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The Evolution of the Bío Bío Delta and the Coastal Plains of the Arauco Gulf, Bío Bío Region: the Holocene Sea-Level Curve of Chile

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ABSTRACT

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Mid-Holocene highstands are characteristic of the Southern Hemisphere. The Chilean coast extends from 17°S to 56°S in a dominant microtidal regime; thus, it is an ideal place to test ages and altitudes of this highstand with minimal errors. However, coseismic events, the dynamic phenomena they triggered (tsunamis), and the behaviour of land in relation to the overriding of the South American Plate over the oceanic Nazca Plate, make it necessary to distinguish these effects from purely eustatic changes. To the south, the glacioisostatic uplift has been approximately measured. At 37°S, the Coronel coastal plain extends several kilometres inland. Its sediment availability has been related to the supplies of the Bo Bo River. From this beach-ridge plain, shell remains gave a radiocarbon age of 4370 ± 90 years before present (YBP), indicating a highstand not higher than 5 m. Further south, at the Carampangue coastal plain, southern coast of the Arauco Gulf, a radiocarbon age of 8010 ± 90 YBP marks the oldest age of this transgression. Some consequences of the earthquake and tsunami of February 27, 2010, are reported here. The radiocarbon ages of these plains permit completion of a Holocene sea-level curve. These Holocene sea-level data were compared to other regions of South America.

ADDITIONAL INDEX WORDS: *Holocene sea level, Delta evolution, Bo Bo River, Chile.*

INTRODUCTION

Thirty years ago, sea level was assumed to vary uniformly worldwide, and therefore mean sea level was considered very useful to discern the relative movements of the land. However, some discrepancies came from differences in the land movement due to tectonics, isostasy, and geoidal variations. In particular, the mid-Holocene highstand triggered controversy since it occurred dominantly in the Southern Hemisphere (Isla, 1989; Angulo, Lessa and de Souza, 2006). In some regions, this sea-level fluctuation caused beach-ridge plains (horizontal sequences) or the infilling of estuaries (vertical sequences). In other regions this fluctuation is masked as a result of vertical movements (uplift, subsidence, isostatic rebounds, geoidal variations) or episodic high sea levels (storms, tsunamis, hurricanes).The coast of Chile is subject to differential tectonic activity (Ortlieb et al., 1996; Araneda *et al.*, 2003; Marquardt *et al.*, 2004; Quezada *et al.*, 2007). At the same time, it is subject to interannual highstands related to El Niño–Southern Oscillation (ENSO) events (Bello *et al.*, 2004), storms, and episodically triggered tsunamis. However, the record of the mid-Holocene highstand was considered a useful tool to discern long-term tectonic changes (Leonard and Wehmiller, 1990; Ota and Paskoff, 1992; Hervé and Ota, 1993).

The purpose of this paper is to describe the Holocene evolution of this region in regard to radiocarbon datings of shell layers sampled at the coastal plain of Coronel and at the Gulf of Arauco. At the same time, some consequences of the earthquake and tsunami of February 27, 2010, are reported. Since these datings corroborate other evidence of the Holocene sea-level fluctuation, a sea-level curve was drawn comparing the data from Chile to other regions of South America.

SETTING

The Chilean coast extends from 17°S to 56°S (Figure 1a), most of it dominated by modern tectonic effects. At northern Chile, the subduction angle of the Nazca Plate beneath the South American Plate varies with latitude, causing different tectonic effects from north to south (Barazangi and Isacks, 1976; Chinn, Isacks and Barazangi, 1980; Krwacyk *et al.* 2006). South of 50°S, the differential movements of three plates, South America, Antarctic, and the Scotian microplate, (Figure 1a), are also responsible for the vertical behaviour of the land (Klepeis and Austin, 1997; Diraisson *et al.*, 2000; Lodolo *et al.*, 2007).

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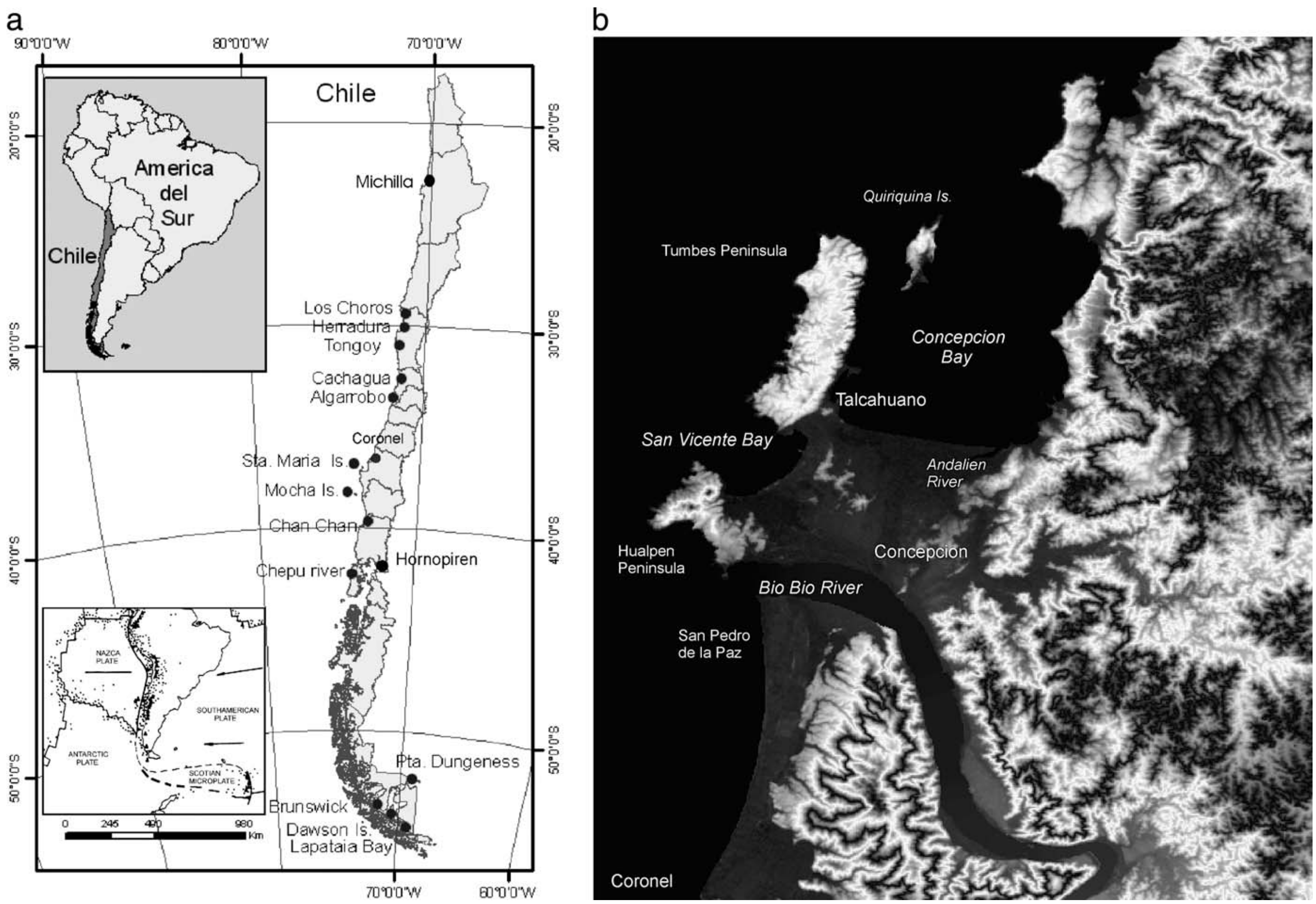

Figure 1. (a) Location map of Chile Holocene highstands in relation to different tectonic emplacements. (b) Digital Terrain Model (90 m resolution) of the Bo Bo delta within a tombolo complex.

Two tectonic domains should be discriminated. First, uplift is assumed to take place where the Nazca Plate is subducting below the South American Plate. The faults normal to coast are responsible for the different behaviour of horsts (capes, peninsulas) and grabens (bays). Second, the South American Plate is moving parallel to the Scotian Microplate; the Magallanes Faulting Zone is responsible for several earthquakes in southern Tierra del Fuego (Isla and Bujalesky, 2004; Lodolo, Donda and Tassone, 2006). The Bo Bo region evolves in relation to the differential movements of different blocks in relation to transform faults such as the Bio Bio–Aluminé Fault (Götze et al. 2006). This fault affects either the main and coastal cordilleras as well as the longitudinal valley (Glodny et al. 2006) and continues into the Bo Bo Canyon (Krawcyk *et al.*, 2006). The Bo Bo River evolved as a complex of tombolos between several blocks (Figure 1b). These blocks are composed by Carboniferous schists to the west and carboniferous diorites to the east.

Microtidal effects are also dominant along the Chilean coastline but are subject to surges derived from strong westerly winds, typical of temperate regions. At the Magellan Strait, tidal ranges up to 7 m are common over the course of the year (Fontolan and Simeoni, 1999).

Tectonic Effects and Quaternary Marine Terraces

One of the major constraints to constructing sea-level curves based on Quaternary marine terraces for different latitudes of Chile can be found in the effects of episodic waves along the coast (Atwater, Jiménez Nuñez, and Vita-Finzi, 1992). Quezada and colleagues (2005) stated that surges induced by tsunamis vary along the coast if the earthquake-triggered waves move from north to south or *vice versa*. During the earthquake of 1960, waves of 12–15 m were estimated for the coast of Valdivia (Pino and Navarro, 2005). This earthquake was considered one of the most recorded by instruments (Atwater, Jiménez Núñez, and Vita-Finzi, 1992; Melnick *et al.*, 2006). Based on cores collected from Lake Puyehue, a recurrence of giant earthquakes between 2000 and 500 years has been estimated (Moernaut *et al.*, 2007).

Quaternary marine terraces are usually used to distinguish tectonic behaviours. Along the Chilean coastline, several marine terraces were defined at Coquimbo, La Serena, and Mejillones Peninsula (Radtke, 1989; Ortlieb *et al.*, 1996). In the area of Caldera-Copiapó, coastal steps were explained by marine terraces, suggesting an uplift of about 0.28 mm/y

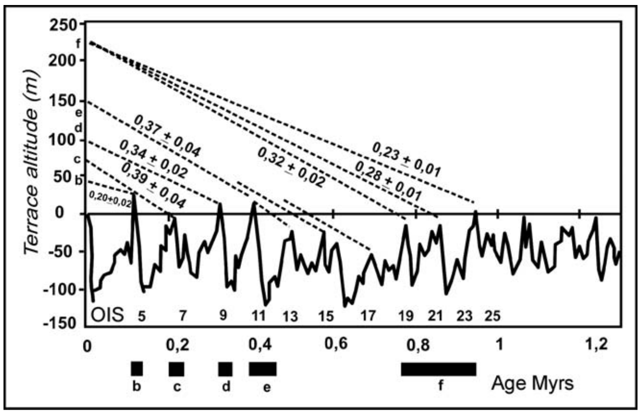

Figure 2. Uplifting rates of Quaternary marine terraces of Chile. OIS, Oxygen isotopic stages (from Quezada et al., 2007).

(Figure 2; Marquardt *et al.*, 2004; Quezada *et al.*, 2007). Pleistocene uplifted terraces have also been described at the Arauco Peninsula (37°30′S; Kaizuka *et al.*, 1973). At Santa Mara Island, an anomalous uplifting trend of 2 mm/y has been estimated (Melnick *et al.*, 2006). Considering some morphological evidence, this terrace is also related to that one spanning Lebu and Cañete.

Holocene Highstands

Although the mid-Holocene highstand could have caused several morphologic features (estuarine plains, reefs, or nonoperative tidal flats), beach-ridge plains are more easily recognized from aerial photographs and satellite images in temperate coasts. These plains usually extend from the foot of former palaeocliffs. Along the coast of Chile, these plains lay on different tectonic domains.

At Caleta Michilla (22°43′S), two marine terraces were recognized. *Mulnia* shells collected 1 m below the low terrace (approximately 6–7 m over mean sea level; MSL) yielded a radiocarbon age of 6725 ± 95 years before present (YBP) (Gx-15475; Leonard and Wehmiller 1990).

Several ridges, parallel to Los Choros beach (29°15′S) have been attributed to palaeobeaches of Holocene age (Castro and Bignardello, 2005). In Baha Herradura (29°58′S), south of Coquimbo, a radiocarbon age of 4090 ± 80 YBP was obtained at an altitude of 2 m, from a 4–5-m marine terrace (Radtke, 1989). In Quebrada Los Chines, barnacles are attached to gravel clasts. At an altitude of about 2 m above MSL, shells of *Argopecten purpuratus* gave an age of 4520 ± 110 YBP (Ota and Paskoff, 1992). The uplift of the Coquimbo block was estimated about 0.1–0.2 m/ky (Ota and Paskoff, 1992). Further south, in Baha Tongoy (30°15′S), mollusc samples of *Protothaca* sp. and *Mactra* sp. were dated from a beach-ridge plain and estuarine deposits, spanning from ages of 6380 ± 120 to 910 ± 90 YBP (Ota and Paskoff, 1992). This beach plain, in the western part of this bay, was related to the Puerto Aldea Fault. Based on these ages, a progradation of 0.13–0.14 m/y was estimated (Ota and Paskoff, 1992).

In Cachagua (32°36′S), molluscs fragments were sampled below a dune at an altitude of 3 m above MSL, yielding an age of 2000 YBP (Radtke, 1989). North of Algarrobo (33°21′S), within the alluvial plain of the Estero San Jerónimo (1.5 km from the coast), wood fragments at an altitude of 3.8 m over the Navigation Reference System (NRS) level were dated in 5660 ± 70 YBP (Hervé et al., 2003). These fragments were sampled from a layer of 25 cm of grey micaceous, silty sandstone containing estuarine molluscs (*Tagelus dombeii*, *Mytilus chilensis* and gastropods of the genera *Hydrobia*), forams (*Ammonia tepida*), ostracods (*Cyprideis beaconensis*), and plant debris. This layer was deposited between two beds of fluvial origin and contains some thin intercalations of siltstones rich in organic matter (Encinas *et al.*, 2006). Pollen analysis of the marine layer suggests a marsh environment, in the sense that Chenopodiinae dominates (72%), while compositae and graminae are less abundant. At Mocha Island (38°22′S; Caleta La Calera), a Holocene terrace bearing mollusc remains has been dated between 5900 ± 85 and 3840 ± 80 YBP at a maximum altitude of 23 m (Kaizuka *et al.*, 1973; Radtke, 1989). However, some anthropogenic influence in the site has been recognized (Radtke, 1989).

In the Valdivia region, at the Chan-Chan 18 archaeological site (39°30′S), a mid-Holocene beach berm bearing charcoal at 8 m over NRS has been dated at 5610 ± 100 and 5460 ± 50 YBP (Pino and Navarro, 2005).

Between the Ro Maulln inlet (41°35′S) and the Chacao Channel (41°45′S), net Late Holocene emergence of the coastline was recognized, notwithstanding that this region was suspected to be submerged triggered by the earthquakes of May 1960 (Atwater, Jiménez Núñez, and Vita-Finzi, 1992). The beach-ridge plain located south of the Maulln inlet provided a peaty mud that yielded an age 4290 ± 110 YBP and remains of roots and branches that gave a radiocarbon age of 4150 ± 60 YBP (Atwater, Jiménez Núñez, and Vita-Finzi, 1992). At the inlet of Ro Ballenar, four sand layers are suggesting four tsunamis that affected this estuarine complex, the most recent is thought to have been produced in 1960 (Atwater, Jiménez Núñez, and Vita-Finzi, 1992). Further to the east, at the area of Hornopirén, mid-Holocene emergence evidences were reported spanning from 3 to 30 m over MSL (Hervé and Ota, 1993). Radiocarbon datings were performed on shells of *Protothaca thaca* in living position. However, as the Ancud Gulf was assumed to be covered by glaciers during the Upper Pleistocene, much of this emergence was assigned to local tectonism and glacioisostatic rebound (Hervé and Ota, 1993). At the inlet of the Chepu River (42°03′S, northwestern Chiloé Island), radiocarbon datings performed from a 5-m terrace gave ages spanning from 5040 ± 85 to 1700 ± 65 YBP (Radtke, 1989).

The coast between Cabo Vrgenes and Punta Dungeness (52°20′S) is a cuspate foreland developed at the Atlantic inlet of the Magellan Strait (Uribe and Zamora, 1981; Codignotto, 1990; González Bonorino *et al.*, 1999). At this beach plain, a sample gave an age of 900 ± 60 radiocarbon YBP (Uribe and Zamora, 1981). On the southern side of the strait, Punta Catalina evolved in relation to the coastal erosion of till deposits and the transport of gravel to the interior of the strait. Patterns of gravel-beach plains are today explaining a complex evolution in relation to the mid-Holocene sea-level fluctuation in a macrotidal regime (Fontolan and Simeoni, 1999). Further south, and very close to the northern limit of the Magellan Faulting Zone (also called Lake Fagnano Fault), maximum altitudes of Holocene beaches at 6–10 m were recognized at northern Dawson Island (53°35′S). This area has been subject to modern tectonics responsible for a system of three horsts (Punta Askew, Punta Santa Ana, and the northern side of the Ro San Juan valley) and two grabens (McCulloch and Bentley, 1998). At New Brunswick Peninsula (53°50′S), some morphological features indicate subsidence (San Nicolás, del Indio and Brookes embayments) while other places suggest uplift (Baha Snug; Fuenzalida and Harambour, 1984). These results challenge the differential movements of horsts and grabens suggested by McCulloch and Bentley (1998).

In the Fuegian Archipelago, evidence of a sea level higher than present during the Holocene has been known since the Swedish Expedition of 1907–1909 (Halle, 1910). The Beagle Channel is a good place to try to discriminate between glacioeustatic, isostatic, and tectonic effects. In Playa Larga, Ushuaia, Argentina (54°50′S), there are well-developed terraces located close to the Olivia River inlet. Five superposed raised beaches developed at 1.6 m (405 ± 55 ^{14}C YBP), 3.8 m (3095 ± 60 ^{14}C YBP), 5.2 m (4335 ± 60 ^{14}C YBP), 7.5 m (5615 ± 60 ^{14}C yrs BP), and 10 m above MSL (Gordillo *et al.*, 1992). The glacial valley that extended from Lago Roca to Baha Lapataia (20 km west of Ushuaia) is a palaeo-fjord that was occupied by a tributary glacier system during the last glacial maximum (about 20,000–18,000 YBP) and sealed by a lateral moraine (Gordillo *et al.*, 1992). Holocene marine deposits are scattered along the surroundings of Baha Lapataia, overlying glacial landforms and reaching a maximum altitude of at least 8.4 m above MSL (Gordillo *et al.*, 1992). A core obtained from this bay gave several radiocarbon ages ranging between 8550 ± 120 and 7260 ± 70 ^{14}C YBP, corroborating the sea-level rise during the Early Holocene at these latitudes (Borromei and Quattrocchio, 2001).

METHODS

Topographic surveys were carried out from the distal portion of the Coronel coastal plain to the present coastline. A Digital Elevation Model (DEM) was downloaded from the Shuttle Radar Terrain Model web site (SRTM; http://srtm.csi.cgiar.com). This DEM has a ground spatial resolution of 90 m and was handled with the Global Mapper v.7.04 (www.globalmapper.com). Old military charts were also handled in order to recognize geomorphological variations. Radiocarbon datings were performed at the Laboratorio de Tritio y Radiocarbono (LATYR, La Plata, Argentina). Corrections regarding the relationships between radiocarbon years and sidereal years were performed. At the same time, LATYR gave advice about marine samples from the Southern Hemisphere (McCormac *et al.*, 2004).

RESULTS

The Coronel Coastal Plain

The Bo Bo River deltaic coastal plain laid over the coastal platform (Glodny *et al.*, 2006) and has been flooded and infilled during the Holocene transgression (Martnez Pardo, 1968).

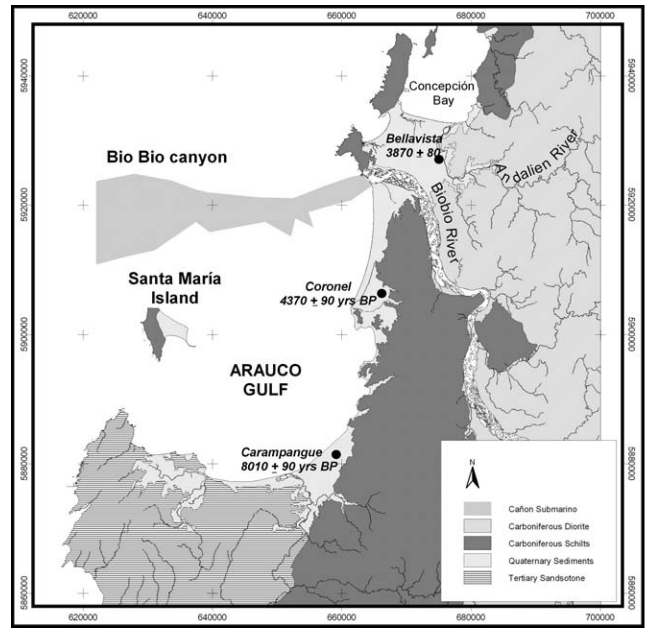

Figure 3. Geological sketch of the Bo Bo delta and Arauco Gulf with sampling sites (modified after Veyl Oñat, 1961).

Much of its evolution is controlled by variations in the orientation of the river within the tombolo agradation induced by the Talcahuano and Hualpén peninsulas (Figure 1b). South of this large estuary, several coastal plains (San Pedro de la Paz, Coronel, Laraquete) extend from the foot of the Cordillera de la Costa to the Pacific Ocean (Figure 3). At the Santa Mara Island, another Holocene coastal plain is attached to the Quaternary marine terrace but extending from west to east (Melnick *et al.*, 2006).

Former radiocarbon datings of the Bo Bo delta were performed from drillings below MSL (Galli, 1968) and outcrops north of Concepción (Campana, 1973; Table 1). The Coronel coastal plain (Figure 3) is 6.3 km wide and distributed into several systems due to the irregularities of the inherited bay. From a well drilled at a distal location of this coastal plain, broken shells were sampled at a depth of 6 m (Table 1). They yielded a conventional radiocarbon age of 4370 ± 90 YBP (LP-2090). Considering the reservoir effect, LATYR Lab suggested an age of 3970 ± 90 YBP. The calibration suggested for marine samples of the Southern Hemisphere (McCormac *et al.*, 2004) was not considered in regard to the variability of the relationship between stable and unstable C triggered by the variability of "old C" at the Eastern Pacific Ocean during ENSO effects (Turney and Palmer, 2007). At Laraquete, some kilometres south (Figure 3), the beach-ridge plain is narrower (3.3 km wide) and composed of well-sorted (0.48 standard deviation) fine sand (2.5 phi units).

The Carampangue Coastal Plain

The Carampangue marsh is located east of Arauco, 5 km from the coast and 1.5 km west of Route 160. The profile

Table 1. *Radiocarbon datings from the Bo Bo delta, Coronel coastal plain, and Carampangue coastal plain.*

	Latitude S	Longitude W	Altitude (m)	^{14}C Age	Corrected by Reservoir Effect	Lab Sample	Reference
Bo Bo delta			−88	8605 ± 115			Galli (1968)
Bellavista I	36°47′	73°02′30″	5	3870 ± 80		IVIC-844	Campana (1973)
Bellavista II	36°47′	73°02′30″	3	3330 ± 80		IVIC-845	Campana (1973)
Coronel	36°59′52″	73°06′54″	6	4370 ± 90	3970 ± 90	LP-2090	This paper
Carampangue	37°15′09″	73°13′01″	0	8010 ± 90	7610 ± 90	LP-2177	This paper

initiated at a depth of 6.71 m as a grey peat 0.77 m thick. Broken shells were collected at a layer about 0.2 m over this peat. These shells were dated in 8010 ± 90 YBP; considering reservoir effect the age should be taken as 7610 ± 90 YBP (LP 2177; Table 1). This layer is overlain by 5.74 m of sand of different grain sizes and colours; the top of this sand layer is 0.96 m thick and mixed with silt. The top of the sequence is composed of another peat 1 m thick. Since the top of this sequence is 6 m high, the dated shells are close to sea level, and they indicate the moment when the sea level was rising toward present MSL.

Delta Evolution

During the last glacial maximum, sea level was approximately 100 m below present (Figure 4a). The Bo Bo and Andalién rivers are assumed to flow together toward the depression today occupied by the Concepción Bay. The rivers of the Arauco watershed also flew to the north, to the Bo Bo Canyon. The Holocene transgression progressively flooded present embayments (Concepción, San Vicente, and Arauco; Figure 4b). Maximum highstand occurred about 6000 YBP. Since then, the Bo Bo River has been infilling the Concepción Bay (Martnez Pardo, 1968). Beach ridges formed at the foot of massifs were composed mainly of Precambrian schists and Cretacic diorites. Volcanic sands delivered by the Bo Bo River were accommodated by wide open embayments (*e.g.*, Laraquete and Coronel embayments). An arm of the Bo Bo delta grew toward San Vicente Bay (Ilabaca, 1979). Former islands (Hualpén, Talcahuano) were transformed into peninsulas. Finally, the river connected to the canyon at the present outlet. Sediments are therefore more efficiently transported toward the slope (Figure 4c). The beach-ridge plain of San Pedro de la Paz has prograded attached to the southern shore of the inlet.

Significant morphological changes were introduced in the last two centuries draining wetlands and improving harbours. During the Independence War (1817), the patriotic troops dealt with the flooded wetlands spanning Concepción City and the Spanish fortifications at Talcahuano (Nellar, 1965; Figure 5a). In Talcahuano City, harbour improvements have significantly changed the original coastal configuration (Figure 5b).

On February 27, 2010, one of the largest earthquakes ever recorded struck this coast. One of the bridges across the Bo Bo River, between Concepción and San Pedro de la Paz, fell down. A major earthquake of this magnitude (8.8 Richter scale) had been forecast for this area (Ruegg *et al.* 2009), but it occurred 105 km NNE of Concepción, off the Maule River estuary. A tsunami wave entered Concepción Bay and caused severe damage at the coast of Talcahuano, particularly where marshes have been transformed into harbour facilities (right side of Figure 5). The area surrounding Carampangue coastal plain, south of the Arauco Gulf, was affected. At Lebu, rocks colonised by kelp were uplifted more than 2 m (Figure 6). Similar phenomena occurred at the villages of Tubul and Llico, within the Arauco Gulf (Figure 3). To the north, to the area of Concepción, preliminary estimations indicated uplifts of 0.4 m for Talcahuano and Bo Bo estuary, and 0.5 for Caleta Lenga. In the area of Maule River, estimations of one of the authors

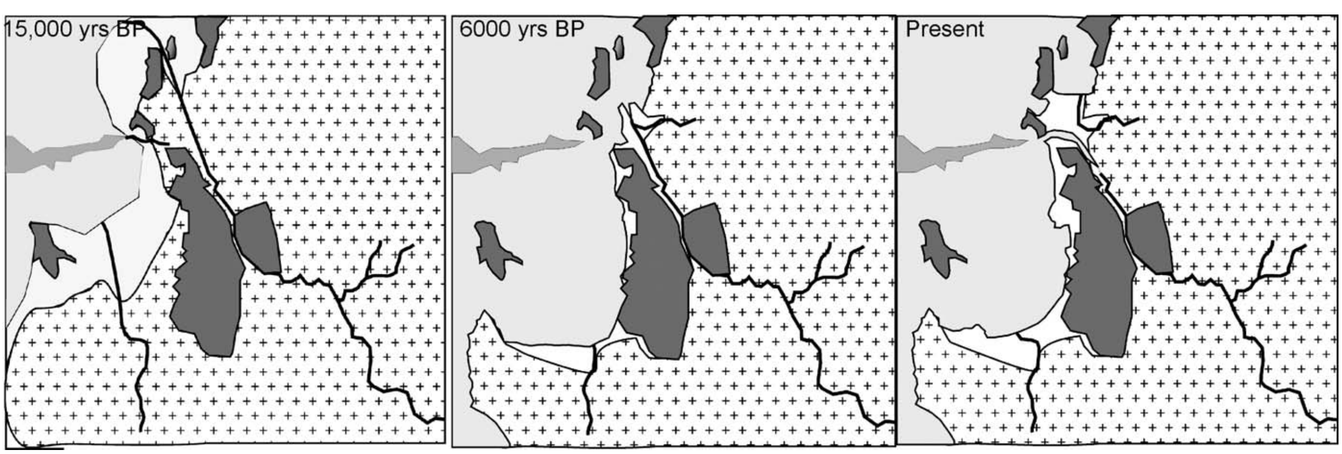

Figure 4. Geomorphological evolution of the Bo Bo delta (modified after Ilabaca, 1979).

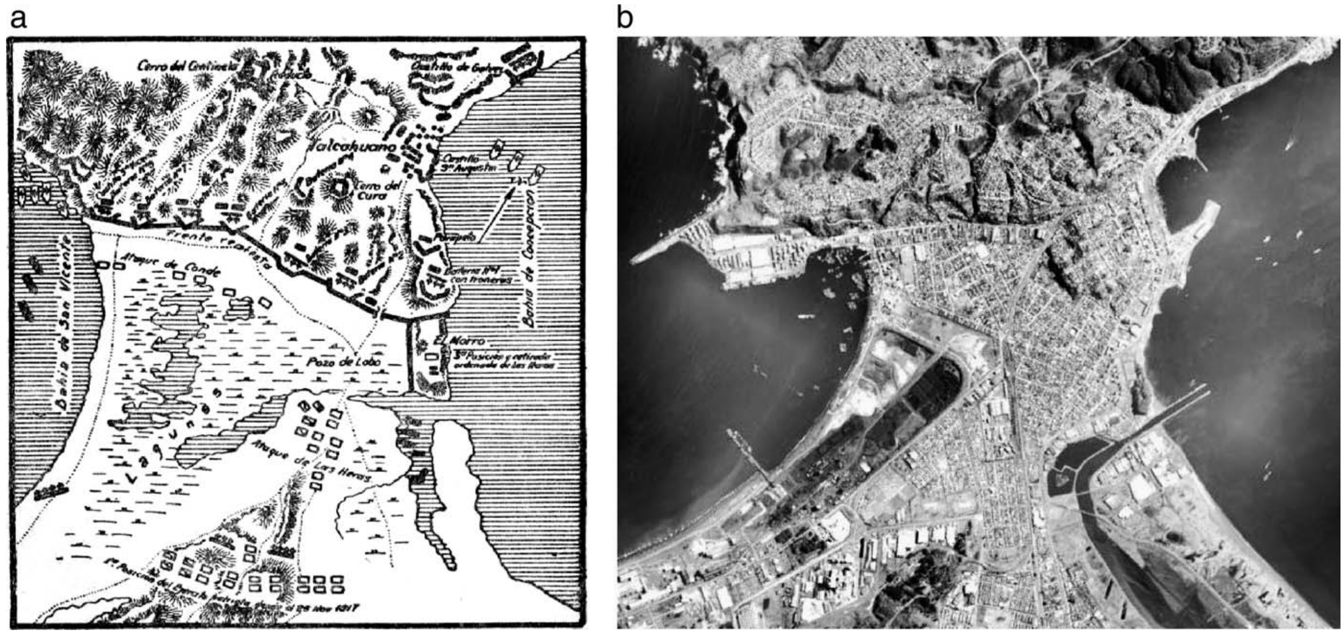

Figure 5. Morphological variations of the Talcahuano area between 1817 and 2007. The map of 1817 is a reproduction of the sketch of the battle that took place on December 6 (Nellar, 1965).

(J.Q.F.) reported the subsidence of 1 m, and 0.35 for the village of Constitución.

A Sea-Level Curve for Chile

Considering the different tectonic domains from Chile, a sea-level curve can been drawn proposing a maximum highstand not higher than 5 m between 6000 and 5000 years ago (Figure 7). Datings related to the shell middens at the Chan Chan site (Pino and Navarro, 2005) and Cholgo Channel (Hervé and Ota, 1993) were disregarded. A distinction between datings performed in northern, central, and southern coasts was considered useful in order to discern local tectonic effects. In the northern coast, ENSO-triggered floods can introduce some noise. At the southern coast of Tierra del Fuego, a tectonic uplift has been estimated (Rabassa, Heusser, and Stuckenrath, 1986; Hervé and Ota, 1993). These Chilean datings were analyzed within the Holocene sea-level database of South America.

DISCUSSION

This curve can be compared to those proposed for Eastern Patagonia (Schellmann and Radtke, 2003), Buenos Aires (Isla, 1998), and southern Brazil (Angulo and Suguio, 1995; Angulo, Lessa, and de Souza, 2006). The sea-level curve delineated for Southern Patagonia and the Fuegian channels is biased to a regional tectonic uplift and a significant reservoir effect. This reservoir effect is evident from the radiocarbon ages from the southernmost areas: 7980 YBP recorded at Puerto del Hambre in the Magellan Strait (Porter, Stuiver, and Heusser, 1984) and 8550 YBP at Baha Lapataia, Beagle Channel (Borromei and Quattrochio, 2001). These old datings for the arrival of the Holocene transgression to the present Fueguian coastline have been explained by tectonism (Rabassa, Heusser, and Stuckenrath, 1986; Gordillo *et al.*, 1992). However, if the ENSO is conditioning the delivering of "old C" to coastal waters via upwelling (Turney and Palmer, 2007), these ages are the response of the interannual exchange of CO_2 between the deep ocean and the atmosphere at high latitudes of the Southern Hemisphere.

Considering the altitudes recorded for the Middle–Late Holocene raised coastal deposits, it is clear that they are suggesting a sea level not higher than 5 m in the dominant microtidal regime of Chile. However, some radiocarbon datings performed at Mocha Island, Valdivia, Hornopirén, and Chiloé indicate higher altitudes in areas affected by the 1960 earthquake. Atwater and colleagues (1992) explained that areas that subsided due to that earthquake can be uplifted during the period after the stroke. The following earthquake would cause the collapse of the crustal bulge built between earthquakes (Atwater, Jiménez Núñez, and Vita-Finzi, 1992). However, and for the same region, some uplifted Holocene terraces have been explained by tectonism (related to the Liquiñe-Ofqui Fault Zone) but without discarding a glacioisostatic rebound during he Holocene (Hervé and Ota, 1993).

Regarding the proposed uplifting trend of 2 mm/y for Santa Mara Island (Melnick *et al.*, 2006), this uplift could be reduced significantly (to 0.67–0.5 mm/y) only considering that the datings around 50,000–30,000 radiocarbon YBP are minimum ages and should be considered to correspond to the Sangamonian highstand (oxygen isotopic stage 5e; 120,000 YBP). Based on coral reef terraces and sea-level estimations based on deep-ocean oxygen isotope ratios, there is no highstand close to

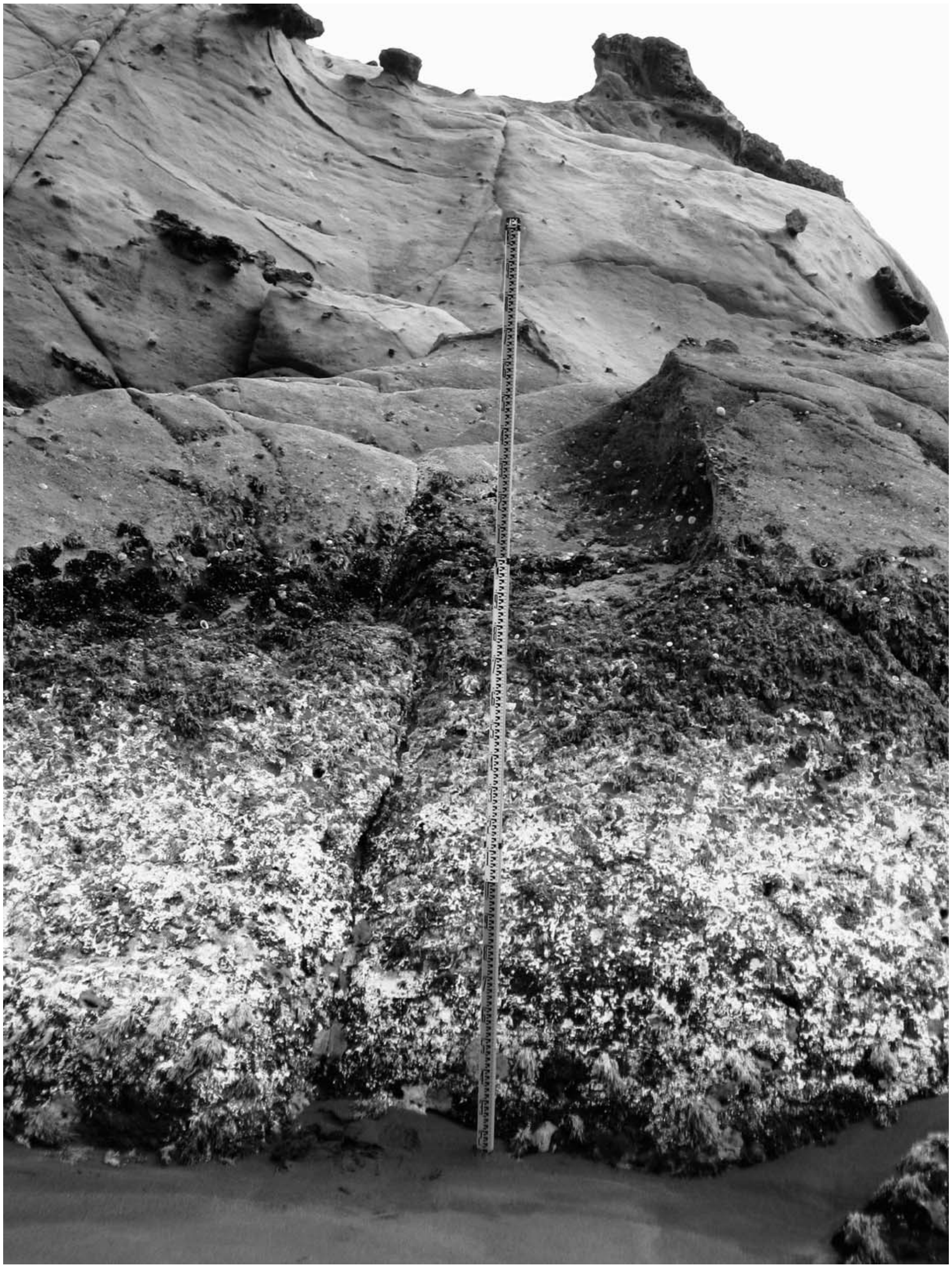

Figure 6. Rock with kelp uplifted more than 2 m in Lebu, Arauco Gulf.

present during those ages around 50,000–30,000 years (Siddall *et al.*, 2003). Dealing with similar latitudes of the Chilean coastline, there are significant differences in the uplifting rates comparing the coastal plains attached to the continent and those related to the blocks detached from the continent (Santa Mara or Mocha Island blocks).

Merging dispersed information, a composed sea-level curve can be considered valid for the Chilean coast (Figure 7). A similar composed curve has been drawn for the Magellan Strait and Beagle Channel region (Porter, Stuiver, and Heusser, 1984) collecting data from different tectonic domains and different response to glacioisostatic components. Within the

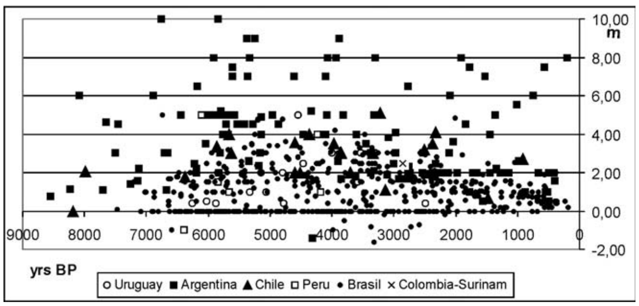

Figure 7. Holocene radiocarbon dates from the South American coast. Data from the Chile coast is graphed as triangles.

Beagle Channel, and considering a regional uplifting rate of 1.5–2.0 mm/y (Rabassa, Heusser, and Stuckenrath, 1986), the ages of Playa Larga (405 ± 55 ^{14}C YBP at +1.7 m) and Baha Brown (985 ± 135 ^{14}C YBP at + 2.6 m) indicate coseismic uplifts above the regional trend (Gordillo *et al.*, 1992). However, these uplifting trends could not be related to the cheniers sequences extended at the Atlantic coast and subject to other sources of errors caused by higher tidal ranges and storm setups (Vilas *et al.*, 1999).

The importance of these deposits of mid-Holocene age is their relationship to the activity of the earlier inhabitants of Patagonia and Tierra del Fuego (Gómez Otero, Lanata, and Prieto, 1998; Orquera and Piana, 1998; Salemme and Bujalesky, 2000; Pino and Navarro 2005). One of the more complete archaeological sequences related to the maximum Holocene highstand is located at the southern Fuegian archipelago: Beagle Channel (Túnel site: 6980 ± 110 ^{14}C YBP; Orquera and Piana, 1998), Pennsula Mitre (Baha Valentn: 5900 ± 80 ^{14}C YBP; Gómez Otero, Lanata, and Prieto, 1998) and Isla de los Estados (Caleta Crossley: 2730 ± 90 ^{14}C YBP; Horwitz, 1990).

In the last years and dealing with beach plains, there has been much controversy about the apparent lack of radiocarbon dates at some gaps during the Late Holocene. The two negative sea-level fluctuations assumed to have occurred in Western Africa (Einsele, Herm, and Schwarz, 1974) and Brazil (Martin, Dominguez, and Bittencourt, 2003) were disputed by some authors (Angulo and Suguio 1995; Angulo, Lessa, and de Souza, 2006), while others were not conclusive about this specific subject (Baker and Haworth, 2000). Vertical sequences infilling estuaries in Buenos Aires coastal plains did not result in any recorded sea-level drop (Isla 1998; Espinosa, De Francesco, and Isla, 2003; Vilanova, Prieto and Espinosa, 2006).

CONCLUSIONS

(1) The Holocene sea-level fluctuation is recorded at the Coronel and Carampangue coastal plains at a maximum altitude not higher than 5 m (over present MSL).
(2) This sea-level fluctuation has been similarly recorded in northern, central, and southern Chile.
(3) The Bo Bo delta evolved conditioned by this sea-level fluctuation between uplifted blocks and the location of the submarine canyon.
(4) The delta was significantly affected by the earthquake and tsunami of February 27, 2010.
(5) Some of these records are undoubtedly altered by modern effects, either by direct tectonic effects (uplifted or subsided blocks) or those triggered by tsunami waves. In this sense, this composed Holocene sea-level curve could be handled in order to evaluate tectonic effects.

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□ **RESUMEN** □

Niveles altos del nivel el mar son caractersticos del Holoceno medio del Hemisferio Sur. La costa chilena se extiende desde 17 a 56°S en un régimen dominado por micromareas, por lo que resulta ideal para testear con buena precisión edades y alturas de este nivel alto del mar. Sin embargo, episodios cossmicos, los eventos dinámicos que generan (tsunamis), y el comportamiento del continente en relación a la Placa de Nazca, hacen necesario distinguir estos efectos de los cambios puramente eustáticos. Hacia el sur, el levantamiento glacioisostático ha sido medido aproximadamente. A 37°S, la planicie costera de Coronel se extiende varios kilómetros hacia el interior. Su abundancia de sedimento ha sido relacionada a los aportes del ro Bio Bio. De esta planicie de cordones de playa restos de conchilla dieron una edad radiocarbónica de 4370 ± 90 años AP, indicando un nivel alto del mar no mayor de 5 m. Algo más al sur, en la costa sur del Golfo de Arauco, una datación radiocarbónica de 8010 ± 90 años AP está registrando la edad máxima de esta transgresión. Se informan además algunas de las consecuencias del terremoto y tsunami del 27 de febrero de 2010. Las edades radiocarbónicas de estas planicies permiten completar una curva del nivel del mar holocénico. Estos datos del nivel del mar durante el Holoceno fueron comparados con otras regiones de Sudamérica.