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Holocene Oxygen and Carbon Isotopic Records of Core OR102-3 off Southeastern Taiwan: Paleoceanographic Implications

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ABSTRACT

The Holocene carbon and oxygen isotopic records of the planktonic foraminifera *Globigerinoides sacculifer* from core OR102-3 off southeastern Taiwan are presented. The isotopic values for this taxon from the Holocene period show ranges from -2.45°/oo to -1.70°/oo for $\delta^{18}O$ and from 2.47°/oo to 1.72°/oo for $\delta^{13}C$, respectively. Paleo-temperatures revealed from transfer function estimates of foraminifera assemblages in this core and in nearby core OR216-17 show that the surface waters in this region remained relatively warm and constant during the Holocene. The $\delta^{18}O$ values of the surface seawaters overlying the two core locations during the Holocene were then calculated using the paleotemperature equation. Results show that oxygen isotopic variations of the local surface waters during the Holocene were within 1°/oo for core OR102-3 and 0.5°/oo for core OR216-17, respectively. Two freshwater spikes are detected for core OR102-3 at about 2400 yrs B.P. and 5700 yrs B.P., but these spikes are not found in core OR216-17. These two freshwater spikes may be related to precipitation increases over eastern Taiwan during those two periods. Carbon isotopic records indicate that the $\delta^{13}C$ of the total dissolved CO_2 in surface waters were almost the same for both cores during the Holocene.

(Key words: Holocene, Stable isotopes, Paleoceanography, Foraminifera)

1. INTRODUCTION

For Monsoon Asia, the Kuroshio Current is an important oceanographic current of the western Pacific. It flows from the southeast towards the northeast off eastern Taiwan at a speed of 1.5-2 knots (Chu, 1974). Surface water in this current maintains a temperature of 28-29°C in summer and 25-26°C in winter. The salinity of the surface water is in the

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range of 34.2-34.7 $^{o}/_{oo}$ (Fan, 1985, 1987). Records of the surface temperature and water characteristics of the Kuroshio Current and nearby region during the geologic past are of interest and essential to the PAGES study.

Studying the marine sediments close to Taiwan has both advantages and disadvantages. On the advantage side, one can recover very high-sedimentation-rate cores and consequently get high resolution records, both of marine and terrestrial inputs, from them. On the other hand, due to the high-sedimentation-rates and terrestrial interferences, the use of oxygen isotopes as a stratigraphic tool, normally valuable for open ocean sediments, is often not applicable. Thus, we have turned to other dating methods to obtain a reliable chronology.

In this study, we present detailed Holocene carbon and oxygen isotopic records from core OR102-3 off southeastern Taiwan. Our objective is to examine the isotopic records with a view to obtaining a better understanding of the paleoceanography of the Kuroshio current during the Holocene.

2. MATERIALS AND METHODS

Piston core OR102-3 was raised from the slope of the Huatung Ridge (22°20.1'N, 121°18.4'E, water depth 1309 m, core length 400 cm) off southeastern Taiwan on April 20, 1987 (Figure 1). Cores were sampled at 10 cm intervals down to its base. Specimens of

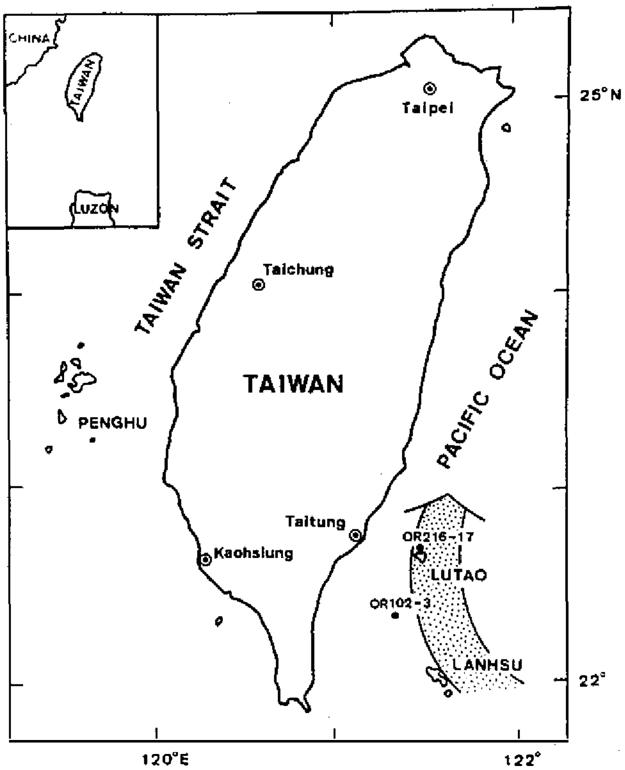

Fig. 1. Location of cores OR102-3P and OR102-17P off eastern Taiwan. The inferred flow path of the Kuroshio Current during the Holocene is indicated in shaded arrow area.

epipelagic species *Globigerinoides sacculifer* were picked from the size fraction of 350-500 μm and cleaned by ultrasonic vibration to remove adhering contaminant materials.

Samples weighing about 2 mg ($\sim$20 tests) were treated with NaClO (5%) at room temperatures for 24 hours to remove organic matter. Carbon dioxide was released by reaction with 100% orthophosphoric acid at 35°C and analyzed in a triple-collector mass spectrometer. Isotopic values are expressed as per mil($^o/_{oo}$) deviation from the PDB standard (Epstein *et al.*, 1953). Calibration was made through analyses of standard carbonates NBS-18 ($\delta^{18}O_{PDB}$ = -23.05$^o/_{oo}$ and $\delta^{13}C_{PDB}$ = - 5.04$^o/_{oo}$) and NBS-19 ($\delta^{18}O_{PDB}$ = -2.20$^o/_{oo}$ and $\delta^{13}C_{PDB}$ = +1.95$^o/_{oo}$). The analytical precisions expressed as 1σ for NBS-18, NBS-19 and our laboratory standards were better than 0.06$^o/_{oo}$. The average difference of duplicate foraminiferal analyses is about 0.12$^o/_{oo}$ for oxygen and 0.09$^o/_{oo}$ for carbon.

3. RESULTS AND DISCUSSION

3.1 ^{14}C Ages and Sedimentation Rates

The AMS ^{14}C dates obtained from mixed planktonic foraminifera for core OR102-3P are listed in Table 1. Using the time scale proposed by Martinson *et al.* (1987) it is obvious that the core covers the periods of oxygen isotope stages 1 to 3. Although the age of the core bottom is beyond the limit of ^{14}C dating, it is estimated from the oxygen isotope record of this core that the core-base age is close to the oxygen isotope stage 3/4 boundary. Thus, an age of about 55ka is assumed for the core base. In the following discussion, ages for individual samples are estimated by interpolation between adjacent dates. Figure 2 shows the age vs. depth relationship for the core OR102-3P. Sedimentation rates indicated in this figure clearly show that the interval of isotope stage 1 had the highest average rate (21 cm/kyr),

Table 1. The ^{14}C dates of foraminifera from cores OR102-3.

Depth (cm)	D^{14}C ($^o/_{oo}$)	^{14}C age (yr)	Corr-age (yr)
2.5	-126.3±7.6	1085±70	690
40	-337.6±5.8	3308±70	2,910
75	-361.9±7.5	3609±95	3,210
100	-443.0±4.8	4701±69	4,300
130	-512.1±5.4	5765±89	5,370
165	-594.7±3.8	7255±74	6,860
210	-705.9±4.9	9830±130	9,400
225	-737.3±3.0	10738±90	10,340
235	-784.0±2.7	12310±100	11,900
240	-843.9±1.8	14918±95	14,500
245	950.4±1.3	24120±200	23,700
260	-981.3±1.7	31950±720	31,600
285	-997.7±0.6	48900±2300	48,500
330		>50000	
400		>50000	

* Reported age is the conventional radiocarbon age before present (BP). Age and D^{14}C are as defined in Stuiver and Polach (1977). The last column represents the reservoir-corrected age obtained by subtracting 400 years (Bard, 1988).

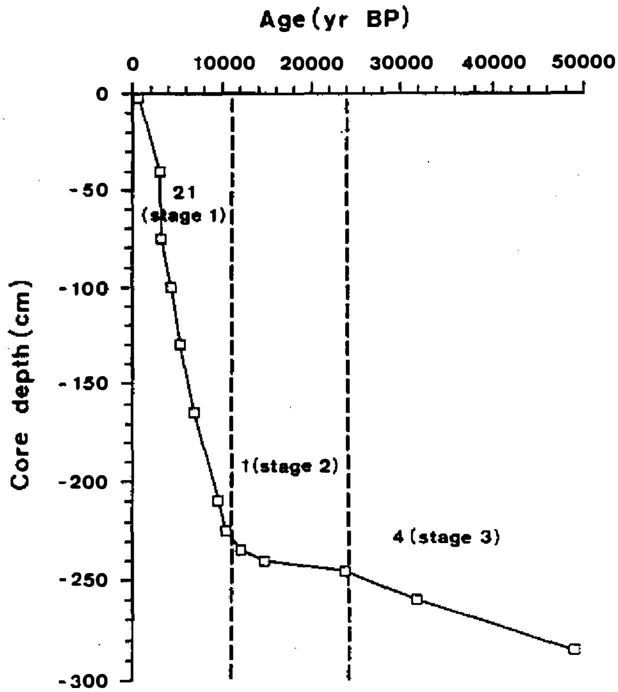

Fig. 2. Age vs. core depth for OR102-3P. Numbers in the plot are the average sedimentation rates (cm/kyr) for oxygen isotope stages 1 to 3. Stage boundary ages are from Martinson *et al.* (1987).

the stage 2 interval had the lowest rate (1 cm/kyr), and stage 3 had a value between them (4 cm/kyr). Because this report discusses only the Holocene part, the cause for the low sedimentation rates during the last glacial time will be presented elsewhere.

3.2 The Isotope Records

The Holocene carbon and oxygen isotopic results from *G. sacculifer* for core OR102-3P (< 10,000 yr B.P.) are listed in Table 2. To obtain a better picture for the studied area of Holocene conditions, we compared isotopic records from core OR102-3 with those of a nearby Holocene core OR216-17 previously studied (Shieh *et al.*, 1991). The Holocene chronology in core OR216-17 was also based on AMS ^{14}C dates of mixed planktonic foraminifera. Figure 3 is the plot of isotopic data vs. age for both cores. Over the interval of time represented, $\delta^{18}O$ values show ranges from -2.45$^o/_{oo}$ to - 1.70$^o/_{oo}$ for OR102-3 and from -2.42$^o/_{oo}$ to -2.07$^o/_{oo}$ for OR216-17. The $\delta^{13}C$ values show ranges from 2.47$^o/_{oo}$ to 1.72$^o/_{oo}$ for OR102-3 and from 2.19$^o/_{oo}$ to 1.84$^o/_{oo}$ for OR216-17. These isotopic values are comparable to those observed in other western Pacific cores (Berger & Killingley, 1977; Berger *et al.*, 1978a, 1978b; Wang *et al.*, 1985; Wang and Chen, 1988). The amplitude of the oxygen isotopic variations in both cores is also relatively small (~0.7$^o/_{oo}$), indicating that temperature and oxygen isotopic variations of surface seawater were relatively minor during the Holocene. The $\delta^{13}C$ trends of G. sacculifer are almost identical for both OR102-3 and OR216-17 cores, presumably as a result of having the same $^{13}C/^{12}C$ ratio of the bicarbonate in the surface water during the Holocene.

Table 2. Oxygen and carbon isotopic data of *G. sacculifer* from core OR102-3.

Depth (cm)	$\delta^{18}O_{PDB}$ (‰)	$\delta^{13}C_{PDB}$ (‰)	$\delta^{18}O_{SMOW}$* (‰)	Temp# (°C)	Salinity@ (‰)	Yrs B.P. $
7.5	-2.27	1.88	0.35	27.7	34.0	990
19	-2.14	2.15	0.49	27.8	34.2	1670
31	-2.45	1.89	0.07	27.2	33.5	2380
43	-2.11	2.10	0.65	28.4	34.5	2940
55	-2.12	2.05	0.55	28.0	34.4	3040
67	-2.07	2.47	0.57	27.8	34.4	3140
79	-2.30	2.20	0.43	28.3	34.1	3380
91	-2.12	2.07	0.55	28.0	34.4	3910
103	-2.12	2.28	0.72	28.8	34.7	4410
115	-2.08	2.14	0.73	28.7	34.7	4840
127	-2.08	2.17	0.55	27.8	34.4	5260
138	-2.38	2.11	0.37	28.4	34.0	5710
151	-2.06	2.07	0.71	28.5	34.6	6260
163	-2.07	2.03	0.67	28.3	34.6	6780
175	-1.96	1.99	0.65	27.7	34.5	7430
180	-1.89	2.00	0.72	27.7	34.7	7720
187	-1.77	1.77	0.84	27.7	34.9	8120
190	-1.81	1.87	0.81	27.7	34.8	8290
199	-1.74	1.80	0.97	28.2	35.1	8800
210	-1.70	1.72	0.95	27.9	35.1	9430
maximum	-1.64	2.47	0.73	29.0	36.1	
minimum	-2.45	1.72	0.07	25.5	33.5	
range	0.81	0.75	0.66	3.5	2.6	
average	-2.04	2.03	0.51	27.4	35.0	

* calculated from the paleotemperature equation (Craig, 1965)
\# derived from transfer functions
@calculated from $\delta^{18}O$-salinity relationship for north Pacific surface water (Craig & Gordon, 1965)
$ ages for individual samples are estimated by interpolation

The sea-surface temperatures were calculated by the transfer function technique (Imbrie & Kipp, 1971) for both OR102-3 and OR216-17 cores using the score of Thompson (1981) for the western Northern Pacific. Table 2 also lists sea surface temperatures derived from transfer functions of foraminifera assemblages. Figure 4 shows the plot of estimated sea surface temperature vs. age for cores OR102-3 and OR216-17. These estimates indicate that the surface waters over the two cores remained relatively warm and constant during the Holocene. The range of temperature variations was about 1.5°C for core OR102-3 and 1.3°C for core OR216-17, respectively. Today, the average yearly sea surface temperature in this region is about 28°C and is in good agreement with the Holocene average of core OR102-3. It is also interesting to note from the transfer function estimates that temperatures between 4000 and 7000 yrs B.P. of both cores were relatively and consistently warmer than those of other Holocene times. This high temperature stage might be related to the hypsithermal period of the Holocene.

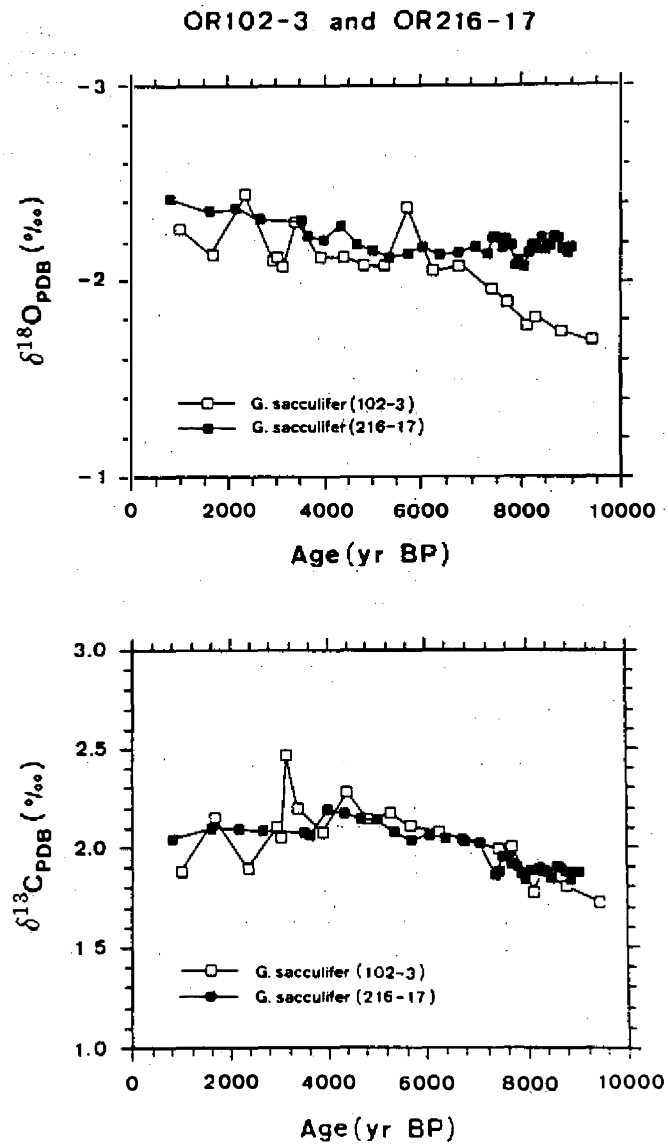

Fig. 3. Oxygen and carbon isotopic variations of *G. sacculifer* plotted against age in cores OR102-3 and OR216-17.

With temperature and foraminifera $\delta^{18}O$ values at hand, the $\delta^{18}O$ values of the surface seawaters at the two core locations during the Holocene can be calculated by using the paleotemperature equation of Craig (1965). Results suggest that the range of oxygen isotopic variations of surface waters (i.e. $\delta^{18}O_{seawater}$) during the Holocene were about $0.9^o/_{oo}$ for core OR102-3 and $0.4^o/_{oo}$ for core OR216-17 (Table 2; Figure 5). Core OR102-3, which is closer to the island of Taiwan may exhibit larger amplitudes in oxygen isotopic values of the surface seawaters than core OR216-17 because of increased influence of freshwater input.

Two $\delta^{18}O$ minima, inferred to represent freshwater spikes, are detected in core OR102-3 at about 2400 yrs B.P. and 5700 yrs B.P., but these spikes are not found in core OR216-17.

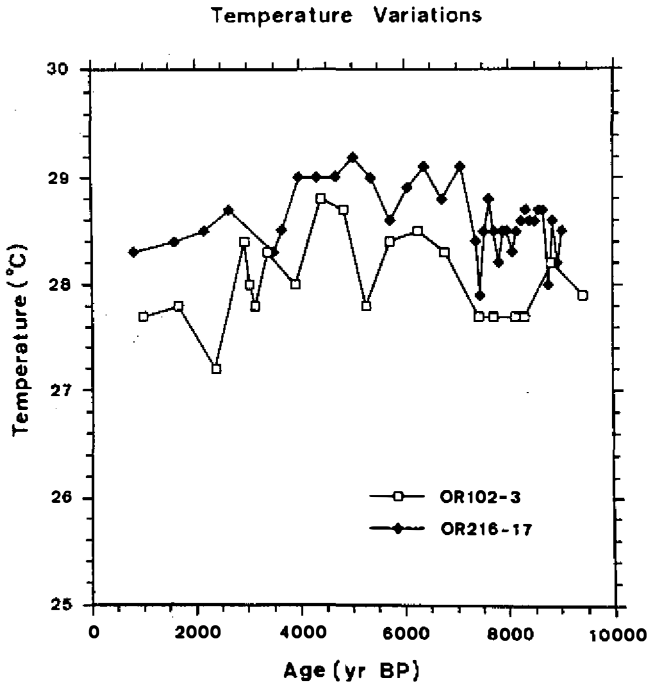

Fig. 4. Temperature variations vs. age in cores OR102-3 and OR216-17.

These two minima were carefully duplicated as other samples did to verify that they are the real signals. Similar freshwater spikes are also found in other Holocene cores raised off eastern Taiwan in previous studies (Wang *et al.*, 1985). Normally, a freshwater source contributes both depleted carbon and oxygen isotopes for the sea surface waters. But corresponding carbon isotope anomalies are not found in OR102-3 as freshwater spikes showed in other cores. The main reason for this discrepancy may be due to heavier carbon isotope compositions in rivers of southeastern Taiwan. Heavy δ^{13}C values of -0.5$^o/_{oo}$ to -2$^o/_{oo}$ were reported for rivers of eastern Taiwan because they flow through thick and exposed marine marble formations which contain relatively heavy carbon isotope compositions (Lee, 1991). If the two minima in OR102-3 were true freshwater spikes, then the source river water should have similar heavier carbon isotopic compositions. This unusual case illustrates that, under special situations as we presented here, freshwater spikes may not show carbon anomalies for marine isotope records.

These freshwater spikes may be related to precipitation increases over eastern Taiwan during the Holocene. However, the exact timing of freshwater spikes in OR102-3 is first reported here from this well-dated core. The absence of freshwater spikes in core OR216-17 implies that the Kuroshio current, flowed over the location of core OR216-17, but did not reach to that of OR102-3 during the Holocene. Apparently, the Kuroshio current can serve as an effective barrier for freshwater dispersion to cores within its main flow (Figure 1).

Using the δ^{18}O-salinity relationship proposed by Craig and Gordon (1965), the paleosalinities can also be calculated from the deduced δ^{18}O values of the surface seawater (Table 2). Results show that the range of salinity variations of the local surface waters during the Holocene were about 1.7$^o/_{oo}$ for core OR102-3 and 0.8$^o/_{oo}$ for core OR216-17 (Figure 5) and are well within observed habitat ranges for *G . sacculifer* (Pastouret *et al.*, 1978).

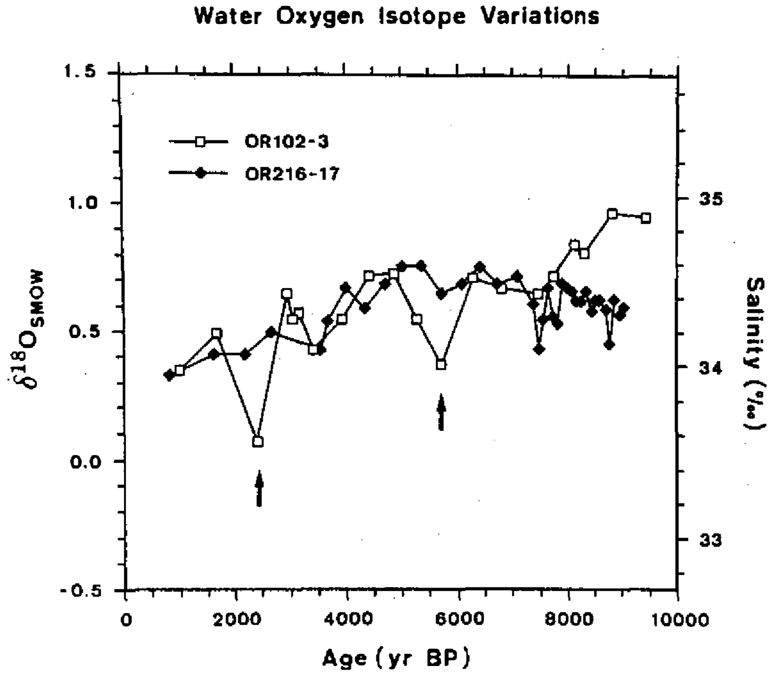

Fig. 5. Oxygen isotope and salinity variations of surface seawater vs. age in cores OR102-3 and OR216-17 (arrow heads indicate inferred freshwater spikes).

In summary, temperature records generated by transfer functions from two cores raised off eastern Taiwan show that the temperatures of surface seawater remained relatively high (27 - 29°C) for the past 9000 yrs. Estimated temperatures between 4000 and 7000 yrs B.P. are relatively warmer than those of other Holocene times, and might be related to the hypsithermal period of the Holocene. The amplitudes of the oxygen isotopic records of surface dwelling foraminifera from these two cores are primarily a reflection of oxygen isotopic variations of local seawater. Fresh water spikes detected in OR102-3 may be related to precipitation increases over eastern Taiwan during the middle and late Holocene period.

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REFERENCES

Bard, E., 1988: Correction of accelerator mass spectrometry ^{14}C ages measured in planktonic foraminifera: paleoceanographic implications. *Paleoceanography*, **3**, 635-645.

Berger, W. H., and J. S. Killingley, 1977: Glacial-Holocene Transition in deep-sea carbonates: Selective dissolution and the stable isotope signal. *Science*, **197**, 563-566.

Berger, W. H., J. S. Killingley, and E. Vincent, 1978a: Stable isotopes in deep-sea carbonates: Box Core ERDC-92, West Equatorial Pacific. *Oceanol. Acta*, **1**, 203-216.

Berger, W. H., L. Diester-Haass, and J. S. Killingley, 1978b: Upwelling off North-West Africa: the Holocene decrease as seen in carbon isotopes and sedimentological indicators. *Oceanol. Acta*, **1**, 3-7.

Chu, T. Y., 1974: The fluctuations of the Kuroshio current in the eastern sea area of Taiwan. *Acta Oceanogr. Taiwanica*, **4**, 1-12.

Craig, H., 1965: The measurement of oxygen isotope paleotemperature. In: E. Tongiorgi (Ed.), Stable Isotopes in Oceanographic Studies and Paleotemperatures, Spoleto, Pisa, 3-24.

Craig, H., and L. I. Gordon, 1965: Deuterium and oxygen-18 variations in the ocean and the marine atmosphere. In: E. Tongiorgi (Ed.), Stable Isotopes in Oceanographic Studies and Paleotemperatures, Spoleto, Pisa, 9-130.

Epstein, S., R. Buchsbaum, H. A. Lowenstam, and H. C. Urey, 1953: Revised carbonate-water isotopic temperature scale. *Geol. Soc. Am. Bull.*, **64**, 1315-1326.

Fan, K. L., 1985: STD measurements in the seas around Taiwan during 1977-1983. Institute of Oceanography, National Taiwan University, Special Publication No. 44, 337pp.

Fan, K. L., 1987: STD measurements in the seas around Taiwan during 1983-1985. Institute of Oceanography, National Taiwan University, Special Publication No. 51, 183pp.

Imbrie, L., and N. G. Kipp, 1971: A new micropaleontological method for quantitative paleoclimatology: Application to a Late Pleistocene Caribbean core. In: K. K. Turekian, (Ed.), The Late Cenozoic Glacial Ages, Yale University Press, New Haven, Conn., 71-181.

Lee, W. Y., 1991: A preliminary study on stable carbon isotope of Kuroshio and adjacent water masses. MS thesis, National Sun Yat-Sun University, 60pp (in Chinese).

Martinson, D. G., N. G. Pisias, J. D. Hays, J. Imbrie, Jr. T. C. Moore, and N. J. Shackleton, 1987: Age dating and the orbital theory of the Ice Ages: Development of a high-resolution 0 to 300,000-year chronostratigraphy. *Quat. Res.*, **27**, 1-29.

Pastouret, L., H. Chamley, G. Delibrias, J. C. Duplessy, and J. Thiede, 1978: Late Quaternary climatic changes in western tropical Africa deduced from deep-sea sedimentation off the Niger delta. *Oceanol. Acta*, **1**, 217-232.

Shieh, Y. T., M. P. Chen, and C. H. Wang, 1991: The indication of paleoceanography from carbon and oxygen isotope records of Holocene planktonic forams in sediment core OR216-17 off northern Lutao, southeastern Taiwan. *Acta Oceano. Taiwanica*, 27, 122-131 (in Chinese).

Stuiver, M., and H. A. Polach, 1977: Reporting of ^{14}C data: *Radiocarbon*, **19**, 355-363.

Thompson, P. R., 1981: Planktonic foraminifera in the western Northern Pacific during the past 150,000 years: comparison of modern and fossil assemblages. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **35**, 241-279.

Wang, C. H., J. C. Chen, and K. K. Liu, 1985: Stable isotope records from Holocene deep-sea sediments off northeastern Taiwan. *Bull. Inst. Earth Sci., Academia Sinica*, **5**, 59-66.

Wang, C. H., and J. C. Chen, 1988: Oxygen and carbon isotopes of planktonic foraminifera in core Leg 4-6 from the southern Okinawa Trough. *Proc. Geol. Soc. China*, **31**, 219-225.