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NOTE AND CORRESPONDENCE

Nannofossil Biochronology of Tephra Layers in Core MD972143, Benham Rise, Western Philippine Sea

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ABSTRACT

During the IMAGES III-IPHIS-Leg II Cruise in June 1997, a long piston core, MD972143 (15°52.262'N, 124°38.96'E, water depth 2989 m), was raised from Benham Rise, east of Luzon in the western Philippine Sea. The core measures 38 m in length, consisting mainly of calcareous ooze. Intercalated conspicuously in this thick sequence of calcareous ooze are 21 volcanic layers. Four major age-diagnostic nannofossil datum levels were recognized: the first appearance datum (FAD) of Emiliania *huxleyi* (0.27 Ma) at 365 cm, the last appearance datum (LAD) of *Pseudoemiliania lacunosa* (0.46 Ma) at 1105 cm, the LAD of *Calcidiscus macintyrei* (1.59 Ma) at 2510 cm and the LAD of *Discoaster broweri* (1.95 Ma) at 2970 cm. A turbidite layer at 33 to 34 m, consisting mainly of foraminiferal sands, appears to truncate the sequence and result in a hiatus. The age of the lowermost part of the core (34-38 m) was constrained as being older than 2.59 Ma (the last appearance of *D. surculus*) and younger than 2.78 Ma (the last appearance of *D. tamalis*). Based upon our preliminary nannofossil biochronology, these tephra layers were deposited at 2.65 Ma (?), 2.1 Ma, 1.9 Ma, 1.7 - 1.8 Ma, 1.5 Ma, 1.35 Ma, 0.9 Ma, 0.8 Ma and 0.5-0.3 Ma, respectively.

(Key words: Philippine Sea, Volcanic ash, Pliocene, Pleistocene, Nannofossil)

1. INTRODUCTION

Volcanogenic particles are one of the major components of atmospheric particulate matter in marine sediments. The completeness and continuous nature of marine sedimentary se-

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quences makes marine tephrochronology an excellent geologic record of past volcanism (Kennett, 1981). Here the term "tephrochronology" is defined as studies "concerned with sequence, correlation and age of tephra deposits" (Kennett, 1981, p. 1374). Once the source areas of the tephra are known, such records may also provide clues for reconstructing the past wind regimes of the upper atmosphere and transportation mechanism. In addition, tephra layers are easily recognized macroscopically, and can therefore serve as isochronous markers for regional stratigraphic correlation.

In the sedimentary sequences of the South China Sea and western Philippine Sea cored during the IMAGES III - IPHIS-Leg II Cruise in June 1997 (Chen *et al.*, 1997), volcanic particles are common constituents and are particularly abundant in several cores obtained around the Philippines. Due to the highly explosive nature of eruptions of island-arc volcanoes, major eruptions would eject massive quantities of ash into the upper troposphere and stratosphere where high-velocity winds would disperse the volcanic dust meridionally and create global ash fallout (Kennett, 1981). In this study, we focus mainly on the macroscopically recognizable tephra layers, whose thicknesses are generally larger than 1cm. Since the thickness of global ash fallout is usually only a few millimeters, the ash layers reported here are believed to be from adjacent areas.

Recent studies of short gravity/piston cores in the northern and central South China Sea have revealed the widespread occurrence of volcanic dusts and the existence of discrete tephra layers in the latest Pleistocene sequences (Feng *et al.*, 1988; Wang *et al.*, 1989; Chen and Zhou, 1993). Three major groups of tephra beds were recognized, dated to be around 11-13 ka, 26 - 42 ka, and 64 - 79 ka in age, respectively (based upon oxygen isotope stratigraphy, Chen and Zhou, 1993). Because of the short length (the longest being 10 m in length) and high sedimentation rate of those cores previously studied, the oldest tephra records so far have not exceeded 80 kyrs in age.

The Neogene tephra deposits in the western Philippine Sea were investigated during Leg 31 of DSDP at Sites 292 and 296 (Donnelly, 1975). Limited by the low recovery rate (~66%) of the topmost 4 cores of DSDP 292 (Ingle *et al.*, 1975) and low sampling resolution (12 samples for the last 2.5 Ma), the tephrochronology of Plio-Pleistocene at this site was only coarsely documented. Obliged to the recent success in obtaining long piston cores of up to 50 meters during the IMAGES III-IPHIS Cruise, we were able to revisit the DSDP 292 site and obtained a continuous sequence to detail the tephrochronology up to 2.7 Ma.

2. CORE MD972143

As a return visit to the DSDP Site 292, the piston core MD972143 (15°52.262'N, 124°38.96'E) penetrated 38 meters of nannofossil ooze at a water depth of 2989 m on Benham Rise, east of Luzon in the western Philippine Sea (Figure 1). The site is located about 400 km southeast of the presently active volcanic centers of northern Luzon and central-southern Luzon. Benham Rise itself represents a relatively small but significant midplate rise at the westernmost edge of the West Philippine Basin. The basement of the rise, a tholeiitic basalt of middle or late Eocene age, was encountered at DSDP Site 292 (McKee, 1975). The origin of Benham Rise is not well known. Karig (1973) suggested that the rise might represent a crustal flexure

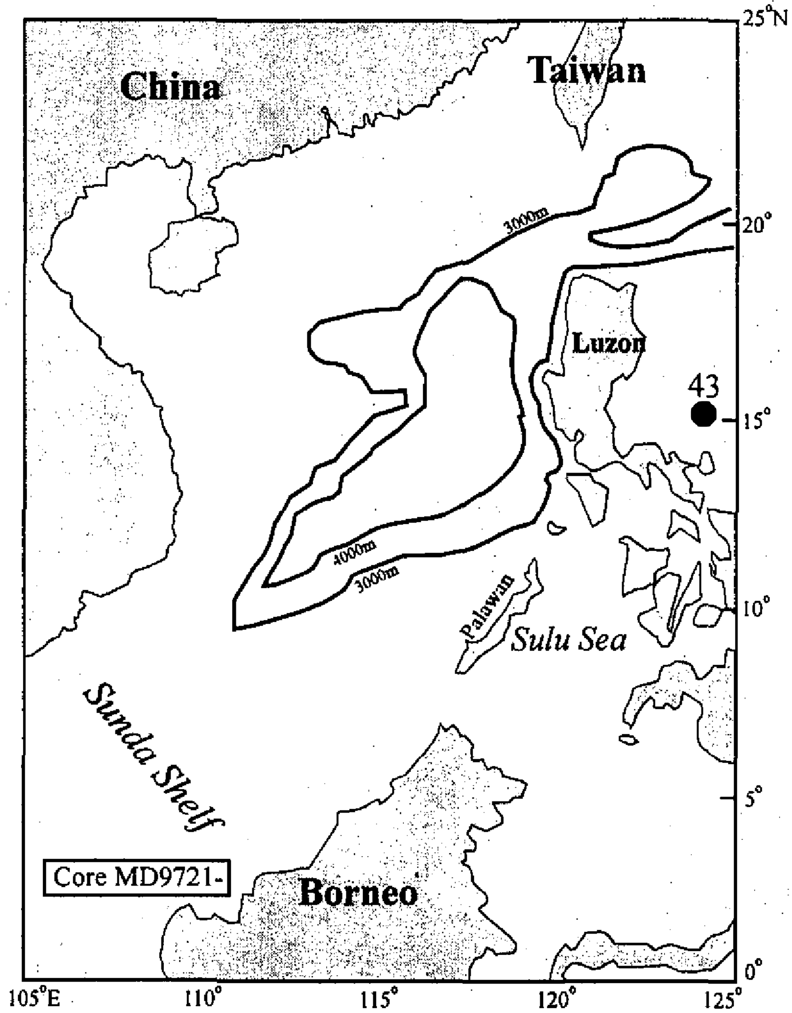

Fig. 1. Location of Core MD972143 in the western Philippine Sea.

related to the cessation of subduction along the east side of Luzon which was uplifted during late Oligocene- early Miocene. Alternatively, the rise could be a product of major volcanism occurring after the formation of the Philippine Basin (Ingle *et al.*, 1975). To the west of the coring site exists a rise crest named Benham Bank with a minimum depth of only 38 meters (Figure 2) (Ingle *et al.*, 1975). Sediments reworked from the shoaler region extending from the bank might have contributed to the MD972143 site as evidenced by the frequently observed reworked Miocene nannofossils in the core. However, the virtual absence of both terrigenous detritus (except aeolian) and shallow-water fossils such as corals or algae, suggests that the site was shielded from any supply of coral banks or terrigenous detritus.

The sequence of core MD972143 consists of dominant calcareous nannofossil ooze with subordinate foraminifera, tephra, radiolarians and sponge spicules. The color is medium yel-

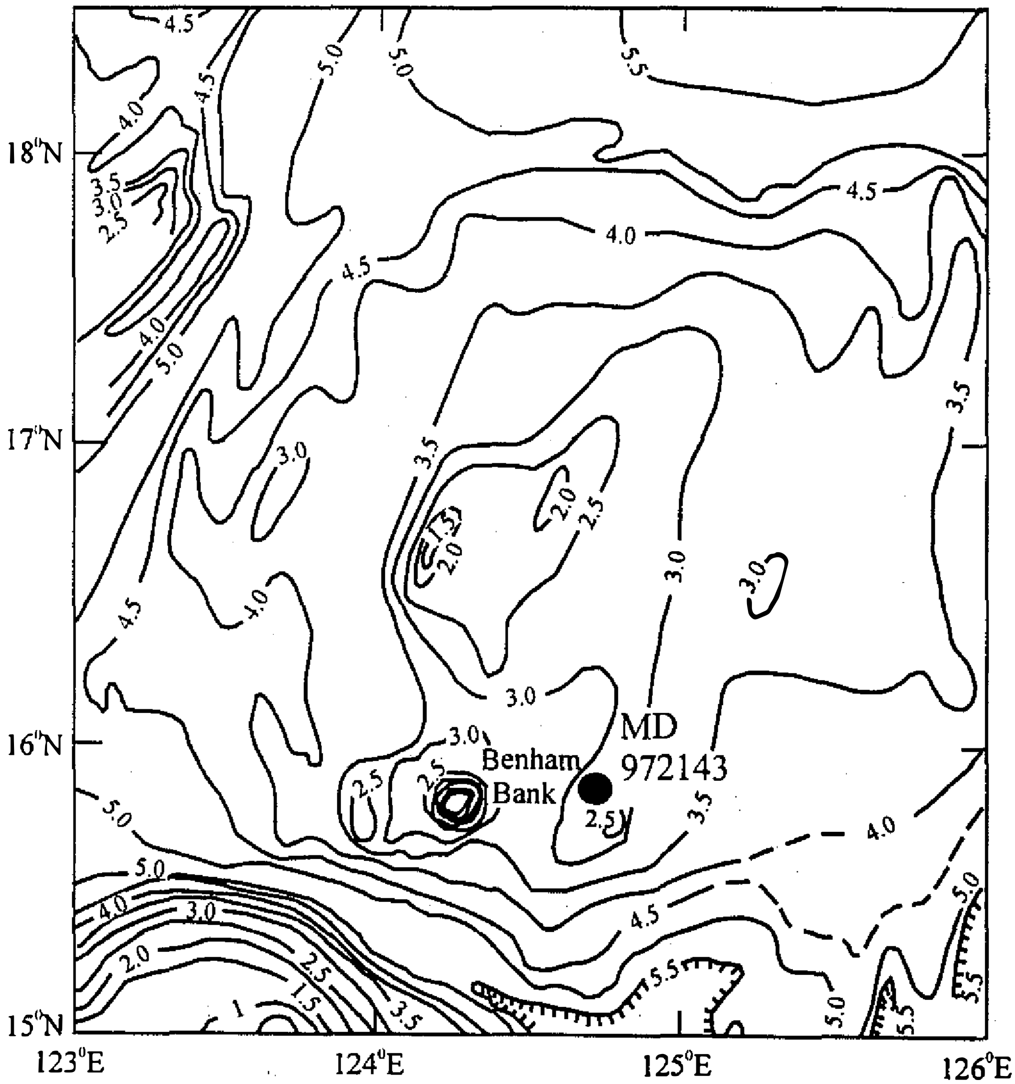

Fig. 2. Detailed bathymetric map of Benham Rise, modified from Ingle et *al.*, (1975). The numbers inserted in contour lines represent water depth in kilometer.

low-brown. Intercalated conspicuously in this thick sequence of nannofossil ooze are 21 layers of volcanic debris (brown-colored and clear volcanic glass, plagioclase and amphibole crystals). The thickness of these layers is generally thicker than 1 cm, with a mode of about 2 cm. The thickest one reaches as much as 12 cm. Some of the thick ash layers show grading. The major source areas for these volcanic debris are primarily the Philippine Archipelago and probably other unknown shallow marine eruptions around the Benham Rise area. The origin of these layers awaits further sedimentary, mineralogical and geochemical studies.

3. PHYSICAL PROPERTIES

The physical properties of Core MD972143 were measured using a multi-sensor track (MST) system. Un-split cores were cut into sections of 1.5 meters and passed through the MST measuring device (for a description, see Wei *et al.*, this volume). The bulk density, P-wave velocity and magnetic susceptibility show less scattering for the nannofossil ooze series. The volcanic ash beds show high values for magnetic susceptibility, but not necessarily for bulk density or P-wave velocity (Figure 3). Due to the sharp contrast in color between volcanic ash layers and pelagic nannofossil ooze, the reflectance shows distinctive low values for volcanic ash layers (Figure 3).

4. PRELIMINARY NANNOFOSSIL BIOCHRONOSTRATIGRAPHY

The calcareous nannofossil biostratigraphy of the DSDP Site 292 was coarsely documented. The upper four sections (comparable to the sequence examined in this study) were dated to be late Pliocene - Holocene (Ellis, 1975). In the past 20 years, the Plio-Pleistocene nannofossil biomagnetostratigraphy has been refined through recent extensive studies of various DSDP and ODP cores (Hills and Thierstein, 1989; Takayama, 1993; Young *et al.*, 1994; Raffi and Flores, 1995). Based upon on-board and on-shore laboratory investigation of nannofossils, four important nannofossil datum levels were recognized (Figures 4 and 5):

First appearance datum (FAD) of *Emiliania huxleyi* (0.27 Ma) at 365 cm
Last appearance datum (LAD) of *Pseudoemiliania lacunosa* (0.46 Ma) at 1105 cm
LAD of *Calcidiscus macintyrei* (1.59 Ma) at 2510 cm
LAD of *Discoaster broweri* (1.95 Ma) at 2970 cm

The sedimentation rates can be estimated accordingly (Figure 5):

365 - 1105 cm: 2.4 cm/kyrs
1105 - 2510 cm: 1.24 cm/kyrs
2510 - 3400 cm: 1.28 cm/kyrs

The lower part of the sequence is truncated by a layer of foraminiferal sand at 3300-3395 cm. The sand layer itself might result from a slumping/turbidity current triggered by eruptive volcanic activity as evidenced by the thick ash layer from 3404-3396 cm. This down-slope slumping might have removed sediments of the upper part of nannofossil Zone NN16, all of Zone NN17 and probably the lower part of Zone NN18. The bottom contact of the ash layer was estimated to be older than 2.59 Ma (LAD of *Discoaster surculus*). The age of the bottom of the core was estimated to be younger than 2.78 Ma (LAD of *Discoaster tamalis*) (Figure 5).

Based upon the age model (Figure 5), the depth of these volcanic sand layers were converted to ages shown in Figure 6. The tephra layers are considered to be deposited at 2.65 Ma (?), 2.1 Ma, 1.9 Ma, 1.7 - 1.8 Ma, 1.5 Ma, 1.35 Ma, 0.9 Ma, 0.8 Ma and 0.5 - 0.3 Ma.

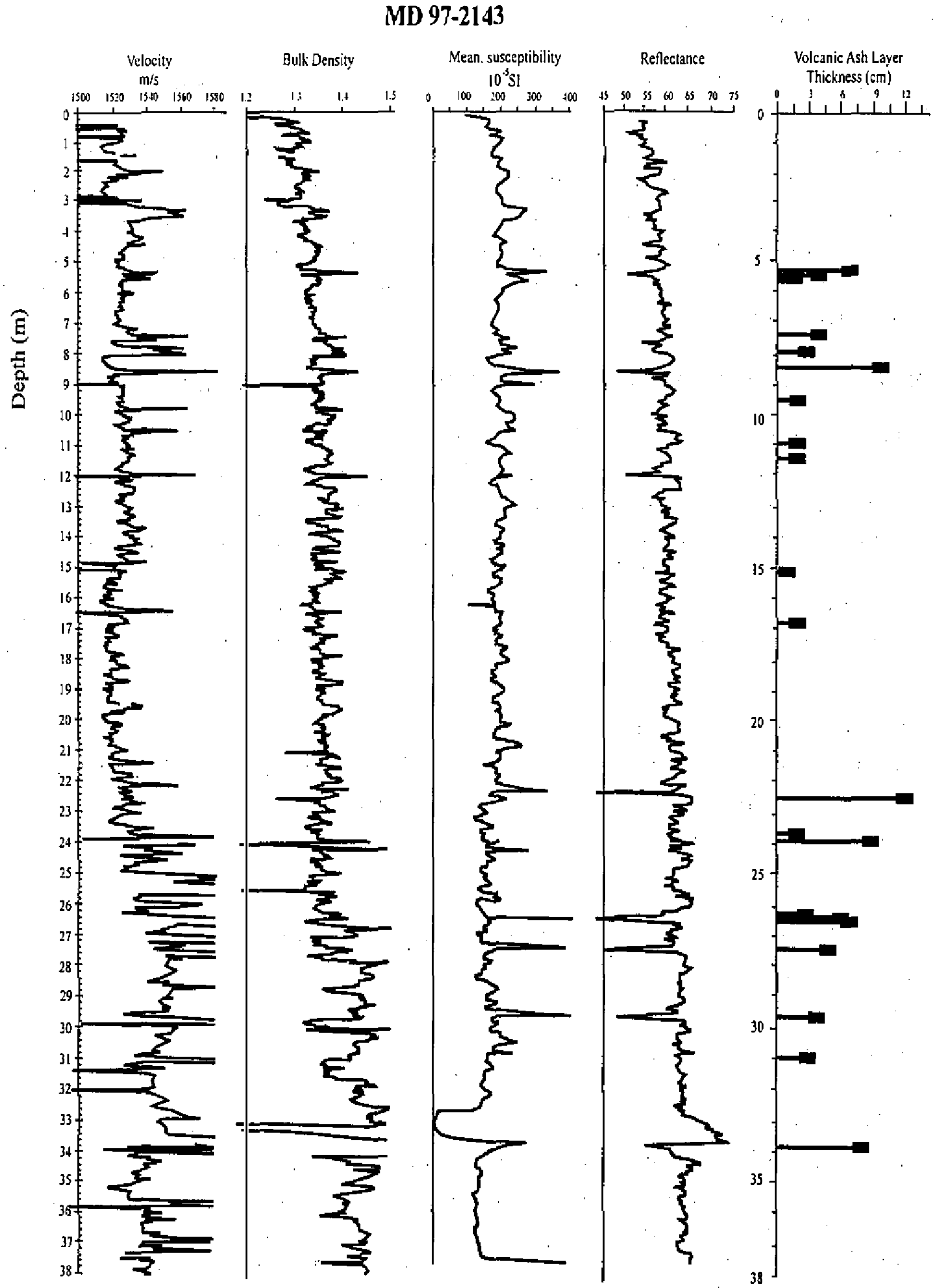

Fig. 3. Time-series of various physical properties including P-wave velocity, bulk density, magnetic susceptibility and reflectance of Core MD 972143. The thickness of volcanic ash layers is also shown in the column on the far right.

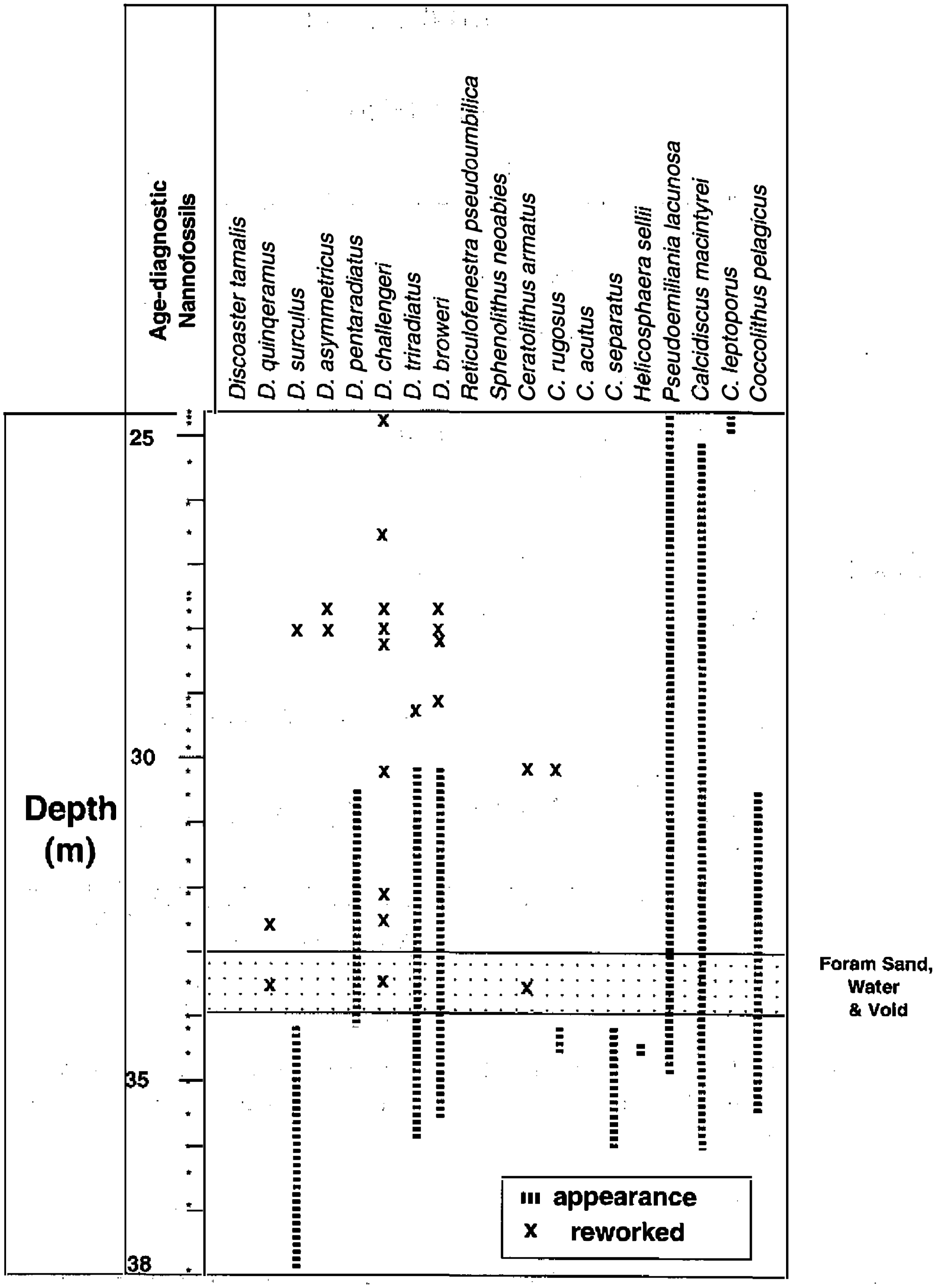

Fig. 4. Occurrence of age-diagnostic calcareous nannofossils in the lower part (24 to 36 m) of the core. Crosses mark the occurrence of reworked nannofossils.

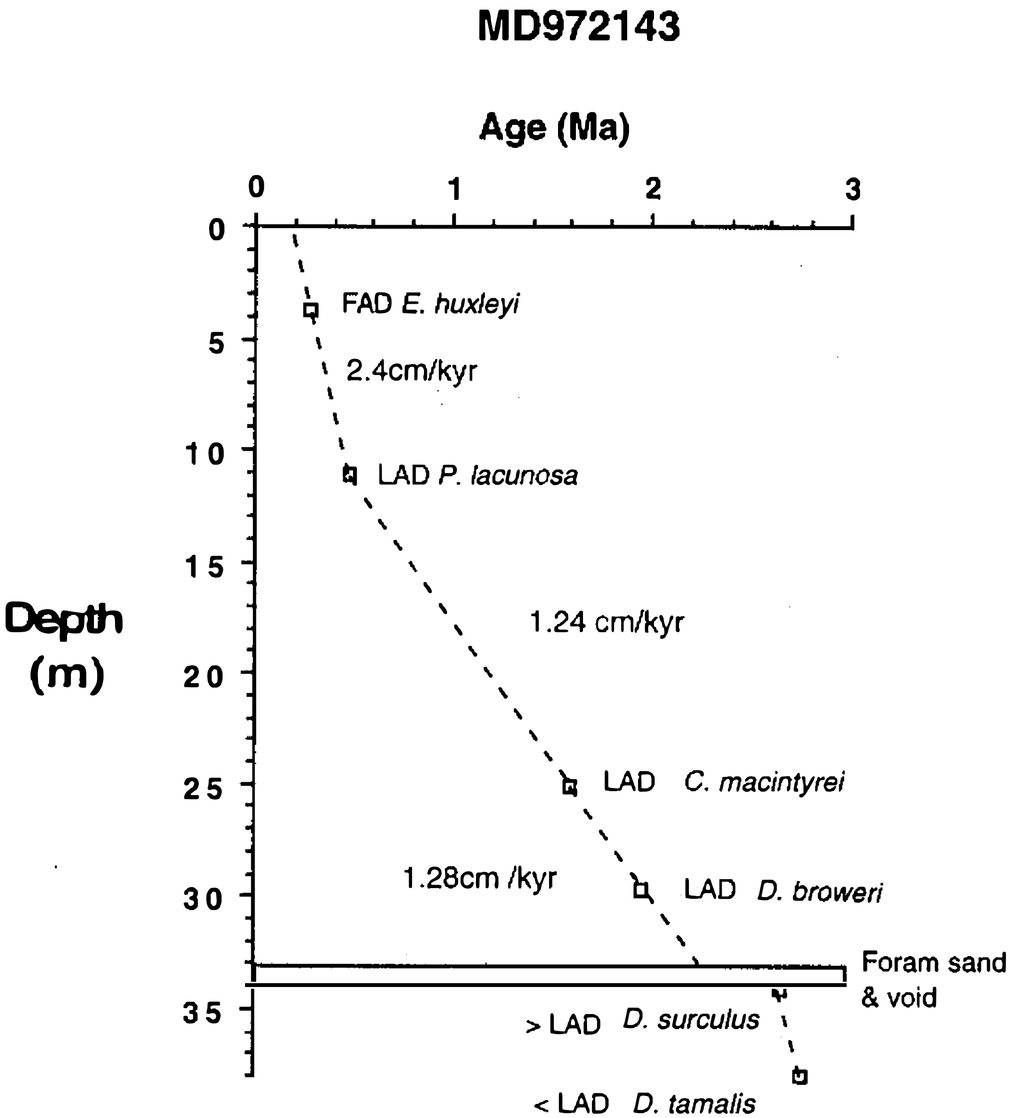

Fig. 5. Depth-age model of Core MD972143 determined by nannofossil datum levels. The stippled bar represents a turbidite sandy layer at 3300 - 3395 cm subdepth.

5. DISCUSSION

Microscopic examination of the intervening pelagic nannofossil ooze in the core revealed that volcanic ashes are almost ubiquitous throughout the core. Therefore, not only the volcanic sand layers described above but also the ashes disseminated in the nannofossil ooze series may provide a potentially good record of volcanism of the Philippine archipelago and probably

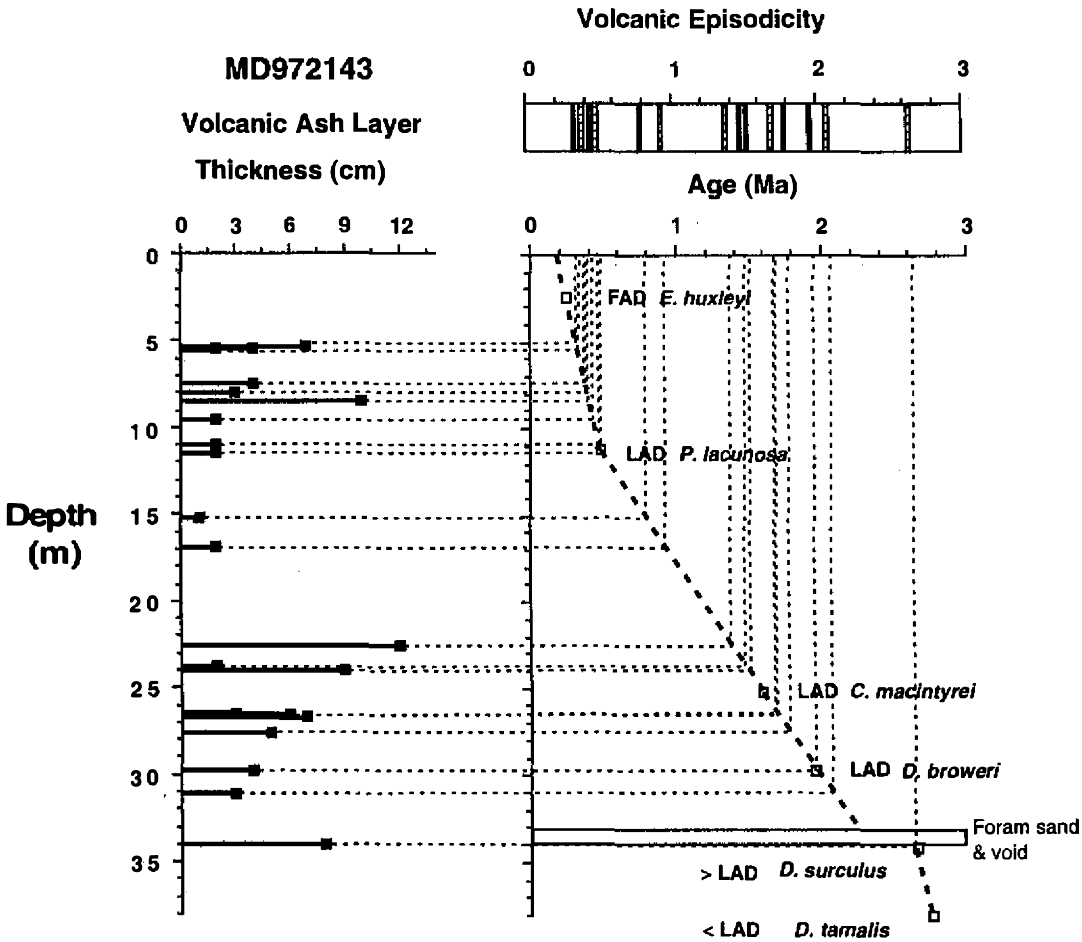

Fig. 6. Age assignments of various volcanic ash layers in MD972143. The age of each volcanic ash layer was obtained by converting its depth to age based upon the depth-age model shown in Fig. 4. Volcanic ash layers were clustered at 2.65 Ma, 2.1 Ma, 1.9 Ma, 1.7 - 1.8 Ma, 1.5 Ma, 1.35 Ma, 0.9 Ma, 0.8 Ma and 0.5 - 0.3 Ma.

Benham Rise *per se*. However, for the tephra layers described above, we suspect that some of them are deposits of turbidity currents caused by debris slides. The frequently observed reworked late-middle Miocene and early Pliocene nannofossils in the sequence (Figure 4) also indicate that this site has been subjected to sedimentation from, at least, the distal part of turbidity currents. Some of the ash layers show upward grading in size from coarse sand to fine silt which may also indicate turbidite in origin. Some of the thick tephra layers might have been formed by brecciation during a landslide event or spallation and granulation as lava erupted into shallow water near Benham Bank. Unless mineralogical composition and chemical signature of these tephra layers are examined, it is hard to determine whether each of the layers is the product of a single eruption or of mixed secondary deposits.

The Tertiary volcanism of Luzon is summarized by Gervasio (1973), Woefe (1981, 1988), Defant *et al.*. (1989) and Knittel *et al* . (1995). The volcanic activity of Luzon commenced from the Oligocene period. At about 5.0 Ma, the activity increased and reached to a maximum during the Quaternary (Woefe, 1981, 1988). Tephrochronology at DSDP Site 292 also showed the same trend (Donnelly, 1975). The number of volcanic ash layers recorded in other DSDP sites (53, 54, 293, 294) in this area show good agreement with the trend (Kennett, 1981). Knittel *et al* (1995) and Yang *et al* (1996) reviewed the tectonic setting of late Miocene to Quaternary volcanism in the Northern Luzon Segment of the Taiwan-Luzon volcanic arc. The Cordillera Central in northwestern Luzon has been the site of relatively extensive Miocene to Pliocene volcanism, but little is known about Quaternary activity. Certainly the sedimentary sequence of Core MD972143 provides a good record to further reveal the nature and timing of volcanism on Luzon Island and the neighboring areas.

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