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VI. MAGNETIZATION OF PELAGIC CLAY IN THE PENRHYN BASIN, SOUTH PACIFIC (GH83-3 AREA)

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Introduction

Pelagic clay with neither siliceous nor calcareous microfossils is distributed widely in the middle latitude of the Pacific (Fig. VI-1). Remanent magnetization of pelagic clay in the North Pacific is known to be unstable except for tens of centimeters to several meters below the surface (Opdyke and Foster, 1970; Kent and Lowrie, 1974; Johnson *et al*., 1975; Prince *et al*., 1980). The unstable magnetization is considered to be viscous remanent magnetization (VRM) in origin (Kent and Lowrie, 1975; Tucker, 1984). Kent and Lowrie (1975) and Prince *et al.* (1980) proposed that the transition from unstable to stable magnetization generally occurs in late Pliocene, and suggested a relation between the unstable-to-stable transition and climatic change. The unstable magnetization is in contrast with the stable magnetization of fossiliferous clay, which is usually almost free from unstable secondary magnetization regardless of its age (Opdyke *et al*., 1966; Theyer and Hammond, 1974; Yamazaki, 1986a, 1992; Yamazaki *et al*., 1991).

We have conducted a series of paleomagnetic and rock-magnetic studies of pelagic-clay cores obtained from the GH83-3 area in the Penrhyn Basin, South Pacific (Yamazaki, 1986b; Yamazaki and Katsura, 1990; Yamazaki *et al*., 1991). Yamazaki (1986) showed that pelagic clay in the South Pacific also has unstable remanent magnetization, and the magnetic overprint can be removed by thermal demagnetization at about 300°C. Yamazaki and Katsura (1990) performed a detailed rock-magnetic study of a pelagic-clay core (Core P411). It was revealed that the dominant magnetic mineral of the pelagic clay is magnetite, and the mean magnetic grain sizes range from 0.02 to 0.15 μm. The mean magnetic grain sizes are inversely proportional to the magnetic viscosity acquisition coefficient, and thus they concluded that the magnitude of the VRM acquisition of the pelagic clay would be controlled by magnetic grain size.

In this report, I summarize the magnetostratigraphy of four pelagic-clay cores (P398, P405, P411 and P412) from the GH83-3 area. Data of magnetic susceptibility and its frequency dependence are also presented, and their relation to the stability of the remanent magnetization is discussed. A part of these data has already been presented in our papers mentioned above.

Keywords: magnetostratigraphy, deep-sea sediment, hiatus, Manihiki Plateau, Hakurei-Maru, Penrhyn Basin

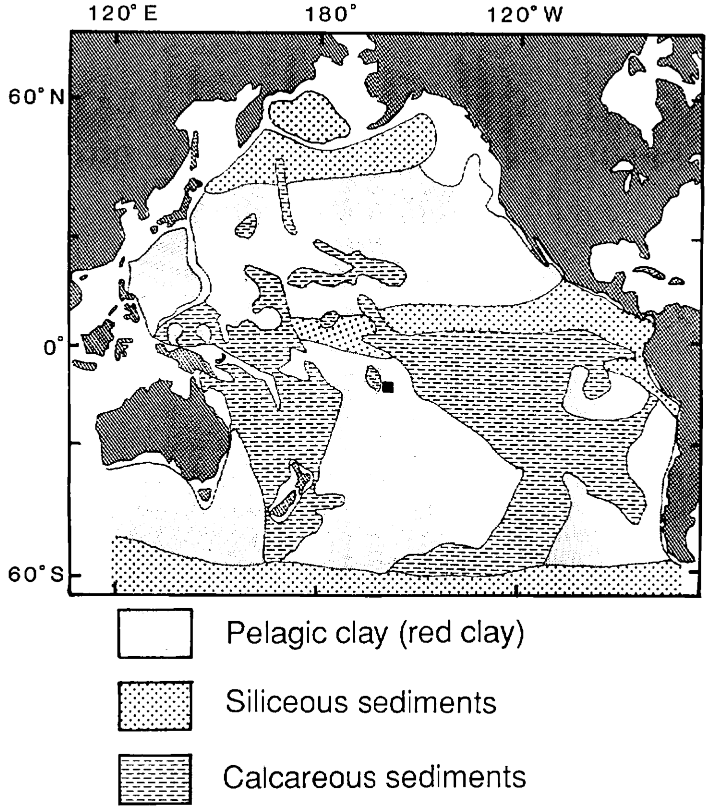

Fig. VI-1 Distribution of deep-sea sediments in the Pacific (Davies and Gorsline, 1976) and the location of the GH83-3 area (solid square).

Samples

Three cores (P405, P411 and P412) were taken from a flat basin of about 5200 m in water depth, and one (P398) from the bottom of a trough of about 5500 m in water depth. The positions and water depths of the coring sites are listed in Table 1. The GH83-3 Area is located far apart from the organic high productivity provinces along the equator and high latitudes. The water depth of the coring sites is below the present CCD (about 4500 m, Berger and Winterer, 1974) as well as through the Neogene (Rea and Leinen, 1985). The cores were hence composed of homogeneous pelagic clay, and completely devoid of siliceous or calcareous microfossils (Nishimura and Saito, Chapter IV of this volume). The color of the sediments was uniformly dark reddish brown (5YR3/2-2.5/2 in Munsell soil color chart) except for the horizon just below hiatuses.

A hiatus with manganese crusts was observed in Cores P411 (at depth of 2.4 m) and P412 (0.4 m), but was not seen in Cores P398 and P405. Rough age estimation of the cores could be done using ichthyoliths (microscopic skeletal debris of fish): the ages of the latter two cores and the sediments above the hiatus of the former two cores are not older than middle Miocene, and the ages below the hiatus are late Paleocene or

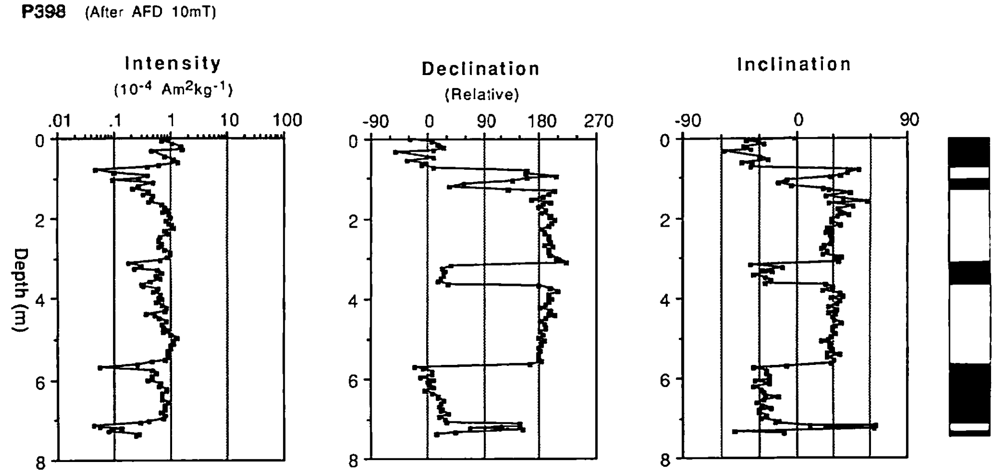

Fig. VI-2 Remanent magnetization of Core P398 after partial alternating-field demagnetization of 10 mT, and interpretation of magnetic polarity (solid: normal, open: reversed). Declination is relative. Intensity was normalized by weight of solids.

Eocene (P411) and late Cretaceous or early Paleocene (P412) (Nishimura and Saito. Chapter IV of this volume). The horizon of this hiatus could be traced widely in the GH83-3 Area as a strong reflector on the records of 3.5 kHz sub-bottom profiler (SBP) (Nishimura *et al.*, Chapter III of this volume). Acoustically transparent layer (Unit I) overlie the strong reflector around the sites of Cores P398 and P405, but not (thinner than the resolution of the 3.5 kHz SBP) around the sites of Cores P411 and P412.

The cores were split into halves on board soon after recovery, and samples for magnetic measurements were taken continuously with plastic cubic cases of 7 cm^3 or $10cm^3$ each. The samples were sealed up carefully to avoid dehydration.

Remanent magnetization

Alternating-field demagnetization

Measurements of the remanent magnetization were done within one year after the cruise in 1983 using an SCT's three-axis cryogenic magnetometer. Several pilot samples were chosen from each core, and stepwise alternating-field (AF) demagnetization experiments were carried out to investigate the stability of the remanent magnetization using a three-axis tumbler system.

Cores P398 and P405 proved to have stable remanent magnetization. Slight secondary magnetization likely of VRM origin could be removed by the AF demagnetization of about 5 mT. The polarity of the remanent magnetization can be clearly recognized (Figs. VI-2 and 3). The median destructive field (MDF) is usually higher than 10 mT.

Cores P411 and P412, on the other hand, suffered secondary magnetization which cannot be removed by the AF demagnetization. Core P411 has the unstable-to-stable transition of remanent magnetization at about 1.5 m in depth. Stepwise AF demagnetization of samples below this boundary (Fig. VI-4a) revealed that more than

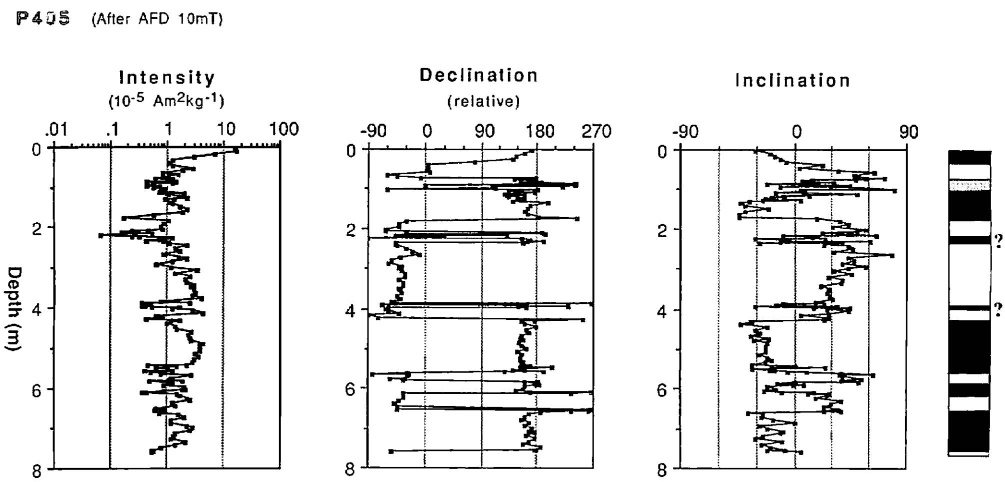

Fig. VI-3 Remanent magnetization of Core P405 after partial alternating-field demagnetization of 7.5 mT, and interpretation of magnetic polarity (solid: normal, open: reversed). Declination is relative. Intensity was normalized by weight of solids.

80% of the initial remanence was destroyed by a peak field of only 5 mT. In higher demagnetization fields, the remanent intensity slightly decreased, and changes in direction after each demagnetization level showed no systematic trend. A routine demagnetization of 10 mT of this core (Fig. VI-5) showed that the secondary magnetization of the upper 1.5 m was somewhat reduced, but below 1.5 m the scatter of the direction increased after the AF demagnetization. Core P412 also showed unstable magnetization below the hiatus at 0.4 m. While it would not be impossible to find a polarity change at about 1.5 m after the AF demagnetization of 10 mT, the scatter of the direction remained large (Fig. VI-6). The MDF was only about 5 mT.

Thermal demagnetization

Progressive thermal demagnetization experiments were run on samples at intervals of 20 to 30 cm in Cores P411 and P412. The residual field in the furnace of the thermal demagnetization apparatus is less than 100 nT during a cooling cycle. Samples were heated in air. When dried, the wet samples shrank almost isotropically without serious deformation or cracking.

Figures VI-4b and 4c illustrate two typical examples (at 3.17 m and 3.4 m of Core P411)(Yamazaki, 1986b). Both had nearly the same direction before demagnetization, but they have been separated into normal and reversed directions of steeper inclination after the treatment at 300°C. Thermal demagnetization at 300°C was hence used for all the specimens of Cores P411 and P412 (Figs. VI-5c and 6c). Compared with the AF demagnetization, the effectiveness of the thermal demagnetization is very clear.

Magnetostratigraphy

The polarity reversal sequence of Core P398 (Fig. VI-2) is correlative with that of the standard from the Gauss chron to the Brunhes chron. The reversal sequence of Core P405 below 4 m closely resembles that of the Gauss chron (Fig. VI-3). The age

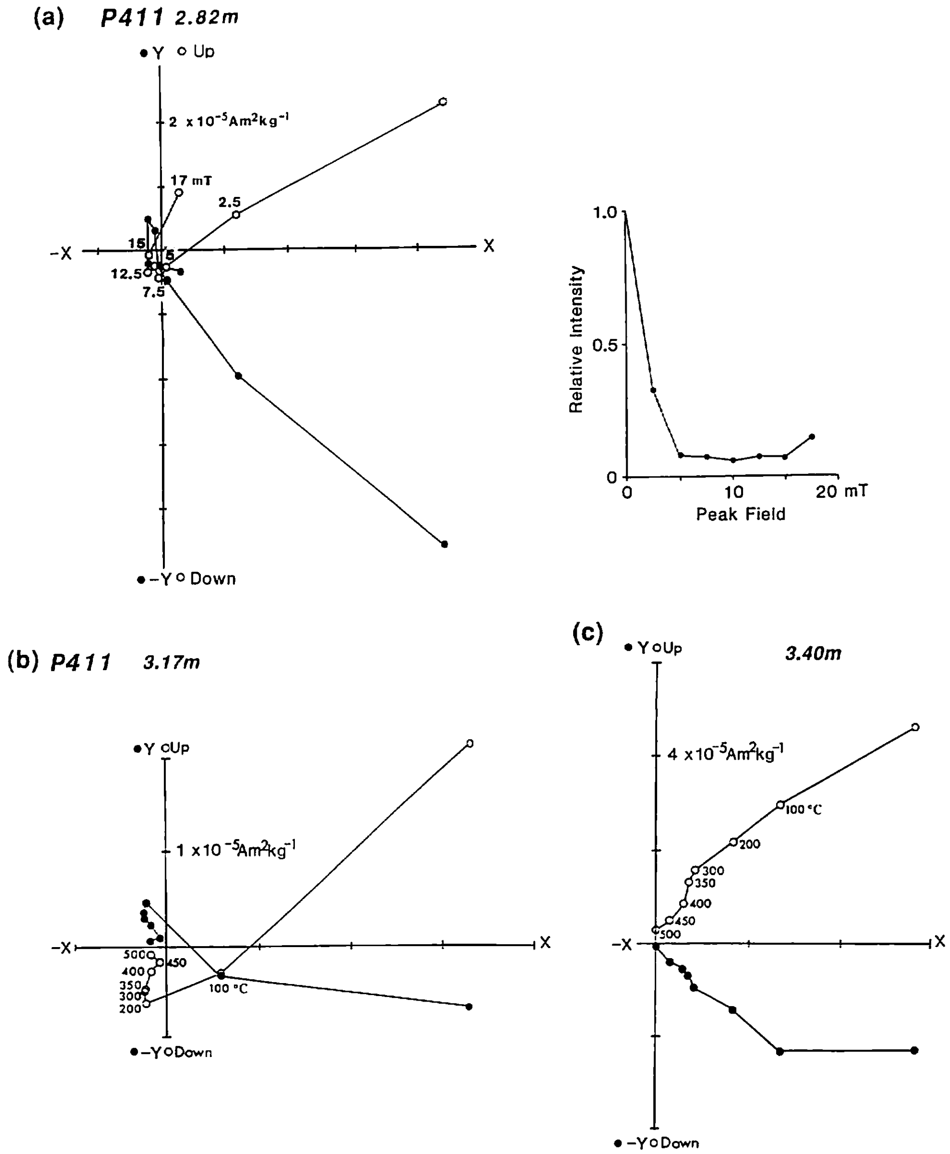

Fig. VI-4 Orthogonal plots of typical progressive demagnetization data of Core P411: alternating-field demagnetization at 2.28 m (a), thermal demagnetization at 3.17 m (b) and 3.40 m (c). Solid and open circles represent projections of vector endpoints on the horizontal and vertical plane, respectively. Horizontal components are relative.

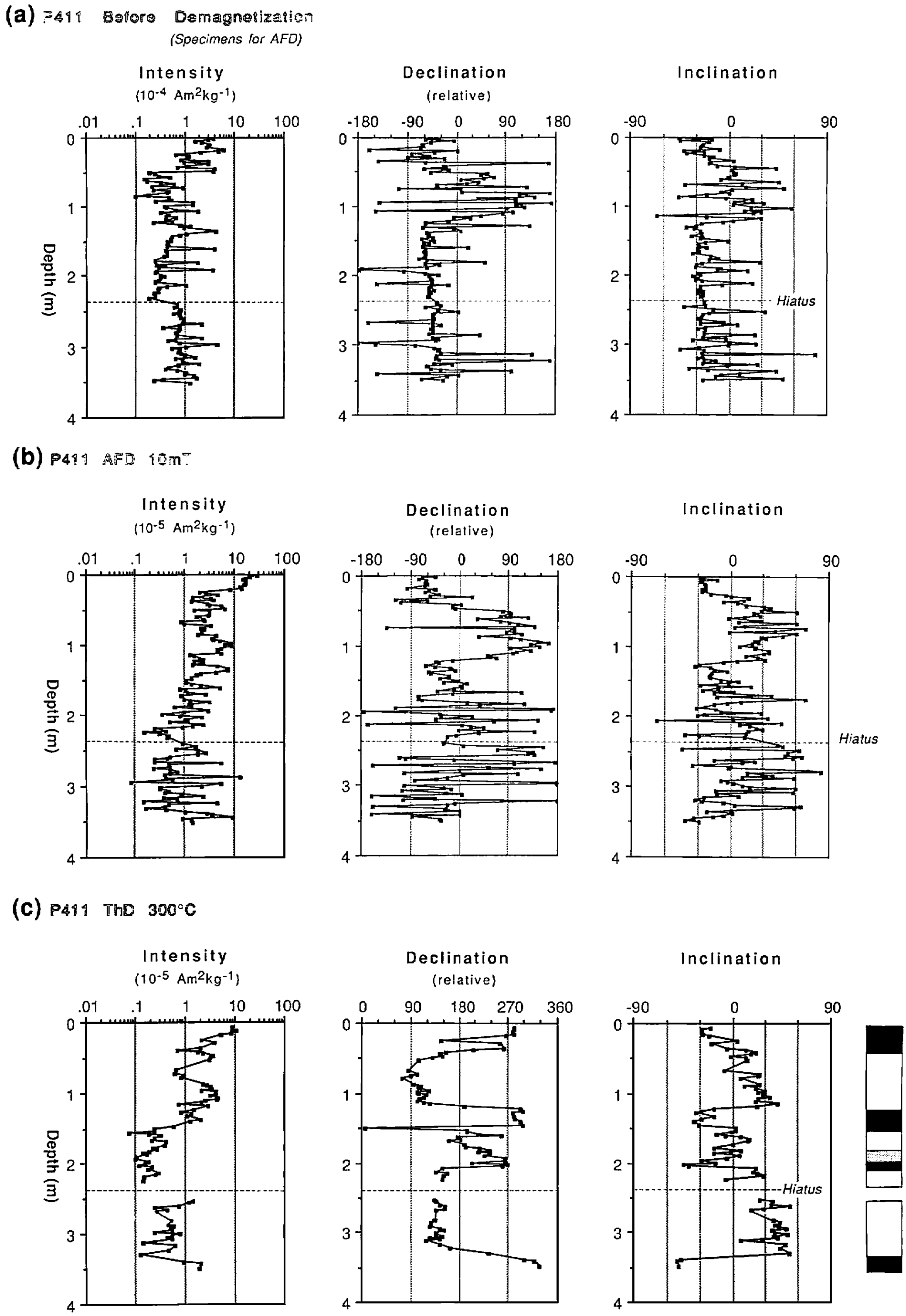

Fig. VI-5 Remanent magnetization of Core P411 before demagnetization (a), after partial alternating-field demagnetization of 10 mT (b), after partial thermal demagnetization of 300°C and magnetic polarity (c). Declination is relative. Intensity was normalized by weight of solids.

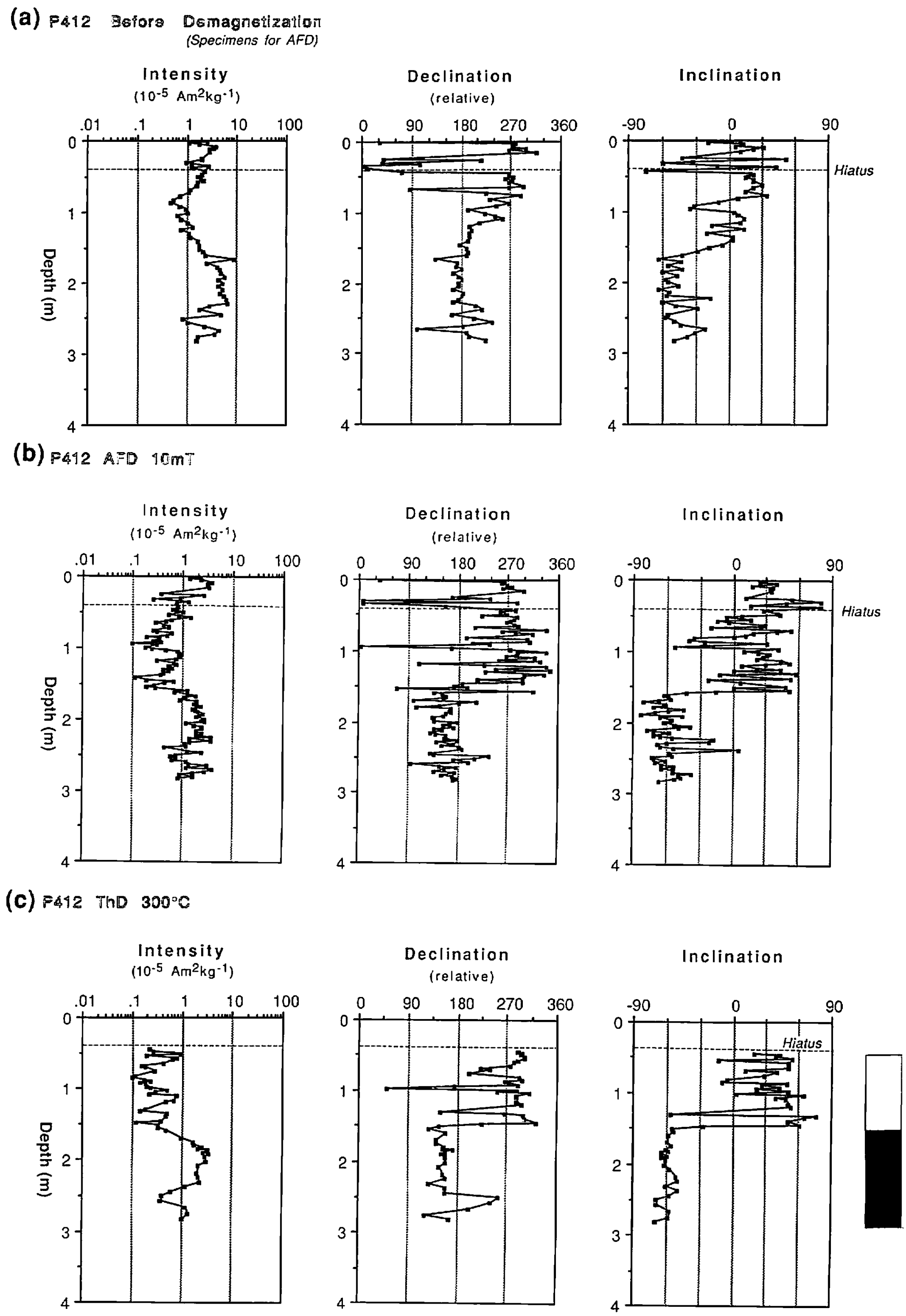

Fig. VI-6 Remanent magnetization of Core P412 before demagnetization (a), after partial alternating-field demagnetization of 10 mT (b), after partial thermal demagnetization of 300°C and magnetic polarity (c). Declination is relative. Intensity was normalized by weight of solids.

assignment above 4 m, however, is not straightforward. A normally magnetized part around 1.5 m may corresponds to the Olduvai subchron, and a hiatus from the Olduvai subchron to the Jaramillo subchron would exist at about 1 m. The sedimentation rate of Cores P398 and P405 during the Matuyama and the Gauss chrons was 2 to 4 m/m.y. In the Brunhes chron, however, the rate decreased significantly, even if the very surface sediments of several tens of centimeters were missing, which sometimes occurs at sampling by a piston-corer.

The polarity of the magnetization of Core P411 was established after the thermal demagnetization. But its correspondence to the standard geomagnetic reversal time scale is still unclear. A possible correlation is that the top normal part is the Brunhes chron and the second normal part at 1.3 m is the Gauss chron or the Olduvai subchron, if assumed no significant hiatus except for the one at 2.4 m. The unstable-to-stable transition of remanent magnetization may have occurred in Late Pliocene in the South Pacific as well as in the North Pacific.

A polarity reversal of Core P412 may be any one of normal-to-reversed transitions in Late Cretaceous. If sedimentation rate of this core is as low as that of the pre-Quaternary pelagic clay in the North Pacific (0.2 to 0.4 m/m.y.; Doyle and Riedel, 1979), the Polarity Chrons 34 (83.00-124.32 Ma; Harland *et al.*, 1990) and 33R (79.09-83.00 Ma) fit best among them.

Paleolatitude

The remanent magnetization of Cores P411 and P412 after the thermal demagnetization gave particular paleolatitudes which agree with those from plate tectonic analysis (Yamazaki, 1986b). This confirms that the secondary magnetization was erased successfully by the thermal demagnetization.

Average inclinations and their 95% confidence limits (vectorial means using relative declination) are $-24° \pm 7.9°$ ($n=39$) for the upper 1.5 m of Core P411, $-41° \pm 7.0°$ ($n=24$) for the part below the hiatus of Core P411, and $-62° \pm 6.4°$ ($n=25$) for the normally magnetized part of Core P412. Reversed directions were converted into normal ones for calculation. The inclinations correspond to the paleolatitudes of 13° S, 23°S, and 43°S, respectively. The first coincides with the present latitude of the cored site. The second is in accordance with the paleolatitude during Eocene deduced from the absolute motion models of the Pacific plate (Lancelot and Larson, 1975; van Andel *et al.*, 1975). The paleo-colatitude small circles of possible pole positions consistent with the mean inclination of Core P412 ($-62° \pm 6.4°$) overlap the confidence ellipse of the pole of the Pacific plate at 81 Ma proposed by Gordon (1983). This age agrees with the ichthyolith age, that is, Late Cretaceous or Early Paleocene.

Magnetic susceptibility

Magnetic susceptibility of the four cores was measured in 1988 using a Bartington M.S. 2 susceptibility meter. The measurement was done at two frequencies of inducing magnetic field, low-frequency at 0.47 kHz and high-frequency at 4.7 kHz (χ_L and χ_H, respectively). Here the frequency dependence of magnetic susceptibility is defined as $(\chi_L - \chi_H)/\chi_L \times 100$ (%).

The grain-size variations of fine magnetic minerals in deep-sea sediments can be estimated from the frequency dependence of magnetic susceptibility (Doh *et al.*, 1988; Yamazaki and Katsura, 1990). When an assemblage of magnetite grains contains a larger amount of SP (super-paramagnetic) grains (less than 0.03 μm in diameter; Dunlop, 1973), the frequency dependence is expected to be larger because the hyperfine SP grains contribute less to the high-frequency susceptibility (Mullins and Tite, 1973; Broemendal *et al.*, 1985).

The magnetically unstable pelagic clay (Cores P411 and P412) has larger values of the frequency dependence of susceptibility than the stable pelagic clay (Cores P398 and P405) (Fig. VI-7). The larger frequency dependence implies the existence of

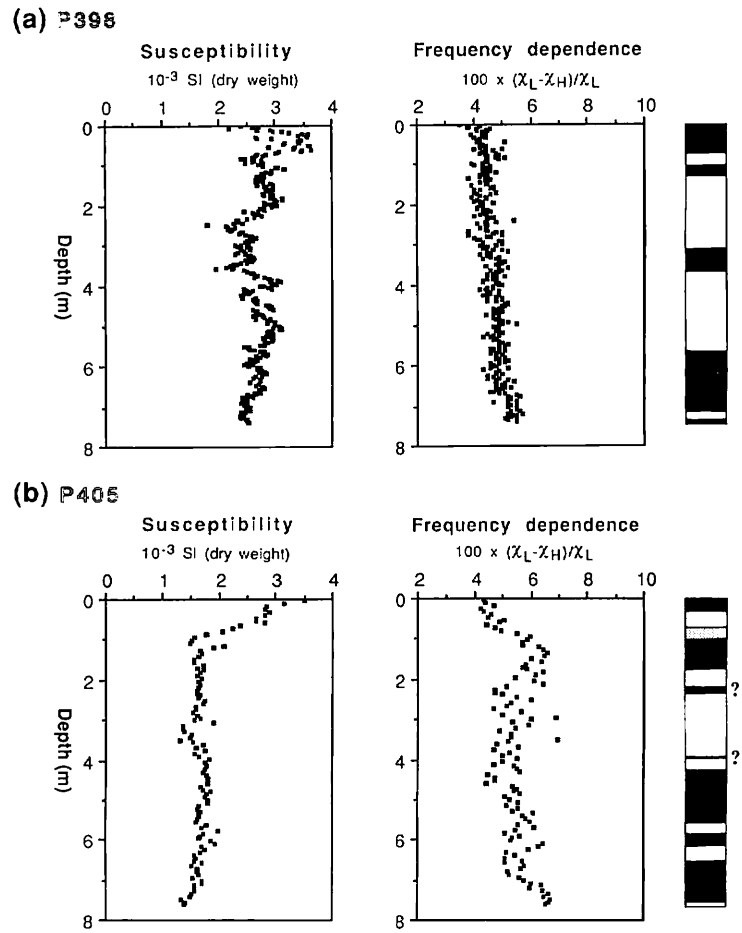

Fig. VI-7 Weak-field low-frequency (0.47 kHz) magnetic susceptibility normalized by weight of solids, and frequency dependence of magnetic susceptibility of Cores P398 (a), P405 (b), P411 (c) and P412 (d). The frequency dependence is defined as 100× (χ_L-χ_H)/χ_L, where χ_L and χ_H are low-frequency (0.47 kHz) and high-frequency (4.7 kHz) susceptibility, respectively. Magnetic polarity determined from the remanent magnetization is shown on the right column.

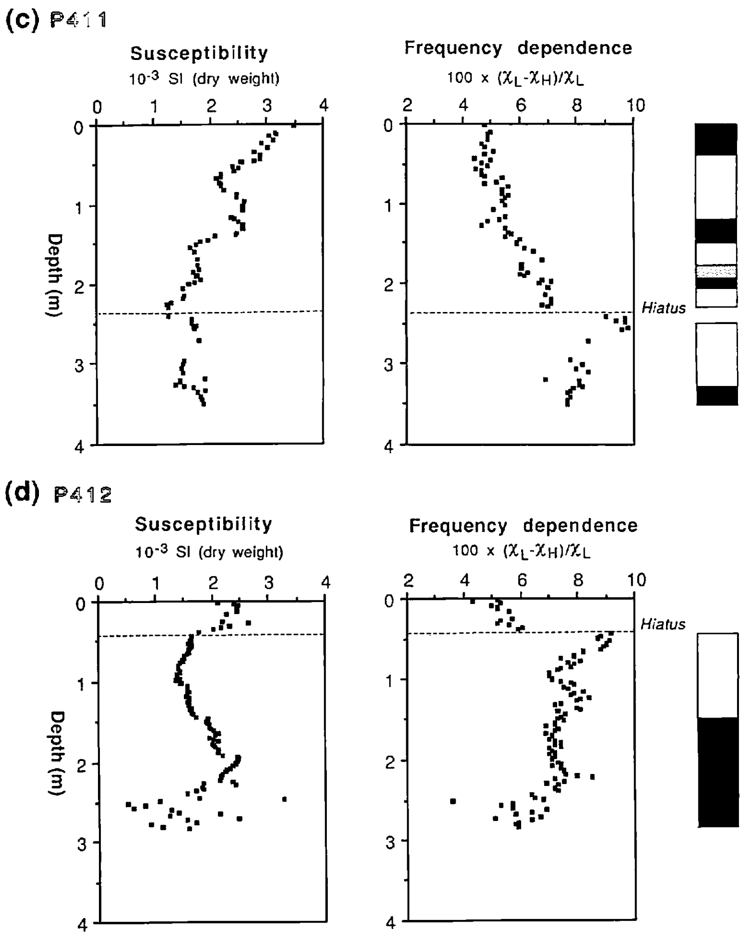

Fig. VI-7 (continued)

larger amount of SP grains, which is consistent with the higher magnetic viscosity of the unstable pelagic clay. The frequency dependence of Core P411 increases remarkably with depth (Fig. VI-7c). The values of upper 1 m are about 5%, and they rise to 8% at 3 m. The values just below the hiatus are particularly large (9% or more). The values below the unstable-to-stable transition at 1.5 m are larger than 6%. Core P412, which has the unstable remanence, also shows large frequency dependence, 7 to 9%, except for the surface (above the hiatus) and the bottom of the core (Fig. VI-7d). On the other hand, Cores P398 and P405 show rather small frequency dependence ranging from 3.5 to 6.5% (Figs. VI-7a and 7b). These cores are magnetically stable.

The variation of magnetic grain size with age were estimated from the variation of the frequency dependence of susceptibility. The variation of the frequency dependence during last 3.5 m.y. shown in Figure VI-8 was constructed from the results of Cores P398 and P405 using their polarity reversal sequences. This figure implies that average magnetic grain size has decreased at least since 3.5 Ma, and the decrease may have been greater in late Pliocene than in Quaternary. If the tentative age-assignment above the hiatus of Core P411 (0 to 5 Ma) is correct, the variation with age of this core

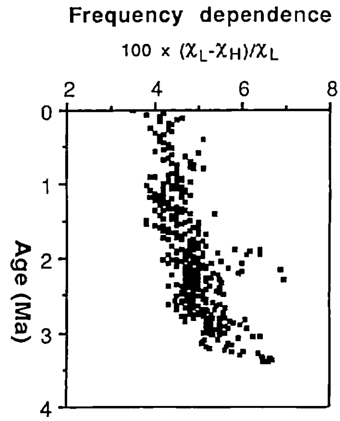

Fig. VI-8 Variation of the frequency dependence of susceptibility with age. The data of Cores P398 and P405 were superimposed. The age of the cores were based on the magnetostratigraphy. The definition of the frequency dependence is the same as that of Figure VI-7.

agrees with that of Cores P398 and P405. The large frequency dependence of Core P412 suggests that magnetic grain size in pelagic clay would be small in the Late Cretaceous or Early Paleocene.

It has been considered that the major source of pelagic clay is atmospherically transported dust (e.g. Rex and Goldberg, 1958). Variations of the intensity of global atmospheric circulation caused by climatic changes would control the grain size of magnetic minerals of pelagic clay (Yamazaki and Katsura, 1990).

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