Revised Magnetostratigraphies Confirm Low Sedimentation Rates in Arctic Ocean Cores

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The general lack of an age-diagnostic biostratigraphy in the Neogene sediments of the abyssal Arctic Ocean has emphasized the importance of magnetostratigraphy in providing chronostratigraphic control in these sediments. Sedimentation rates interpreted from early magnetostratigraphic studies of cores taken from the T3 ice island in the western Mendeleev Plain were estimated to be on the order of 1 mm/10^3 yr; however, recent amino acid epimerization studies of a core from the same area have suggested sedimentation rates of almost 15 mm/10^3 yr. This controversy has led us to reexamine the paleomagnetism of several of these cores. Our alternating field demagnetization studies indicate that many of these cores have an intense, high coercivity overprint, acquired after the core was opened, that is adequately removed only after treatment at 20 to 70 mT. We have remeasured samples from two cores after demagnetizations up to 80 mT and can confirm the position of the Brunhes/Matuyama boundary originally identified in the cores. In addition, the Jaramillo and Olduvai subchrons are identified. Average sedimentation rates in these two cores are 2–3 mm/10^3 yr, similar to the original estimates based on reversal stratigraphy, as well as those determined from recent radiocarbon studies, but incompatible with the amino acid-based dates. © 1988 University of Washington.

INTRODUCTION

The chronostratigraphy of the Neogene sediments of the abyssal Arctic Ocean is poorly understood due to the general lack of an age diagnostic biostratigraphy. On the western margin of the Mendeleev Plain in the Canada Basin magnetostratigraphic studies of cores collected at depths of approximately 2850 m from ice station T3 sites seemed to indicate low sedimentation rates on the order of 1.0 to 3.0 mm/10^3 yr (Clark, 1970; Hunkins *et al.,* 1971; Clark *et al.,* 1980, 1984), consistent with the magnetostratigraphy reported earlier by Lin'kova (1965) at Station 6 from the vicinity of the Lomonosov Ridge (Fig. 1). However, Sejrup *et al.* (1984) argued that the available paleomagnetic data from the T3 cores were unacceptably contaminated with unexplained noise which, combined with the lack of documentation of the alternating field (AF) demagnetization behavior of samples, made it difficult to judge the reliability of the reported results. Sejrup *et al.*

(1984) concluded that the magnetostratigraphies of available Arctic Ocean cores were not sufficiently well understood to exclude more rapid sedimentation rates and suggested sedimentation rates on the order of 15 mm/10^3 yr for core T3-67-11 based on their amino acid epimerization studies. More recently, Aksu (1985) and Aksu and Mudie (1985) interpreted paleomagnetic and palynological data from CESAR cores collected from the physiographically distinct Alpha Ridge, approximately 1000 km north of the T3 cores and at water depths of about 1500 m (Fig. 1), to indicate low sedimentation rates of 1.0 to 1.5 mm/10^3 yr for the past 4.25 myr. Amino acid epimerization analyses of foraminifera from the CESAR cores (Macko and Aksu, 1986) also suggested similar sedimentation rates. Although the Alpha Ridge cores come from shallower and morphologically different seafloor, their sedimentation rates compare well with the results of earlier magnetostratigraphic work in the Arctic Ocean as well
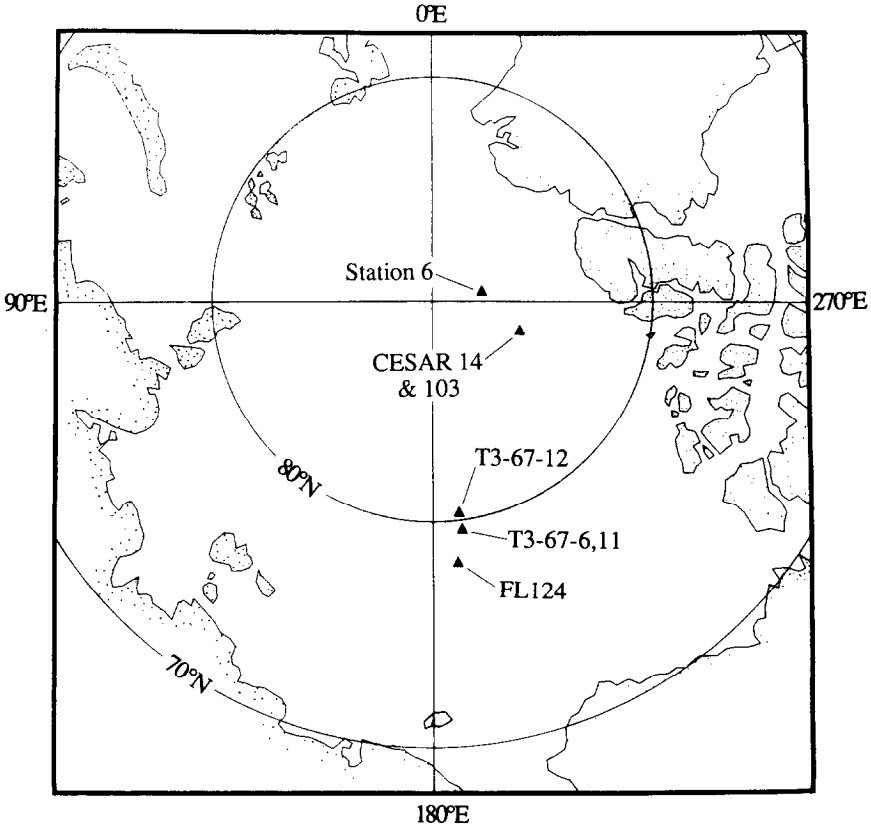
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FIG. 1. Sites from which cores discussed in the text were taken. Samples from T3-67-6 and T3-67-12 were analyzed in this study.

as radiocarbon constraints on sedimentation rates in the uppermost 5 cm in core FL 124 from the Canada Basin (Clark *et al.*, 1986).

Because some questions still remain as to the reliability of the original intepretation of the T3 core magnetostratigraphies, we selected two cores used in the Hunkins *et al.* (1971) study for remeasurement. We hoped to answer three questions in the course of this study: Is the published interpretation of slow sedimentation in the deep Canada Basin correct? What are the sources of noise in the data and how can they be minimized? If the noise were reduced can further useful details of the magnetostratigraphic record be extracted from the cores?

DATA

Unfortunately, too little of core T3-67-11 remains with known orientation to produce a continuous polarity record. Based on availability of reliable material, two nearby cores were selected for more detailed study: T3-67-6 from 2815 m at 79°44' N, 173°04' W and T3-67-12 from 2867 m at 80°21' N, 173°31' W (Fig. 1). These cores were included in the study of Hunkins *et al.* (1971). Core T3-67-6 was cited by these authors as an example of their best data and is one of the few cases (Clark *et al.*, 1984) where the actual magnetic inclination data and details of the demagnetization treatment have been published for cores from the Canada Basin. The paleomagnetics of

T3-67-12 and most other T3 cores was simply presented as interpretations of normal and reversed polarity. The original paleomagnetic data (Fig. 2) illustrate some of the problems involved in their interpretation.

The Brunhes/Matuyama boundary was picked at 220 cm in T3-67-6 and at 100 cm in T3-67-12. There is, however, considerable scatter in the remanent inclinations even after the 5 mT AF demagnetization treatment used in the original study, enough so that the definition of polarity magnetozones is highly uncertain. In contrast, the declination records in both cores are far more coherent than the inclination records. At such high-latitude sites the expected dipole inclination is $\cong \pm 85°$ and thus one would expect the declinations to be very scattered, reflecting the relatively small horizontal component of the high-latitude geomagnetic field. Most of the declinations are, in fact, essentially normal to the split face of the core and do not reverse as the inclination reverses.

Most of the samples from T3-67-6 and T3-67-12 used in the Hunkins et al. (1971) study were recovered for remeasurement, although a number of the original samples were missing and additional samples were taken from the cores. New samples comprised approximately 16% of the samples analyzed in this study. In all cases the samples had volumes of 5–10 cm^3 and were measured with a two-axis cryogenic magnetometer after progressive AF demagnetization treatments. The natural remanent magnetization intensities of the samples after 5 mT AF demagnitization were approximately 10^{-2} to 10^{-3} amp/m. IRM (isothermal remanent magnetization) experiments show that 95% of remanence induced at 1.5 T is achieved by 0.2 T, with a remanent coercivity of about 40 mT, suggesting that magnetite is present in the sediment and responsible for part or all of the remanence.

Progressive AF demagnetization shows that a dominant, near-horizontal (i.e., perpendicular to the core axis) magnetization is typically the component first removed (Fig. 3). The horizontal component's maximum coercivity ranges up to 70 mT and is highly variable even among adjacent samples. After the horizontal overprint is removed, the expected steep magnetic vectors are revealed. Further insight into the timing of the acquisition of the horizontal magnetization component is provided by the manner in which the core was opened and stored. The core was taken in a plastic liner and transported to the core library intact. The core was opened and split into halves along an arbitrary plane parallel to the axis of the core and was allowed to dry in two pieces with the split faces upward, in the steeply dipping ($\cong 60°$) ambient field at Lamont. Analyses of samples taken at the same depth from opposite halves of the core show that the horizontal overprints are antiparallel within the whole-core frame of reference; i.e., these magnetizations are essentially perpendicular to the split faces of the core and parallel to the steep storage field (Fig. 3). These relationships confirm that despite its high stability, the horizontal overprint is of recent origin (post-splitting) and unrelated to the local geomagnetic field in the Arctic.

INTERPRETATION

The AF demagnetization experiments suggest that the marked constancy in the declinations after 5 mT treatment is caused by this horizontal overprint and that steep magnetizations, more likely related to a record of geomagnetic polarity, can be recovered with higher demagnetization treatments. This observation is borne out by what we regard as improved polarity records from both cores after treatment at 40–80 mT (Fig. 4). These records now show the expected scatter in declinations and a serial consistency of inclinations (compare Figs. 2 and 4) allowing magnetozones to be identified more confidently and
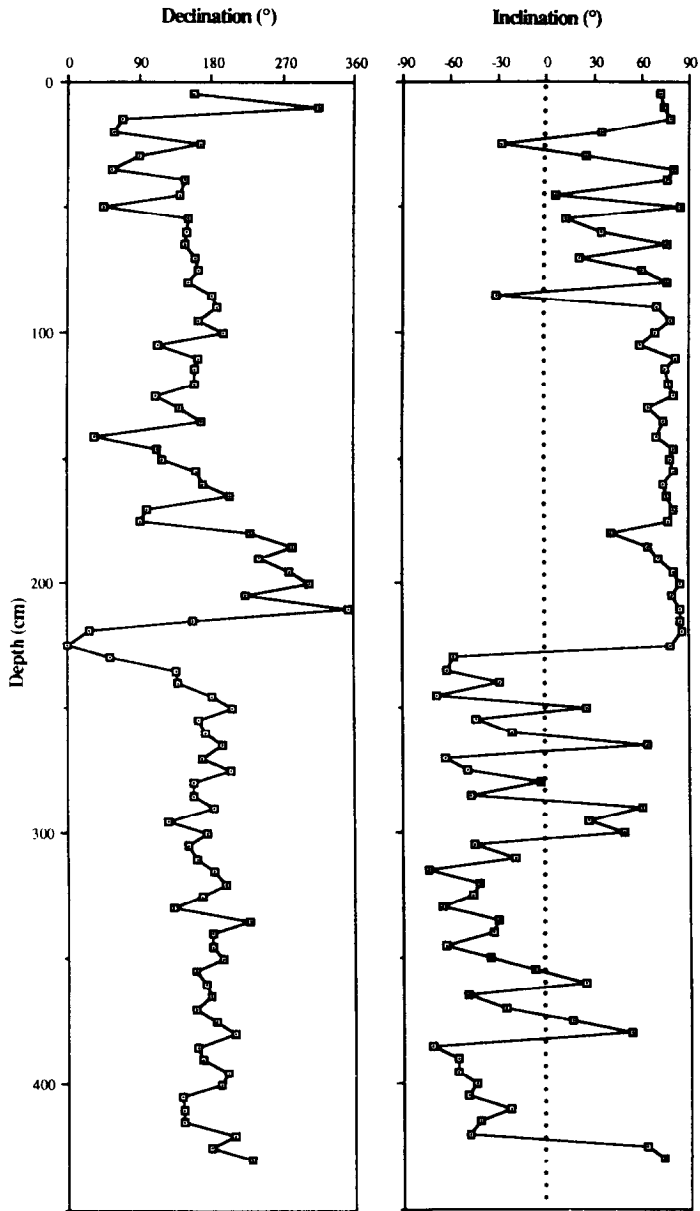
T3-67-6

5mT

FIG. 2. Remanent magnetization directions after 5 mT demagnetization as determined by Hunkins *et al.* (1971). The declination datum was arbitrarily chosen as perpendicular to and zero toward the split face of the "B" tray core.
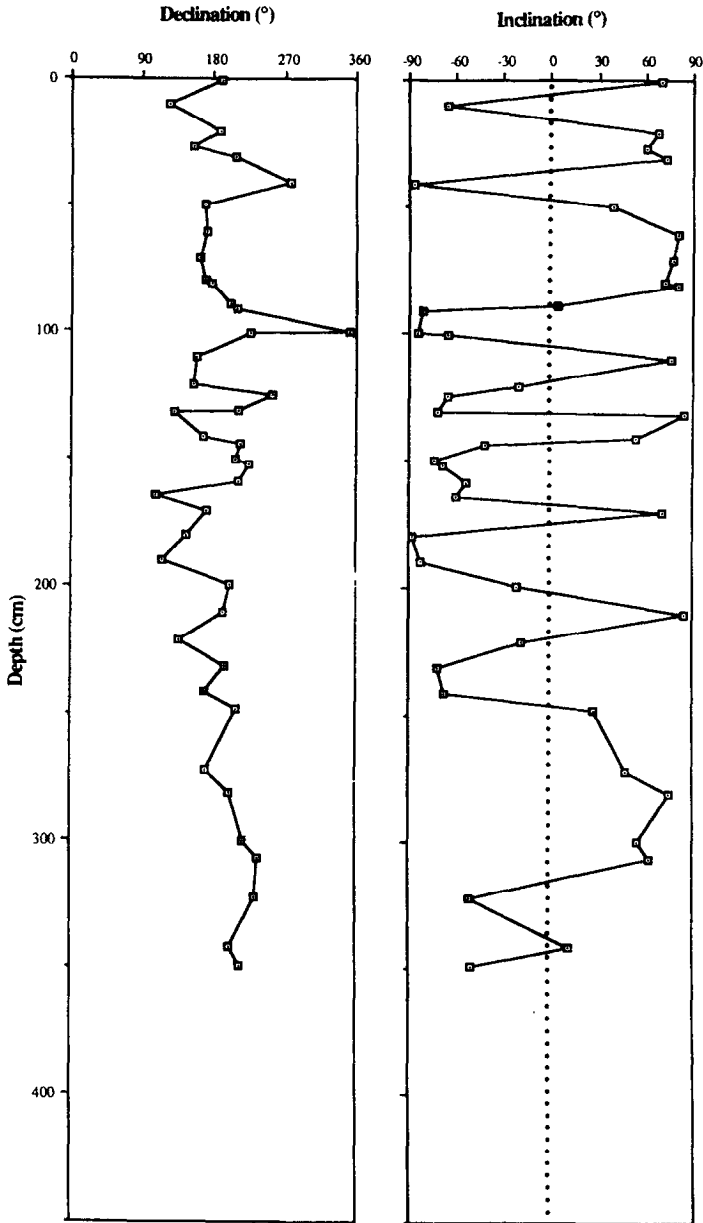
T3-67-12

5 m T

FIG. 2—*Continued.*

correlated with the geomagnetic polarity time scale.

The changes in polarity at 220 cm in T3-67-6 and at 100 cm in T3-67-12 most probably correlate with the Brunhes/Matuyama boundary, the same interpretation (within 10 cm) made by Hunkins *et al.* (1971). The scattered shallow inclinations in the upper 85 cm of T3-67-6 can be attributed to the sediment disturbance that often occurs near core tops. Further demagnetization and measurement of avail-
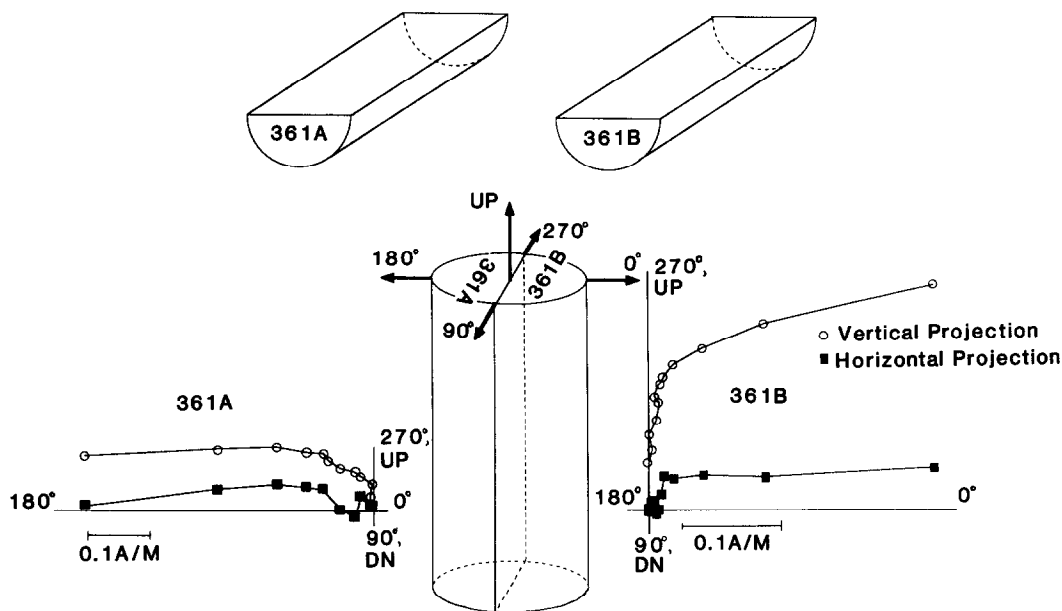
FIG. 3. Progressive AF demagnetization of NRM of samples from opposite halves of core T3-67-6 at 361 cm depth reveals antiparallel horizontal overprints. Note the recovery of magnetization components with steep negative inclinations after the removal of the horizontal overprints. AF demagnetization steps were NRM, 5, 10, 15, 20, 25, 30, 35, 45, 55, 70, 90 mT.

able material from T3-67-11 indicates normal polarity above 132 cm and mixed reversed and normal polarity as well as intermediate directions from 132 to 231 cm, broadly consistent (within 22 cm) with Hunkin's *et al.* (1971) original interpretation. However, the available sample distribution is too spotty to form a continuous polarity record for T3-67-11.

Below the Brunhes/Matuyama boundary, demagnetization to 80 mT reveals predominately reversely magnetized sediments of the Matuyama with possibly two normal polarity subzones in each core. The short normal polarity interval between 263 and 266 cm in T3-67-6 is recorded in two adjacent samples and can be correlated to the Jaramillo subchron. A single normal polarity sample occurs at a similar stratigraphic position in T3-67-12; however, the lack of additional material prevented us from taking replicate samples near 129 cm. The interpretation of a normal polarity zone (possibly the Olduvai) at the base of T3-67-06 is also uncertain because only a

single sample was available at 430 cm. Nevertheless, T3-67-12 shows a well-defined normal polarity zone between 275 and 310 cm which most probably correlates with the Olduvai subchron. From 310 cm to the base at 370 cm, this core is reversely magnetized.

DISCUSSION

High coercivity overprints, such as those observed in T3-67-6 and T3-67-12, are not usually observed in deep-sea sediments in which characteristic magnetizations are generally isolated with demagnetizing fields less than 15 mT (Opdyke, 1972). However, high coercivity overprints were also noted in CESAR cores from the Alpha Ridge by Aksu (1985) who used demagnetization fields as high as 40 mT to isolate stable directions, and by Løvlie *et al.* (1986) who used 50 mT AF demagnetization to remove "a dominating magnetic component perpendicular to the sampling surface of the cores." Thus, sediment cores from the Arctic Basin may be particularly suscep-
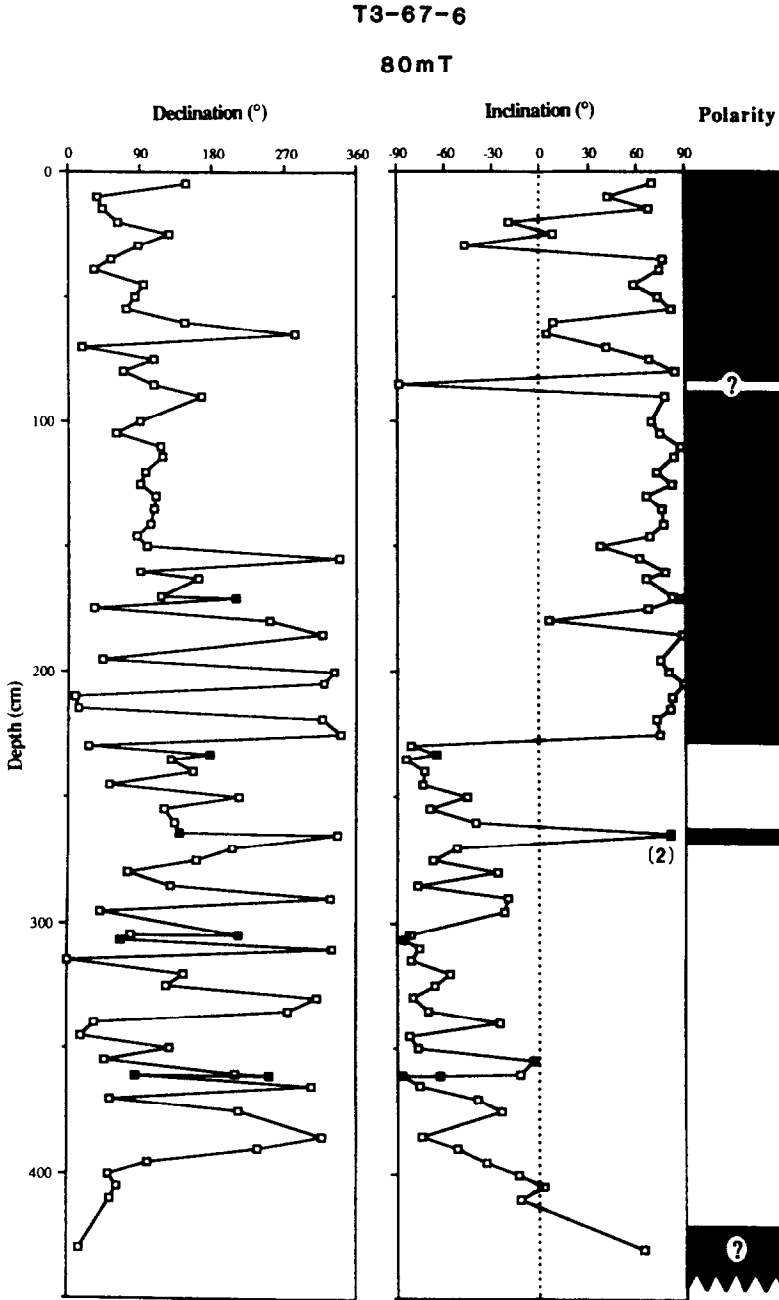
T3-67-6

80mT

FIG. 4. Remanent magnetization directions after 80 mT demagnetization in cores T3-67-6 and T3-67-12. Solid symbols represent new samples taken to replace missing samples or to fill gaps in the original Hunkins *et al.* (1971) sample set. The black (normal polarity) and white (reversed polarity) columns indicate our interpretation of the magnetostratigraphy. Polarity intervals interpreted from a single sample are indicated with a question mark; the positive polarity interval in T3-67-6 between 263 and 266 cm is based on two samples.
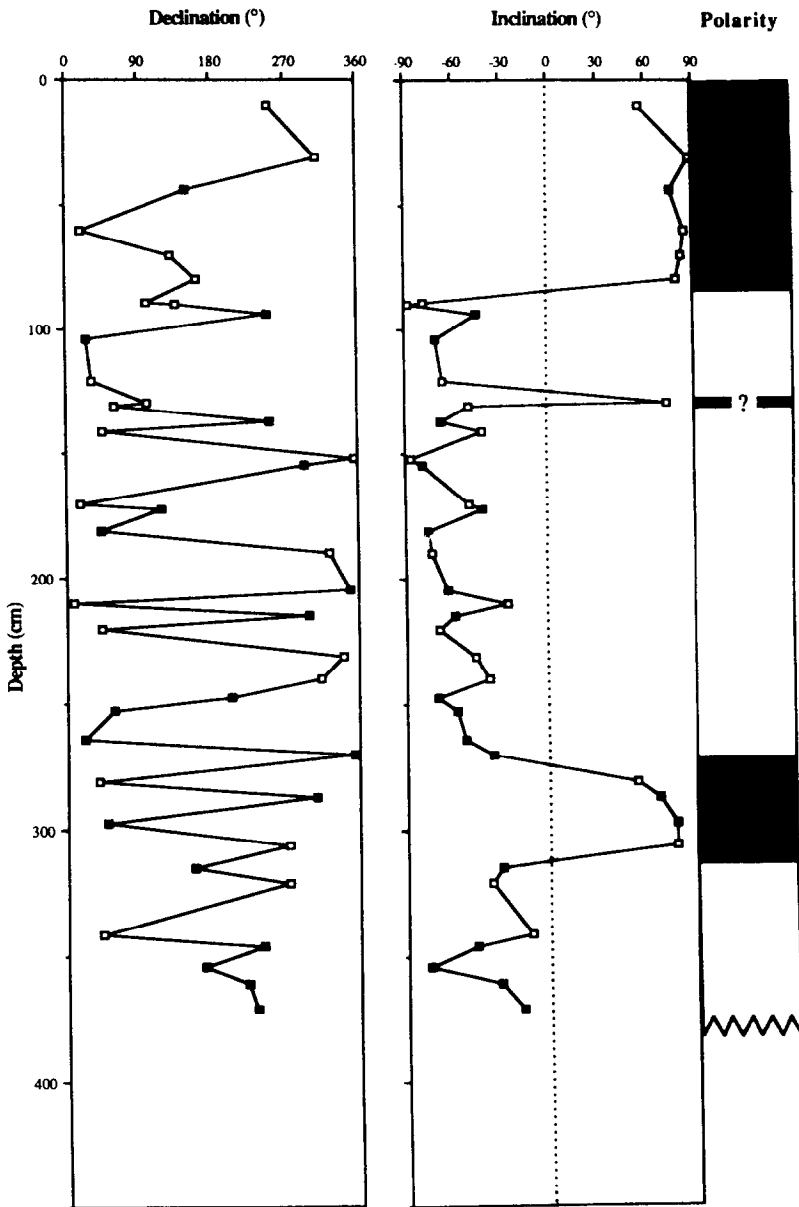
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T3-67-12

80mT

FIG. 4—*Continued.*

tible to acquisition of stable secondary magnetizations.

Samples from T3-67-6 and T3-67-12 stored in random orientations acquired VRMs (viscous remanent magnetizations) in the laboratory with intensities compa-rable to the intensity of the stable rema-nence. These viscous magnetizations are easily removed with a 5 to 20 mT AF treat-ment, which typically affects the horizontal overprint little if at all. Presumably the cores were not exposed to fields much in

excess of the present 0.05 mT ambient laboratory field during storage, so the generation of a high coercivity overprint observed in the T3 cores may be related to the physical and chemical changes that take place in a core after it is exposed to the atmosphere and dries (Johnson *et al.*, 1975). If a similar mechanism is responsible for overprints in the CESAR cores, the overprinting process must occur in the early stages of drying because the CESAR cores were measured while still wet (Aksu, 1985).

Based on correlations to the geomagnetic timescale, an interpretation of sedimentation rates in the two cores is possible (Fig. 5 and Table 1). The sedimentation rate we have determined for T3-67-12 is 1.2 mm/10^3

yr during the Brunhes and 2.0 mm/10^3 yr from the Brunhes/Matuyama boundary to the base of the Olduvai, with an extrapolated age of 2.2 myr for the base of the core. We cannot exclude the possibility that the lower sedimentation rate for the Brunhes in T3-67-12 is due to the loss of a portion of the uppermost sedimentary section during coring. Core T3-67-6 has a more rapid and uniform sedimentation rate of about 2.8 mm/10^3 yr from the Jaramillo to the top of the core. The extrapolated age (1.5 myr) for the base of T3-67-6 indicates that the core penetrated close to the expected level of the Olduvai subchronozone; thus, the one unreplicated positive inclination sample from the base of T3-67-6
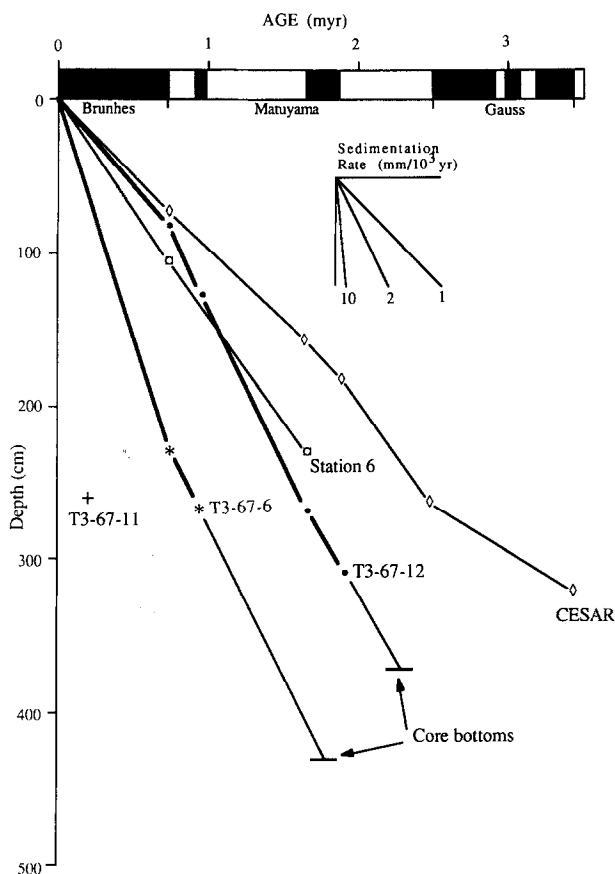

FIG. 5. Sediment depth versus inferred age in T3-67-6 and T3-67-12 compared with magnetostratigraphies from Station 6 of Lin'kova (1965) and CESAR cores 14 and 103 (Aksu, 1985). The age estimate for the 260-cm level in T3-67-11 of 188,000 yr is from the amino acid studies of Sejrup (1984). The geomagnetic polarity time scale is that of Berggren *et al.* (1985).

TABLE 1. MAGNETIC POLARITY BOUNDARIES

Transition	Depth in core (cm)		Age (10^3 yr)
	T3-67-6	T3-67-12	
Brunhes/ Matuyama	228	85	730
Upper Jaramillo	262	128	910
Lower Jaramillo	268	130	980
Upper Olduvai	—	271	1660
Lower Olduvai	—	311	1880

might indeed represent normal polarity. According to magnetostratigraphic correlations, the Pliocene–Pleistocene boundary is placed just younger than the Olduvai subchron at about 1.6 myr (Berggren *et al.*, 1985). Core T3-67-6 therefore encompasses practically the entire Pleistocene in its 430 cm length, whereas core T3-67-12 includes a record of the upper Pliocene and the Pleistocene over its 350 cm. These are minimum estimates for the time represented by the cores, based on the simplest and most reasonable interpretation of polarity. If a significant hiatus were present, the lower normal polarities could correlate with pre-Olduvai normal polarity chrons and thus the cores could represent a longer interval, but this is judged to be unlikely.

In summary, a reexamination of the magnetostratigraphies of T3-67-6 and T3-67-12 confirms the original interpretation of the position of the Brunhes/Matuyama boundary in these cores by Hunkins *et al.* (1971). An intense high coercivity overprint, acquired shortly after the cores were opened, dominates the magnetization of both cores, but with sufficient AF demagnetization reliable polarity determinations can be made. Transitional zones between polarity intervals are not observed in these cores; reversals typically take place in less than 5 cm, which is what one would expect if sedimentation rates are on the order of 1–2 mm/10^3 yr, given geomagnetic transi-

tion durations of about 10,000 yr. The improved magnetostratigraphic records obtained from T3-67-6 and T3-67-12 strongly suggest that Canada Basin sedimentation rates throughout the Pleistocene are similar to the rates determined for the last 40,000 yr with radiocarbon dating by Clark *et al.* (1986) and up to an order of magnitude lower than those proposed on the basis of amino acid epimerization studies by Sejrup *et al.* (1984).

ACKNOWLEDGMENTS

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