



## MICROFAUNAL INDICATIONS OF LATE MIOCENE DEEP-WATER BASINS OFF THE CENTRAL COAST OF CHILE

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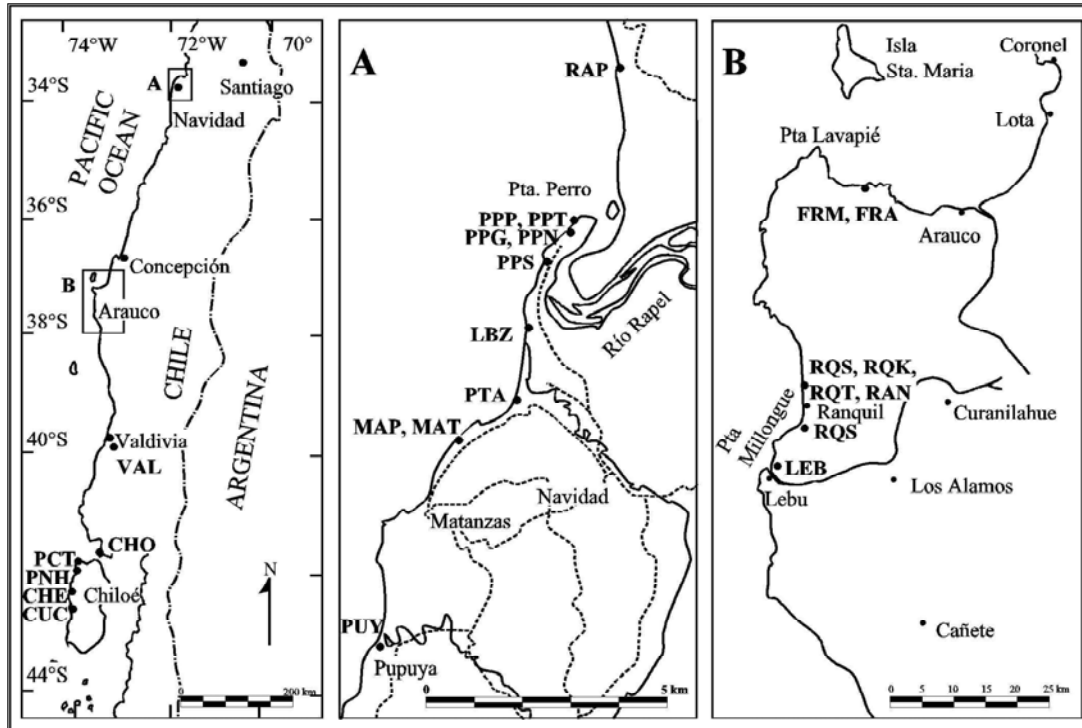
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### INTRODUCTION

Microfossils are well known tools for determining biostratigraphic ages and depositional paleoenvironments. Although numerous microplankton analyses have been performed on samples from the central coast of Chile, the regional Miocene microfauna has never been fully documented. Our study is based on 49 samples collected from 24 localities representing three units that crop out along the central coast of Chile (Figure 1): (1) the Navidad Formation in an area beginning approximately 130 km southwest of Santiago, (2) the Ranquil Formation on Peninsula Arauco, and (3) the Lacui Formation on Chiloe Island. Also included are core samples from an 83-foot interval of ENAP Navidad #5 (NAV in Figures 3 and 4). This investigation has been undertaken to answer questions paramount to other research on these units: (1) What are the ages of these exposures? (2) How correlative are they with each other? (3) What are the depositional histories and environments represented by these deposits?



**Figure 1.** Map showing localities from which micropaleontologic samples were obtained for this study (modified from Nielsen and DeVries, 2002).

## PREVIOUS WORK

Martínez and Osorio (1964) assigned the Navidad Formation at Punta Perro to the Tortonian based on its planktic foraminifers and discoasters. Correlating with Patagonian molluscan biostratigraphy, Tavera (1968) placed the Navidad Formation in the Burdigalian, which Dremel's (in Herm, 1969) study of planktic foraminifera supported. Osorio (1978) referred to the ostracodes of the Río Rapel section as upper Miocene and bathyal, but it is not clear if he based his interpretations on correlation with Caribbean ostracodes or planktic foraminifers, or both. He also noted the discrepancy between previous studies and suggested that it could be due to their sampling of disparate stratigraphic levels within the formation.

Using the cliff exposures at Punta Perro, Etchart (1973) assigned the middle Miocene strata to the La Boca Formation and the upper Miocene beds to the Navidad Formation, and divided both formations into numbered members. Most workers, however, have not recognized the La Boca Formation due to its questionable age assignment (Osorio, 1978). Tavera (1979) adopted Etchart's division of the Navidad Formation and named its members, from oldest to youngest, the Navidad, Lincancho, and Rapel.

Martínez-Pardo (1990) apparently referred to all of the Chilean marine Miocene sediments as the Navidad Formation, which he correlated with the lower of two transgressive sequences that he recognized in Chile and Peru. He referred to this event as Neogene South East Pacific Sequence I (NSEPS-I), bounded by stratigraphically adjacent

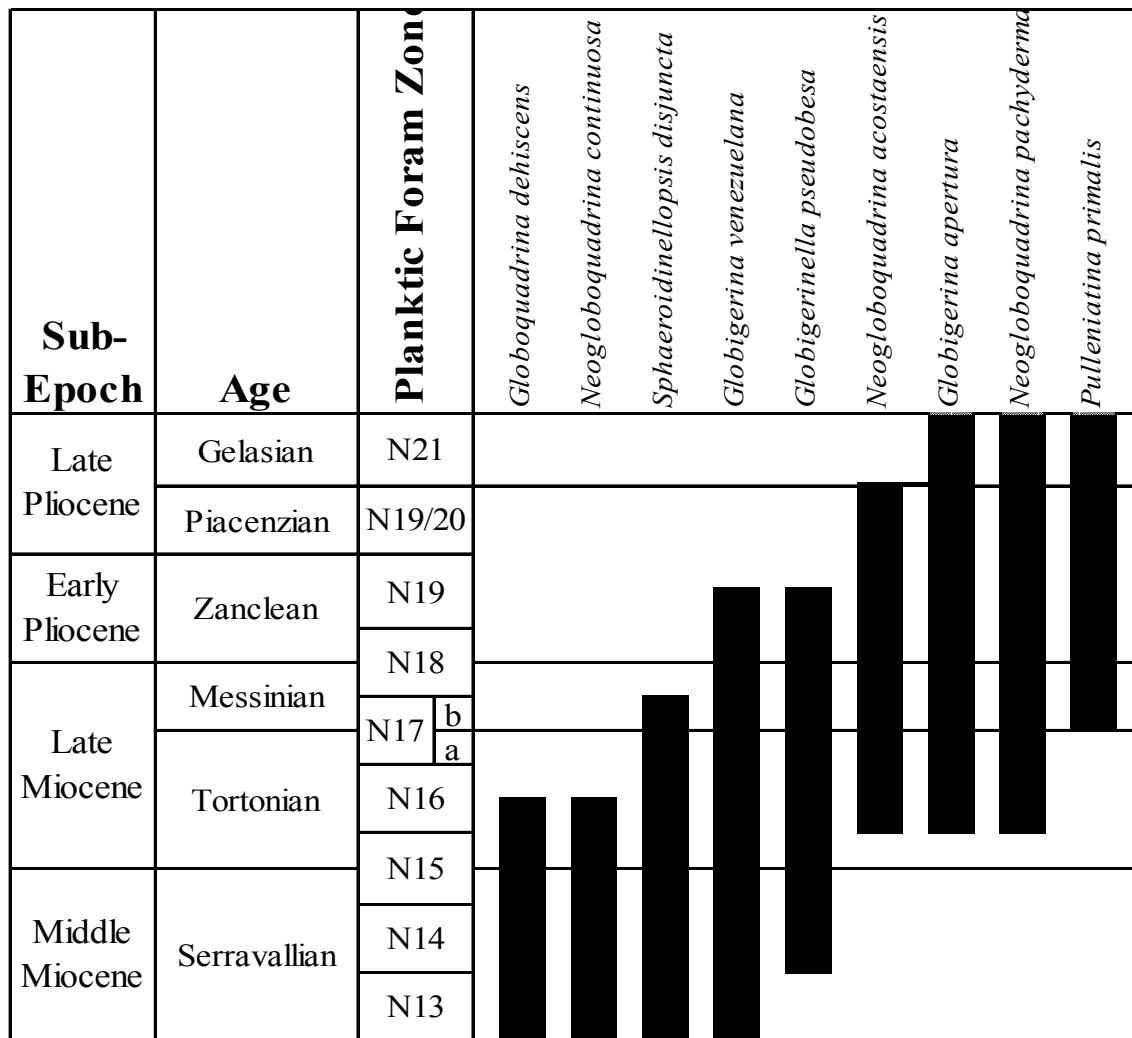
hiatuses below and above. NSEPS-I consists of a lower subcycle extending from 19 Ma (Burdigalian) to 13 Ma (Serravallian) with maximum transgression at 14 Ma (Serravallian), and an upper subcycle extending from 13 Ma to 10 Ma (Tortonian) with maximum transgression at approximately 11 Ma. It has been difficult for subsequent workers to incorporate these interpretations into their research because the locality data and detailed paleontologic evidence they are based were not presented.

Upon examining planktic foraminifers from the Punta Perro section, Ibaraki (1992) recorded the presence of *Neogloboquadrina acostaensis*, which has its first appearance datum in Zone N16, adding credence to the Tortonian age assigned by Martínez and Osorio (1964). Subsequent palynologic analysis of the basal member of the Navidad Formation (Meón et al., 1994) resulted in correlation with the late early to late Miocene, which neither refined nor disputed the Tortonian assignment. Nonetheless, correlations recently based on shark teeth (Suárez and Encinas, 2002; Encinas and Suárez, 2002.) and Peruvian molluscan biostratigraphy (DeVries and Nielsen, this Congress; DeVries & Frassinetti 2003) suggest that the deposits are upper Oligocene or early Miocene.

## **BIOSTRATIGRAPHY**

Many of the assemblages that we examined, particularly those that are relatively well-preserved, include species of planktic foraminifera that have late Miocene datums. For most of the sections studied, the concurrent range of the planktic indices identified in this study is delineated within planktic foram Zone N16 at approximately 10-11 Ma by the overlapping FADs (first appearance datums) of *Globigerina apertura*, *Neogloboquadrina acostaensis*, and *Ngq. pachyderma* with the LADs (last appearance datums) of *Globoquadrina dehiscens* and *Ngq. continuosa* (Figures 2-4). Transitional forms representing the *Ngq. continuosa-pachyderma* lineage affirm the N16 assignment, which supports the Tortonian age assigned to the Navidad Formation by Martínez and Osorio (1964) and Ibaraki (1992). However, the results provided by Martínez and Osorio (1964) also suggest that the Navidad Formation ranges younger, as they identified *Candeina nitida* (N17b FAD, Messinian) and *Globorotalia miocenica* (N19/20 FAD, Piacenzian) in their material. The only samples in our study that appear to range into the Messinian are those of the Ranquil Formation at Punta el Fraille (FRA-II) and the Lacui Formation at Chiloe (CUC), both of which yielded *Pulleniatina primalis* (N17b FAD).

Approximately 100 ostracode species have been identified in this study. The vast majority are endemic to the Miocene of the southeast Pacific, although some also occur in the Caribbean and southwest Atlantic. Among the fauna are species originally described from the Miocene and lower Pliocene of Trinidad, Miocene of Brazil, and upper Oligocene and lower Miocene of Argentina and Tierra del Fuego.



**Figure 2.** Biostratigraphic ranges of diagnostic planktic foraminifera encountered in this study. Note that all of these species occur within the late Miocene interval of N16-N17 (approximately 10-6 Ma). (Based on Kennett and Srinivasan, 1983; Bolli and Saunders, 1985; and Berggren et al., 1995)

### DEPOSITIONAL PALEOENVIRONMENT

All of the samples examined in this study yielded mixed-depth assemblages of benthic foraminifers and ostracodes, indicating the prevalence of downslope transport. This phenomenon is not surprising, as gravity-driven debris flows triggered by seismic events characterize sedimentation along active tectonic margins. The upper-depth limits of several benthic foraminifers in the Chilean Miocene (Table 1) are based on the distributions of similar taxa currently living along the Pacific margin of central South America (Bandy and Rodolfo, 1964;

Planktic Foram Markers	Ranquil Fm.					Navidad Fm.						Lacui Fm.			
	FRA	FRM	LEB	RAN	RQT	LBZ	MAT	NAV	PPN	PPP	RAP	CHO	CUC	PCB	PNH
<i>Globigerina apertura</i>	X							X	X	X		X			
<i>Globigerina venezuelana</i>		X						X	X	X	X				
<i>Globigerinella pseudobesa</i>	X		X	X	X			X	X	X	X	X		X	
<i>Globoquadrina dehiscens</i>	X			X	X	X	X	X			X	X			
<i>Ngq. acostaensis</i>	X							X				X		X	
<i>Ngq. continuosa</i>								X				X		X	
<i>Ngq. pachyderma</i>								X							
<i>Pulleniatina primalis</i>	X												X		
<i>Ss. disjuncta</i>							X	X		X					

**Figure 3.** Recorded occurrences of key planktic foraminifera at sections examined in this study.

Age	Planktic Foram Zone	Ranquil Fm					Navidad Fm						Lacui Fm			
		FRA	FRM	LEB	RAN	RQT	LBZ	MAT	NAV	PPN	PPP	RAP	CHO	CUC	PCB	PNH
Placenzian	N19/20															
Zanclean	N19															
	N18															
Messinian	N17a	b	II													
		a														
Tortonian	N16	I														
Serravallian	N15															
	N14															
	N13															

**Figure 4.** The age interval for each section investigated in this study, as determined from the concurrent ranges of their planktic foraminifera (Figure 3). Note that most of the intervals shown

have only the lower part of Zone N16 in common (darker shading), and several are restricted to it. FRA I and II are stratigraphically distinct samples. PNH did not yield any planktic foraminifera.

**Table 1.** Upper-depth limits of selected benthic foraminifera in the late Miocene of Chile.

<u>Shelf Edge</u> <i>Hoeglundina elegans</i>	<u>Upper Middle Bathyal</u> <i>Ammodiscus incertus</i> <i>Cibicidoides wuellerstorfi</i>	<u>Lower Middle Bathyal</u> <i>Pleurostomella elliptica</i> <i>Sphaeroidina bulloides</i>
<u>Upper Bathyal</u> <i>Bulimina striata mexicana</i> <i>Chilostomella ovoidea</i> <i>Hanzawaia concentrica</i> <i>Martinottiella communis</i> <i>Oridorsalis tener</i> <i>Pullenia bulloides</i> <i>Rectuvigerina transversa</i>	<i>Cyclammina bradyi</i> <i>Ehrenbergina fyfei</i> <i>Gyroidina lamarckiana</i> <i>Gyroidina neosoldanii</i> <i>Laticarinina pauperata</i> <i>Melonis barleeanus</i> <i>Neouvigerina hispida</i> <i>Pyrgo depressa</i> <i>Pyrgo murrhina</i>	<u>Lower Bathyal</u> <i>Bathysiphon filiformis</i> <i>Melonis pompilioides</i> <i>Osangularia bengalensis</i> <i>Siphonodosaria advena</i>

Resig, 1981). Among the lower middle bathyal and lower bathyal indicators in the Chilean Miocene are species of *Bathysiphon*, *Melonis*, *Osangularia*, *Pleurostomella*, *Siphonodosaria*, and *Sphaeroidina* that are similar to those van Morkhoven et al. (1986) classified as cosmopolitan deep-water taxa.

As with the foraminifera, many of the Chilean Miocene ostracodes are extant in the southeast Pacific, southwest Atlantic, Caribbean, and Southern Ocean and their modern depth distributions also suggest that our Miocene assemblages are mixed depth associations resulting from downslope displacement.

Planktic foraminifera of the genera *Marginotruncana* (Late Cretaceous LAD) and *Catapsydrax* (early Miocene LAD) in a few of our samples indicate reworking of notably older sediments. Ostracode species originally described from pre-Tortonian deposits elsewhere and recognized in our samples from the Lacui Formation may also be the result of this phenomenon. Reworking is also evident in the assemblage reported by Martínez and Osorio (1964), which included *Discoaster deflandrei* and *D. musicus*, both of which have Serravallian LADs (Perch-Nielsen 1985), as well as *Catapsydrax*.

The tectonic borderland of central Chile during the late Miocene appears to have been a series of deep basins that intermittently accumulated sediments displaced from shallower depths. Encinas et al. (in press and this Congress) have recognized sedimentary features in the Navidad Formation such as Bouma sequences, slides, slumps, sedimentary breccia and massive sandstones with load structures, water escape structures, sheared mud flames and basal rip-up mudclasts. These reveal that gravity driven flows, such as turbidity currents, sandy debris flows, debris flows, slides, and slumps, were primary modes of sediment transport and deposition off the coast of central Chile during the late Miocene.

## COMPARISON OF UNITS

The late Miocene assemblages of foraminifera and ostracodes of central Chile have high species diversities exaggerated by bathymetric mixing. Overall, they comprise a temperate fauna that has some taxa in common with the lower latitudes of the East Pacific and Caribbean, as well others that range into the Southern Ocean. Of approximately 200 benthic foraminiferal species identified in this study, only 5% occur in all three formations. The Navidad and Ranquil Formations have about 21% of their species in common, whereas their commonalities with the Lacui Formation are about 13%. If the rarer species are excluded from these calculations, the faunal dissimilarities between the units become comparatively small. The ostracode distributions among these three units have similar commonalities. Thus, we suggest that these three geographically distinct formations are probably within the same faunal province.

## CONCLUSIONS

This microfaunal study reveals that the Navidad, Ranquil, and Lacui Formations along the central coast of Chile are late Miocene, deep-water (>1500 m) deposits that include coeval sediments derived from shallower depths and, in some cases, reworked sediments from significantly older deposits. This interpretation fits well with the late Miocene scenario of a series of deep coastal basins along this tectonic margin. Interpretations of the regional geology should be revised accordingly.

## ACKNOWLEDGEMENTS

K. Finger gratefully acknowledges the University of California Museum of Paleontology for supporting his research and enabling him to present this paper at the Congress. A. Encinas was supported by Proyecto Fondecyt 1010691, Programa MECE Educación Superior UCH0010, Beca PG/50/02 of the Departamento de Postgrado y Postítulo-Universidad de Chile. S. Nielsen gratefully acknowledges funding by the University of Hamburg and Deutsche Forschungsgemeinschaft (DFG) grant Ba 675/25. Special thanks go to Klaus Bandel (University of Hamburg) for field support, general assistance, and enlightening discussions. We also thank archivo técnico de la ENAP for permission to publish our data on their Navidad #5 core samples.

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