# Neogene evolution of surface marine climate in the Pacific and notes on related events

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**ABSTRACT**

*Pacific Neogene events related to the evolution of the Neogene surface marine climate on the Pacific coast of central Japan and on the Pacific coast of central and northern South America are reviewed from a standpoint of future studies. The evolution of surface marine climate is presented here by utilizing variations in the ratio of warm water planktonic foraminifera to the total assemblage in respective horizons of reference sections. During the Neogene, three warm episodes in Japan at about 15.5 Ma, 5.7 Ma, and 3 Ma, and three warm episodes in South America at about 15.5 Ma, 11.5 Ma, and 5.7 Ma, respectively, are recognized. In addition, a prolonged cool episode is noticed in about 15-12 Ma on both sides of the Pacific Ocean. Revised chronological calibrations are made on accelerated lineage biotic evolutions in accordance with a stepwise decline of surface sea-water temperature that occurred during the latest Neogene in central Japan and northern Chile, both in middle latitudes.*

*Keywords: Neogene, marine climate, Pacific Ocean gateways, accelerated evolution.*

**RESUMEN**

*Se revisan los eventos del Neógeno en el Pacífico relacionados con la evolución del clima de la superficie marina en la costa del Pacífico del centro de Japón y en la costa del Pacífico de Centroamérica y del norte de Sudamérica desde un punto de vista de estudios futuros. Se presenta aquí la evolución del clima de la superficie marina utilizando variaciones en la proporción de los foraminíferos planctónicos de aguas cálidas con respecto al conjunto total en los horizontes respectivos de secciones de referencia. Se reconocen durante el Neógeno tres episodios cálidos en Japón a aprox. 15.5 Ma, 5.7 Ma y 3 Ma, y tres episodios cálidos en Sudamérica a aprox.15.5 Ma, 11.5 Ma y 5.7 Ma. Además, se registra un prolongado episodio frío a aprox. 15-12 Ma en ambos lados del Pacífico. Se hacen calibraciones cronológicas revisadas sobre evoluciones bióticas de linaje acelerado de acuerdo con una disminución gradual de la temperatura de la superficie marina que ocurrió durante el Neógeno más tardío en la región central de Japón y el norte de Chile, ambas en latitudes medias.*

*Palabras clave: Neógeno, clima marino, Océano Pacífico, evolución acelerada.*

## INTRODUCTION

The recent progress in studies on Neogene bio- and chronostratigraphy enables us to examine the evolution of surface marine climate on both sides of the Pacific Ocean by utilizing faunal changes in reference sections in Japan and South America. The timing of closures of two major Pacific Ocean gateways, the Indonesian and Central American seaways, has been discussed with reference to climatically warm episodes which occurred as responses to these closures (Tsuchi, 1997). In this article, notes on Pacific Neogene events related to the evolution of surface marine climate are discussed in regard to future studies. In addition, revised chronologic calibrations of accelerated lineage biotic evolutions (Tsuchi, 1992a) are examined during the latest Neogene in the middle latitude areas of central Japan and northern Chile.

## NEOGENE SURFACE MARINE CLIMATE ON THE PACIFIC COAST OF SOUTH AMERICA

On the Pacific coast of South America, marine Neogene sequences have a scattered distribution. A recent bio- and chronostratigraphic correlation chart along the Pacific coast of South America is presented in Figure 1. These Neogene bio- and chrono-stratigraphic studies have been made since 1985 in collaboration with the RCPNS/IGCP national working groups of Colombia, Ecuador, Peru and Chile, and the Andean studies group of Shizuoka University, Japan (Tsuchi, 1992b, 1997). The correlation and age-assignments of sequences have mainly been made by means of planktonic foraminifera and calcareous nannoplankton, and additionally by diatoms. Neogene variations in the ratio of warm water planktonic foraminifera to the total planktonic foraminiferal assemblage on the Pacific coast of central and northern South America are shown in Figure 2. The figure is based on data mainly from the Caleta Herradula de Mejillones section (23°05’S) near Antofagasta in northern Chile, and additionally from the Camana section (16°35’S) in southern Peru and the Esmeraldas section (0°55’N) in northwestern Ecuador. The left side of the figure shows combined variations from these three sections. The ratio for the modern coastal ocean near the Esmeraldas section is also given.

## THE EVOLUTION OF SURFACE MARINE CLIMATE ON BOTH SIDES OF THE PACIFIC OCEAN

The correlation of Neogene surface marine climate interpreted from faunal trends of planktonic foraminifera in Japan and South America is shown in Figure 3. The distribution of marine Neogene sequences and locations of two reference sections in Japan are indicated in Figure 4. A schematic map of the Pacific Ocean during the early Miocene, *ca*. 17 Ma, is also given in Figure 5.

Variations in the ratio of warm water planktonic foraminifera to the total planktonic foraminiferal assemblage on the Pacific coast of Japan in the left side of the figure have been drawn on the basis of data mainly from the Kakegawa section (34°45’N) and additionally from the Tomioka section (36°15’N) in the Kanto region, both in central Japan (Figure 4). At present, along the Pacific coast of Japan, the warm Kuroshio current effectively influences southwestern Japan and the cold Oyashio current affects northeastern Japan. Similar oceanic conditions are likely to have occurred during the Neogene on the Pacific side of the Japanese Islands. Accordingly, Neogene molluscan warm water faunas of open shallow water assemblages on the Pacific coast of southwestern Japan can be clearly divided into five phases, from older to younger, (1) warm-temperate Ashiya fauna, (2) tropical Kadonosawa fauna, (3) subtropical Sagara fauna, (4) subtropical Kakegawa fauna, and (5) warm-temperate Recent Kuroshio current fauna (Figure 3). The 2nd, 3rd and 4th faunas have their acmes at about 15.5 Ma, 5.7 Ma and 3 Ma, respectively. Increased numbers of warm elements occur in each of the faunas indicating a northward migration and ages of these acmes are consistent with respective warm episodes recorded by planktonic foraminifera.

In comparison, three warm episodes in Japan at about 15.5 Ma, 5.7 Ma and 3 Ma, and three warm episodes in South America at about 15.5 Ma, 11.5 Ma and 5.7 Ma, respectively, are recognized (Figure 3). In addition, a prolonged cool episode is noticed in about 15-12 Ma on both sides of the Pacific Ocean.

In South America, the above-mentioned three Neogene warm episodes correspond, respectively, to a horizon containing rich tropical larger forminifera in the Camana section in Peru in the early Middle Miocene, Zone N8b, around 15.5 Ma, to a horizon of rich warm water planktonic foraminifera in northern Chile and of calcareous interecalations in rather biosiliceous facies in Ecuador in the latest Middle Miocene, Zone N14, at *ca*. 11.5 Ma, and to a horizon of the subtropical mollusca-bearing Navidad fauna (Covacevich and Frassinetti, 1980) in central Chile in the late Late Miocene, Zone N17b, at *ca*. 5.7 Ma.

As shown in Figure 1, the extensive development of biosiliceous facies along the coast of Peru commenced in the Middle Miocene at *ca*. 14 Ma, suggesting strong coastal upwelling during the period. Facies in Chile and Ecuador are also somewhat biosiliceous during the same period. The South American coast along the Pacific Ocean is, at the present time, strongly influenced by the cold Peru (or Humboldt) current from Chile to most of Ecuador, and is known as a typical region of coastal upwelling.

## NOTES ON RELATED PACIFIC NEOGENE EVENTS

### Events related to a warm episode around 15.5 Ma

This pronounced warm episode culminated in the early Middle Miocene, Zone N8b, around 15.5 Ma (formerly dated as 16 Ma) has been called the “mid-Neogene climatic optimum” and it seems to have a pan-Pacific scale, as expansions of diverse tropical faunas are recorded from New Zealand and South Australia from

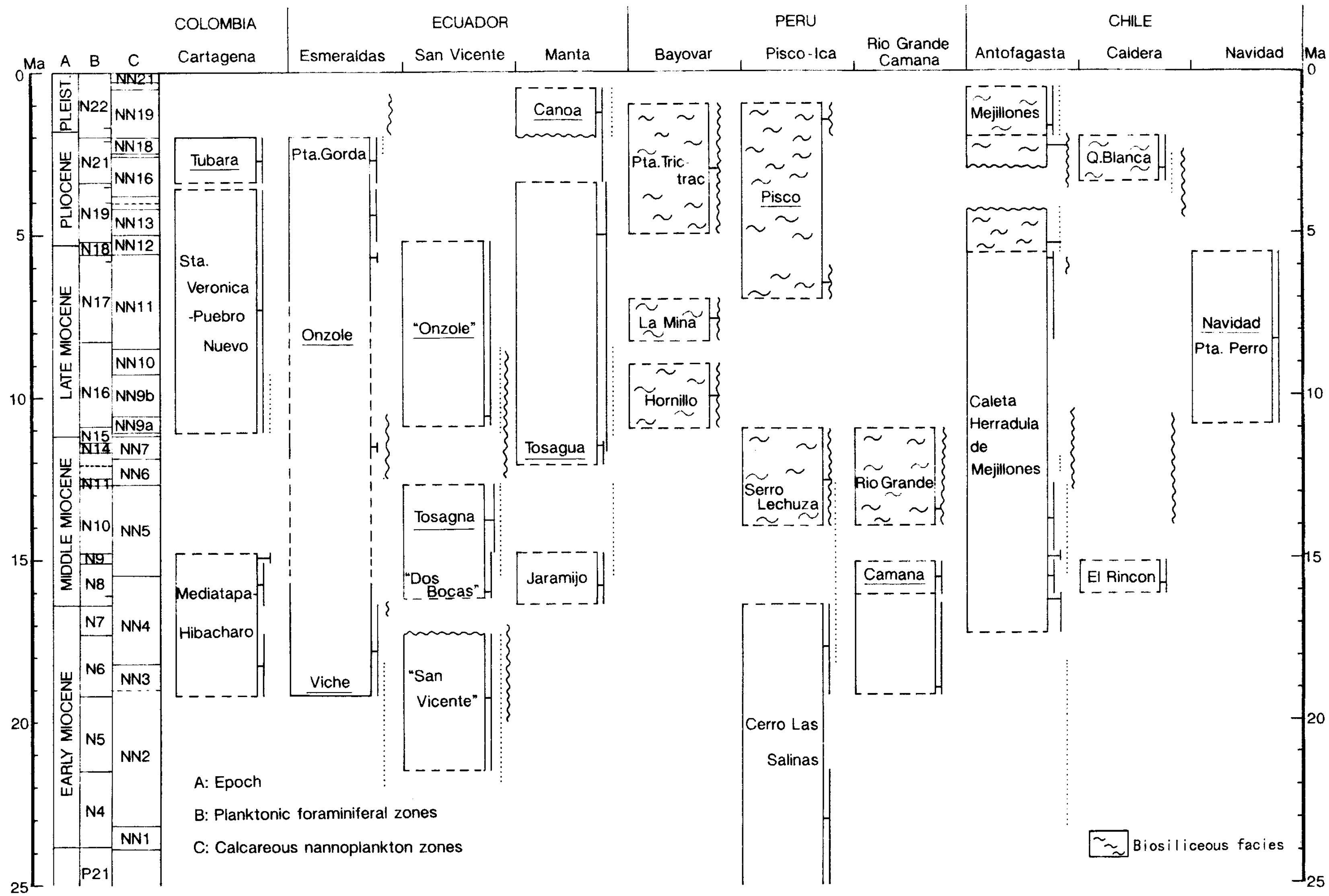


Figure 1. Biochronostratigraphic correlation of representative marine sections on the Pacific coast of South America. The Cartagena section in Colombia is on the Caribbean side, at the present time. The correlation and age assignments are made by means of planktonic foraminifera (vertical line), calcareous nannoplankton (dotted line) and diatoms (wavy line). Names of sections and formations (underlined) are in boxes. Geographic distribution of Neogene marine sequences exposed on the Pacific coast of South America is shown in Figure 2.

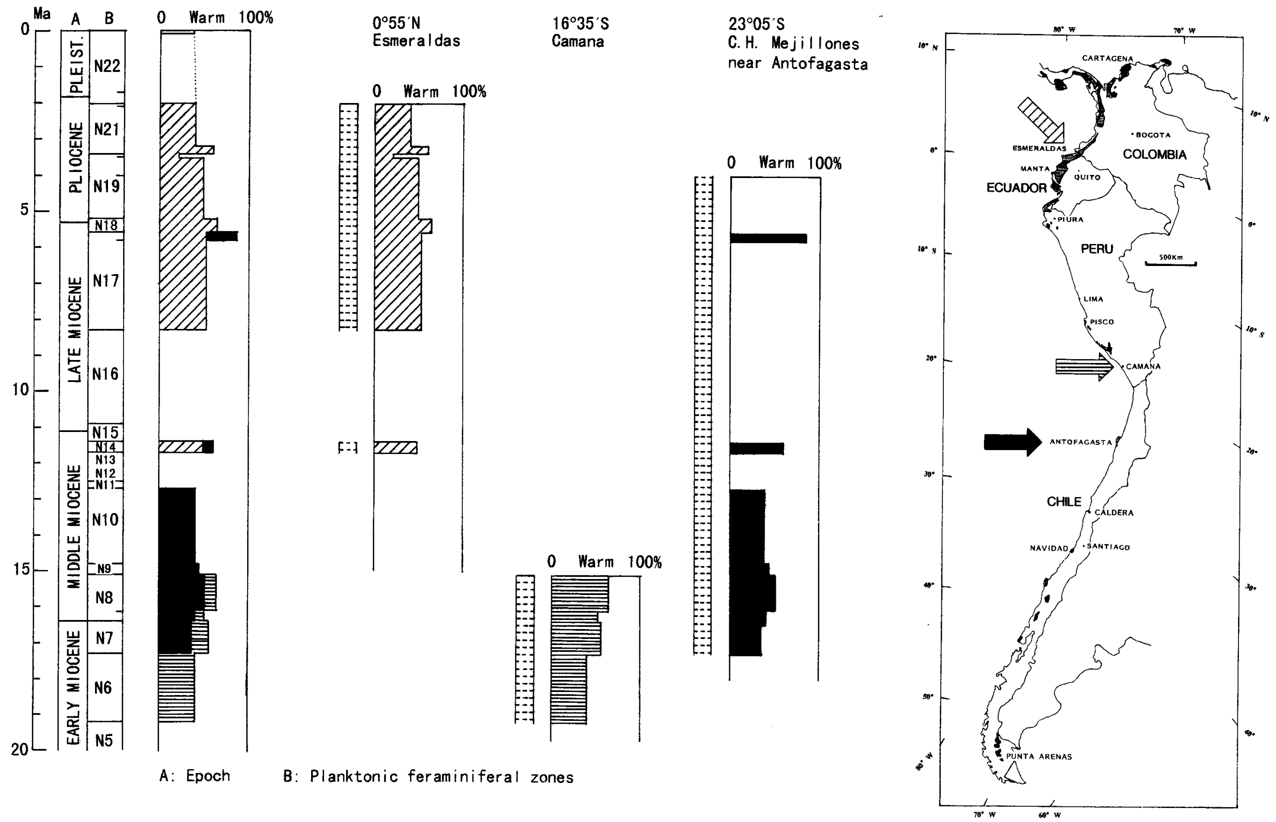


Figure 2. Variations in the ratio of warm-water planktonic forminifera to the total planktonic faunas in three Neogene reference sections along the Pacific coast of central and northern South America (based on data from Ibaraki, 1990, 1992a, b, c, 2000). The left side of the figure shows combined variations from these three sections. The ratio for the modern coastal ocean near Esmeraldas is also given. The ratio of the main section (C. H. de Mejillones, 23°05’S) is shown by black colored one and those of additional sections by banded ones. A similar figure in Tsuchi (1997) has slightly been revised on the basis of recent data. The distribution of marine Neogene sequences on the Pacific coast of South America is shown in the right side of the figure.

the same time (Tsuchi, 1992a). In Japan, during the episode, tropical molluscan faunas extended their distribution to northern Japan, and mangrove trees and reef-building corals have also been found in many areas in central Japan.

The closing of the Indonesian seaway or the Pacific-Indian Oceans gateway strongly intensified both the Pacific gyral circulation and the warm Kuroshio current at *ca*. 16 Ma, and affected the marine fauna along the Pacific coast of southwestern Japan. The timing of the closure has been estimated sometime during the Middle Miocene based on biogeographic and paleoceanographic evidences (Kennett *et al.*, 1985), and at about 17-15 Ma from a viewpoint of neotectonics of the Indonesian arcs (Nishimura and Suparka, 1997). Considering the prominence of this warm episode in southwestern Japan, the tectonic event responsible for the closure most likely occurred rapidly during the latest early Miocene just before this warm episode. For further elucidation, it will be necessary to examine marine climatic circumstances of correlative reference sections in Indonesia and Southeast Asian countries, including paleogeomagnetic researches.

## Events related to a cool episode in *ca.* 15-12 Ma

A relatively prolonged cool episode is recognized during the late Middle Miocene, Zone N9-N13, *ca*. 15-12 Ma on both sides of the Pacific Ocean.

During the episode, the Sea of Japan opened mainly due to a quickly clockwise rotation of the Southwest Japan arc at *ca*. 15 Ma (Hirooka, 1992). As a result, an extensive hiatus developed on the Pacific coast of central Japan during *ca*. 15-12 Ma, so that the time of inception of the subtropical Sagara molluscan fauna is unknown. Thus, the surface marine climate of this period has been drawn from the Tomioka section on behalf of the Kakegawa section.

In South America, an anticlockwise bending of the

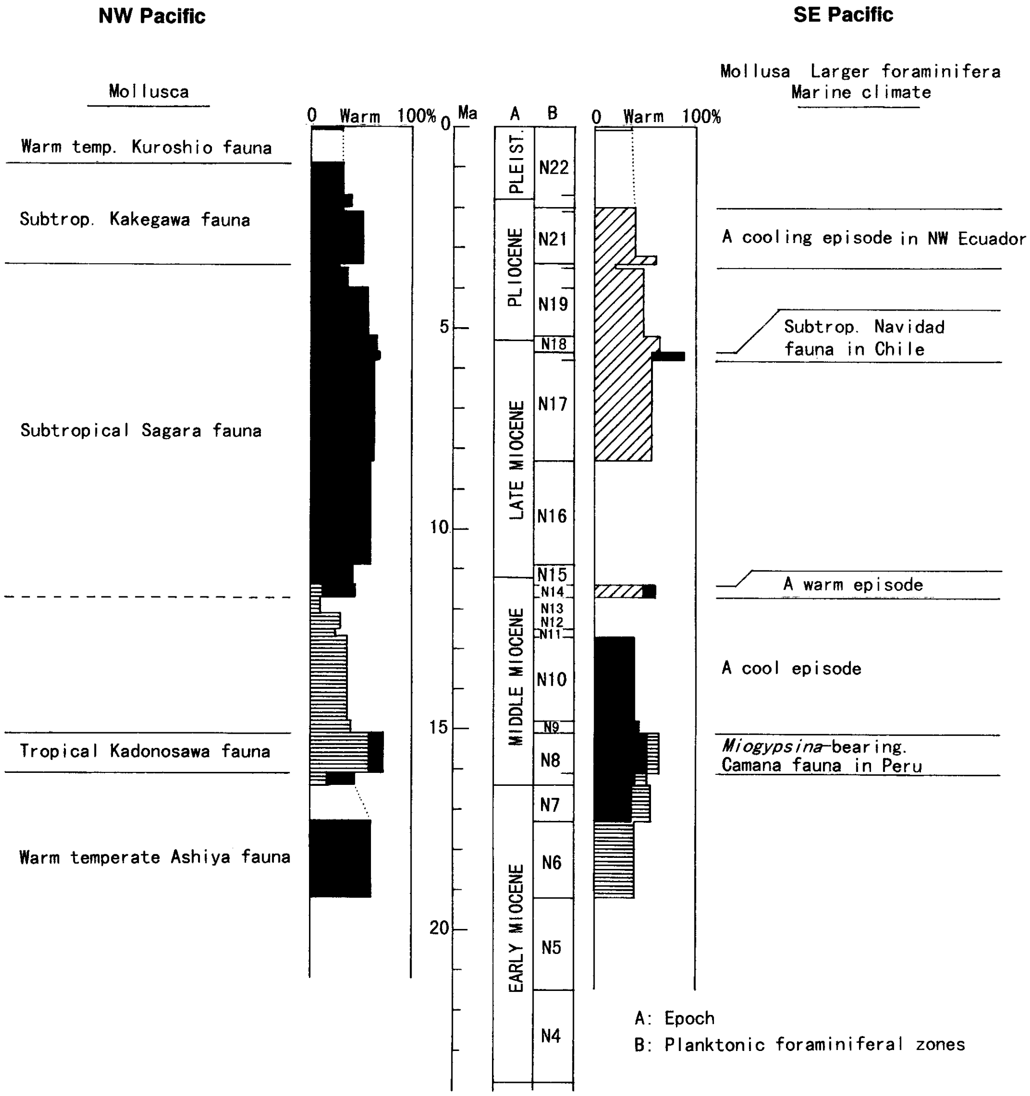


Figure 3. Correlation of Neogene surface marine climate interpreted from planktonic foraminifera in central Japan and in central and northern South America. The figure shows combined variations from two sections in Japan and three sections in South America, respectively. Ratios of main sections (the Kakegawa section in Japan, 34°45'N, and the C. H. de Mejillones section in Chile) are shown by black colored ones, and those of additional sections by banded ones. The ratio for the modern coastal ocean near Kakegawa in Japan is also given. Locations of these reference sections are indicated in Figures 2 and 4, respectively. Events referring to mollusca and larger forminifera are also given in both sides. The similar figure in Tsuchi (1997) has slightly been revised.

central part of the Andean Mountain range is estimated to have occurred sometime during the Miocene (Heki *et al.*, 1983; Kono, 1986). This tectonic event would have shifted the direction of the Peruvian coast and affected ocean currents and coastal upwelling. Considering the abrupt and extensive expansion of biosiliceous facies on the Peruvean coast beginning *ca.* 14 Ma, the bending might have occurred promptly around 15Ma. For the further elucidation, it will be necessary to examine reference sections on the Peruvian coast, including paleogeomagnetic researches to improve correlation and dating of these sequences.

## Events related to a warm episode at *ca.* 11.5 Ma

An evidence of a warm episode can be found as a horizon containing rich warm water planktonic foraminifera in the Caleta Herradula de Mejillones section in northern Chile and also within horizons of calcareous intercalations of somewhat biosiliceous facies in Ecuador in the latest Middle Miocene, Zone N14, *ca.* 11.5 Ma. In contrast, this interval in Japan does not seem to be a markedly warm interval. Concerning this episode, it is desirable to make further examinations of its extent in time and space.

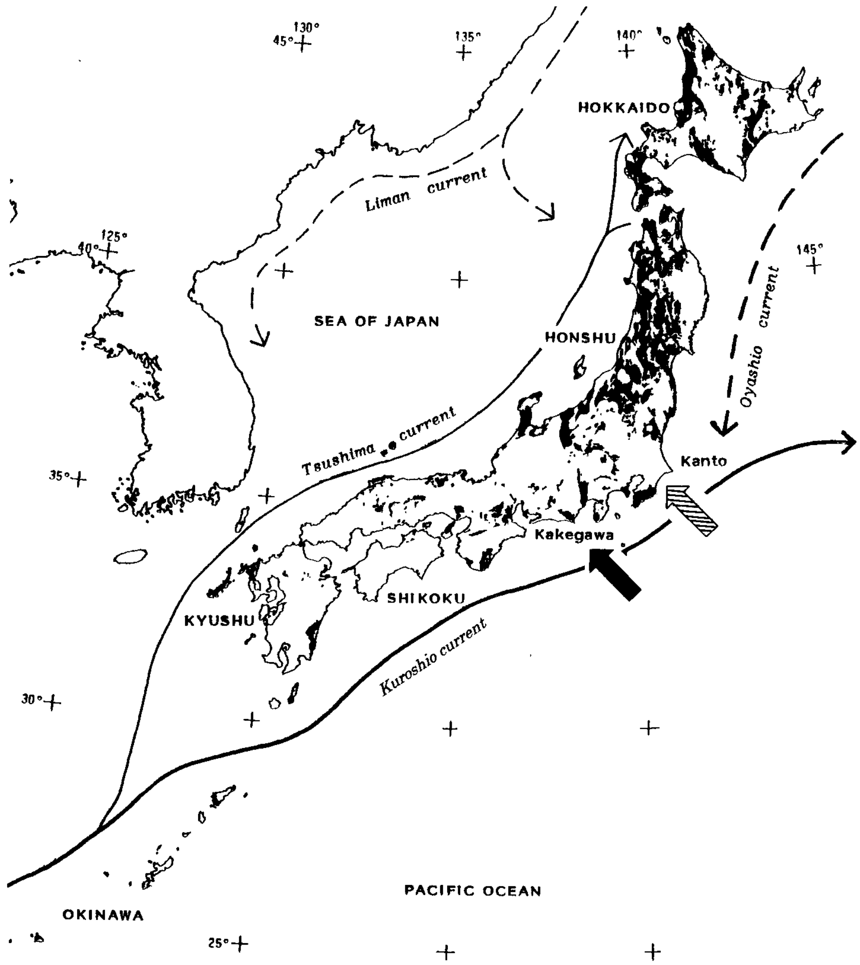


Figure 4. The distribution of marine Neogene sequences in Japan. Locations of two reference sections (the Kakegawa section, and the Tomioka section in the Kanto region) are indicated by arrows. Main ocean currents around the Japanese Islands at the present time are also given. Warm current: Solid lines. Cold current: Broken lines.

## Events related to a warm episode at *ca.* 5.7 Ma

This episode is noticed as a horizon including abundant warm water planktonic forminifera in the Caleta Herradula de Mejillones section in northern Chile and also represented by the horizon of the Navidad fauna in central Chile containing rich subtropical mollusca in the late Late Miocene, Zone N17b, *ca.* 5.7 Ma. This warm episode may have also a possibility of the pan-Pacific scale.

Concerning the closure tectonics of the Indonesian seaway, its final phase of the closure might have been occurring in an interval during the Late Miocene just prior to the 5.7 Ma warm episode. For the further elucidation, much more studies of marine sections in the western and eastern Pacific region are necessary as mentioned in the case of the warm episode around 15.5 Ma.

## Events related to both warm and cooling episodes at *ca.* 3 Ma

A warm episode represented by the acme of the subtropical Kakegawa fauna is recognized in Japan during the mid to late Pliocene, Zone 21a, *ca.* 3.35-2.2 Ma. In contrast, a fluctuating decline in surface marine temperatures is recorded in horizons of the Esmeraldas section in Ecuador since the mid Pliocene, Zone N19c, *ca.* 3.5 Ma (Ibaraki, this volume). These events can be interpreted as responses of the effective closing of the Central American seaway, which would have intensified the Pacific gyral circulation, including the warm Kuroshio current, as suggested by the ocean circulation model (Maier-Reimer *et al.*, 1990), so affecting marine faunas along the Pacific coast of southwestern Japan. In South America, on the other hand, a fluctuating decrease in surface seawater temperature along the

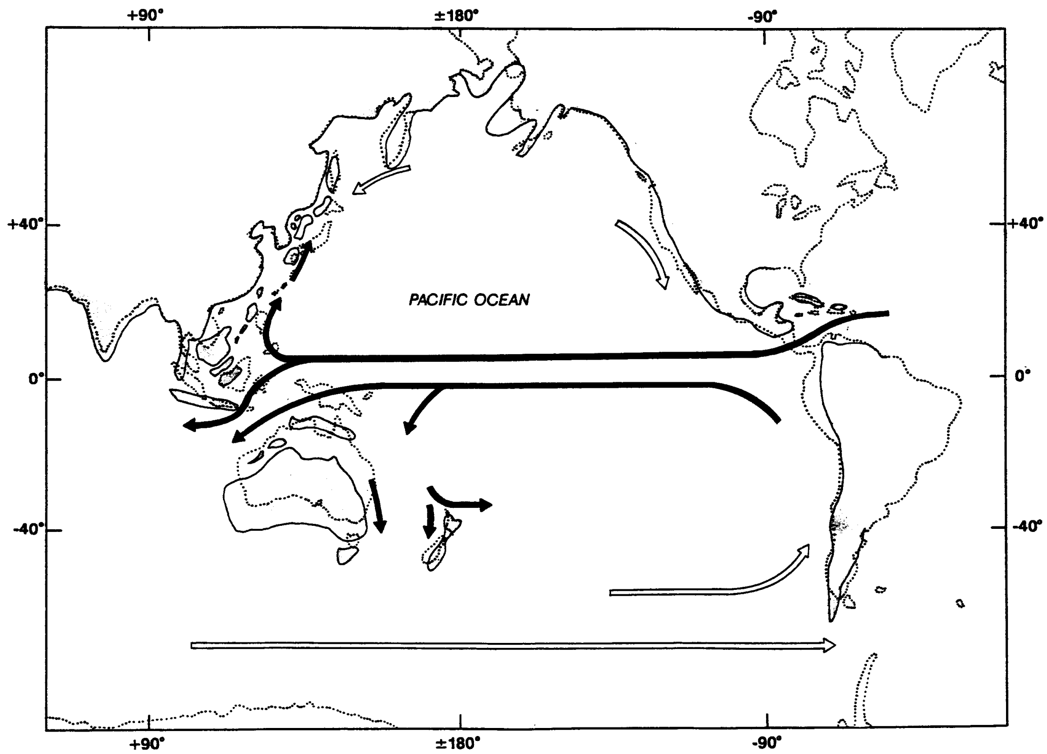


Figure 5. A schematic map illustrating the patterns of principal surface currents in the Pacific Ocean during the Early Miocene, *ca.* 17 Ma. Slightly modified from Tsuchi and Ingle (1992). Warm current: Black colored arrows. Cold current: White colored arrows.

Pacific coast of northwestern Ecuador since 3.5 Ma is a probable evidence of an increased coastal upwelling caused by the closing of the Central American Seaway (Tsuchi, 1997). For the further elucidation, it is necessary to make more examinations on surface marine climate circumstances of correlative reference sections, especially on the Pacific coast of Central America and those in Southeast Asian countries.

## Accelerated biotic lineage evolution since *ca.* 3 Ma

Accelerated biotic lineage evolutions have been examined in central Japan and northern Chile in accordance with a stepwise decline of surface seawater temperature since the late Pliocene, Zone N21, *ca.* 3 Ma (Tsuchi, 1992a). The evolution of the gastropod *Suchium suchiense-giganteum* bioseries, an endemic species group, in the Kakegawa molluscan fauna on the Pacific coast of central Japan is shown in Figure 6. The timing of evolutionary changes of respective forms has been revised on the basis of the recent chronologic calibrations by Berggren *et al.* (1995a, b). As shown in Figure 6, the *Suchium suchiense-giganteum* bioseries demonstrates an accelerated lineage evolution in shell form during the period from 3.35 to 1.8 Ma (formerly dated as 3.0 to 1.6 Ma). *Suchium giganteum* is a living from on the Pacific coast of central Japan. The surface ornamentation of these ancestral forms is characterized by many spiral cords and tubercles, which change gradually and diminish in descendant taxa. Thus, the *Suchium suchiense-giganteum* bioseries has modified its shell form in every 0.39 m. y. on average. The accelerated evolution recognized here seems to be closely related to a phased decline of surface seawater temperature as evidenced by the planktonic foraminiferal assemblage and the contents of tropical mollusca. Such accelerated evolutionary changes in shell form are typical of the Japanese endemic taxa, although tropical elements of the fauna have long ranges without any modification of their shell form or surface ornamentation (Figure 7; Tsuchi, 1992a).

Concerning the evolution of *Turritella cingulatiformis-cingulata* bioseries in northern Chile (Tsuchi, 1992a), the change in shell form from *T. cingulatiformis* to *T.* cf. *cingulatiformis* was examined in the Quebrada Blanca section during *ca.* 3.0 to 2.0 Ma, within the range of *Neogloboquadrina asanoi* (planktonic foraminifera). The horizon of *T.* cf. *cingulata* was also recorded in high-level terrace deposits near the same locality, which are assignable to an age of *ca.* 0.3 Ma. *T. cingulata* is now living in sandy substrates on the coast of northern Chile. Thus, this bioseries modified its form in reducing

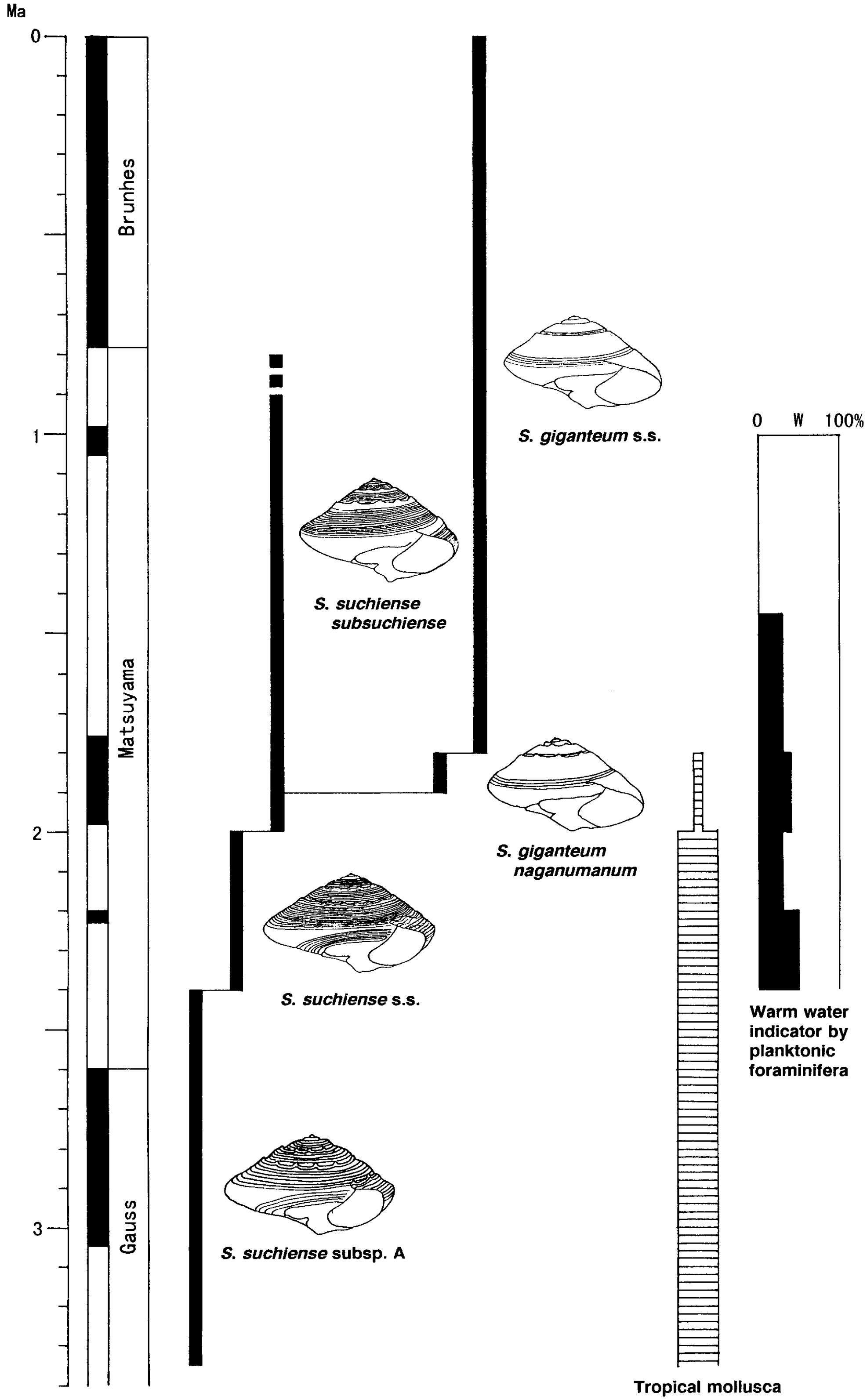


Figure 6. An accelerated lineage evolution demonstrated by *Suchium suchiense-giganteum* bioseries in the Kakegawa section in central Japan. The timing of evolutionary changes, the reduction of tropical mollusca within the molluscan fauna, and phased declines of surface seawater temperature estimated from planktonic foraminiferal assemblages in the same section are also given in the right side. Chronologic calibrations have been revised on the basis of Berggren *et al.* (1995a,b). Paleomagnetic stratigraphy is also indicated (black – normal polarity, white – reversed).

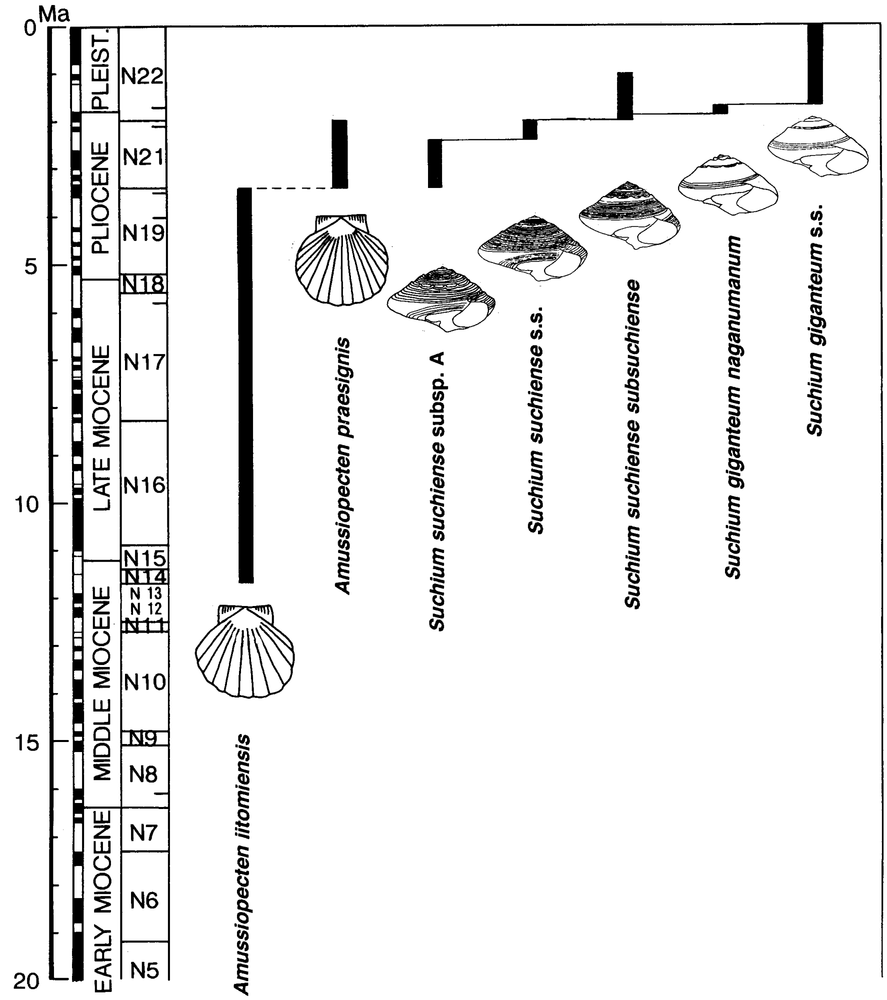


Figure 7. Chronologic distributions of some representative Neogene mollusca on the Pacific coast of central Japan. The figure indicates accelerated lineage evolutions of endeminc bioseries of *Suchium suchiense-giganteum* in comparison with two tropical forms of *Amussiopecten* in the left side. Chronologic calibrations of Tsuchi (1992a) have been revised. Paleomagnetic events and planktonic foraminiferal zones are after Berggren *et al.* (1995a, b).

the swell in every 0.75 m. y. on average, and the modification seems to have occurred also in accordance with a stepwise decline of surface seawater temperature. Concerning the evolution of this bioseries, however, it is to be desirable to make further detailed examinations of lineages that are well-constrained by chronology and by surface seawater temperatures.

No such accelerated evolutionary change in shell form has been known in mollusca of tropical seas. On both sides of the Isthmus of Panama, for example, di-versifications of a species group of *Pitar dione* are well known. In middle latitudes, tropical and boreal water species appear and disappear in accordance with the rise and fall of seawater temperature, where endemic mollusca survive by modifying their shell forms. An accelerated lineage evolution may, therefore, be a characteristic bioevent in the middle latitude areas.

**SUMMARY**

The Neogene evolution of surface marine climate is presented by utilizing variations in the ratio of warm water planktonic forminifera to the total planktonic foraminiferal assemblage in respective horizons of reference sections in central Japan and those in central and northern South America in both sides of the Pacific Ocean.

Comparing the evolution of surface marine climate on both sides of the Pacific Ocean, three warm episodes in Japan at about 15.5 Ma, 5.7 Ma and 3 Ma, and three warm episodes in South America at about 15.5 Ma, 11.5 Ma and 5.7 Ma are recognized. In addition, a prolonged cool episode in *ca.* 15-12 Ma is recognized on both sides of the Pacific Ocean.

A pronounced warm episode culminating in the

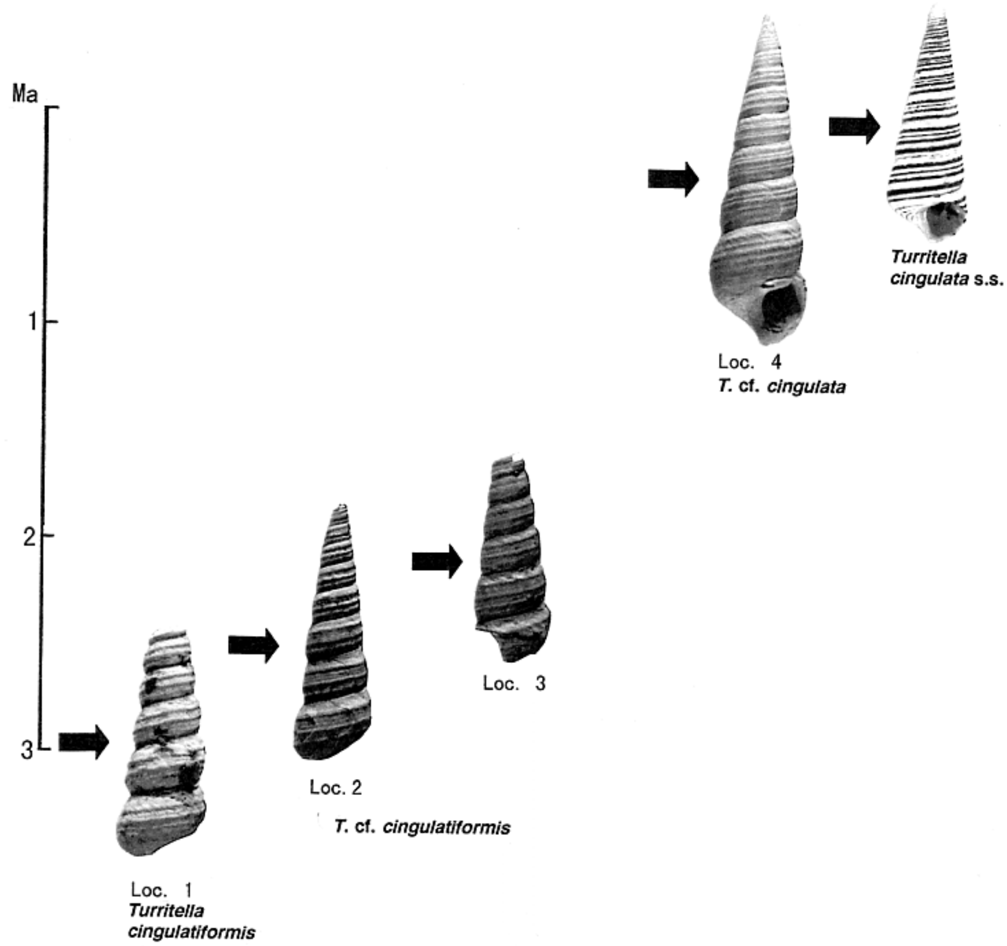


Figure 8. An accelerated lineage evolution of *Turritella cingulatiformis-cingulata* bioseries in northern Chile. Specimens were examined in the Quebrada Blanca section near Caldera. Loc. 1, 2 & 3: The base and upper horizons of the section. Loc. 4: A horizon of the high-level terrace deposits.

early Middle Miocene, Zone N8b, at about 15.5 Ma, the so-called "mid-Neogene climatic optimum", seems to have had a pan-Pacific scale. The closing of the Indonesian seaway in an interval just before the episode is a possible cause of this warm event. If this is the case, the closing tectonics might have been a rapid process, considering a prominence of the warm episode in southwestern Japan. A prolonged cool episode in the late Middle Miocene, Zones N9-N13, during *ca*. 15-12 Ma, is recognized on both sides of the Pacific Ocean. During this interval, the opening of the Sea of Japan occurred around 15 Ma, due to a quick rotation of the Southwest Japan arc. Considering the abrupt and extensive expansion of biosiliceous facies on the Peruvian coast since *ca*. 14 Ma, the oroclinal bending of the central Andean Mountain range might have occurred also in a quick process during the Middle Miocene at around 15 Ma. Concerning this tectonic hypothesis, it is necessary to make further exminations on the Peruvian coast.

A warm episode in the latest Middle Miocene, Zone N14, *ca*. 11.5 Ma, is known to contain rich warm water planktonic foraminifera in northern Chile and to be characterized by calcareous intercalations within biosiliceous facies in Ecuador. In Japan, however, there is no evidence of such a markedly warm interval.

A warm episode in the latest Late Miocene, Zone N17b, *ca*. 5.7 Ma, is noticed as containing the rich subtropical mollusca-bearing Navidad fauna in central Chile and as the acme of a gradual flourish of the subtropical Sagara molluscan fauna in Japan. It is possible that this event may have been a response to a step in the long phased process of the closure of the Indonesian seaway or its final phase. Concerning the timing and the process of the closure of the Indonesian seaway, further exminations are required.

A warm episode in the mid to late Pliocene, Zone N21, *ca*. 3.35-2.0 Ma, in Japan, and a fluctuant cooling episode nearly the same duration since the late Pliocene, Zone N19c, 3.5 Ma, in Ecuador can be interpreted as responses of the effective closing of the Central American seaway. The closing would have intensified the warm Kuroshio current along the Pacific coast of southwestern Japan, similarly the closure of the Indonesian seaway. A fluctuating decline of surface seawater temperature in northwestern Ecuador since 3.5 Ma is the evidence of an increased coastal upwelling due to the effective closing of the seaway. On the closing process of the Central American seaway, it is desirable to make further examinations of Neogene marine sections at key locations around the Pacific rim.

Accelerated biotic lineage evolutions are examined in endemic molluscan bioseries in central Japan and northern Chile during the latest Neogene in accordance with a stepwise decline of surface seawater temperature. Revised chronologic calibrations have been made as to the timing of evolutionary changes of respective forms. In central Japan, an endemic molluscan bioseries, *Suchium suchiense-giganteum* modified its shell form between 3.35 to 1.8 Ma, every 0.39 m.y. on average, closely related to a phased decline of surface seawater temperature. In northern Chile, *Turritella cingulatiformis-cingulata* bioseries has demonstrated its modification from 3 Ma to the present, every 0.75 m.y. on average. The accelerated lineage biotic evolution will be a characteristic bioevent in middle latitudes.

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## REFERENCES

Berggren, W.A., Kent, D.V., Swisher, C.C., Aubry, M.-P., 1995a, A revised Cenozoic geochronology and chronostratigraphy: SEPM (Society for Sedimentary Geology), Special Publication, 54, 129-212.

Berggren, W.A., Hilgen, F.J., Langeries, C.G., Kent, D.V., Obradovich, J.D., Raffi, I., Raymo, M.E., Shackleton, N.J., 1995b, Late Neogene chronology: new perspectives in high-resolution stratigraphy: Geological Society of America, Bulletin, 107, 1272-1287.

Covacevich, V., Frassinetti, D., 1980, El genero *Ficus* en el Mioceno de Chile central con descripcion de *F. gayana* sp. nov., Gastropoda: Ficidae: Boletín del Museo Nacional de Historia Natural de Chile, 37, 281-294.

Heki, K., Hamano, Y., Kono, M., 1983, Rotation of the Peruvian Block from paleomagnetic studies of the Central Andes: Nature, v. 305, p. 514-516.

Hirooka, K., 1992, Paleomagnetic evidence of the deformation of Japan and its paleo-geography during the Neogene, *in* Tsuchi, R., Ingle, J.C.Jr. (eds.), Pacific Neogene; Environment, Evolution and Events: Tokyo, Japan, University of Tokyo Press, 151-156.

Ibaraki, M., 1990, Neogene planktonic foraminifera and events in Japan: Palaeogeography, Palaeoclimatology, Palaeoecology, 77, 335-343.

Ibaraki, M., 1992a, Neogene planktonic foraminifera of the Camana Formation, Peru: their geologic age and paleoceanographic implications: Shizuoka University, Reports of Andean Studies, Special Volume, 4, 9-20.

Ibaraki, M., 1992b, Planktonic foraminifera from the Navidad Formation, Chile: their geologic age and paleoceanographic implications, *in* Ishizaki, K., Saito, T. (eds.), Centenary of Japanese Micropaleontology: Tokyo, Japan, Terra Sci. Pub. Com., 91-95.

Ibaraki, M., 1992c, Geologic age of biosiliceous sediments in Peru and Chile based upon planktonic foraminifera: Chile, Servicio Nacional de Geologia y Mineria, Revista Geológica de Chile, 19 (1), 61-66.

Ibaraki, M., 2000, Responses of planktonic foraminifera to the emergence of the Isthmus of Panama: (this volume).

Kennett, J.P., Keller, G., Srinivasan, M.S., 1985, Miocene planktonic foraminiferal biogeography and paleoceanographic development of the Indo-Pacific region, *in* Kennett, J.P. (ed.), The Miocene Ocean: Paleogeography and Biogeography: Geological Society of America, Memoir, 163, 197-236.

Kono, M., 1986, Reports of geophysical studies of the Central Andes (Second Phase): Tokyo Institute of Technology, Department of Applied Phys., Andes Science 3, 157p.

Maier-Reimer, E., Mikolajewicz, U., Crowley, T., 1990, Ocean general circulation model sensitivity experiment with an open Central American Isthmus: Paleoceanography, 5, 349-366.

Nishimura, S., Suparka, S., 1997, Tectonic approach to the Neogene evolution of Pacific -Indian Ocean seaways: Tectonophysics, 281, 1-16.

Tsuchi, R., 1992a, Pacific Neogene climatic optimum and accelerated biotic evolution in time and space, *in* Tsuchi, R., Ingle, J.C.Jr. (eds.), Pacific Neogene: Environment, Evolution and Events: Tokyo, Japan, University of Tokyo Press, 237-250.

Tsuchi, R. (ed.), 1992b, Pacific Neogene Events in Japan and South America: Shizuoka University, Reports of Andean Studies, Special Volume, 4, 50p.

Tsuchi, R., 1997, Marine climatic responses to Neogene tectonics of the Pacific Ocean seaways: Tectonophysics, 281, 113-124.

Tsuchi, R and Ingle, J.C. Jr., (eds.), 1992, Pacific Neogene; Environment, Evolution and Events: Tokyo, Japan, University of Tokyo Press, 257 p.

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