

# Holocene deposits on the coast of north-central Chile: radiocarbon ages and implications for coastal changes

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## ABSTRACT

Eight radiocarbon-dated shell samples collected from the emerged marine deposits on Bahía Herradura near Coquimbo and Bahía Tongoy areas, north-central Chile, provide new constraints on the rate of coastal change during the Holocene. The Holocene transgression culminated ca. 6,000 yr B.P. based on a shell age from estuarine deposits in Estero Tongoy. In Bahía Tongoy, the spatial separation of parallel beach ridges of ca. 910 yr B.P. and ca. 2,300-2,400 yr B.P. suggests a progradation rate of ca. 0.14 m/yr. Assuming a constant progradation rate, the oldest Holocene beach ridge is ca. 5,400 yr B.P. The Holocene uplift is very small, probably 2-3 m in most cases, and 4-5 m in the most rapidly uplifting area (Altos de Talinay). The low Holocene uplift rates are similar to the ones obtained from the elevation above present sea level of the last interglacial terrace in this region.

*Key words:* Holocene marine deposits, Beach ridge, Uplift rate, Radiocarbon age, North-central Chile.

## RESUMEN

**Depósitos holocenos en la costa del norte-centro de Chile: edades radiométricas  $C^{14}$  e implicaciones para los cambios costeros.** Muestras de conchas recolectadas en la terraza marina más baja de las bahías de Coquimbo, Herradura y Tongoy en el Norte Chico de Chile (30°S) informan sobre la evolución de la costa durante el Holoceno. La transgresión posglacial terminó, probablemente, hace 6.000 años, según lo indicado por la edad de depósitos estuarinos en el estero de Tongoy. En la bahía Tongoy, una comparación entre la posición de la playa hace 900 años y hace 2.300-2.400 años A.P., indica una velocidad de progradación del orden de 0,14 m por año. La edad de la playa holocena más antigua sería de 5.400 años A.P. si la velocidad de progradación fuera constante. En los alrededores de Coquimbo y Tongoy, el solevantamiento de la costa durante el Holoceno ha sido de poca importancia, probablemente menos de 3 m y menos de 5 m en el sector más inestable de los Altos de Talinay. Estas estimaciones concuerdan con las que se pueden hacer para la terraza marina del último período interglacial en esta región.

*Palabras claves:* Depósitos marinos holocenos, Cordón de playa, Velocidad de solevantamiento, Dataciones radiocarbónicas, Norte Chico, Chile.

## INTRODUCTION

The study area is the coast along Bahía Tongoy (Tongoy Bay) and Bahía Herradura (Herradura Bay) near 30°S, north-central Chile (Fig. 1). Most of the

coastal line of this area is fringed by Holocene emergent terraces or beach ridges. Two radiocarbon ages for Holocene shells were reported from Estero

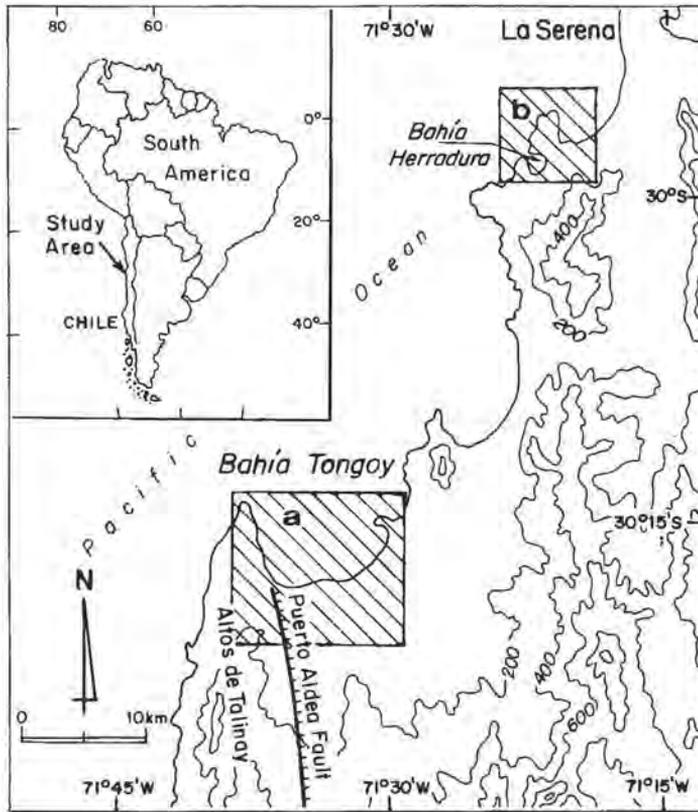


FIG. 1. Map showing the location of the study area (a and b). Contours: 200 m interval after La Serena 1:500,000 topographic map. Inset shows the location of figure 1. Puerto Aldea Fault limits the Altos de Talinay to the west and lowland to the east.

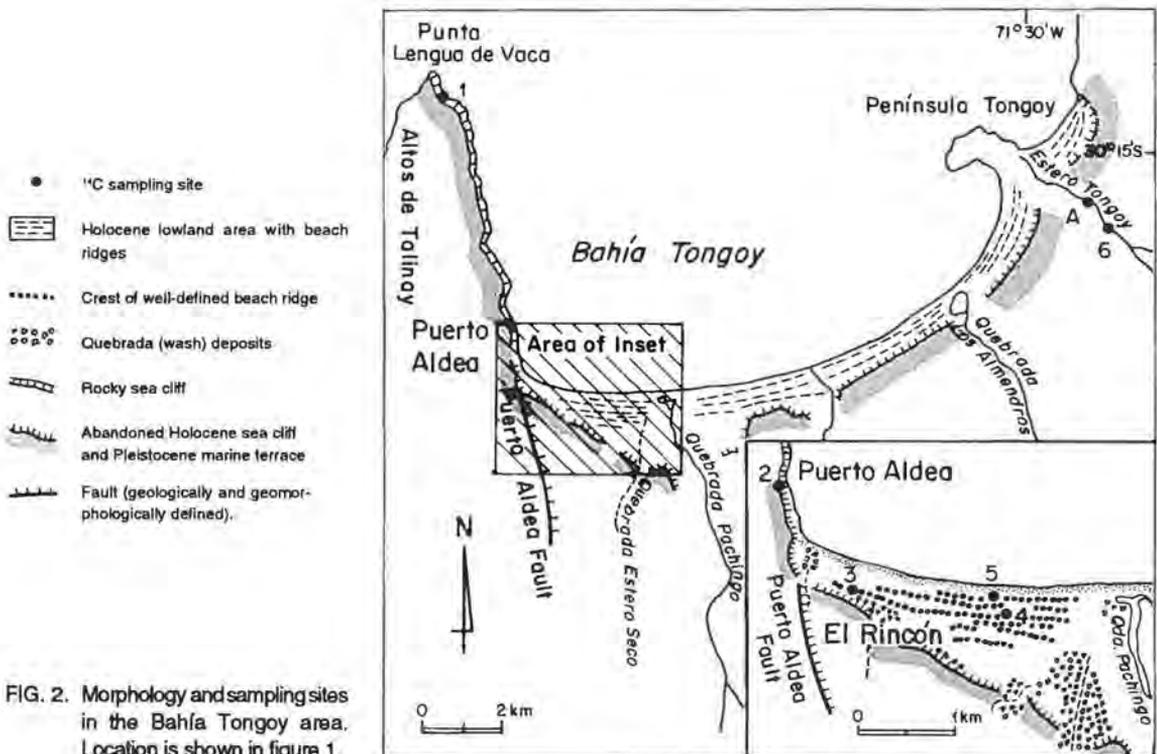
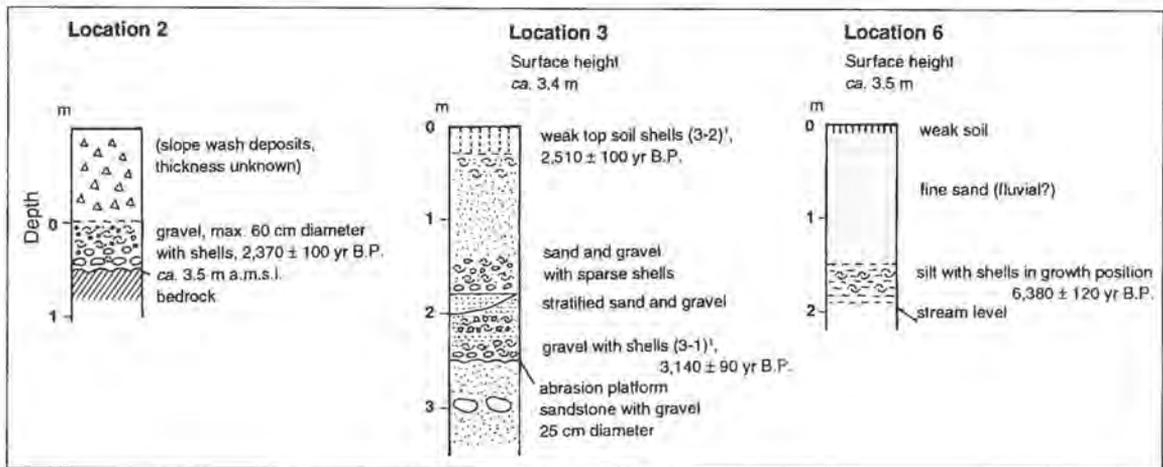


FIG. 2. Morphology and sampling sites in the Bahía Tongoy area. Location is shown in figure 1.



<sup>1</sup> Sample numbers corresponding to Table 1.

FIG. 3. Section of Holocene deposits. Locations are shown in figure 2.

Tongoy (Location A in figure 2) and Bahía Herradura (Location B in figure 5) by Paskoff (1973). No previous study, however, was done on Holocene sea level history and Holocene coastal evolution in the study area.

The purpose of this paper is to report eight new radiocarbon ages from Holocene deposits and to discuss the Holocene transgression, coastal progradation rate and vertical movement based on these materials.

In the western part of the study area, a conspicuous normal fault (Puerto Aldea Fault; Paskoff, 1970) forms the eastern margin of north-south trending Altos de Talinay highlands (Fig. 1), which are composed of sedimentary and igneous metamorphosed Paleozoic rocks, and intrusive Mesozoic rocks (Gana, 1991). The coastal area to the west of this fault is mostly underlain by Miocene-Pliocene sedimentary rocks, but Mesozoic rocks are exposed in headland areas (Thomas, 1967).

Well-preserved marine terraces characterize the

coastal areas (Figs. 2, 5). The paleontology (Herm, 1969) and morphostratigraphy (Paskoff, 1970) of the marine terraces, particularly in the Bahía Coquimbo area (Fig. 5), have been studied. The Herradura II terrace at Coquimbo, about 15-20 m in altitude, is the lowest of five major Pleistocene terraces in this area (Paskoff, 1970); it is probably of last Interglacial age based on amino acid ratio (Hsu *et al.*, 1989) and ESR analysis (Radtke, 1989) of shells. The uplift rate at Coquimbo is thus very low, about 0.1-0.2 m/kyr (Leonard and Wehmiller, 1992).

A low marine terrace below Herradura II, at less than 7 m around the bays of Coquimbo and Tongoy, was reported as early as the middle of last century by Darwin (1846) and Domeyko (1848), and later by Brüggén (1929). These authors attributed this low terrace to recent continental uplift. Radiocarbon ages from the terrace in Bahía Herradura ( $3,700 \pm 120$  yr B.P.) and Bahía Tongoy ( $2,400 \pm 240$  yr B.P.) confirm a Holocene age for this terrace (Paskoff, 1973).

## DESCRIPTION OF RADIOCARBON LOCALITIES

### BAHIA TONGOY

The Altos de Talinay highlands are fringed by cliffs along a rocky coast. Holocene deposits occur only locally as beach deposits filling emerged notches

or on very narrow abrasion platforms. Along the lowlands, to the east of the Puerto Aldea Fault, a well-developed beach extends for 15 km. Two samples (Locations 1 and 2 in figure 2, table 1) were obtained from the rocky eastern coast of the Altos de Talinay,

four samples (Locations 3, 4, and 5 in figure 2, Table 1) from beach ridges located west of Quebrada Pachingo, and one sample from the lower reach of the Estero Tongoy (Location 6 in figure 2, Table 1). Below, sites from the southwestern part of the area to the northeastern part are described.

Location 1 is an elevated marine notch, which is 5.1 m a.s.l. at its retreat point and is covered with beach sand with shell fragments, exposed in a quarry about 600 m southeast of the Punta Lengua de Vaca (Fig. 2). Radiocarbon age for these shell fragments is  $3,220 \pm 80$  yr B.P.

Location 2 is in beach deposits composed of well-rounded boulders up to 60 cm in diameter with shell fragments, resting on an abrasion platform at ca. 3.5 m a.s.l., overlain by slope wash deposits (Figs. 2, 3). These shell fragments have an age of  $2,370 \pm 100$  yr B.P.

Location 3 is a quarry about 100 m seaward from the abandoned Holocene sea cliff and just north of a main track heading to Puerto Aldea. Of all the sampling sites in Holocene deposits, this site is the closest to the abandoned Holocene sea cliff, but is actually located on the fourth beach ridge from the cliff (Fig. 2). Beach deposits rest unconformably on an abrasion platform, about 1.0 m in altitude, which truncates Miocene sandstone. They are composed of stratified

sand and gravel, with abundant well-preserved shells (Fig. 3). The radiocarbon age for a lower sample (3-1) at 1.1 m a.s.l., immediately above the abrasion platform, is  $3,140 \pm 90$  yr B.P. An upper sample (3-2) at 3.2 m a.s.l. yields an age of  $2,510 \pm 100$  yr B.P.

Location 4 is situated on the extension of the ridge on which Location 3 is, and Location 5 is on the outermost fossil beach ridge (Fig. 2). At these localities, beach deposits are mainly composed of rounded gravels with little fine-grained matrix, but including abundant shells and shell fragments. The radiocarbon age is  $2,330 \pm 80$  yr B.P. (ca. 4.1 m a.s.l.) for Location 4 and  $910 \pm 90$  yr B.P. (ca. 2.7 m a.s.l.) for Location 5.

Location 6 is a section on the right bank of Estero Tongoy (Figs. 2-4). This is the only locality where Holocene estuarine deposits were identified in the study area. At Location 6, an estuarine silt bed, which has abundant fossil shells with paired valves, is exposed. The silt bed is overlain by fine sand, probably of fluvial origin. The upper limit of the estuarine deposits was not confirmed at this locality. Fossil shells in estuarine deposits at ca. 1.8 m a.s.l. yield an age of  $6,380 \pm 120$  yr B.P.

Shell fragments with an age of  $2,400 \pm 240$  yr B.P. (Location A; Paskoff, 1973) were collected from beach deposits at about 1 km downstream from Location 6 (Fig. 2).



FIG. 4. A view of Location 6 on the right bank of Estero Tongoy. Holocene estuarine deposits which have shells in growth position, are exposed just above the stream level.

TABLE 1. RADIOCARBON AGES FOR SHELLS FROM HOLOCENE SEDIMENTS OF THE BAHIA TONGOY AND BAHIA HERRADURA AREAS

Location <sup>1</sup>	Sample number <sup>2</sup>	<sup>14</sup> C age (yr B.P.) <sup>3</sup>	Species	Environment altitude (m a.s.l.) <sup>5</sup>	
1	GaK-15002	3,220± 80	<i>Protothaca</i> sp.	beach	5.1
2	GaK-14998	2,370±100	<i>Protothaca</i> sp.	beach	3.5
3-1	GaK-14999	3,140± 90	<i>Mactra</i> sp.	beach	1.1
3-2	GaK-15003	2,510±100	<i>Mactra</i> sp.	beach	3.2
4	GaK-15000	2,330± 80	<i>Mactra</i> sp.	beach	4.1
5	GaK-15001	910± 90	<i>Mactra</i> sp.	beach	2.7
6	GaK-14997	6,380±120	<i>Protothaca</i> sp. <sup>4</sup>	estuary	1.8
A		2,400±240	shell	beach	ca. 2.0
7	GaK-14996	4,520±110	<i>Argopecten</i> <i>purpuratus</i>	beach	2.0
B		3,700±120	shell	beach	2.0

## Notes:

<sup>1</sup> Locations 1-7 correspond to this study. Locations A and B are after Paskoff (1973).

<sup>2</sup> Dated at Gakushuin University, Japan, except for Locations A and B which were dated at the Institute of Geology, University of Bordeaux.

<sup>3</sup> Using Libby's half life (5,570 yr) with 2 standard deviations.

<sup>4</sup> Collected in growth position.

<sup>5</sup> Heights were measured by handlevel and hand-held barometer, referring to the present sea level and corrected to the altitude above mean sea level, using tide table. Errors of height measurement are estimated to be ca. ±0.5 m, up to ca. ± 1 m at Location 6 which is far from the coast.

### BAHIA HERRADURA

At Location 7, beach deposits including abundant shell fragments are exposed in the right bank of Quebrada Los Chines (Figs. 5, 6; Table 1).

Barnacles are attached to some rounded gravels. Shells from this site at about 2.0 m a.s.l. are dated at 4,520±110 yr B.P. This age is much older than the 3,700±120 yr B.P. previously reported by Paskoff (1973).

## HOLOCENE SEA LEVEL HISTORY AND COASTAL EVOLUTION

### THE HOLOCENE MAXIMUM TRANSGRESSION. BAHIA TONGOY

One sample from the estuarine silt at Location 6 in Bahía Tongoy provides the oldest radiocarbon age (6,380±120 yr B.P.) for Holocene transgressive deposits in north-central Chile. The Holocene transgression reached at least about 3 km inland from the present coast, resulting in the formation of a narrow drowned valley along Estero Tongoy, and probably culminated slightly later than the above-mentioned ages. It is tentatively assumed that the sea level reached a slightly higher position than the sample horizon, probably about 3 m a.s.l. at maximum ca. 6,000 yr B.P., considering the elevation of the abrasion platform and beach ridges in the

Bahía Tongoy area described in section 2.

However, it is difficult to determine the position of sea level at the time of the culmination of the transgression and the amount of vertical movement during the Holocene. This is because the upper limit of estuarine deposits is not determined exactly at Location 6, and no Holocene sea level curve is available from north-central Chile at present.

The height of sea level at the culmination of the transgression estimated from Estero Tongoy sample is significantly lower than the height of ca. 30 m in Isla Mocha, central Chile (Kaizuka *et al.*, 1973) and the height of more than 20 m in southern Chile (Hervé, F. and Ota, Y.; in preparation). The uplift rate of the Bahía Tongoy area is evidently low.

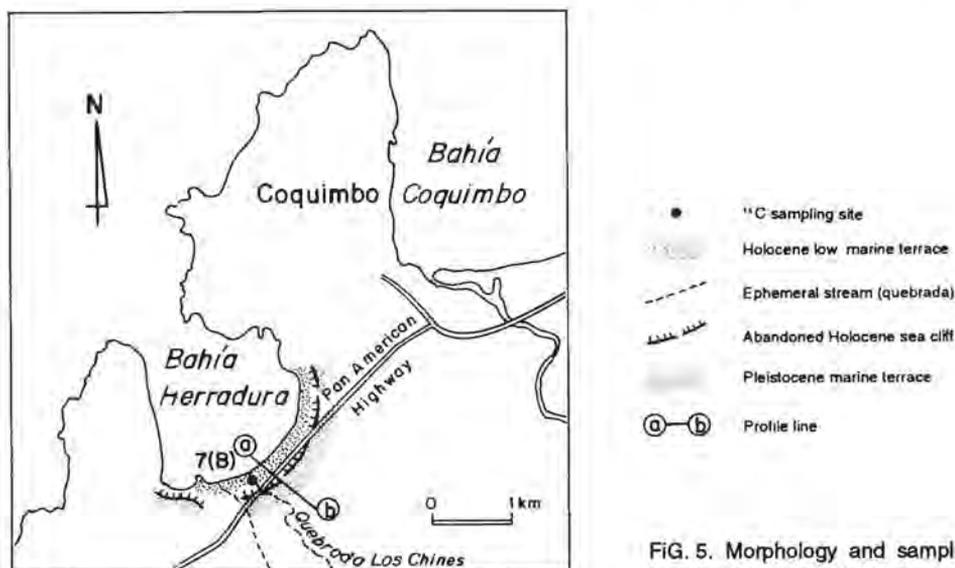


FIG. 5. Morphology and sampling sites in the Bahía Coquimbo area.

#### HOLOCENE UPLIFT BAHIA TONGOY AND BAHIA HERRADURA

In addition to the emerged estuarine deposit at Estero Tongoy, there is evidence which indicates a slow uplift in the Bahía Tongoy and Bahía Herradura areas.

On the eastern coast of the Altos de Talinay, two radiocarbon ages indicate that beach deposits, filling a notch or resting on an abrasion platform cutting the hard Paleozoic-Mesozoic rocks, are Holocene in age ( $3,220 \pm 80$  yr B.P. at ca. 5 m a.s.l. at Location 1, and  $2,370 \pm 100$  yr B.P. at ca. 3.5 m at Location 2). No positive evidence is available for establishing the sea level position of the culmination of the Holocene sea level rise of these localities. However, the erosional topography beneath the Holocene deposits probably represents that position, which was not higher than ca. 5 m. Radiocarbon ages younger than ca. 6,000 yr B.P. at these locations are probably due to deposition of younger deposits which reoccupied a previous sea level position, as suggested by Paskoff (1970).

At Location 3, the abrasion platform beneath the Holocene deposits is 1.1 m a.s.l., slightly lower than Locations 1 and 2.

It is difficult to compare this altitude directly with those at Locations 1 and 2, because Location 3 is situated in the embayment and is seaward from the

inner margin of the Holocene terrace, and also because the abrasion platform at Location 3 is underlain by soft Tertiary rocks. However, a slight emergence during the Holocene can be postulated. No evidence is available for Holocene activity of the Puerto Aldea Fault.

Around Bahía Herradura, it is not possible to give a precise altitude of sea level at the time of the culmination of the Holocene transgression. However, it cannot be higher than a few meters according to the topographic profile (Fig. 6).

The amount of Holocene uplift in the study area is very small, judged by the above-mentioned data; <5 m on the eastern coast of the Altos de Talinay highlands and <3 m in the other areas. This estimate is consistent with the low uplift rate since the last interglacial (ca. 0.1-0.2 m/kyr, Hsu *et al.*, 1989). No evidence of an episodic uplift during the Holocene is available from any locality in the study area. The Bahía Tongoy and Bahía Herradura areas have remained relatively stable during the late Quaternary. This may indicate a different nature of the subduction zone on this area along the Perú-Chile Trench from that of the central and southern part of Chile, where a typical Chilean-type subduction (e.g. Uyeda, 1982) with a shallow dipping Benioff Zone associated with strong compression and resultant high rate of uplift is known.

### BEACH RIDGE DEVELOPMENT. BAHIA TONGOY

A series of beach ridges around Bahía Tongoy has resulted from both a fall of relative sea level and from progradation of the shoreline due to high sediment discharge by several ephemeral streams. Successive shoreline positions are marked by individual beach ridges. The radiocarbon age of the youngest fossil beach ridge is  $910 \pm 90$  yr B.P.

Similar radiocarbon ages from Location 3 and Location 4 ( $2,510 \pm 100$  yr B.P. at Location 3 and  $2,330 \pm 80$  yr B.P. at Location 4) confirm that both sites are located on the same beach ridge.

The shoreline prograded about 210 m between *ca.* 2,300-2,500 yr B.P. and *ca.* 900 yr B.P., giving an average rate of 0.14 m/yr. The calculated progradation rate between *ca.* 900 yr B.P. and the present (distance is *ca.* 120 m) is similar: 0.13 m/yr. If the same rate applies to the earlier beach ridges, the oldest beach ridge, which is about 420 m inland from the *ca.* 2,300-2,500 yr B.P. beach ridge, is *ca.* 5,400 yr B.P. This estimated age is slightly younger than the inferred age of the culmination of Holocene transgression (*ca.* 6,000 yr B.P.). The age seems to be reasonable, considering that the oldest beach

ridge was formed after the emergence of estuarine deposits.

### HOLOCENE EMERGENCE AND HUMAN OCCUPATION. BAHIA HERRADURA

Prior to radiocarbon datings the low marine terrace below the last interglacial terrace on Bahía Herradura (Herradura II terrace) was thought to be of Holocene age on archeological grounds (Paskoff, 1970). Near Location 7 (Fig. 5), remnants of the preceramic 'Anzuelo de Concha culture' (shell middens at *ca.* 6,000 yr B.P.) are never found on this low terrace, but only at the top of the abandoned sea cliff which forms the outer edge of Herradura II terrace. Artifacts and shell middens of the younger 'El Molle culture' (about 2,000 yr B.P.) are occasionally located on the low terrace (Fig. 6, after Montané, 1964). Thus, this low terrace was still submerged at *ca.* 6,000 yr B.P., but had emerged by *ca.* 2,000 yr B.P. when the El Molle people settled on it. Two radiocarbon ages from Location 7 ( $4,520 \pm 110$  yr B.P.) and Location B (same locality as Location 7, but different sample:  $3,700 \pm 120$  yr B.P.) confirm this estimate, although we cannot interpret an age difference of these two samples at present.

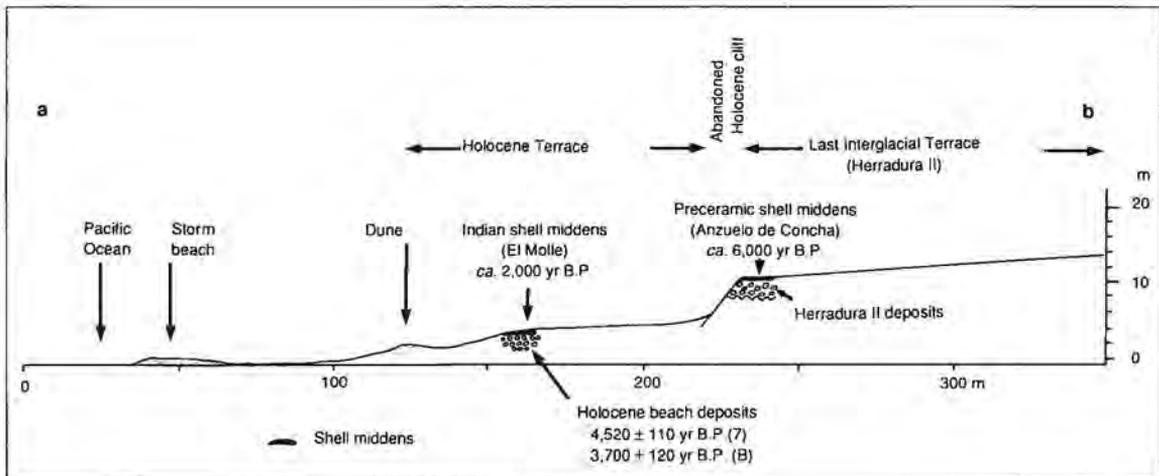


FIG. 6. Profile of marine terraces near Location 7, Bahía Herradura, modified from Paskoff (1970). Topographical profile is after Montané (1964).

## SUMMARY AND CONCLUSIONS

Postglacial relative sea level rise in the study area probably culminated at ca. 6,000 yr B.P. at a slightly higher position (less than ca. 5 m on the rocky coast of the Altos de Talinay and less than 3 m in the other areas) than the present sea level.

The amount of Holocene tectonic uplift appears to be very small and has been consistent with a low uplift rate since the last Interglacial. The Holocene progradation rate of the beach ridge system in the Bahía Tongoy area is ca. 0.14-0.13 m/yr.

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