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GEOLOGICAL NOTE

Finding of a Holocene marine layer in Algarrobo (33°22'S), central Chile. Implications for coastal uplift

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ABSTRACT

A buried Holocene marine bed was discovered upon drilling a water well in Algarrobo (33°22'S), located on the coast of central Chile. Radiocarbon dating of a wood fragment found within the deposit indicates an age of 6450 cal yr BP. The top of this bed, 0.25 m-thick, was reached at an elevation of 3.8 m above mean sea level. This bed contains abundant monospecific faunas of foraminifers (*Ammonia tepida*) and ostracodes (*Cyprideis beaconensis*), indicative of deposition in a very shallow, transitional marine environment. Palynologic analysis reveals a *Chenopodiaceae*-dominated (~70%) assemblage, indicating a relatively arid and warm climate.

Key words: Mid-Holocene, Marine transgression, Algarrobo, Central Chile.

RESUMEN

Hallazgo de una capa marina del Holoceno en Algarrobo (33°22'S), Chile central. Implicancias con respecto al alzamiento costero. Una capa marina de edad holocena fue descubierta durante las faenas de excavación de un pozo en Algarrobo (33°22'S), situado en la zona costera de Chile central. Un fragmento de madera incorporado en este estrato dio una edad ^{14}C de 6450 cal yr BP. El techo de esta capa, de 0,25 m de espesor, se sitúa a una altura de 3,8 m sobre el nivel medio del mar. Esta capa presenta una fauna abundante y monoespecífica de foraminíferos de la especie *Ammonia tepida* y de ostrácodos de la especie *Cyprideis beaconensis*, que son indicativos de un ambiente marino somero y transicional. El análisis palinológico indica la presencia de una asociación dominada por *Chenopodiaceae* (70%), indicativa de un clima relativamente árido y cálido.

Palabras claves: Holoceno medio, Transgresión marina, Algarrobo, Chile central.

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INTRODUCTION

Pleistocene terraces are widespread along the coast of Chile and have been a subject of study since the 19th century (*e.g.,* d'Orbigny, 1842; Darwin, 1846; Domeyko, 1848; Herm, 1969; Paskoff, 1970, 1977; Leonard and Wehmiller, 1992; Ota *et al*., 1995; Ortlieb *et al*., 1996; Marquardt *et al*., 2004). Studies on marine Holocene deposits, however, are scarcer and have focused on coastal areas with very high uplift rates, such as Isla Mocha (Nelson and Manley, 1992) and Chiloe (Hervé and Ota, 1993). Drilling of a water well in the San Jerónimo Creek, near Algarrobo, led to the casual discovery of a buried Holocene marine bed within fluvial deposits. We consider this finding important because there is no prior record of marine Holocene deposits in this part of central Chile. In addition, this discovery implies the possibility of new Holocene findings in the area, which would permit the calculation of coastal uplift rates and to determine if these rates are enhanced by the nearby aseismic Juan Fernández Ridge, which is subducted 30 km north of Algarrobo.

GEOLOGICAL SETTING

Algarrobo (33°22'S, 71°39'W) is located on the coast of central Chile about 100 km west of Santiago, on the western side of the Coastal Cordillera (Fig. 1). This mountain range is about 25 to 40 km wide, 1-2 km high and trends north-south, parallel to the Peru-Chile Trench. At the study area the Coastal Cordillera has a basement of Paleozoic and Mesozoic plutonic and metamorphic rocks. Overlying strata are represented by a small outcrop of Cretaceous and Eocene marine sedimentary rocks at Algarrobo beach and Neogene marine deposits that are most extensive south of this locality (Gana *et al*., 1996; Wall *et al*., 1996). The structure of this area is dominated by faults and lineaments oriented in a NW and NE direction (Gana *et al*., 1996; Wall *et al*., 1996). This region constituted a convergent margin at least since the Jurasic (Jaillard *et al*., 2000; Ramos and Aleman, 2000). At present, the Nazca plate is being subducted under the South American plate with a dip angle of ~30°, a convergence direction of N77°E, an obliquity or 13° and a convergence rate of 7-8 cm/year (DeMets *et al*., 1994; Angermann *et al*., 1999; Yáñez *et al*., 2001). The age of the oceanic plate subducted in the study area is about 39 Ma (Yáñez and Cembrano, 2004). Algarrobo is located approximately 30 km south of the aseismic Juan Fernández ridge, which is being subducted west of Valparaíso (Fig. 1) and has not experimented significant latitudinal changes during the last 10 million years (Yáñez *et al*., 2001). This ridge has been considered to be the cause of a flat-slab subduction area that extends between 28° and 33°S (see Yáñez *et al*., 2001).

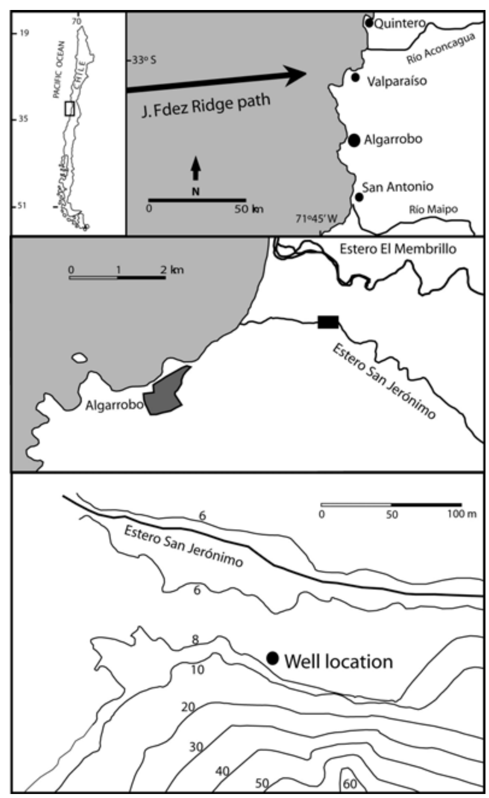

FIG. 1. Location map. The upper inset shows the location of the study area in Chile and the path of the aseismic Juan Fernández Ridge. The central inset shows the location of the well near Algarrobo. The bottom inset shows details of the position of the well inside the Estero San Jerónimo Valley.

FINDINGS

The Algarrobo marine bed was discovered by chance upon examining sediments unearthed during the excavation of a water well on the southern bank of the San Jerónimo Creek. The well is located approximately 1,500 m east of the coastline, near Algarrobo (Fig. 1). The marine layer was also perforated during the drilling of another well located approximately 100 metres away, on the northern side of the creek. However, this well was completed before we could have access to the excavated sediments. The top of the well examined in this study lies at 6.4 m above sea level and its bottom is located at a depth of 5,85 m a.m.s.l. The lithology transected by this well comprises, from top to base (Fig. 2):

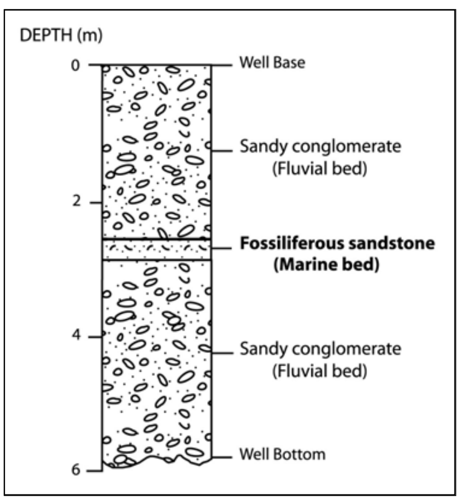

FIG. 2. Core of Algarrobo well showing the position of the Holocene fossiliferous marine bed between two fluvial beds. The top of the well lies at 6.4 m above sea level.

- 0.1 m soil horizon with abundant vegetal matter.
- 2.5 m white to yellow very coarse sandstone to microconglomerate, composed of subrounded granules of quartz, feldspar and biotite and a sandy matrix. It contains scarce granitic clasts centimetres in size. It shows a slightly erosive basal contact.
- 0.25 m grey, micaceous, silty sandstone containing molluscs, foraminifers, ostracods and plant debris. It shows some thin intercalations of siltstones rich in organic matter.
- 3 m sandstone bed similar to the one situated at the top of the succession.

From the measured lithologic column and the height of the well base we calculated that the top of the marine stratum occurs at 3.8 m a.m.s.l.

Radiocarbon dating was performed on a wood fragment obtained from the marine bed yielding an age of 5660±70 yr BP ($\delta^{13}C$ -25.8 ‰; βeta -174841; Beta Analitic Inc. laboratory, Florida, USA). An age of 6450 cal yr BP (middle Holocene) was obtained after their calibration with CALIB 5.0. (M. Stuiver, P.J. Reimer, R.W. Reimer)[1]. This constitutes a maximum age, since it was obtained from a wood fragment. All dates in this paper have been calibrated by us and are given in calendar years.

Sediment washing and screening of the marine bed yielded abundant specimens of only two species of microfossils, the benthic foraminifer *Ammonia tepida* (Cushman) and the ostracode *Cyprideis beaconensis* (LeRoy) (Fig. 3). In addition, abundant gastropods of the genus *Hydrobia* (Fig. 3) and scarce bivalves of the species *Tagelus dombeii* (Lamarck) and *Mytilus chilensis* Hupé were also found. Most of the fossils were very well preserved and not fragmented. The fossil association is indicative of deposition in a very shallow, transitional marine environment (Sandberg, 1964; Murray, 1991).

Pollen analysis of the marine bed was also carried out. A sediment sample of 3 cm^3 was pre-treated according to standard techniques (KOH, HF and Acetolysis) (Faegri and Iversen, 1989). The basic pollen sum includes at least 300 terrestrial pollen grains (excluding aquatics and fern taxa) that were analyzed at magnifications of 400X and 1000X. Palynologic processing revealed a pollen spectrum dominated by halophytes (*Chenopodiaceae*, 72%) and other herbaceous taxa (*Compositae*, 8.5%; *Gramineas*, 1.8%), with traces of arboreal pollen such as *Schinus* (8.5%) and *Escallonia* (3.6%). The *Chenopodiaceae* include common species that thrive along the shores of saline lakes and lagoons in central Chile (Villa-Martínez *et al*., 2003). The pollen assemblage also reveals a nearby community of sclerophyllous shrubs.

[1] 2005. CALIB 5.0 [http://radiocarbon.pa.qub.ac.uk/calib/calib.html].

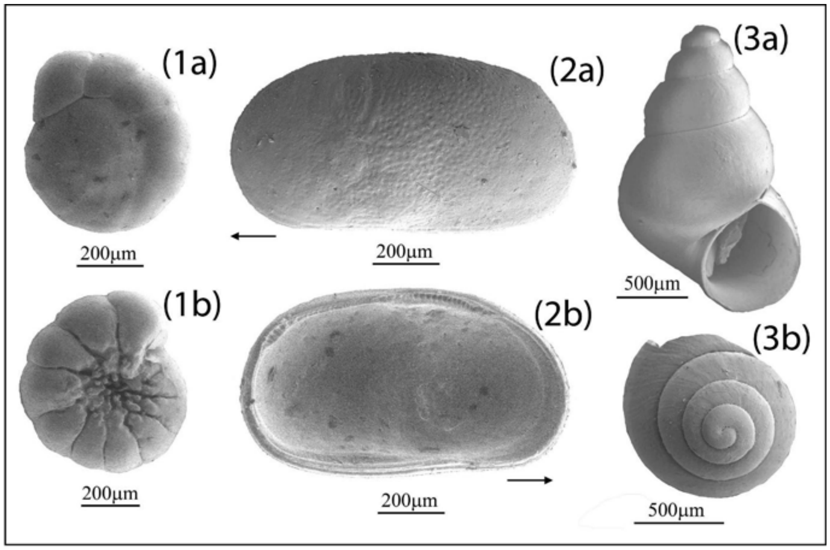

FIG. 3. Estuarine fossil assemblage of the Algarobo bed. **1.** Foraminifer *Ammonia tepida* (Cushman) **a.** spiral view, **b.** umbilical view; **2.** Ostracode *Cyprideis beaconensis* (LeRoy), left valve (arrow points to anterior), **a.** exterior view, **b.** interior view; **3.** Gastropod *Hydrobia* sp.: **a.** lateral view, **b.** spiral view.

DISCUSSION

From the data described above we conclude that the Algarrobo marine bed accumulated over older fluvial deposits during a transgression that inundated the estero San Jerónimo Valley, forming an estuary during the middle Holocene. Evidence for an estuarine environment includes a pollen assemblage dominated by salt-tolerant halophytes, the occurrence of plant debris and a transitional marine fauna typical of a brackish water environment. The fossil species suggest that this layer was probably deposited in less than a meter of water (Sandberg, 1964; Murray, 1991). A catastrophic and short-lived origin for this bed, such as a washover fan behind a beach ridge or a tsunami, is discarded because the fossil fauna are not fragmented and are entirely dominated by transitional species. If the layer had been deposited by a tsunami, for example, the fauna would probably have been open marine and more fragmented. After the marine transgression the sea retreated and fluvial sediments prograded over the marine layer.

The radiocarbon age determined for the Algarrobo bed in general fits well with those obtained for other Chilean deposits that have been associated with the highest stand of Holocene sea level. The maximum Holocene transgression has been dated at 7635 cal yr BP in Caleta Michilla (22°43') by Leonard and Wehmiller (1991), at 7325 cal yr BP in Bahía Tongoy (30°S) by Ota and Paskoff (1993), and at 7380 cal yr BP in Estrecho de Magallanes (southern Chile) by McCulloch and Davies (2001). Although the global evolution of the sea-level during the Holocene is controversial (see for example Tooley, 1993; Fleming *et al*., 1998; Lambeck and Chappel, 2001), different authors have identified in several parts of the world a maximum Holocene high-stand that took place between approximately 6000 to 8000 yr BP (*e.g.,* Tooley, 1993; Codignotto and Aguirre, 1993; Bezerra *et al*., 1998; Rostami *et al*., 2000; Dabrio *et al*., 2000) and it is coincidental with the cited values for the highest Holocene stand in Chile.

Considering that the Algarrobo marine bed is located at an elevation of 3.8 m a.m.s.l., and it has an age of 6445 yr BP the uplift rate for this area during the last ~6500 years can be calculated. However, to estimate coastal uplift of marine deposits, one of the problems is to determine the sea level at the time of bed deposition. Brazilian terraces formed between 6000 to 7500 yr BP and at present are found at elevations of 0-1 m a.m.s.l. (Bezerra *et al.,* 1998). As the Atlantic coast of Brazil is on the passive margin of South America, we assume that the maximum elevation of one meter for middle Holocene marine terraces in that area is due to eustatism. Therefore, we considered a sea-level drop of one meter during the last ~6500 yrs and we calculated an uplift rate of approximately 0.4 m/ky for the Algarrobo area during that time interval. However, we must consider this data as a minimum estimate because the Algarrobo layer was deposited in an estuarine environment.

A comparison of the Algarrobo marine bed elevation with the height reached by coeval Holocene terraces from other parts of Chile can give us an idea of the magnitude of uplift for the study area. Ota and Paskoff (1993) dated an estuarine level 3 m a.m.s.l. in Bahía Tongoy (30°S) at 7325 cal yr BP. At Caleta Michilla (22°43'S), north of Antofagasta, a Holocene terrace at 6-7 m a.m.s.l. yielded an age of 7635 cal yr BP (Leonard and Wehmiller, 1991). However, Ortlieb (1995) suggests that this terrace could have been deposited by a tsunami event. Hervé and Ota (1993) calculated very high uplift rates of 3.1 to 9.6 m/ky for a set of Holocene terraces on Chiloé Island (42-43°S), which they attributed to local deformation caused by the activity of the Liquiñe-Ofqui fault. Tectonic uplift is also important on Isla Mocha (38°S), where 38 m of uplift during the past 6000 years has resulted in 18 raised shorelines (Nelson and Manley, 1992). This phenomenon is due to high stress between two major segments of the nearby subduction zone, according to Melnick *et al*. (2003).

In comparison to the uplift rates determined for the aforementioned Holocene marine deposits in Chile, the elevation rate for the Algarrobo layer falls within the average range and it is considerably lower than those calculated for Holocene terraces in Chiloé (Hervé and Ota, 1993) and Isla Mocha (Nelson and Manley, 1992). This result is interesting since Algarrobo is located at approximately 30 km south of the Juan Fernández Ridge (JFR) collision point and, according to the calculations of Kay and Mpodozis (2002), it should be within the influence of this ridge. The subduction of aseismic ridges produces major coastal uplift, as observed with the Nazca Ridge in Perú (Le Roux *et al*., 2000; Macharé and Ortlieb, 1992) and postulated by Yáñez *et al*. (2002) and Le Roux *et al*. (2005) for the JFR. However, the elevation rate of the Holocene Algarrobo bed appears normal compared with coeval terraces in Chile. We are conscious that we have a single data point for our study area. Furthermore, although the fauna indicate a shallow transitional environment the Algarrobo bed was deposited in an estuarine setting and does not indicate the exact position of the paleo sea-level. In addition, the period considered (~6000 yr.) is too short to have a good control of the influence of the JFR on the coastal uplift. However, we consider that the data constitutes an incentive to the search for new Pleistocene and Holocene marine deposits in the area around the JFR collision point, calculate coastal uplift rates and constrain the influence of the aseismic ridge at these rates.

Palynologic analysis of the Algarrobo marine bed reveals a *Chenopodiaceae*-dominated (~70%) assemblage at 6450 cal yr BP, indicating a relatively arid and warm climate. These data are in agreement with different studies that show evidence of an arid climate that prevailed in central Chile during the mid-Holocene, changing to cooler and wetter conditions at approximately 5700 cal yr BP. Evidence of a mid-Holocene dry climate comes from the study of grain-size distributions and clay mineralogies in sediment cores from the continental slope of central Chile at 33°S (Lamy *et al*., 1999) as well as from pollen analysis in Laguna de Aculeo (33°S) (Jenny *et al*., 2002; Villa-Martínez *et al*., 2003) and the Quintero II swamp forest (33°S) (Villa-Martínez and Villagrán, 1997).

CONCLUSIONS

A buried Holocene marine layer was discovered upon drilling a water well in the town of Algarrobo (33°22'S). This bed contains fossils indicative of a shallow estuarine environment and a pollen assemblage dominated by *Chenopodiaceae*, indicating a relatively warm and arid climate. Radiocarbon dating of a wood fragment obtained from this stratum yields an age of 6450 cal yr BP (middle Holocene). The top of the marine layer lies at an elevation of 3.8 m above mean sea level, indicating an average Holocene coastal uplift rate for this site when compared with coeval marine deposits in Chile.

The discovery of this marine bed opens up the possibility of finding other Holocene deposits along the coast of central Chile, which would allow to constrain the influence of the aseismic Juan Fernández Ridge on coastal uplift rates for this area.

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