An 84-kyr paleomagnetic record from the sediments of Lake Baikal, Siberia

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Abstract. We have conducted a paleomagnetic study of sediment cores obtained from the Selenga prodelta region of Lake Baikal, Russia. This record, which spans approximately the last 84 kyr, contributes to a better understanding of the nature of geomagnetic field behavior in Siberia and is a useful correlation and dating tool. We demonstrate that the Lake Baikal sediments are recording variations in the geomagnetic field. The directional record displays secular variation behavior with a geomagnetic excursion at 20 ka and additional excursions appearing as large-amplitude secular variation at 41, 61, and 67 ka. Smoothing of the geomagnetic excursion behavior occurs in Lake Baikal sediments owing to the intermediate sedimentation rate (13 cm kyr^{-1}). The Lake Baikal relative paleointensity record correlates to absolute paleointensity data for the last 10 kyr and to relative paleointensity records from the Mediterranean Sea and Indian Ocean for the last 84 kyr. This correlation suggests a strong global (i.e., dipole) component to these records and further supports the reliability of sediments as recorders of relative geomagnetic paleointensity. We show that a relative geomagnetic intensity stratigraphy has a potential resolution of 7 kyr by correlating continental and marine records. The geomagnetic intensity stratigraphy helps constrain the age of the difficult to date Lake Baikal sediments.

Introduction

A paleomagnetic study involves measuring the natural remanent magnetization (inclination, declination, and intensity of magnetization) of natural materials. Paleomagnetic secular variation (PSV), the small-amplitude, short-period (10^2-10^4 years) variation in the geomagnetic field, has been shown to be a useful correlation tool over distances as great as 3000 km [*King et al.*, 1983a]. In addition, globally distributed secular variation records have been used to provide insight on the geodynamo [*Hagee and Olson,* 1989; *Bloxham,* 1992]. Measurements of past geomagnetic field intensity can be either absolute or relative in nature. Samples (lava flows and fired archeological materials) that acquire a magnetization by cooling from high temperature can yield a spot reading of the absolute paleointensity. Owing to the discontinuous distribution in time and space of these materials, the resulting absolute intensity record is spotty and is not ideal for establishing a geomagnetic intensity stratigraphy. Although sedimentary sequences only yield a record of relative paleointensity variation (provided the record is properly normalized), sediments can provide a long and continuous record with high temporal resolution and global coverage [*King et al.*, 1983a; *Tauxe,* 1993].

In this paper we present a paleomagnetic record obtained from cores taken on the Selenga prodelta region of Lake Baikal, Siberia. First, we demonstrate that the Lake Baikal sediments are suitable for paleomagnetic study by addressing the criteria of *Thompson* [1984], *King et al.* [1983b], and *Tauxe* [1993]. We then develop stacked directional and relative paleointensity records for Lake Baikal. The directional record is smoothed because of the intermediate sedimentation rate. The relative intensity record correlates to relative paleointensity records from the Mediterranean Sea and Indian Ocean, suggestive of a global (i.e., dipole) component to these records. Finally, we use the Lake Baikal record to provide insight on the development of a geomagnetic intensity stratigraphy.

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Geological Setting

Lake Baikal, located in south central Siberia, is the world's deepest (1620 m) and most voluminous (23,000 km^3) lake (Figure 1). The lake occupies the Baikal depression, the largest basin in the active Baikal rift zone. Within the Baikal depression, more than 7500 m of lacustrine sediment has accumulated since the middle Miocene [*Klitgord et al.*, 1991; *Hutchinson et al.*, 1992]. Although the drainage basin was glaciated, the lake was not, and so sediments from previous glacial/interglacial cycles are preserved within the lake [*Grosswald,* 1980; *Peck et al.*, 1994]. As the world's oldest existing lake, Lake Baikal provides an opportunity to yield a long, continuous paleomagnetic record filling an important gap in the global distribution of these records.

In this paper we report results from cores taken on the bathymetric high in front of the Selenga delta (Figure 1). This bathymetric high is not due solely to deltaic sedimentation

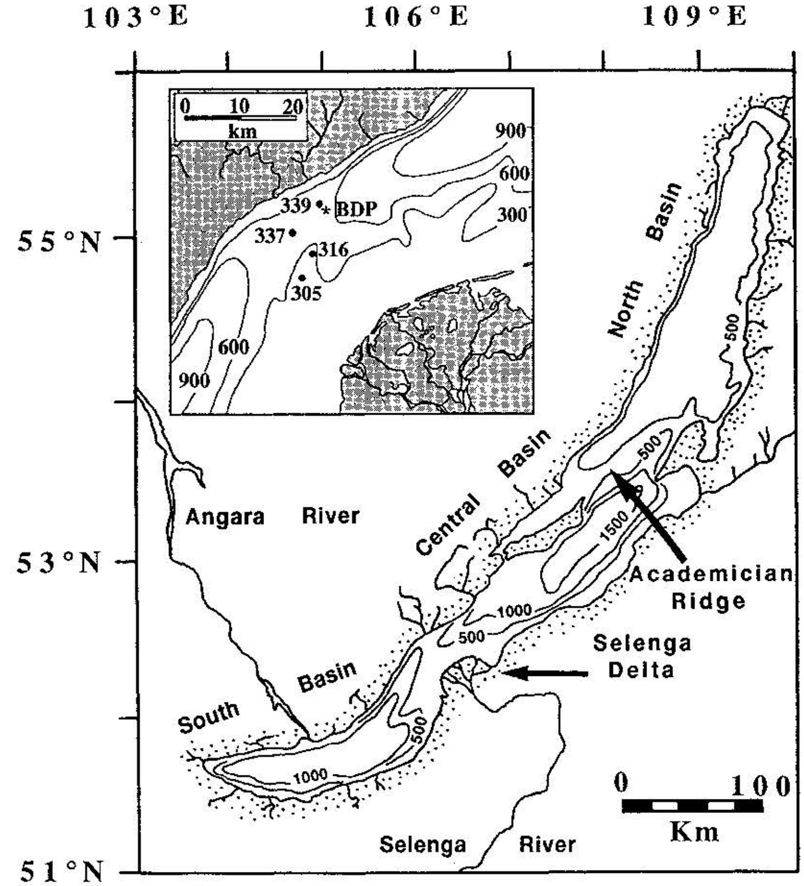

Figure 1. Bathymetric map of Lake Baikal. Isobath interval is 500 m. Inset shows core site locations on the Selenga prodelta region of Lake Baikal. At each core site, multiple cores were obtained.

but is a complex accommodation zone of basement blocks resulting in a basement high. Fault scarps control the orientation of delta front distributary channels to align parallel to the rift axis. The channels divert coarse-grained sediment away from the delta front toward the sides of the delta, feeding large fans built into the south and central basins [*Colman et al.*, 1993a]. Fine-grained hemipelagic sedimentation occurs at the core sites at an intermediate sedimentation rate of about 0.15 mm yr^{-1} [*Colman et al.*, 1993b]. Sediment accumulating at the core sites during the present interglacial consists of diatomaceous mud. Biogenic silica attains as much as 20, 22, and 55% in cores 305A5, 316T3, and 339T2, respectively [*Carter and Colman*, 1994]. Total organic carbon (TOC) attains less than 3%, and $CaCO_3$ is not preserved in these sediments [*Lake Baikal Paleoclimate Project Members*, 1992]. During the last glacial period, mud (undifferentiated clay, clayey silt, and silty clay) accumulated at the core sites with biogenic silica and TOC content at or near 0% [*Carter and Colman*, 1994; *Lake Baikal Paleoclimate Project Members*, 1992]. In the six cores studied, only one very fine sand layer was observed at 434-436 cm depth in core 337P2. Complete and detailed core descriptions for the cores used in this study are given by *Colman et al.* [1994].

Methods

Field programs to gather sediment cores and seismic reflection profiles were undertaken from 1990 to 1992 as part of a Lake Baikal paleolimnologic study [*Lake Baikal Paleoclimate Project Members*, 1992]. Multiple cores were obtained from each station (Figure 1) using a variety of corer types, including gravity, trigger weight, modified Kullenberg piston, and box corers (labeled A, T, P, and B, respectively). The gravity cores are 10 cm in diameter, whereas the trigger weight and piston cores are both 6.5 cm in diameter. Advanced piston coring (APC) modeled after the Ocean Drilling Program's sediment recovery method was undertaken to retrieve sediment cores during the winter of 1993 by a Russian-American-Japanese team. Two APC holes (BDP-93-H1 and BDP-92-H2) were completed to a depth of approximately 100 m each (Figure 1). Individual APC cores averaged 1.5 m in length and are 5.7 cm in diameter.

Whole core, low-field magnetic susceptibility (K) of all cores was measured at 3-cm intervals with a Bartington Instruments pass-through loop sensor.

Seven cores were continuously subsampled every 2 cm using an oriented minicorer (stainless steel tube with a square cross section and sharp cutting edge) in order to minimize disturbance. The sediment was extruded from the minicorer into 5-cm^3 cubic plastic boxes. Low-frequency (0.43 kHz) magnetic susceptibility was measured with a Bartington Instruments single-sample sensor. The natural remanent magnetization (NRM) of the subsamples was measured with a cryogenic magnetometer. Forty-two pilot samples were stepwise, alternating field (AF) demagnetized and remeasured after each step. An optimum blanket field demagnetization treatment (10 mT) was determined on the basis of Zijderveld and demagnetization plots from the pilot samples. The remaining samples were demagnetized at the optimum blanket field (10 mT) and then remeasured. Because the cores were not oriented to magnetic north during the coring procedure, absolute declination profiles were not obtained. However, within a core all sections were oriented with respect to each other. Therefore relative declination profiles were produced by normalizing individual declination values by the mean declination of the core. Anhysteric remanent magnetization (ARM) was induced in the samples with a Schonstedt GSD-1 demagnetizer operating at a peak AF field of 0.1 T and a steady field of 0.1 mT and measured on the cryogenic magnetometer. The ARM is normalized to the steady field and expressed as K_{ARM}. Saturation isothermal remanent magnetization (SIRM) was induced in the samples by an electromagnet using a field of 1.2 T and measured on the cryogenic magnetometer. An induced back IRM (bIRM) was imparted to the samples by subjecting them to a reversed field of 0.3 T generated by the electromagnet and measured on the cryogenic magnetometer. A Micromag alternating gradient force magnetometer was used to measure the hysteresis parameters on a subset of samples.

The magnetic component of the sediment was extracted from eight samples from core 305A5 using a magnetized needle and circulation system modified from *Petersen et al.* [1986]. Saturation magnetization (M_s), corrected for paramagnetic contributions, was used to calculate the extraction procedure efficiency, which was 73-94%. The magnetic extracts were analyzed with a JEOL 1200EX transmission electron microscope (TEM) equipped with a Noran Voyager Ge X ray microdetector for energy dispersive spectra (EDS) analysis. In addition, extracts were analyzed on a Scintag XDS2000 X ray diffractometer.

Results

Core Correlation

Magnetic susceptibility profiles provide a rapid method for core correlation on a variety of scales. Box cores and trigger cores often recover an undisturbed sediment surface, so that correlation of K profiles allows the extent of core disturbance or surficial sediment loss by the piston core to be determined. The lack of correlation between the piston core (P) and the companion trigger core (T) indicates that the piston cores failed to recover the surficial sediment at stations 316, 337, and 339 (Figure 2). The lack of recovery was likely due to a faulty trigger arm causing a delay in the release of the piston in the piston corer. As a result of the incomplete recovery by the piston corer, the trigger and piston cores from a single site could not be joined to produce a composite record.

When correlated on a larger scale, K profiles indicate the lateral continuity of sedimentation on the Selenga prodelta (Figure 2). However, the variation in thickness of correlative units indicates lateral variation in the sedimentation rate, with the lowest rate at site 316 (Figure 2). The arrows in Figure 2 mark the location of a distinctive inclination feature (a large-amplitude secular variation swing) that occurs in the same relative position on all K profiles, indicating that K is not time transgressive. This inclination feature does not coincide with a major K feature or lithologic change, indicating that it is a geomagnetic feature rather than a sedimentologic feature. Therefore K is a reliable correlation tool within this region of Lake Baikal.

After the initial visual correlation, core correlations were completed using Corpac, an inverse correlation method of *Martinson et al.* [1982]. Both the linear correlation coefficient (C) and the coefficient of determination (R^2) were calculated using Corpac. Sediments do not behave as perfect linear recorders of a single forcing function (i.e., geomagnetic field). Instead, sediments respond both linearly and nonlinearly to a variety of forcing functions and can also distort the signal that is being recorded. Because of these limiting aspects of the geological record, perfect correlations (C = 1) are not to be expected. For example, *Martinson et al.*, [1987] found that 50% of the variance (C = 0.71) in the marine oxygen-isotope record could be described by a linear response to orbital forcing. We use the following qualifying terms to describe correlations presented in this paper: $C \geq 0.7$ highly correlated; $0.7 < C \geq 0.5$, moderately correlated; and $C < 0.5$, low correlation.

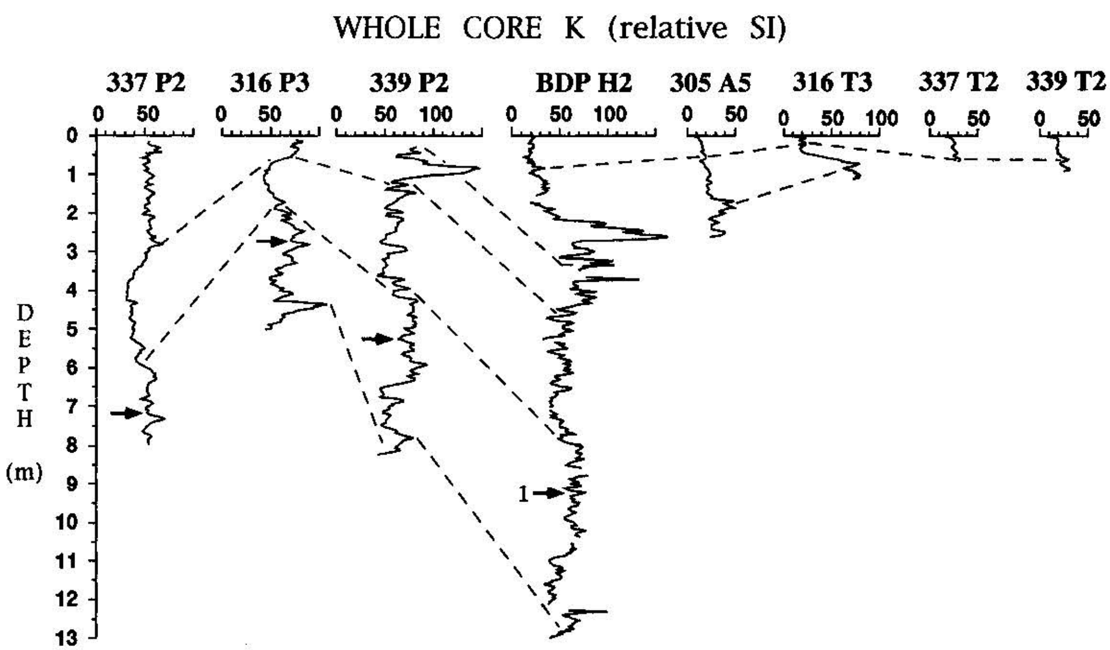

Figure 2. Correlation of whole core magnetic susceptibility profiles for cores obtained from the Selenga prodelta. The arrows mark the location of a distinctive inclination feature that occurs in the same relative position on each of the deep K profiles. The gaps in the BDP-93-H2 profile are located between individual cores in the hole.

The steps described below were followed to obtain correlated and stacked profiles. First, 48 of the 1276 samples, mostly from the disturbed piston core tops, failed the directional reliability criteria and were deleted. An additional 113 samples failed the intensity criteria (see normalized intensity results) and were deleted. Because the subsampling interval was 2 cm, new interpolated values were obtained only at core breaks and the few deleted sample depths. Inclination was the most appropriate parameter to establish the correlation framework because (1) it contains higher-frequency structure than the susceptibility or normalized intensity records, and (2) unlike declination, the inclination record is not adversely affected by core twist.

To achieve a complete, composite sediment section, the correlation proceeded in three steps. First, the trigger cores (337 T2 and 316 T3) were correlated to core 305 A5 to produce a short-core stack (Figure 3). Inclination values for core 339 T2 are substantially shallower than the inclination of the field owing to a geocentric axial dipole (GAD), possibly because the corer entered the sediment at an angle; therefore this core was not used in the stack. Second, a long-core stack was constructed by correlating cores 337 P2 and 316 P3 to core 339 P2. The upper approximately 1 m of core 337 P2, which is not present in core 339 P2, was then spliced onto the top of the long-core stack. Because of the incomplete recovery by the piston corer, the short- and long-core stacks have only about 1 m of overlap (Figure 3). The third step was to correlate the overlapping portion of the long-core stack to the short-core stack ($C = 0.79$) to produce a complete sediment section. This correlation is supported by accelerator mass spectrometry (AMS) radiocarbon ages [*Colman et al.,* 1996]. Radiocarbon ages in core 305 A5 were extrapolated to the base of the short-core stack. Radiocarbon ages in core 339 P2 were extrapolated to the top of the long-core stack. Correlating the inclination profiles of the long- and short-core stacks resulted in a 600-year shift toward younger ages for the initial age estimate of core 337 P2. Because the average one sigma error is ±568 years for the radiocarbon ages used to construct the initial age model for core 337 P2, a shift of 600 years due to correlation is negligible.

Paleomagnetic Directional Results

Before directional profiles from Lake Baikal can be used for magnetostratigraphic studies, it first must be demonstrated that the directional profiles are a reliable record of the geomagnetic field. In this section we address the reliability criteria of *Thompson* [1984] to determine if directional variations recorded in the sediment reflect variations in the geomagnetic field.

All 42 pilot samples selected for stepwise AF demagnetization of the NRM exhibit a stable, single-directional

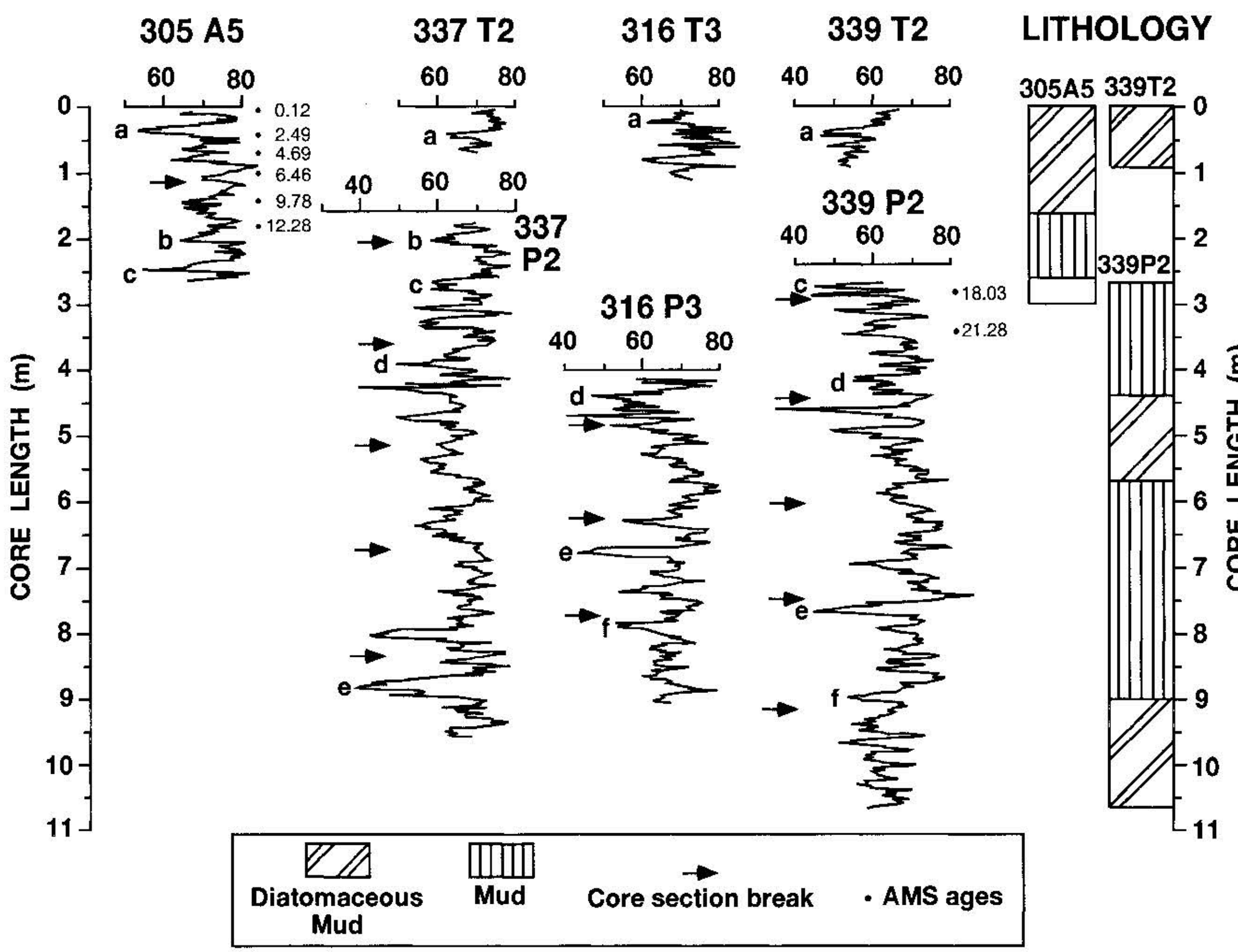

Figure 3. Inclination profiles and lithology logs for cores from the Selenga prodelta. The lack of overlap between the piston (P) and trigger (T) cores is readily apparent. Arrows mark section breaks within the cores. Letters mark correlative inclination features. AMS radiocarbon ages (ka) are shown for cores 305 A5 and 339 P2 [*Colman et al.,* 1996].

component after cleaning at 10 mT (Figure 4). The mean inclination of the pilot samples after demagnetization at 10 mT is 65°, close to the inclination of the field due to a GAD for the site latitude (69°). The average intensity of initial magnetization (M_0) is 22.1 mA/m. The pilot samples demagnetized at 10 mT retained between 71 and 92% of M_0. The median destructive field (required to remove half of M_0) ranged between 20 and 34 mT, indicative of stable remanence properties. All 42 pilot samples demagnetized in a similar manner, indicating a similar coercivity spectrum of NRM throughout the cores.

The rock magnetic results, presented in the next section, reveal that pseudo-single-domain magnetite dominates the remanence-bearing component of the sediment.

Sedimentary structures were examined so that samples likely affected by disturbance or lithologic control could be

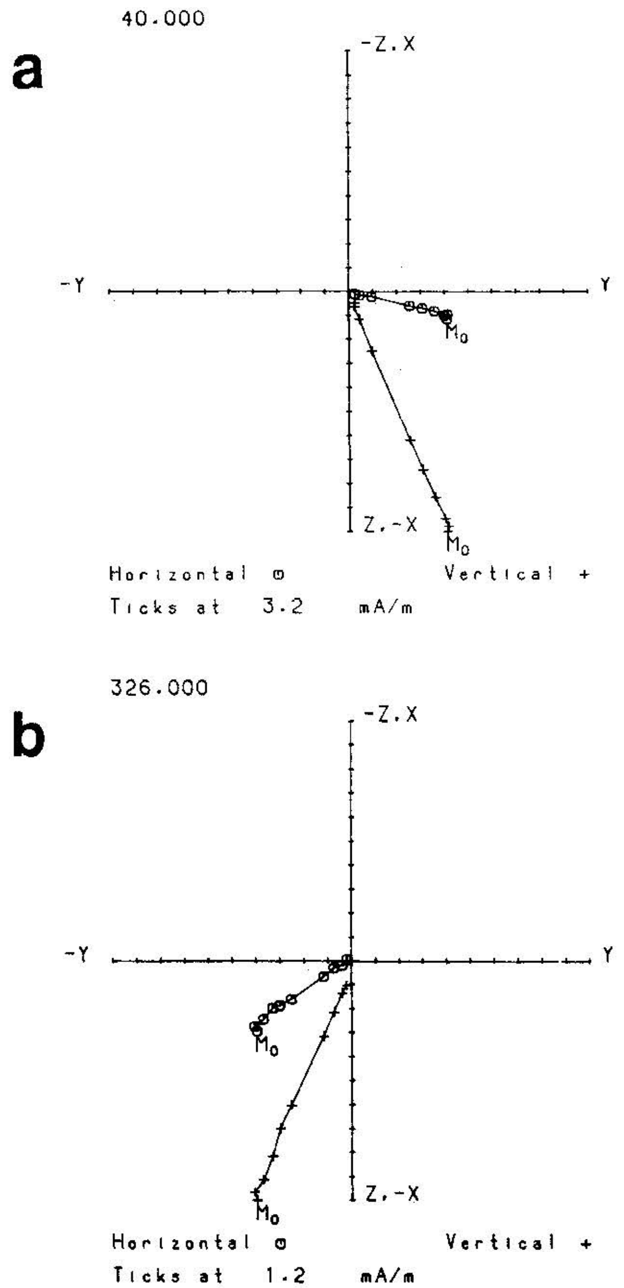

Figure 4. Typical Zijderveld plots from pilot samples from core 337 P2: (a) 40 cm and (b) 326 cm.

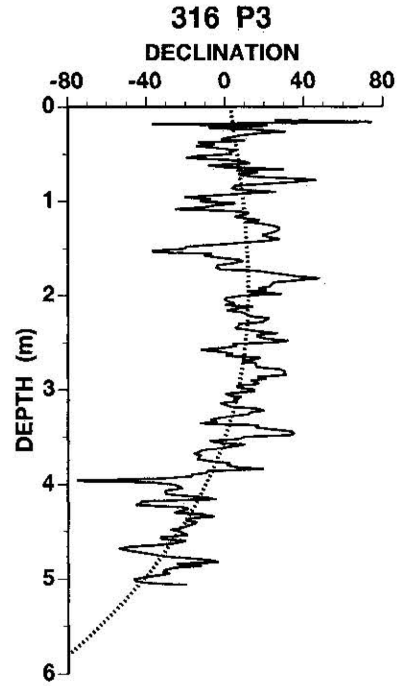

Figure 5. Declination plot for core 316 P3 after AF demagnetization at 10 mT. Declination profile shows major core twist, which was removed by applying a third-order polynomial (dashed line) to the profile.

deleted [*Thompson*, 1984]. Relatively few (48 of 1276 samples) samples were deleted, probably a result of careful core site selection based on analyses of seismic reflection profiles. Areas of faulting and onlap/offlap reflectors were avoided, and areas of parallel, draped reflectors were targeted with the goal of coring undisturbed sediment [*Lake Baikal Paleoclimate Project Members*, 1992]. The piston coring procedure often disturbs the sediment being cored [*McCoy*, 1980]. Sedimentary structures showed no signs of flow-in or deformed horizonal laminations. However, a corkscrew motion by the piston corer during entry into the sediment is evident in the declination profile of core 316 P3 (Figure 5) and to a lesser extent in cores 339 P2 and 337 P2. The declination profile for core 316 P3 was detrended using a third-order polynomial in order to remove the effects of core twist, whereas the profiles for cores 339 P2 and 337 P2 were not manipulated.

Thompson [1984] indicated that directional reproducibility on a variety of scales is the most important of the paleomagnetic reliability criteria. First, paired samples were obtained from cores 337 P2 and 337 T2 every 10 cm and yielded average angular standard deviations of 3.1° and 5.6° for inclination and declination, respectively. These values are lower than the average angular standard deviations between consecutive samples in these cores, which is 8.1° and 23.9° for inclination and declination, respectively. Second, the directional profiles of cores from four separate coring sites are correlative (Figures 6 and 7). The correlation of the inclination profiles resulted in new depth scales used to plot the declination and intensity profiles. There is a moderate to high degree of correlation between the inclination profiles, with linear correlation coefficients of 0.54 and 0.77 for cores 316 T3 and 337 T2, respectively, when correlated to 305 A5 (Figure 6). Mean inclination values of 71°, 72°, and 72° for cores 337 T2, 316 T3, and 305 A5, respectively, are similar to the inclination of the field due to a GAD for the site latitude (69°) (Figure 6). The relative declination record for core 337

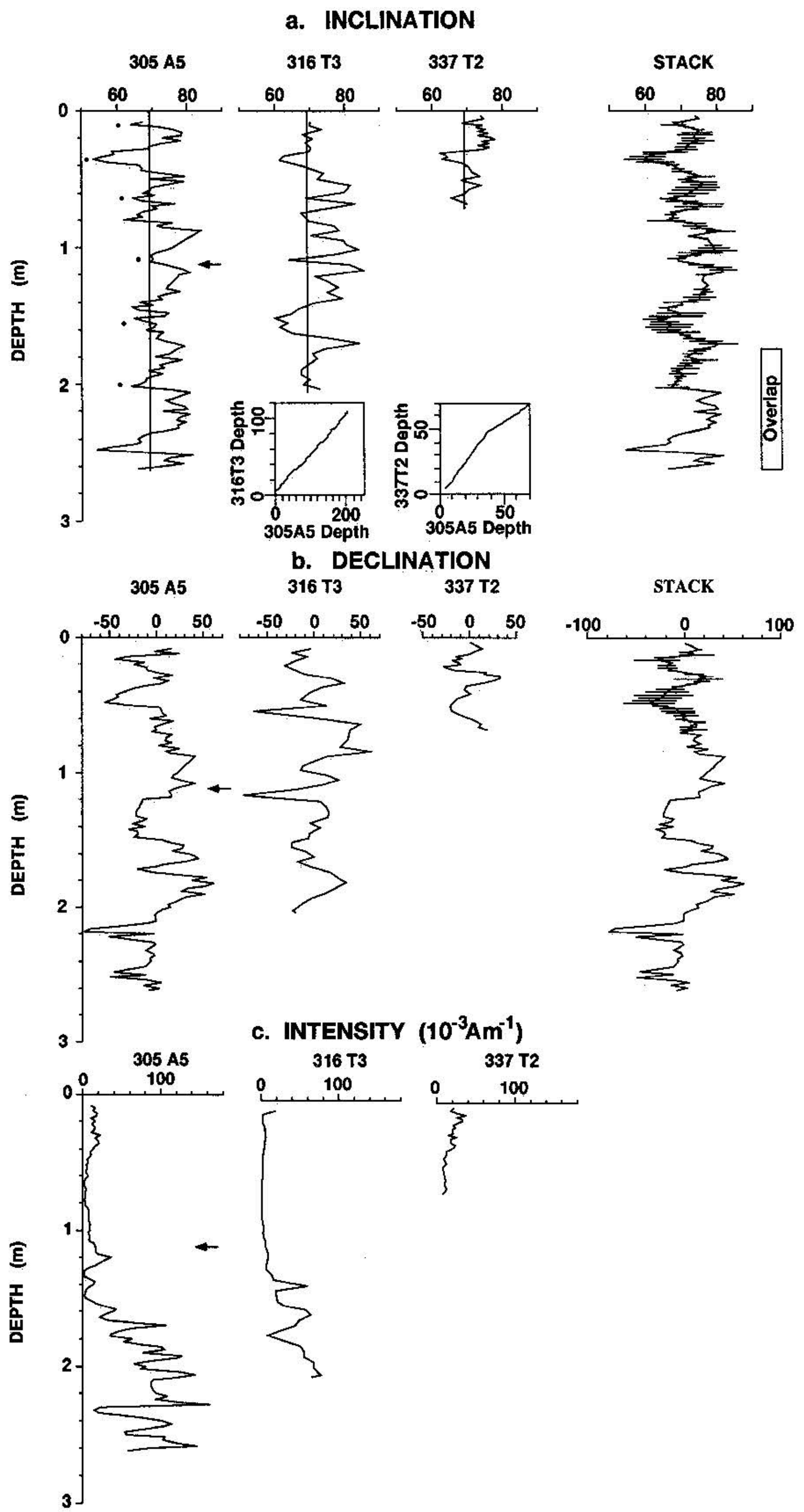

Figure 6. (a) Correlated inclination profiles after AF demagnetization at 10 mT for the three short cores using core 305A5 as the reference core. Inset shows the mapping function resulting from the correlation. Vertical lines represent the inclination of the field due to a GAD for the site latitude. Dots mark the location of tie point features, and arrows mark core section breaks. (b) Declination profiles (10 mT) plotted using the correlated inclination depth scale. Stacked inclination and declination records are shown at right. Error bars (1 s.d.) are shown by the shaded lines. (c) Intensity of remanent magnetization (10 mT) plotted using the correlated inclination depth scale.

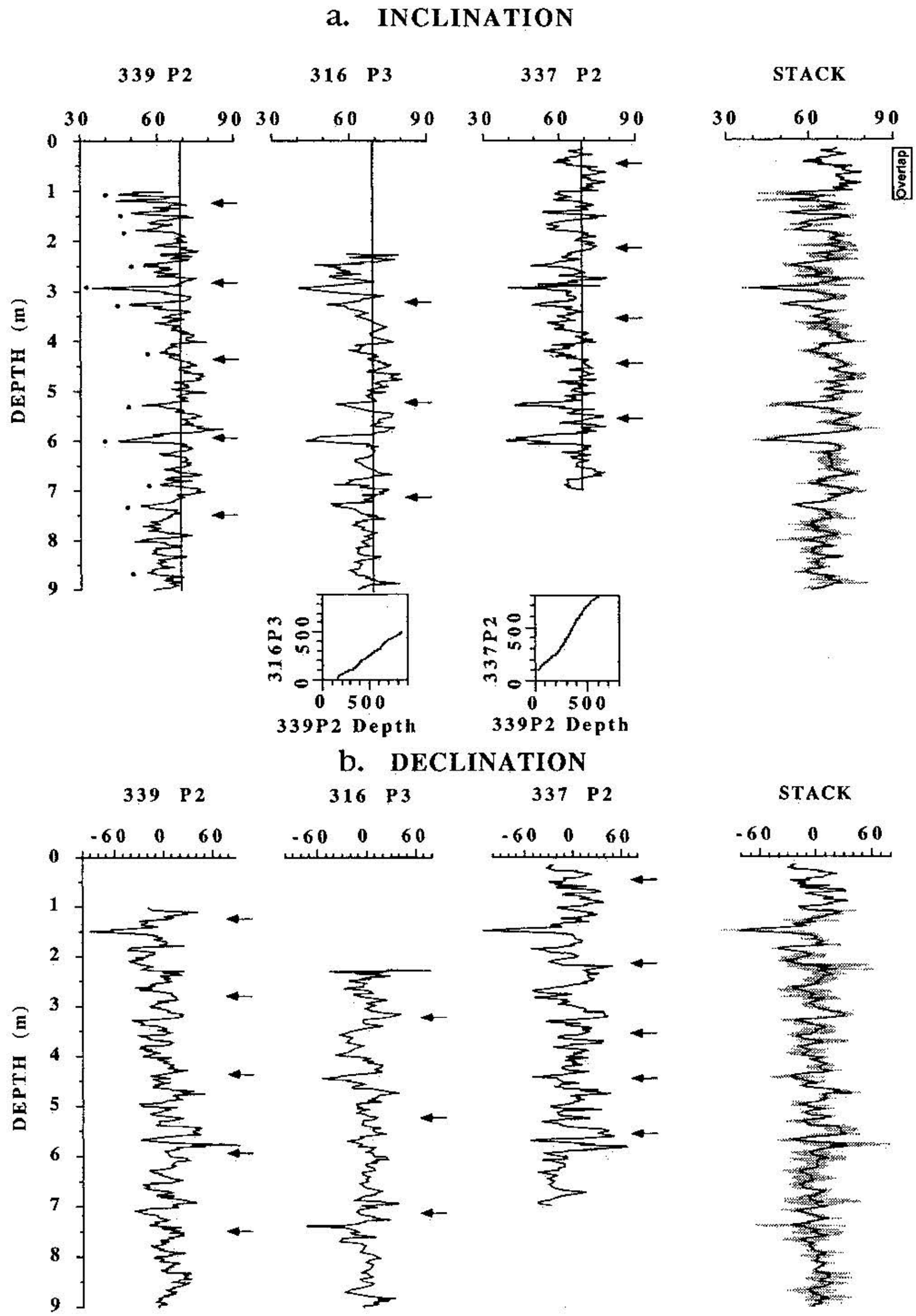

Figure 7. (a) Correlated inclination profiles after AF demagnetization at 10 mT for the three long cores using core 339 P2 as the reference core. Inset shows the mapping function resulting from the correlation. Vertical lines represent the inclination of the field due to a GAD for the site latitude. Dots mark the location of tie point features, and arrows mark core section breaks. (b) Declination profiles (10 mT) plotted using the correlated inclination depth scale. Stacked inclination and declination records are shown at right. Error bars (1 s.d.) are shown by the shaded lines. (c) Intensity of remanent magnetization (10 mT) plotted using the correlated inclination depth scale.

T2 shows a moderate degree of correlation (C = 0.62) with respect to core 305 A5. Core 316 T3 shows no correlation to 305 A5 (C = 0.13) and was not used to construct the stacked declination record.

There is a high degree of correlation between the inclination profiles, with linear correlation coefficients of 0.72 for both cores 316 P3 and 337 P2 when correlated to core 339 P2 (Figure 7). Mean inclination values of 65°, 66°, and 67° for cores 337 P2, 339 P2, and 316 P3, respectively, are similar to the inclination of the field due to a GAD. The declination values show a low degree of correlation (Figure 7), with correlation coefficients of 0.30 and 0.48 for cores 316 P3 and 337

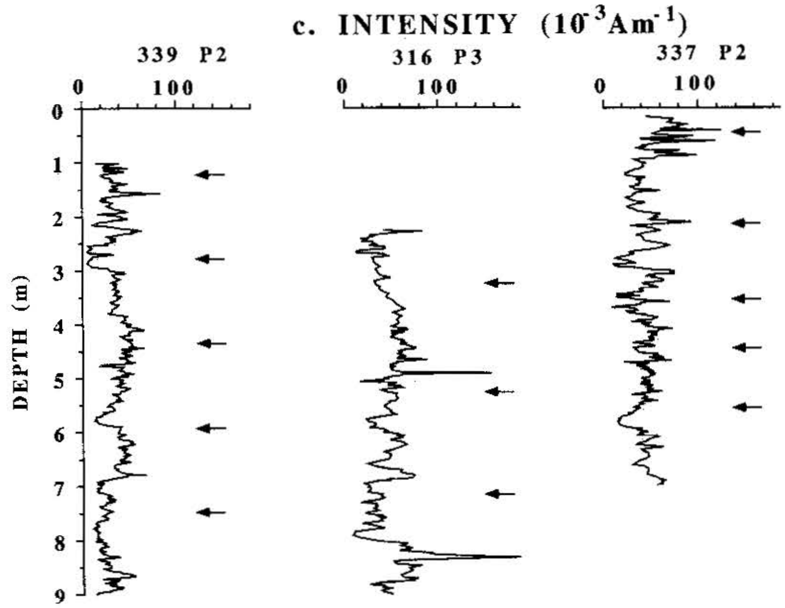

Figure 7. (continued)

P2, with respect to core 339 P2. The poor declination correlation between these cores may result from core twist, especially in core 316 P3.

The third, and most important, scale for directional reproducibility is regional, where directional profiles from several lakes should be similar. This reproducibility test will have to wait until additional secular variation studies are made in south central Siberia.

To summarize, the Lake Baikal directional records have stable magnetizations, meet *Thompson's* [1984] reliability criteria, and thus are likely to be accurate records of variations in the geomagnetic field. The standard deviation and angular standard deviation calculated at each depth level were averaged for the short- and long-core stacks (Table 1). These values are based on either two or three samples, depending on the number of cores comprising the stack (Figures 6 and 7). Although limited by the small sample size, the graphic representation of the standard deviation provides a useful visual estimate of the similarity between individual cores (Figures 6 and 7).

As described in the preceding section, the short- and long-core inclination stacks were combined. However, the declination profiles have a low correlation in the region of overlap between the short- and long-core stacks. The poor correlation is due in part to the large-amplitude (90°) change in core 305 A5 at a depth of 215 cm (Figure 6), which is not present in the correlative section of core 337 P2 (Figure 7). Owing to the low degree of correlation, the declination record from core 305 A5 was not stacked with that of 337 P2, and the region of overlap is composed of data only from core 337 P2. Therefore the declination record should be regarded with caution until additional cores spanning this interval become available.

Table 1. Average Standard Deviation and Average Angular Standard Deviation (ASD) for the Short- and Long-Core Stacked Records

	s.d.	a.s.d.
Short-core Stack		
Inclination, deg	3.2	3.4
Declination, deg	12.5	16.1
Long-core Stack		
Inclination, deg	3.2	3.3
Declination, deg	11.7	11.8

Calculations for s.d. and a.s.d. at each depth level were averaged for the entire stacked records.

Normalized Intensity

In order to develop a relative paleointensity record, it is necessary to demonstrate that the sediments are recording variations in the geomagnetic field intensity. In this section we address each of the paleointensity criteria established by *King et al.* [1983b] and *Tauxe* [1993].

Several of the relative paleointensity criteria help ensure that the normalized intensity records reflect variations in the geomagnetic field and not variations in lithology. First, magnetic concentration variations must be low, with maximum concentrations being greater than minimum concentrations by a factor of 10 or less [*Tauxe,* 1993]. Intervals of low magnetic concentration are represented by several contiguous samples (Figures 2, 6, and 7). Samples ($N = 52$) with magnetic concentrations (K, NRM, K_{ARM}, SIRM) greater than a factor of 10 of the minimum concentration generally occur as single-sample spikes and were deleted.

The second criterion is that the dominant remanence-bearing mineral be magnetite in the 1 to 15-μm size range [*King et al.,* 1983b]. X ray diffraction (XRD) analysis of the magnetic extracts reveals magnetite to be the dominant remanence-bearing mineral (Figure 8). TEM-EDS analyses of the extracts reveal abundant angular to subrounded opaque grains with compositions of Fe and O and Fe, Ti, and O, suggestive of magnetite and titanomagnetite (Figure 9). Although EDS can only indicate elemental composition (not the mineral phase), magnetite is the most likely mineral phase based on XRD analysis of the extracts. Because the extracts indicate that magnetite dominates the magnetic mineral assemblage, we applied the rapidly measured S ratio (-bIRM/SIRM) for downcore magnetic mineral assemblage identification. The S ratio reflects variations in the coercivity spectrum of the magnetic mineral assemblage and is the ratio of lower-coercivity minerals (i.e., magnetite and maghemite) to higher-

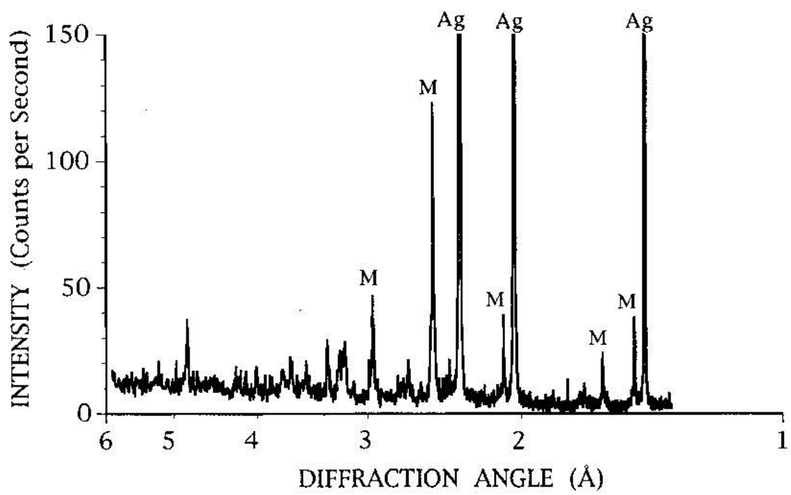

Figure 8. Representative X ray diffraction pattern for the magnetic extract from 32.5 cm depth in core 305 A5. Characteristic magnetite peaks at 2.97, 2.53, 2.09, 1.62, and 1.48 Å are labeled with M. Peaks labeled Ag are from the silver filter holding the sample.

coercivity minerals (i.e., hematite and goethite) [*Thompson and Oldfield*, 1986; *King and Channell*, 1991]. The *S* ratio can be converted into the percentage of magnetization carried by the low-coercivity component [(1 + *S* ratio) /2] [*Meynadier et al.*, 1992]. Samples ($N = 61$) containing less than 93% of their remanence carried by low-coercivity minerals were deleted, ensuring a uniform magnetic mineralogy dominated by magnetite-maghemite (Figure 10). In order to estimate the magnetic grain size, we use both the ratio K_{ARM}/K (a measure of the fine magnetic fraction) and hysteresis parameters (a measure of the central tendency of the magnetic fraction) [*King et al.*, 1982]. Samples remaining after deletion of concentration and mineralogy outliers are plotted as K versus K_{ARM} (Figure 11). The linear trend to the data indicates a relatively uniform magnetic grain size in these sediments (Figure 11). Twenty-six pilot samples shown on the Day plot [*Day et al.*, 1977] lie within the pseudo-single-domain (PSD) range, indicating an appropriate grain size in the 1 to 15-μm range (Figure 12).

A third criterion [*Tauxe*, 1993] is to demonstrate that the normalized intensity records are not coherent with the bulk rock magnetic parameters and hence not controlled by lithologic variations. Shared variance was calculated between the normalized intensity and the bulk rock magnetic parameters using the method described by *Martinson et al.* [1987] (Table 2). Table 2 indicates that there is low shared variance between normalized intensity and the bulk rock magnetic parameters that reflect magnetic concentration, grain size, and mineralogy.

Several additional criteria help to establish the reliability of the normalized intensity records as a measure of geomagnetic intensity [*Tauxe*, 1993]. First, a single, well-defined component of the NRM is required to calculate paleointensity. Figure 4 indicates that after AF demagnetization at 10 mT, the NRM meets this criterion; therefore both the NRM and ARM demagnetized at 10 mT were used to construct the normalized intensity records. Second, the NRM must accurately record the geomagnetic field direction; this criterion was shown to be met in the preceding section. Third, in order to calculate paleointensity, normalization for concentration variations should be done by several methods, all yielding similar results. Table

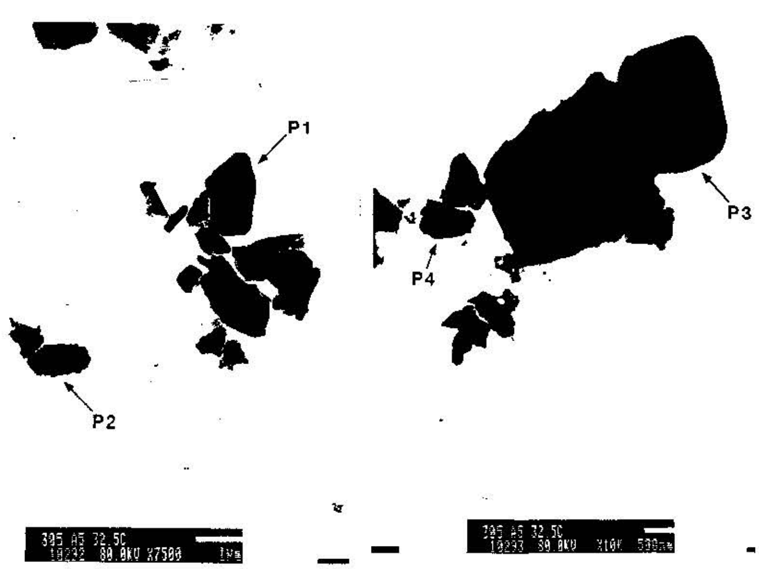

Figure 9a. TEM microphotographs of magnetically extracted grains in a sample from 32.5 cm depth in core 305 A5.

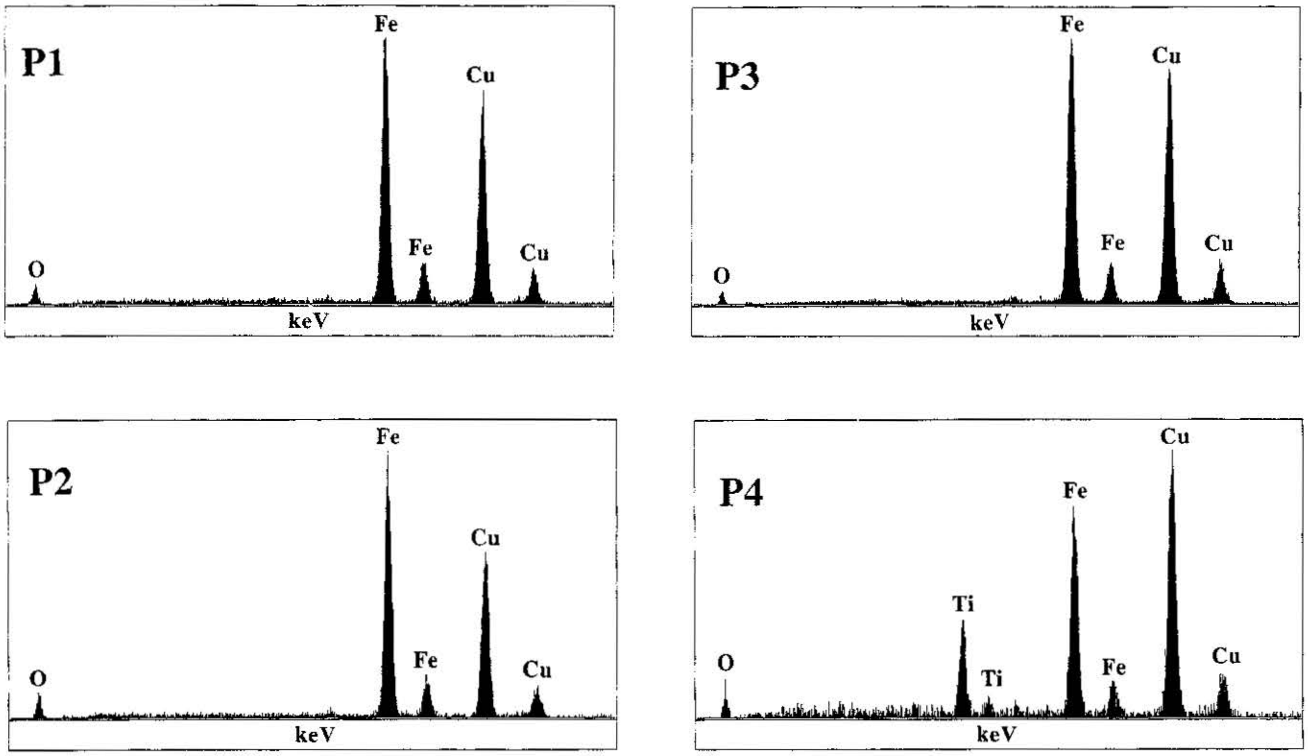

Figure 9b. EDS of grains labeled with a P number shown in Figure 9a. The grains have an Fe and O as well as an Fe, Ti, and O composition; the Cu is from the TEM grid.

2 indicates high shared variance between the three methods of normalization (*K*, ARM, SIRM). Although the three methods of normalization yield essenially the same intensity records, we have chosen ARM as the preferred normalizer based on Levi-Banerjee plots [*Levi and Banerjee*, 1976] (Figure 13). The NRM, ARM, and SIRM all have similar demagnetization curves; however, the ARM is only about 4 times as strong as the NRM, whereas the SIRM is about 180 times as strong as the NRM. The NRM/SIRM ratio increases between 0 and 20 mT cleaning and then decreases; therefore normalization by SIRM is very sensitive to the AF field used for demagnetization. The NRM/ARM versus demagnetizing field is flat up to fields of 60 mT and is therefore not as dependent on the field chosen for demagnetization. Fourth, multiple normalized intensity records from the same region should be highly correlated. The NRM/ARM intensity records plotted on depth scales resulting from the correlation of the inclination profiles reveal a high degree of correlation of 0.70 and 0.79 for cores 316 P3 and 337 P2, respectively, with regard to core 339 P2 (Figure 14). Fifth, the normalized paleointensity records should agree with absolute paleointensity measurements [*King et al.*, 1983b]. There is a first-order agreement between

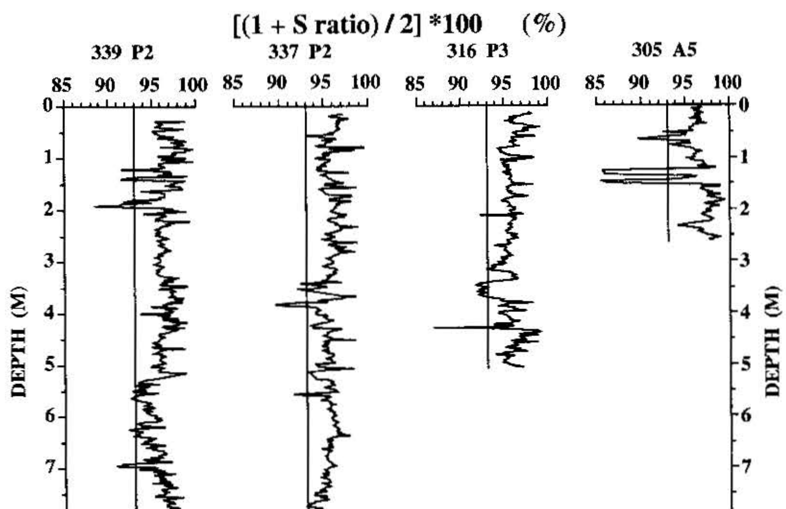

Figure 10. Downcore profiles of the percentage of remanence carried by low-coercivity minerals (i.e., magnetite-maghemite). Vertical line is drawn at the 93 percentile. See text for explanation.

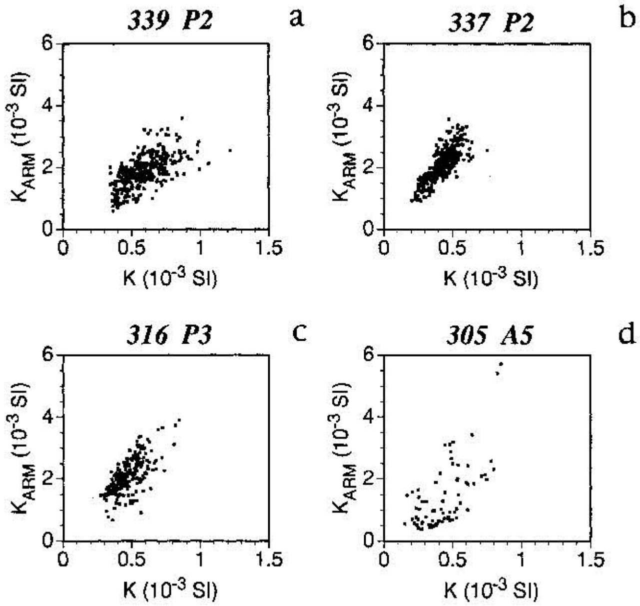

Figure 11. K_{ARM} versus K plots for four cores after mineralogy and concentration outliers have been deleted: (a) core 339 P2, (b) core 337 P2, (c) core 316 P3, and (d) core 305A5.

the Lake Baikal normalized intensity record, a record of the globally averaged dipole moment [*McElhinny and Senanayake*, 1982], and additional absolute paleointensity data (Figure 15).

To summarize, the Lake Baikal normalized paleointensity records meet all of the suitability criteria of *King et al.* [1983b] and *Tauxe* [1993] and therefore can be considered relative paleointensity records that likely reflect past variations in the geomagnetic field intensity in south central Siberia. Because many of the samples from the base of core 305 A5 failed the concentration reliablity criterion (Figure 6), the short and long stacks do not overlap. The individual normalized paleointensity profiles for the long piston cores have been scaled by their mean and stacked to yield the composite profile shown in Figure 14.

Chronology

An age model for the short-core stack was obtained by plotting the AMS radiocarbon ages [*Colman et al.*, 1996] at the correlative depth in the short-core stack based on the correlation of the inclination profiles (Figure 16). Surficial sediment samples are approximately 1220 ^{14}C years B.P., possibly because of the influx of old carbon from the watershed and the resuspension/redeposition of autochthonous algal carbon. An age of 610 ^{14}C years B.P., determined from a sediment trap sample consisting largely of diatoms, provides an estimate of the age of settling particles. An age of 2680 ^{14}C years B.P. was determined from suspended sediment of the Selenga River and provides an indication of the age of detrital carbon. Owing to the effects of bomb carbon these ages are minima. Core top loss does not account for the surficial age offset because box cores, which preserved surficial sediment, also have a similar surficial age offset [*Colman et al.*, 1996]. In light of these considerations, the surficial age offset was subtracted from all radocarbon ages used to date the cores. The age model for the short-core stack is based on the linear sedimentation rate derived from radiocarbon ages (Figure 16) and extrapolated to the base of the stack.

AMS radiocarbon ages [*Colman et al.*, 1996] were transferred to the depth scale for the complete stacked record resulting from the correlation of the short- and long-core inclination stacks. AMS ages for BDP-93-1 and BDP-93-2 were transferred to the complete-stack depth scale using K correlation. AMS radiocarbon ages display a linear trend in sedimentation rate back to about 23 ka (Figure 16). Deglaciation in Siberia dates to about 13 ka [*Klein*, 1971], with major changes in the drainage of large Siberian proglacial lakes occurring at about 13.5 ka [*Grosswald*, 1980]. The linear sedimentation rate remains unchanged across the deglacial transition, although there is a change in lithology at this time [*Carter and Colman*, 1994] (Figure 16). Beyond 23 ka, the radiocarbon ages show frequent age reversals and a steep gradient, with some radiocarbon ages following the contamination curve, indicating that some Lake Baikal radio-carbon ages older than 23 ka likely suffer from contamination by modern carbon. Contamination of the low-organic glacial sediment by microbial growth after the core was split is likely to have yielded erroneously young ages [*Geyh et al.*, 1974: *Colman et al.*, 1996].

Additional means are required to estimate the age of Lake Baikal sediment beyond the limit of reliable radiocarbon dating (~23 ka). Because Lake Baikal is undersaturated with respect to $CaCO_3$, an oxygen isotope stratigraphy, potentially useful for dating, cannot be obtained. However, the rock magnetic record, a proxy of climate change, provides a method of estimating the age of Lake Baikal sediment [*Peck et al.*, 1994]. The Lake Baikal rock magnetic climate proxy record is correlated to dated climate change records such as the marine oxygen isotope record, a measure of global ice volume [*Martinson et al.*, 1987]. The Selenga River delivers approximately half of the fluvial input to Lake Baikal, and prodelta sediments are dominated by terrigenous sediment input. Subsurface biogenic silica attains 18%, considerably lower than 55% for sediment accumulating on Academician Ridge [*Carter and Colman*, 1994]. Because Academician Ridge is an isolated structural high removed from direct fluvial input, glacial/interglacial transitions show marked changes as terrigenous and biogenic sediment flux responds to changes in climate [*Peck et al.*, 1994]. Although changes in biogenic sediment flux are less apparent on the prodelta than on Academician Ridge, earlier glacial/interglacial cycles can be identified in Selenga prodelta cores and can be correlated to the marine oxygen isotope record (Figure 17). On the basis of this correlation, four tie points provide age estimates: the marine oxygen isotope stage 1/2 boundary, mid stage 3, mid stage 4, and the stage 4/5 boundary. An identical correlation is achieved using biogenic silica, where biogenic silica peaks

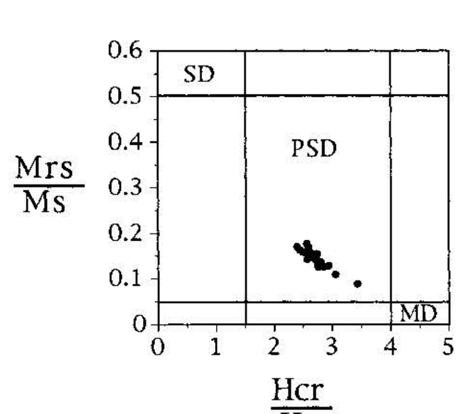

Figure 12. Pilot samples plotted on a Day plot [after *Day et al.*, 1977] all lie within the pseudo-single-domain (PSD) range. Cores 337 P2 ($N = 11$), 339 T2 ($N = 7$), and 305 A5 ($N = 8$).

Table 2. Shared Variance Between Relative Intensity (NRM/ARM) and Rock Magnetic Parameters

Core	NRM/ARM (10 mT)				
	339P2	316P3	337P2	305A5 0-150 cm	337T2
Magnetic concentration					
K	0.10	0.16	0.30	0.12	0.21
K_{ARM}	0.04	0.17	0.20	0.25	0.01
SIRM	0.02	0.04	0.13	0.35	0.01
Magnetic grain size					
K_{ARM}/K	0.01	0.01	0.01	0.01	0.02
K_{ARM}/SIRM	0.00	0.05	0.01	0.01	0.01
Magnetic mineralogy					
H ratio	0.04	0.22	0.22	0.19	0.01
S ratio	0.01	0.02	0.03	0.45	0.01
Intensity					
NRM	0.48	0.48	0.29	0.54	0.40
Relative intensity					
NRM/K	0.64	0.77	0.78	0.27	0.45
NRM/SIRM	0.63	0.79	0.79	0.24	0.52

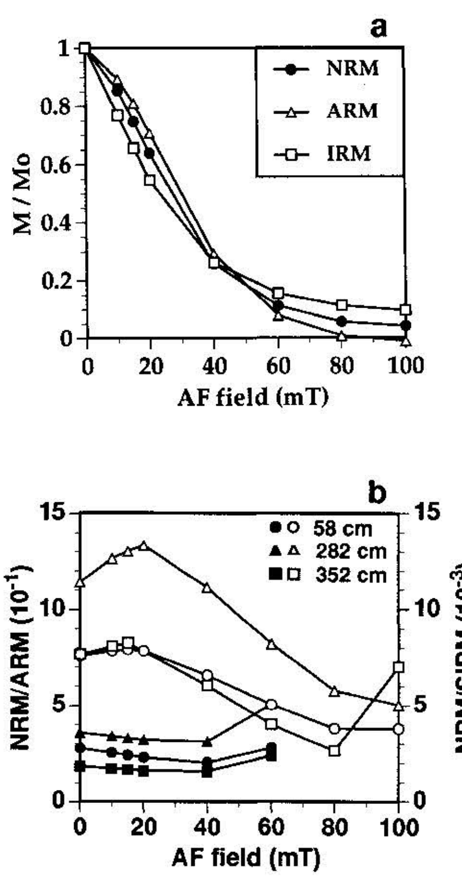

Figure 13. (a) Normalized demagnetization curves for the NRM, ARM, and SIRM of sample 282 cm from core 316P3. (b) NRM/ARM (solid symbols) and NRM/SIRM (open symbols) versus demagnetizing field for three samples from core 316P3. Division by values close to zero for the ARM prevents plotting of the NRM/ARM ratio at fields of 80 mT or greater.

correspond to warmer, more productive interglacial periods [*Carter and Colman*, 1994]. Error bars (0.5 m) were estimated for the position of the older tie points within the sediment, because other climate proxies in the core may lead or lag the rock magnetic proxy. The relationship of the different climate proxies to each other will become more apparent as these studies are completed. An age error of 5 kyr was estimated to reflect the uncertainty of the lead/lag relationship between the continental and marine climate records. The China loess record of continental climate lags the marine oxygen isotope record by as much as 5 kyr [*Imbrie et al.*, 1993] and serves as the basis for our age error estimate. The age model for the long-core stack consists of linear interpolation between reliable radiocarbon ages less than 23 ka and the three older climate tie points.

Discussion

Paleomagnetic Secular Variation

Combining the short- and long-core stacks results in a directional profile that spans the last 84 kyr and displays paleomagnetic secular variation (PSV) behavior (Figure 18). An angular deviation of 48° from the axial dipole field direction indicates the presence of a geomagnetic excursion at 20 ka. Four intervals of pronounced directional swings at 41, 61, and 67 ka are characterized by angular deviations of less than 30° from the axial dipole field direction. We have already demonstrated that the Lake Baikal sediments are recording changes in the geomagnetic field. The four directional swings are also believed to reflect geomagnetic field changes, because these swings are not associated with core breaks and appear in each of the individual cores that compose the stacked record (Figures 6 and 7).

There are similarities between the inclination records from Lake Baikal and Lake Biwa, Japan (35°13'N, 136°01'E), which is located approximately 3000 km to the southeast (Figure 19). The Lake Biwa age model consists of linear interpolation between new age estimates of 10 and 120 ka for the Lake Biwa drill cores [*Meyers et al.*, 1993]. Sedimentation rates are unlikely to have been constant during this interval;

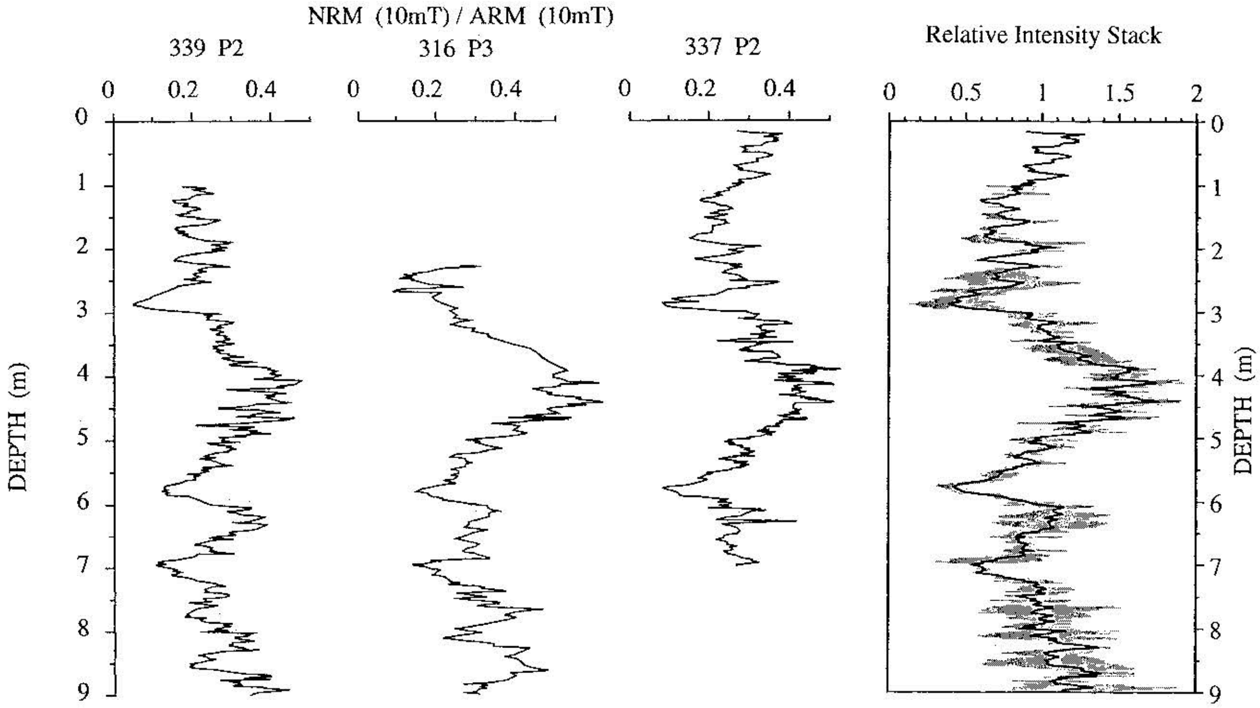

Figure 14. Normalized (by ARM) intensity records for the three long piston cores. Stacked record is given at right with error bars (1 s.d.) shown by shaded lines.

therefore the age estimate is a first-order approximation (Figure 19). However, the interpolated age estimate of 25.5 ka for the ash horizon (AT) at 26 m depth is similar to the radiometrically determined age of 24.7 ka [*Ohno et al.*, 1993]. The Lake

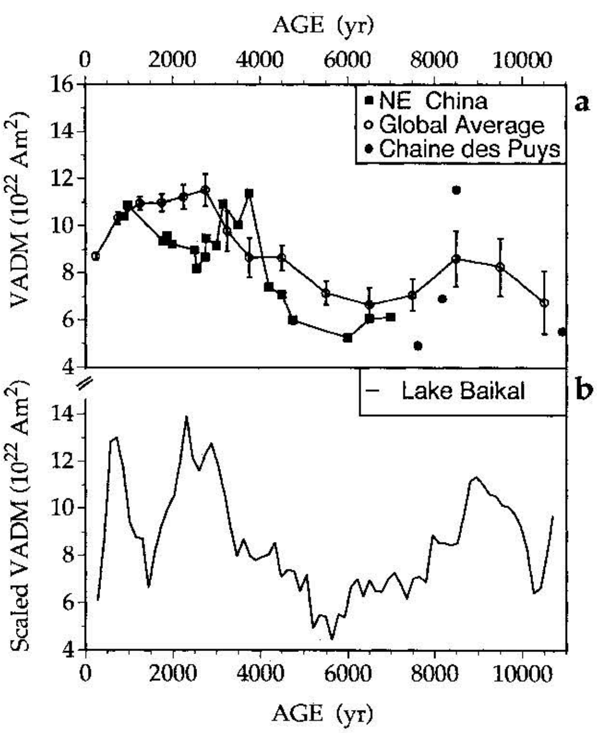

Figure 15. (a) VADM records for NE China [*Yang et al.*, 1993], the global average [*McElhinny and Senanayake*, 1982], and Chaine des Puys, France (tabulated by *Thouveny et al.* [1993]). (b) Scaled relative paleointensity record from Lake Baikal short-core stack.

Biwa drill core has a high sedimentation rate (80 cm kyr^{-1}) and shallow (often negative) inclination anomalies (Figure 19). The inclination profiles from Lake Biwa and Lake Baikal contain many correlative inclination swings; however, the low-amplitude short-period PSV changes are not similar (Figure 19). The Lake Biwa inclination record contains many samples with low inclination and the entire record averages about 10° below the inclination of the field owing to a GAD for the site latitude (Figure 19). Early drill core, core handling, and subsampling technology may be responsible for introducing artifacts to the inclination record.

Although the Lake Baikal directional record displays one excursion and three pronounced inclination swings, the interpretation of this record can provide some support for the occurrence of several excursions of the geomagnetic field during the last 84 kyr. Each of the large-amplitude changes in the Baikal record is examined, beginning with the most recent. There is a sharp swing of 85° of the declination (in five samples) at 20 ka, corresponding to an interval of shallow inclination between 18 and 22 ka (Figure 18). These features are reproducible in multiple cores from Lake Baikal (Figure 7). No anomalous directions were observed at this time in a record from Japan [*Ohno et al.*, 1993]. Several departures of the virtual geomagnetic pole are present in the sediment record from Lac du Bouchet, France between 18 and 22 ka [*Thouveny and Creer*, 1992].

At 41 ka there is a shallowing in inclination to 38° (Figure 18). This inclination feature (in five samples) corresponds in age to the widely reported Laschamp excursion [*Bonhommet and Zahringer*, 1969; *Champion et al.*, 1988; *Petrova and Pospelova*, 1990; *Nowaczyk et al.*, 1994; *Yamazaki and Ioka*, 1994], although the directional behavior is strictly secular variation in the Lake Baikal record. This inclination swing correlates to excursion behavior in the Lake Biwa record (features H and I, Figure 19).

At 61 ka (in five samples) and 67 ka (in eight samples) there are two periods of shallow inclination (Figure 18). These features correlate remarkably well in age to excursions from

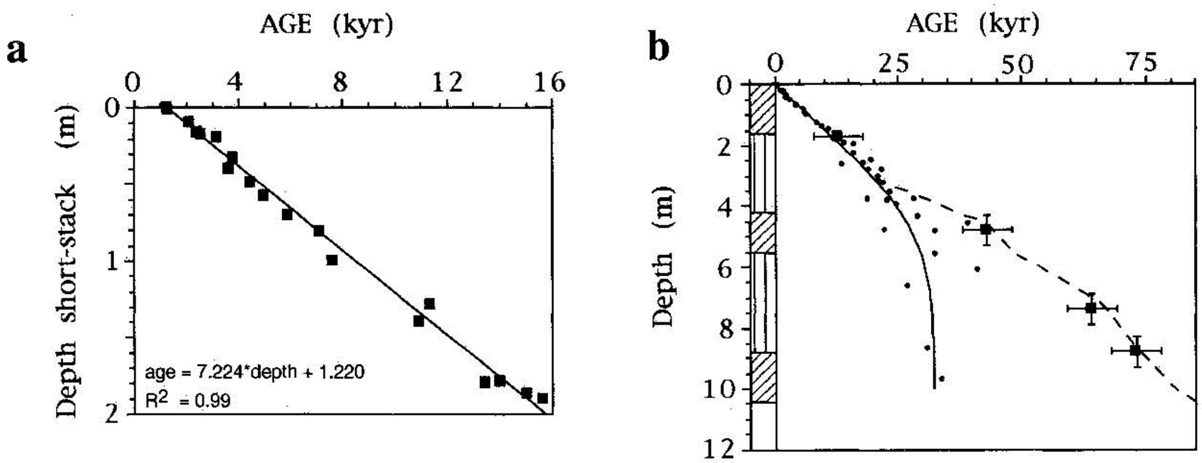

Figure 16. (a) Radiocarbon ages from Selenga prodelta cores plotted on the short-core stack depth scale obtained by correlating inclination profiles. Note the linear trend in sedimentation rate and the surficial age offset of 1220 years. (b) Radiocarbon ages (circles) from Selenga prodelta cores plotted on the depth scale for the complete stack. Solid line represents contamination by 2% modern carbon on radiocarbon ages with a linear sedimentation rate (Figure 16). Squares represent ages of tie points from correlation of Lake Baikal rock magnetic climate proxies to the marine oxygen isotope record [*Martinson et al.,* 1987]. Dashed line represents age model resulting from the correlation of Lake Baikal and marine relative intensity records (Figure 20). Lithologic column shows diatomaceous sediment (diagonal lines) and clayey sediment (vertical lines). Radiocarbon ages are from *Colman et al.* [1996].

Lake Biwa (features J, K, L, and M, Figure 19). No excursion behavior has been reported during this time interval in several global compilations of excursions [*Champion et al.,* 1988; *Petrova and Pospelova,* 1990; *Nowaczyk et al.,* 1994]. The excursion behavior at 59-66 kyr in Lake Biwa and the correlative large-amplitude PSV changes in Lake Baikal may reflect a regional nondipole anomaly or a more global but unreported excursion. Careful examination of this age interval for anomalous geomagnetic directions is warranted, especially in sediment sequences of high accumulation (>30 cm kyr^{-1}). For

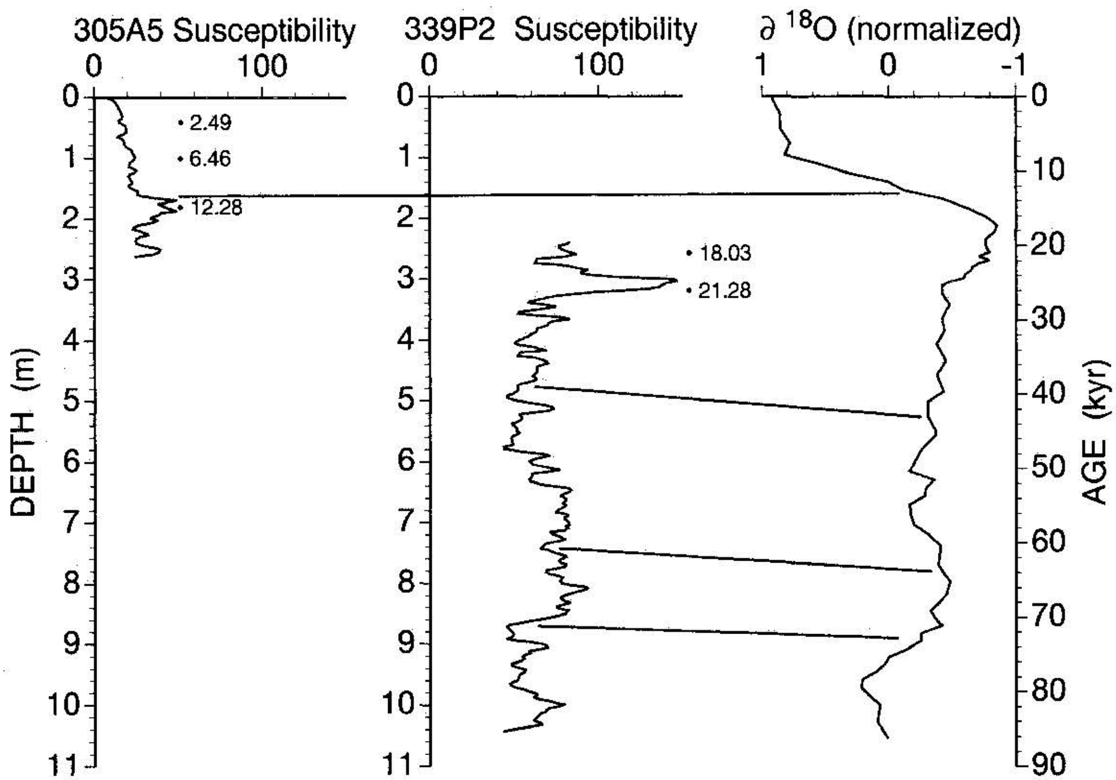

Figure 17. Correlation of Lake Baikal K profiles (relative SI units) to the marine oxygen isotope record [*Martinson et al.,* 1987].

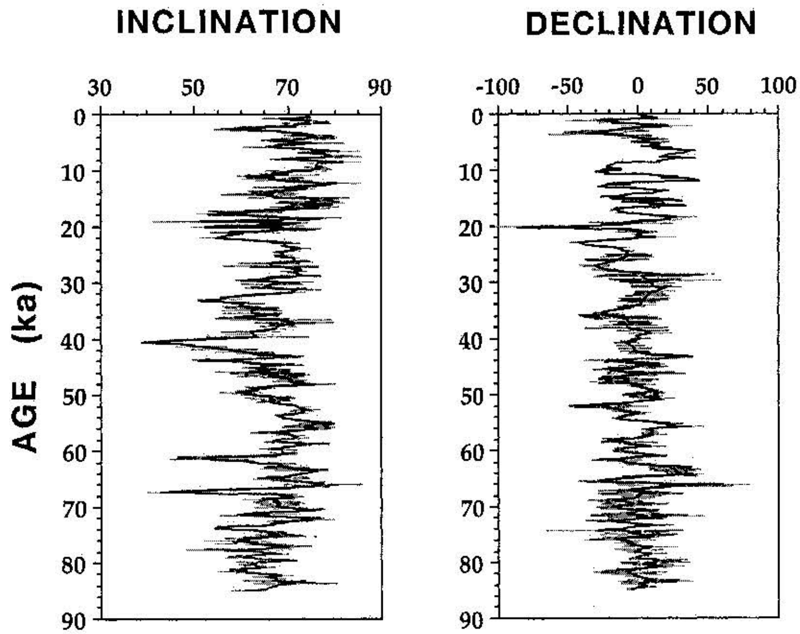

Figure 18. Stacked inclination and declination profiles (10 mT) versus age resulting from the correlation of the relative intensity profiles. Error (1 s.d.) is shown by shaded lines.

example, *Thouveny et al.* [1990] report an interval with wide departure from the axial dipole at 55 ka from Lac du Bouchet, France. Considering errors in dating these three records, the directional feature in the Lac du Bouchet record at 55 ka may be the same feature observed in the Lakes Baikal and Biwa records at about 61 ka.

Effect of Sedimentation Rate on the PDRM Recording Process and Comparison of PSV Records

Sedimentary sequences often acquire a record of the geomagnetic field (PDRM) at a depth in the sediment column referred to as the lock-in depth. At this depth, magnetic grains

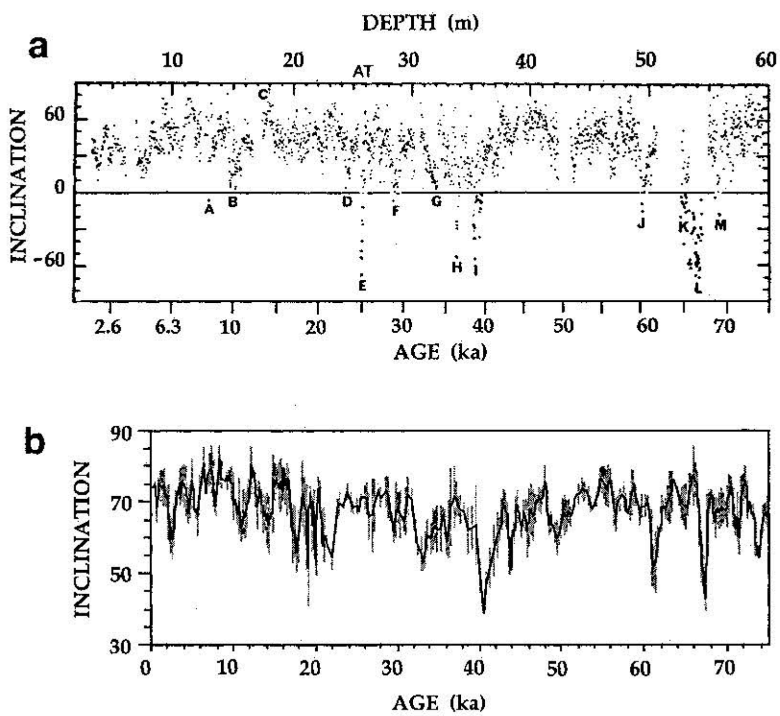

Figure 19. Comparison of inclination profiles from Lake Baikal and Lake Biwa. (a) Inclination record from Lake Biwa, Japan [*Kawai et al.*, 1975]; age scale after *Meyers et al.* [1993]. AT refers to ash horizon AT. Raw inclination data for the Lake Biwa drill hole below 30 m are lost and no longer available for plotting (S. Horie, personal communication, 1995). (b) Stacked inclination record from Lake Baikal. Error (1 s.d.) is shown by shaded lines.

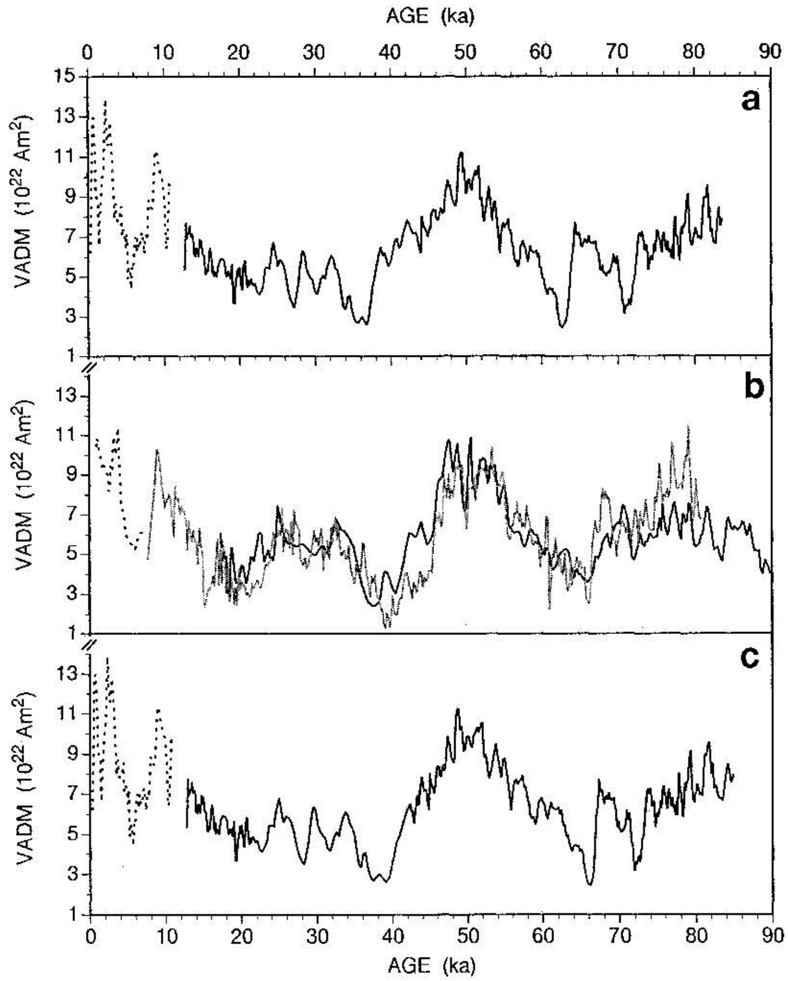

Figure 20. Comparison of relative paleointensity records. (a) Lake Baikal relative paleointensity record (dotted line, 305 A5 and 337 T2; solid line, stacked long cores) plotted using AMS radiocarbon ages and the climate proxy age model. (b) Mediterranean Sea (shaded line) [*Tric et al.*, 1992], Somali Basin (solid line) [*Meynadier et al.*, 1992], and NE China (dotted line) [*Yang et al.*, 1993] absolute intensity. (c) Lake Baikal relative paleointensity record (dotted line, 305 A5 and 337 T2; solid line, stacked long cores) plotted after correlating to the Somali Basin record.

are not free to realign with the changing geomagnetic field. The lock-in depth depends on the porosity and the size, shape and concentration of both the remanence carriers and the matix. The time required to reach the lock-in depth depends on the sedimentation rate and is called the lock-in delay [*Verosub*, 1977]. *Lund and Keigwin* [1994] discuss the effects that slow sedimentation rates have on smoothing the PSV record. In the presence of limited bioturbation, sedimentation rates of <1 cm kyr^{-1} are not likely to preserve PSV; rates of 10 cm kyr^{-1} smooth PSV by 50%; whereas rates of >30 cm kyr^{-1} do not greatly smooth PSV. At intermediate rates (10 cm kyr^{-1}), short-wavelength features are more likely to be smoothed than long-wavelength features. In general, the lock-in delay has the following effects on PSV records: (1) it attenuates the amplitude of oscillations, (2) it introduces a phase lag, and (3) it decreases the magnetic intensity because of cancellation of magnetic moments of grains aligned in opposite directions [*Verosub*, 1977; *Thouveny and Creer*, 1992]. The problem of PSV smoothing is amplified with excursions during the last 80 kyr, because these excursions are believed to be short-lived features, perhaps several hundreds of years long [*Thouveny et al.*, 1990; *Thouveny and Creer*, 1992].

The net sedimentation rate of Lake Baikal cores used to construct the stacked PSV record (Figure 18) is about 13 cm kyr^{-1}. A result of this intermediate sedimentation rate is a smoothed PSV record where excursion behavior at Laschamp time and at 61-67 kyr is recorded as large-amplitude PSV. Through comparison to lava flow records, *Thouveny et al.* [1990] determined that the Lac du Bouchet PSV record has been attenuated by approximately 19%.

Even with the intermediate sedimentation rate (13 cm kyr^{-1}), the smoothed Lake Baikal directional profiles for the last 84 kyr are useful for future regional correlations in south central Siberia. PSV correlation may help date other sedimentary sequences through correlation to the Lake Baikal age model. In order to generate a master curve for south central Siberia, additional PSV curves need to be acquired from other lakes in the region and correlated to the Lake Baikal record.

Lake Baikal Relative Paleointensity

We have demonstrated that Lake Baikal sediments meet the relative paleointensity reliable criteria. On the basis of the assumption that the sediments have linearly recorded geomagnetic intensity, we convert the relative paleointensity (NRM/ARM 10 mT) to virtual axial dipole moment (VADM) following a method similar to that used by *Thouveny et al.* [1993]. First, to remove the effects of dipole wobble, relative

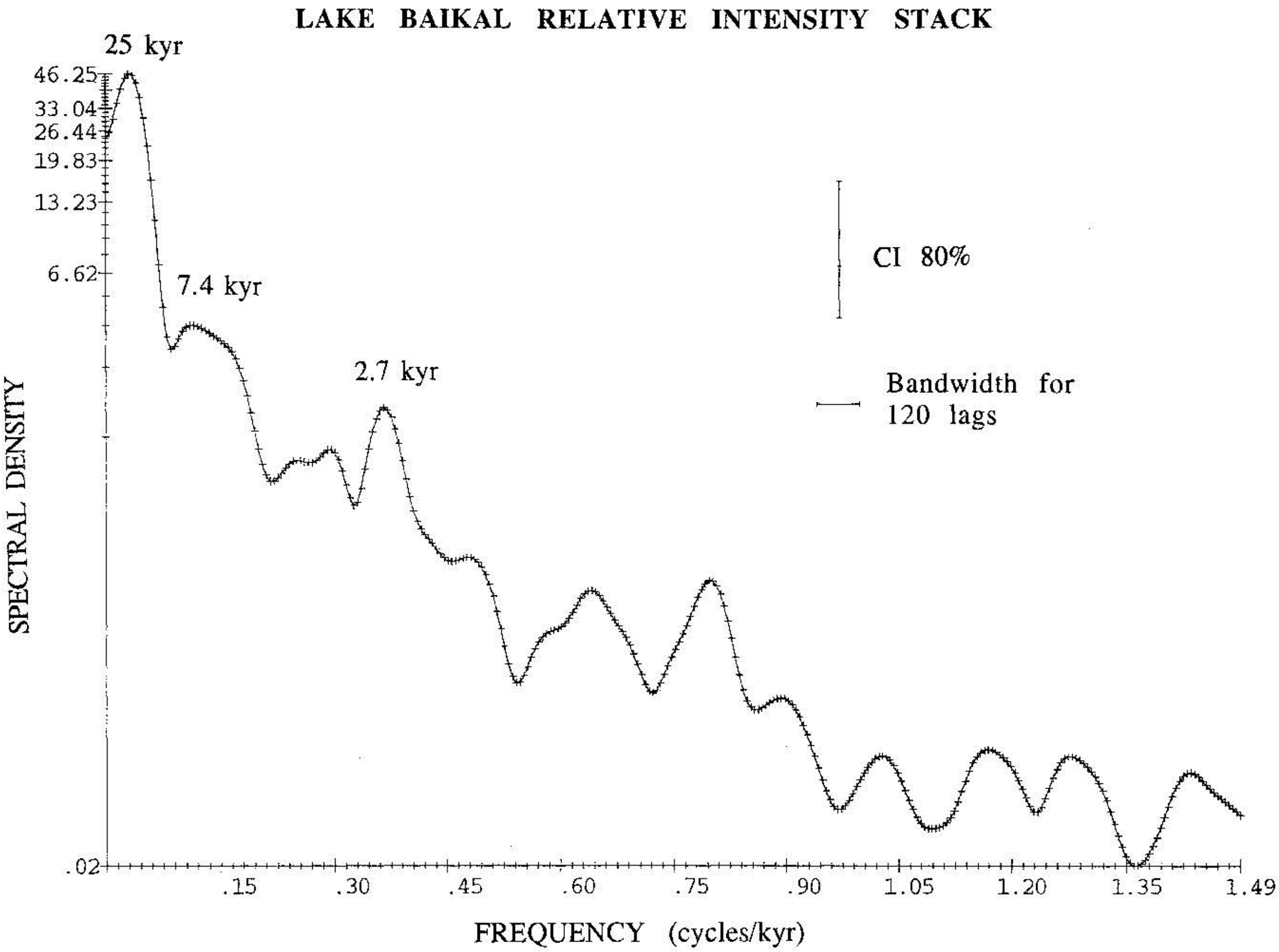

Figure 21. Spectrum of the Lake Baikal relative intensity record. Significant peaks in power are labeled in kiloyears.

virtual dipole moment (VDM) values were calculated using the stacked inclination and relative paleointensity data. The VDM profiles, normalized to a mean of unity, were then scaled to VADM. The mean of NE China absolute intensity values for the last 7 kyr (8.64×10^{22} A m^2) [*Yang et al.*, 1993] was used as a scaling factor for the Lake Baikal short-core stack, which spans the last 11 kyr. A scaling factor of 6.3×10^{22} A m^2 (averaged volcanic data for 0-160 kyr) [*Tric et al.*, 1994] was used for the long-core stack spanning 12-84 kyr.

Although there is a first-order degree of correlation between the Lake Baikal and northeastern China intensity records, the Lake Baikal record appears to lag the Chinese record by about 1000 years (Figure 15). *Yang et al.* [1993] report a westward drift rate of about 0.13° yr^{-1} for the nondipole anomaly that produced the intensity low at about 2500 ka in archeomagnetic data from northeastern China (Figure 15). This drift rate would place the intensity low at Lake Baikal (longitude 106°E) approximately 140 years later. An intensity low appears in the Lake Baikal record at about 1500 ka, or 1000 years later than the northeastern China record. In addition, the peak at about 3500 ka in the China record appears at 2500 ka in the Lake Baikal record (Figure 15). The 1000-year age discrepancy between expected and observed paleointensity features likely results from errors associated with dating the two records. For reasons stated in the chronology section, we have subtracted 1200 years from the radiocarbon ages used to date Baikal sediment, and this may account for part of the age discrepancy (Figure 15).

The stacked relative intensity record from Lake Baikal correlates to relative intensity records from the Mediterranean Sea [*Tric et al.*, 1992] and the Somali Basin [*Meynadier et al.*, 1992]. With each relative intensity record fixed on its own age model (Figures 20A and 20B), the Lake Baikal record has moderate correlation coefficients of 0.54 and 0.69 when correlated to the Mediterranean Sea and Somali Basin records, respectively. These relative intensity records are from three distinct sedimentary environments representing two separate oceanic basins located approximately 8000 km from the lake in central Asia. The moderate degree of correlation is suggestive of a dominant global (i.e., dipolar) character to these records. Assuming that the Mediterranean Sea and Somali Basin age models are correct, it is interesting to note that in some intervals the Lake Baikal record is in better agreement with the record from the Mediterranean Sea (e.g., sharp rise in the Mediterranean Sea record at 66 ka). At other intervals the Baikal and Somali Basin records show the closest agreement (e.g., shoulder to the rise at 42-45 ka in the Somali record). The Lake Baikal relative intensity record is also similar to other published records that are more globally distributed, including records from the North Atlantic [*Weeks et al.*, 1995] and the western Pacific [*Yamazaki and Ioka*, 1994; *Tauxe and Wu*, 1990]. All of these records display an intensity low at about 40 ka and a high at about 50 ka. The intensity low present at about 65 ka in the Somali Basin, Mediterranean Sea, and Lake Baikal records appears at about 60 ka in the records from the North Atlantic and western Pacific Oceans.

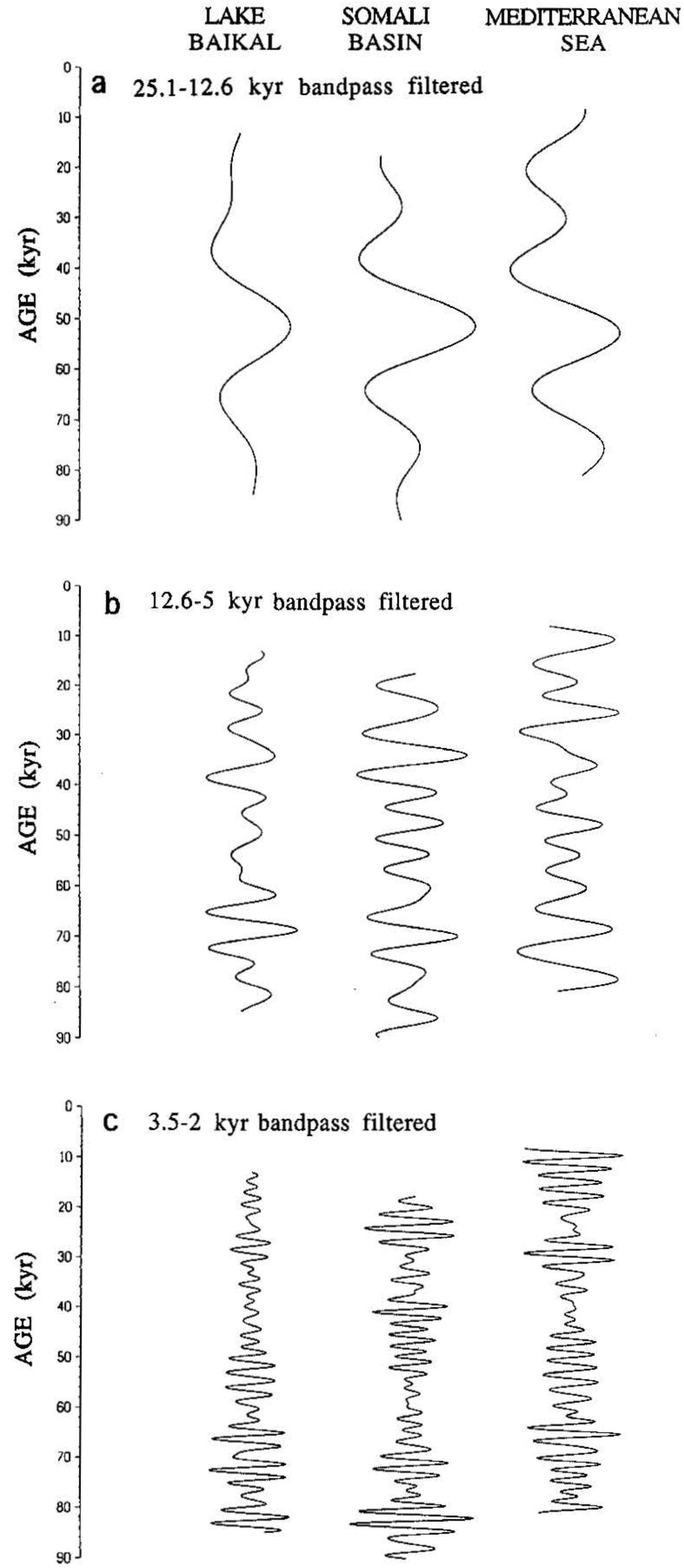

Figure 22. Band-pass-filtered relative intensity records from Lake Baikal, Somali Basin [*Meynadier et al.*, 1992], and the Mediterranean Sea [*Tric et al.*, 1992]. Band-pass filters used are (a) 25.1-12.6 kyr, (b) 12.6-5 kyr, and (c) 3.5-2 kyr.

The age models for the Mediterranean Sea and Somali Basin records are based on oxygen isotope stratigraphy, which we assume to be more reliable than the Baikal climate proxy age model [*Tric et al.*, 1992; *Meynadier et al.*, 1992]. The age model for the Lake Baikal record is based on AMS radiocarbon ages for the last 21 kyr and the correlation of the rock magnetic properties to the marine oxygen isotope record. Because the climate proxy tie points used to estimate the age of Lake Baikal sediment have first-order age errors of ± 5 kyr and depth errors of ± 0.5 m, correlating the three paleointensity records while allowing the Baikal record to move in time is warranted. The refined correlation for the Lake Baikal record resulted in high correlation coefficients of 0.71 and 0.82 for the Mediterranean Sea and Somali Basin records, respectively (Figures 20B and 20C). The resulting Lake Baikal age model from the relative intensity correlation is shown in Figure 16 (dashed line). The relative intensity age model (dashed line) intersects (within the errors) each of the climate proxy tie point age estimates (squares) (Figure 16). Therefore the additional correlation of the relative intensity records supports the initial assumption of rock magnetics as a climate proxy record. The correlation between the better dated marine records and the Lake Baikal record (Figures 20B and 20C) provides an additional means of constraining the age of Lake Baikal sediment beyond the range of reliable radiocarbon dating.

Geomagnetic Intensity Stratigraphy

The Lake Baikal relative intensity record further supports the reliability of sediments as recorders of relative geomagnetic paleointensity. The correlation of the three paleointensity records (Figure 20) reveals the potential for the development of a new magnetostratigraphic tool based on geomagnetic paleointensity. This study of Lake Baikal sediment demonstrates that such a relative intensity stratigraphy can be used to date and globally correlate sedimentary records of climate change that are not well suited for traditional dating methods (Figures 16 and 20).

Although continued work is required to attain a global geomagnetic intensity stratigraphy, we can use the Lake Baikal record to estimate the potential resolution of such a stratigraphy. Spectral analysis of the 84-kyr Lake Baikal paleointensity record, using the correlated age model (Figure 20), reveals significant peaks at periods of about 25, 7.4, and 2.7 kyr (Figure 21). The Lake Baikal, Somali Basin, and Mediterranean Sea relative intensity records were band-pass filtered at three resolutions (Figure 22). Not only is there a high degree of correlation between the complete relative intensity records from Lake Baikal, Somali Basin, and the Mediterranean Sea (Figure 20), there is also good visual correlation between these three sites for the low and intermediate band-pass filtered records (Figures 22A and 22B). The correlation at periods of about 23 and 7 kyr (Figures 22A and 22B) suggests a potential resolution of about 7 kyr for the geomagnetic intensity stratigraphy during the last 80 kyr. Additional relative intensity records with good global distribution and age control are needed to determine if correlation to 7-kyr resolution is possible at distances greater than 8000 km.

An intensity stratigraphy would be unlikely to provide global correlations at periods shorter than about 7 kyr. However, these short-period paleointensity fluctuations may be very useful for regional correlation (Figure 14) [*King et al.*, 1983a; *Tauxe*, 1993]. The lack of similarity of the records band-pass filtered at 3.5-2 kyr (Figure 22) suggests that with the existing age control, short-period relative intensity fluctuations are not correlative between sites 8000 km distant. In general, the following factors may limit the resolution of a global geomagnetic intensity stratigraphy. First, short-period, high-resolution relative intensity records appear to be influenced by the regional nondipole field and hence not suitable for global correlation [*Tauxe*, 1993]. Second, low sedimentation rates and long lock-in delays have a smoothing effect on geomagnetic records [*Verosub*, 1977; *Thouveny and Creer*, 1992; *Lund and Keigwin*, 1994]. Third, stacking relative intensity profiles from individual cores can attenuate high-frequency variability [*Meynadier et al.*, 1992].

In order to attain a geomagnetic intensity stratigraphy, additional detailed paleomagnetic records with good global coverage are required in order to assess the global character of the paleointensity record. Rapid sedimentation sites need to be targeted, with rates similar to Lake Baikal (13 cm kyr^{-1}) lying at the lower limit. Each of the paleomagnetic reliability criteria [*Thompson*, 1984; *King et al.*, 1983b; *Tauxe*, 1993] needs to be addressed so that the quality of each record can be assessed. Finally, high-quality chronologies need to be obtained using radiometric methods, orbitally calibrated oxygen isotope stratigraphies, and other climate proxy data.

Conclusions

We have shown that the sediments from the Selenga prodelta region (Lake Baikal) meet the criteria required for the construction of a reliable paleomagnetic record. The resulting 84-kyr records of inclination and declination display PSV behavior. Excursion behavior is present at 20 ka and has been smoothed to appear as large-amplitude PSV at 41, 61, and 67 ka. Smoothing of the geomagnetic excursion behavior in Lake Baikal sediments can be explained by the intermediate sedimentation rate (13 cm kyr^{-1}) for these cores. Future PSV studies should examine the interval between 61 and 67 ka for geomagnetic excursion behavior, because large-amplitude PSV (excursion) behavior is present in the Lake Baikal (Lake Biwa) record at this time. The stacked PSV record from Lake Baikal fills an important gap in the global distribution of PSV records and thereby contributes to a better understanding of the nature of the geomagnetic field. The Lake Baikal PSV record will be useful for future regional correlations in south central Siberia, because the Baikal PSV record has an age model based on radiocarbon dating, climate proxy correlation, and relative geomagnetic intensity correlation.

The Lake Baikal relative paleointensity record correlates well to better dated relative intensity records from the Mediterranean Sea ($C = 0.71$) and the Somali Basin ($C = 0.82$), suggestive of the dominant global character to these records. This correlation also substantiates the existing age estimate for Lake Baikal sediments, thus confirming rock magnetics to be a useful proxy of paleoclimate. The Lake Baikal relative intensity record provides an important advance toward the goal of developing a global geomagnetic intensity stratigraphy. This study further supports the reliability of sediments as recorders of relative geomagnetic intensity and indicates that paleointensity correlation between sites as far apart as 8000 km may be possible to about 7-kyr resolution.

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