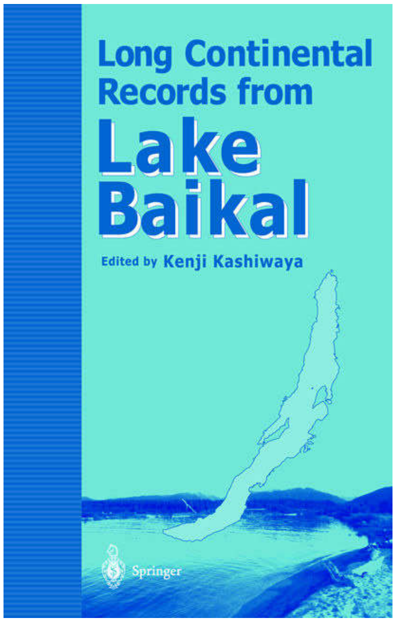

Reprint from
K. Kashiwaya (Ed.)
Long Continental Records from Lake Baikal
Springer

Paleomagnetism and Paleoenvironmental Magnetism Studied on BDP-98 Sedimentary Cores from Lake Baikal

Hideo Sakai[1], Shigehiro Nomura[1], Masae Horii[2], Kenji Kashiwaya[3], Takayoshi Kawai[4], Vadim Kravchinsky[5], and John Peck[6]

Summary. Paleomagnetic and rock-magnetic studies were conducted on two sedimentary cores, BDP-98-1 (200 m in length) and BDP-98-2 (ca. 410 m in length from 191 m to 600 m deep), drilled at the Academician Ridge of Lake Baikal.

The magnetic inclination records assigned to the geomagnetic polarity time scale (GPTS) indicate that BDP-98-1 attained an age of 5 Ma. For BDP-98-2, owing to the long reversed interval between 290 m and 350 m, it became difficult to find a correlation to GPTS. A correlation tested in this study suggests that the basal age is over 11 Ma at 600 m deep. The average sedimentation rate for BDP-98-1 and the upper 50 m of BDP-98-2 is estimated as 4.1 cm/kyr. The sedimentation over the long reversed interval is as high as 29.3 cm/kyr, and below this depth, to 600 m, the rate is about 4.5 cm/kyr.

The magnetic properties of the BDP-98-1 sediment were also studied. The rock-magnetic parameter of anhysteretic remanent magnetization (ARM) susceptibility/susceptibility decreases after about 3 Ma, while the susceptibility increases. Spectral analyses on the susceptibility show that the shift in spectral character from a 100-kyr eccentricity cycle to a 41-kyr obliquity cycle occurred at ca. 3 Ma. These characteristic changes may be correlated with the change in the paleoenvironment in the Baikal region caused by the intensification of northern hemisphere glaciation. After 1.2 Ma, the susceptibility variation increases in amplitude, which may be correlated with the elevation of the Himalayas and Tibetan Plateau, which reached above the snow line at 1.2 Ma.

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Key words. Lake Baikal, Paleomagnetism, Magnetic property, Magnetostratigraphy, Paleoenvironment

1 Introduction

Lake Baikal, in eastern Siberia, is one of the deepest, most voluminous, and oldest freshwater lakes in the world. It is an important and unique site for paleoclimatic studies because of its high latitude, continental-interior setting, and long, continuous stratigraphic record.

In Lake Baikal, several paleomagnetic studies have recently been carried out on cores of lake sediment (e.g., Peck et al. 1996; Sakai et al. 1997, 2000, 2001; Kravchinsky et al. 1998; Horii et al. 2001; Krainov et al. 2001). In this chapter, we show the results of paleomagnetic and rock-magnetic studies on the BDP-98 cores drilled by the International Baikal Drilling Project (BDP) during the winter of 1998. Two of the cores (BDP-98-1 and BDP-98-2) were drilled at Academician Ridge in Lake Baikal (Fig. 1). Near the BDP-98 site, a BDP-96 core 200 m long had been drilled during the winter of 1996.

The drilling of BDP-98-1 (length 200 m) was conducted by piston coring. BDP-98-2 (about 410 m long) was drilled from 191 m to 600 m deep. In the upper portion (depth <277 m), drilling by piston coring was done, and the lower portion (277–600 m) was drilled by rotary coring. The recovery of the core was over 90%. The BDP-98-2 core is the longest that has been drilled at Baikal, so valuable data on the paleoenvironment and the Earth's science were expected. This study had two purposes. One was to examine the magnetostratigraphy to obtain the age-scale of the sedimentary sequence. The other was to study the paleoclimate and paleoenvironment through the magnetic properties of the sediment.

2 Samples for Magnetic Study, Experimental Methods, and Apparatus

The cores were divided into subcores of 2-m length, and each subcore was cut in half lengthwise (split). Samples for paleomagnetic study were taken in plastic cube cases of 10 cm^3 at an interval of 5 or 10 cm. These discrete samples were divided between the Russian, USA, and Japanese groups. In this chapter, we give the data from the Japanese samples (the sampling interval being 15 or 30 cm).

The remanent magnetization was measured using a pass-through-type cryogenic magnetometer (2G Enterprise 760R), and the magnetic cleaning was done by the alternating field (AF) demagnetization method. Magnetic susceptibility was measured with an AGICO KLY-3 meter.

Firstly, the pilot samples from discrete samples were step-wisely AF demagnetized to 90 mT in 5 mT steps. In most of the samples, the secondary magnetization was eliminated by demagnetization to 15 mT, so that the other samples

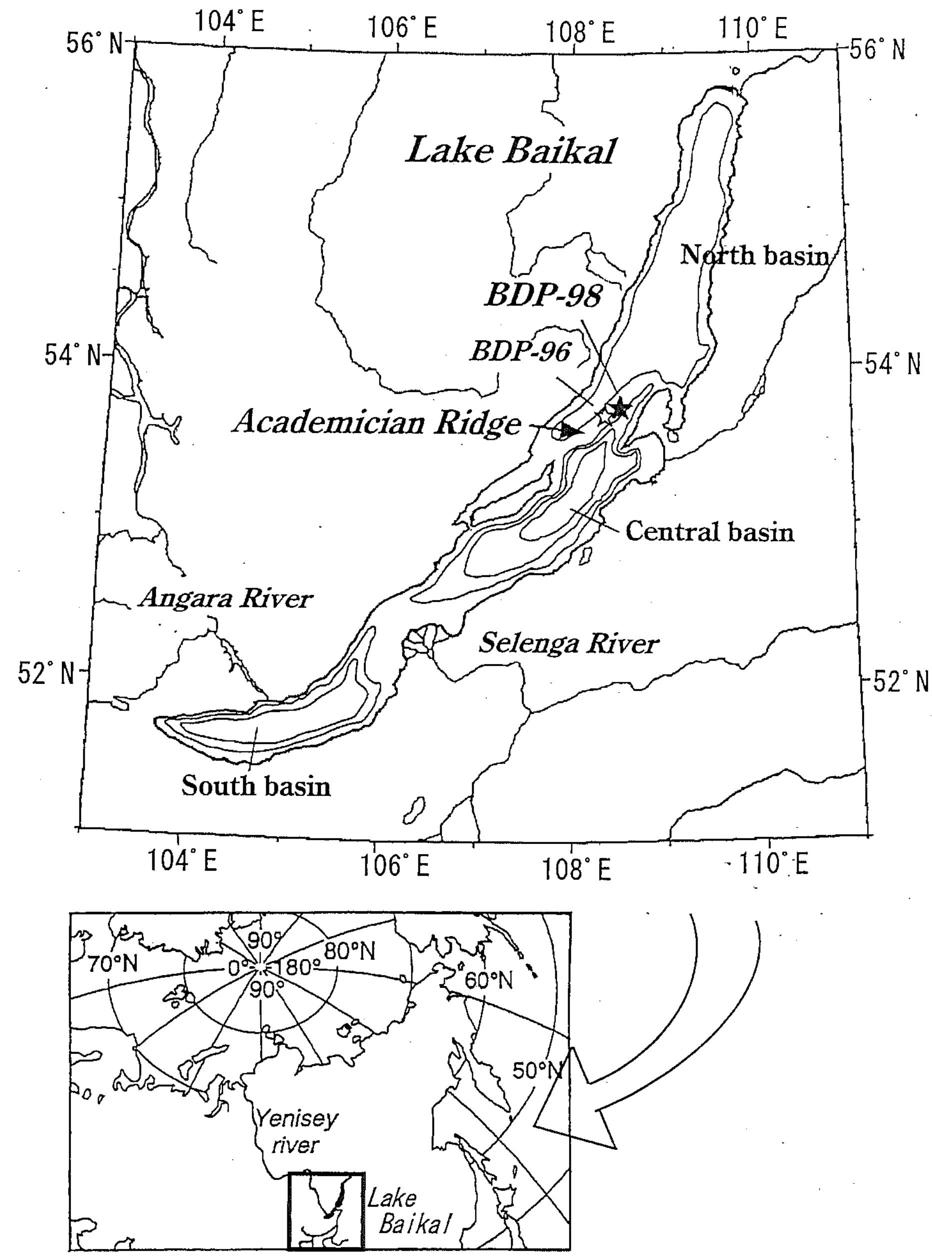

Fig. 1. Drilling point (53°44′48″N, 108°24′31″E, water depth 337 m) of BDP-98 at Academician Ridge in the central part of Lake Baikal

were demagnetized in four steps of 5, 10, 15, and 20 mT. The paleomagnetic data after 15 mT AF demagnetization are mainly used in the following discussion.

3 Paleomagnetic Results and Magnetostratigraphy

Figure 2 shows the direction and intensity of the remanent magnetization of the discrete samples for two cores. We can identify clear polarity reversals both in inclination and declination records.

3.1 BDP-98-1 Core

Figure 3 shows the inclination data of the BDP-98-1 core. The inclination change with depth shows a clear polarity reversal pattern. Comparison with the geomagnetic polarity timescale of Cande and Kent (1995) reveals the geomagnetic polarity epochs of Brunhes normal polarity, Matuyama reversed polarity, Gauss normal polarity, and Gilbert reversed polarity. Most of the geomagnetic events during the above polarity epochs were also identified. This indicates that the BDP-98-1 core covers an age of ca. 5 Ma.

The depth-age scale in Fig. 4 suggests that sedimentation at the rate of 4.1 cm/kyr proceeded fairly constantly. The similar result shown in the lower figure was obtained from the BDP-96 core (see Fig. 1). That is, sedimentation during the past 5 Ma at Academician Ridge has proceeded under a quiet environment with no remarkable tectonic event.

Several short inclination anomalies (reversed and/or narrow inclination zones) found during the Brunhes epoch (Fig. 3) may be correlated to the geomagnetic excursions, as discussed for BDP-96 (Kravchinsky et al. 1998). Further study is necessary to examine whether these are the formerly unknown geomagnetic events.

3.2 BDP-98-2 Core

The core depth is calibrated to the data of A. Tanaka, of the National Institute of Environmental Studies in Japan. Below 277 m depth, owing to the long reversed interval between 290 m and 350 m, it becomes difficult to find a correlation to any reference geomagnetic time-scale. Figure 5 is one reasonable correlation, which suggests that the basal age of the core is over 11 million years. In Fig. 6, the geomagnetic polarity assignment for BDP-98-1 and BDP-98-2 are summarized together.

The magnetostratigraphy of BDP-98-2 needs more information, and will be examined by new and/or additional data, taking the following subjects into consideration: (a) the depth adjustment between BDP-98-1 and BDP-98-2; (b) how to interpret the long reversed region.

Figure 7 shows the variation in sedimentation rate. The rate for the long reversed interval (290–350 m) is high at 29.3 cm/kyr. Then below 350–600 m, the rate becomes about 4.5 cm/kyr, which is comparable with the rate for BDP-98-1 of 4.1 cm/kyr.

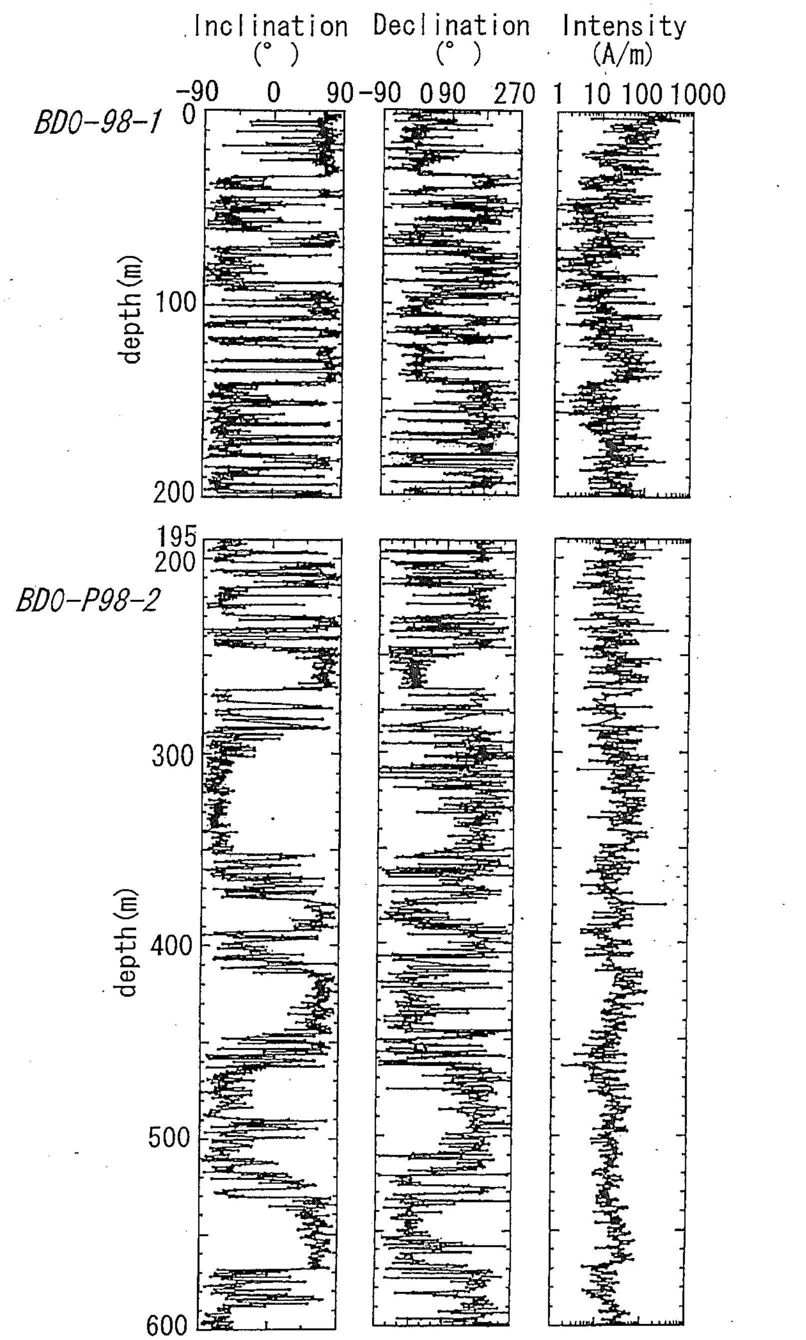

FIG. 2. Variation of inclination, declination, and intensity of remanent magnetization with depth from discrete samples of BDP-98 cores after 15 mT alternating field demagnetization

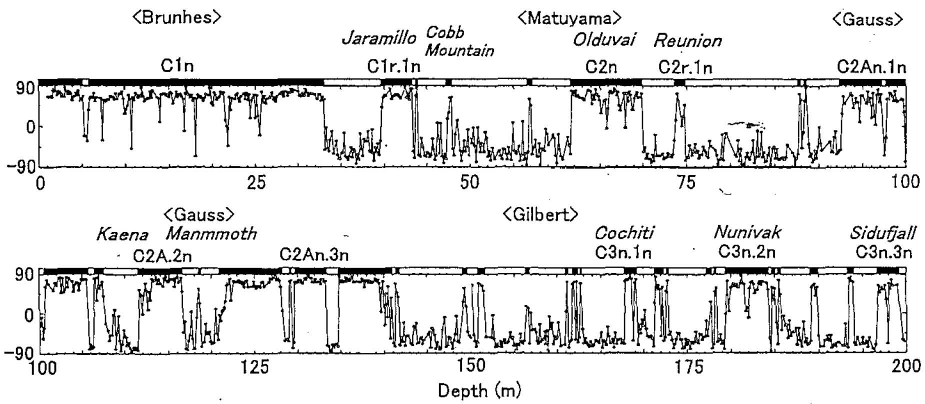

FIG. 3. Variation of inclination with depth for the BDP-98-1 core. In the figure, the geomagnetic polarity time-scale of Cande and Kent (1995) is used

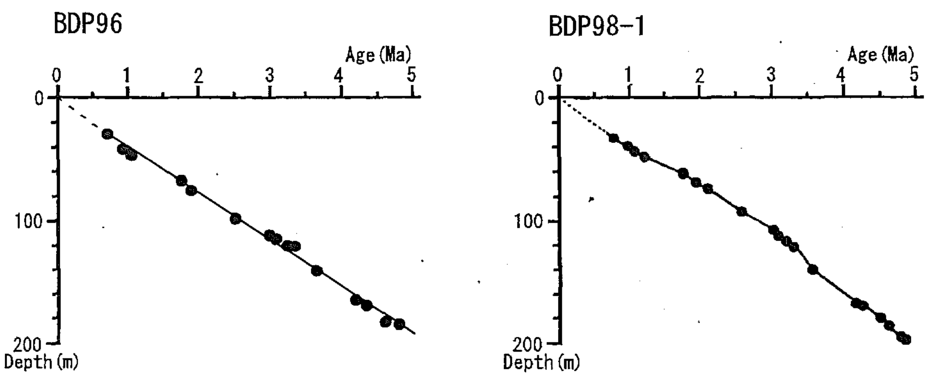

FIG. 4. Depth–age diagram for the polarity boundary of geomagnetic events and epochs for BDP-96 (*left*) and BDP-98-1 (*right*) cores (Sakai et al. 2000)

4 Magnetic Properties of BDP-98-1 and the Paleoenvironment

Figure 8b shows the variation in magnetic susceptibility of BDP-98-1. We can see an increase in susceptibility from ca. 3 Ma, which agrees with the BDP-96 susceptibility shown in Fig. 8a. This increase in susceptibility may be caused by an increase in the magnetic mineral concentration in the lake sediment. Thermal analysis shows that the magnetic mineral responsible for remanent magnetiza-

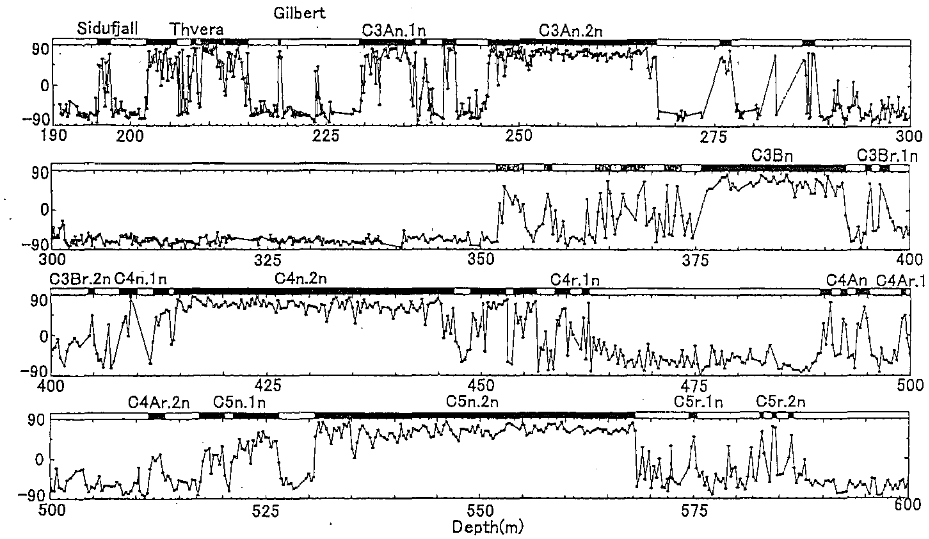

FIG. 5. Variation of inclination with depth for the BDP-98-2 core. In the figure, the geomagnetic polarity time-scale of Cande and Kent (1995) is used

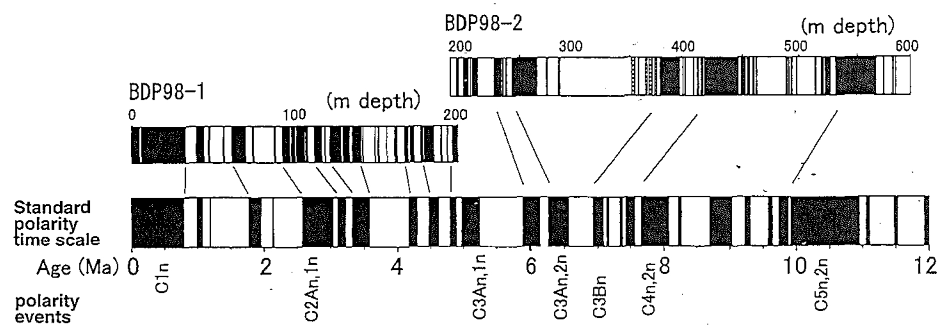

FIG. 6. Depth–age diagram for the polarity boundary of geomagnetic events and epochs for the BDP-98 core. In the lower part, the geomagnetic polarity time-scale of Cande and Kent (1995) is referred.

tion of the sediment around the Academician Ridge is magnetite (Sakai et al. 2000). King et al. (1982) reported that the anhysteretic remanent magnetization (ARM) is sensitive to the grain size of magnetite and that ARM susceptibility/susceptibility has an inverse correlation with the change in the grain size of the magnetite in the sediment. In Fig. 8c, ARM susceptibility/susceptibility shows a decrease from about 3 Ma. We thus conclude that the quantity of magnetite

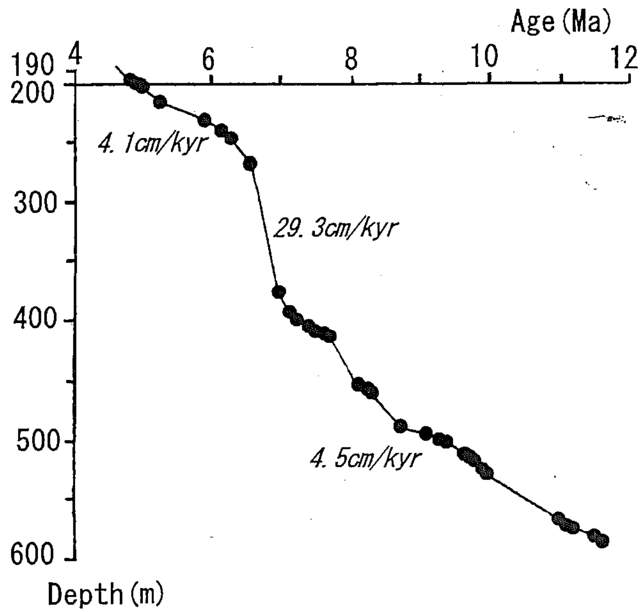

FIG. 7. Assignment of inclination (polarity) records for BDP-98-1 and BDP-98-2 cores with the geomagnetic polarity reversal events

with a fine grain size has increased in the BDP-96 and BDP-98 sedimentary sequences since ca. 3 Ma.

Figure 9 shows the result of a spectral analysis of susceptibility in relation to Milankovich cycles. On the right-hand side of the figure, we see the shift in the periodogram between a 100-kyr eccentricity cycle and a 41-kyr obliquity cycle around 3 Ma.

The above-mentioned changes in the susceptibility and rockmagnetic parameters of lake sediment may have been caused by a paleoenvironmental change around the Lake Baikal area. The intensification of the northern hemisphere glaciation occurred around 3 Ma due to the uplift of the Himalayan and Rocky Mountains (Masuda 1991) and/or the progressive closing of the Panamanian isthmus (Driscoll and Haug 1998). Accordingly, the climate in the Lake Baikal area became cooler, which may have affected the magnetic properties and/or the concentration of fine-grain magnetite in the sediment of Lake Baikal.

Figure 8b shows that the susceptibility and its amplitude of fluctuation increased after 1.2 Ma. Spectral analysis (Fig. 9) shows a shift in the spectral character from a 41-kyr obliquity cycle to 100-kyr eccentricity cycle over this period. The concentration of magnetic minerals in the sediment may have been affected by the change in the sedimentary environment around 1.2 Ma. The probable reason for this change is that the Himalayas and the Tibetan Plateau were raised above the snow line (Yasunari and Seki 1992).

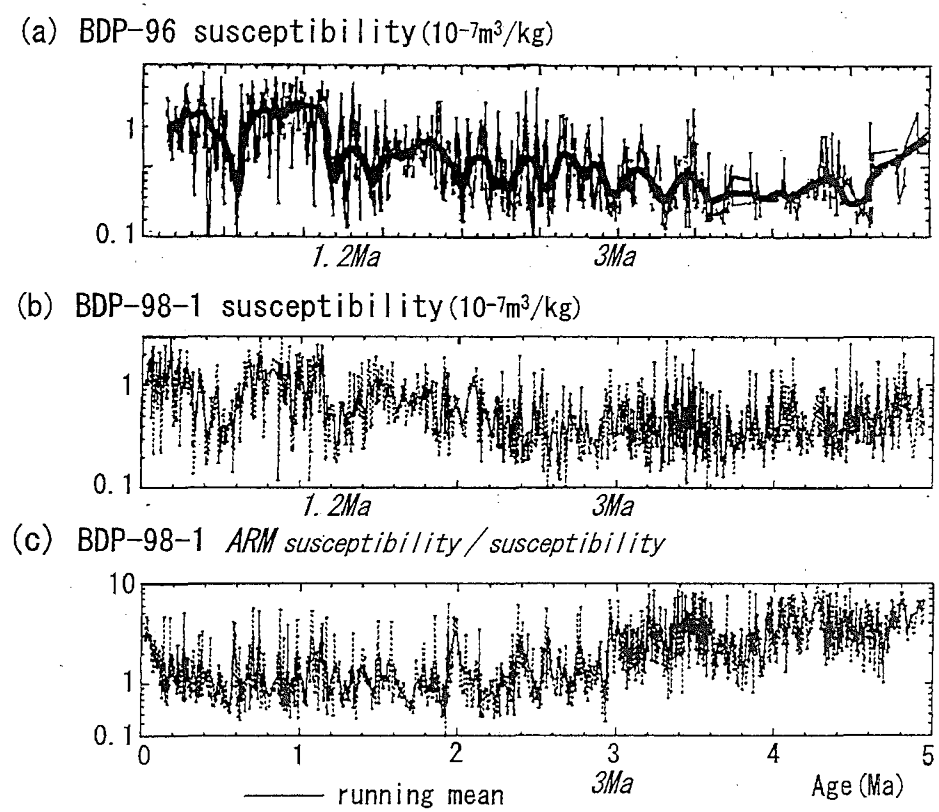

FIG. 8. Variation of susceptibility (BDP-96, BDP-98-1) and ARM susceptibility/susceptibility (BDP-98-1) with age

In summary, a global change in the climate and the environment is clearly recorded in the magnetic properties of Lake Baikal sediment. The mechanism by which these variations in magnetic properties and/or magnetic minerals correlate to the paleoclimate may be not simple. We should consider it as not only a change in the source of the sediment supply, and a change in magnetic minerals, but the effect of bacterial magnetite (Peck and King 1996; Sakai et al. 2000).

5 Concluding Remarks

Paleomagnetic and rock-magnetic (paleoenvironmental) studies were conducted on two BDP-98 sedimentary cores from Lake Baikal.

Magnetostratigraphy indicated that the BDP-98-1 core showed an age of 5 Ma. In the BDP-98-2 core, owing to the long reversed interval between 290 m and

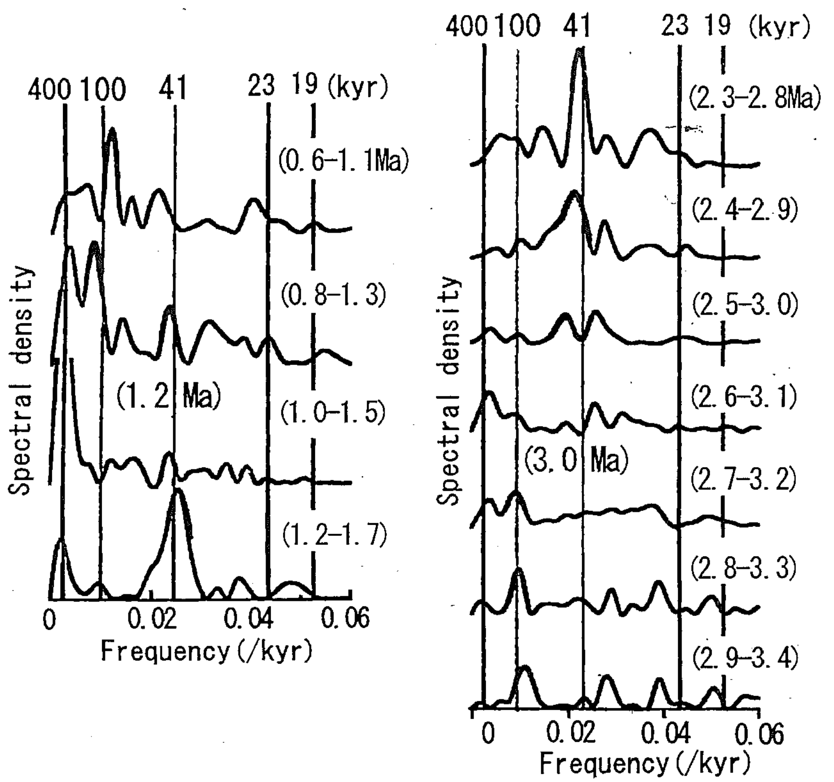

FIG. 9. Spectral analysis of the susceptibility shown in the BDP-98-1 core

350m depth, it was more difficult to find a correlation to a reference geomagnetic time-scale. A reasonable correlation in this study suggests that the basal age of the core is over 11 million years. The magnetostratigraphy of BDP-98-2 will be examined further by new and/or additional data.

The average sedimentation rate for BDP-98-1 and the upper 50m of BDP-98-2 is estimated to be 4.1cm/kyr. Sedimentation over the long reversed interval proceeded at the high rate of 29.3cm/kyr, and below c.a. 400m, to 600m, the rate was about 4.5cm/kyr.

An analysis of magnetic susceptibility was done on the BDP-98-1 core. The susceptibility increases from about 3Ma, while the magnetic property of ARM susceptibility/susceptibility decreases. The concentration of fine-grain magnetite in the sediment may have increased since ca. 3Ma. This may be correlated with a climatic cooling in the Lake Baikal area which correlates with the global event of northern hemisphere glaciation intensification.

The amplitude of the fluctuation in susceptibility increases after 1.2Ma. The periodogram indicates a shift in spectral character from a 41-kyr obliquity

cycle to a 100-kyr eccentricity cycle over this period. The change in the sedimentary environment may have occurred around ca. 1.2Ma. A probable reason for the change is the elevation of the Himalayas and the Tibetan Plateau above the snow line.

Thus, both the geomagnetic dipole polarity change and the global climatic change are clearly recorded in the magnetization of the Lake Baikal sediment.

Acknowledgments. We acknowledge the BDP (Baikal Drilling Project) members from Russia, the USA, and Japan for their help in this study.

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