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ROCKMAGNETIC ANALYSIS OF SEDIMENTARY SEQUENCES FOR PALEO-ENVIRONMENTAL RESEARCH

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Abstract: Rockmagnetic analyses are conducted to examine their utility for paleo-environmental research on the following three sedimentary sequences: (1) samples from the Omma Formation of central Japan; (2) cores drilled off the Noosa Heads, Australia; (3) a core drilled from Honnör Submarine Valley, Antarctica. The sequences (1) and (2) show clear variation of magnetic properties consistent with the changes of depositional environment which correspond to the change of sedimentary circumstances such as Quaternary glacial-interglacial change. Three drilled cores of sequence (2) show high values in magnetic susceptibility during the time range from 14 to 18 ka. The age of the sequence (3) is inferred to be beyond the Holocene, however, a preliminary result of magnetic susceptibility for the core shows no remarkable variation.

1. Introduction

Remanent magnetization of sediment has been utilized in the magnetostratigraphy and the rockmagnetic analysis is used to examine the reliability of remanence. Several studies suggest that the variation of magnetic susceptibility has good correlation with climatic indicators such as oxygen isotope data (*e.g.*, KENT, 1982; ROBINSON, 1986). Since then, there has been renewal of interest in application of rockmagnetic technique to paleo-environmental research, *i.e.* environmental magnetism (THOMPSON and OLDFIELD, 1986). The variation in magnetic properties of sediment (*e.g.* composition, concentration and grain size of the magnetic material) is a sensitive indicator of variation in environmental processes (BLOEMENDAL and DEMENOCAL, 1989; KING and CHANNELL, 1991).

The advantages of the rockmagnetic method are non-destructive and rapid measurement. The mechanism of correlation between magnetic properties and paleoenvironmental change seems to depend on several elements. Therefore, studies with the rock-magnetic method are necessary to examine its efficiency as an indicator of the paleo-environment and to investigate its mechanism.

In this study, magnetic properties including susceptibility are studied for three Quaternary sedimentary sequences. The efficiency of the method as an indicator of the paleo-environment is examined and also its mechanism is investigated.

2. Samples and Methods

Three sedimentary sequences are studied. They are (1) a sequence of the Omma Formation, early Pleistocene in the central Japan; (2) sediment cores deposited after the last glacial period off the Noosa Heads, Queensland, Australia; (3) a core from the glacio-marine sediment in Honnör Submarine Valley in Lützow-Holm Bay, Antarctica.

They were subjected to the following experiments on magnetic properties. The low-field magnetic susceptibility was measured for each sequence. For the sequences (1) and (2), discrete samples were collected, and susceptibilities were measured using a Bartington susceptibility meter "MS-2". For sequence (3), whole core measurement was made continuously with a core scanning type sensor.

Anhysteretic remanent magnetization (ARM) was measured on the discrete samples from sequence (2). The ARM was induced in an alternating magnetic field (AF) of 0.1 T and a direct field of 0.05 mT. Isothermal remanent magnetization (IRM) was measured on discrete samples from sequences (1) and (2). The IRM was induced in a direct magnetic field of 1.0 T.

Magnetic hysteresis parameters were measured for sequences (1) and (2). The parameters saturation magnetization (Js), saturation remanence (Jr), coercive force (Hc), remanent coercivity (Hrc) were determined by the NIPR vibration sample magnetometer system. These magnetic hysteresis parameters were then analyzed to investigate the magnetic domain structure. Also, the method using the demagnetization curve of ARM and IRM, such as the modified Lowrie-Fuller test (Maher and Taylor, 1988), is attempted to identify the magnetic grain size and/or domain structure of sequence (2).

3. Results and Discussion

3.1. Sedimentary sequence of the Omma Formation

The Omma Formation distributed in Ishikawa Prefecture is well known for its early Pleistocene shallow marine strata (Fig. 1). The age of the sedimentary sequence is studied in detail by paleomagnetic and biostratigraphic analyses (Sakai *et al.*, 1993; Takayama *et al.*, 1988). On the basis of the litho- and biofacies, the Omma Formation is divided into lower, middle and upper parts. The middle part of the Omma Formation includes the 11 sedimentary cycles corresponding to the sea-level change (Kitamura *et al.*, 1994). The individual cycle thickness ranges from 2 to 12 m. The sediment in each cycle is divided into three lithofacies, (A) a basal shell bed, (B) a well-sorted fine-grained sandstone and (C) a muddy fine- to very fine-grained sandstone. Each cycle is most likely ascribed to have formed under the glacio-eustatic sea-level change (0–100 m) demonstrated by changes in molluscan associations (Kitamura and Kondo, 1990). Figure 1 shows the stratigraphical columnar section and the result of susceptibility for the Omma sequence. The fluctuation in the magnetic susceptibility shows an inverse correlation with sea-level change. That is, when the paleo sea-level is high, the susceptibility is low, and vice versa. Since the

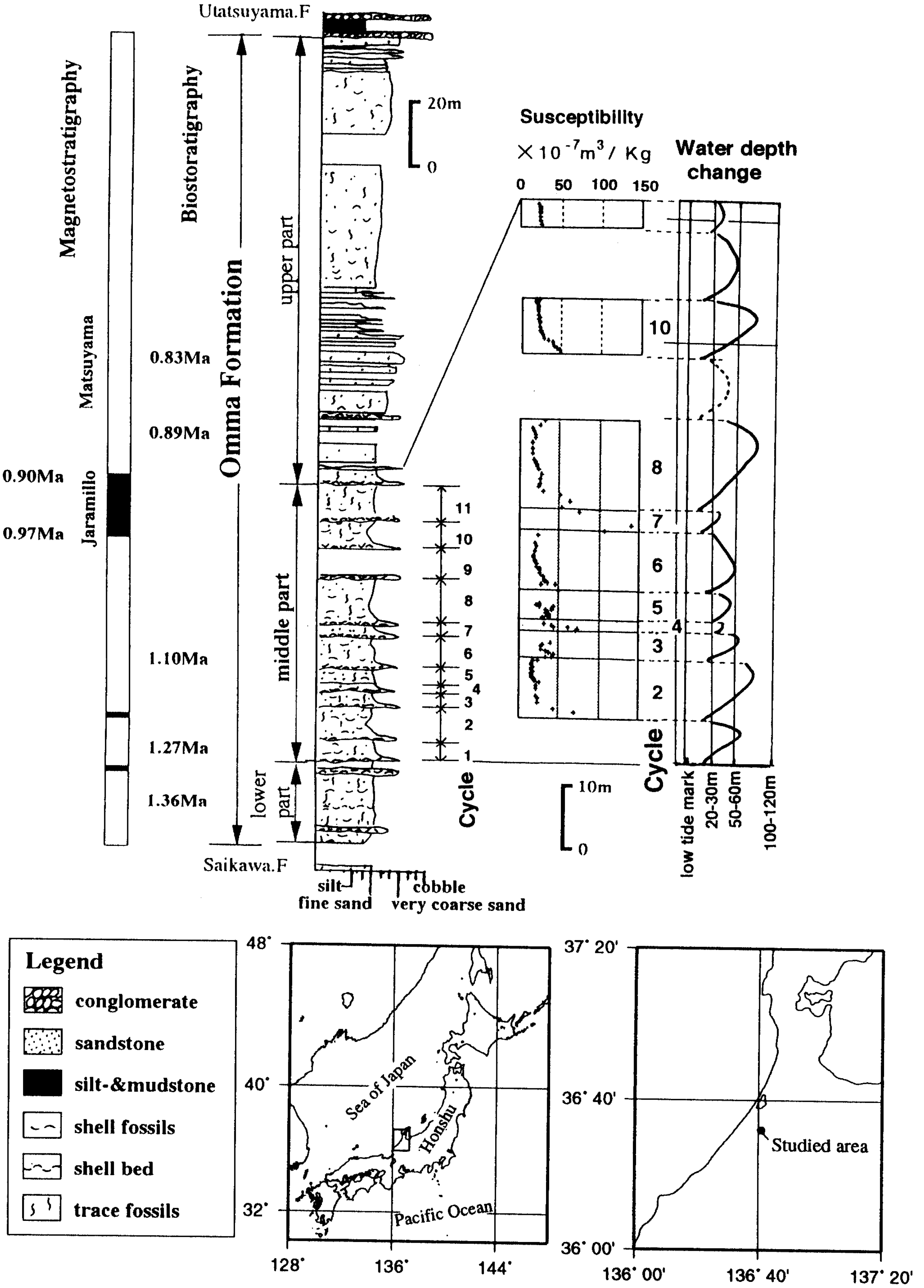


Fig. 1. *Location of the Omma Formation, and the results of susceptibility measurements. The lithology and water depth change are after* Kitamura *et al. (1993).*

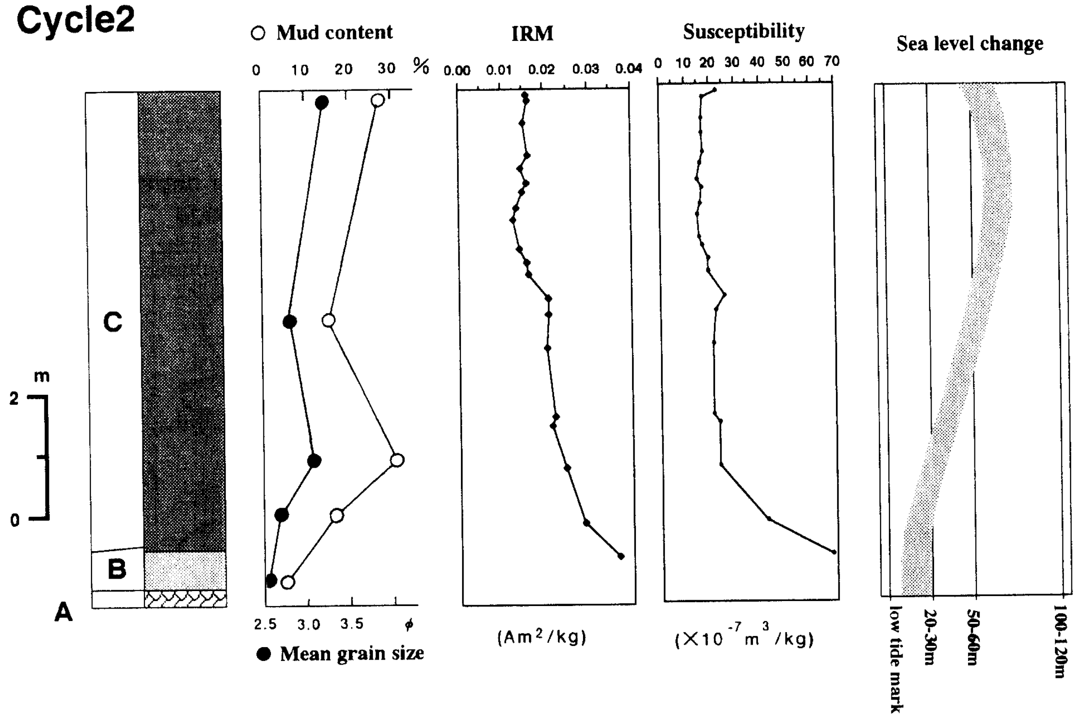


*Fig. 2. Lithofacies, mean grain size, mud content and sea-level change (*Kitamura *and* Kondo*, 1990), IRM and susceptibility for the cycle 2 of the Omma Formation. Lithofacies: A = basal shell bed, B = well-sorted fine-grained sandstone, C = muddy very fine-grained sandstone.*

sea-level change in the Omma Formation is glacio-eustatic, the high sea-level corresponds to warm climate.

Figure 2 shows the correlation between magnetic properties of IRM and susceptibility, and lithological variations of mean grain size and mud content (Kitamura and Kondo, 1990) for cycle 2. The susceptibility is especially high in lithofacies B.

Magnetic hysteresis was measured for the samples from lithofacies B and C from several cycles', the results are shown in Table 1. The samples have relativeiy strong magnetization and low coercivity. The magnetic domain structure was investigated by the method of Day *et al.* (1977). The result in Fig. 3 indicates that the magnetic grains of the studied samples have the pseudo-single to multi domain structure. The result also suggests that the size of magnetic grains is almost uniform. Hence the susceptibility change in Fig. 2 may reflect fluctuations in concentration of magnetic grain. The change of sea-level can cause such variations in concentration of magnetic grains.

We propose a model to explain the inverse correlation between susceptibility and sea-level change observed in the Omma sequence, as in Fig. 4. When sea-level rises, the study site departs from the supply area of terrigenous material so that few heavy magnetic grains are transported to the site. In contrast, the regression of sea-level causes sedimentation of heavy grains because the study area becomes shallower, and then the magnetic grains will be easily transported and deposited there.

Table 1. Hysteresis for samples of the Omma Formation.

Lithofacies	Susceptibility m^3/kg	*Js* Am^2/kg	*Jr* Am^2/kg	*Hc* mT	*Hrc* mT
B	6.81E-06	0.104	0.006	6.048	26.78
B	3.14E-06	0.116	0.007	6.619	27.61
B	1.35E-05	0.117	0.008	7.878	34.98
B	5.61E-06	0.148	0.008	5.791	27.13
B	2.64E-06	0.192	0.018	10.27	39.95
C	1.70E-06	0.137	0.01	7.759	30.43
C	4.47E-06	0.113	0.007	6.744	27.45
C	1.72E-06	0.103	0.008	7.802	27.6
C	2.29E-06	0.157	0.016	9.982	34.54
C	1.84E-06	0.247	0.012	8.1	29

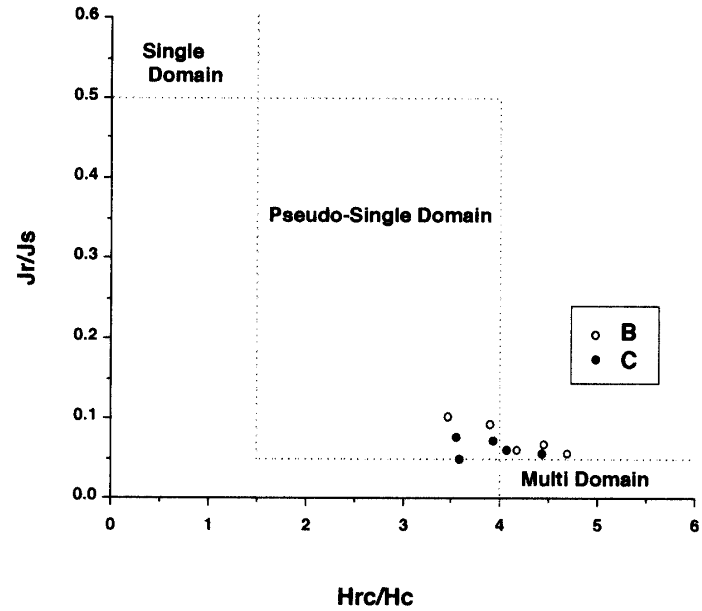


Fig. 3. Hysteresis parameter and domain structure by the method of DAY *et al. (1977) for sediment sample from facies B (open circle) and facies C (solid circle) in the Omma Formation.*

3.2. Sediment cores off Noosa Heads

Off the east coast of Australia including the Great Barrier Reef, carbonate sediments are formed widely. Core samples were collected from off the east coast of Queensland to investigate the facies relationship of sub-tropical and warm temperate carbonate (TSUJI *et al.*, 1993). Three cores were taken from different sites, from the continental shelf to the continental slope on the same latitude. The lengths of the cores are 1.5 m for site VC-15, 3.5 m for site GC-19, and 3.2 m for site GC-23. The water depths of each site are 136 m for site VC-15, 353 m for the site GC-19, and 842 m for the site GC-23 (Fig. 5). The sediments mainly consist of dark green fine sand and silt. Radiocarbon dating of these cores (TSUJI *et al.*, 1993) shows that the sedimentary sequence covers the time span from the last glacial period to the recent.

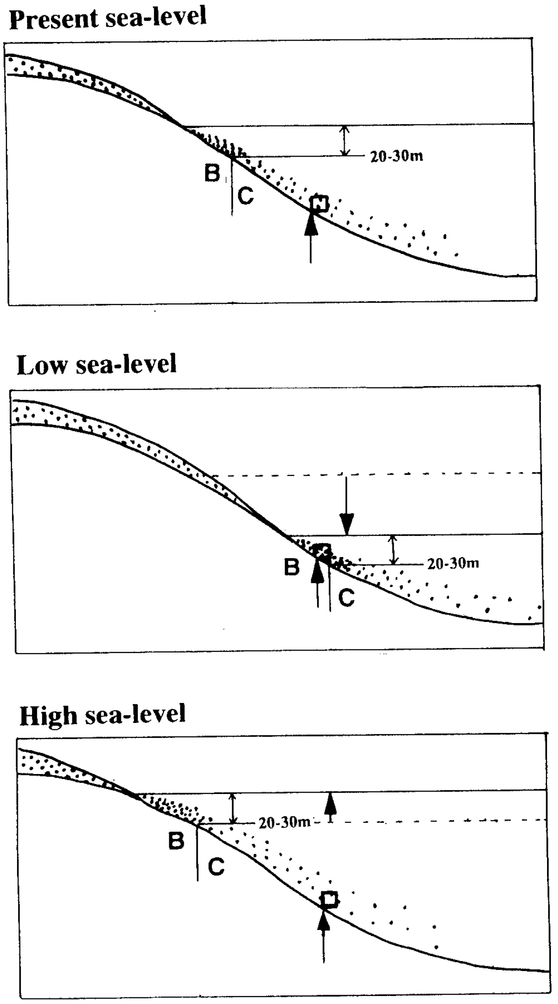


Fig. 4. Schematic diagrams of a model to explain the inverse correlation between susceptibility and sea-level change in the Omma Formation.

Figure 6 shows the magnetic susceptibility and the radiocarbon age. In each core, the magnetic susceptibility has peak values during the time range 14 to 18 ka. The time range seems to be correlated with the last glacial period. The appearance of high values of susceptibility during a glacial time is the same as the result for the Omma Formation.

Contents of $CaCO_3$ and sand were measured for the core from the deepest site GC-23. The susceptibility of the core is higher than those of other two cores. Figure 7 shows the $CaCO_3$ results compared with susceptibility. The sand content variation with depth is similar to that of the $CaCO_3$ content. The fluctuation in susceptibility shows an inverse correlation with the $CaCO_3$ content. It is suggested that the content of magnetic grains is diluted by biogenious material ($CaCO_3$) in a warm environment (Sato *et al.*, 1993).

The domain structure of magnetic grain for the GC-23 was investigated by both methods of hysteresis analysis and the modified Lowrie-Fuller test. Samples are collected from depths of 12, 50, 90, 130, 190, 215 and 225 cm.

Figure 8 shows hysteresis analysis for the samples from depths of 12, 50, 190, 215 and 225 cm. They show a pseudo-single domain structure. We could not obtain data from the samples from 90 and 130 cm because their magnetization was too weak to measure.

Figure 9 shows the result of the modified Lowrie-Fuller test. The median destructive

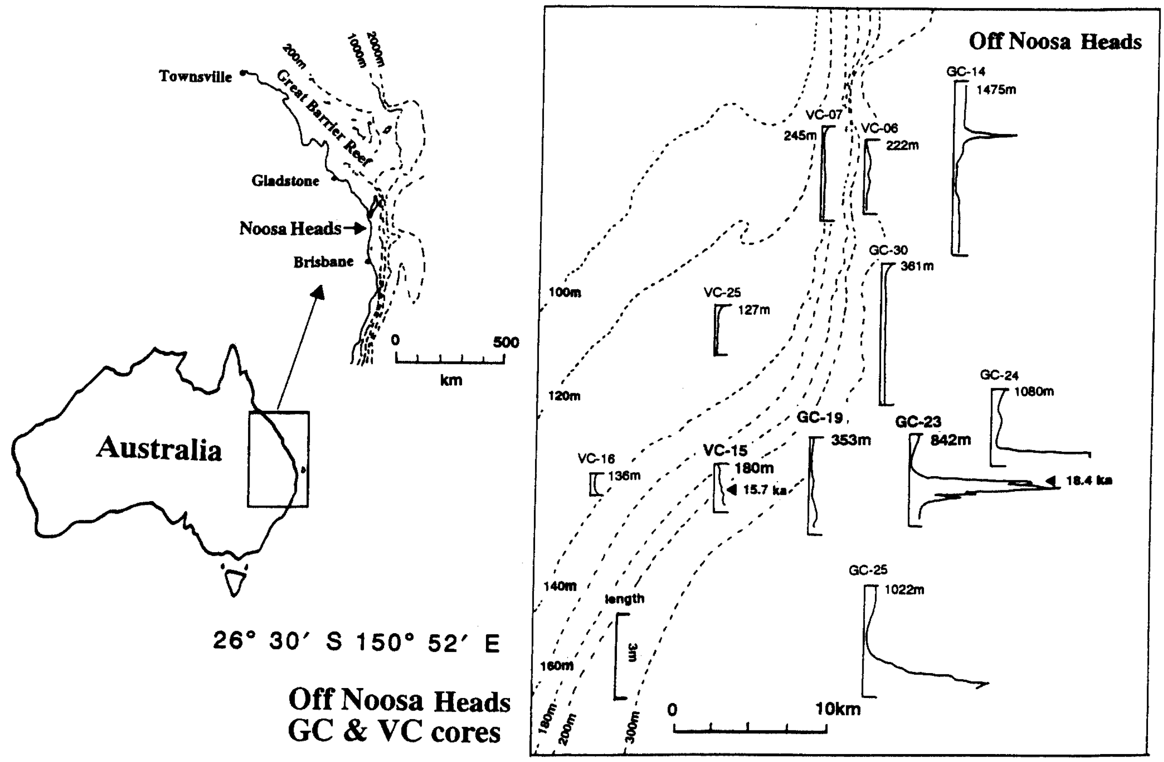


Fig. 5. Bathymetric map off Noosa Heads and location of the drilling sites.

fields (MDF; the field value when normalized remanence is 0.5) are compared. The samples from depths of 90 and 130 cm show that the MDF of ARM is lower than the MDF of IRM, demonstrating the multi-domain type response. These samples have different IRM acquisition curves from the others, that is, the IRM is not saturated even in a field of 1.2 T. It is possible that the dominant magnetic mineral of these samples is the high coercivity mineral (ex. hematite).

The above results indicate that the magnetic minerals of the samples, from depths of area with lower susceptibility, have a multi-domain type structure, while the samples from other depths have a pseudo-single domain structure. Also, the results of the IRM acquisition experiment suggest changes of domain structure and mineralogy for depths of lower susceptibility. These depths correspond to the period of high sea-level after the last glacial period. It is likely that the grain size and composition of magnetic mineral are controlled by the sedimentary mechanism during transitional period. In the period, for example, transgressive sand sheet is deposited. (Swift *et al.*, 1971; Saito *et al.*, 1989).

3.3. Sediment core in Honnör Submarine Valley in Lützow-Holm Bay

Lützow-Holm Bay is located on the Antarctic continental shelf. Several ice streams (glaciers) flow in Lützow-Holm Bay which is covered with perennial sea ice in the present. The sediment rate is very low in such a condition. Harada *et al.* (1995) radiocarbon datied a core (Lh2) sampled from a 557 m-deep drowned glacial trough in Lützow-Holm Bay (Fig. 10). They dated ages older than 10000 yBP for parts of the core lower than 100 cm with an age of 14000 yBP at the bottom (129 cm) of the core. The core (81-110901)

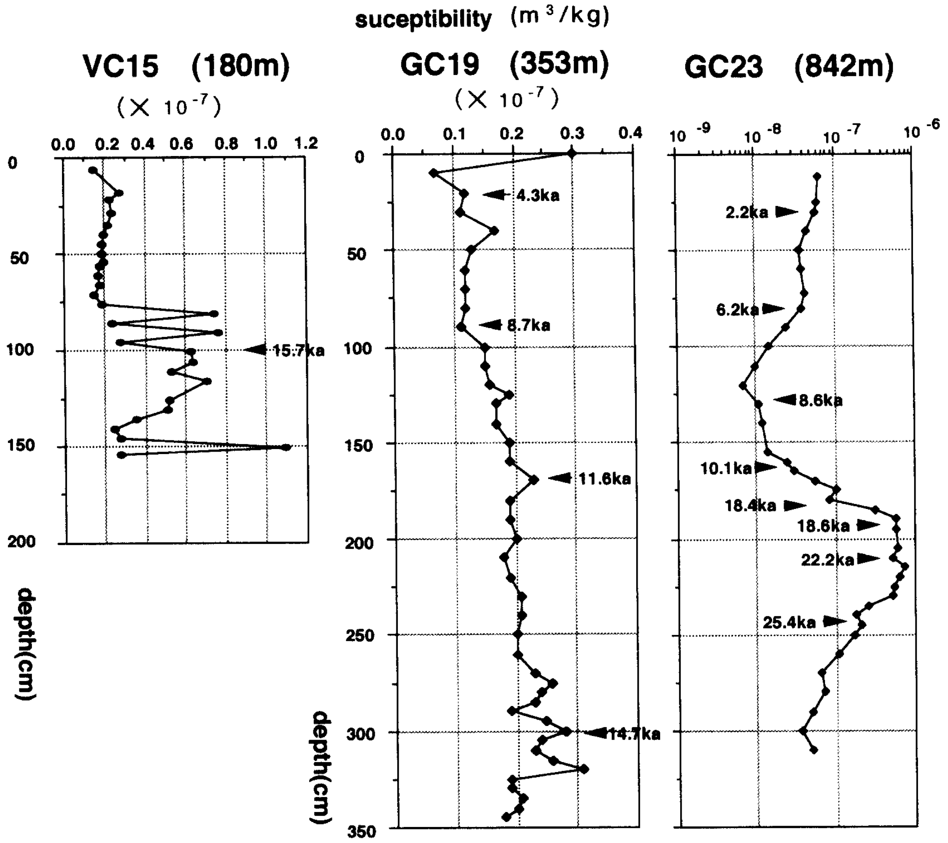


Fig. 6. *Susceptibility and radiocarbon dating of the VC-15, GC-19 and GC-23 cores.*

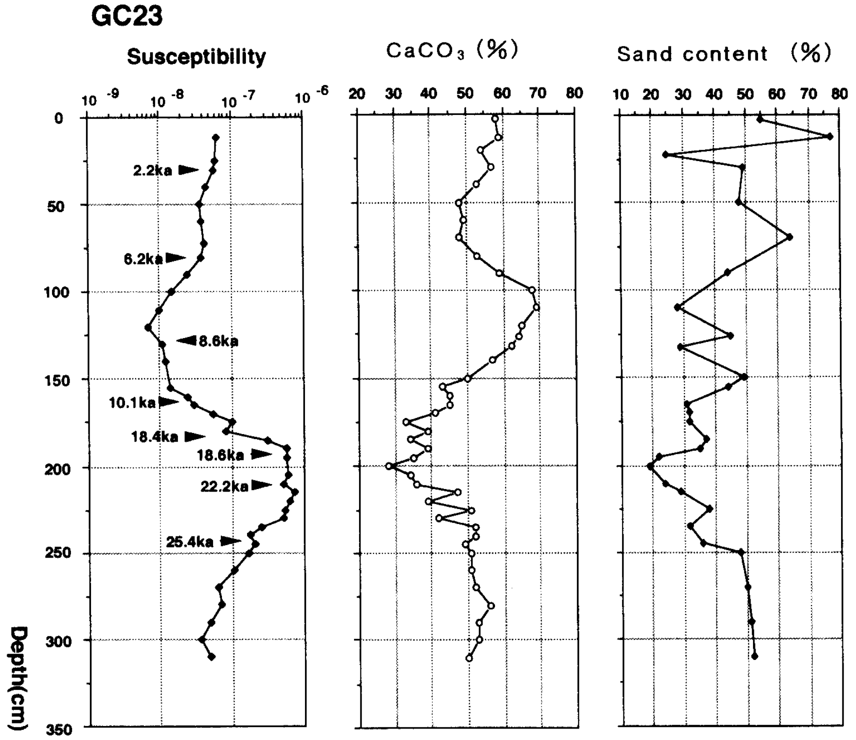


Fig. 7. *Susceptibility, CaCO₃ content and sand content of the GC-23 core.*

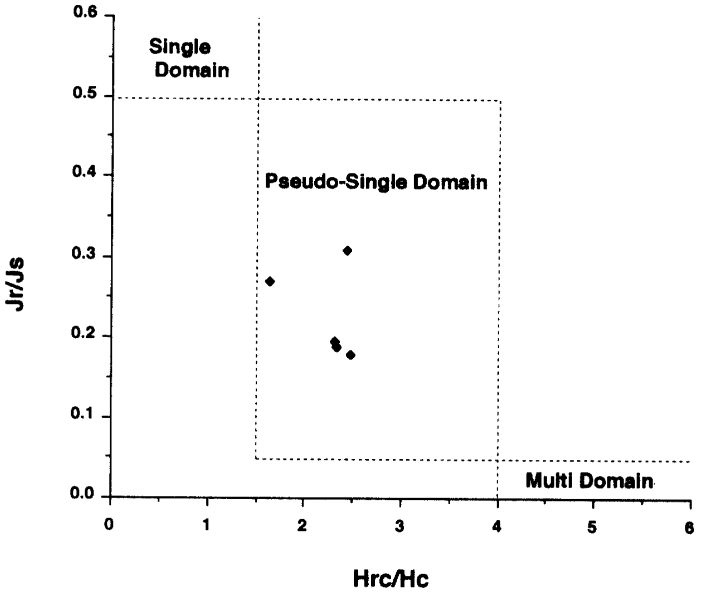


Fig. 8. *Hysteresis parameter and domain structure for sediment samples from GC-23, off Noosa Heads.*

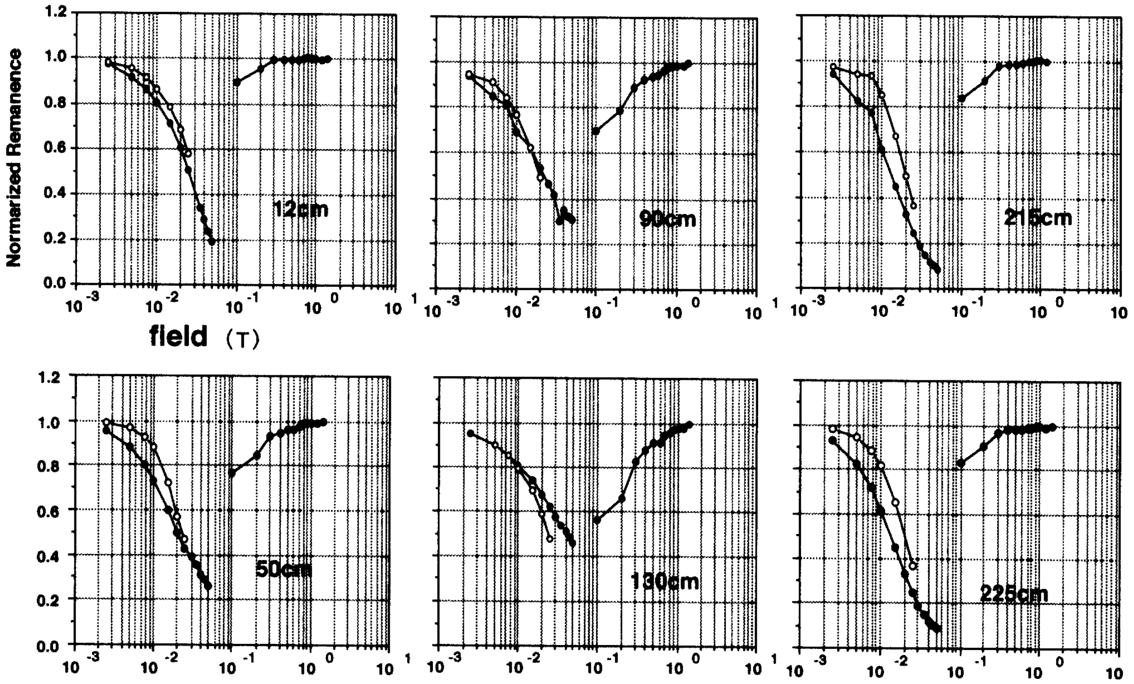


Fig. 9. *A modified Lowrie-Fuller test (after* MAHER *and* TAYLOR, *1988). Acquisition of IRM (right) and AF demagnetization of IRM (left open circles) and ARM (left solid circles) for samples from GC-23.*

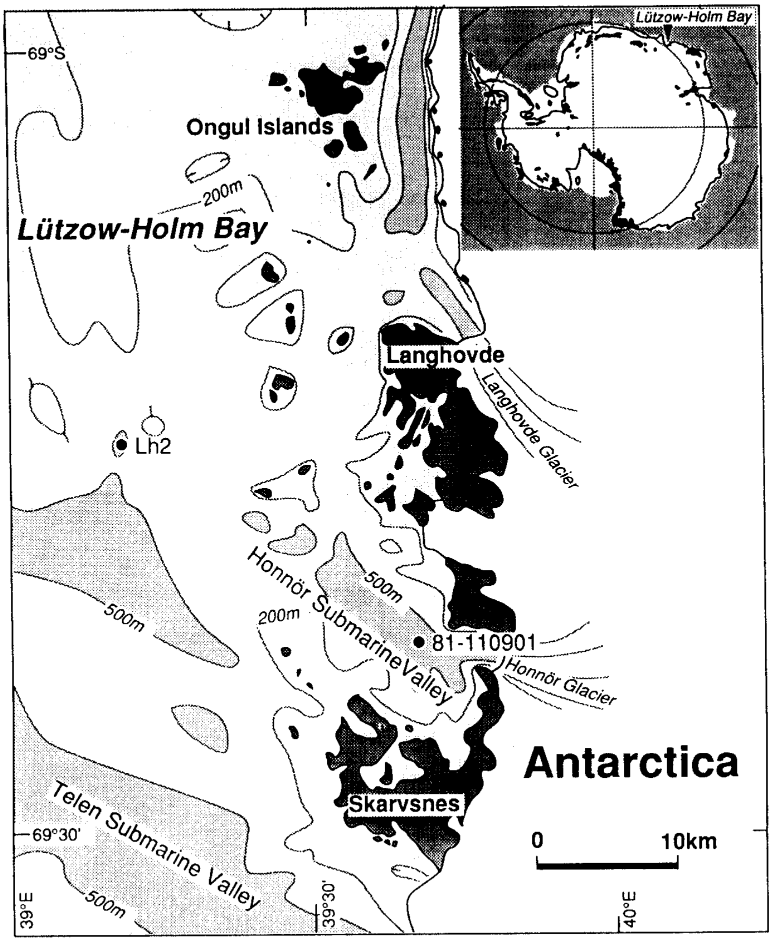


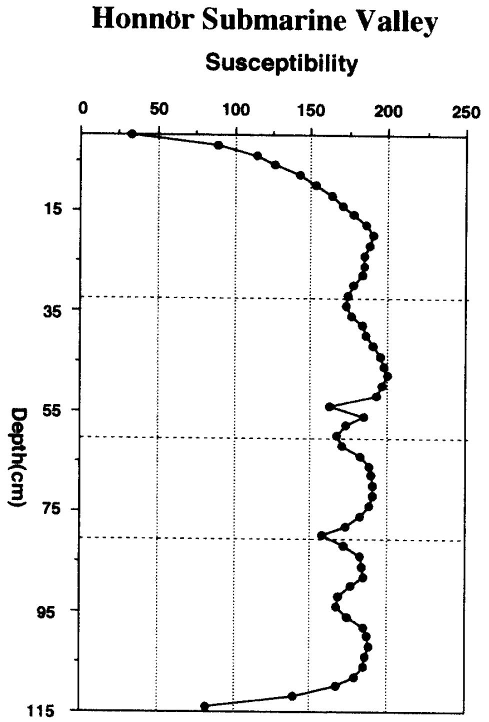
Fig. 10. Bathymetric map of the northeastern part of Lützow-Holm Bay, and sampling site of core 81-110901 and core Lh2 (HARADA *et al., 1995).*

was sampled from Honnör Submarine Valley, 683 m deep and 20 km southeast of site Lh2 (Fig. 10), and is 115 cm in length. From an analogy of similar locality and length of two cores, the age of the core 81-110901 is probably beyond the Holocene.

The core 81-110901 was divided into four sub-cores. A preliminary measurement of susceptibility was made on each sub-core by the whole-core susceptibility meter. Figure 11 shows the compiled data from the results of the measurements for the sub-cores. The susceptibility minima which appeared at the sub-core boundaries are considered to be due to the edge effect. Besides these minima, there exists no remarkable variation. This result suggests that sea-level change does not necessarily cause fluctuations of susceptibility of some sedimentary sequences deposited under the perennial sea ice area.

4. Conclusion

The magnetic susceptibility changes for both the Omma sequence and the drilled core from off Noosa Heads, Australia show inverse correlation with the changes of paleo-climatic indicators, sea-level change and $CaCO_3$ content. The result indicates that the susceptibility minimum appears in the warm environment and the maximum in the cold environment.


Honnör Submarine Valley

Susceptibility

Fig. 11. *Susceptibility of the core from Honnör Submarine Valley. Sub-core boundaries are expressed by dashed lines.*

The results in this study and former studies (*e.g.*, Bloemendal and DeMenocal, 1989) show that using rock magnetic properties such as susceptibility is a useful technique in discussion of the paleo-environmental and/or paleo-climatic evolution.

However, the Antarctic core shows no significant change of susceptibility. This result seems to be an instructive example. Mechanisms to cause fluctuations of susceptibility are probably complex, depending on local environment. Local sedimentary environmental factors such as mineralogy, grain size of magnetic mineral, and whether temperate or polar should be investigated in further work.

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