

Marsh Foraminiferal Assemblages in the Valdivia Estuary, South-central Chile, Relative to Vascular Plants and Sea Level

Anne E. Jennings[†], Alan R. Nelson[‡], David B. Scott[§], and Juan Carlos Aravena^{*}

[†]INSTAAR and Department
of Geological Sciences
Campus Box 450
University of Colorado
Boulder, CO 80309, U.S.A.

[‡]U.S. Geological Survey
MS 966, P.O. Box 25046
Denver, CO 80225, U.S.A.

[§]Centre for Marine Geology
Dalhousie University
Halifax, Nova Scotia,
B3H 3J5, Canada

^{*}Sección Botánica
Departamento de Biología
Facultad Ciencias
Universidad de Chile
Casilla 653, Santiago, Chile

ABSTRACT



JENNINGS, A.E.; NELSON, A.R.; SCOTT, D.B., and ARAVENA, J.C., 1995. Marsh foraminiferal assemblages in the Valdivia estuary, south-central Chile, relative to vascular plants and sea level. *Journal of Coastal Research*, 11(1), 107-123. Fort Lauderdale (Florida), ISSN 0749-0208.

High marsh foraminiferal assemblages are distinct from those of the low marsh, mud flat, and upland floral zones in two transects across tidal marshes in the Valdivia estuary of south-central Chile. Assemblages from the high marsh, mapped on the basis of vascular plant communities, consist mostly of *Trochammina salsa* and have higher concentrations of foraminifera than samples from lower intertidal zones. Fossil assemblages in a core that records the sudden subsidence of the Valdivia estuary during the great earthquake of 1960 cannot be used to estimate the amount of sudden sea-level rise during the earthquake because the core contains only low marsh/mud flat assemblages, which are indistinguishable from one another. The 0.8-0.5 m vertical range of the high marsh assemblage zone, and the undefined ranges of the low marsh/mud flat and upland zones also limit the precision of estimates of relative sea-level change. More precise estimates of the amount of land-level change during past great earthquakes in this region will require identification of assemblage zones with narrower elevational ranges.

The Valdivia high marsh foraminiferal assemblages differ dramatically from other reported high marsh assemblages from the mid-latitude Americas in being dominated by *Trochammina salsa*. Our study of the large populations of the genus *Trochammina* Cushman and Brönnimann encountered along the transects indicates that the two species of *Trochammina* that have been described previously should be combined into the single species, *Trochammina salsa*.

ADDITIONAL INDEX WORDS: Holocene sea-level changes, salt-marsh foraminifera, Chilean coast, intertidal zonation, littoral paleoenvironments, coastal paleoseismology, *Trochammina salsa*.

INTRODUCTION

Prediction and mitigation of the effects of sea-level rise on the world's coasts caused by storm surges, tsunamis, greenhouse gas effects, or tectonic subsidence require an understanding of Holocene sea-level change (ISLA, 1989; BRYANT, 1991; WARRICK *et al.*, 1993; TOOLEY and JELGERSMA, 1993). For example, in central western North America intertidal sequences yield evidence of repeated great subduction zone earthquakes and tsunamis (DARIENZO and PETERSON, 1990; ATWATER, 1992); whereas on the passive continental margin of eastern North America, similar stratigraphic sequences help evaluate evidence for gradual nonseismic coastal subsidence (GEHRELS and BELKNAP, 1993).

Studies of intertidal foraminiferal assemblages are particularly valuable in understanding sea-

level changes on such mid-latitude coasts, because they may provide a precise means of reconstructing Holocene sea-level histories. On the west coast of South America, a handful of studies have been done in an attempt to reconstruct such histories in detail (*e.g.*, SANDWEISS, 1986; WELLS, 1990; ORTLIEB and MARCHARÉ, 1989), and none have been based on foraminiferal assemblages.

An understanding of the relation of modern foraminiferal assemblages to tide levels is a prerequisite for interpreting sea-level changes from fossil faunas. Detailed studies of modern assemblages along transects through the intertidal zone show that some assemblages have a narrow elevational range with respect to tide levels (SCOTT and MEDIOLI, 1986; SCOTT and LECKIE, 1990). Where assemblages with narrow ranges can be identified in the subsurface, former tide levels can be precisely located (SCOTT and MEDIOLI, 1980). Foraminifera of the nearshore environments of north-

ern and eastern South America have been studied extensively (summarized by BOLTOVSKOY and WRIGHT, 1976). We know of only one known study of intertidal foraminifera in western South America—a study of marsh foraminifers in the mangrove swamps of Ecuador (BOLTOVSKOY and VIDARTE, 1977). Marsh foraminifera along the extensive coast of Argentina have received modest attention. Except for the vertically zoned assemblages studied by SCOTT *et al.* (1990), research on South American intertidal foraminifera has concentrated on mangrove swamps rather than on marshes (BOLTOVSKOY and HINCAPIÉ DE MARTÍNEZ, 1983; ZANINETTI *et al.*, 1977; BOLTOVSKOY and VIDARTE, 1977).

In this paper we report on foraminiferal assemblages and their vertical zonation relative to plant communities along two marsh transects in the Valdivia estuary of south-central Chile (Figure 1). We test the zonation by using it to interpret samples from a core in an attempt to estimate the amount of coseismic subsidence in the estuary during the great earthquake of A.D. 1960. We also discuss the limitations of the foraminiferal zonation for reconstructing past changes in relative sea-level in south-central Chile and for understanding the history of subduction zone earthquakes (*e.g.*, JENNINGS and NELSON, 1992; LI, 1992). Finally, based on study of the large populations of the genus *Trochamminita* Cushman and Brönnimann encountered along the transects we argue that the two species of *Trochamminita* that have been described previously should be combined into one species, *Trochamminita salsa*.

THE VALDIVIA ESTUARY

Setting

The Valdivia estuary consists of the lower parts of two major rivers, five smaller rivers, two large bays, and interconnecting channels (Figure 1B). Steep forested slopes, including the scarps of Pleistocene fluvial terraces (WEISCHET, 1960; ILLIES, 1970) line many shores in the lower estuary. Tides in the estuary are diurnal with mean ranges of about 0.9 m at Valdivia and Corral (NATIONAL OCEAN SERVICE, 1988). The climate is humid temperate (Figure 1C).

In May 1960 the estuary was severely shaken by a series of earthquakes caused by subduction of the Nazca plate beneath the South America plate (Figure 1A; PLAFKER and SAVAGE, 1970). The main shock in the series, with a moment mag-

nitude of 9.5, was the largest earthquake ever recorded with seismographs (CIFUENTES, 1989). Strong currents generated by the tsunami accompanying the main shock reversed the flow of the Río Valdivia (SEVIERS *et al.*, 1963; WEISCHET, 1963), but we found no evidence of erosion or deposition from these currents at our core site in the river (Figure 1B; discussed below).

The major permanent effect of the 1960 earthquake on the estuary was instantaneous flooding of large parts of the river valleys due to regional tectonic subsidence (WRIGHT and MELLA, 1963; PLAFKER and SAVAGE, 1970). The flooding almost doubled the surface area of the estuary at high tide. About 400 km² of farmland were inundated in the Valdivia region (WRIGHT and MELLA, 1963). Subsidence during the largest subduction zone earthquakes flooded coasts in Japan and Alaska (PLAFKER, 1972; YOSHIKAWA *et al.*, 1981). The nearly 1,000-km-long, 100-km-wide area of south-central Chile that subsided in 1960 is the longest coast to have subsided during an earthquake (Figure 1A). Most observers reported about 1.5 m of tectonic and compaction-induced subsidence in the vicinity of Valdivia (WEISCHET, 1960, 1963; WRIGHT and MELLA, 1963). PLAFKER and SAVAGE (1970, their Table 1) measured about 2.7 m of subsidence near Valdivia and 1.8–2.1 m at Corral. Our observations of submerged trees and fences in 1989 within 3 km of Isla San Francisco (near core SF, Figure 1B) suggest the 1960 surface along this part of the Río Valdivia subsided at least 2 m through the combined effects of regional subsidence and local compaction of soft sediments.

Our modern study sites are in the middle reaches of the Valdivia estuary. Transect DR sampled a marsh and adjacent mud flat developed on and behind a low berm on an alluvial fan in a small cove on the north shore of Isla Del Rey about 13 km from the sea. Transect AC is located on a small fan bordering a deep channel of the Río Angachilla about 24 km upriver from the sea. Aerial photographs taken prior to the 1960 earthquake show that small trees and brush covered both transect sites: the present tidal marshes are <25 years old. Construction of a dirt road has disturbed the upper edge of the marsh near the end of transect AC. The mid-estuary position of our transect sites in this river-dominated estuary suggests salinities are below 10‰ for most of the year, but higher during the summer (DÜRRSCHMIT, 1980). HAUENSTEIN and RAMÍREZ (1986) measured a salinity of 7.2‰ near transect DR (Figure 1B). Average

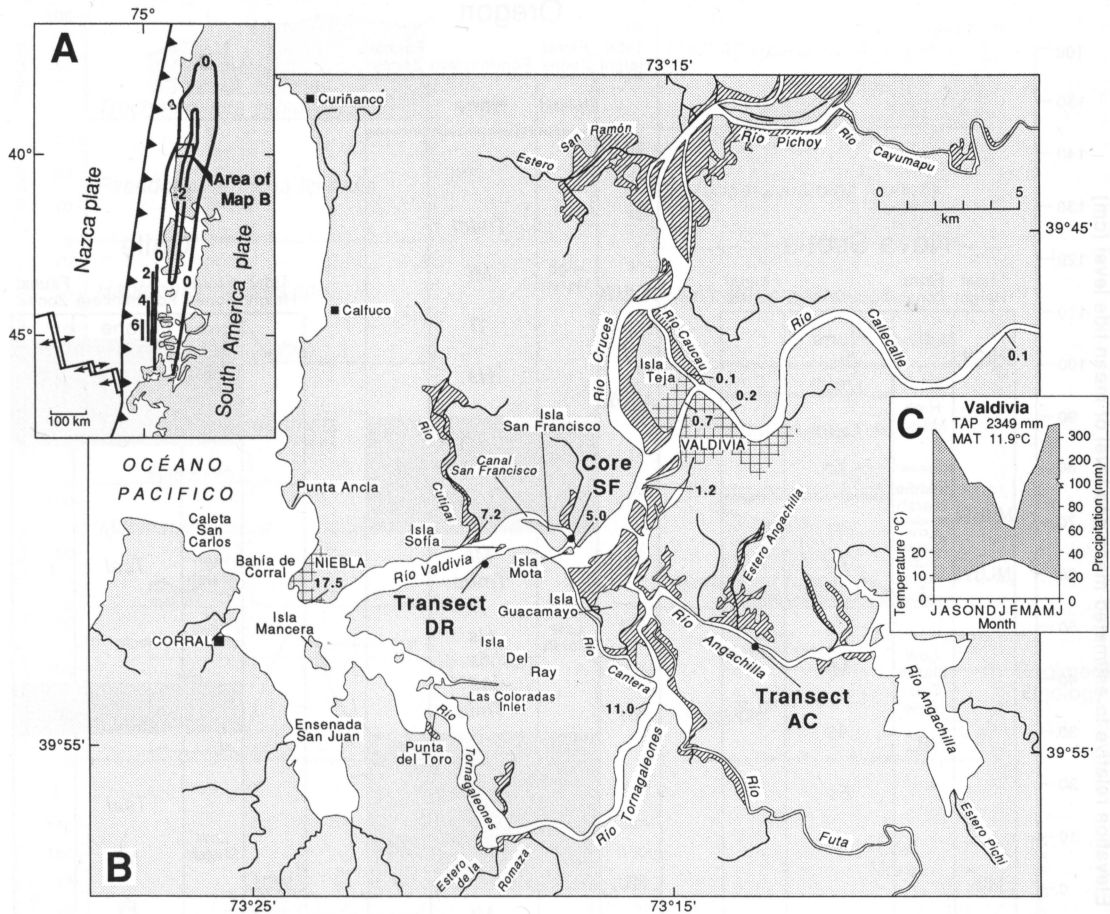


Figure 1. (A) Location of the Valdivia estuary region in south-central Chile. Contours (in meters) show land-level change during the May 1960 earthquake (from ATWATER, 1992 after PLAFKER and SAVAGE, 1970). Barbed line shows edge of the South America plate where the Nazca plate is being subducted beneath it. Paired lines show spreading ridges; other lines show transform faults. (B) Location of two transects and one gouge core in the Valdivia estuary. The Isla Del Rey (transect DR; S 39°51'40", W 73°19'21") and Río Angachilla (transect AC; S 39°52'54", W 73°14'8") transects traverse small, post-1960 marshes that fringe small inlets along the sides of this river-dominated estuary. The core was collected on the edge of a low marsh that developed following the 1960 earthquake in the Canal de San Francisco (S 39°51'18", W 73°17'25"). Ruled pattern shows larger areas of floodplain and marsh that were above the reach of higher tides prior to 1960, but that are now intertidal. Cross-hatched pattern shows urban areas. Bold numbers along the Río Valdivia and Río Callecalte are one-day salinity measurements in parts per thousand from HAUNSTEIN and RAMÍREZ (1986, their Table 1 and Figure 2). (C) Monthly temperatures (MAT, mean annual temperature) and precipitation (TAP, total annual precipitation) for Valdivia (from HAUNSTEIN and RAMÍREZ, 1986, their Figure 1).

salinities at Transect AC, 11 km farther upstream from the sea than the site of DR, must be much lower (probably <2‰).

Zonation of Intertidal Plants Relative to Sea Level

As on other humid temperate coasts (CHAPMAN, 1960; FREY and BASAN, 1985; ADAM, 1990), the vertical ecologic zonation of the intertidal zone in

the Valdivia estuary is based on the distribution of vascular plant communities (Figure 2), which reflect their different tolerances to salinity, submergence, substrate, and other environmental factors (AÑAZCO, 1978; RAMÍREZ *et al.*, 1979; RAMÍREZ and AÑAZCO, 1982; OTEY, 1986). Community differences at the more than 20 sites we visited generally reflect differing rates of freshwater input, sediment aggradation, and plant suc-

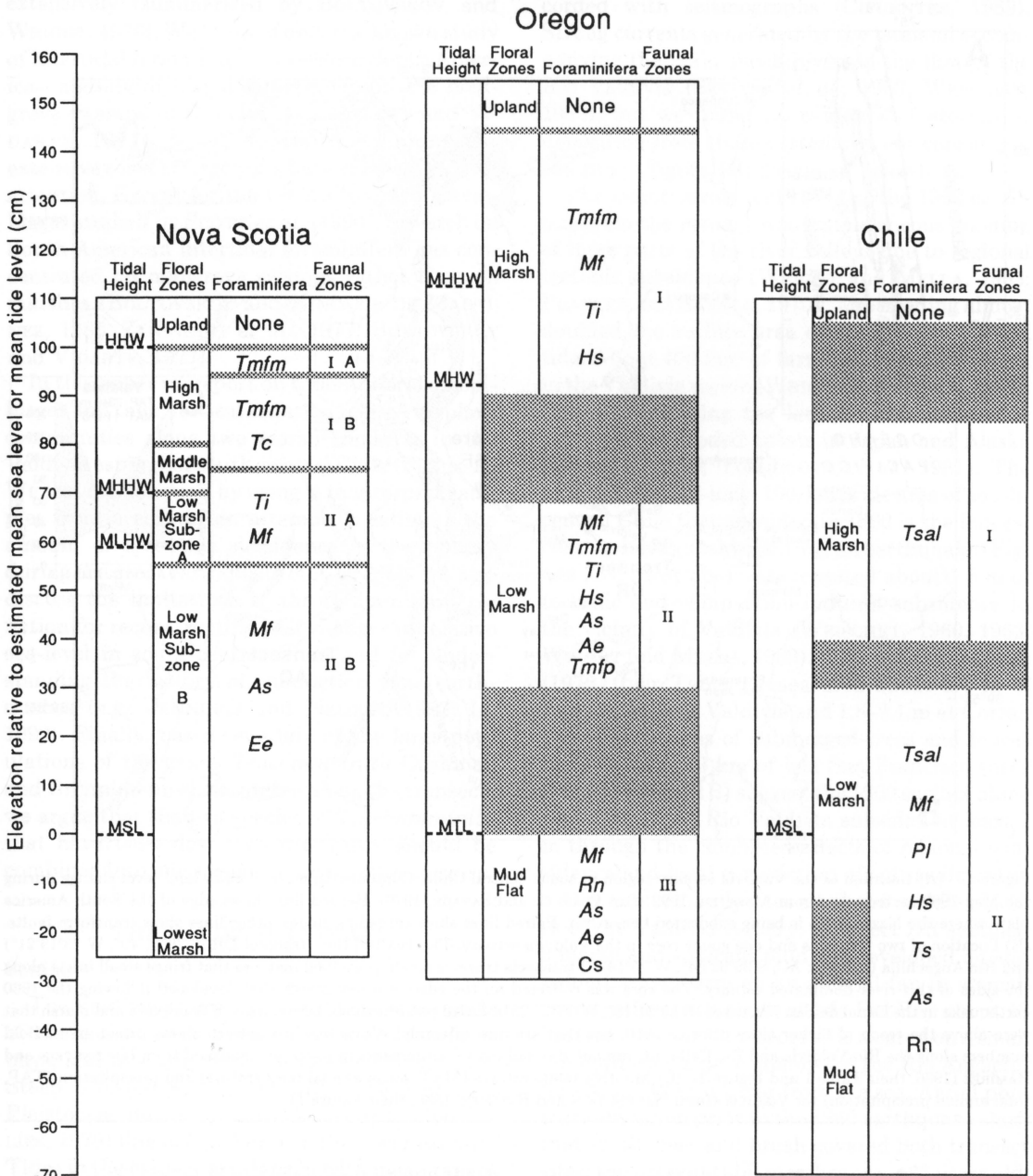


Figure 2. Summary of tidal data, floral (vascular plant) zones, foraminiferal assemblages, and foraminiferal faunal zones for tidal marshes on three cool, humid-temperate coasts: eastern Nova Scotia, central Oregon, and south-central Chile. Foraminifera species abbreviated as follows: Tsal = *Trochammina salsa*, Tmfm = *Trochammina macrescens f. macrescens*, Tmfp = *Trochammina macrescens f. polystoma*, Ti = *Trochammina inflata*, Tc = *Tiphotrecha comprimata*, Mf = *Miliammina fusca*, Hs = *Haplophragmoides* spp., As = *Ammotium salsum*, Ae = *Ammobaculites exiguus*, Pl = *Pseudothurammina limnetis*, Rn = *Reophax nana*, Ee = *Elphidium excavatum*, Cs = calcareous and other estuarine species. The upper edge of the marsh is assumed to mark highest high water (HHW; e.g., SCOTT and MEDIOLI, 1986; SCOTT and LECKIE, 1990). Nova Scotia diagram from SCOTT and MEDIOLI (1980); Oregon diagram from JENNINGS and NELSON (1992). Foraminiferal assemblages can be used to distinguish low marsh (Faunal Zone II) and high marsh (Faunal Zone I) zones in all three areas, but assemblages do not distinguish the low marsh floral zone from the mud flat in south-central Chile.

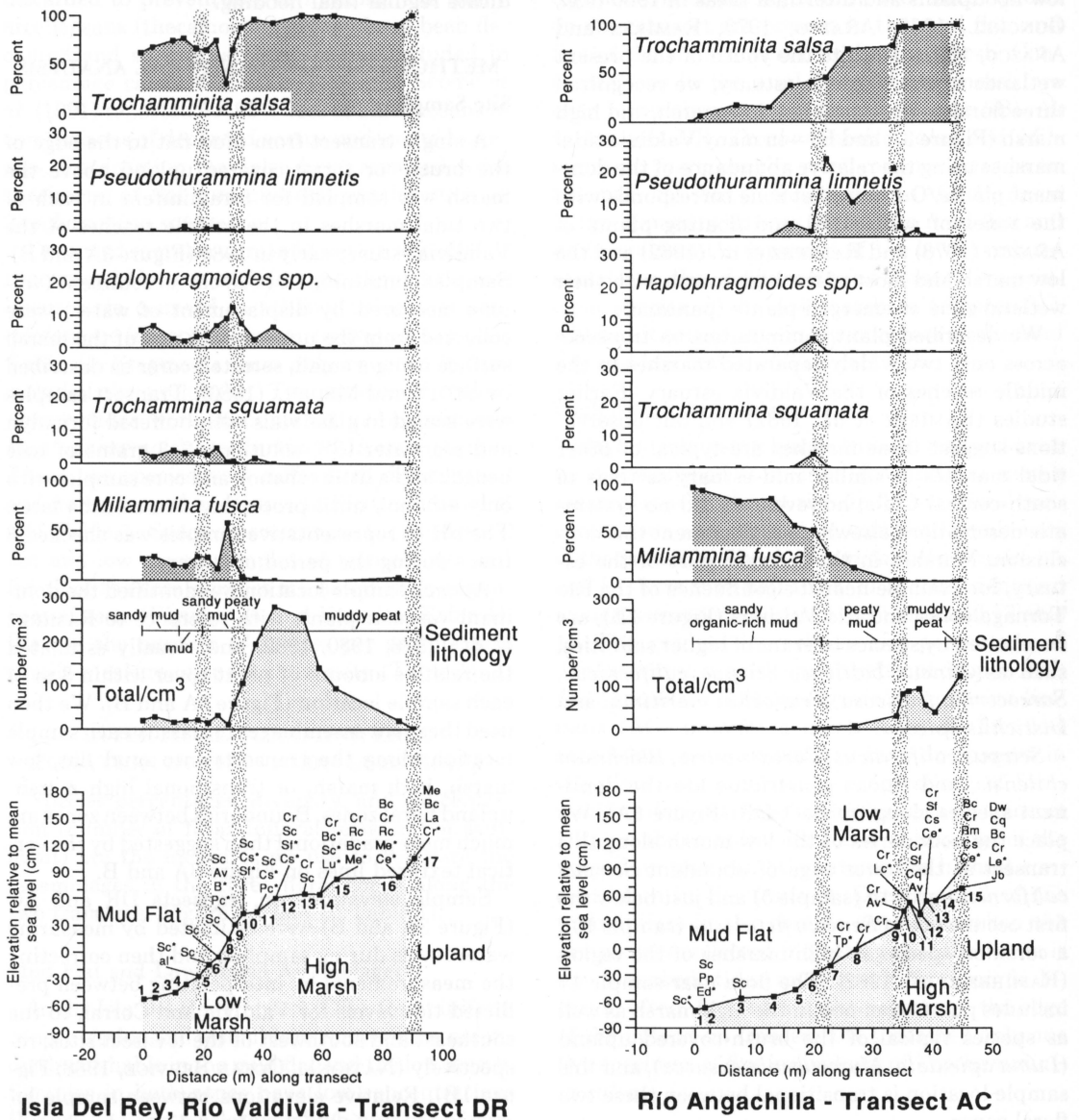


Figure 3. Elevation, dominant vascular plant species at sample sites, number of foraminiferal tests/cm³ of sediment, sediment lithology, and percentages of common foraminiferal species for samples from transect DR (A) and transect AC (B). Common terms for sediment lithologies are those used in describing core SF (Figure 4). Vascular plant communities suggest four floral zones along the transects, but the boundaries between zones (textured vertical lines) are gradational. Sample numbers are in bold numerals. Relative areal cover (plant species covering the largest area at the top of the column) of common tidal marsh plant species shown by columns of letters as follows. Av = *Aster vahlii*, B = *Bromus* sp., Bc = *Blechnum chilensis*, Ce = *Cyperus eragrostis*, Cq = *Chusquea quila*, Cr = *Carex riparia*, Cs = *Calyptegia saepium*, Dw = *Drimys winteri*, Ed = *Egeria densa*, Jb = *Juncus balticus*, La = *Luma apiculata*, Lc = *Libertia chilensis*, Le = *Lycopus europeus*, Lu = *Lotus uliginosus*, Me = *Myrceugenia exsucca*, Pc = *Polygonum chilensis*, Pp = *Potamogeton pectinatus*, Rc = *Rubus constrictus*, Rm = *Rubus mara*, Sc = *Scirpus californicus*, Sf = *Senecio fistulosus*, Tp = *Triglochin palustre*, al = unidentified algae, * = <10% cover. Dw, Ed, La, Lu, Me, Pp, Sc, Sf, and Tp are particularly characteristic of the elevational zones in which they occur in other tidal marshes in the region. Elevations relative to mean sea level on each transect estimated from water levels measured during sampling and tide tables (NATIONAL OCEAN SERVICE, 1988).

cession following the catastrophic submergence of low floodplains and intertidal areas in 1960 (*e.g.*, GUNCKEL, 1963; AÑAZCO, 1978; RAMÍREZ and AÑAZCO, 1982). Despite the youth of the present wetlands in the Valdivia estuary, we recognized three floral zones—mud flat, low marsh, and high marsh (Figure 3A and B)—in many Valdivia tidal marshes using the relative abundance of the dominant plants. Our mud flat zone corresponds with the zones of submerged and floating plants of AÑAZCO (1978) and RAMÍREZ *et al.* (1982) and the low marsh and most of the high marsh with their wetland zone of emerged plants (pantano).

We described plant communities on transects across only two widely separated marshes in the middle reaches of the Valdivia estuary. Earlier studies (RAMÍREZ *et al.*, 1982) and our observations suggest these marshes are typical of other tidal marshes in similar mid-estuary settings in south-central Chile; however, we did no systematic descriptions elsewhere to document this conclusion. Marshes in the seaward part of the estuary, for example near the confluence of the Río Tornagaleones and Río Valdivia (Figure 1B), are dominated by species tolerant of higher salinities, such as *Juncus balticus*, *Scirpus californicus*, *Sarcocornia fruticosa*, *Triglochin maritima*, and *Distichlis spicata*.

Scirpus californicus, *Carex riparia*, *Blechnum chilensis*, and *Rubus constrictus* are the dominant species along transect DR (Figure 3A). We place the boundaries of the low marsh along this transect at the lower edge of abundant *Scirpus californicus* growth (sample 5) and just below the first occurrence of *Senecio fistulosus* (sample 10), a common species in high marshes of the region (RAMÍREZ *et al.*, 1982). The flora near sample 17 includes plants common in the high marsh as well as species typical of the brush-covered upland (*Luma apiculata*, *Myrceugenia exsucca*), and this sample location is transitional between these two floral zones.

On transect AC scattered individuals of *Scirpus californicus* grow at low elevations well out on the mud flat (Figure 2B). The dominance of *Carex riparia* on this transect probably reflects the low salinity of this freshwater dominated site. We place the high marsh/low marsh boundary at the elevation of sample 10, where species typical of the high marsh, such as *Aster vahlii* and *Senecio fistulosus*, make their first appearance. The presence of *Drimys winteri* near sample 15 indicates the start of the transition to the upland floral zone

and abundant foraminifera (discussed below) indicate regular tidal flooding.

METHODS OF FORAMINIFERAL ANALYSIS

Site Sampling

A single transect from mud flat to the edge of the brush- or forest-covered upland above the marsh was sampled for foraminifera in each of two tidal marshes in the middle reaches of the Valdivia estuary early in 1989 (Figure 3A and B). Samples containing 12 to 23 cm³ of sediment (volume measured by displacement of water) were collected from the upper 10–15 mm of the marsh surface using a small, serrated corer as described by SCOTT and MEDIOLI (1980). Transect samples were sealed in glass vials with buffered formalyn and sea water (5% solution), 2–3 grains of rose bengal, and a little ethanol, and core samples with only ethanol, until processing five months later. The pH of representative samples was checked 6 times during the period of storage.

At each sample location we identified the dominant vascular plants with reference to RAMÍREZ *et al.* (1976, 1980, 1982) and visually estimated the relative amount of plant cover within 3 m of each sample location (Figure 3A and B). We then used the plant assemblages to classify each sample location along the transects into mud flat, low marsh, high marsh, or transitional high marsh-upland floral zones. Boundaries between zones are much more gradational than suggested by the vertical textured lines on Figure 3A and B.

Sample elevations on transects DR and AC (Figure 3A and B) were estimated by measuring water levels during sampling and then correcting the measurements by interpolating between predicted tide levels for Valdivia and Corral, to the southeast and southwest of the transect sites, respectively (NATIONAL OCEAN SERVICE, 1988; Figure 1B). Relative elevations between sample locations, measured with a theodolite and rod, were reproducible within 1–2 cm and cumulative error along transects was probably <10 cm. Distance between samples along the transects was measured with a cloth tape (precision ±0.2 m).

Foraminiferal Analyses

Foraminifera samples from the transects and core SF were wet sieved at 500 μm and 63 μm and organic matter was decanted from the resulting 500–63 μm mineral and foraminifera fraction. Both the decanted and >500 μm fractions were ex-

amed under the stereomicroscope before being discarded to prevent loss of foraminifera. Many arcellaceans (thecamoebians) may have been decanted and so arcellaceans are not included in percentage calculations. For example, SCOTT *et al.* (1991) reported 90–95% loss of arcellaceans in comparisons of decanted versus undecanted samples. Decantation may also have removed some specimens of flat foraminiferal species such as *Trochammina squamata*.

Decanted samples were split with a wet splitter (SCOTT and HERMELIN, 1993) and about 300 specimens were counted in ethanol using a stereomicroscope (except in low concentration samples, Table 1). Fragments were only counted if they included the proloculus. Two species of *Haplophragmoides* were encountered in the samples: *Haplophragmoides wilberti* and *H. manilaensis*. These two species were difficult to differentiate and were grouped as *H. spp.* in Figures 3A and B and Table 1. Species percentages for most mud flat and low marsh samples of transect AC and for all of the core samples are based on low numbers of tests (Figures 3A and B and 4; Table 1). We use the number of species per sample as a simple measure of species diversity (Table 1).

INTERTIDAL FORAMINIFERAL ZONATION IN THE VALDIVIA ESTUARY

Species percentages, diversity, and concentration (number of foraminiferal tests/cm³ of sediment) are the measures we use to compare the assemblages in the three floral zones along the two transects (Figure 3A and B; Table 1).

Mud Flat and Low Marsh Assemblages

In the Isla Del Rey transect (DR), foraminiferal concentration and assemblage composition are indistinguishable in the mud flat and the low marsh. Samples in both zones have low concentrations (Figure 3A) and a relatively high number of species (9–10 of the total of 11 species identified on this transect were present in these zones). *Trochammina salsa*, *Miliammina fusca*, or both dominate the assemblages in both zones. *Haplophragmoides* spp. and *Trochammina squamata* occur in low percentages across both zones. No calcareous foraminifera were found. As foraminifera were well preserved, low concentrations are probably the result of high sedimentation rates rather than poor preservation.

In the Río Angachilla transect (AC), assem-

blages on the mud flat and low marsh are more distinct. Six of the eight total identified species on the transect are present in the mud flat, and five of the six also occur in the low marsh. Concentrations in the mud flat and low marsh are even lower than in transect DR (Figure 3B). As in transect DR, *Trochammina salsa* and *Miliammina fusca* are the most common species on the mud flat, but in this transect (AC) *M. fusca* is the dominant species across the mud flat and an insignificant component of the low marsh assemblages. *Pseudothurammina limnetis* is a principal species of the low marsh in transect AC, whereas it occurs only in low numbers on the mud flat and low marsh of Transect DR.

High Marsh Assemblages

High marsh assemblages in both transects can be distinguished from mud flat and low marsh assemblages by abrupt rises in foraminiferal concentrations and the almost complete dominance of the faunas by *Trochammina salsa* (Figure 3A and B). Less than half the 8–11 species identified along the transects occur in the high marsh (Table 1). The gradual increase in the percentage of *Trochammina salsa* and the abrupt drop in *Miliammina fusca* (DR) or *Pseudothurammina limnetis* (AC) produce a much more distinct low marsh/high marsh boundary than do changes in the plant communities. Concentrations of foraminifera decline across the high marsh on transect DR, but the sample collected near the edge of the upland on transect AC contains the highest concentration in the transect. Over a third of the foraminifera in this sample were alive when the sample was collected indicating that the fauna is not reworked; tides must reach this sample location often. In contrast, the sample on the edge of the upland on transect DR contained only one live specimen of five individuals of *Trochammina salsa*.

Discussion of Foraminiferal Zonation

Foraminiferal assemblages do not differ significantly between the mud flat and low marsh floral zones on two transects in the Valdivia estuary, but high marsh assemblages are distinct from those of the mud flat, low marsh, and upland. The mud flat and low marsh zones are characterized by low foraminiferal concentrations and the co-dominance of *Miliammina fusca* and *Trochammina salsa*. *Pseudothurammina limnetis* is a principal species of the low marsh in transect AC; it is also

Table 1. Intertidal zone, sediment texture, elevation, depth, and foraminiferal percentages for samples from surface transects DR and AC and core SF in the tidal marshes of the Valdivia estuary.

Sample Number	Intertidal Zone	Sediment Texture	Distance (m) ^a	Elevation or Depth (cm) ^b	Total Concentration (no./cm ³)	Number Tests Counted	Live/Total Ratio	Species Percentages													Percent Unidentified	Number Species		
								<i>Trichammnia salsa</i>	<i>Haplophragmoides</i> sp.	<i>Mitiammina fusca</i>	<i>Ammotium salsum</i>	<i>Reophax nana</i>	<i>Pseudohurammnia limnetis</i>	<i>Trichammnia squamata</i>	<i>Textularia earlandi</i>	<i>Polysaccammnia ipohalina</i>	<i>Trichammnia inflata</i>	<i>Trichammnia macrescens</i>	<i>Trichammnia mac. f. polystoma</i>	<i>Tiphotocha comprinata</i>				
DR-1	MF	sl	0	-53	21	255	0.01	64	5	23	0	0	4	0	0	0	0	0	0	0	0	0	4	5
DR-2	MF	sl	5	-51	26	350	0.04	69	7	23	0	0	2	0	0	0	0	0	0	0	0	0	0	4
DR-3	MF	ls	11	-46	18	267	0.04	76	3	17	0	0	4	0	0	0	0	0	0	0	0	0	0	5
DR-4	MF	sil	15	-37	18	265	0.04	76	2	16	0	1	3	0	0	0	0	0	0	0	0	0	0	6
DR-5	MF	sil	18	-27	22	284	0.06	68	4	24	0	0	4	0	0	0	0	0	0	0	0	0	0	6
DR-6	LM	sl	22	-14	17	242	0.08	67	4	24	1	0	2	0	0	0	0	0	0	0	0	0	0	7
DR-7	LM	sl	26	-6	32	284	0.09	75	7	12	0	1	5	0	0	0	0	0	0	0	0	0	0	7
DR-8	LM	sl	28	16	8	164	0.34	31	9	58	0	1	1	0	0	0	0	0	0	0	0	0	0	5
DR-9	LM	sl	31	31	61	280	0.15	66	13	20	0	0	1	0	0	0	0	0	0	0	0	0	0	5
DR-10	HM	sl	34	44	107	234	0.07	88	8	4	0	0	0	0	0	0	0	0	0	0	0	0	0	3
DR-11	HM	sl	38	45	189	414	0.11	96	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4
DR-12	HM	sl	45	61	282	669	0.09	94	6	<0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	3
DR-13	HM	sl	54	66	260	366	0.04	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
DR-14	HM	sl	59	66	143	321	0.09	99	<0.5	<0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	3
DR-15	HM	sl	65	83	95	244	0.05	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
DR-16	HM	sl	87	85	23	217	0.28	90	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3
DR-17	U	sil	92	107	<1	5	0.20	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
AC-1	MF	sl	0	-70	2	31	0.06	0	0	97	3	0	0	0	0	0	0	0	0	0	0	0	0	2
AC-2	MF	sl	2	-68	1	17	0.00	6	0	94	0	0	0	0	0	0	0	0	0	0	0	0	0	2
AC-3	MF	sl	8	-58	3	37	0.05	19	0	81	0	0	0	0	0	0	0	0	0	0	0	0	0	2
AC-4	MF	sl	13	-54	2	26	0.12	15	0	85	0	0	0	0	0	0	0	0	0	0	0	0	0	2
AC-5	MF	sl	17	-47	2	26	0.15	38	0	58	0	4	0	0	0	0	0	0	0	0	0	0	0	3
AC-6	MF	sl	21	-28	2	25	0.24	40	4	52	0	0	4	0	0	0	0	0	0	0	0	0	0	3
AC-7	LM	sl	23	-20	2	29	0.10	45	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	4
AC-8	LM	sl	27	0	6	90	0.07	74	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	4
AC-9	LM	sl	35	26	28	>300	0.15	77	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
AC-10	HM	sl	36	41	80	>300	0.28	96	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
AC-11	HM	sl	37	52	87	>300	0.37	99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

Table 1. Continued.

Sample Number ^a	Intertidal Zone ^b	Sediment Texture ^c	Distance (m) ^d	Elevation or Depth (cm) ^e	Total Concentration (no./cm ³)	Number Tests Counted	Live/Total Ratio	Species Percentages												Number Species				
								<i>Ammotium salsum</i>	<i>Miliammina fusca</i>	<i>Haplophragmoides</i> sp.	<i>Trochammina salsa</i>	<i>Trochammina squamata</i>	<i>Textularia earlandi</i>	<i>Polysaccamina ipohalina</i>	<i>Trochammina inflata</i>	<i>Trochammina macrescens</i>	<i>Trochammina mac. f. polystoma</i>	<i>Tiphotocha comprinata</i>	Percent Unidentified					
AC-12	HM	sil	38	38	91	>300	0.19	98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
AC-13	HM	sil	39	53	59	>300	0.29	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
AC-14	HM	1	41	54	37	>300	0.34	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
AC-15	HM	1	45	69	121	>300	0.36	100	0	<0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	2
SF-1	—	1	—	5	<1	6	—	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
SF-2	—	sil	—	40	7	96	—	79	2	15	0	0	0	0	0	0	0	0	0	0	0	0	0	5
SF-3	—	sil	—	60	4	56	—	77	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	4
SF-4	—	sil	—	80	2	34	—	35	0	59	0	0	0	6	0	0	0	0	0	0	0	0	0	3
SF-5	—	sil	—	100	1	15	—	20	0	80	0	0	0	0	0	0	0	0	0	0	0	0	0	2
SF-6	—	csi	—	110	1	9	—	0	11	67	0	11	0	11	0	0	0	0	0	0	0	0	0	4
SF-7	—	csi	—	120	<1	1	—	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
SF-8	—	csi	—	123	7	14	—	21	7	57	0	0	0	7	0	0	0	0	0	0	0	0	0	4
SF-9	—	1	—	125	2	22	—	45	0	50	0	0	0	5	0	0	0	0	0	0	0	0	0	3
SF-10	—	1	—	130	5	52	—	62	15	12	0	0	0	2	0	0	0	0	0	0	0	0	10	5
SF-11	—	sil	—	150	<1	6	—	83	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	3
SF-12	—	ls	—	185	1	5	—	0	0	80	0	0	0	20	0	0	0	0	0	0	0	0	0	2

^a DR-, AC-, and SF- in the column headings refer to samples in transects AC and DR and core SF, respectively. Dash indicates no data
^b Determined in field using the distribution and relative abundance of common vascular plants (e.g., RAMIREZ *et al.*, 1982). MF = mud flat, LM = low marsh, HM = high marsh, and U = brush- or forest-covered upland
^c Texture determined in the field using soil description terms (SOIL SURVEY STAFF, 1975). l = loam, ls = loamy sand, sil = silt loam, sl = sandy loam, csi = clayey silt
^d Distance along surface transect perpendicular to shoreline
^e Estimated elevation relative to mean tide level for transect samples (DR and AC); depth in core SF for core samples

characteristic of the low marsh in Massachusetts (SCOTT and LECKIE, 1990). In our transects, the high marsh (Faunal Zone I, Figure 2) is easily distinguished from the low marsh and mud flat (Faunal Zone II) by the abrupt increase in foraminiferal concentrations and the almost complete dominance of *Trochamminita salsa*. The upland lacks foraminifera.

The two-fold foraminiferal zonation developed for the Valdivia estuary (Figure 2) is less useful than other, more detailed zonations for reconstructing former sea-level changes. The four faunal zones (two with narrow vertical ranges) identified in an early study of marsh foraminifera in Nova Scotia (Figure 2; SCOTT and MEDIOLI, 1980) allow precise development of sea-level histories. This is especially true at sites where sedimentation is continuous and sea-level changes are assumed to be gradual. On the central west coast of North America, reconstructing past sea-level changes is much less precise because faunal zones have larger vertical ranges, because only three zones have been identified and some changes are coseismic (instantaneous) rather than gradual. In sediment sequences that record sudden coseismic changes, faunal zone boundaries in the sequence may not correspond with the upper and lower limits of the vertical range of the zones. In such sequences, fossil assemblages immediately above or below transgressive or regressive contacts could represent any vertical position in their respective assemblage zones (JENNINGS and NELSON, 1992).

In the Valdivia estuary we are further restricted in having only two assemblage zones. In this area a lower limit could be placed on the size of a coseismic rise in relative sea level, represented by fossil assemblage changes in a core, only if sediment with a low marsh/mud flat assemblage overlies an upland soil. The minimum vertical range of Faunal Zone I in Valdivia is 0.5 m (Figure 2) and so a change from an upland environment (no foraminifera) to a low marsh/mud flat environment might occur during as little as 0.5 m of subsidence. Foraminiferal assemblage changes set no limit on the maximum amount of subsidence marked by an upland-low marsh/mud flat contact, because the elevation of the lower boundary of Faunal Zone II and the upper boundary of the upland floral zone are undefined. The largest amount of regional coseismic subsidence ever recorded is 2.7 m, measured near Valdivia in 1960. This amount may be near an upper limit for this type of subsidence. The only constraint on the

size of former sea-level changes, provided by fossil assemblage changes between vertically adjacent faunal zones, is that a change cannot exceed the combined vertical range of the zones (*e.g.*, JENNINGS and NELSON, 1992; NELSON and KASHIMA, 1993).

Identification of additional foraminiferal zones with narrower elevational ranges would improve our ability to resolve past sea-level changes in the Valdivia region. For example, more transects with more closely spaced samples over a greater elevational range might show that *Pseudothuramina limnetis* can be used to distinguish the mud flat from the low marsh, or that *Miliammina fusca* is much more abundant than *Trochamminita salsa* in the lower part of the mud flat. A three- or four-part zonation might allow a two- to three-fold increase in the precision of estimates of the size of past sea-level changes. Such an increase would allow past earthquakes that produced about 1 m of regional subsidence to be distinguished from those that produced <0.5 m or >2 m of subsidence.

Comparison with Assemblages of Other Temperate Marshes

The foraminiferal assemblages in the high marshes of the Valdivia estuary are distinct compared to other high marsh assemblages in the mid-latitude Americas in being dominated by *Trochamminita salsa* (Figure 2). This species has only been described from mangrove swamps in Trinidad (CUSHMAN and BRÖNNIMANN, 1948; SAUNDERS, 1957) and Brazil (ZANINETTI *et al.*, 1977) and from marshes in New Zealand (HAYWARD and HOLLIS, in press). In the marshes of northern California (LI, 1992), central Oregon (JENNINGS and NELSON, 1992), southern British Columbia (WILLIAMS, 1989; PATTERSON, 1990), the Canadian Maritime provinces (SCOTT and MEDIOLI, 1980), New England (SCOTT and LECKIE, 1990; THOMAS and VAREKAMP, 1991), and eastern South America (SCOTT *et al.*, 1990), the high marsh zone (Zone I, Figure 2) is dominated by one or more of the following species: *Trochammina macrescens* (either forma *macrescens* or forma *polystoma*), *Trochammina inflata*, and *Tiphotrocha comprimata*. The reason why these species are replaced by *Trochamminita salsa* in the Valdivia estuary is unclear; most other reported assemblages from tidal marshes in temperate, subtropical, subarctic, or tropical regions do not contain *T. salsa*. The only other area where this species has been

reported as abundant is in New Zealand, at about the same latitude as Valdivia. Perhaps *T. salsa* is restricted to mid-latitude coasts of the South Pacific.

Aside from the presence of *T. salsa*, the Valdivia low marsh/mud flat assemblages are similar to low marsh/mud flat assemblages elsewhere (Figure 2). Foraminiferal concentrations, however, are very low compared to concentrations in other similar environments, probably because of the high rate of sedimentation in response to the catastrophic flooding of the estuary in 1960.

APPLICATION OF ZONATION TO PALEO-SEALEVEL STUDIES IN SOUTHERN CHILE

To test the use of changes in foraminiferal assemblages in sequences of intertidal sediment for reconstructing past sea-level changes in southern Chile, we analyzed foraminifera in a core that penetrated a marsh soil submerged and buried by intertidal mud following the 1960 earthquake. Our aim was to determine if assemblage changes across the upper contact of the buried soil would suggest a rise in sea-level comparable to the rise of at least 1.5 m observed following the earthquake. As explained below, our test was inconclusive because of the limited faunal zonation (only two zones) in the Valdivia area and because the soil beneath the 1960 mud in the core was a low marsh soil rather than a high marsh or upland soil.

Coring along the margins of the Valdivia estuary suggests preserved tidal marsh soils, buried following the 1960 earthquake, are rare. There are probably two reasons for this. First, prior to 1960 much of the now flooded areas of the Valdivia estuary (Figure 1B) were grazed, partly diked, floodplain soils rather than tidal marsh soils. Second, along the edges of the present estuary where the water is shallow enough for hand coring, waves have eroded most of the former soils on the now flooded and buried floodplains and small areas of adjacent marsh.

Core SF was collected with a 1-m-long, 25-mm-diameter, half-cylinder gouge corer (e.g., VAN DE PLASSCHE, 1991; NELSON, 1992) on the edge of a small island in what is now a channel of the Río Valdivia (Canal de San Francisco; Figure 1B) at the east end of Isla San Francisco. Aerial photographs show that in 1944 the core site was at the marshy edge of a low-lying pasture, about 50 m from a narrow tidal channel. Because the core

site is now at the transitional boundary between low marsh and mud flat floral zones, sediment aggradation following the >1.5 m of subsidence in 1960 must have been rapid. Hand leveling to nearby fence posts and bushes drowned in 1960 indicates at least 1 m of post-1960 aggradation.

The lithologies in the core record the gradual aggradation of a tidal marsh soil, which was rapidly buried by soft, soupy mud following the 1960 earthquake. The soil consists of 3 cm of laminated, partly detrital peat over 6 cm of fibrous peat, over 21 cm of muddy peat with abundant fibrous roots (Figure 4). The vertical orientation of fibers in the peaty units, their gradational contacts, and the coarse organic texture of the fibrous peat suggest these units represent a buried marsh soil. However, the lithologies of these units do not indicate whether the soil formed in a low or high (intertidal) marsh or in a freshwater marsh. Based only on the elevation of the site and the 120 cm depth of the now-buried 1960 surface, the site was probably intertidal prior to 1960. Small rootlets in the detrital peat suggest it accumulated gradually, probably in a small depression on the surface of the marsh. The sharp upper contact on the detrital peat and the lack of rootlets in the overlying mud suggest rapid deposition of the mud following subsidence in 1960. About 15 m to the east, in another core, a 7-mm-thick, very fine sand bed overlying the peat may have been deposited by the 1960 tsunami. Muddy sand and sands that floor a former tidal channel underlie the 25 cm of peaty mud and rooted mud below the peat.

Despite the significant change in lithologies in the core, the composition of the foraminiferal assemblages suggests (at the most) a change from low marsh to mud flat (Figure 4; Faunal Zone II of Figure 2). The low-concentration but well-preserved assemblages are comparable to those in the mud flat and low marsh on Transect AC and reflect rapid sedimentation after the earthquake followed by plant colonization. When the lowest concentration samples (1, 6, 7, and 11, Figure 4; Table 1) are ignored, the assemblages change very little at the contact between the detrital peat and overlying mud. The presence of *Reophax nana* in Sample 6 at 110 cm could indicate either a mud flat or low marsh environment for the 1.2 m of post-1960 sediment above the peat. *Reophax nana* characterizes the mud flat in central Oregon tidal marshes (JENNINGS and NELSON, 1992), although it only occurs in one of our modern mud flat samples (Table 1). The lack of rootlets in the mud

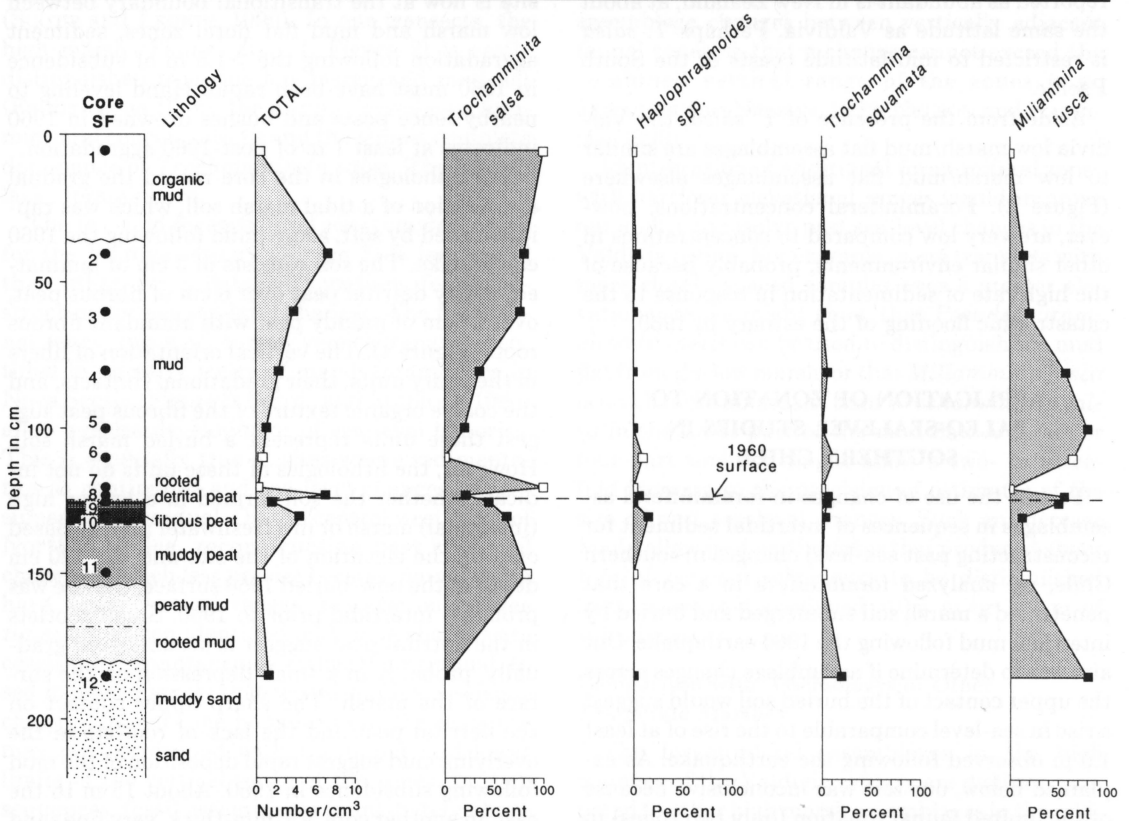


Figure 4. Lithologies, foraminiferal concentrations, and percentage of selected foraminiferal species in samples from core SF collected from the Canal de San Francisco (Figure 1B). Open squares show very low concentration samples (Table 1). The ground surface that was submerged due to 1.5–2.7 m of coseismic subsidence in 1960 is marked by the dashed line.

above the peat, however, confirm a mud flat rather than low marsh environment. The gradual decrease in the percentage of *Miliammina fusca* and increase in *Trochammina salsa* probably reflects the rapid shoaling of the core site since 1960.

Muddy sand and sand beneath the rooted mud on which the peaty soil is developed could not have been deposited by the 1960 tsunami. Accounts of the tsunami (WEISCHET, 1960; SEVIERS *et al.*, 1963) suggest that soils along the main river channels in the lower parts of the estuary below Isla San Francisco may have been eroded by the strong currents generated by the tsunami (Figure 1B). However, the core site was probably protected from the strongest waves and currents by its position in the lee of Isla San Francisco and Isla Mota; the narrow channel near the site also drained to the southeast, almost opposite to the direction in which the tsunami waves moved up

the Río Valdivia. Foraminifera in the peaty units show they form a low marsh soil and such a soil could not have developed on the sand and then have been buried by >1 m of mud in <30 years.

The stratigraphy and foraminiferal assemblages in core SF are consistent with the sudden, coseismic 1.5–2.7 m rise in sea level reported in 1960, but they cannot distinguish a large rise from a very small one because the low marsh zone borders the mud flat. The vertical ranges of the low marsh floral zones on our two transects are 44–70 cm, but because the lower boundary of Faunal Zone II is unknown, the rise in sea-level could be as much as 2–3 m. Alternatively, because the low marsh adjoins the mud flat, the lithologic change across the peat might represent just a few centimeters of sea-level rise. Thus, the results of our test using the assemblages in core SF are consistent with our earlier conclusions

about applying the Valdivia faunal zones to the reconstruction of past sea-level changes. Until more detailed zonations are developed, these methods will place few constraints on the size of past episodes of subsidence during great earthquakes.

CONCLUSIONS

High marsh foraminiferal assemblages are distinct from those of the low marsh, mud flat, and upland floral zones in two reconnaissance transects across marshes in the Valdivia estuary. Samples from the high marsh, mapped on the basis of plant communities, consist mostly of *Trochamminita salsa* and have higher concentrations of foraminifera than samples from lower intertidal zones. The species composition of assemblages from the low marsh and mud flat floral zones are indistinguishable from one another, and concentrations of foraminifera are very low. Upland samples are barren of foraminifera.

The identification of only two faunal zones, neither one with a narrow elevational range, limits the use of foraminiferal assemblages in reconstructing sea-level histories in this region. Fossil assemblages in core SF, which records the sudden subsidence of the Valdivia estuary during the great earthquake of 1960, cannot be used to estimate the amount of sudden sea-level rise during the earthquake. More precise estimates of the size of past coseismic changes in relative sea level will require identification of more assemblage zones with narrower elevational ranges.

High marsh foraminiferal assemblages in the Valdivia estuary differ from other reported high marsh assemblages in being dominated by *Trochamminita salsa*. The high marshes of the mid-latitude coasts of North America and eastern South America are dominated by *Trochammina macrescens* (forma *macrescens* or forma *polystoma*), *Trochammina inflata*, or *Tiphotrocha comprimata*.

SYSTEMATIC PALEONTOLOGY

Here we list original species and authors and a few current references for our species. Also included is discussion of *Trochamminita salsa*.

Haplophragmoides spp.

This group probably consists of *H. manilaensis* Anderson and *H. wilberti* Anderson. With so few specimens, we did not attempt to identify them

to species level. For a more thorough discussion of these two species see SCOTT *et al.* (1991).

Miliammina fusca (Brady)

Quinqueloculina fusca BRADY, 1870, p. 47, pl. 11, figures 2, 3.

Miliammina fusca (Brady). PHLEGER and WALTON, 1950, p. 280, pl. 1, figures 1, 4; SCOTT *et al.*, 1991, p. 386, pl. 1, figures 1, 4.

Pseudothurammina limnetis (Scott and Medioli)

Thurammina(?) *limnetis* SCOTT and MEDIOLI, 1980, p. 43, 44, pl. 1, figures 1-3.

Pseudothurammina limnetis (Scott and Medioli). SCOTT, MEDIOLI, and WILLIAMSON, in SCOTT *et al.*, 1981, p. 126, 127.

Trochammina squamata Parker and Jones

Trochammina squamata PARKER and JONES, 1865, p. 407, pl. 15, figures 30, 31a-c.

Trochamminita salsa (Cushman and Brönnimann)

Labrospira salsa CUSHMAN and BRÖNNIMANN, 1948, p. 16, pl. 3, figures 5, 6.

Trochamminita irregularis CUSHMAN and BRÖNNIMANN, 1948, p. 17, pl. 4, figures 1-3; SAUNDERS, 1957, emended, p. 4, 5, p. 12, figures 2-8. *Trochamminita salsa* (Cushman and Brönnimann). SAUNDERS, 1957, p. 6, pl. 1, figures 3-8.

Remarks: Although we have placed *T. irregularis* as a junior synonym of *T. salsa* because it is described one page earlier in the same publication, *T. irregularis* remains as the type species of *Trochamminita*, as first described in CUSHMAN and BRÖNNIMANN (1948). However, precedence requires that the proper name of this species is *T. salsa*.

The genus *Trochamminita* was first described by Cushman and Brönnimann in 1948. It comprised a single species, *Trochamminita irregularis*. The specimens were found in brackish water sediments in Trinidad, an island off the NE coast of Venezuela. In Cushman and Brönnimann's original description, *Trochamminita* has an early trochoid stage with chambers added irregularly in the adult stage. The early stage is attributed with an interiomarginal aperture that changes to an areal rounded aperture with a raised rim in a later stage. SAUNDERS (1957) emended *Trocham-*

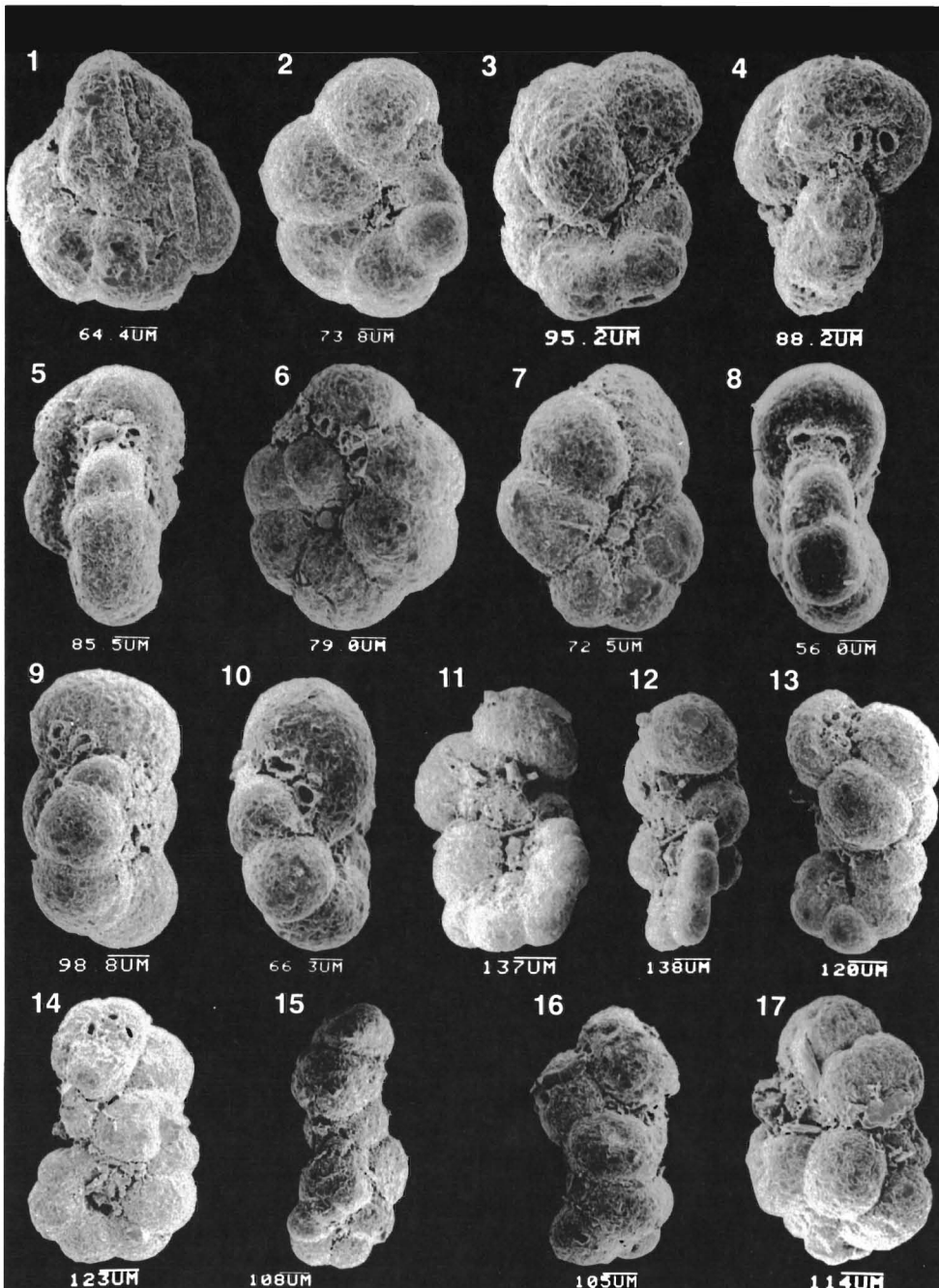


Figure 5. Photographs 1–17. *Trochamminita salsa* (Cushman and Brönnimann). Number in microns beneath each specimen indicates length of scale line. Photographs 1–7 are typical relatively regularly coiled individuals of the “*salsa*” form. Photographs 8–10 illustrate the transition between the “*salsa*” and “*irregularis*” forms. Photographs 11–15 illustrate typical “*irregularis*” types but note that the initial chambers are “*salsa*” type and the specimens begin to uncoil. Photographs 16 and 17 are completely irregular. All specimens are from sample AC-10 (Table 1).

minita, asserting that it has an early planispiral stage rather than an early trochospiral stage. SAUNDERS (1957) also noted that he did not find the early interiomarginal aperture, but rather single and multiple areal primary apertures. In accordance with the emended generic characteristics of *Trochamminita*, SAUNDERS (1957) moved *Labrospira salsa* (Cushman and Brönnimann) to *Trochamminita salsa*.

In our samples from the Valdivia estuary, we find a morphologic continuum of specimens ranging from those fitting the description of *Trochamminita salsa* to those fitting the description of *T. irregularis* (Figure 5). The characteristics offered by Saunders and by Cushman and Brönnimann are insufficient to separate intergrades between these two end members, but they did not have the abundant fauna that we have to verify the continuum. Much of the difference between the original two species can probably be attributed to juvenile vs. adult characteristics, or just intra-specific variation that is common in many of these agglutinated marine forms (e.g., *Trochammina macrescens*, see SCOTT and MEDIOLI, 1980). J.B. Saunders (oral communication to D.B. Scott, 1993) recently examined our specimens and agrees that *T. salsa* and *T. irregularis* are a single species.

ACKNOWLEDGEMENTS

Our work in the Valdivia estuary was part of a paleo-seismic study of the coast of south-central Chile largely supported by a U.S. Geological Survey Gilbert Fellowship to Brian Atwater, Alan Nelson, and Susan Bartsch-Winkler. Nelson is supported by the National Earthquake Hazards Reduction Program of the U.S. Geological Survey. We particularly thank Mario Pino, Universidad Austral de Chile, for providing facilities, logistical support, discussions, and encouragement during our field studies. Antonio Gallegos provided able field assistance. Discussions with John B. Saunders, Bill Manley, Carolina Villagran, and Brian Atwater were helpful. Comments by Eileen Hemphill-Haley, John Hollin, Roland Gehrels, and two anonymous reviewers improved the manuscript. Lee-Ann Bradley drew the figures. This paper is a contribution to IGCP Project 274 (Coastal evolution in the Quaternary) and to the INQUA Neotectonics Commission.

LITERATURE CITED

ADAM, P., 1990. *Saltmarsh Ecology*. Cambridge: Cambridge University Press, 466p.

- AÑAZCO, N.E., 1978. Estudios Ecológicos en Poblaciones de *Scirpus Californicus* (Mey.) Steudl. en la Provincia de Valdivia, Chile. Unpublished M.S. Thesis, Valdivia, Chile: Universidad Austral de Chile, 53p.
- ATWATER, B.F., 1992. Geologic evidence for earthquakes during the past 2000 years along the Copalis River, southern coastal Washington. *Journal of Geophysical Research*, 97, No. B2, 1901–1919.
- ATWATER, B.F.; NÚÑEZ, H.J., and VITA-FINZI, C., 1992. Net late Holocene emergence despite earthquake-induced submergence, south-central Chile. In: OTA, Y., NELSON, A.R., and BERRYMAN, K.R. (eds.), Impacts of tectonics on Quaternary coastal evolution. *Quaternary International*, 15/16, 77–85.
- BOLTOVSKOY, E. and HINCAPIÉ DE MARTÍNEZ, H., 1983. Foraminíferos del manglar de Tesca, Cartagena, Colombia. *Revista Española de Micropaleontología*, 15, 205–220.
- BOLTOVSKOY, E. and WRIGHT, R., 1976. *Recent Foraminifera*. The Hague: Dr. W. Junk b.v. Publishers, 515p.
- BOLTOVSKOY, E. and VIDARTE, L.M., 1977. Foraminíferos de la zona de manglar de Guayaquil (Ecuador). *Revista del Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" E. Instituto Nacional de Investigación de las Ciencias Naturales*, 5, 31–40.
- BRADY, H.B., 1870. In: BRADY, G.S. and ROBERTSON, D. The ostracoda and foraminifera of tidal rivers. With analysis and descriptions of foraminifera by H.B. Brady, Part II, *Annual Magazine of Natural History*. Series 4,6, 273–306.
- BRYANT, E., 1991. *Natural Hazards*. Cambridge, U.K.: Cambridge University Press, 310p.
- CHAPMAN, V.J., 1960. *Saltmarshes and Salt Deserts of the World*. London: Leonard Hill LTP, 392p.
- CIFUENTES, I.L., 1989. The 1960 Chilean earthquakes. *Journal of Geophysical Research*, 94, B1, 665–680.
- CUSHMAN, J.A. and BRÖNNIMANN, P., 1948. Some new genera and species of foraminifera from brackish water of Trinidad. *Cushman Laboratory for Foraminiferal Research, Contributions*, 24(1), 15–22.
- DARIENZO, M.E. and PETERSON, C.D., 1990. Episodic tectonic subsidence of late Holocene salt marshes, northern Oregon coast, central Cascadia margin, U.S.A. *Tectonics*, 7, 833–857.
- DÜRRSCHMIT, M., 1980. Some ecological observations on environmental parameters, planktonic seasonal succession, and biomass in Río Cruces (Prov. Valdivia), South Chile. *Archiv. für Hydrobiologie*, 88, 345–363.
- FREY, R.W. and BASAN, P.B., 1985. Coastal salt marshes. In: DAVIS, R.A. JR. (ed.), *Coastal Sedimentary Environments*. New York: Springer-Verlag, pp. 225–302.
- GEHRELS, W.R. and BELKNAP, D.F., 1993. Neotectonic history of eastern Maine evaluated from historic sea-level data and ¹⁴C dates on salt-marsh peats. *Geology*, 21, 615–618.
- GUNCKEL, H., 1963. Se forma una nueva vegetación hidrófila a orillas del río Valdivia, a raíz del terremoto. *Boletín de la Universidad de Chile*, 37, 32–35.
- HAUENSTEIN, E. and RAMÍREZ, C., 1986. The influence of salinity on the distribution of *Egeria densa* in the Valdivia river basin, Chile. *Archiv für Hydrobiologie*, 107, 511–519.
- HAYWARD, B. and HOLLIS, C., in press. Brackish water

- foraminifera in New Zealand: A taxonomic and ecologic review. *Micropaleontology*.
- ILLIES, H., 1970. *Geología de los Alrededores de Valdivia y Volcanismo y Tectónica en Márgenes del Pacífico en Chile Meridional*. Valdivia, Chile: Instituto de Geología y Geografía, Universidad Austral de Chile, 64p.
- ISLA, F.I., 1989. Holocene sea-level fluctuation in the Southern Hemisphere. *Quaternary Science Reviews*, 8, 359–368.
- JENNINGS, A.E. and NELSON, A.R., 1992. Foraminiferal assemblage zones in Oregon tidal marshes—Relation to marsh floral zones and sea level. *Journal of Foraminiferal Research*, 22, 13–29.
- LI, WEN-HAO, 1992. Evidence for the Late Holocene Coseismic Subsidence in the Lower Eel River Valley, Humboldt County, Northern California: An Application of Foraminiferal Zonation to Indicate Tectonic Submergence. Unpublished M.S. Thesis, Arcata, California: Humboldt State University, Department of Geology, 92p.
- NATIONAL OCEAN SERVICE, 1988. *Tide Tables 1989—West Coast of North and South America*. Washington, D.C.: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 234p.
- NELSON, A.R., 1992. Holocene tidal-marsh stratigraphy in south-central Oregon—Evidence for localized sudden submergence in the Cascadia subduction zone. In: FLETCHER, C.P. and WEHMILLER, J.F. (eds.), *Quaternary coasts of the United States—Marine and lacustrine systems*. *Society for Sedimentary Geology Special Publication* 48, 287–301.
- NELSON, A.R. and KASHIMA, K., 1993. Diatom zonation in southern Oregon tidal marshes relative to vascular plants, foraminifera, and sea level. *Journal of Coastal Research*, 9, 673–697.
- ORTLIEB, L. and MARCHARÉ, J., 1989. Neotectonics and Holocene sea level fluctuations along the Peruvian coast: A debate. *Bulletin of the INQUA Neotectonics Commission*, 12, 83–84.
- OTTEY, M.A., 1986. Analisis Estadístico de Gradientes Vegetacionales en Marismas del Sur de Chile. Unpublished M.S. Thesis, Valdivia, Chile: Universidad Austral de Chile, 114p.
- PARKER, W.K. and JONES, T.R., 1865. On some foraminifera from the North Atlantic and Arctic Oceans, including Davis Strait and Baffins Bay. *Royal Society of London, Philosophical Transactions*, 155, 325–441.
- PATTERSON, R.T., 1990. Intertidal benthic foraminiferal biofacies on the Fraser River Delta, British Columbia—Modern distribution and paleoecological importance. *Micropaleontology*, 36, 229–245.
- PHLEGER, F.B. and WALTON, W.R., 1950. Ecology of marsh and bay foraminifera, Barnstable, Massachusetts. *American Journal of Science*, 248, 274–294.
- PLAFKER, G., 1972. Alaskan earthquake of 1964 and Chilean earthquake of 1960—Implications for arc tectonics. *Journal of Geophysical Research*, 77, no. 5, 901–925.
- PLAFKER, G. and SAVAGE, J.C., 1970. Mechanism of the Chilean earthquakes of May 21 and 22, 1960. *Geological Society of America Bulletin*, 81, 1001–1030.
- RAMÍREZ, G. C. and AÑAZCO, N.E., 1982. Variaciones estacionales en el desarrollo de *Scirpus californicus*, *Typha angustifolia* y *Phragmites communis* en pantanos Valdivianos. *Agro Sur*, 10, 111–123.
- RAMÍREZ, G.C.; GODOY, B.R.; CONTRERAS, F.D., and STEGMAIER, W.E., 1982. *Guía de Plantas Acuáticas y Palustres Valdivianas*. Valdivia, Chile: Publicación Instituto de Botánica, Facultad de Ciencias, Universidad Austral de Chile, 42p.
- RAMÍREZ, G.C.; ROMERO, M., and RIVEROS, M., 1976. Lista de cormófitos acuáticos de la región de Valdivia. *Publicación Ocasional Museo Nacional Historia Natural*, 22, 3–12.
- RAMÍREZ, G.C.; ROMERO, M., and RIVEROS, M., 1979. Habit, habitat, origin and geographical distribution of Chilean vascular hydrophytes. *Aquatic Botany*, 7, 241–253.
- RAMÍREZ, G.C.; ROMERO, M., and RIVEROS, M., 1980. Lista de cormófitos palustres de la región de Valdivia. *Boletín Museo Nacional Historia Natural*, 37, 153–177.
- SANDWEISS, D.H., 1986. The beach ridges at Santa, Peru—El Niño, uplift, and prehistory. *Geoarcheology*, 1, 17–28.
- SAUNDERS, J.B., 1957. Trochamminidae and certain lituolidae (foraminifera) from the recent brackish water sediments of Trinidad, British West Indies. *Smithsonian Miscellaneous Collections*, 134, (5), Publ. 4270, 1–16.
- SCOTT, D.B. and HERMELIN, J.O.R., 1993. A device for precision splitting of micropaleontological samples in liquid suspension. *Journal of Paleontology*, 67, 151–154.
- SCOTT, D.B. and MEDIOLI, F.S., 1980. Quantitative studies of marsh foraminifera distributions in Nova Scotia—Implications for sea level studies. Washington, D.C.: Cushman Foundation for Foraminiferal Research, *Special Publication No. 17*, 58p.
- SCOTT, D.B. and MEDIOLI, F.S., 1986. Foraminifera as sea-level indicators. In: VAN DE PLASSCHE, O. (ed.), *Sea-level Research—A Manual for the Collection and Evaluation of Data*. Norwich, U.K.: Geo Books, pp. 435–456.
- SCOTT, D.B.; SCHNACK, E.J.; FERRERO, L.; ESPINOSA, M., and BARBOSA, C.F., 1990. Recent marsh foraminifera from the east coast of South America—Comparison to the northern hemisphere. In: HEMLEBEN, C.; KAMINSKI, M.A.; KUHN, W., and SCOTT, D.B. (eds.), *Paleoecology, Biostratigraphy, Paleoceanography, and Taxonomy of Agglutinated Foraminifera. NATO ASI Series C* (Kluwer Publishing 237, 717–738).
- SCOTT, D.B.; SUTER, J.R., and KOSTERS, E.C., 1991. Marsh foraminifera and arcellaceans of the Lower Mississippi Delta: Controls on spatial distributions. *Micropaleontology*, 37, 373–392.
- SCOTT, D.B.; WILLIAMSON, M.A., and DUFFETT, T.E., 1981. Marsh foraminifera of Prince Edward Island: Their recent distribution and application for former sea-level studies. *Maritime Sediments and Atlantic Geology*, 17, 98–129.
- SCOTT, D.K. and LECKIE, R.M., 1990. Foraminiferal zonation of Great Sippewissett salt marsh. *Journal of Foraminiferal Research*, 20, 248–266.
- SEVIERS, H.A.; VILLEGAS, C., and BARROS, G., 1963. The seismic sea wave of the 22 May 1960 along the Chilean coast. *Bulletin of the Seismological Society of America*, 53, 1125–1190.

- SOIL SURVEY STAFF, 1975. Soil taxonomy—A basic system of soil classification for making and interpreting soil surveys. *USDA-SCS Handbook no. 436*, (U.S. Government Printing Office, Washington, D.C., 754p.)
- THOMAS, E. and VAREKAMP, J.C., 1991. Paleo-environmental analyses of marsh sequences (Clinton, Connecticut): Evidence for punctuated rise in relative sealevel during the latest Holocene. In: GAYES, P.T.; LEWIS, R.S., and BOKUNIEWICZ, H.G. (eds.), Quaternary coastal evolution of southern New England. *Journal of Coastal Research, Special Issue No. 11*, 125–158.
- TOOLEY, M.J. and JELGERSMA, S., 1993. Impacts of sea-level rise on European coastal lowlands. *Institute of British Geographers Special Publication No. 27*, (Blackwell, Oxford, U.K., 265p.)
- VAN DE PLASSCHE, O., 1991. Late Holocene sea-level fluctuations on the shore of Connecticut inferred from transgressive and regressive overlap boundaries in salt-marsh deposits. In: GAYES, P.T.; LEWIS, R.S., and BOKUNIEWICZ, H.G. (eds.), Quaternary coastal evolution of southern New England. *Journal of Coastal Research, Special Issue No. 11*, 159–179.
- WARRICK, R.A.; BARROW, E.M., and WIGLEY, T.M.L., 1993. *Climate and Sea Level Change: Observations, Projections, and Implications*. Cambridge, U.K.: Cambridge University Press, 424p.
- WELLS, L.E., 1990. Holocene history of the El Niño phenomenon as recorded in flood sediments of northern coastal Peru. *Geology*, 18, 1134–1138.
- WEISCHET, W., 1960. Contribuciones al estudio de las transformaciones geográficas en la parte septentrional del sur de Chile por efecto del sismo del 22 de Mayo de 1960. *Publicación No. 15 de Instituto de Geología* (Facultad de Ciencias Físicas y Matemáticas, Santiago, Chile Universidad de Chile, 50p.)
- WEISCHET, W., 1963. Further observations of geologic and geomorphic changes resulting from the catastrophic earthquake of May 1960, in Chile. *Bulletin of the Seismological Society of America*, 53, 1237–1257.
- WILLIAMS, H.F.L., 1989. Foraminiferal zonation on the Fraser River delta and their application to paleoenvironmental interpretations. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 73, 39–50.
- WRIGHT, C. and MELLA, A., 1963. Modifications to the soil pattern of south-central Chile resulting from seismic and associated phenomena during the period May to August 1960. *Bulletin of the Seismological Society of America*, 53, 1367–1402.
- YOSHIKAWA, T.; KAIZUKA, S., and OTA, Y., 1981. *The Landforms of Japan*. Tokyo: University of Tokyo Press, 222p.
- ZANINETTI, L.; BRÖNNIMANN, P.; BEURLEN, G., and MOURA, J.A., 1977. La mangrove de Guaratiba et la Baie de Sepetiba, Etat de Rio de Janeiro, Brésil: Foraminifères et ecologie. *Archives des Sciences*, 30, Pt. 2, 161–178.

□ RESUMEN □

Ensamblajes de foraminíferos de la marisma superior son distintos a los ensamblajes de las zonas florales de la marisma inferior, de la ciénaga, y del terreno supramareal a lo largo de dos transectos en las marismas mareales modernas en el estuario de Valdivia en Chile Sur Central. Ensamblajes de la marisma superior, trazadas usando las comunidades de plantas vasculares, consisten mayormente de *Trochammina salsa*. Las concentraciones de foraminíferos en estos ensamblajes son más altas que las concentraciones en muestras de las zonas intermareales inferiores. Pero los ensamblajes fósiles en un testigo que registra la subsidencia repentina del estuario de Valdivia durante el gran terremoto de 1960 no pueden ser usados para estimar la magnitud de la repentina elevación del nivel del mar durante el terremoto porque el testigo contiene sólo ensamblajes de la marisma inferior/ciénaga, que son indistinguibles una de otra. El rango vertical de 0.5–0.8 m de la zona del ensamble de la marisma superior y los rangos indefinidos de las zonas marisma inferior/ciénaga y terreno supramareal limitan también la precisión de las estimaciones del cambio en el nivel del mar. Estimaciones más precisas de la magnitud del cambio en el nivel del terreno durante grandes terremotos anteriores en esta región requerirán identificación de zonas de ensamblajes con rangos de elevación más estrechos.

Los ensamblajes de foraminíferos de marisma superior en Valdivia difieren dramáticamente de otros ensamblajes de marismas superiores de latitudes medias de América en estar dominados por *Trochammina salsa*. Nuestro estudio de grandes poblaciones del género *Trochammina* Cushman y Brönnimann encontrados a lo largo de los transectos indican que las dos especies de *Trochammina* que han sido descritas previamente deberían estar combinadas en una sola especie, *Trochammina salsa*.