Responses of planktonic foraminifera to the emergence of the Isthmus of Panama

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ABSTRACT

Pliocene-Pleistocene planktonic foraminiferal assemblages of the Esmeraldas section in northwestern Ecuador and of Hole 1039B off Costa Rica are analyzed. In the Esmeraldas section, an abrupt cooling of the sea-water temperature is recognized between 3.35 and 3.95 Ma, in which Neogloboquadrina spp. and intermediate water dwellers increase in abundance. In the section off Costa Rica, the sea-water temperature declined just before 4.2 Ma, when planktonic foraminifera become absent, but increased afterwards as evidenced by abundant occurrences in Zone N22 to the Recent. These faunal changes are considered to be responses to the emergence of the Isthmus of Panama.

Keywords: Planktonic foraminifera, Ecuador, off Costa Rica, Pliocene, Pleistocene

RESUMEN

Se analizan las formaciones foraminíferas planctónicas del Plioceno-Pleistoceno que se encuentran en la región de Las Esmeraldas en el noroeste de Ecuador y en el sitio 1039B del ODP, frente a las costas de Costa Rica. En Las Esmeraldas se ha identificado un enfriamiento abrupto del agua marina entre 3.35 y 3.95 Ma, periodo en el cual hay un aumento en la abundancia de Neogloboquadrina spp. así como de organismos que viven en aguas intermedias. En la sección frente a las costas de Costa Rica, la temperatura del agua marina descendió justo antes de 4.2 Ma, desapareciendo las formaciones planctónicas foraminíferas, pero después aumentaron, como lo evidencia su abundante presencia de la zona N22 hasta el periodo Reciente. Estos cambios en la fauna se consideran respuestas a la surgencia del Istmo de Panamá.

Palabras clave: Foraminíferos planctónicos, Ecuador, costa de Costa Rica, Plioceno, Pleistoceno.

INTRODUCTION

The closing of the Central American seaway severed the communication between the equatorial Pacific and Atlantic Oceans and the Caribbean Sea. An expansion of coastal upwelling in the southeast Pacific and an abrupt cooling of the surface seawater temperature along the coast of Ecuador, occurring around 3.5 Ma, are considered to be coincident with the closing of the Central American seaway (Ibaraki, 1997).

Biochronologic and quantitative analyses of planktonic foraminifera from the Esmeraldas section in northwestern Ecuador and from ODP Site 1039 off Costa Rica are examined in the sequences dated from 5 to 3 Ma (Figure 1).

Figure 1. Location of the Hole 1039B off Costa Rica and the Esmeraldas section of Ecuador.

METHODS

Analyses of planktonic foraminifera presented here have been made in rock samples from the Esmeraldas area of northwestern Ecuador and in core samples of Site 1039 off Costa Rica. Rock samples for planktonic foraminifera analysis were obtained in 1986, 1993 and 1996 from selected Neogene sequences. Dried rock samples of 100g each were crushed and treated by the naphtha and Glauber's salt methods. Core samples of Site 1039 used sequences of 10 cm^3 and all core-catcher samples. Samples were washed through a 250-mesh screen and dried in an oven. Planktonic foraminiferal specimens larger than 0.125 mm in size were selected from washed residue, and all the specimens were picked up. The biostratigraphic zonation of planktonic foraminifera is that of Blow (1969), and chronologic calibrations of Blow's zones are based on those given by Berggren *et al*. (1995).

PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY

Esmeraldas section in northwestern Ecuador

Neogene sequences are exposed near the mouth of the River Esmeraldas in northwestern Ecuador. The Esmeraldas section includes horizons of Zones N17 to N21 of the Pliocene based on planktonic foraminiferal analyses (Figure 2). In samples of Zone N18, *Globoquadrina baroemoenensis* and *Globoquadrina dehiscens* are present. In the samples of Zone N19 *Sphaeroidinella dehiscens* occur, and a coiling change of *Pulleniatina* is recognized. The base of Zone N21 is distinguished by the joint occurrence of *Globorotalia tosaensis* and *Globorotalia ungulata*. The coiling change in *Pulleniatina* spp. from sinistral to dextral is recognized in a horizon of Zone N19 that is dated at 3.95 Ma.

In the sequences of Zones N17 to N21, planktonic foraminifera are common and constantly found in the section (Figure 3). The ratios of *Globigerinoides sacculifer* and *Globigerinoides ruber* to the total assemblage are always below 10 percent in the section (Figure 4). The ratio of *Neogloboquadrina* spp. abruptly increases in the upper part of Zone N19. This interval is coincident with an abrupt falling in the ratio of warm-water dwellers (Figure 4). Ratios of surface water dwellers are relatively constant in the section while ratios of intermediate water dwellers fluctuate, especially increasing in abundance in the upper part of Zone N19 (Figure 5). The ratio of warm-water dwellers is about 50% which is not so a high percentage as that found in other tropical regions.

Pliocene to Pleistocene sediments in the Hole 1039B

Hole 1039B is located on the bottom of the Middle American Trench off Costa Rica. Biostratigraphical analyses by means of planktonic foraminifera were made on 148 samples from Cores 170-1039B-18X through 1H, representing about 160 meters in total thickness. The sequence includes Zones N19 through N23, Pliocene to Pleistocene in age (Figures 2 and 6). The last occurrence of *Globoturborotalita nepenthes*, which indicates an age of 4.2 Ma, is recognized in Sample

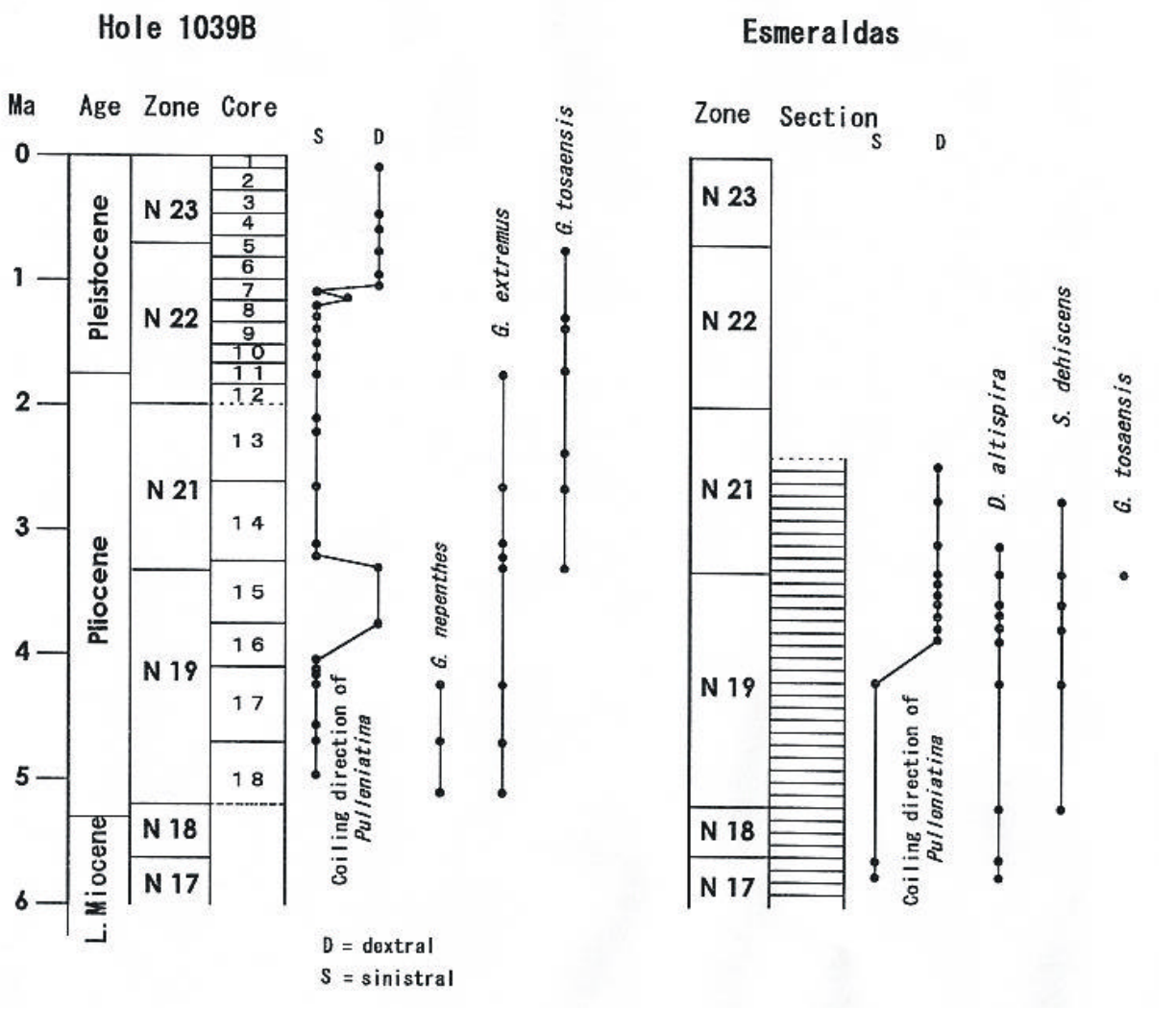

Figure 2. Biochronological correlation of Hole 1039B and the Esmeraldas section based on planktonic foraminiferal biostratigraphy and coiling directions of *Pulleniatina* population.

1039B-17X-2, 46-49 cm.

The first appearance of *Globorotalia tosaensis* is recognized in Sample 1039B-15X-1, 46-48 cm, which indicates an age of 3.5 Ma, being assignable to the base of Zone N21 of the Pliocene. The lower sequences, Cores 18X through the middle part of 15X, are therefore assignable to Zone N19 of the Pliocene. In Zone N19, occurrences of *Globoturborotalita nepenthes*, *Dentoglobigerina altispira*, *Globorotalia margaritae*, and *Sphaeroidinellopsis seminulina* are recorded. The top of Zone N21 can not be established, and the horizon is tentatively placed in the base of Core 11X. The last occurrence of *Globigerinoides extremus* is recognized in Sample 170-1039B-11H-5, 46-49 cm, indicating that the sample is approximately correlative with the Pliocene / Pleistocene boundary (1.77 Ma). The last occurrence of *Globorotalia tosaensis* is also recognized in Sample 170-1039B-5H-7, 45-47 cm, which indicates an age of 0.65 Ma, correlating with the base of Zone N23. Changes in the coiling direction of *Pulleniatina* spp. are recognized at three intervals. The coiling change from sinistral to dextral, between Sample 170-1039 B-16 X-4, 46-49 cm, and 15X-4, 46-48 cm, is estimated at 3.95 Ma (Figure 2).

Planktonic foraminifera are barren or rare in Zones N19 and N21. However, in Zone N22 through the early half of Zone N23, planktonic foraminifera are continuously and commonly found in most samples (Figure 6). Planktonic foraminiferal assemblages consist of abundant warm-water taxa. The ratio of warm-water planktonic foraminifera gradually decreases to the upper sections, from Zone N19 to Zone N23, although, a horizon of a temporal decrease is recognized in an early part of Zone N19 (Figures 7and 9). It is suggested that the surface seawater temperature abruptly drops at this horizon. Ratios of surface and intermediate water dwellers

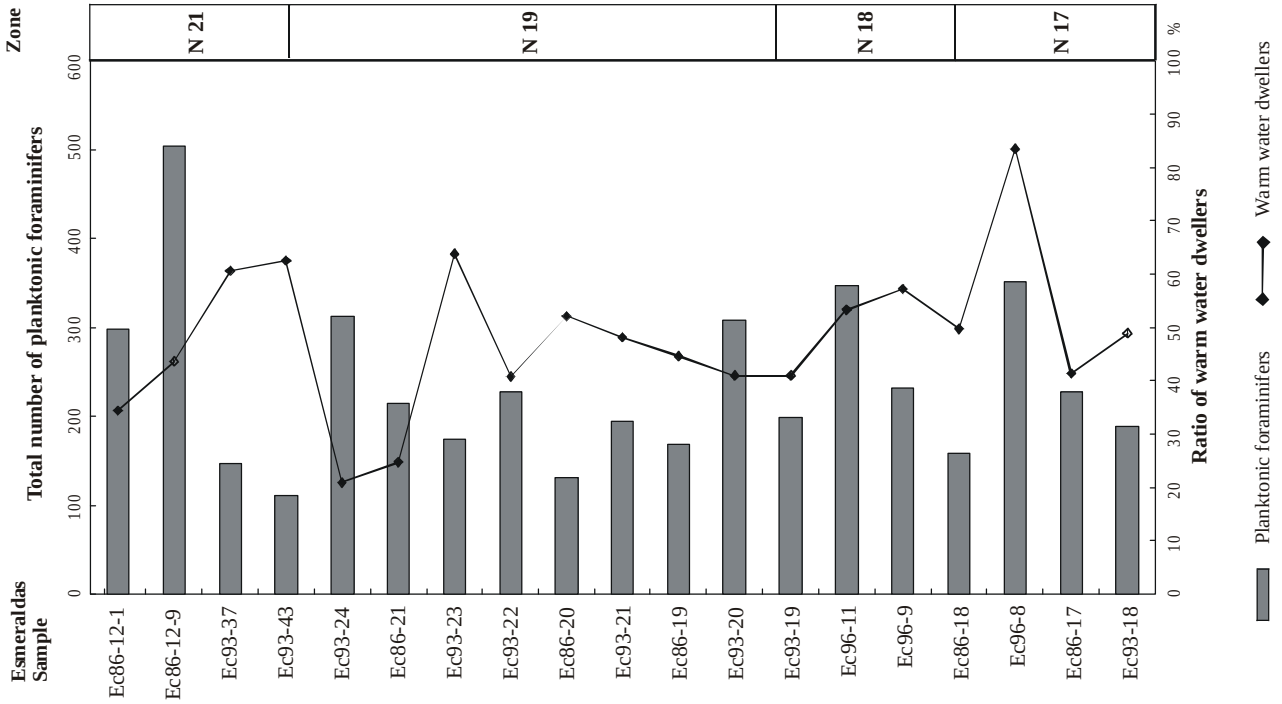

Figure 3. Total number of planktonic foraminifera and ratio of warm-water dwellers to the total assemblage in the Esmeraldas section.

are nearly the same in Zones N19 and N21 (Figure 8). The maximum divergence between surface and intermediate water dwellers begins in early Zone N22 and continues up to the Recent. *Globigerinoides ruber* and *Globigerinoides sacculifer* are high salinity tolerant species. No *Globigerinoides ruber* was found in sequences of Zone N19. The ratio of *Globigerinoides sacculifer*, except in some samples, remains under 10% throughout the cores (Figure 7). In Zone N19, it is considered that surface sea warm water current off Costa Rica was weak.

PALEOCEANOGRAPHIC EVENTS

The biochronologic analyses of planktonic foraminifera indicate that both the Esmeraldas section in northwestern Ecuador and the ODP Site 1039 off Costa Rica include sequences of the Pliocene-Pleistocene, 5-3 Ma in age (Figure 9).

The final closing of the Central American seaway is estimated to have occurred at *ca*. 4.4-3 Ma in the Pliocene, separating the equatorial Pacific and Atlantic Oceans and the Caribbean Sea (*e.g.* Saito, 1976; Keigwin, 1978, 1982; Coates, *et al.*, 1992). Changes in the composition of planktonic foraminiferal assemblages occurring in the stratigraphic interval, and associated with the closing of the Central American seaway have been reported from the Caribbean Sea and the Atlantic Ocean. An increase of the surface seawater salinity, an increase of *Globigerinoides sacculifer*, and a temporary disappearance of *Pulleniatina* spp. in the Atlantic Ocean have been associated to the closing of the Central American seaway (Keigwin, 1982, Keller *et al.*, 1989). In sections of the Esmeraldas and Hole 1039 off Costa Rica, some planktonic foraminiferal events occur in association with the closure of the Central American seaway.

In the Esmeraldas section of Ecuador, the ratio of tropical-subtropical dwellers to the total assemblage abruptly decreases in the interval of 3.35-3.95 Ma (Figure 9), while in the Hole 1039B, a similar change occurred in a horizon a little older than 4.2 Ma. In the Esmeraldas section, decreases of warm-water dwellers are coincident with increases of intermediate water dwellers and *Neogloboquadrina* spp. *Neogloboquadrina dutertrei* is known to occur in upwelling regions (Be, 1977) and in areas adjacent to upwelling centers (Ibaraki, 1992). The abrupt appearance of *Neogloboquadrina* spp. in the Esmeraldas section is therefore interpreted as evidence of an increased coastal upwelling in this region. The associated decrease in seawater temperature, abundant occurrences of *Neogloboquadrina* spp., and intermediate water dwellers in the upper part of Zone N19 are considered to be due to an increased coastal upwelling in this region. These events are coincident with the effective closing of the Central American seaway in the later part of Zone N19 (3.95-3.35 Ma).

In the Late Miocene, some straits of the Central American seaway seem to have existed besides the main

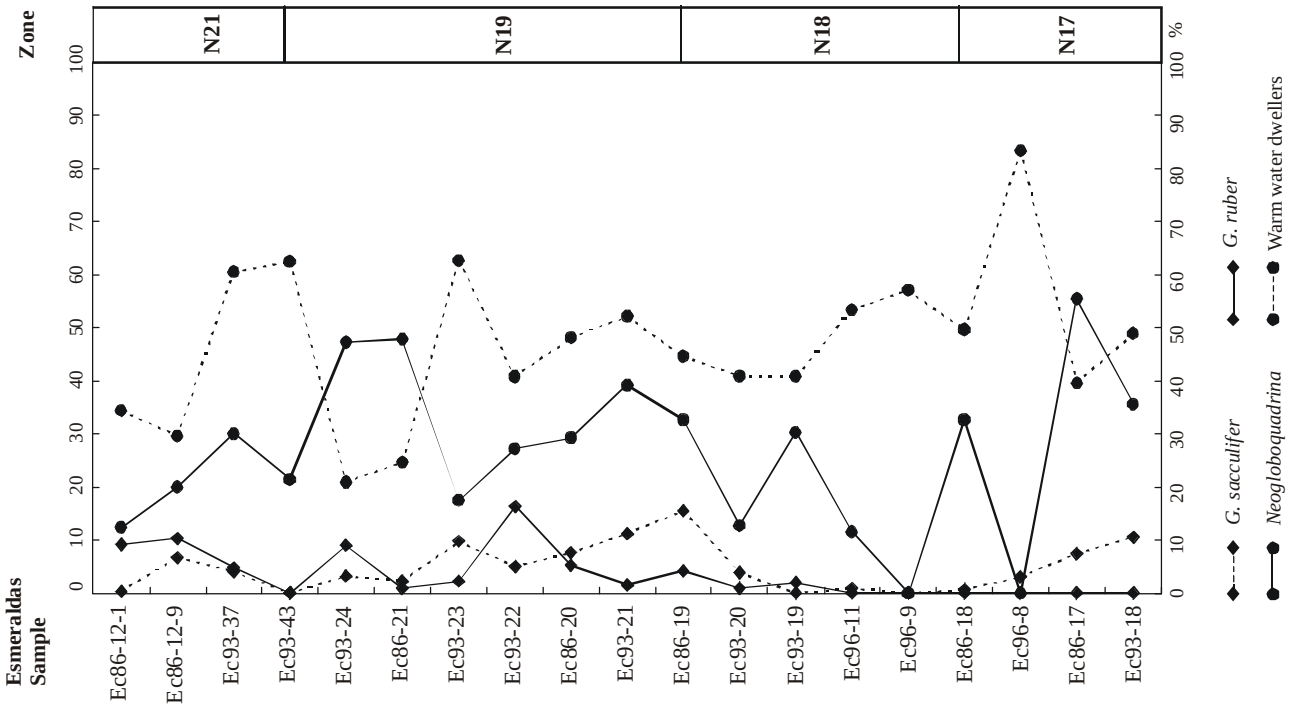

Figure 4. Ratio of warm-water dwellers to the total assemblage and those of *Globigerinoides sacculifer*, *Globigerinoides ruber* and *Neogloboquadrina* spp. in the Esmeraldas section.

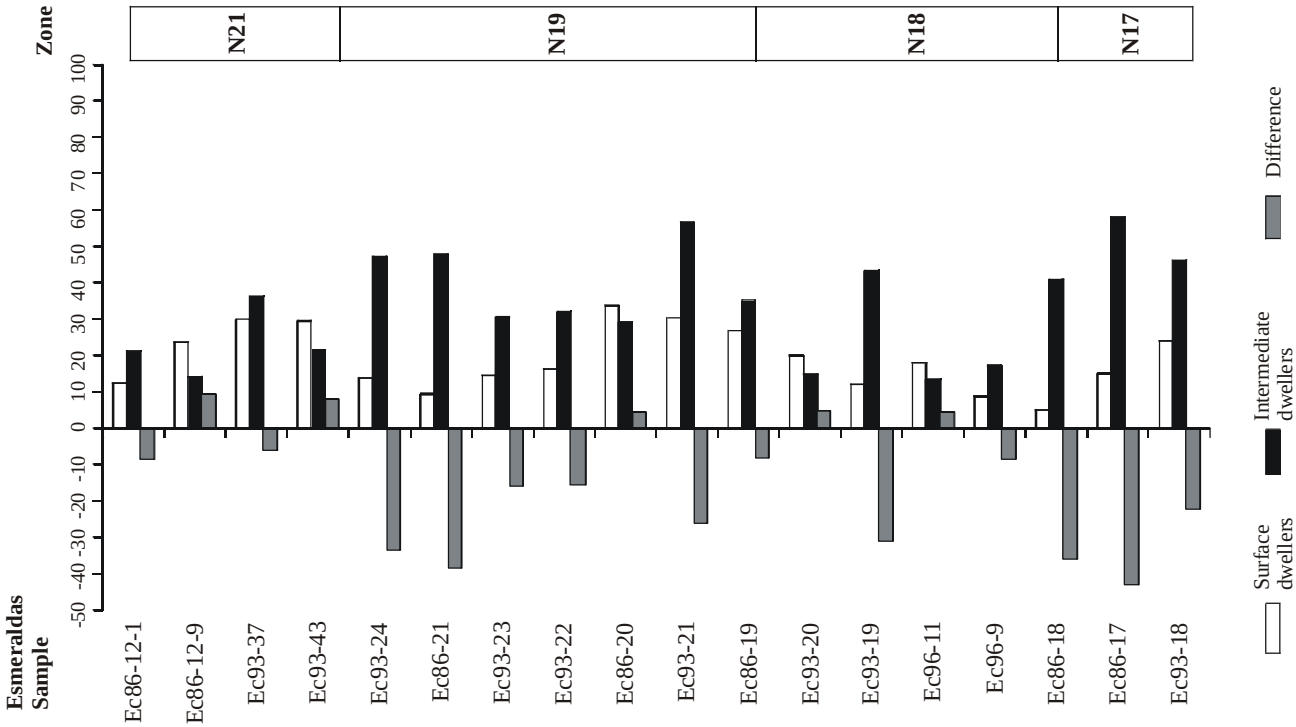

Figure 5. Ratios of surface and intermediate water dwellers and difference of surface and intermediate dwellers to the total assemblage in the Esmeraldas section.

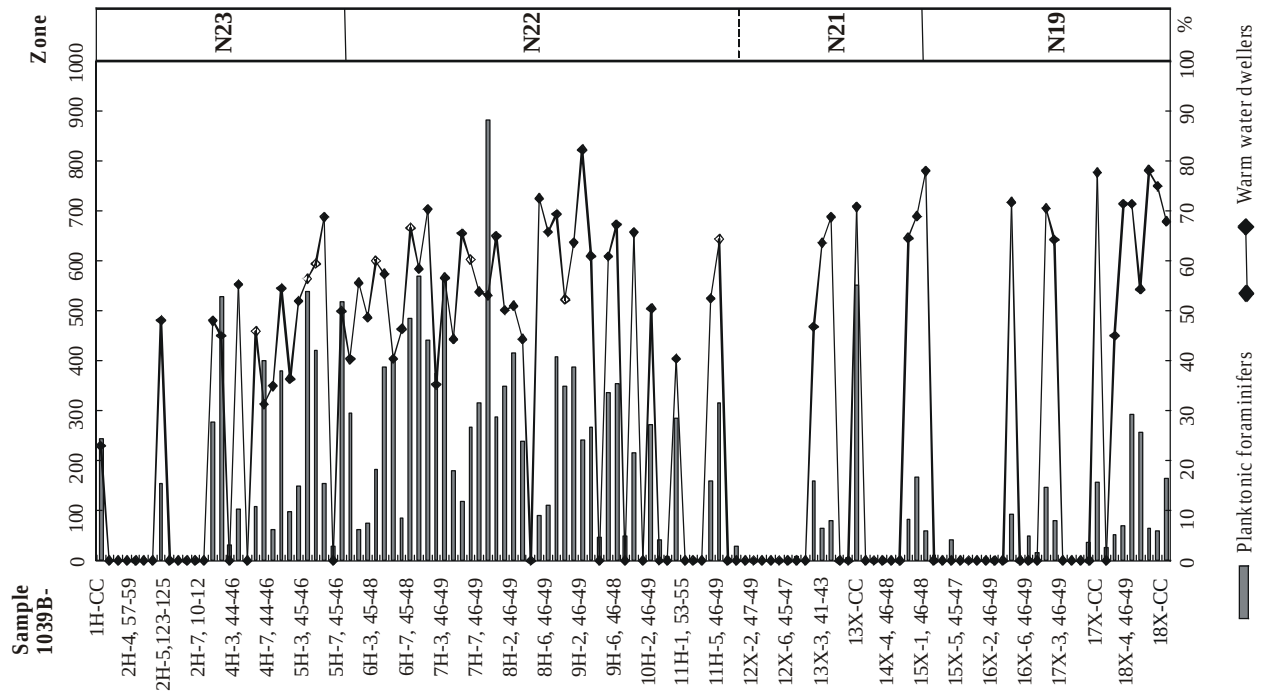

Figure 6. Total number of planktonic foraminifera and the ratio of warm-water dwellers to the total assemblage in Hole 1039B-18X though 1H.

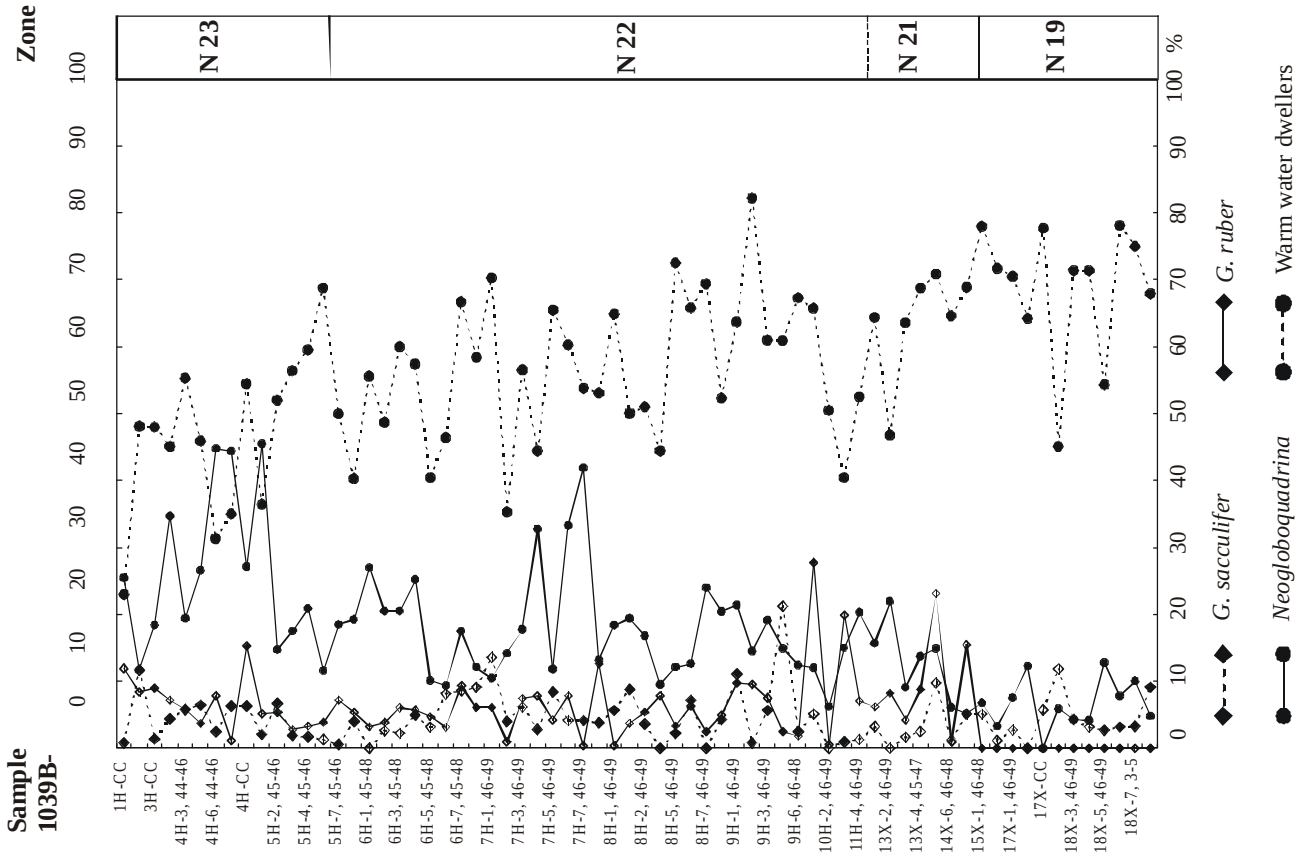

Figure 7. The ratio of warm-water dwellers to the total assemblage and those of *Globigerinoides sacculifer*, *Globigerinoides ruber*, and *Neogloboquadrina* spp. in Hole 1039B-18X through 1H.

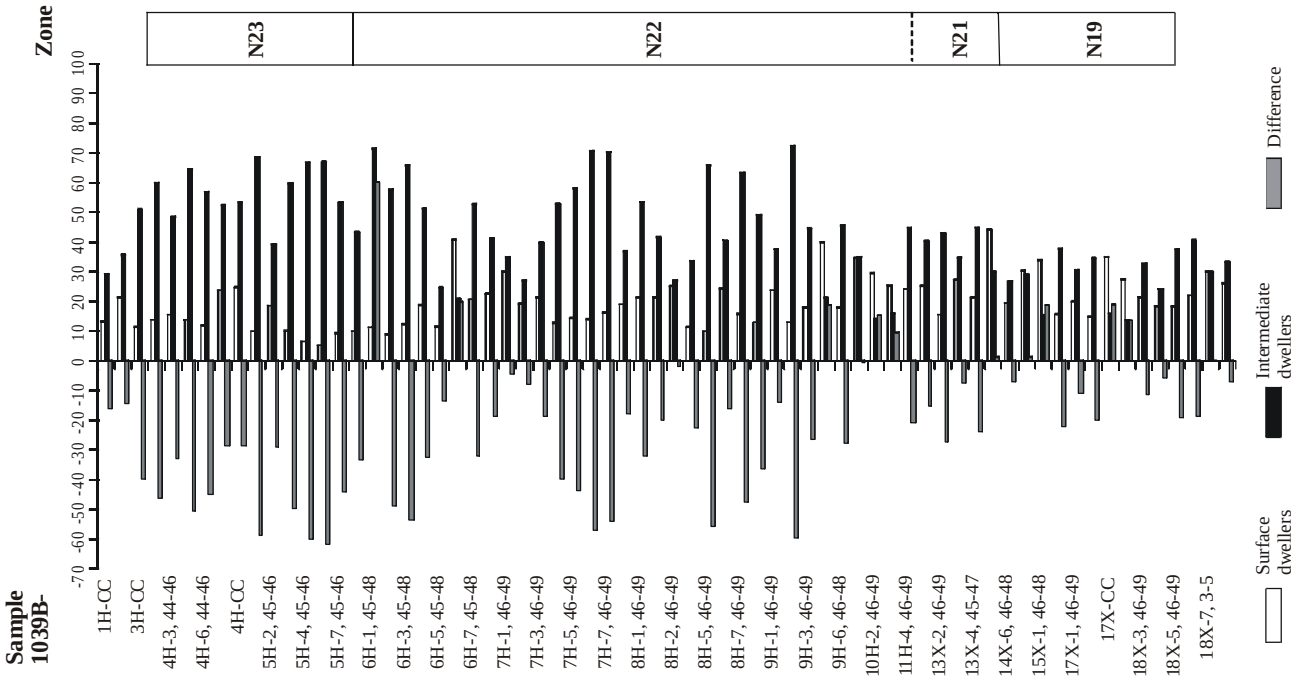

Figure 8. Ratios of surface and intermediate water dwellers and difference of surface and intermediate water dwellers to the total assemblage in the Hole 1039B-18X through 1H.

seaway (Collins *et al*., 1996). In the samples off Costa Rica, a cooling episode occurs short before 4.2Ma. This cooling episode is considered to be in association with the closure of a strait in the north side of Costa Rica. In this horizon, changes in planktonic foraminiferal components are least recognized. After this cooling event, the frequency of occurrence of planktonic foraminifera becomes barren or rare. This interval of Zone N19 is dated at about 3.95 to 3.35 Ma. The event is consistent with the cooling event of Ecuador and seems to be coincident with the effective closing of the Central American seaway.

A step-like increase in the abundance of intermediate water dwellers relative to surface water dwellers begins at the early part of Zone N22, assignable to *ca*. 2 Ma. Keller *et al.* (1989) reported that the maximum divergence of surface and intermediate water dwellers both in the eastern Pacific and the Caribbean began at 1.9 Ma and continue up to the present. The results off Costa Rica are consistent with those of the eastern Pacific and the Caribbean. Thus, it is suggested that the Central American seaway finally closed at about 2 Ma.

The closure of Central American seaway would change the oceanographic conditions of the coastal side of Ecuador. The relative abundance of tropical-subtropical planktonic foraminifera abruptly decreases in the upper part of Zone N19 (*ca*. 3.95-3.35 Ma) along the Pacific Coast of northwestern Ecuador. These data indicate an abrupt decline in surface seawater temperatures at that time. The abrupt decreases in surface seawater temperatures and the abundant occurrence of intermediate water dwellers and *Neogloboquadrina* spp. in the interval suggest that an increased coastal upwelling commenced in the coastal area of Ecuador.

Globigerinoides sacculifer and *Globigerinoides ruber* are high salinity tolerant species. In the Caribbean Sea both the species become abundant at about 4.6 Ma (Keller, 1989), probably coincident with one of the closures of the Central American seaway. In sections of the Esmeraldas and Hole 1039B, *Globigerinoides sacculifer* and *Globigerinoides ruber* are rarely found in Zone N19. This fact suggests differences in the surface seawater conditions between the Pacific and the Caribbean side.

CONCLUSIONS

Planktonic foraminiferal faunal changes examined in sections of Ecuador and off Costa Rica are recognized prior to 4.2 Ma, between 3.95-3.35 Ma , and at *ca.* 2 Ma. These changes occur in association with the gradual closing of Central American seaway.

The first cooling episode is dated a little older than 4.2 Ma off Costa Rica and it would be associated with the closure of a north side gate-way across Costa Rica. A prominent faunal change marks the second cooling event. In the Pacific coastal side of Ecuador, the surface seawater temperature abruptly declined, and in areas off

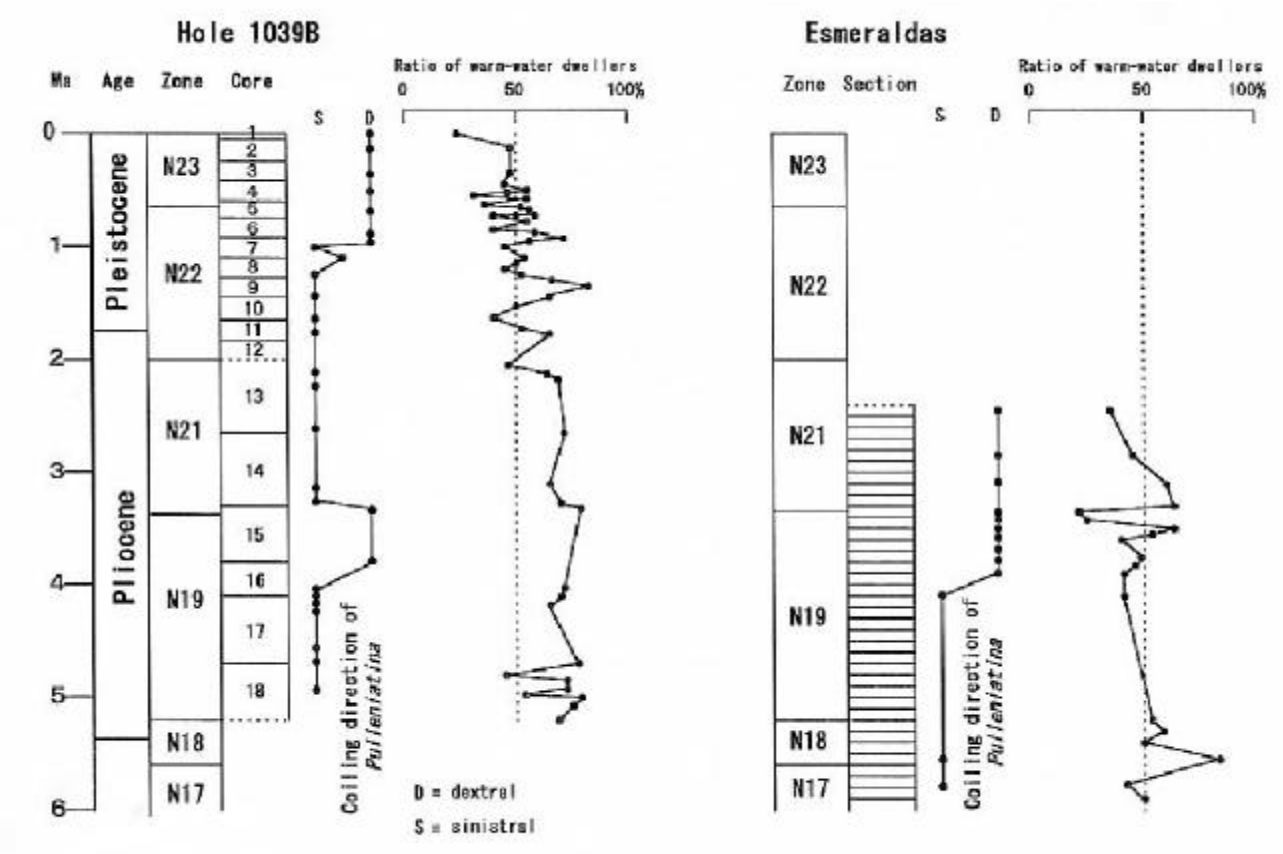

Figure 9. Coiling changes (sinistral or dextral) in *Pulleniatina* and ratios of warm-water dwellers to the total planktonic foraminiferal assemblages in Hole 1039B-18X through 1H and the Esmeraldas section.

Costa Rica planktonic foraminifera became barren. This event occurred at 3.95-3.35 Ma in relation to the main closing event. The maximum divergence of both intermediate and surface water dwellers begins at about 2 Ma in relation to the final closure of the Central American seaway and continues up to the Recent.

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