

Age Model and Oxygen Isotope Stratigraphy of Site ODP1202 in the Southern Okinawa Trough, Northwestern Pacific

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ABSTRACT

The two sedimentary sequences drilled at Holes 1202B and 1202D were correlated based upon direct lithologic observation, shipboard logging of magnetic susceptibility, and bulk density to form a stacked record of 410 m in length. Calcareous nannofossil and planktic foraminiferal occurrences confine the bottom of the record to be younger than 85 ka, whereas the sediments in the interval ~225 - 280 mbsf in Hole 1202D are apparently of turbidite origin. Eleven AMS carbon-14 datings of planktic foraminifera and scaphopod samples from Hole 1202B suggest that the upper 110 m has a continuous record dating back over the past 28 thousand years.

An oxygen isotope stratigraphy based upon planktic foraminifera *Neoglobobulimina dutertrei* was established from the stacked sequence. The upper part of the $\delta^{18}\text{O}$ profile can be well correlated to that from the central Okinawa Trough site DGKS9603 (Li et al. 2001) in both trend and absolute values whereas the lower part is considered to belong to marine oxygen isotope stage 4. The sedimentation rates have been always high at this site, ranging from 1.5 to 16 meters per thousand years.

(Key words: Age model, Oxygen isotope stratigraphy, Okinawa Trough, Quaternary)

1. INTRODUCTION

The two eyes of history are geography and chronology.

James A. Carfield (1831 - 1881)

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By its very nature that younger sediments were superimposed on the older ones, sedimentary record provides a direct record of events in chronological order, yet, only in a relative sense. To know the exact rate of changes recorded in a sedimentary sequence, one needs to have knowledge of absolute dates of such events. To decipher the lead and lag of events recorded in different sequences and regions, one ought to make precise age determination and correlation among different records. Before inferring any evolutionary scenarios for a sedimentary record under investigation, a major challenge has always been how to establish a reliable chronological framework.

The main thrust of this paper is to establish a chronological framework for two cores obtained from the ODP Site 1202, Leg 195 in the Okinawa Trough, northwest Pacific (Fig. 1). Site 1202 was designed to obtain a high-resolution record of paleoceanographic changes of the Kuroshio during the late Quaternary from the southern slope of the southernmost Okinawa Trough. A total of four holes were drilled from a water depth of 1274 m at 24°48'N, 122°30'E. The sedimentary sequences obtained from the four holes vary from 97.5 m to 410 m in length (Fig. 2).

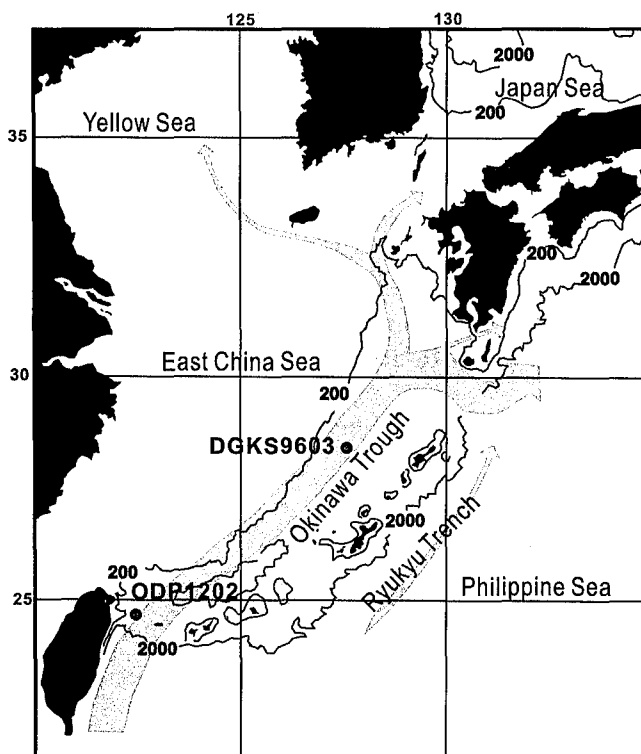


Fig. 1. Locations of two sedimentary cores (ODP1202 and DGKS9603) discussed in this study in the Okinawa Trough. Both sites are distributed along the main path of Kuroshio marked by the gray belt. Contour lines: 200 m and 2000 m in depth.

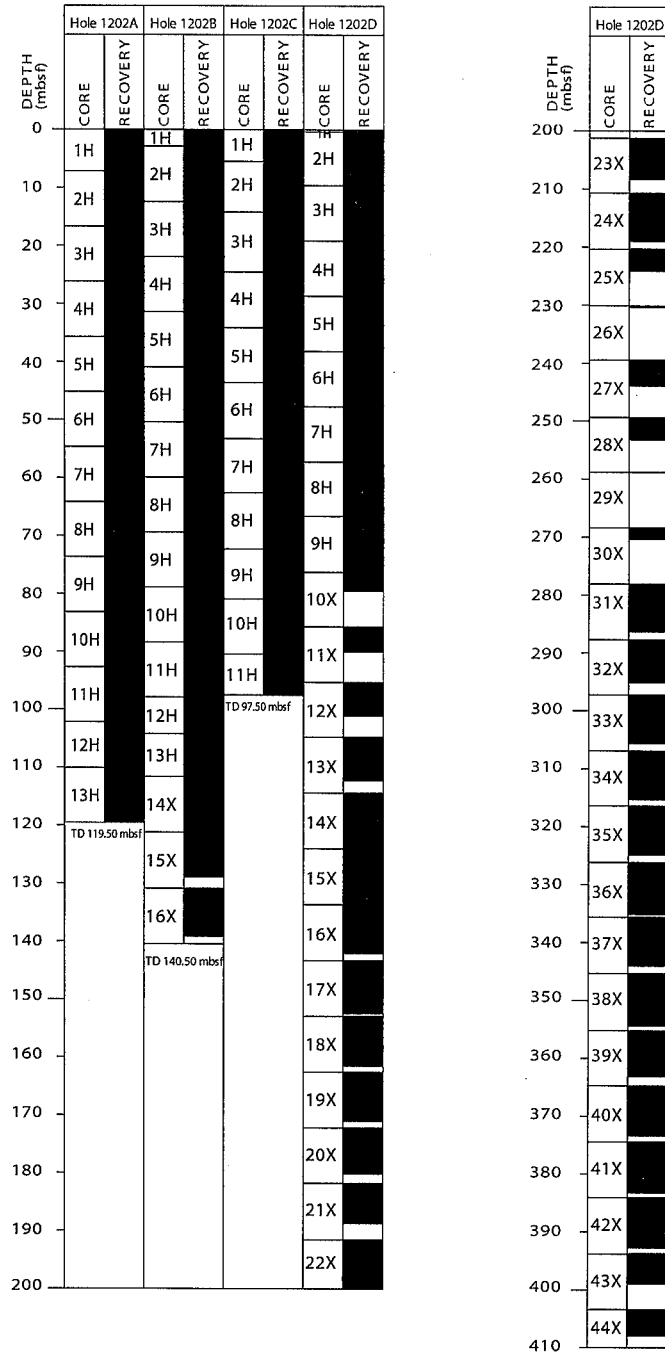


Fig. 2. Recovery of sedimentary sequences by Advanced Piston Cores (abbreviated by H) and Extended Core Barrels (X) in ODP Holes 1202B and 1202D. The core depths are recorded as meters below sea floor (mbsf).

Because time constraints did not permit a splicing of the sedimentary sequences cored from the four holes using shipboard measurements of physical properties, all the cores are reported in terms of meters below sea floor (mbsf) instead of composite depth. Only the intervals within 0 - 140 mbsf of the four holes were run through the Multisensor Track (MST) during Leg 195 whereas the lower sections recovered from depths between 140 and 410 mbsf in Hole 1202D were run through the MST during Leg 196. The MST measured volume magnetic susceptibility (MSL), density using gamma ray attenuation (GRA), and *P*-wave velocity (Shipboard Scientific Party 2002). A comparison of the GRA bulk density measurements made during Legs 195 and 196 on samples from Hole 1202D suggests that the measurements made during Leg 196 were not reliable. The bulk density values were $\sim 0.3 - 0.5 \text{ g cm}^{-3}$ lower than the Leg 195 measurements for the same depths (0 - 140 mbsf). The reduction of density is apparently caused by desiccation or pooling of water (Shipboard Scientific Party 2002). The magnetic susceptibility and density profiles show an excellent correlation between holes on a scale of meters, but the noise caused by gas expansion voids precluded correlation at smaller scales ($< 1 \text{ m}$), and therefore, these holes could not be spliced to make a composite record (Shipboard Scientific Party 2002). It was decided that Holes 1202B and 1202D were to be sampled for all post-cruise studies.

This study attempts to correlate the top 140 meters of these two holes using lithologic and physical properties. In addition, an age model is established for the stacked sequence based upon carbon-14 dating and oxygen isotope stratigraphy of biogenic carbonates.

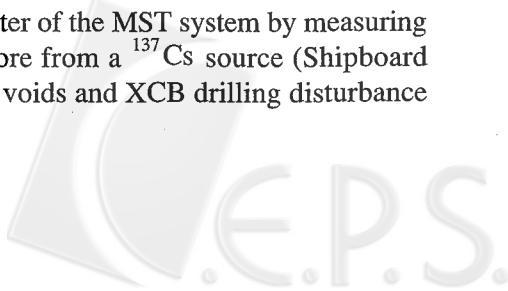
2. MATERIAL AND METHODS

Correlation between Holes 1202B and 1202D

A detailed observation of lithologic variation of Holes 1202B and 1202D was conducted at the ODP Gulf Repository, Texas A & M University (see Huang et al. 2005). Unique occurrences of pumice, layers of concentrated echinoderm spines and enriched pelecypoda were employed as lithologic markers for correlation. For instance, a pumice layer was observed at 85.03 m in Hole 1202B, correspondingly the highest magnetic susceptibility of about 6000×10^{-5} (SI units) was recorded by the MST at about the same depth (note that this peak value is off the scale of Fig. 3). This particular layer of pumice with high magnetic susceptibility was also observed at the depth of 79.56 m in Hole 1202D (Fig. 3).

In addition, profiles of volume magnetic susceptibility and density (derived from gamma-ray attenuation) were used to assist correlation. Magnetic susceptibility is the degree to which a material can be magnetized by an external magnetic field; it, in turn, is a function of the amount and kind of magnetic minerals in a sample. Magnetic susceptibility thus reflects lithologic variation. In this study, it was measured at 5-cm intervals along the core providing a high-resolution record.

The bulk density was gauged by the GRA densiometer of the MST system by measuring the attenuation of gamma rays traveling through the core from a ^{137}Cs source (Shipboard Scientific party 2002). The noise introduced by the gas voids and XCB drilling disturbance



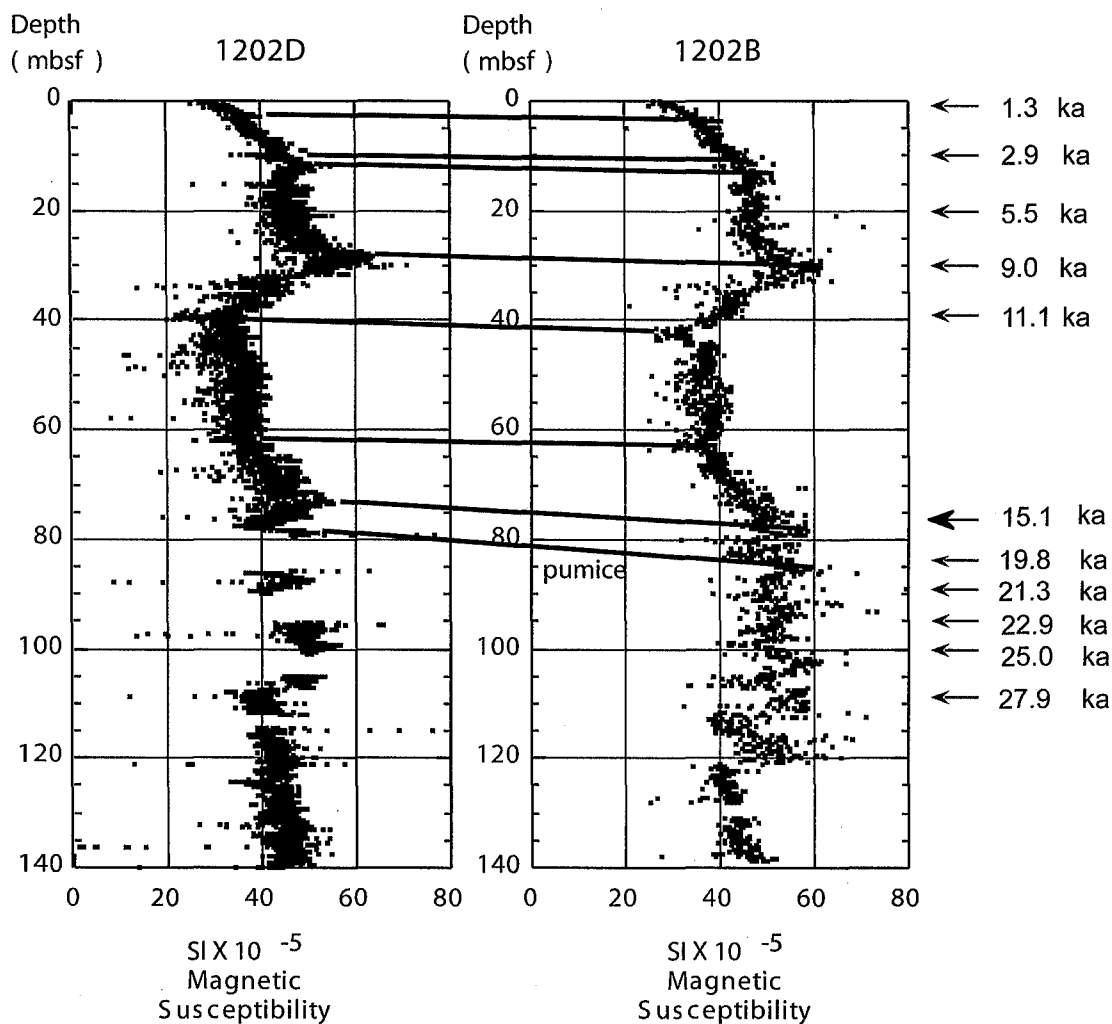


Fig. 3. Correlation between ODP Holes 1202B and 1202D based upon volume magnetic susceptibility. The raw data were adopted from on board measurements during Leg 195 (Shipboard Scientific Party 2002). The pumice layer was marked by high magnetic susceptibility (off the limit of the plots) and validated by direct observation of the core during a post-cruise examination. Also marked are Carbon-14 dates in thousand years (ka) of calendar age for Hole B.

has made the correlation difficult at scales of < 1 m. As a result, we used only the highest density values as the best estimates for the bulk density of the measured sediments (Fig. 4).

Correlations between these two holes were made separately based upon the above-mentioned criteria or profiles. Most of the correlation lines are consistent among the three sets (Figs. 3 and 4), while the discrepant ones were then evaluated individually. Those correlation

lines that show the best consistency were retained and listed in Table 1. For instance, the pumice layer at ~85 mbsf in Hole 1202B shows the highest magnetic susceptibility and a generally low range of bulk density (Figs. 3 and 4), the corresponding interval in Hole 1202D is positioned at ~79 mbsf just above a coring break. The four coring breaks in the interval 80 - 115 mbsf in Hole 1202D make it difficult to correlate the sequence with Hole 1202B. We

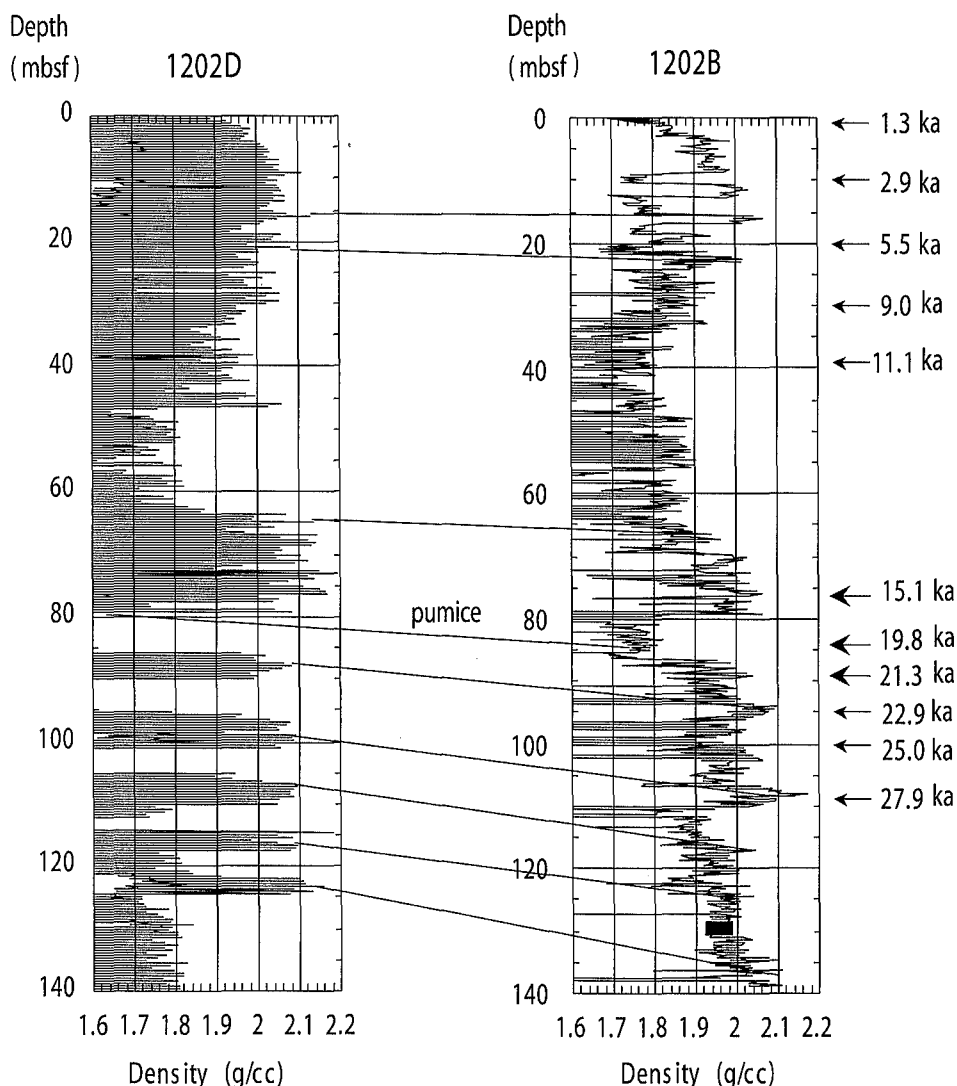


Fig. 4. Correlation between ODP Holes 1202B and 1202D based upon characteristics of bulk density measured by the GRA densiometer of the Multi-Sensor Track (MST) system on board Leg 195 (Shipboard Scientific party 2002). The pumice layer serves as a benchmark marker. Also marked are Carbon-14 dates in thousand years (ka) of calendar age for Hole B.

Table 1. Correlation tie-points between Holes 1202B and D and corresponding ages in Hole 1202B.

MD1202B	MD1202D	Marker	Calendar age BP
3.65m	2.86m	mag. suscep. peak	1.60 ka
11.50m	11.44m	mag. suscep. peak	3.05 ka
16.20m	16.10m	density peak	4.33 ka
22.40m	20.90m	density peak	6.10 ka
22.79m	21.08m	echinoderm-rich	6.23 ka
27.11m	26.04m	pelecypod-rich	7.61 ka
30.20m	29.92m	mag. suscep. peak	8.60 ka
42.05m	40.00m	mag. suscep. minimum	11.36 ka
50.05m	48.78m	mag. suscep. minimum	12.21 ka
63.55m	62.00m	mag. suscep. peak	13.65 ka
66.31m	64.80m	density peak	13.94 ka
78.60m	73.20m	mag. suscep. peak	16.01 ka
85.03m	79.56m	pumice layer	20.18 ka
94.10m	87.80m	density peak	22.43 ka
108.10m	99.20m	density peak	27.53 ka
117.20m	107.20m	density peak	28.61 ka
124.40m	117.00m	density peak	29.41 ka
136.20m	123.00m	density peak	31.74 ka

assumed that Hole 1202D recovered only high-density materials (silt and clay) via the Extended Core Barrel (XCB), and therefore, the recovered sections were correlated to the intervals of high bulk density in Hole 1202B (Fig. 4). Magnetic susceptibility was used to make further constraints and to assist in correlation. Consequently, the interval between 125 and 140 mbsf in Hole 1202D is of low density and finds no corresponding interval in Hole 1202B.

AMS C-14 Dating

Samples were obtained from the ODP Repository every 1.5 m from Hole 1202B (0.5 - 142 mbsf) and 1202D (143.9 - 407.0 m). More than 300 specimens of surface-water dwelling planktic foraminifera, including *Globigerinoides* spp. and *Orbulina universa*, were picked exhaustively from the > 250 μ size fraction of 10 selected intervals where there were sufficient foraminifera. For sample 1202B 1H2W-36-47 cm (1.92 mbsf), a scaphopod was picked for analysis. CO₂ gas, yielded from the picked specimens, was sent to the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences, New Zealand for AMS dating. The

reported C-14 ages were converted to “calendar ages” using the CALIB rev 4.4 Program (<http://radiocarbon.pa.qub.ac.uk/calib/>). In the conversion, we adopted a $\Delta R = 35 \pm 25$ years (the local difference in reservoir age from 400 years in the southern Okinawa Trough) as determined from annually banded corals of Ishigaki Island (Hideshima et al. 2001). The calibrated ages were then converted into thousand years BP (ka before AD1950) (Table 2). For those conventional radiocarbon ages older than 20,265 yrBP, the dates were converted to calendar ages using the polynomial equation of Bard et al. (1998):

$$[\text{cal BP}] = -3.0126 \times 10^{-6} \times [^{14}\text{C age BP}]^2 + 1.2896 \times [^{14}\text{C age BP}] - 1005.$$

Table 2. AMS Carbon-14 dating results for ODP Hole 1202B. The conversion of ^{14}C age to calendar age was done using CALIB 4.4 (<http://radiocarbon.pa.qub.ac.uk/calib/>).

Sample ID	Material	Depth (mbsf)	^{14}C year BP	Margin	Calendar year BP
1H2W-36-47	scaphopoda	1.92	1783	45	1295
2H6W-34-46cm + 50-56	planktics	10.88	3153	40	2886
3H6W-34-45.5+50-56	planktics	20.48	5135	45	5486
4HCC	planktics	31.35	8554	70	8971
5H6W-40-56cm	planktics	39.35	10205	55	11074
9H6W-40-56cm	planktics	77.35	13340	95	15111
10H4W	planktics	83.79	17111	70	19753
10HCC	planktics	88.35	18478	90	21328
11H6W-40-50	planktics	96.35	19810	100	22859
12H3W-40-56	planktics	101.38	20910	120	24998
13H4W	planktics	109.1	23430	140	27911

Stable Isotope Analysis of Planktic Foraminifera

Specimens of *Neoglobobadrina dutertrei*, a thermocline-dwelling planktic foraminifera, were picked the 355~425 μ size fraction were picked for oxygen and carbon isotopic analyses. Cleaned specimens were reacted with phosphoric acid at 90°C in the heating block of the Micromass MultiCarb automation system. The CO_2 gas generated was analyzed using a Micromass IsoPrime isotope ratio mass spectrometer housed in the Department of Earth Sciences, National Taiwan Normal University. The carbonate standard NBS-19 was used to calibrate to the Peedee belemnite (PDB) standard. The average precision of the NBS standard analyzed was 0.03 ‰ for $\delta^{13}\text{C}$ and 0.08 ‰ for $\delta^{18}\text{O}$ (N = 113).

3. RESULTS AND DISCUSSION

Age Model and Sedimentation Rates of ODP1202B

The depth-age relationship of Hole 1202B is well constrained by the 11 carbon-14 dating points (Fig. 5A). The sedimentation rates are relatively high, varying between 1.5 and 9 m kyr⁻¹. Such high sedimentation rates are unprecedented in the Okinawa Trough and somewhat unexpected. Previous published results from southern Okinawa Trough sites recorded sedimentation rates of about 50 cm kyr⁻¹. For instance, Site RN96-PC 1 at 24°58.5'N, 122°56.1'E records an average rate of 40 cm kyr⁻¹ (Ujiie et al. 2003) while at a northern site, Core 255 (25°12'N, 123°07'E) has an average rate of 60 cm kyr⁻¹ for the last 8 kyr (Jian et al. 2000). For the similar time interval of the last 20 kyr, Hole 1202B has accumulated ~30 meters of sediment, showing an average sedimentation rate almost one order higher than other sites. The large accumulation of sediments at this site suggests that Hole 1202B is located at a localized deposition center. The sediments are mainly composed of fine terrestrial clay and silt. The coarse-sized fraction (> 63 μ), made up chiefly of foraminifers, only accounts for 1 to 6% of the sediments (Fig. 5C). The percentage of coarse fraction decreased to less than 1% in the intervals with the highest sedimentation rate (~9 m kyr⁻¹) from 11 to 15 ka (Figs. 5B and C). The scarcity of foraminifers in this interval due to dilution by enormous terrestrial material has caused difficulty in obtaining enough specimens for C-14 dating and isotopic analysis.

Correlation between Hole 1202B and 1202D

The upper 0 - 80 m of the Holes 1202B and 1202D can be well correlated based upon lithologic marker beds and magnetic susceptibility variation (Figs. 3 and 4). Recovery breaks in the lower section of Hole 1202D makes the record fragmentary and difficult to correlate with Hole 1202B. Nevertheless, all the five discontinuously recovered intervals in Hole 1202D between 85 and 125 mbsf show high bulk density, conceivably of silt and clay in component. These beds are correlated with the high-density counterparts in Hole 1202B (Fig. 4). As a result, 18 tie points are recognized, and an age model has been built for the top 140 m of Hole 1202D (Table 1).

Biostratigraphic Constrains of Hole 1202D

The age-diagnostic marker for nannofossil Zone NN21, *Emiliana huxleyi*, occurs persistently throughout the sequence, suggesting that the drilled sequence is younger than 0.25 Ma (Berggren et al. 1995; Nash et al. 1998). Furthermore, the relative abundance of *E. huxleyi* is comparable to that of *Gephyrocapsa oceanica* throughout the sequence (Su and Wei 2005), suggesting that the bottom of Hole 1202D is still within the acme zone of *E. huxleyi*. The age of the bottom of the acme zone in the Pacific has been dated to be at 85 ka (Berggren et al. 1995). The absence of pink *Globigerinoides ruber*, on the other hand, delimits the sequence to be younger than 127 ka (Lee et al. 1999; Wei et al. 2000). Moreover, the persistent appearance of orange-colored tiny *Zeaglobigerina rubescens* indicates that the sediments recovered are young and fresh (Parker and Berger 1971).

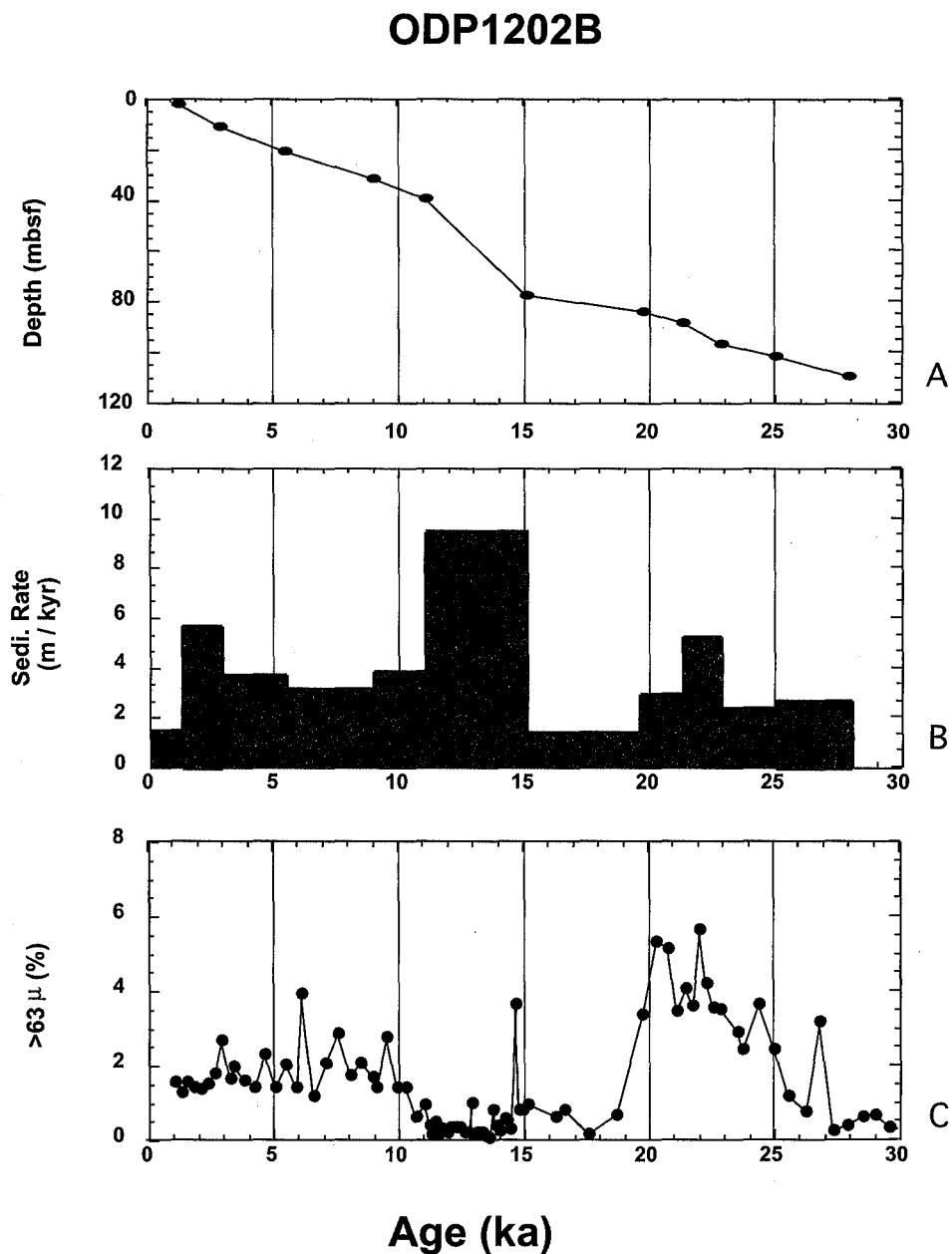


Fig. 5. (A) Depth-age relationship of Hole 1202B based upon AMS carbon-14 dating of 11 samples. (B) Sedimentation rates of the upper 110 m of Hole 1202B. (C) Variation in percentage of coarse size fraction (> 63 μ) through the last 30 kyr in Hole 1202B.

Oxygen Isotope Stratigraphy

Oxygen isotope stratigraphy provides another reliable means for correlation and age assignment. Figure 6 shows a stacked profile of oxygen isotopic ratio compiled from Holes 1202B and 1202D, with correlation lines with the $\delta^{18}\text{O}$ profile of DGKS9603 generated from the same species, *N. dutertrei*, in a central Okinawa Trough site (Li et al. 2002). As assisted by dense AMS carbon-14 dating in both cores, the oxygen isotope profiles of the past 35 kyr shows an excellent match between the two sites (Fig. 7). Profiles of carbon isotopes also show good agreement between the two sites except for the lower most sections (Fig. 7).

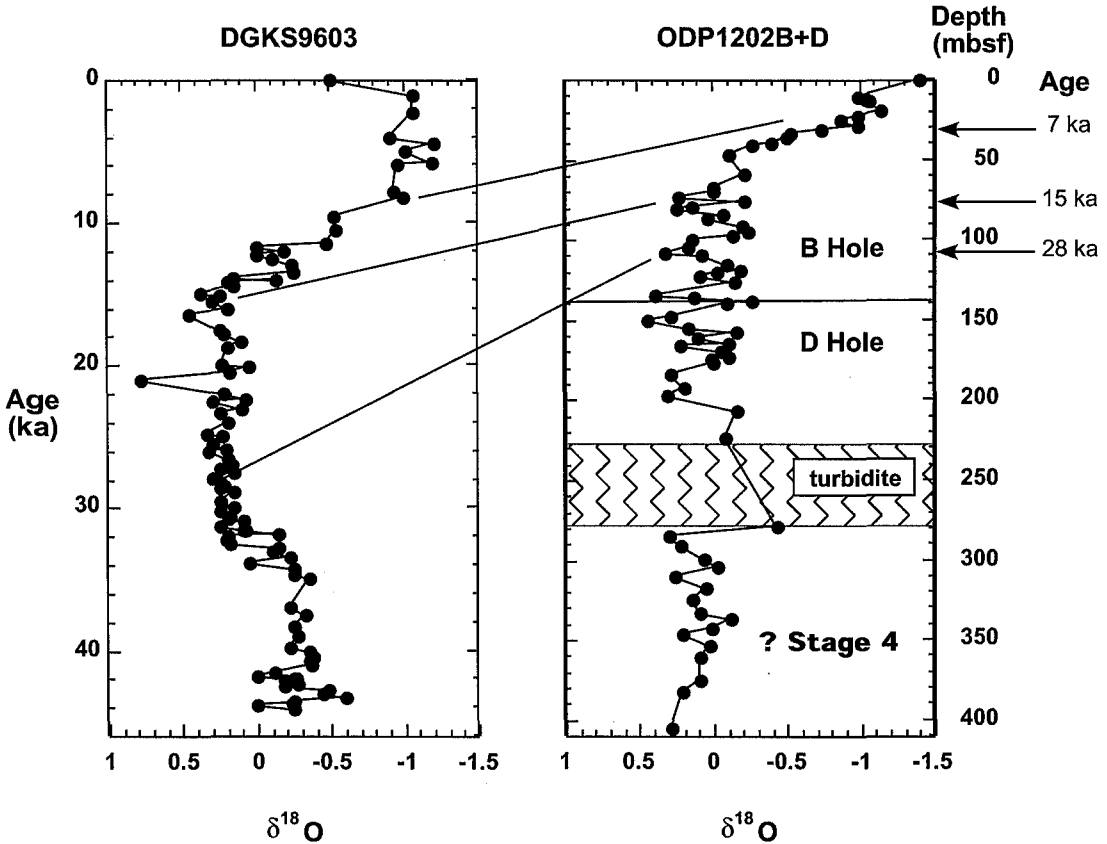


Fig. 6. Oxygen isotopic profiles of Site DGKS9603 and ODP 1202. Both profiles are generated from the same species, *Neogloboquadrina dutertrei* but from different size fractions. For Site DGKS, the foraminiferal specimens are from 300 - 355 μ (Li et al. 2001), whereas that of Hole 1202 are from 355 - 425 μ . Correlation between these two sites in the upper sections is aided by AMS C-14 dating of both sequences.

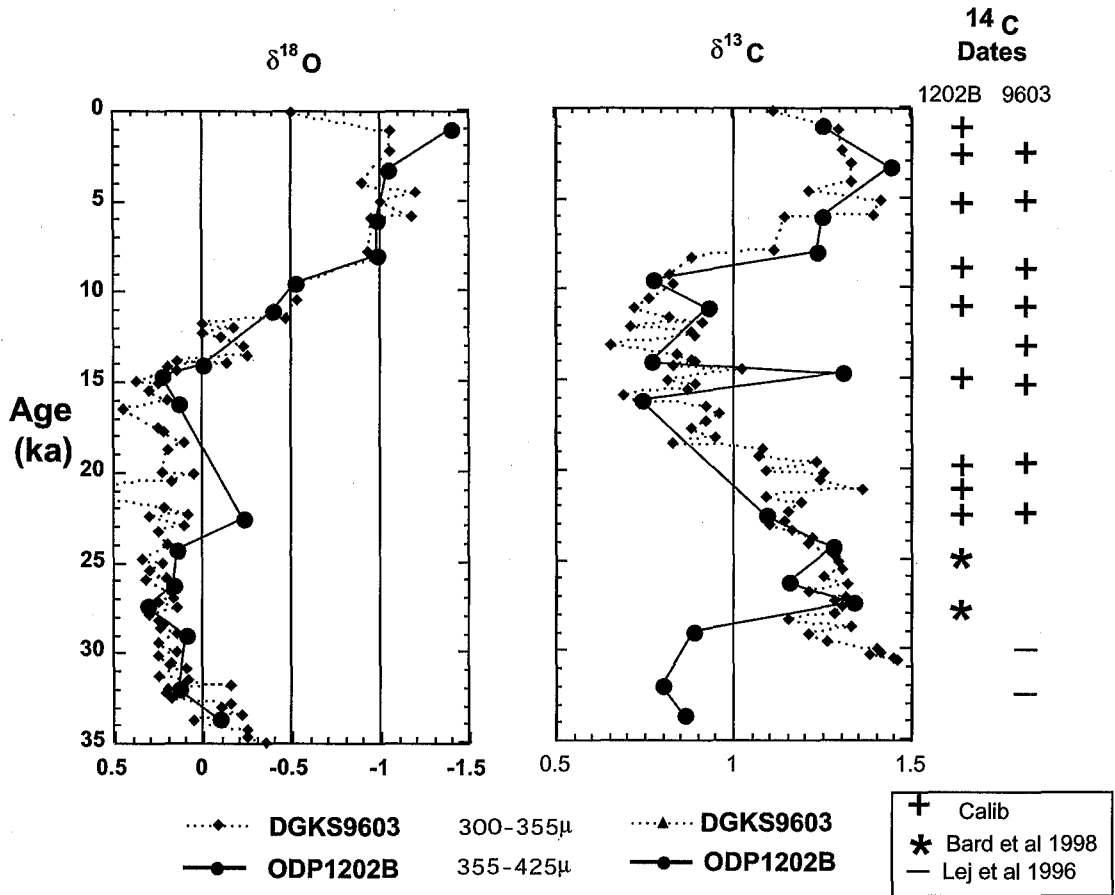


Fig. 7. Time-series of oxygen and carbon isotopic variation in Hole 1202B and DGKS9603. The oxygen isotope data of DGKS9603 are from Li et al (2001) while the carbon isotope data are from Li et al. (2002). Both sequences are furnished with many AMS C-14 dates converted to calendar year before present. The AMS C-14 dating points are marked by +. Note that the calendar age conversion for C-14 ages older than 25,000 years in Core DGKS9603 was done based upon Lej et al. (1996).

The lower sections in Hole 1202D are hard to correlate with that of DGKS9603, partly due to the lack of distinctive characteristics in the profiles and partly due to the sedimentary break caused by the “turbidite” between 230 and 280 mbsf (Fig. 6). The $\delta^{18}\text{O}$ values in the interval between 140 - 228 mbsf are comparable to that of the lower part of Hole 1202B, presumably being of marine oxygen isotope stages (MIS) 2 and 3 (Fig. 6). On the other hand, the $\delta^{18}\text{O}$ values of the lower part (below the “turbidite” interval) are still in the same range of positive values, and cannot be correlated with the lower part of Site DGKS9603. As con-

strained by nannofossil and planktic foraminiferal biostratigraphic evidence (discussed in the previous section), the bottom of Hole 1202D cannot be older than 85 ka. This brackets the questioned section to be in the range of MIS 4.

To further determine the age for Hole 1202D (280 - 410 mbsf), we did a wiggle matching of the $\delta^{18}\text{O}$ profile with that of *G. ruber* generated from Site MD972142 in the South China Sea (Wei et al. 2003) and the result is shown in Fig. 8. The upper sections (138 to 207 mbsf) of Hole 1202D are correlated to MIS 3 with an age assignment of 33.7 to 39.7 ka while the lower part (278 to 406 mbsf) is correlated with MIS 4 between 52 and 68 ka (Table 3). The correlation is somewhat tentative, because the two species that yielded the oxygen isotopic signals have dwelled in different levels of the water column, and the hydrological conditions of the Okinawa Trough are not necessarily the same as that in the South China Sea. However, for the time being, the lack of comparable $\delta^{18}\text{O}$ record generated from *N. dutertrei* from Asian subtropical waters hinders a more decisive correlation.

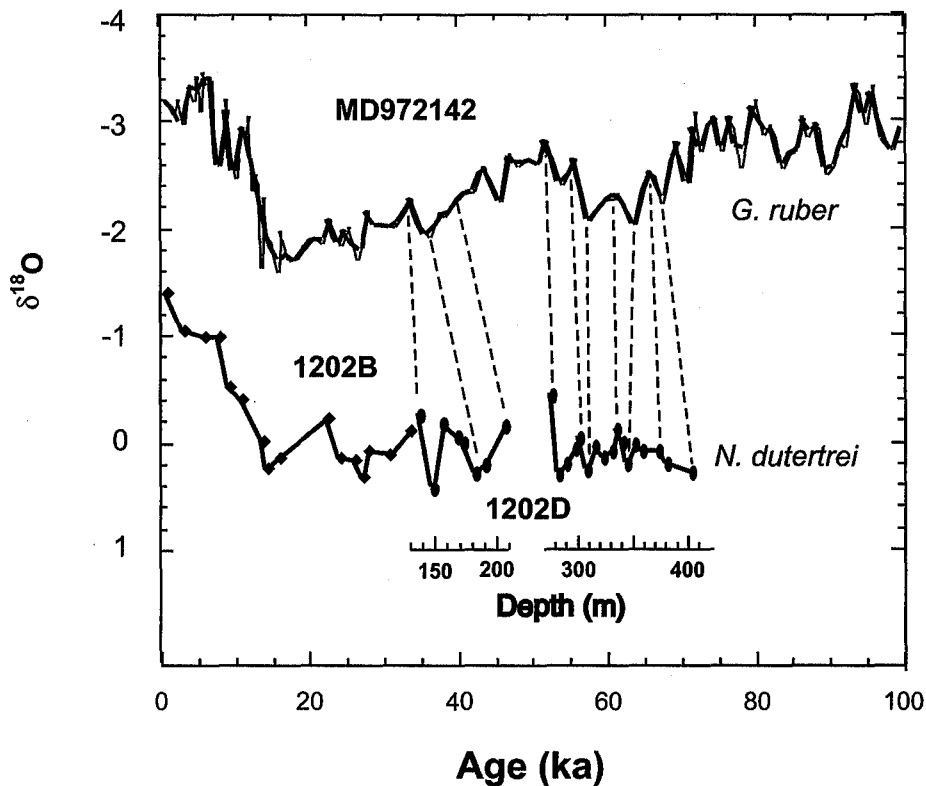


Fig. 8. Correlation of oxygen isotopic profiles between Hole 1202 and MD972142 (Wei et al. 2003). The bold curve of MD972142 represents the moving average of the raw data represented by the thin lines.

Table 3. Depth-age relationship in Hole 1202D.

<u>Depth (m)</u>	<u>Age (ka)</u>
2.86	1.60
11.44	3.05
16.10	4.33
20.90	6.10
21.08	6.23
26.04	7.61
29.92	8.60
40.00	11.36
48.78	12.21
62.00	13.65
64.80	13.94
73.20	16.01
79.56	20.18
87.80	22.43
99.20	27.53
107.20	30.97
138.80	33.70
184.00	36.45
207.32	39.73
278.60	52.00
310.50	57.84
336.40	62.05
346.10	64.00
405.50	67.56

Age model for ODP Site 1202

Furnished by various means of stratigraphic correlation and age determination, Holes 1202B and 1202D can be correlated, dated and stacked. The resultant $\delta^{18}\text{O}$ profile plotted against age is presented in the bottom panel of Fig. 9. The sedimentation rates are generally high throughout the record, ranging from ~ 2 to 16 m kyr^{-1} . The extremely high rates calculated for the uppermost and lowermost sections of Hole 1202D might be erroneous as they are poorly correlated. However, one could confidently conclude that the sequence generally reflects high accumulation rates, with an average of $\sim 5 \text{ m kyr}^{-1}$. The sediments are composed

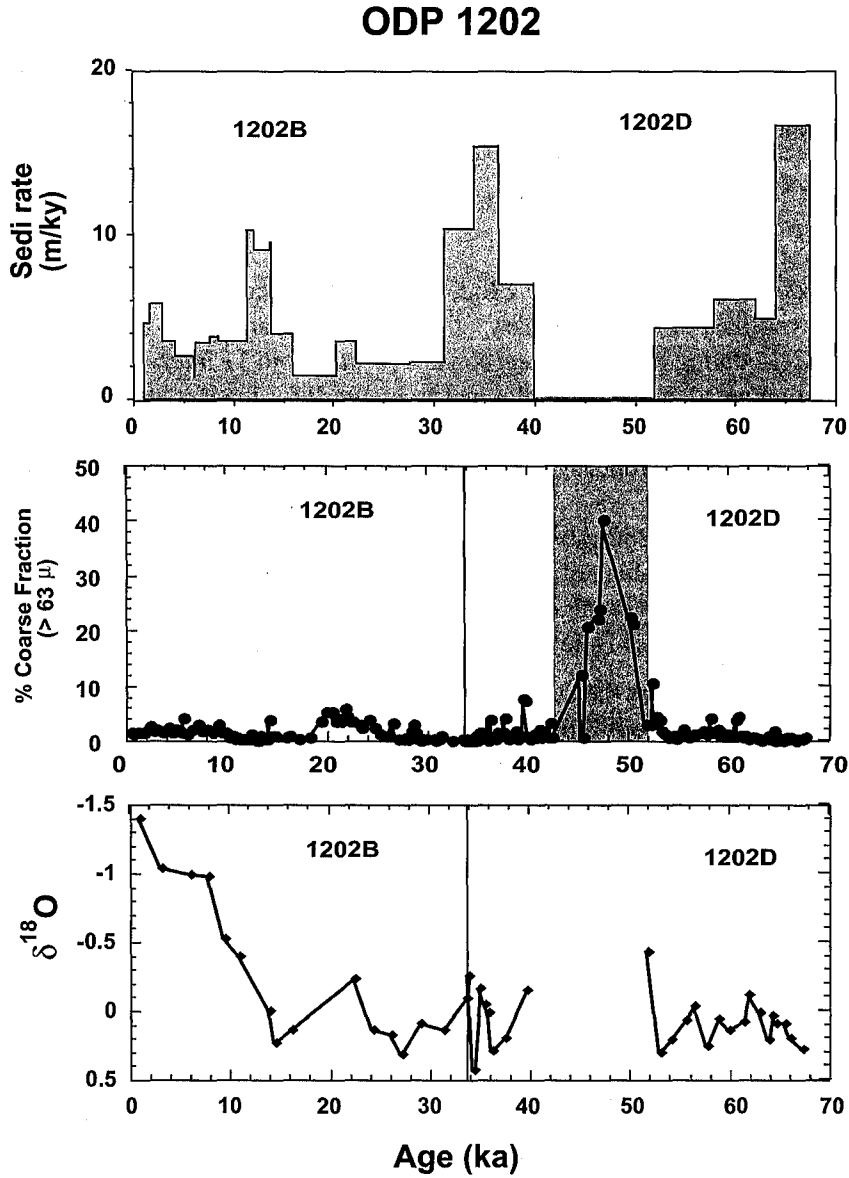


Fig. 9. Upper panel: Sedimentation rates of the past 68 kyr of Hole 1202D. The depth-age pairs for the age model are listed in Table 3. Middle: Percentage of coarse fraction (> 63 μ) of Hole 1202B and 1202D. The shaded pattern marks the interval of high abundance of sandy particles in the middle section of Hole 1202D, implying the occurrence of turbidites during 42 to 52 ka. Lower panel: Stacked oxygen isotopic profiles of Holes 1202B and 1202D.

mainly of fine terrestrial silt and clay. The only exception is the interval between 230 - 280 mbsf, consisting with coarse sandy particles (Fig. 9). This interval is probably of turbidite origin (Huang et al. 2005). The high amount of accumulation of terrestrial sediments at this site has contributed to an extremely high-resolution record; however, it has significantly diluted microfossil components.

4. SUMMARY

Despite its deep penetration of Site 1202, the recovered sedimentary sequence appears to record only the very last of the Quaternary - the last 70 thousand years or so.

The AMS C-14 dating of biogenic carbonates picked from 11 intervals down to 110 mbsf allows constructing an adequate chronological framework for the last 28 thousand years. The average sedimentation rate of the topmost 110 meters of the record is about 4.2 m kyr^{-1} , a rate of an order higher than that reported previously from the neighboring sites in the southern Okinawa Trough.

The interval from 230~280 mbsf is of poor recovery, and the recovered sediments are sandy, marked by high percentage of coarse sediments ($> 63 \mu$). This ~50 m interval is apparently a turbidite dominated interval, deposited presumably somewhere between 40 and 52 ka (Fig. 9, Table 3). The bottom of Hole 1202D is still younger than marine oxygen isotope stage 5.

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