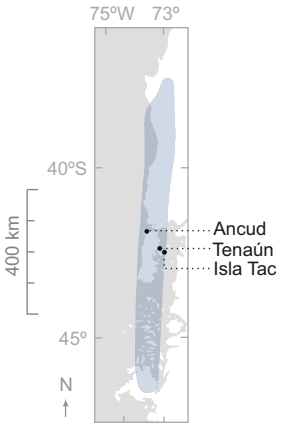


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 16

The Chilean hydrographer Francisco Vidal Gormaz (p. 20), writing in 1877, questioned Darwin's argument for pervasive coastal uplift in Chile. Vidal Gormaz had heard accounts of coastal subsidence (as in record 14) and had seen such tangible evidence for himself (18). Here he cites observations of an English sailor, Archy, who had witnessed the 1837 earthquake in the Islas Guaitecas south of Chiloé. The other sailor was known as Yates to Enrique Simpson, who employed him (19, 21).

In the Chiloé islands two witnesses to phenomena that took place in the Chonos during the strong temblor of 1837 still exist, the English sailors Archy and Yate. The first one was in the Guaitecas the day of the phenomenon and he has assured us that when he sailed again in this archipelago he could notice the disappearance of small islands well known to him, likewise he observed great destruction in others and the presence of banks and rocks where before there were none.

Existen todavía en las islas de Chiloé dos testigos de los fenómenos verificados en los Chonos por el fuerte temblor de tierra de 1837, los marinos ingleses Archy i Yate[s]. El primero se hallaba en las Guaitecas el dia del fenómeno i nos ha asegurado que cuando volvió a navegar por entre aquel archipiélago pudo notar la desaparición de pequeñas islas que le eran conocidas, como asi mismo observar grandes destrozos en otras y la presencia de bancos i de rocas donde antes no las habia.

Source: "Hundimiento o solevantamiento de los archipiélagos australes de Chile". Francisco Vidal Gormaz. *Dated 1877. Printed in:* Memoria premiada por la Universidad de Chile en 1877. Imprenta Mejía, Santiago de Chile, 1901, p. 8.

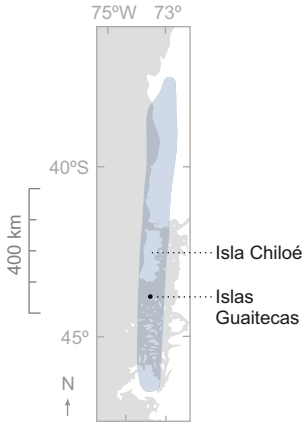
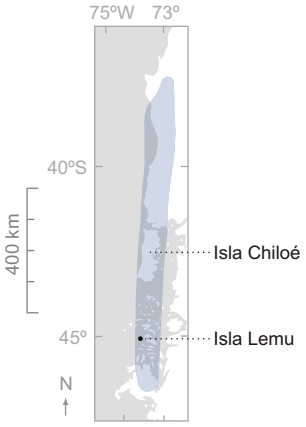


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 17

Darwin famously witnessed the Concepción earthquake of 1835. Though not on hand for the more southerly earthquake of 1837, he read about uplift it reportedly caused. This uplift occurred on Lemu, an island 120 km south of Chiloé. The report, by Coste, was published in 1838. Here Darwin cites it in "The geology of the voyage of H.M.S. Beagle," first published 1846.



In the Chonos Archipielago, the island of Lemus [Lemu] (lat. 44° 30'), was, according to M. [Monsieur] Coste, suddenly elevated eight feet, during the earthquake of 1837, he adds "des roches jadis toujours couvertes par la mer, restant aujourd'hui constamment découvertes [rocks almost always covered by the sea now remain constantly uncovered]."

Source: The works of Charles Darwin. Edited by P.H. Barrett & R.B. Freeman. Volume 9. The geology of the voyage of H.M.S. Beagle. Part III: Geological observations on South America, p. 31.

Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 18

Laguna San Rafael is a fjord at the latitude of the south end of the 1960 rupture. A young Francisco Vidal Gormaz explored the fjord in 1857 while serving as an assistant to Francisco Hudson. Two decades later, as part of his case for coastal subsidence in Chile, Vidal Gormaz tells what he and Hudson saw. He describes the remains of a forest on the fjord's floor, and he infers that the 1837 earthquake explains the forest's submergence. Vidal Gormaz seems unaware that the same trees had been observed, already submerged, in 1766 (20, 21).

[...] in the extreme south of San Rafael channel [now called Laguna San Rafael] […], beyond the parallel 46°30' latitude S, it was seen in 1857 when the tide rose it hid a great number of trees some still alive, although wasted by the salty element in which they lay. A *chalupa* [longboat] struck against a tree arm, opening a great hole […]. When the tide fell, it was seen that the boat had cleaved on the remains of a forest whose roots were hidden in the sea […]. Only a recent sinking of that region could have produced such a phenomenon, and this must be the date of the earthquake previously cited [1837].

[...] en el estremo sur del canal de San Rafael […], sobre el paralelo de 46°30' de latitud S, se vió en 1857 que cuando subia la marea ocultaba gran numero de árboles todavía vivos algunos de ellos, aunque extenuados por el elemento salado en que yacian. Una chalupa […] choco con un brazo de un árbol, abriéndose un gran agujero […]. Cuando bajo la marea, se vió que la embarcación habia surcado por sobre los restos de un bosque cuyas raices estaban escondidas en el mar […]. Solo un hundimiento reciente de aquella region puede haber ocasionado tal fenómeno, i este debe ser la fecha del terremoto antes citado.

Source: "Hundimiento o solevantamiento de los archipiélagos australes de Chile". Francisco Vidal Gormaz. *Dated 1877. Printed in:* Memoria premiada por la Universidad de Chile en 1877. Imprenta Mejía, Santiago de Chile, 1901, p. 7.

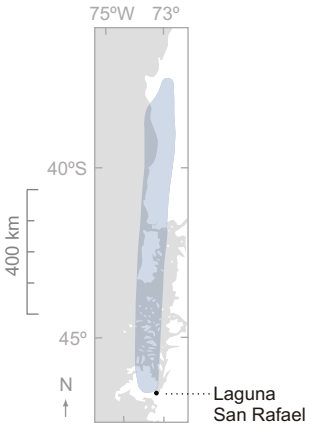


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 19

In 1871, fourteen years after the survey by Hudson and Vidal Gormaz, Enrique Simpson, resurveyed Laguna San Rafael and inferred that the area had subsided during the 1837 earthquake.

Simpson's sources included an English sailor, John Yates. In 1837, Yates was working the archipelago south of Chiloé as a práctico *(local pilot). Yates recalled changes in the islands. He didn't remember the specific places, but he assured Simpson that subsidence had occurred there around the time of the 1837 earthquake. Yates, who worked for Simpson, seemed an authoritative source. His decades of experience in the region included a stint as pilot of the H.M.S. Beagle with Robert Fitzroy in 1835.*

However, in a subsequent report issued in 1873 (21), Simpson would cite 18th-century evidence for a history more complicated than what Yates recounted (20).

[…] all the southern floor of this large fjord [Elefantes, the southern part of which includes Laguna San Rafael] is composed of terrain that is low and sometimes flooded, and in its banks, submerged in the water […], there is a forest of dead trees […]; which could never have sprouted under this condition. This […], has to be attributed to a comparatively recent sinking of the terrains. Indeed, the pilot [Yates] told me that after a large earthquake, in 1837, he himself had observed many changes in the islands and that, although he didn't remember anything of the places in question, he believed it possible that the sinking had occurred at the same time as the earthquake.

[…] todo el fondo sur de este gran seno [Elefantes, la parte sur del cual incluye Laguna San Rafael] se compone de terrenos bajos anegadizos, i en sus márjenes, sumerjidas en el agua […], se encuentra un bosque de árboles muertos […]; los cuales jamas pudieron haber brotado bajo esta condicion. Esto […], no puede atribuirse sino a un hundimiento comparativamente reciente de los terrenos. En efecto, el práctico me contó que despues de un gran terremoto, en 1837, él mismo habia observado muchas alteraciones en las islas i que, aunque no recordaba nada de los lugares en cuestion, creia posible que el hundimiento hubiese tenido lugar al mismo tiempo que el terremoto.

Source: "Esploraciones hechas por la corbeta Chacabuco, al mando del capitán de fragata D. Enrique M. Simpson, en los archipiélagos de Guaitecas, Chonos i Taitao". *Chilean Navy report dated 1871. In:* Anuario Hidrográfico de la Marina de Chile Nº 1, Imprenta Nacional, Santiago de Chile, 1875, pp. 3-147; p. 30.

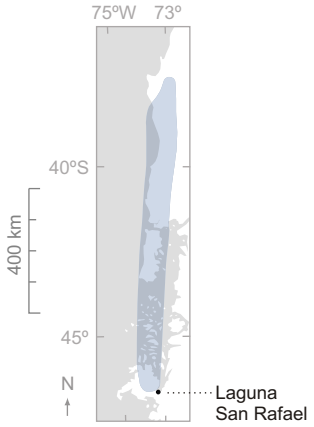


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 20

A Jesuit priest, José García, based in Chiloé, logged a missionary voyage to the territory of the Chonos Indians in 1766-1767. His notes on dead and suffering trees, below, made Enrique Simpson doubt that Laguna San Rafael subsided solely in 1837 (21).

[…] up to Mecas point, where it gets narrow again; when one reached this point islets and stockades are found with so many standing poles that from far away it looks like a harbor with ships. All this land is subject to flooding: around four o'clock in the afternoon we anchored in Mecas harbor [Caleta Mecas], all full of trunks and branches. […] Day 9. Weather allowed us to leave Mecas harbor after noon, turning the bow to the west to avoid some marshes full of dried trees; after six cuadras [~0.7 km] we steered to the south, leaving on the west a muddy river; after half a league it began seeing the grove more leafy, and the channel seemed like a river with low and flooded banks.

[…] hasta la punta de Mecas, donde estrecha otra vez; al llegar a esta punta se descubren isletones i empalizadas con tantos palos parados que de lejos parece bahia de navios. Toda es tierra anegadiza: como a las cuatro de la tarde dimos fondo en el puerto Mecas [Caleta Mecas], todo lleno de troncos i palos. […] Dia 9. Dió lugar el tiempo para dejar el puerto Mecas después de mediodía, enderezando la proa al poniente para desechar unas ciénagas llenas de árboles secos; pasadas seis cuadras fuimos enderezando al sur, dejando al poniente un rio cenagoso; a media legua empezó a verse la arboleda mas frondosa, i el canal parecia un rio con sus costas bajas i anegadizas.

Source: "Diario de viaje i navegacion hechos por el padre José García, de la Compañía de Jesus, desde su mision de Caylin, en Chiloé hacia el sur, en los años 1766 i 1767". *Dated 1766-1767. Collected in:* Anales de la Universidad de Chile, tomo XXXIX, 2º Semestre, Santiago de Chile, 1871, pp. 351-358; 357-358.

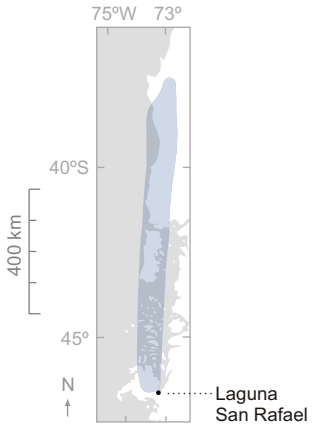


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

Record 21

Enrique Simpson repeatedly visited Laguna San Rafael, which includes Elefantes fjord. In 1873, in a Chilean Navy report on his third survey, he seems to retract his earlier inference that the 1837 earthquake lowered a forest into the fjord (record 19). Yet Simpson also proposes that the area's subsidence occurred repeatedly, in which case some of the trees may record the 1837 earthquake after all.

The Elefantes fjord, from Celtu to Mecas points, is about 6 to 7 miles wide […]. Upon arriving at Mecas point one sees, to the South, the forest of dead trees, which at a distance resemble ships' masts in a drydock. The lowland where one finds the trees has suffered large lowerings, so that now the tide floods them as it does Celtu point. The pilot Yates was convinced that the cause of the sinking was the 1837 earthquake, that made many alterations on other places of the archipelago and that he himself could observe, and as I mentioned in my previous report; since then I have received an account from Father García, of the Jesuit order, who visited these regions in 1766, and he mentioned the same trees or trunks at an identical location [record 20]. Therefore the cause of the sinking should have happened far before than the given date. The strange thing of this, is the endurance of the wood, and I can not but believe that the sinking has been successive and the stockade extended much farther to the north than it does now; reaching possibly up to the islets of Mecas point, because at low tide a large beach is exposed with mounds that seem to have been roots.

El seno de Elefantes, desde punta Celtu a Mecas, tiene de 6 a 7 millas de ancho […]. Al llegar a punta Mecas se divisa, al Sur, el bosque de árboles muertos, que a la distancia parecen mástiles de buques en un dique a flote. El terreno vajo en que se encuentran estos árboles ha sufrido grandes hundimientos, de modo que ahora la marea los inunda lo mismo que en punta Celtu. El práctico Yates estaba en la persuasion que la causa de este hundimiento fuese el terremoto de 1837, que hizo muchas alteraciones en otras partes del Archipiélago i que él mismo pudo presenciar, i así lo mencioné en mi memoria anterior; pero desde entónces ha llegado a mis manos la relacion del Padre García, de la Compañía de Jesus, quien visitó estas comarcas en 1766, i éste menciona los mismos árboles o troncos en idéntica situacion. De este modo que la causa del hundimiento debió haber tenido lugar mucho ántes de la espresada fecha. La parte estraña de esto, es la duracion de las maderas, i no puedo menos de creer que los hundimientos han sido sucesivos i que la empalizada se estendia mucho mas al Norte de lo que existe ahora; llegando posiblemente hasta los islotes de punta Mecas, pues a baja marea queda en descubierto un gran desplayo con solo túmulos que parecen haber sido raices.

Source: "Esploraciones hechas por la corbeta Chacabuco, al mando del capitán de fragata D. Enrique M. Simpson, en los archipiélagos de Guaitecas, Chonos i Taitao". *Chilean Navy report dated 1873. In:* Anuario Hidrográfico de la Marina de Chile Nº 1, Imprenta Nacional, Santiago de Chile, 1875, pp. 3-147; p. 131.

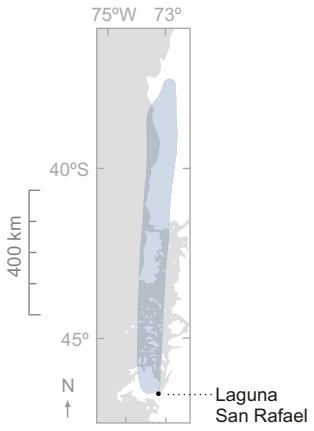


Table S1. Written records from Chile of the 1575, 1737, and 1837 earthquakes, *continued*

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Table S2. Radiocarbon ages. Gray bands separate entries by event, which is listed in center column.

No.	Lab no. (Beta-)	Fig-ure	Material	$^{13}C/^{12}C$	Stratigraphic position	Age of material relative to age of event	Event (printed Fig. 2)	^{14}C age and error (^{14}C yr BP)		Age range (cal yr AD [+] or BC [-])		Interpretation
1	31740	S3a	*Juncus balticus* rhizomes	-26.0	Exhumed on present tidal flat (as in Fig. 2a, lower photo)	Older or same	A (1960)	150	70	1668	1953	Large fibrous rhizomes of perennial plant; composed mainly of photosynthate from the decades before the 1960 earthquake. Plant killed by tidal submergence soon after 1960.
2	179374	S3a	Charcoal	-25.7	Few centimeters below top of soil	Older	B	390	40	1437	1634	Samples 2-5 each consist of charcoal of stems <3 mm diameter, probably from shrubs or herbs. Their pooled mean age is 425±20 ^{14}C yr BP (two-sigma range mainly in AD 1450-1505, the rest in 1588-1616). This pooled mean, measured on charcoal, gives the age of a fire that occurred before event B. Because it comes from a widely preserved layer a few centimeters below the uneroded top of the soil, the charcoal probably dates from the final century before the event.
3	179376	S3a	Charcoal	-23.9	2 cm below top of soil	Older	B	400	40	1454	1626	
4	179373	S3a	Charcoal	-26.1	Few centimeters below top of soil	Older	B	440	40	1432	1624	
5	179375	S3a	Charcoal	-26.8	1 cm below top of soil	Oider	B	470	40	1410	1619	
6	192081	S3b	*Scirpus americanus* rhizome	-25.1	2 cm below top of soil	Older or same	C	670	40	1291	1400	Pooled mean age of samples 6-8: 716±25 ^{14}C yr BP (AD 1280-1387). This pooled mean gives a limiting-maximum age for the event C. The age is close to the event age if, as the highest rhizomes in the soil, the rhizomes belong to plants killed by the event.
7	189638	S3b	*Scirpus americanus* rhizome	-26.6	3.5 cm below top of soil	Older or same	C	740	40	1249	1390	
8	189639	S3b	*Juncus balticus* rhizome	-26.4	1 cm below top of soil	Older or same	C	750	50	1222	1390	
9	191254	S3b	*Juncus balticus* rhizome	-26.2	3 cm below top of soil	Older or same	C	1020	40	994	1154	Age of sample 9 not used because it is seven standard deviations from the pooled mean age of otherwise adjoining samples 6-8
10	179372	S3a	*Juncus procerus* culm bases	-26.0	Rooted in soil and surrounded by sand	Same	D	990	40	1021	1181	Age of freshwater plant probably killed by tidal submergence after having been surrounded by tsunami sand. Implies age of AD 1020-1180 for event D

Table S2. Radiocarbon ages, *continued*

No.	Lab no. (Beta-)	Fig-ure	Material	$^{13}C/^{12}C$	Stratigraphic position	Age of material relative to age of event	Event (printed Fig. 2)	^{14}C age and error (^{14}C yr BP)		Age range (cal yr AD [+] or BC [-])		Interpretation
11	191253	S3b	*Juncus balticus* rhizome	-24.0	2 cm below top of soil	Older or same	D	1090	40	895	1132	Age of plant living or already dead at time of event D. Consistent with age of AD 1020-1180 for event D
12	189626	S3a	*Spartina densiflora* rhizomes	-14.0	Low in profile of soil of sample 10, 11 cm below top of soil	Older	D	2670	150	-1128	-388	Age doubtful; paired with sample 10, implies no subsidence event for more than 1000 years before event D
13	179377	S3a	*Spartina densiflora* rhizomes	-14.2	6-7 cm below the soil top and 2 cm above the underlying sand	Older	F?	1450	40	566	757	Loose limiting-maximum age for event doubtfully correlated with event F.
14	191252	S3a	Carbonized *Scirpus americanus* rhizome	-24.9	3 cm below top of soil	Older	F	1530	40	441	654	Samples 14-16 give limiting-maximum ages for event F and limiting-minimum ages for the preceding, event E. We do not compute a pooled age for the three samples because samples 14 and 16 differ in age and because sample 15 differs in material dated.
15	191250	S3a	Charcoal	-26.2	Few centimeters below top of soil	Older	F	1690	40	263	540	
16	30293	S3a	Carbonized *Scirpus americanus* rhizome	-24.9	2-5 cm below top of soil	Older	F	1830	90	29	528	
17	191251	S3a	Stick with bark	-29.8	10 cm below top of soil of uncertain correlation	Older	G or H	1870	40	84	330	Limiting-maximum age for event G, H, or both
18	191255	S3a	Twig with bark	-27.4	8 cm below bioturbated, probably eroded top of soil	Older	H	1970	40	-18	222	Limiting-maximum age for event H

Table S2. Radiocarbon ages, *continued*

All samples were calibrated with Southern Hemisphere data of McCormac et al. (1) and the software Calib Rev 5.0 <http://www.calib.org>.

1. McCormac, F.G., Hogg, A.G., Blackwell, P.G., Buck, C.E., Higham, T.F.G., and Reimer, P.J. ShCal04, Southern Hemisphere calibration, , 0-11.0 cal kyr BP. *Radiocarbon* **46,** 1087-1092 (2004).

Table S3. Percentages of dominant diatom species plotted in Fig. S4

SAMPLE DEPTH (cm)	5	6	7	8	9	9.8	23.5	24.5	25.5	26.8	28	29.4	30.8	31.8	33	35.5	44.3	44.8	45.3	46.4	47.5	48.5	50	69.2	71.3	74	74.5	75.6	76.5	82.2	82.7	83.4
INDIVIDUALS COUNTED	226	249	266	279	279	270	278	209	181	156	216	240	277	261	264	302	286	239	298	282	265	265	315	237	382	315	292	322	226	286	287	326
Freshwater taxa																																
Diadesmis contenta	0.0	0.0	0.0	0.0	0.0	0.0	19.8	1.0	1.1	5.1	13.4	17.9	4.3	0.0	0.0	0.0	17.5	4.2	5.4	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diploneis ovalis	10.2	27.7	25.2	19.7	9.3	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.0	0.0	0.3	1.4	0.0	0.0	0.3	0.0	3.4	0.0	0.0	0.0	0.0	11.2	4.2	3.7
Eunotia paludosa	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	10.3	16.2	6.3	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eunotia praerupta	0.0	0.0	0.0	0.0	0.0	0.0	2.9	5.3	1.7	5.1	3.7	10.8	0.0	0.4	0.4	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eunotia spp	0.0	0.0	0.0	0.0	0.0	0.0	2.5	8.6	4.4	0.0	5.6	6.7	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hantzschia amphioxys	0.0	0.0	0.0	0.0	0.0	0.0	16.5	18.7	5.5	9.6	5.1	0.0	4.7	0.8	5.3	0.0	9.1	1.3	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Luticola mutica	0.0	0.0	0.0	0.0	0.0	0.0	9.7	1.0	0.0	0.0	0.0	0.8	2.2	0.0	0.0	0.0	2.1	5.9	0.0	0.0	0.4	1.1	0.0	0.0	0.0	1.0	0.0	0.6	0.4	0.0	0.0	0.3
Martyana martyi	4.4	7.2	4.9	3.2	9.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	7.0	3.1	0.4	7.7	3.2	2.6	4.2	3.8	0.0	0.8	0.6	1.0	3.4	1.3	1.4	1.0	0.0
Pinnularia divergens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	11.1	11.3	0.7	0.0	0.0	0.0	0.0	1.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinnularia hemiptera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.6	7.4	0.0	1.4	0.0	0.4	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinnularia subrabenhorstii	0.0	0.0	0.0	0.0	0.0	0.0	43.2	47.4	42.5	17.9	20.8	16.3	6.1	1.9	0.4	0.0	2.1	1.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brackish taxa																																
Caloneis bacillum	0.0	6.4	15.4	20.1	11.5	15.9	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Caloneis westii	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	3.0	0.0	0.0	0.7	1.4	1.5	1.5	0.0	0.0	0.0	4.1	2.7	3.7	4.9	0.7	0.3	0.0
Cosmioneis pusilla	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.4	0.0	0.0	0.4	0.0	0.0	0.0	2.1	7.1	0.0	0.0	0.0	0.0	3.8	2.4	4.6
Navicula cincta	6.6	0.8	3.4	4.7	5.7	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Navicula gregaria	0.0	0.0	0.0	2.9	3.6	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Navicula libonensis	15.0	4.0	1.5	3.9	3.6	12.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	1.5	0.0	0.0	1.3	0.0	0.0	2.8	6.2	0.7	0.3	0.3
Navicula phyllepta	3.5	0.8	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Navicula pseudolanceolata	2.2	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula salinarum	6.6	12.9	10.2	11.1	12.9	18.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Navicula tenelloides	6.2	0.0	5.3	2.5	12.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.6
Nitzschia palustris	11.5	1.6	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.6	0.0	0.0	0.0	0.0	0.7	0.0
Nitzschia sigma	0.4	0.8	0.0	0.7	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.8	0.7	2.3	0.4	9.6	1.4	2.5	11.4	7.4	6.8	1.9	3.2	0.0	3.4	20.3	14.0	5.0	13.7	0.0	0.3	2.5
Pseudopodosira kosugii	2.7	0.8	3.0	4.3	1.8	1.1	0.0	1.9	8.8	5.1	0.0	5.4	35.4	46.7	54.5	10.6	24.8	38.9	32.6	34.0	31.3	31.3	19.4	16.9	23.3	11.4	25.0	27.3	12.8	30.1	42.2	44.5
Pseudopodosira westii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.9	0.0	6.9	7.3	3.8	0.0	6.6	0.0	6.4	3.9	3.8	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pseudostaurosira perminuta	0.9	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhopalodia brevissonii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.9	1.4	0.0	4.0
Brackish and marine taxa																																
Achnanthes delicatula	0.0	5.2	3.0	0.7	3.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	2.3	3.8	3.4	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0
Diploneis smithii	0.9	0.8	0.0	0.0	0.0	1.9	0.0	1.4	6.6	2.6	0.0	7.9	15.5	18.8	20.8	8.6	9.1	5.9	11.1	11.0	2.6	2.3	2.2	18.1	30.4	10.8	13.0	2.8	3.1	10.1	11.1	8.0
Navicula digitoradiata	1.8	3.2	3.0	5.7	2.9	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Paralia sulcata	2.7	0.8	1.5	2.2	0.0	6.7	0.0	3.8	15.5	4.5	2.3	5.8	1.8	7.7	5.7	9.3	7.7	9.2	7.7	4.6	9.8	6.0	7.3	12.7	0.8	4.1	14.0	5.6	9.3	5.2	3.5	6.4
Rhaphoneis surirella	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	4.9	0.0	0.3	0.0
Tabularia fasciculata	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.6	0.0	0.4	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	1.5	0.6	0.0	0.3	16.2	0.0	1.6	1.8	0.0	0.0	0.0
Marine taxa																																
Actinoptychus senarius	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	2.1	3.8	4.9	7.0	0.0	0.5	1.3	5.5	2.8	12.8	2.8	4.2	0.6
Odontenlla aurita	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	1.4	0.8	1.1	4.4	0.8	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0
Marine (subtidal?) taxa																																
Auliscus sculptus	0.9	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	1.7	0.0	1.7	1.0	4.6	0.8	0.4	0.0	0.0	0.0	3.8	0.0	2.2	3.5	1.7	1.4	2.5
Cerataulus sp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	2.5	2.1	0.0	0.0	0.0	0.0	0.7	4.2	0.0
Unknown taxa																																
Diploneis sp-1	0.9	2.0	3.8	0.0	0.0	0.0	0.0	1.9	2.8	2.6	0.0	4.2	6.9	2.7	0.4	2.6	2.8	10.9	4.7	4.6	2.6	0.4	1.0	18.1	5.0	1.3	6.2	0.0	0.4	11.5	3.8	11.7
Staurosirella sp	3.5	5.2	4.9	2.2	11.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	4.6	0.0	9.6	21.1	31.3	31.4	11.8	4.5	7.9	7.2	27.3	8.0	4.5	3.5	0.0

Table S4. Counts of annual rings in dead trees near Misquihué

Species	Common name	Rings
Myrceugenia exsucca	Patagua	80
Myrceugenia exsucca	Patagua	84
Blepharocalyx cruckshanksii	Temu	101
Blepharocalyx cruckshanksii	Temu	103
Aextoxicon punctatum	Olivillo	125
Luma apiculata	Arrayán	145
Blepharocalyx cruckshanksii	Temu	171
Luma apiculata	Arrayán	178
Myrceugenia exsucca	Patagua	188
Blepharocalyx cruckshanksii	Temu	204
Luma apiculata	Arrayán	208
Luma apiculata	Arrayán	216
Myrceugenia exsucca	Patagua	219
Blepharocalyx cruckshanksii	Temu	261
Blepharocalyx cruckshanksii	Temu	271

NOTE
We counted annual rings along three radii on entire, sanded cross sections of dead trees from Misquihué (printed Fig. 3; supplementary Fig. S1d,e). Each counted ring was traced around the slab.