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Late Quaternary Palaeocenography in Eastern Asia

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ABSTRACT

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The paper presents the paleoceanography of the north-western Pacific during the latest Pleistocene, based mainly on marine records. At 15,300 (PT2) years B.P., the Kuroshio current began to flow northward. It passed south of Kyushu around 31° N latitude and ran to the east. At 13,000 (PT1) years B.P., the front of the Kuroshio reached as far as Ise Bay around 33° N latitude and at 6,000–5,000 years B.P. it extended to 43° latitude. In contrast, at around 10,000 (PR1) 15,000 (PR2), and 20,000 (PR3) years B.P. it seems likely that the cold Oyashio penetrated far to the south. In general, times of southward shift of the cold water coincide with those of intensive tectonism in East Asia. Therefore, large-scale changes in ocean circulation in the north-western Pacific are related to intensive tectonism.

ADDITIONAL INDEX WORDS: *Pacific, tectonism, ocean circulation.*

OBJECTIVES

The north-western Pacific and adjacent seas play an important part in global climate through effects from the changes of the Kuroshio. Most notably, Japan is hydrographically situated in the transition zone between cold water and warm water currents. At the last glaciation maximum around 20,000 years B.P., the front of the Kuroshio was located off the east coast of the Ryukyu Islands (THOMPSON and SHACKLETON, 1980), whereas during the Holocene climatic optimum it penetrated as far as the north of Japan (TAIRA, 1995).

Based mainly on the available pollen and marine records, and on radiocarbon data related paleocenographic changes, this paper presents a generalized paleoceanographic evolution for the period 20,000 to 10,000 years B.P.

MATERIAL

In south Taiwan, there is a transgression that began with the development of coral reefs at c. 25,000 years B.P. and continued until 20,000 years B.P. (HASHIMOTO *et al.*, 1972). The coral reefs aged >20,000 years B.P. were subjected to intermittent uplift since 20,000 years B.P. and the tilting uplift was maximized around 10,000 years B.P. Accordingly, the traces of coral reefs aged 10,000–20,000 years B.P. are limited to a few places such as the crevices formed on abrasion planes (HAHIMOTO *et al.*, 1972). The Hsiaokangshan raised coral reef aged 15,300 years B.P. in south Taiwan is found >200 m above the present sea level, and the Hsitou raised coral reef aged 13,000 years B.P., c. 50 m above the present sea level (HASHIMOTO *et al.*, 1972; HASHIMOTO and TAIRA, 1974). The Wangsha coral reefs situated c. 50–65 m above the present sea level in south Taiwan, discovered by LIN (1968), was dated at 14,000 and 17,000 years B.P., and Holocene raised coral reefs are found c. 20 m above the present sea level. Therefore, transgressions in this area occurred around 21,000–25,000 (PT3), 17,000–15,300 (PT2) and 14,000–13,000 (PT1) years B.P., while regressions corresponding to hiatus of reef building corals occurred around 20,000–17,500 (PR3), 15,000–14,500 (PR2), and 12,500–10,000 (PR1) years B.P. Furthermore, it seems likely that uplift of this area from 20,000–10,000 years B.P. was very rapid. Rapid crustal movements in the late Pleistocene like those of southern Taiwan is reported also from the South China Sea (CHEN and JIAO, 1983).

On Okinawa Island, a coral reef sample dated 13,700 years B.P. taken from 48 m below the present sea level off the west coast, overlies the limestone far older than 20,000 years B.P. (AKIYAMA, 1975), and the coral 4 m above sea level from Nagake, Okinawa is dated at 22,450 years B.P. (KIGOSHI, 1967). Therefore, the periods of transgression on Okinawa correlate with PT1 and PT3 in southern Taiwan.

In the Ariake area Kyushu (location C on fig. 1), raised marine deposits (so-called Oue Formation) 10 m above the present sea level include warm marine species of molluscs that yield ages of 25,900–22,100 years B.P. (ARIAKE BAY RESEARCH GROUP, 1965). Humus soil (so-called the Matuhashi Formation) 1 m above present sea level include pollen grains characteristic of relatively warm condition and is dated at 15,350 years B.P. (ARIAKE BAY RESEARCH GROUP, 1965). Some borings in this area disclose marine and brackish deposits (Shimabara-Kaiwan Formation) in the latest Pleistocene 20 m below present sea level which include a flora close to that of the present day (ARIAKE BAY RESEARCH GROUP, 1965). Therefore, these formations in this area are correlated with PT1, PT2, and PT3, respectively. From these marine and terrestrial records of southern Taiwan, Okinawa and southern Kyushu, it seems likely that the Kuroshio current in this region reached the coast at PT1, PT2, and PT3.

In the Nobi plain (location D), marine and freshwater beds

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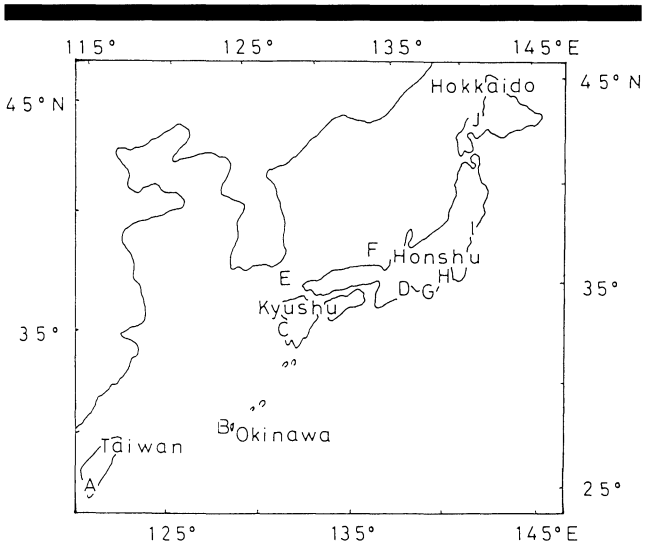

Figure 1. Map showing localities discussed in the text.

below present sea level include marine diatoms reflecting relatively warm temperatures (MORI, 1981). Although the radiocarbon age of the beds is not known, it is correlated with PT1, based on stratigraphic position (MORI, 1981).

In the Enoura Bay (location G), marine shallow-water shells collected from the seafloor at a water depth of 260 m are cold-loving species and the radiocarbon date gives the age of 15,900 years B.P. (KIGOSHI *et al.*, 1969). This fact shows that in PT2 the Oyashio cold current flowed into this area. Today, the front of the Oyashio current is located off the coasts of Sendai (location I), but in PT2 the current penetrated much farther south, displacing the Kuroshio warm current.

In the Ekoda, Tokyo (location H), pollen records from a section on river terrace (total thickness c. 3 m) are divided into several: zones warming, cold (11,840 years B.P.), warming, and cold (28,770 years B.P.) (KWANTO LOAM RESEARCH GROUP, 1965). Therefore, it seems that around 11,840 years B.P. (PR1) the Oyashio current flowed off Tokyo.

Off Sendai (location I), cold-loving mollusc shells from cores in deep water from 688 to 80 m are dated at 10,060 (PR1), 12,380 (PR1), and 14,350 (PT1) years B.P. (SAITO *et al.*, 1989). The facts show that the Oyashio current around 10,000–14,000 years B.P. (PT1, PR1) flowed off Sendai.

In the Tsushima trough (location E) situated in the Korea Strait, mollusc shells were collected from the seafloor at 140–195 m water depth which are cold-loving species and the radiocarbon dates gave the ages of 14,200 (PT1) and 15,000 years B.P. (PT2) (HABE and KOSUGE, 1970). Therefore, it seems that at PT1 cold water flowed into the strait.

In the Iki basin (location F), radiocarbon and fossil data were obtained from piston cores at 1,115–935 m water depth (Oba, 1982). The uppermost layer (80 cm thick) in these cores contain planktonic foraminiferal fauna indicative of warm conditions, while below 90 cm the sediments contain planktonic foraminifera indicative of cold conditions as a whole. Therefore, it is thought that the uppermost layer represents Holocene deposits (OBA, 1982). Between 105 and 130 cm, is observed a spike including warm species that suggest a northward shift of the Tsushima warm current. It is probable that the peak is correlated with PT1, although its exact time remains unknown.

In the Ishikari plain (location J), pollen assemblages recovered from a humus layer at a depth 70 m below sea level recorded relatively milder climate and mollusc shells from a thin marine layer overlying the humus layer are dated at 26,320 years B.P. (MATSUSHITA, 1979). The facts show that in PT3 warm water probably extended this area. Exact environments in PT1 are unknown.

PALAEOCEANOGRAPHY

Modern Oceanography: The NW Pacific

According to HIDAKA (1966), the Kuroshio originates from the warm equatorial water, flows north-easterly east off Taiwan, and then runs off the west coasts of Okinawa. A branch of the Kuroshio sweeps past the west coasts of Kyushu, and flows into the Sea of Japan through the Tsushima Strait. The major part of the Kuroshio flows south of Kyushu, northward along the east coasts of Honshu, and then it turns to the east between latitudes 36° and 37° N. Between latitudes c. 37° and 40° N, the Kuroshio meets the Oyashio cold current off northern Honshu.

Mid-Holocene Climatic Optimum: Approximately 5,000–6,000 Years B.P.

According to TAIRA (1995), the front of the Kuoshio on the Pacific side of Japan extended to the vicinity of southern Hokkaido around 43° N, and in the Sea of Japan the Tsushima Current reached northern Hokkaido as far north as 45° N, and thence the warm water was further carried into the Sea of Okhotsk through the Soya Strait. Therefore, the facts show that during the Holocene climatic optimum the Kurohsio reached much farther north than today.

13,000 (PT1) Years B.P.

The paleoceanography at PT1, PT2, and PT3 in Figure 2 is compiled from palynological and marine data (Table 1). At PT1 the Kuroshio sweeps the east coasts of Taiwan, and then flows through the East China Sea. Farther, north the main part of the Kuroshio sweeps the area south of Honshu, and its front reached Ise Bay around 23° N latitude. A branch of the Kuroshio sweeps the west coasts of Kyushu and flows into the Sea of Japan through the Tsushima Strait. Pollen records of marine deposits at PT1 in the Niigata plain indicate climatic conditions similar to those in this area at the present day (WADA, 1972) so that it seems that the Tsushima current reached latitude 38° N off Niigata.

15,300 (PT2) and 21,000–25,000 (PT3) years B.P.

At PT2 and PT3, the Kuroshio moves northward off the east coasts of Taiwan, and flows along the Okinawa trough (Figure 2). It seems that after it passes south of Kyushu, it runs to the east.

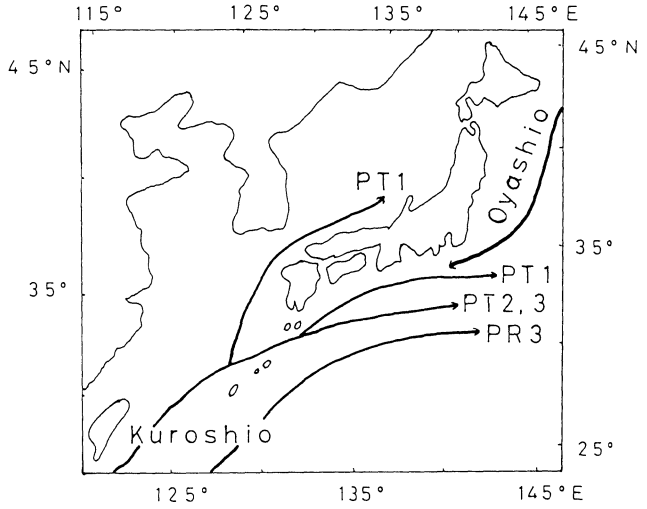

Figure 2. Ocean currents of East Asia at 10,000–25,000 B.P. 1 20,000–18,000 B.P. (PR3) (THOMPSON and SHACKLETON, 1980), 2 21,000–25,000 B.P. (PT3), 3 15,300 B.P. (PT2), 4 13,000 B.P. (PT1).

18,000–20,000 (PR3) Years B.P.

According to Thompson and Schackleton (1980), it seems that the Kuroshio flows far off-shore of the eastern coasts of the Okinawa Islands.

TECTONISM AND PALAEOCEANOGRAPHY

In general, it is reported that intense volcanism and tectonism occurred in Japan close to the plate boundary from 10,000 to 20,000 and around 130,000 years B.P. (TAIRA, 1983). TAIRA (1981) also showed that during the Holocene periods of intense tectonism in eastern Asia are correlated with cooling events. In a similar way, intermittent uplifts in southern Taiwan have occurred since 20,000 years B.P. (HASHIMOTO and TAIRA, 1974). Furthermore, it seems that times of transgression in southern Taiwan during the late glacial coincide with those of abrupt northward shift of the Kuroshio in Japan, while times of uplift in southern Taiwan coincide with those of southward shift of the cold Oyashio current in Japan (Figure 2). The facts suggest that climatic changes on a time-scale of 10^3 years are associated with tectonism.

NAITO (1977) suggested that higher-frequency variations in mass redistribution over the Earth's surface (water, ice and air) induce low-frequency variations in slow deformation within the Earth (change in the differential rotation between core and mantle and rotational and load deformations of lithosphere and mantle). Accordingly, stresses appear to have been accumulating slowly within the Earth during the last 100,000 years due to mass redistribution induced by short climatic changes. It seems likely that they were suddenly released in the late glacial, which led to a critical condition. As a result, it is thought that intense volcanism and tectonism occurred in eastern Asia close to its plate boundary from

Table 1. *Radiocarbon dates and relative climatic conditions of late Pleistocene deposits in eastern Asia.*

*L		Lab. No	^{14}C Age (yr B.P.)	Material (climate)	Altitude (m)	Reference
A	PT1	N-1637	13,000 ± 220	coral reef (warm water)	c. 50	1
	PT2	N-719	15,300 ± 260	coral reef (warm water)	>200	2
	PT3		>21,000	coral reef (warm water)	c. 30–150	2
B	PT1	N-1967	13,700 ± 180	coral reef (warm water)	c. −48	3
	PT2	no record				
	PT3	Gak-810	22,450 ± 650	coral reef (warm water)	c. 4	4
C	PT1	relative age from stratigraphy		pollen (similar to present)	c. −20	5
	PT2	N-1967	15,350 ± 350	pollen (similar to present)	c. 1	5
	PT3	Gak-381	25,900 ± 1,000	mollusc (warm water)	c. 10	5
		Gak-274	22,100 ± 9, 00	mollusc (warm water)	c. 10	5
D	PT1	relative age from stratigraphy		diatom (warm water)	<−40	6
	PR3	Gak-2978	18,200 ± 500	pollen (cooler than present)	c. −45	7
	PT2	Gak-2980	16,700 ± 500	pollen (cooler than present)	c. −45	7
E	PT1	no record	14,200 ± 300	mollusc (cold water)	−140 ~ 195	8
	PT2	no record	15,800 ± 400	mollusc (cold water)	−140 ~ 195	8
F	PT1	relative age from stratigraphy		foraminifera (warm water)	−1115 ~ 935 (piston cores)	9
G	PT2	Gak-858	15,900 ± 300	mollusc (cold water)	c. −260	10
H	PR1	Gak-172	11,840 ± 300	pollen (colder)	c. 35	11
	PT3	Gak-174	28, 770 ± 2,600	pollen (cold)	c. 34.5	11
I	PR1	JGS-344	10,060 ± 230	mollusc (cold water)	c. −80 ~ 688	12
	PR1	JGS-290	12,380 ± 150	mollusc (cold water)	c. −80 ~ 688	12
	PT1	JGS-292	14,350 ± 240	mollusc (cold water)	c. −80 ~ 688	12
J	PT3	Gak-4955	26,320 ± 100	pollen (relatively warm)	c. −70	13

[a] L; locations are shown on Figure 1.
[b] See explanation in text; PT1, PT2, PT3 and PR1.
1 = HASHIMOTO and TAIRA (1974): 2 = HASHIMOTO and TAIRA et al., (1972): 3 = AKIYAMA (1975): 4 = KIGOSHI (1967): 5 = ARIAKE BAY RESEARCH GROUP (1965): 6 = MORI (1981): 7 = FURUKAWA (1972): 8 = HABE AND KOSUGE (1970): 9 = OBA (1982): 10 = KIGOSHI et al., (1969): 11 = KWANTO LOAM RESEARCH GROUP (1965): 12 = SAITO et al., (1989): 13 = MATSUSHITA (1979).

about 10,000 to 20,000 B.P. and around 130,000 B.P. MÖRNER (1996) suggested that large-scale displacements of the Kuroshio on time-scale of 10^3 occurred due to sudden geoid changes. MÖRNER (1996) also found a correlation between the Earth's rate of rotation and ocean circulation over parts of the North Atlantic during the last 20,000 years. It seems that changes of the Gulf Stream in the North Atlantic at about 10,000–20,000 years B.P. (MÖRNER, 1996) correspond to those of the Kuroshio. Therefore, it is concluded that changes of ocean circulation on globe were induced by sudden geoidal change due to a sudden release of energy within the Earth.

CONCLUSIONS

This paper discusses the paleoceanography of the northwestern Pacific during the late Quaternary, which is based mainly on marine records. At 15,300 B.P. (PT2), the Kuroshio began to flow northward. Furthermore, it passed south of Kyushu around 31° N latitude and ran to the east. At 13,000 (PT1), the front of the Kuroshio reached Ise Bay around 33° N latitude and at 5,000–6,000 B.P., it extended to 43° N latitude. At intervals around 10,000 (PR1), 15,000 (PR2), and 20,000 (PR3) BP, it seems that the cold Oyashio current penetrated far to the south. In general, it seems that times of northward shift of the Kuroshio coincide with those of northward shift of the Gulf Stream according to MÖRNER (1995). Therefore, it is concluded that large-scale changes in oceanic circulation in the northwest Pacific were induced by a global source and appear to have resulted from adjustment of the Earth due to mass redistribution within the planet itself.

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