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3. Leg 195 Synthesis: Site 1202—Late Quaternary Sedimentation and Paleoceanography in the Southern Okinawa Trough[1]

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ABSTRACT

Ocean Drilling Program (ODP) Site 1202 was designed to study the sedimentary history of the southern Okinawa Trough and the paleoceanographic changes of the Kuroshio Current in the northwestern Pacific Ocean. This synthesis reviews some of the major results of recent studies of the southern Okinawa Trough and summarizes the principal findings of Leg 195 onboard scientists and shore-based postcruise researchers.

Despite its deep penetration to 410 m below seafloor, Site 1202 records only the past ~68 k.y., mainly because of the high sedimentation rate at this site. The lower sections contain numerous turbidite layers with distinctive phased sources of sediment supply. The upper 130 m (0–30 ka) is free of turbidite disturbance and provides a high-resolution record for magnetic, sedimentologic, and paleoceanographic studies. Between 30 and 11 ka, when sea level was low, the sediments came from both East China and Taiwan. After 11 ka, Taiwan sources became dominant and the Kuroshio Current entered the Okinawa Trough. Sea-surface temperature rose from ~23°C during the last glacial and deglaciation interval to ~26°C in the Holocene. The monotonous Holocene sediment provides a high-resolution, high-quality record of magnetic intensity, which may serve as a good reference for regional and global correlation.

[1]Wei, K.-Y., 2006. Leg 195 synthesis: Site 1202—late Quaternary sedimentation and paleoceanography in the southern Okinawa Trough. *In* Shinohara, M., Salisbury, M.H., and Richter, C. (Eds.), *Proc. ODP, Sci. Results,* 195, 1–31 [Online]. Available from World Wide Web: <http://www-odp.tamu.edu/publications/195_SR/VOLUME/SYNTH/SYNTH3.PDF>. [Cited YYYY-MM-DD]
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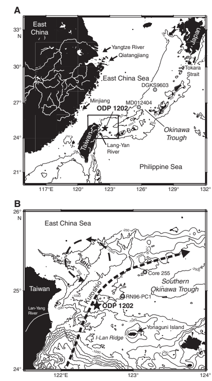
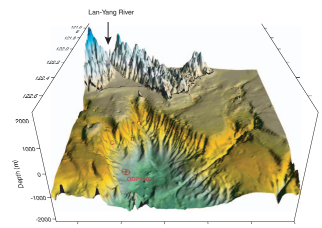
INTRODUCTION

Between 28 April and 1 May 2001, four holes were drilled at Site 1202 (24°48′N, 122°30′E) off northeast Taiwan during Ocean Drilling Program (ODP) Leg 195 (Fig. **F1**). This marked the first international scientific drilling of the Okinawa Trough under the auspices of the Deep Sea Drilling Project (DSDP) or ODP. The site is located on a gentle topographic high on the southern slope of the southern Okinawa Trough at 1274 m water depth (Fig. **F2**). Site 1202 was designed to obtain a high-resolution record of paleoceanographic changes of the Kuroshio Current during the latest Quaternary (Salisbury, Shinohara, Richter, et al., 2002).

F1. Location map of Site 1202, p. 18.



F2. Topography of the Southern Okinawa Trough and northeast corner of Taiwan, p. 19.



The Kuroshio Current is the largest western boundary surface current in the North Pacific Ocean (e.g., Hsueh, 2000; Liu et al., 2003; Lee and Chao, 2003; Liang et al., 2003). It plays an important role in the meridional transport of heat, mass, momentum, and moisture from the Western Pacific Warm Pool to high latitudes in the North Pacific. Its role in the Pacific is as important as that of the Gulf Stream in the North Atlantic, but very little is known of its evolution except during the latest Quaternary. Because most seafloor in the western Pacific is deeper than the carbonate compensation depth (CCD) (~3500 m), it is difficult to obtain a suitable sequence to study the origin and history of the Kuroshio Current. Site 1202 was chosen for drilling because it lies under the path of the Kuroshio Current and its shallow water depth in the southern Okinawa Trough.

Deep scientific drilling had never before been conducted in the Okinawa Trough. Drilling at Site 1202 would open a deep time window into the sedimentary record, allowing long-term paleoceanographic changes and the effects of tectonics and sea-level fluctuations on sedimentation in the trough to be examined for the first time. However, because the sedimentation rate at Site 1202 (3.4 m/k.y.) was much higher than those previously documented (~0.5–1.1 m/k.y.), the sedimentary record spanned less than ~120 k.y. despite the deep penetration to 408 meters below seafloor (mbsf) (Shipboard Scientific Party, 2002). Almost concurrent with the Leg 195 expedition, the *Marion Dufrense* cored a series of piston cores in the southern Okinawa Trough for the International Marine Past Global Change Study (IMAGES) program. The results from Site 1202, compared with dating results from IMAGES cores and other recent studies of sediment traps and short box-cores in the area, explain well the high sedimentation rates observed in the deep hole.

Although some Site 1202 postcruise studies are still under way, this article synthesizes the available results. Most of the postcruise research results were assembled for publication in a special issue of *Terrestrial, Atmospheric, and Oceanic Sciences* in 2005 (TAO, 16[1]). Other sources include several personal communications from researchers. To facilitate interpretation of the results from Site 1202, the results of recent tectonic, oceanographic, and sedimentologic studies of the region are also summarized.

TECTONIC SETTING

The Okinawa Trough, extending from southwest Kyushu, Japan, to the Lan-Yang plain of northeastern Taiwan, is a tectonically active intracontinental backarc basin situated between the East China Sea continental shelf and the Ryukyu arc (Uyeda, 1977; Lee et al., 1980;

Letouzey and Kimura, 1985; Sibuet et al., 1987, 1998; Sibuet and Hsu, 1997; Park et al., 1998). Opening of the Okinawa Trough commenced during the middle Miocene (~10–6 Ma) (Sibuet et al., 1995; Miki, 1995), but it became inactive after the arc-continent collision of Taiwan and the Philippine Sea plate. As opening ceased, deposits of the Shimajiri Group (mainly of Pliocene in age) accumulated over a wide area on the East China Sea continental shelf and the forearc region (Park et al., 1998). Between ~1.7 and 0.5 Ma, the Southern Okinawa Trough and Ryukyu arc was formed (Ujiié, 1994). Meanwhile, postcollisional lithospheric extension occurred in the northern Taiwan mountain belt, making room for southwestward propagation of backarc rifting (Teng, 1996; Wang et al., 1999; Shinjo et al., 1999; Chung et al., 2000). Based on magnetic and geochronological data, Miki (1995) proposed that the second phase of opening was characterized by wedge mode opening in the southern Okinawa Trough and parallel rifting in the central Okinawa Trough.

Sibuet et al. (1998) suggested that the initiation of subsidence and block faulting along the central axis of the Okinawa Trough took place at ~2 Ma, based on the supposed development of sedimentary basins between the Okinawa Trough and Kyushu (Letouzey and Kimura, 1985; Kimura, 1985) and the uplift of the Ryukyu arc during the Pleistocene between 1.7 and 0.5 Ma (Ujiié, 1994). Although the age of the penultimate rifting of Okinawa Trough is still open to further investigation, most researchers agree that the last extension has occurred during the past 0.1 m.y. (Furukawa et al., 1991; Sibuet et al., 1995; see also Sibuet et al., 1998, for a review) on the basis of seismic correlation with drilling results (Tsuburaya and Sata, 1985). Furthermore, Ujiié et al. (1991) and Ujiié and Ujiié (1999) suggested that there was a bridge connecting the central–southern part of the Ryukyu arc with Taiwan, preventing inflow of the Kuroshio Current to the Okinawa Trough during the last glacial stage.

OCEANOGRAPHIC SETTING AND DEPOSITIONAL REGIME

Circulation in the Okinawa Trough, the deepest part of the East China Sea, is governed by the prevailing East Asia monsoons and remote forcing from the Kuroshio Current and Taiwan Strait (Lee and Chao, 2003). Besides the Kuroshio Current, the other major input of water to the Okinawa Trough is riverine influx from the Yangtze River (928 km^3/yr) (Zhang et al., 1990), Minjiang River (58.4 km^3/yr), Qiantangjiang River (35.3 km^3/yr) (Lee and Chao, 2003), and Lan-Yang River (2.73 km^3/yr) (Hsu et al., 2004). The main ocean current affecting the southern Okinawa Trough is the Kuroshio, which flows northward along the eastern coast of Taiwan with a maximum speed 100 cm/s and a width of 100 km (Liang et al., 2003). The water transported by the Kuroshio Current, estimated by Nitani (1972), Chu (1976), and Liu (1983), varies from 19 to 47 Sv (Sverdrup: 1 Sv = 10^6 m^3/s). The estimated depth of the Kuroshio Current varies from a few hundred meters to 1000 m. The Kuroshio Current enters the Okinawa Trough through Suao-Yonaguni Pass on the I-Lan Ridge and then flows along the shelf break (Fig. **F1B**) (Liang et al., 2003). Inside the Okinawa Trough the main axis of the Kuroshio Current varies seasonally, moving close to the coast in winter and away from the coast in summer (Sun, 1987).

The northeastward-flowing Kuroshio Current follows the curved isobaths and leaves the East China Sea through Tokara Strait, south of Kyushu, Japan (Fig. F1). Upon encroaching the continental shelf, part of the Kuroshio flows southwest and forms permanent cyclonic eddies above Mien-Hua Canyon (MHC in Fig. F1B) (Hsu et al., 1998, 2000; Tang et al., 2000; Liang et al., 2003). These eddies represent important cells of water mixing and a mechanism for trapping and sucking suspended sediments into the canyons, from which they are subsequently transported laterally by contour currents (Hsu et al., 1998).

The southern Okinawa Trough has the highest sedimentation rates in the Okinawa Trough. Documented modern sedimentation rates reach 0.10–0.95 cm/yr (Chung and Chang, 1995), 10 times higher than those observed in the northern and central trough (<0.01–0.08 cm/yr) (Ikehara, 1995). Present sedimentation rates near Site 1202 are estimated to be 0.30–0.50 cm/yr (Lee et al., 2004).

The mouth of the Lan-Yang River flows directly into the southern end of the Okinawa Trough (Figs. F1, F2). The annual sediment discharge of the Lan-Yang River amounts to 6–9 Mt/yr, making it a major source of sediment supply to the trough (Jeng et al., 2003; Kao and Liu, 2000; Liu et al., 2003; Hsu et al., 2004). The distribution of sand, silt, and clay grains in seafloor sediments indicates that the sediment discharged from the Lan-Yang River can be transported up to 70 km offshore. However, the silt and clay portions are entrained in the Kuroshio Current and dispersed farther toward the northeast before being deposited preferentially on the southeast side of the Kuroshio (Chen and Kuo, 1980; Lee et al., 2004). Contour lines of silt and clay contents in percent are semiparallel to the topographic contours (Chen and Kuo, 1980). The silt and clay contents at Site 1202 were estimated to be 35% and 45%, respectively (Chen et al., 1992).

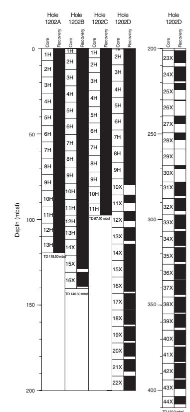
Regarding the dispersal of sediments from East China Sea to the southern trough, Liu et al. (2000) proposed a conceptual model to illustrate the possible routes of sediment transport: the Yangtze River delivers 478 Mt/yr of sediment onto the East China Sea shelf (Milliman and Meade, 1983), and a substantial fraction of the fine-grained sediments from the Yangtze River is transported by the China Coastal Current southward along the coast of mainland China (Beardsley et al., 1985; Milliman et al., 1985; Chao, 1991). In the northernmost section of the Taiwan Strait, the sediments are transported eastward to enter the Okinawa Trough (Liu et al., 2003). As the main stream of the Kuroshio Current encounters the shelf break along the northeast rim of the Okinawa Trough, cyclonic eddies form and the southwest arms of the cyclonic eddies send sediments down to the southern Okinawa Trough. Such sediments, together with the fluvial sediments exported from the rivers of eastern Taiwan, are entrained in the eddy and deposited later around the eddy's center (Hsu et al., 1998). The influence of undercurrents at intermediate depths reaches 550–800 m (Hung et al., 1999). The highest modern sedimentation rates have been observed along the southwestern corner of the southern Okinawa Trough, and Site 1202 is situated very near the depocenter (Huh et al., 2004; Lee et al., 2004).

Observations from sediment traps (Hsu et al., 2004) show that the sediment fluxes to the southern Okinawa Trough are much higher than those in other marginal seas and display great temporal and spatial variability. Spatially, the sediment fluxes exhibit a seaward decline from northeastern Taiwan to the central trough. On the continental slope, however, the flux increases with water depth, implying strong lateral transport of lithogenic particles. The temporal variation has a strong positive correlation with water runoff from the Lan-Yang River, whereas the highest fluxes were associated with typhoon-induced floods and, occasionally, with large earthquakes (Hsu et al., 2004; Huh et al., 2004). The Kuroshio Current may transport a significant portion of the fluvial sediment from the east coast of Taiwan (72 Mt/yr) (Water Resources Bureau, 1997) toward the southern Okinawa Trough. Furthermore, based upon regional hydrography and the spatial distribution pattern of particulate Al (as an indicator of the lithogenic component of total suspended matter), Hsu et al. (1998) considered that terrigenous sediment from the rivers of eastern Taiwan is the main source of the southern Okinawa Trough deposition.

LITHOLOGY AND LITHOLOGICAL CORRELATION

At Site 1202, ~760 m of sediment was obtained from four holes. Holes 1202A, 1202B, 1202C, and the upper part of Hole 1202D were drilled using the advanced piston corer (APC), whereas the lower part of Hole 1202D was drilled using the extended core barrel (XCB) (Fig. **F3**). Because of time constraints, only the interval between 0 and 140 mbsf was run on the multisensor track (MST) during Leg 195, whereas the lower section between 140 and 410 mbsf in Hole 1202D was run during Leg 196. The MST measured three physical property parameters: density, magnetic susceptibility, and *P*-wave velocity. A comparison of the 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 Leg 196 bulk density values were 0.3–0.5 g/cm^3 lower than the Leg 195 measurements for the same depths (0–140 mbsf), due to desiccation and/or pooling of water (Shipboard Scientific Party, 2002). Aside from this, magnetic susceptibility and bulk density show good correlation among the holes on a scale of meters, but the noise caused by gas expansion voids hampered correlation at smaller scales (<1 m) and therefore precluded splicing the holes into a composite record (Shipboard Scientific Party, 2002).

F3. Recovery of sediments at Site 1202, p. 20.

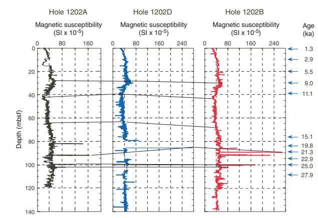


The lower sections below ~130 mbsf at Site 1202 contain numerous turbidite layers. The low recovery between 220 and 280 mbsf in Hole 1202D (Fig. **F3**) is attributed to high sand content. To better understand the occurrence of such turbidite deposits at the site, C.-Y. Huang et al. (2005) conducted a very detailed, quantitative description of all of the cores from Hole 1202D. All visible turbidite structures, such as occurrences of silt/sand layers, grain size grading, basal erosion, cross ripples, detritus composition, and redeposited shallow-water microfossils, were noted. Detailed descriptions of individual cores from Hole 1202D are presented graphically in 41 figures (C.-Y. Huang et al., 2005). In addition, the thickness percentage of silt/sand layers in every core section is calculated and graphically summarized (Fig. **F6A**). The percentages of the coarse fraction (>63 µm) in the bulk sediments show very similar profiles (Fig. **F6B**). It is evident that turbidity current deposition was frequent at this site, particularly in the interval from 175 to 325 mbsf, and peaked between 230 and 280 mbsf (Wei et al., 2005). Only the uppermost 130 m of Holes 1202B and 1202D are free of visible silt/sand layers (C.-Y. Huang et al., 2005).

In the intervals where no sand/silt layers are intercalated, the core is composed of monotonous dark gray hemipelagic clay and fine silt-sized sediments (Salisbury, Shinohara, Richter, et al., 2002). In descending order of abundance, the clay fraction consists of illite, chlorite, kaolinite, and smectite (Diekmann et al., submitted [N1]). Microfossils such as foraminifers and radiolarians are scarce, as shown by their low percentages (<5 wt%) in the coarse fraction (>63 µm) in the uppermost 120 m (0–29 ka) of the section where no turbidites exist (Fig. F6B).

Hole 1202B was chosen as the focus for paleoceanographic and sedimentological studies because of its deep penetration and good recovery (Fig. F3). To make a complete stacked record for Site 1202, the upper section of Hole 1202D was correlated with Hole 1202B using observed lithological characteristics and physical properties by Wei et al. (2005). Similar efforts were conducted to correlate Hole 1202A with Hole 1202B in the current synthesis. As an example, Figure F4 shows the correlation lines among the three holes using volume magnetic susceptibility. Most of the correlation lines are consistent among the three sets; the most consistent are listed in Table T1, along with their assigned ages.

F4. Correlation among using magnetic susceptibility, p. 21.



T1. Correlation depths and ages, p. 29.

T2. AMS dating results, p. 30.

CHRONOLOGY

The chronology of the uppermost 110 m of Hole 1202B (Table T2) has been established by ^{14}C dating performed at the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences, New Zealand. More than 300 specimens of surface water–dwelling planktonic foraminifers, including *Globigerinoides* spp. and *Orbulina universa,* from the >250-µm size fraction of 10 selected intervals were dated. In addition, a scaphopod was picked from interval 195-1202B-1H-2, 36–47 cm (1.92 mbsf) for analysis (Wei et al., 2005). The reported ^{14}C ages were converted to "calendar ages" using CALIB Program (revision 4.4) (radiocarbon.pa.qub.ac.uk/calib). In the conversion, ΔR (the local difference in reservoir age from 400 yr in the southern Okinawa Trough) was assigned as determined from annually banded corals from Ishigaki Island (Hideshima et al., 2001):

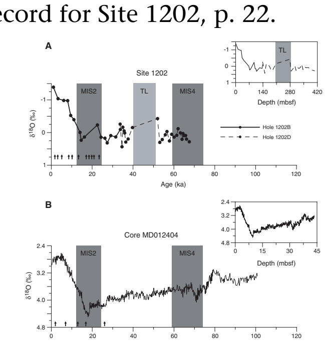
$$\Delta R = 35 \pm 25 \text{ yr.}$$

The calibrated ages were then converted into thousand years before present (BP) (k.y. before AD1950). For those conventional radiocarbon ages older than 20,265 yr BP, the dates were converted to calendar ages using the polynomial equation of Bard et al. (1998):

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

To further establish a chronological framework for the combined stacked records, specimens of *Neogloboquadrina dutertrei,* a thermocline-dwelling planktonic foraminifer, were picked from the 355- to 425-µm size fraction for oxygen and carbon isotopic analyses. The upper part of the resultant $\delta^{18}O$ profile (Fig. F5A) 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 was considered to belong to the marine oxygen isotope Stage (MIS) 4 through correlation with site MD972142 in the South China Sea (Wei et al., 2003b). As a result, the bottom of Hole 1202D is estimated to be ~68 ka (Wei et al., 2005). This conclusion was also supported by Chang et al. (2005), who correlated the oxygen isotope stratigraphy at Site 1202 with that of IMAGES core MD 12404 from the central Okinawa Trough (Fig. F5).

F5. Planktonic foraminiferal $\delta^{18}O$ record for Site 1202, p. 22.



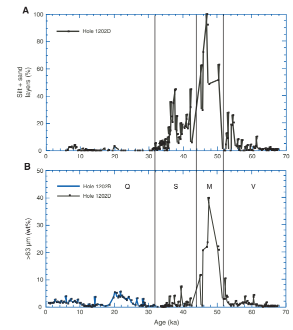
TURBIDITE DEPSITION FROM 68 TO 30 KA

The history of turbidite deposition at Site 1202 can be subdivided into four stages based on the main constituents of the coarse grains in sediment (Figs. F6, F7):

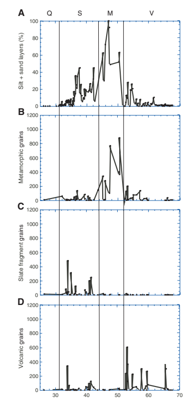
1. A volcanics-dominated stage (V),
2. A stage dominated by metamorphic grains (M),
3. A slate chip-dominated stage (S), and
4. A quiescent stage (Q) when turbidites were absent or negligible.

A brief description and interpretation is given below. According to C.-Y. Huang et al. (2005), during MIS 4, the site was already bathed in deep ocean water, as it is today, as shown by the common occurrence of deep-sea benthic foraminifers. Submarine volcanic eruptions related to back-arc rifting were frequent and therefore supplied more pumice and volcanic grains to the site during MIS 4 and early MIS 3 (65–52 ka) (Fig. F7D). Distal turbidites in the form of fine sandy layers also occurred and became more frequent during this interval. The next 10 k.y. (52–42 ka) witnessed frequent deposition of turbidites and truncations. The turbidite layers can reach up to 15 cm in thickness and are rich in mica flakes and quartz grains, presumably derived from the terrains of Central Range of Taiwan. Microfossils, if present, are almost all displaced biota from the continental shelf (C.-Y. Huang et al., 2005). Occasionally, bark and crustacean remains are present, implying quick burial and proximity to a terrestrial source region. The thickness and frequency of turbidite deposition decreased from 42 to 36 ka and finally decreased to zero by ~32 ka (Figs. F6, F7A). Notably, slate chips became enriched in the turbidite layers after 42 ka and became predominant until 32 ka (Fig. F7C) (C.-Y. Huang et al., 2005). The reason behind such a major change in the composition of the turbidites is not clear. C.-Y. Huang et al. (2005) suggested implicitly that a major switch of transporting conduit may have occurred from an old submarine canyon (Channel C in Fig. F2) to the present channel (Channel A, which connects directly to the mouth of Lan-Yang River). This might have been related to the jumping of rifting axis to the north, or to northward migration of the Lan-Yang River during deltaic development, or a combination of both.

F6. Silt/sand layer thickness and bulk sediment coarse fraction, p. 23.



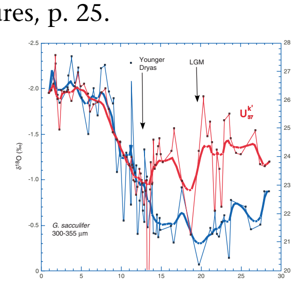
F7. Metamorphic grains, slate chips, and volcanic grains in coarse fraction, p. 24.



PALEOCEANOGRAPHY DURING THE PAST 28 K.Y.

Both sea-surface temperatures (SSTs) reconstructed by $U^{k'}_{37}$ and $\delta^{18}O$ values of the surface-dwelling planktonic foraminifer *Globigerinoides sacculifer* show high-frequency and large-amplitude variations through the last 28 k.y. (Fig. F8) (Zhao et al., 2005). The high variability may be related to the fact that short-term episodic events can be recorded in rapidly deposited sediments. Because the analyses are not necessarily high resolution, a moving average profile best reflects the general history (Fig. F8). The SSTs during the latest Pleistocene (28–10 ka) remained at ~24°C, with the coldest occurring at the Last Glacial Maximum (LGM; 19–18 ka) and the Younger Dryas (13–12 ka), respectively. The SST rose from the LGM to the late Holocene in two steps: the first took place from 18 to 14 ka, before the reversal of the Younger Dr-

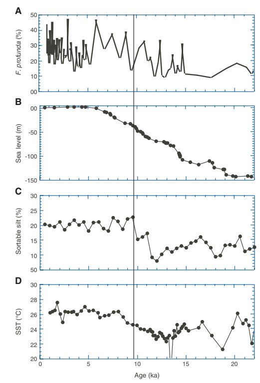
F8. Changes in sea-surface temperatures, p. 25.



yas (13–12 ka), and the second began at 11.5 ka and lasted until 7.0 ka (Fig. **F8**). The second rise of SST is conspicuous, as temperature rose quickly from 22° to 26°C in 3.5 k.y. The trend is also reflected by the parallel lowering in $\delta^{18}O$ values of the planktonic foraminifer *G. sacculifer* (Fig. **F8**). It appears that this second warming trend lasted longer here than in other areas. For instance, the Greenland ice core GISP 2 shows that air temperatures reached Holocene values at ~10 ka and decreased slightly during the Holocene (Stuiver et al., 1995).

Su and Wei (2005) examined calcareous nannofossil assemblages of the past 13 k.y. They found that a major change in floral composition took place at 9 ka. Before 9 ka the nannofossil assemblages were dominated by *Emiliania huxleyi* and *Gephyrocapsa* spp., whereas after 9 ka, deep-dwelling *Florisphaera profunda* became more abundant (Fig. **F9A**) at the expense of *Gephyrocapsa*. Su and Wei (2005) interpreted that such a change implies that the Kuroshio Current reentered into the southern Okinawa Trough at the same time. This interpretation is consistent with the granulometric data that the content of sortable silt (10–63 µm in grain size) reached a high stable value at 9.5 ka (Fig. **F9C**) (see next section for discussion). The timing of the floral change, however, predated the final rise of the SST to stable, high temperature at ~7 ka (Fig. **F9D**). This implies that the floral composition of the calcareous nannoplankton in the southern Okinawa Trough was affected mainly by the invasion of the Kuroshio Current to the trough rather than the local SST change.

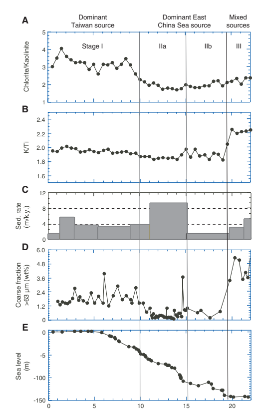
F9. Nannofossils, sea-surface temperature, granulometry, and sea level, p. 26.



CHANGING SEDIMENTARY REGIMES DURING THE PAST 30 K.Y.

The upper 120 m of Hole 1202B, deposited during the past 30 k.y., is free of major turbidite disturbance. The sedimentation rates are relatively high, varying between 1.5 and 9 m/k.y. (Fig. **F10C**) (Wei et al., 2005). Such high sedimentation rates are unprecedented in the Okinawa Trough and were unexpected. Previous published results from southern Okinawa Trough sites recorded sedimentation rates of ~40–115 cm/k.y. For instance, site RN96-PC 1 (24°58.5′N, 122°56.1′E) records an average rate of 40 cm/k.y. and site RN 93-PC5 a rate of 116 cm/k.y. (Ujiié and Ujiié, 1999; Ujiié et al., 2003), site MD12404 (26°38.84′N, 125°48.75′E) shows 50 cm/k.y. (Chang, et al., 2005), and core 255 (25°12′N, 123°7′E) shows 60 cm/k.y. (Jian et al., 2000). Hole 1202B, on the other hand, has accumulated ~30 m of sediments over the last 8 k.y. and thus displays an average sedimentation rate an order of magnitude higher than that at any of the other sites. The high accumulation rate suggests that Site 1202 is located at a localized deposition center. The sediments are mainly composed of fine terrestrial clay and silt (Diekmann et al., submitted [**N1**]). The coarse-sized fraction (>63 µm), made up chiefly of foraminifers, only accounts for 1% to 6% of the sediments (Fig. **F10D**). The coarse fraction decreased to <1% in intervals with the highest sedimentation rate (~9 m/k.y.) from 11 to 15 ka (Fig. **F10C, F10D**).

F10. Sediment characteristics during the past 22 k.y., p. 27.



A chronicle of the changes in the modes and sources of detrital input was inferred based upon sediment granulometry, clay mineralogy, and major element data (Diekmann et al., submitted [**N1**]). Several factors influenced the depositional regimes, including path of the Kuroshio Current, sea level, modes of fluvial runoff, neotectonics, and possibly changes in the monsoon system. In descending order of abundance, the clay mineral assemblage consists of illite (55%–75%), chlorite (15%–25%), kaolinite (5%–13%), and smectites (3%–12%). In Taiwan, illite and chlorite are abundant in widespread slates and schists as well as in soils, whereas kaolinite and smectites only occur locally (Chen, 1973; Dorsey et al., 1988). In contrast, the solid load of the Yangtze River provides conspicuous amounts of kaolinite in addition to illite and chlorite (Chen, 1973). The modern distribution of kaolinite in surfacial sediments in the East China Sea and the Okinawa Trough traces the spread of sediments from the Yangtze River (Aoki and Oinuma, 1974). Here, the chlorite/kaolinite ratio is used to gauge the relative contribution of sediments supplied from Taiwan vs. East China (Fig. F10A). It is clear that the Taiwan source became dominant only during the Holocene.

Grain size data display clearly that there are two major modes of sedimentation in the southern Okinawa Trough: (1) between 30 and 11.5 ka (MIS 3–2), when the sortable silt was low, and (2) afterward, when it was high (Fig. F9C). Apparently, sea level plays a crucial role in regulating the depositional regime. Diekmann et al. (submitted [N1]) interpreted that when sea level was low from 30 to 11.5 ka the Kuroshio Current did not enter the Okinawa Trough and water circulation in the trough was relatively sluggish. The influence of the Kuroshio Current began to increase between 11.5 and 9.5 ka, and the detrital sediment supply from Taiwan increased significantly, reaching a high stable value at 9 ka (Fig. F10A). It appears that only when sea level rose to –50 to –40 m relative to the present stand did the Kuroshio Current begin to invade the trough. On the other hand, Ujiié and Ujiié (1999) postulated that a major tectonic subsidence of Ilan Ridge occurred at 10 ka. More recently, Ujiié et al. (2003) inferred from planktonic foraminiferal census data that the Kuroshio Current strengthened after 13 ka and reached its full strength at ~10 ka.

The last 25 k.y. can be subdivided into three stages based upon all available proxies (Fig. F10).

Stage III

Before 19.5 ka (Stage III in Fig. F10), when sea level was low, the sediments deposited at Site 1202 were an admixture from Taiwan island and East China continent sources as indicated by the intermediate chlorite/kaolinite ratio (Fig. F10A); because of low sea level, both the input sources were located relatively close to the site, and the percentage of the coarse fraction (>63 µm) was high (Fig. F10C). The sediments deposited during Stage III are characterized by high K/Ti (Fig. F10B). The potassium is derived from K-bearing feldspars and sheet silicates from both the East China continent and Taiwan and is particularly enriched in the clays. On the other hand, titanium is found in both sources but is higher in the upper continent crust, indicating provenance of the East China continent (Yang et al., 2004).

Stage II

When sea level began to rise during the early stage of deglaciation between 19.5 and 15 ka (Stage IIb) (Fig. F10E), the sediment source from the Yangtze River became more distant and sedimentation rates began to drop. Meanwhile, the rising sea level washed and winnowed the East China Sea continental shelf and continuously released reworked fine particles into the water column. This washing and winnowing processes became more intense when the sea level rose quickly during Stage IIa (15–11 ka) (Fig. F10E), and the sedimentation rates reached their highest levels of 9 m/k.y. (Fig. F10C). The sediments were dominated by fine particles (Figs. F9C, F10D) transported from the East China Sea continental shelf, and clay content reached a maximum of ~40%. The reason that Taiwan became a less important source during 15–11 ka is because a good portion of the sediments supplied by the Lan-Yang River was trapped in the Lan-Yang Plain. Wei et al. (2003a) showed that sediments as thick as 230 m accumulated between 15 and 3 ka to form the Lan-Yang Delta. Sedimentation of the Lan-Yang Delta was in aggredation mode from 15 to 5 ka and switched to progradation after 5 ka (Chen et al., 2004). Thus, the southern Okinawa Trough received less sediment from the Lan-Yang River during Stage IIa, particularly the period of rapid sea level rise.

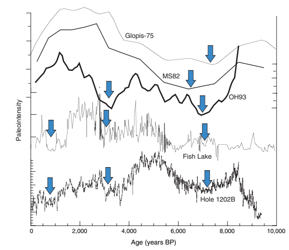
Transition

Between 11 and 9 ka, when sea level rose to a stand of approximately –50 m to –40 m relative to the present sea level (Lambeck et al., 2002), the Kuroshio Current entered the Okinawa Trough and the sediments from Taiwan began to increase, as indicated by an increase in the chlorite/kaolinite ratio (Fig. F10A). This interval is coined as "transitional" by Diekmann et al. (submitted [N1]). The Taiwanese source became dominant after 9 ka and has maintained a stable, high level of contribution until the present. The increase in sediment grain size (Figs. F9C, F10D) is believed to reflect the closeness of the sediment source (Taiwan) on one hand and a stronger current velocity on the other hand. The increase in abundance of sortable silt (10–63 µm size range) implies an increase in strength of the contour currents (McCave et al., 1995). Overall, the increase in grain size, particularly the sortable silt portion, is related to the vigor of the Kuroshio Current, which enhances both surface and undercurrents in the southern Okinawa Trough. Diekmann et al. (submitted [N1]) envisioned that once the strong Kuroshio Current entered the trough after 11 ka, it transported the coarse terrigenous silts from Taiwan over long distance into the southern Okinawa Trough, and the associated eddies formed on the edge of the continental shelf enhanced trapping and sucking of sediments into deeper water levels through the Mien-Hua Canyon systems, feeding the lateral-flowing nepholoid layers along the continental slope. Therefore, the increase in sortable silt content at ~11 ka marks a major change in the circulation regime brought about mainly by invasion of the Kuroshio Current into the trough. The strength of the Kuroshio Current remained constant throughout the Holocene (Fig. F9C). Interestingly, there was an increase in sediment input from Taiwan at ~1.5 ka that resulted in an increase in the chlorite/kaolinite ratio and a higher sedimentation rate (Fig. F10A, F10C), even though the percentage of sortable silt remained the same. The increase in the sedimentation rate is mainly due to a higher input of sediments, caused probably by heavier precipitation or more frequent seismic activity. Coincidentally, pollen and grain size data from sediments from northern Taiwan suggest that the precipitation increased at ~2–1.5 ka (Liew and Tseng, 1999; Liew and Hsieh, 2000).

MAGNETIC PALEOINTENSITY DURING THE HOLOCENE

Recent studies have shown that millennial-scale variation of the geomagnetic field has the potential for global correlation. To further explore this possibility, Richter et al. (in press) measured magnetic secular variation and relative paleointensity in continuous U-channel samples from the uppermost 36 m of Hole 1202B. Owing to the high sedimentation rate (394 cm/k.y., on average), it was possible to obtain an extremely high resolution (~10 yr) record of magnetic paleointensity of the entire Holocene, the first of this kind for East Asia. Comparison of this record with records from other regions revealed that there is a broad similarity among the various records but also showed some major discrepancies (Fig. **F11**). The major difference shown by Hole 1202B is the existence of a major paleointensity peak during the middle Holocene (between 5.0 and 4.5 ka), whereas other records tend to have high values from 3.0 to 1.5 ka. These discrepancies make it difficult to use paleointensity curves for global correlation at present. Nevertheless, the overall similarity between two high-resolution records, namely Hole 1202B and Fish Lake in Oregon, shows that the method has promise.

F11. Comparison of Holocene magnetic paleointensity to other records, p. 28.



OTHER CHARACTERISTICS OF SEDIMENTS

Jean et al. (2005) isolated and identified indigenous bacteria strains from the sediments of Holes 1202A and 1202D to a depth of 358 mbsf. The isolated sulfate-reducing bacteria show a strong phylogenetic affinity to *Bacillus subtilis* and *Pseudomonas putida* strains. Culturing experiments revealed that the isolated bacteria could survive extreme conditions including temperatures >45°C, salinities as high as 60‰–65‰ and pH values as high as 10. Although these bacteria can be adapted to either aerobic or anaerobic conditions and were capable of consuming Fe, Cu^{2+}, Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}, and F^{-}, no associated biogenic minerals have been identified in the sediments to date.

To assess fluid migration and water-sediment interactions at various depths in the drill hole, K.-F. Huang et al. (2005) measured major ions, boron concentrations, and boron isotopic ratios in pore water squeezed from Site 1202 cores. They found that the major ions and boron do not behave conservatively and are likely to be affected by sedimentary diagenetic processes. Apparently, boron released from clays is one of the most important boron sources in pore water, but other processes, such as precipitation of carbonates, low-temperature ash alteration, and interaction with terrigenous sediments also play important roles.

SUMMARY: LATE QUATERNARY HISTORY OF THE SOUTHERN OKINAWA TROUGH

Rifting of the Okinawa Trough reactivated at ~100 ka, causing the trough to propagate southwest and the Lan-Yang Plain of northern Taiwan (an extension of the Okinawa Trough) to subside. During MIS 4, tentatively dated as 68–52 ka, rifting-related volcanic activity was common in the vicinity of Site 1202, contributing volcanic grains and causing small-scale turbidity currents (Fig. **F7D**). Several large-scale turbidity currents occurred and laid down thick turbidites between ~52 and 44 ka in response to major seismic activity or slope failure. It is possible that slope failure occurred in Channel C (Fig. **F2**), which was likely filled in part with metamorphic fragments transported from East Taiwan before the current Lan-Yang River drainage was formed. This explains why the coarse grains in the turbidites consist predominantly of metamorphic fragments (Fig. **F7B**). The source then switched to the newly developed Lan-Yang River and its extended canyon (Channel A in Fig. **F2**), causing the coarse grains of the turbidites to become dominated by slate chips derived from the Lan-Yang drainage (Fig. **F7C**). After 32 ka, the turbidity currents decreased and the site received mainly fine-grained sediments from the sea surface as well as nepholoid layers.

Between 30 and 19.5 ka, the site received sediments mainly from East China and, to a lesser extent, Taiwan. Sea level was at low stand, and the shore line of East China was near the continental break, feeding sediments from the Yangtze and other rivers directly into Okinawa Trough. Fluctuation of sea level caused reworking and sorting of coastal sediments, leading to the deposition of fine particles at Site 1202. After the LGM, sea level began to rise at ~19 ka (Fig. **F9B**). Initially, the sea level rise may have caused some sediments to become trapped on the continental shelf and the sedimentation rates to decrease slightly (Fig. **F10C**), but the major contributor of sediments was still river runoff from East China, as reflected by the low chlorite/kaolinite ratio (Fig. **F10A**). Sea level rose rapidly from 15 to 11 ka and caused stronger flushing and mobilization of sorted, reworked fine particles from the East China Sea continental shelf, resulting in the deposition of thick layers of clay-rich sediments at rates as high as 9 m/k.y. Once sea level rose to –50 m relative to the current stand, the Kuroshio Current entered the Okinawa Trough and dramatically changed the circulation pattern of surface and undercurrents so that sediments derived from Taiwan have mostly been transported to Site 1202 by surface currents and subsurface nepholoid layers. The strength of the Kuroshio Current fluctuated slightly during the Holocene, and the supply of sediments from Taiwan increased at ~1.5 ka (Fig. **F10A**) in response to increased precipitation in northern Taiwan (Liew and Tseng, 1999; Liew and Hsieh, 2000). The entrance of the Kuroshio Current caused *Florisphaera profunda,* a deep-dwelling coccolithophorid, to increase in the Okinawa Trough (Fig. **F9A**); meanwhile, SST rose continuously during 13 to 8 ka from 23° to 26.5°C (Fig. **F9E**).

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Figure F1. **A.** Location map of ODP Site 1202 and other cores mentioned in the text. **B.** Close-up from A, showing the details of bathymetry and the paths of the Kuroshio Current and its branches adjacent to Site 1202.

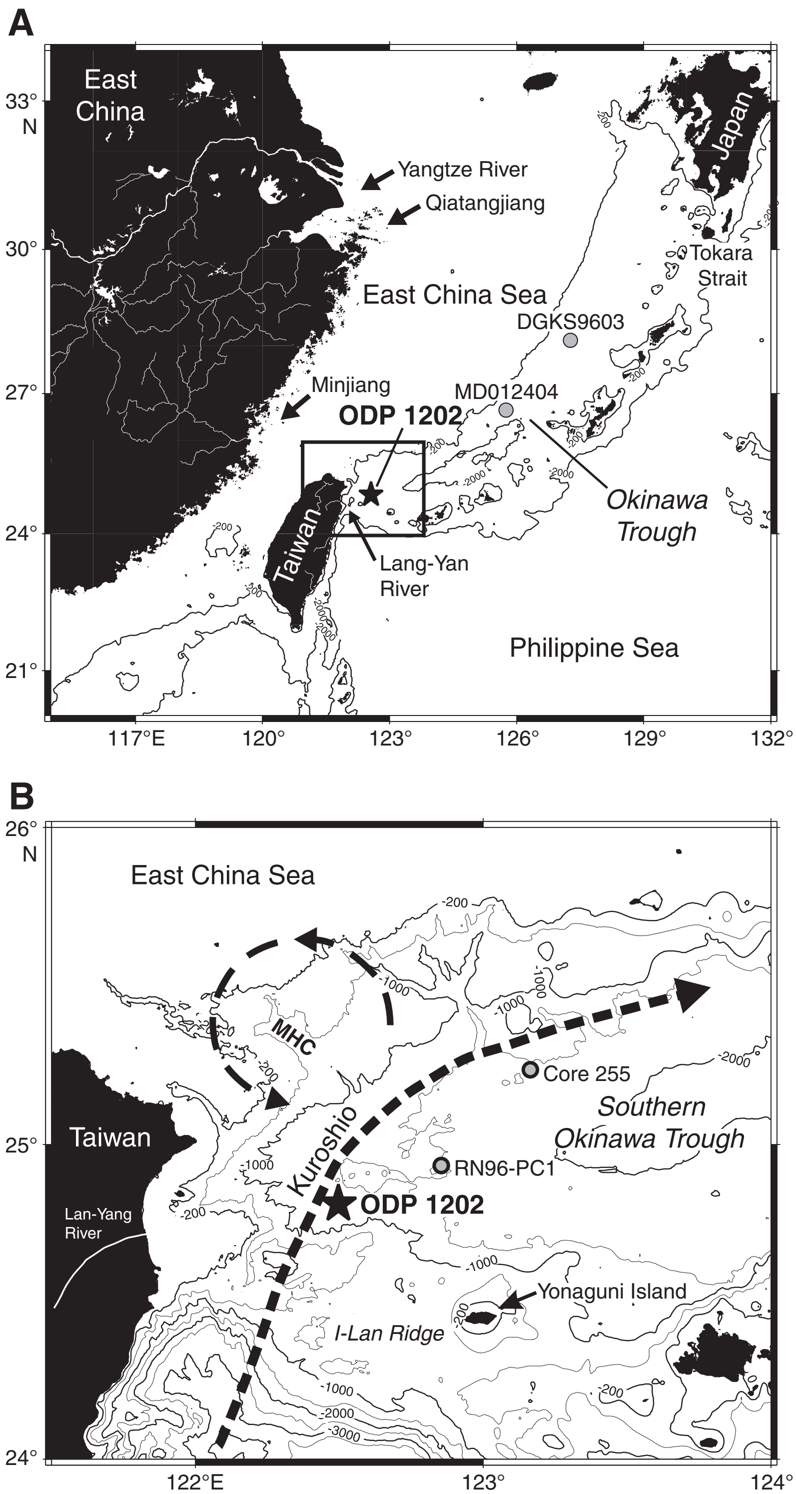

Figure F2. Topography of the Southern Okinawa Trough and northeast corner of Taiwan looking from the axis of the trough toward the Lan-Yang River and its delta plain on northeast Taiwan. The map was generated from the digital data compiled in Liu et al. (1998) with exaggerated elevation. The location of Site 1202 is marked by the red circle-cross symbol. Three canyons (A, B, and C) indicate major conduits that supply sediments to the southern Okinawa Trough.

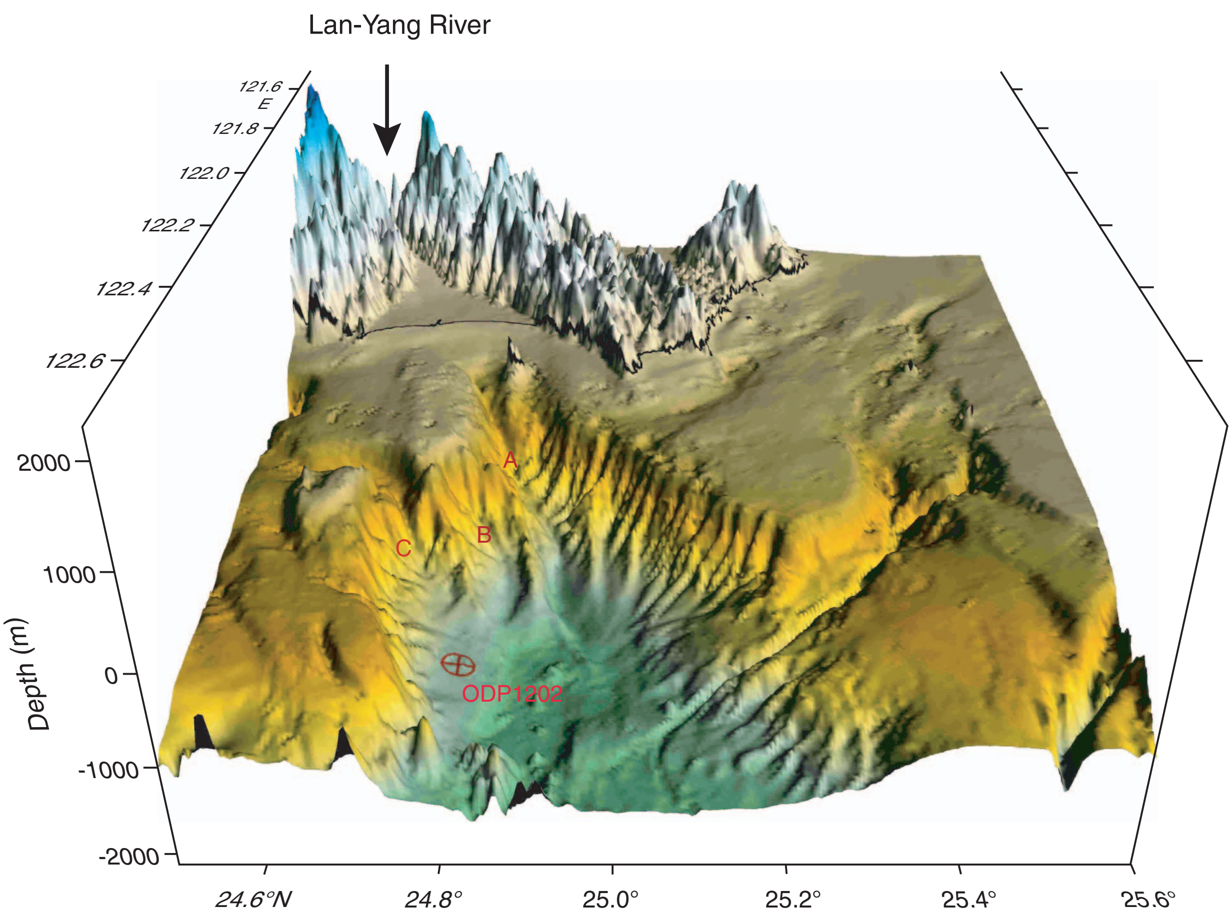

Figure F3. Recovery of sediments in Holes 1202A, 1202B, 1202C, and 1202D. Hole 1202D is the deepest with a total of 410 m penetration, consisting of nine APC cores (195-1202D-1H through 9H) and 35 XCB cores (195-1202D-10X through 44X). TD = total depth.

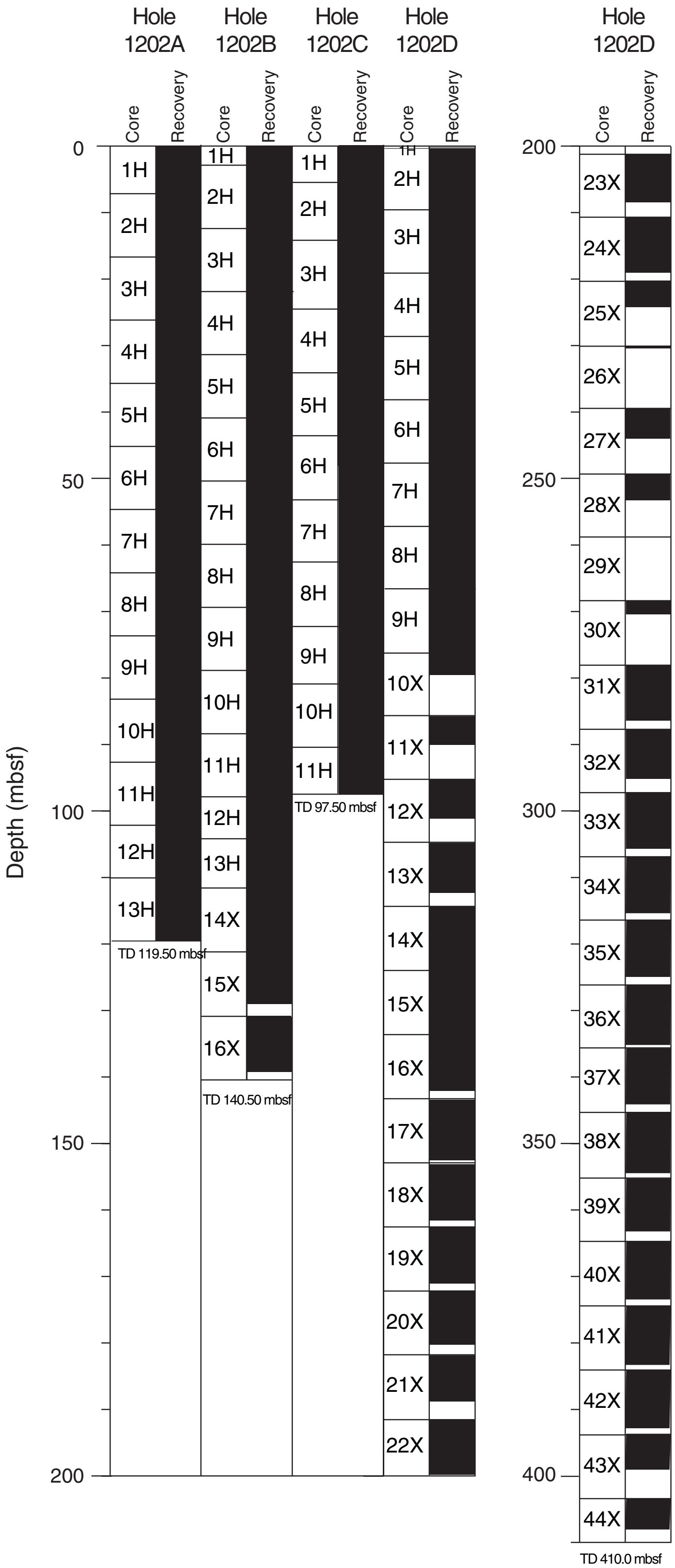

Figure F4. Correlation among Holes 1202A, 1202B, and 1202D using magnetic susceptibility. Also marked are calendar ages converted from ^{14}C dates for Hole 1202B in Wei et al. (2005).

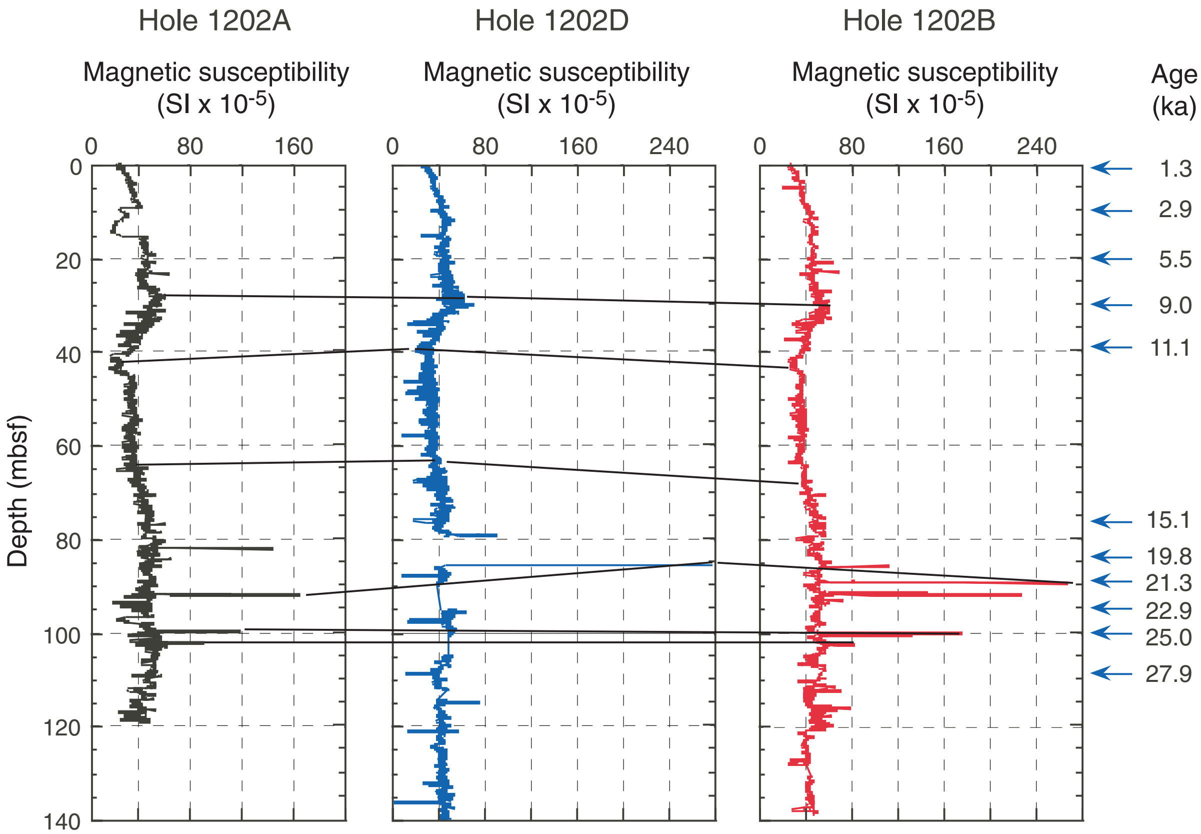

Figure F5. A. Planktontic foraminiferal (*Neogloboquadrina dutertrei*) $\delta^{18}O$ record for Site 1202 plotted against age. Radiocarbon dating points by Wei et al. (2005) are indicated by black arrows. TL = interval containing turbidites. **B.** Benthic foraminiferal (*Uvigerina* spp.) $\delta^{18}O$ profile for Core MD012404 plotted against age. MIS = marine oxygen isotope stage (reproduced from Chang et al., 2005).

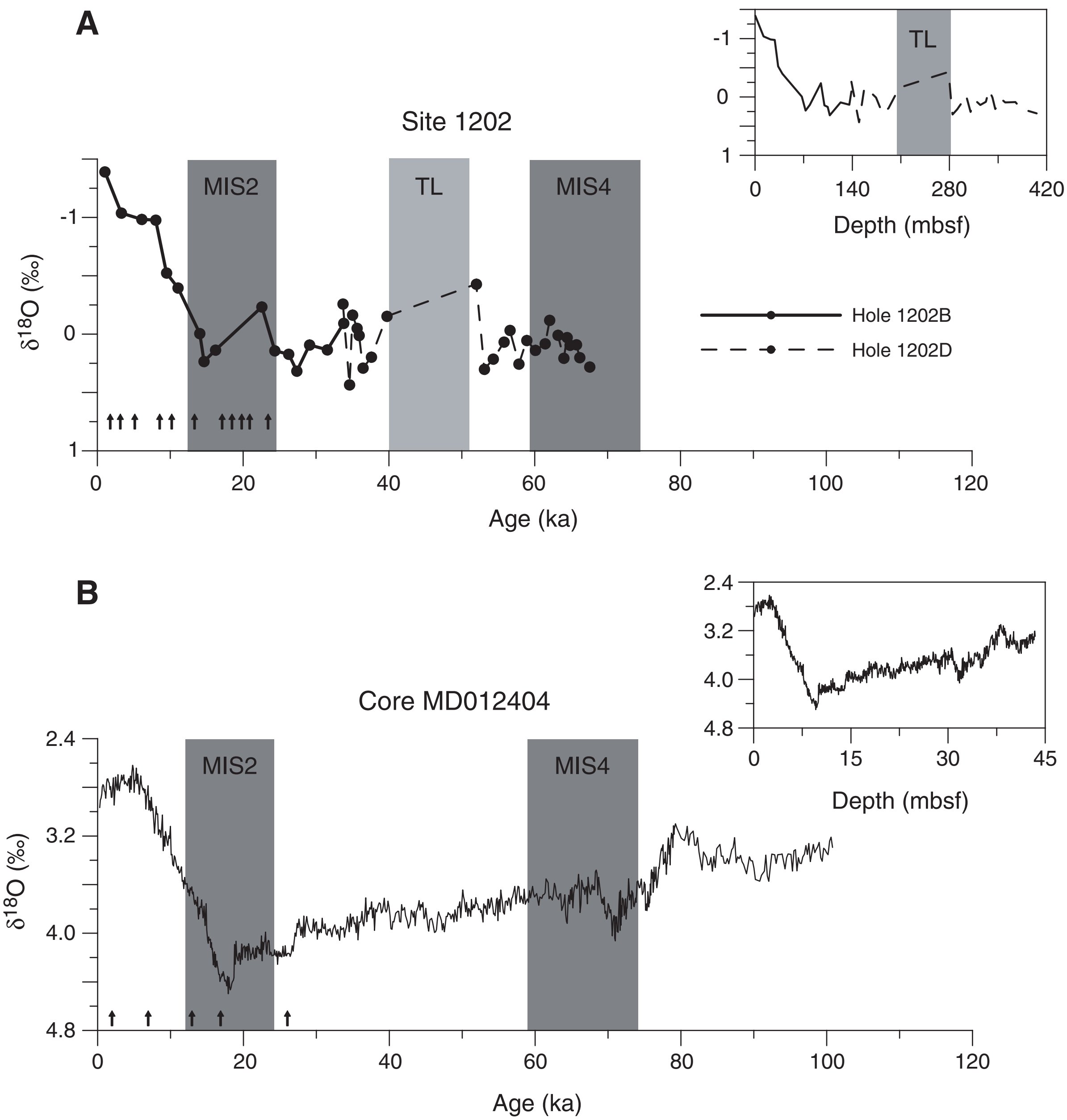

Figure F6. A. Percentage of silt/sand layer thickness in total length of each core section plotted against age in Hole 1202D (data from Huang et al., 2005). **B.** Weight percentage of coarse fraction in bulk sediment in Holes 1202B and 1202D. In terms of turbidite deposition, the record can be divided into volcanic (V), metamorphic (M), slate (S), and quiescent (Q) stages. (see Fig. F7, p. 24, and text for details).

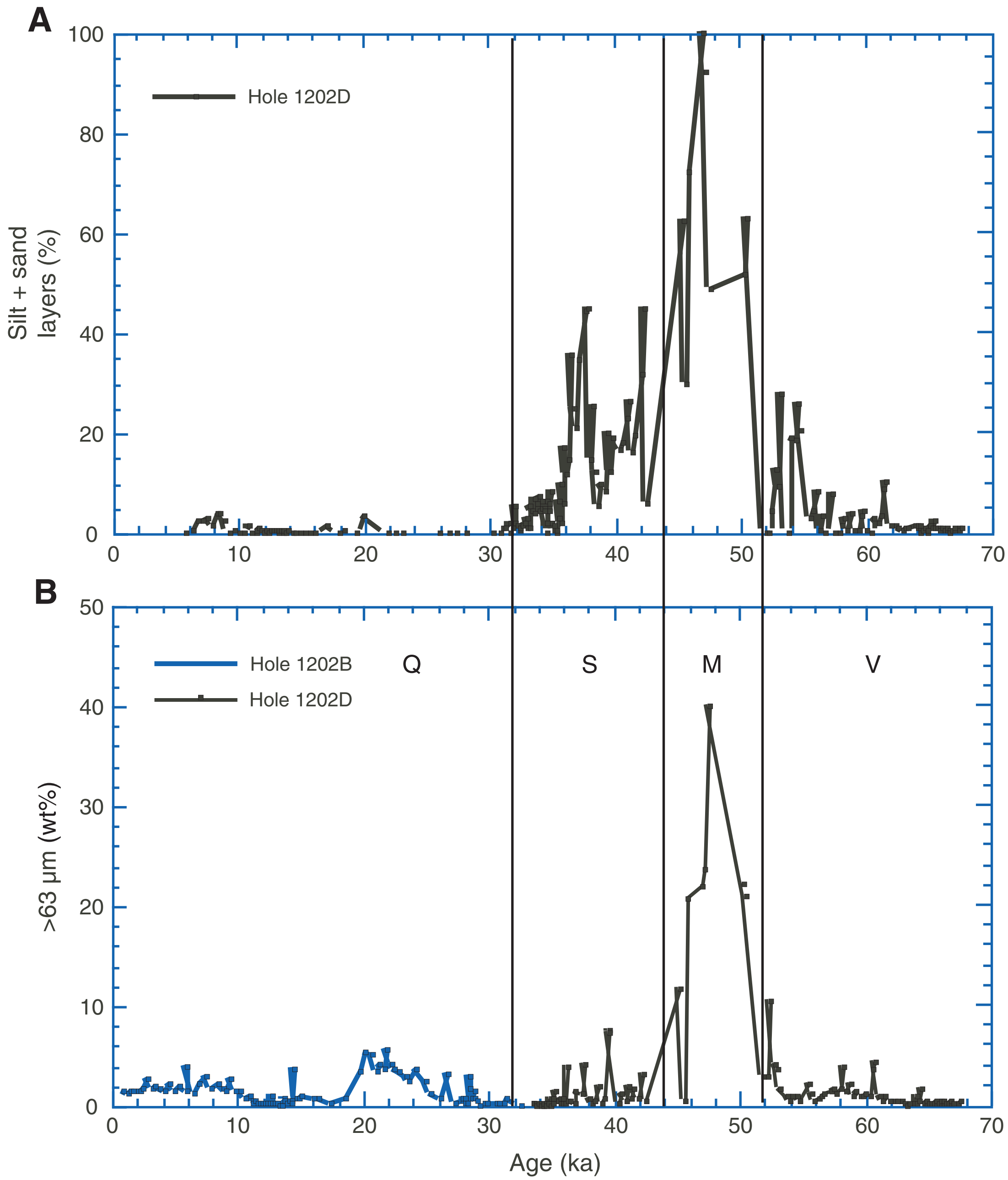

Figure F7. Absolute abundance of (**A**) metamorphic grains, (**B**) slate chips, and (**C**) volcanic grains in the coarse fraction (>250 µm) of the sediments in Hole 1202D (data from C.-Y. Huang et al., 2005). V = volcanic, M = metamorphic, S = slate, Q = quiescent.

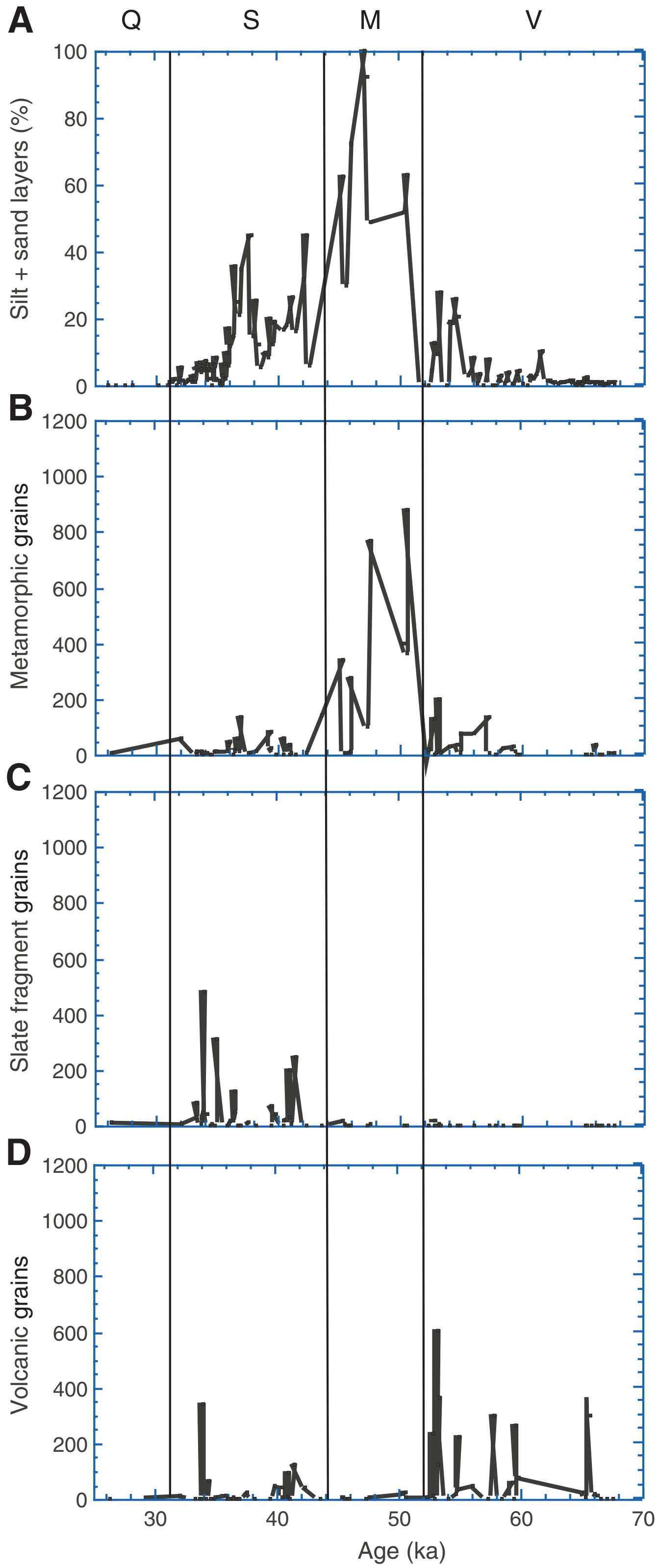

Figure F8. Changes in sea-surface temperatures (SSTs) derived from $U^{k'}_{37}$ index and planktonic foraminiferal (*Globigerinoides sacculifer*) $\delta^{18}O$ for the past 29 k.y. in Hole 1202B. The SST data are from Zhao et al. (2005). Bold lines mark the moving averages. LGM = Last Glacial Maximum.

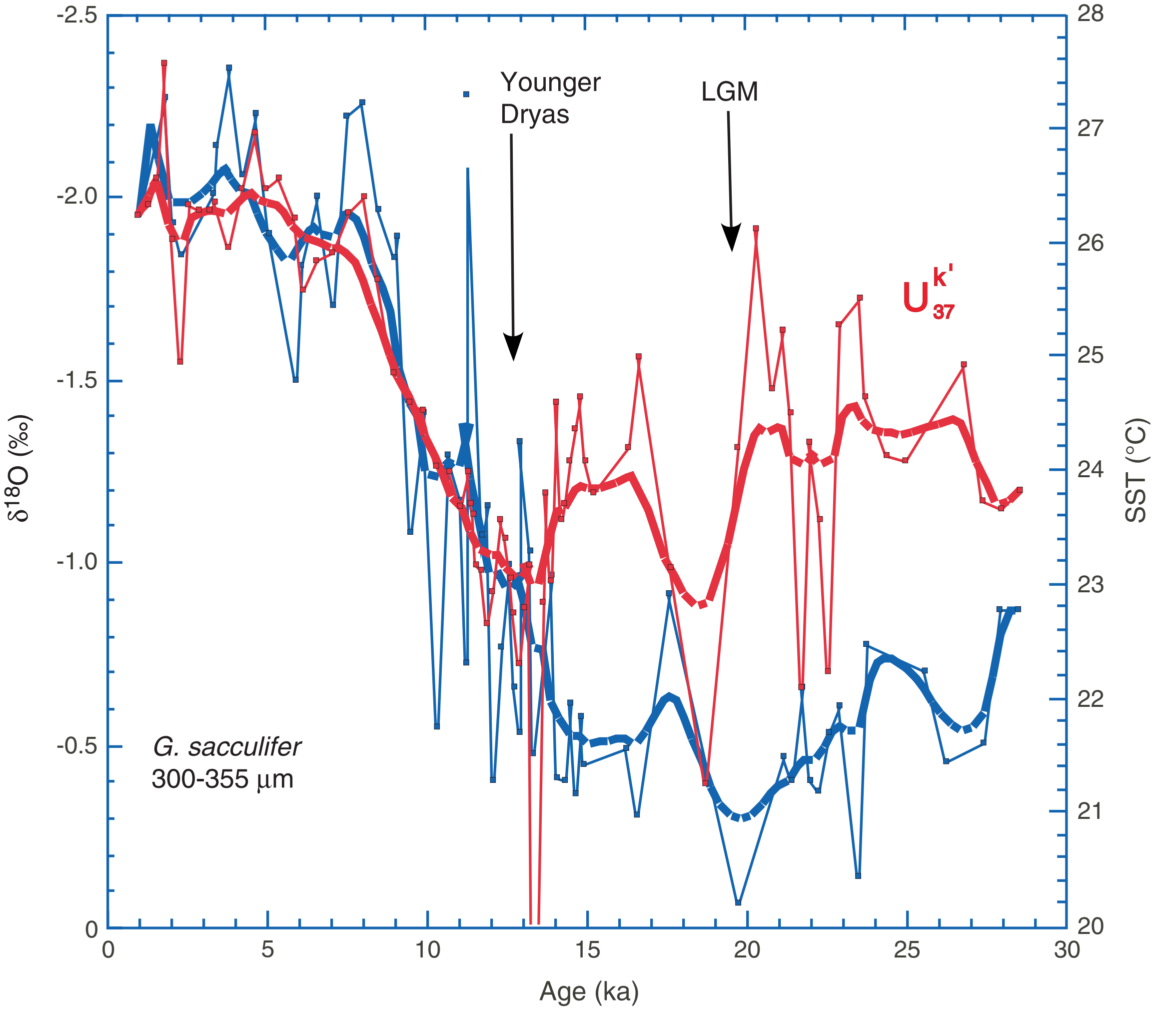

Figure F9. Comparison between calcareous nannofossil abundance, sea-surface temperature, sediment granulometry, and sea level during the past 13 k.y. **A.** Percentage of deep-dwelling nannofossil *Florisphaera profunda* (data from X. Su, pers. comm., 2005). **B.** Sea level variation compiled from Lambeck et al. (2002) and Chen and Liu (1996). **C.** Percentage of sortable silt (10–63 µm) in the silt fraction (Diekmann et al., submitted [N1]). **D.** Sea-surface temperature derived from $U^{k'}_{37}$ (Zhao et al., 2005).

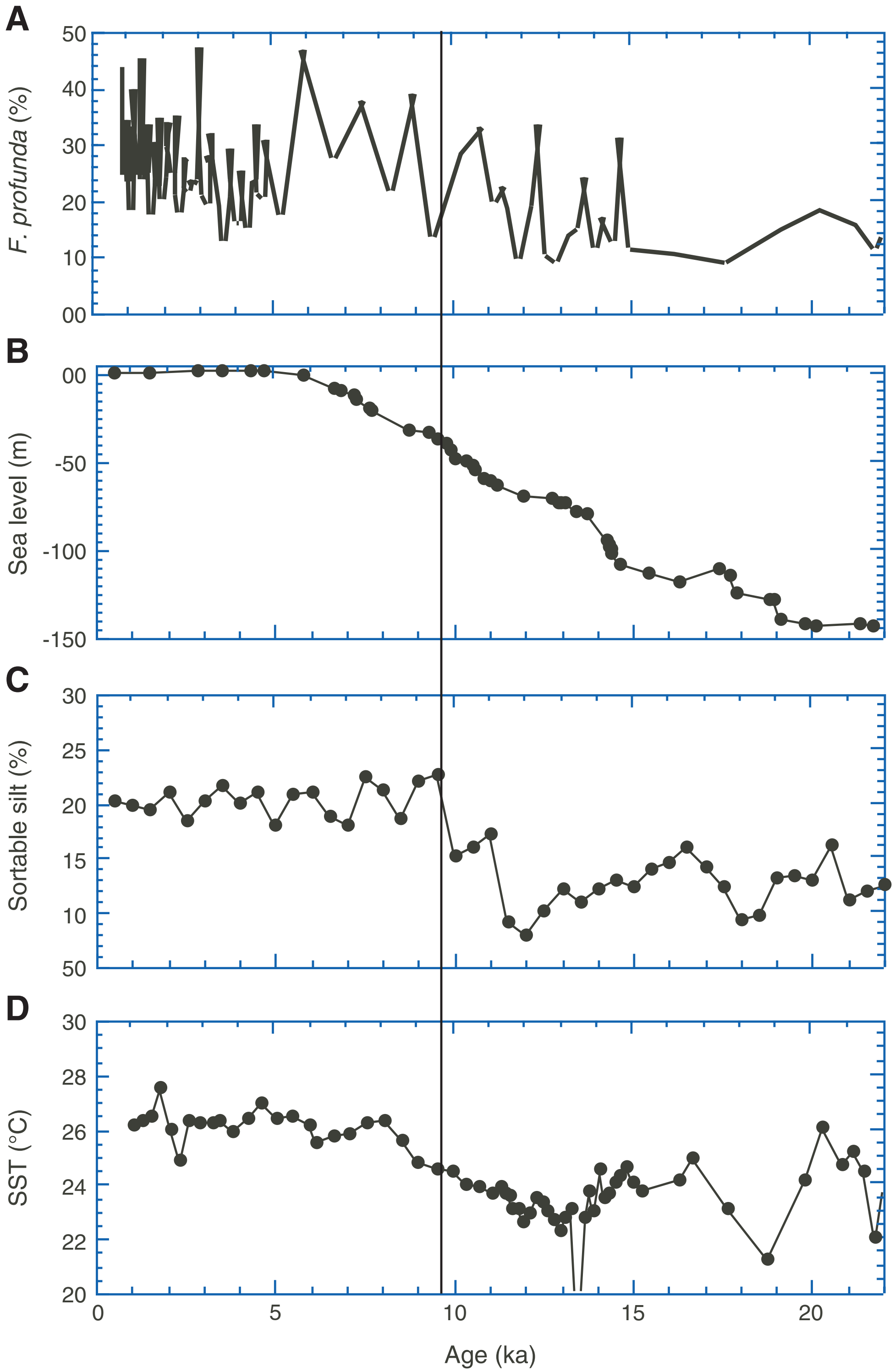

Figure F10. Sediment characteristics during the past 22 k.y. **A.** Chlorite/kaolinite ratio. **B.** K/Ti ratio (data from Diekmann et al., submitted [N1]). **C.** Sedimentation rate (Wei et al., 2005). **D.** Percentage of coarse fraction >63 µm. **E.** Sea level variation compiled from Lambeck et al. (2002) and Chen and Liu (1996).

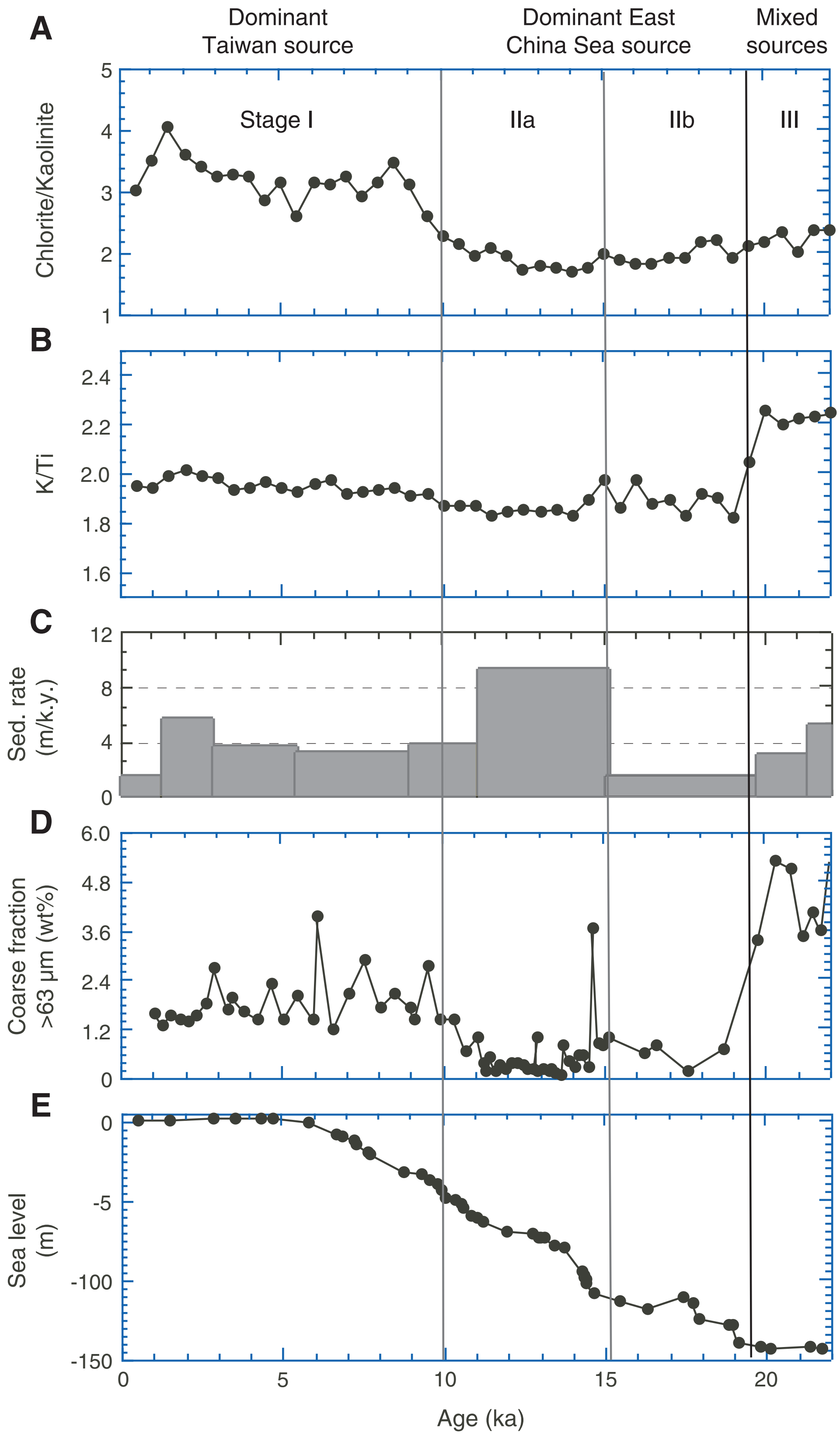

Figure F11. Comparison and correlation of Holocene magnetic paleointensity recorded in Hole 1202B to other records (Richter et al., in press). The blue arrows mark correlation points between records. BP = before present.

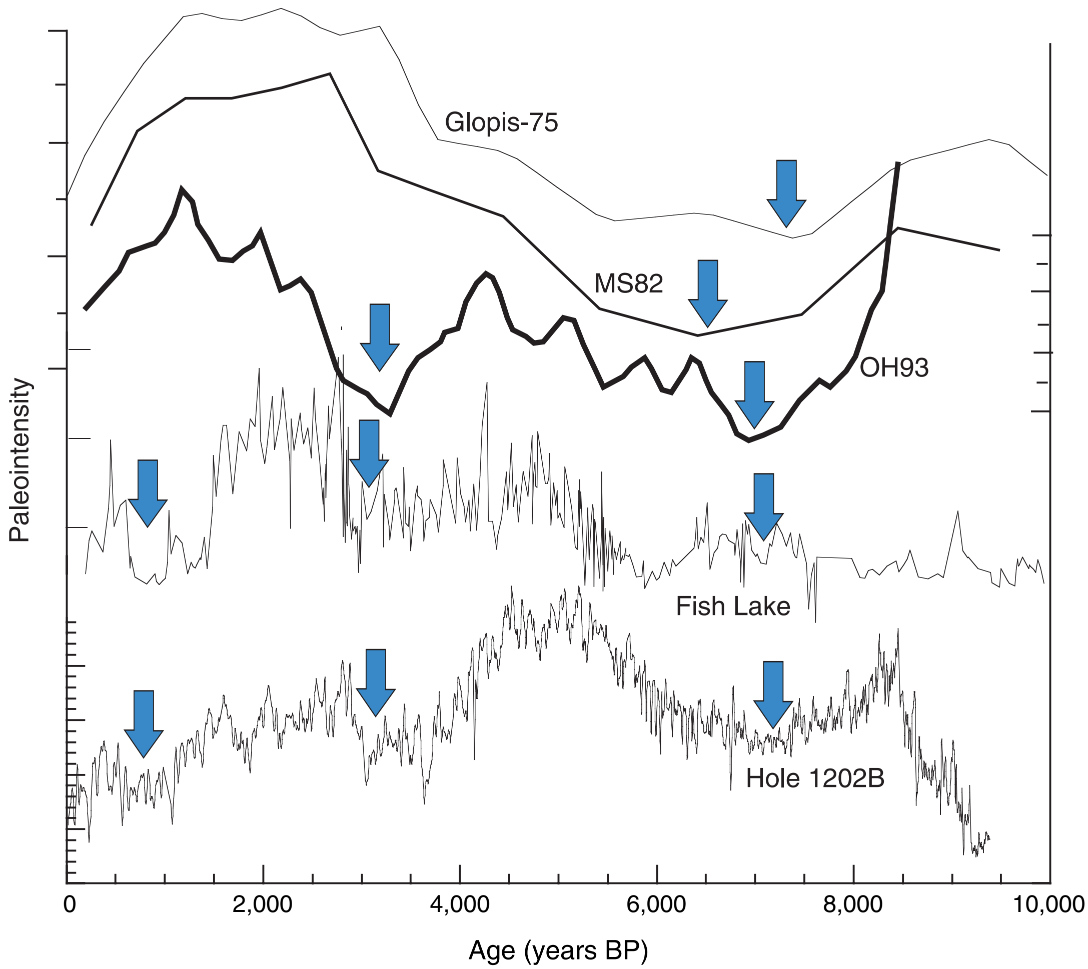

Table T1. Correlation depths among Holes 1202A, 1202B, and 1202D with corresponding calendar ages in Hole 1202B.

Depth (mbsf)				
Hole 1202A	Hole 1202B	Hole 1202D	Marker	Age (ka)
4.25	3.65	2.86	Magnetic susceptibility peak	1.60
	11.50	11.44	Magnetic susceptibility peak	3.05
	16.20	16.10	Density peak	4.33
	22.40	20.90	Density peak	6.10
	22.79	21.08	Echinoderm-rich	6.23
24.65	24.40		Magnetic susceptibility minimum	6.74
	27.11	26.04	Pelecypod-rich	7.61
	30.20	29.92	Magnetic susceptibility peak	8.60
28.55	30.65		Magnetic susceptibility peak	8.78
41.70	42.05	40.00	Magnetic susceptibility minimum	11.36
47.35	46.50		Magnetic susceptibility kink point	11.84
	50.05	48.78	Magnetic susceptibility minimum	12.21
	63.55	62.00	Magnetic susceptibility peak	13.65
64.70	63.75		Magnetic susceptibility kink point	13.67
	66.31	64.80	Density peak	13.94
	78.60	73.20	Magnetic susceptibility peak	16.01
80.20	79.10		Density peak	16.37
80.50	79.30		Magnetic susceptibility peak	16.52
	85.03	79.56	Pumice layer	20.18
88.40	89.20		Density peak	21.49
94.10	87.80		Density peak	22.43
102.20	102.65		Magnetic susceptibility peak	25.48
112.95	108.10	99.20	Density peak	27.53
	117.20	107.20	Density peak	28.61
	124.40	117.00	Density peak	29.41
	136.20	123.00	Density peak	31.74

Notes: Ages before present. From Wei et al., 2005.

Table T2. AMS ^{14}C dating results, Hole 1202B.

Core, section, interval (cm)	Analyzed material	Depth (mbsf)	Measured ^{14}C year BP	Margin (year)	Converted calendar year BP
195-1202B-					
1H-2, 36–47	Scaphopoda	1.92	1,783	45	1,295
2H-6, 34–46 + 50–56	Planktonic foraminifers	10.88	3,153	40	2,886
3H-6, 34–45.5 + 50–56	Planktonic foraminifers	20.48	5,135	45	5,486
4H-CC	Planktonic foraminifers	31.35	8,554	70	8,971
5H-6, 40–56	Planktonic foraminifers	39.35	10,205	55	11,074
9H-6, 40–56	Planktonic foraminifers	77.35	13,340	95	15,111
10H-4, 50–56	Planktonic foraminifers	83.79	17,111	70	19,753
10H-CC	Planktonic foraminifers	88.35	18,478	90	21,328
11H-6, 40–50	Planktonic foraminifers	96.35	19,810	100	22,859
12H-3, 40–56	Planktonic foraminifers	101.38	20,910	120	24,998
13H-4, 40–50	Planktonic foraminifers	109.10	23,430	140	27,911

Notes: BP = before present. Conversion of ^{14}C age to calendar age was done using CALIB 4.4 (**http://radiocarbon.pa.qub.ac.uk/calib/**).

CHAPTER NOTE*

N1. Diekmann, B., Hofmann, J., Henrich, R., Röhl, U., and Fütterer, D.K., submitted. Detrital sediment supply at ODP Site 1202 in the southern Okinawa Trough and its relation to sea-level changes, Kuroshio dynamics, and palaeoclimate during the last 30,000 years. *Mar. Geol.*

*Dates reflect file corrections or revisions.