High-resolution diatom/clay record in Lake Baikal from grey scale, and magnetic susceptibility over Holocene and Termination I

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Abstract: Tracing past climate signals from Lake Baikal sediments with a "multi-annual" resolution by conventional techniques is a difficult challenge since the sedimentation rates from Termination I up to the present range from 0.004 to 0.17 mm/year. In this paper, climate signals are reconstructed from three continuous sediment records from Vydrino Shoulder and Posolsky Bank in the Southern Basin, and Continent Ridge in the Northern Basin. For each coring site, a calendar age model was constructed using calibrated radiocarbon ages. The magnetic susceptibility is used to better constrain the age models over OIS4 to OIS1. The cores have been hardened using polymerized technique in order to allow the easy cut of thin sections that contain evidence for narrow biogenic/clayey laminations. The grey scale taken from the thin sections is used here as a high-resolution proxy record of diatom/clay ratio. The grey density values are qualitatively interpreted against the sediment components by optical microscopy from the thin sections. In the Northern Basin, the Continent station provides the best age model and sediment resolution over the Termination I period. In particular, four optima (i.e. Bölling, Alleröd, Atlantic, and Subboreal) are indicated by substantial increases of the grey scale, whereas cold periods like the Younger Dryas correspond to lower grey scale values. We emphasize that the short-term variations in the grey scale at 20 µm resolution could correspond to short climate responses in Lake Baikal sediments.

Keywords: Lake Baikal; core polymerization; thin section; grey scale; magnetic susceptibility; Late Quaternary

1. Introduction

Natural lake sediment archives represent continuous continental records suitable for the comparison of high-frequency climate variability around the world (Holivar program, Battarbee, 2003). Lake Baikal (52°N) is the world's largest freshwater lake and contains a long sediment archive suitable for tracing past and recent climate changes in Eurasia (e.g. Prokopenko et al., 2001a,b,c). The composition of Lake Baikal sediment alternates between biogenic silica-rich and more compact clayey intervals (BDP Members, 1997). At low resolution, this clay/diatom ratio mirrors global variations of glacial-interglacial periods in Siberia (Khotinsky, 1984, 1989). Highest diatom abundance occurs in the warmest climate intervals, whereas cold periods are marked by lower diatom productivity (Bezrukova et al., 1991; Qiu et al., 1993; Granina et al., 1993; Williams and Jenkins, 1993; Bradbury et al., 1994; Carter and Colman, 1994; Karabanov et al., 1999; Rioual et al., 2005-this volume; Swann et al., 2005-this volume).

Lake Baikal biogenic responses to atmospheric circulation are linked to thermal characteristics of the lake cycle and the rate of vertical exchange between surface waters and deep waters. The nutrients in the upper water layers are recycled about four times before being lost into the deep waters, while the deep water renewal rate is approximately 8 years (Weiss et al., 1991). Retrieving a high-resolution record of Lake Baikal paleoproductivity is limited by the absence of varved micro structure and the low sedimentation rates at the sites suitable for paleoclimate reconstructions (i.e. stations undisturbed by turbidity currents). With accumulation rates of 0.05-0.14 mm/year in the Southern Basin and 0.04-0.06 mm/year in the Northern Basin (Fig. 1), the standard 5 mm data acquisition technique on cored sediments corresponds to a time resolution of only between 100 and 30 years. Therefore, a 1 mm data acquisition represents on average 10 years of accumulated sediments. Thinner diatom/clay laminations, however, can only be determined in thin sections (Francus, 1998).

In this paper, sediment cycles of Lake Baikal are analysed by magnetic susceptibility (MS) and grey scale (GS) on the cores selected for absolute dating methods over the last termination. MS is measured from polymerized and polished core blocks with a 5 mm step (~ 100 years resolution), while GS provides a higher resolution of 20 µm (<l year resolution). The grey scale was measured on the thin sections rather than on the fresh cut surface of the cores as more laminations were observed in thin sections. Both MS and GS measurements are qualitatively checked by optical microscope observations.

2. Material

We analysed three short gravity cores of 60-100 cm and three kasten cores of 200-400 cm length (Fig. 2) from selected sites by seismic survey during campaigns on Vereshchagin in 2001 (European CONTINENT project; Charlet et al., 2005-this volume). The stations correspond to elevated sub-lacustrine plateaux with minimal turbidite supply: Vydrino Shoulder and Posolsky Bank in the Southern Basin, Continent Ridge in the Northern Basin (Figs. 1 and 2). The short cores were opened in the University of Liege. The kasten cores were opened in Geo-ForschungsZentrum (GFZ, Potsdam), sampled with 1 m long U-channels. The uppermost centimetres of the short cores are characterized by an oxidized layer composed of dense clayey sediments mixed with iron oxides (Fig. 2). The kasten cores were correlated with short cores using magnetic susceptibility. Based on the sedimentation rates of the kasten cores, the short cores from Vydrino Shoulder (CON01-433-6) and Posolsky Bank (CON01-427-8) both span approximately 4 ky, and the one from Continent Ridge (CON01-416-12) 16.5 ky. The kasten cores cover a time period of approximately 12 ky for the Vydrino site (CON01-605-5), 60 ky for the Continent site (CON01-603-5), and 70 ky for the Posolsky Site (CON01-606-3). The calendar age models of the kasten cores were constructed using calibrated radiocarbon ages obtained on concentrated pollen samples (Piotrowska et al., in press). For the older part of the cores, the ages were extrapolated from mean sedimentation rates calculated by linear regression and constrained by magneto stratigraphy obtained on parallel cores (Demory et al., 2005-this volume). Note "ka" in the text and figures refers to calibrated BP ages.

Fig. 1: Map of Lake Baikal (52-56°N, 104-110°E) with location of studied coring sites of Continent cruise 2001 (data from INTAS Project 99-1669). For each site we present the calendar age model based on AMS ^{14}C dating of pollen concentrates from long cores. The values indicate the range of sedimentation rates variations (for the last 25 ka BP). For the Posolsky site, the sedimentation rates at the base of the core have been calculated by linear regression.
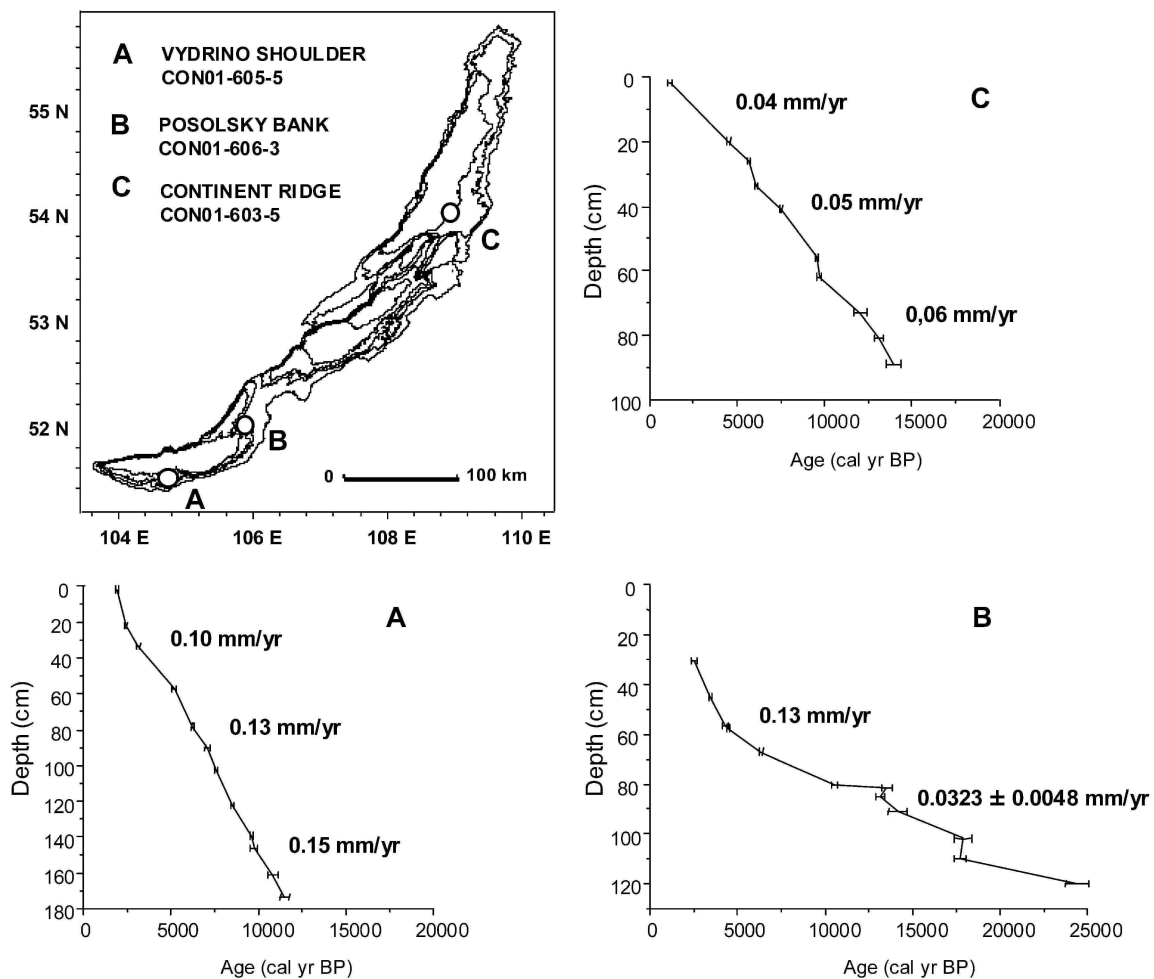
3. Method

A brief outline of core lyophilization and sediment polymerization is given below.

3.1. Cores lyophilization

The kasten cores were sampled with three to four long plastic U-channels (100 cm length x 5 cm wide x 1.5 cm deep) to cut large format thin sections (Fig. 3). The U-channels were stored in a deep-freeze to solidify the sediment, and to avoid its oxidation. The short cores were not sub-sampled and were treated within the coring tube. We used the freeze-drying method to dry the sediment cores after Pike and Kemp (1996). Sediments were frozen quickly to avoid ice crystal formation, and then the ice was sublimated under vacuum overnight. The vapour pressure above the ice was determined according to phase diagram of water, and the vapour produced was trapped into a condenser (see also Francus, 1998). As freeze-dried clays are soft and sensitive to air humidity, we treated them without delay for consolidation by impregnation-polymerization.

3.2. Sediment impregnation-polymerization

Clay saturation by resin was performed under low vacuum (900 mbar) with a rotary pump ($5m^3$ h^{-1}). We used similar apparatus as for the drying step: a vacuum chamber equipped with a condenser to trap the organic vapour (i.e. polymers and acetone, may destroy the pump). Samples were placed into the chamber within a solvent-resistant mould, and polymer resin was progressively added in, i.e. four steps. We employed Norsodyne S 2010 V (supplier: Cray Valley) or TRA (supplier: Finres group), mixed with 0.2% of catalyst (Interox), 0.1% of accelerator (Octoate Cobalt 49), and less than 10% solvent (acetone). When samples were saturated by the resin, the polymerization rate was accelerated by a final curing stage in a dry oven with a temperature below 40 °C to prevent cracking (see also Ashley 1973).

Thin sections were prepared from the blocs after standard techniques (e.g. Murphy, 1986). However, we used diamond discs (80, 250, 600) rather than silicium carbur for polishing, as they facilitate the production of large slides with an equal thickness.

3.3. Magnetic susceptibility and grey scale measurements

The magnetic susceptibility (MS) has been measured using a Bartington MS2-E point sensor with a 5 mm progression step. The MS was taken from polymerized U-channels to allow a direct comparison between MS values along the cores with observations made on thin sections.

Grey scale (GS) measurements have been done after Schaaf and Thurow (1994), and Nederbragt and Thurow (2001) methods. The GS was taken from digital TIF images of thin sections in order to capture subtle grey densities differences in the laminated intervals, which are only visible in thin sections (Fig. 4). Samples were prepared with the same resin mixture and temperature of polymerization to maintain a constant resin colour during the core treatment. Because the thickness of the thin sections has a strong influence on the final GS values, the thin sections were remade from the blocks until a thickness of 30 µm was reached. Thin sections of poor quality were not treated for grey scale measurements (e.g. at the base of core CON01-416-12). In addition, the large format thin section (140x70 mm) was preferred over standard format (90x15 mm) as the larger ones allowed a better visual control of the lateral sediment fabric. The grey scale was measured from 8-bit grey scale images (0—black; 256—white) by the ImageJ software (Rasband, W.S., ImageJ, National Institutes of Health, Bethesda, MD, USA, http://rsb.info.nih.gov/ij/, 1997-2004). For each thin section, the scan axis corresponds to approximately 5500 pixels of 20 µm each (i.e. 500 measurements per centimetre of sediment). The thin sections were digitized with a slide scanner and with a constant image acquisition in black and white mode. For tracing thin light diatom-rich layers, the grey scale axes were duplicated perpendicular to laminated sediment accumulation in the best preserved part of the material, avoiding outside disturbances (cracks, bio-turbations). The grey scale values were extracted from single pixel lines on each image and then converted to depth scale to obtain a continuous record. Then, the best line was selected according to the observation of laminations from the GS in comparison with lamination count in thin section. The blanks (256) linked to cracks were removed from the data set. The space between two consecutive thin sections (1mm) has been taken into account by a blank in the data, and represents a negligible gap compared to the numbers of measurements along the cores (approximately 200,000 for a 5 m core).

Fig. 2: *Composite log of the short cores (left side) and the kasten cores (right side) from the three coring sites of CONTINENT cruise 2001 on Lake Baikal. The log consists of compilations of black and white digital images. The light grey corresponds to clayey diatom-rich sediments, the dark grey to predominantly clayey sediments, and the black levels in the uppermost sediments indicate oxidized layers. The boxes indicate the different sediment core sections. The total core length is reported below each core. The short cores and the kasten cores were correlated using the magnetic susceptibility. The AMS C ages (right side) are given in calendar years BP. Open circles indicate the sample depth for C radiocarbon dating.*
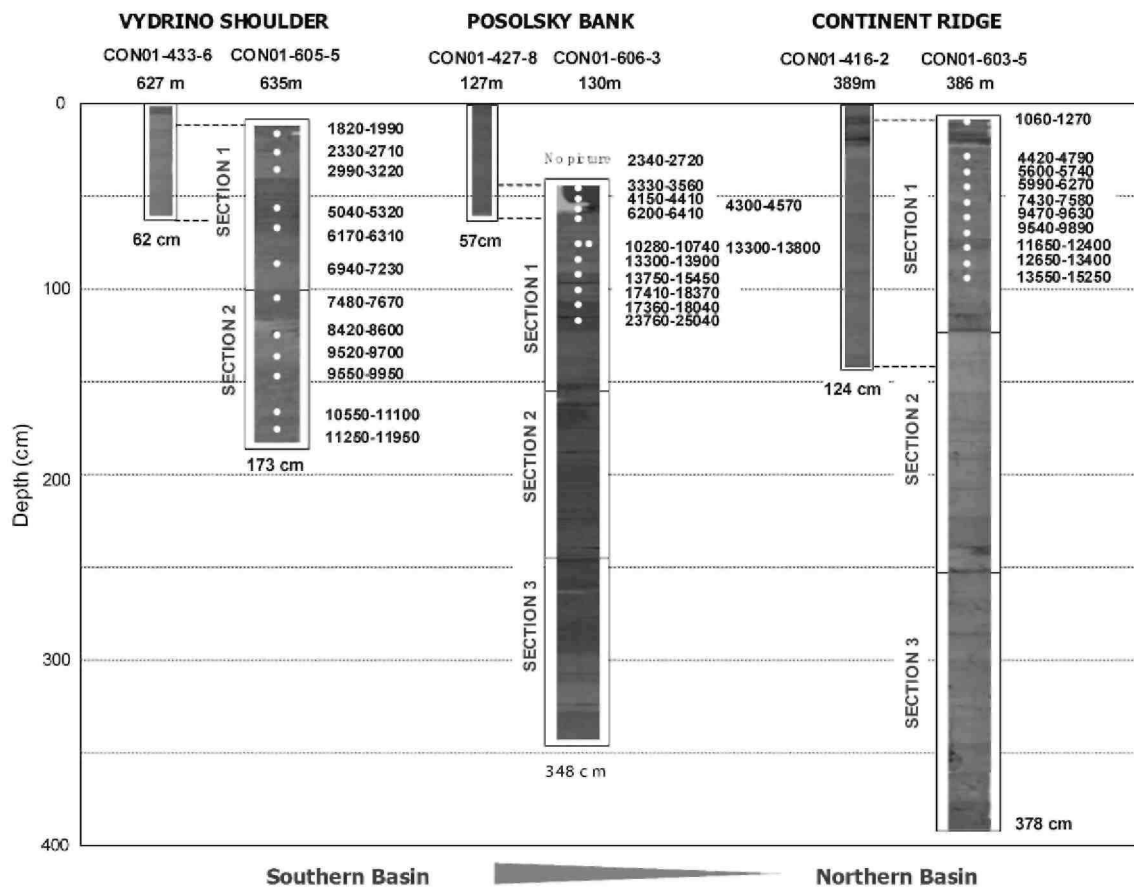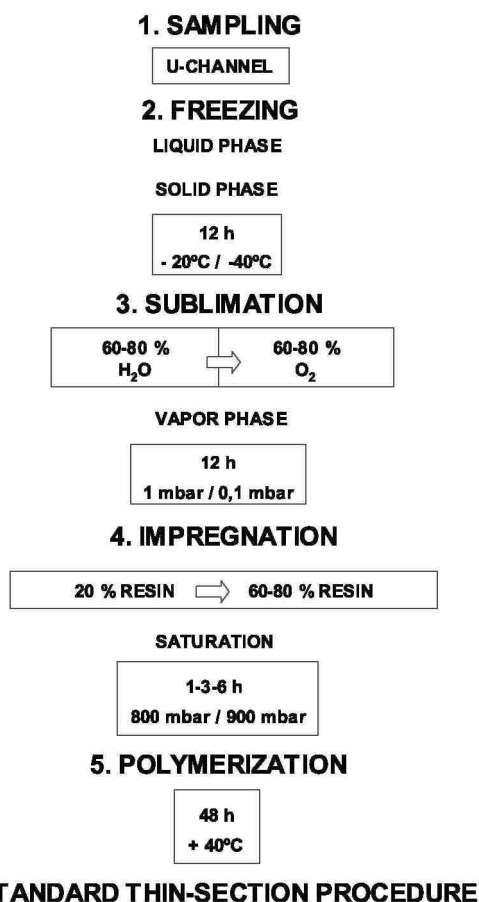
Fig. 3: *Pretreatment for long core lyophilization/polymerization and thin-section preparation of wet unconsolidated sediments. The numbers correspond to the different preparation steps.*

1. SAMPLING

> U-CHANNEL

2. FREEZING

LIQUID PHASE

SOLID PHASE

> 12 h
> - 20°C / -40°C

3. SUBLIMATION

> 60-80 % H₂O ⟹ 60-80 % O₂

VAPOR PHASE

> 12 h
> 1 mbar / 0,1 mbar

4. IMPREGNATION

> 20 % RESIN ⟹ 60-80 % RESIN

SATURATION

> 1-3-6 h
> 800 mbar / 900 mbar

5. POLYMERIZATION

> 48 h
> + 40°C

6. STANDARD THIN-SECTION PROCEDURE

4. Results

4.1. Holocene record

4.1.1. Magnetic susceptibility in short cores

In the three short cores, MS values are low and tend to decrease during the Holocene (Fig. 5). In the Vydrino core, CON01-433-6, MS varies from 25×10^{-6} S.I. at the base (62 cm; 4.8 ka) to 10×10^{-6} S.I. at the top (average values around 20×10^{-6} S.I.). In the Posolsky core, CON01-427-8, is characterized by slightly higher values (60×10^{-6} S.I. at 57 cm; 4 ka). The increasing MS values in Posolsky is more probably related to a detrital supply from the nearby Selenga River. Evolution of the MS in the Continent core, CON01-416-12, is similar to Vydrino site (average values around 20×10^{-6} S.I. during the Holocene). The higher MS values (up to $40-50 \times 10^{-6}$ S.I.) from 16.5 to 10.5 ka (120-80 cm depth) correspond to clayey sediment accumulated during the Late Glacial period. The Termination I is only recorded in the Continent short core.

Fig. 4: *Digitized image of laminated sediment in thin section from Continent Ridge site, core CON01-603-5, against GS (at 30 cm depth). On the left side, distance is represented in µm; on the right side, the estimates of years have been calculated from the mean sedimentation rates. Variations of GS are related to the alternation of distinct diatoms and clayey thin layers (50-200 µm). The high grey density values correspond to the diatom-rich layers, the low density values to the clayey sediment. The GS provides a proxy record of multi-annual variations in the diatom concentration during the Subboreal period.*
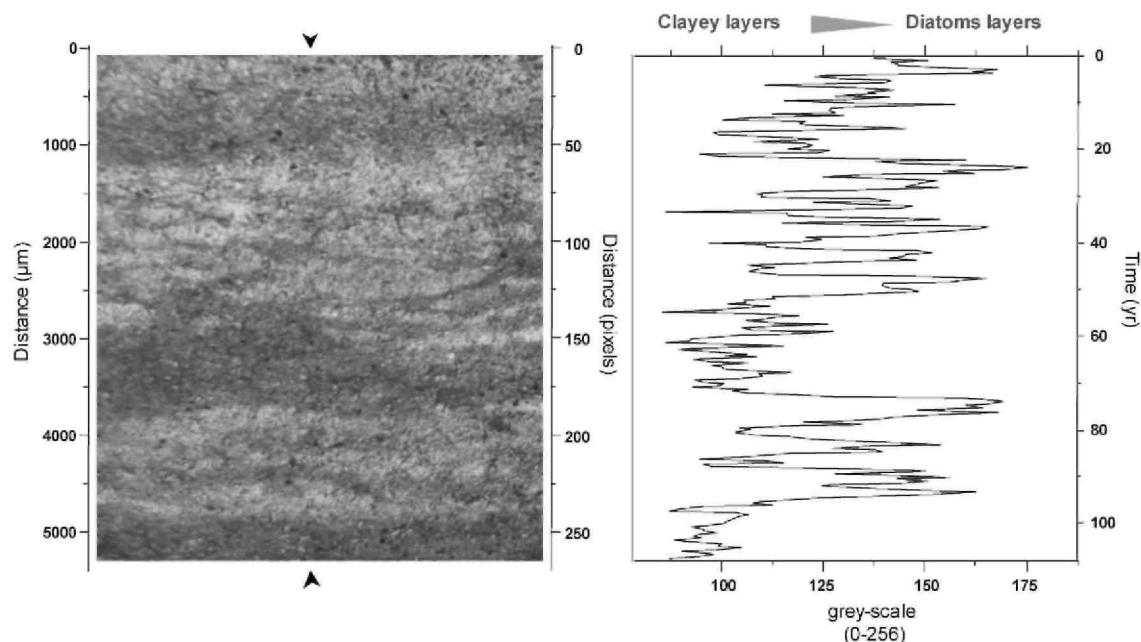
Based on thin-section qualitative observations, the low MS anomalies are concurrent with the diatom-rich sediments (Fig. 5, picture 5), whereas the MS peaks characterize the clayey intervals or oxidized layers (Fig. 5, picture 1). In addition, we were able to visually characterize the origin of some unreliable high MS peaks, which occur in the uppermost centimetres of the cores and are related to Fe sulfide phases. There is some uncertainty about the identification of the opaque minerals in micromorphology, but the structures of these phases are based on a cubic, close-packed framework typical of Fe sulfide crystal chains formed by magnetic bacteria (i.e. greigite, Fig. 5, picture 2). Other studies give evidence of a strong influence of iron sulfide, i.e. greigite rearrangement, at the top of the cores (Demory et al., 2005-this volume). As this mineral is unstable and may be reformed over a period of days to a week, this signal is not taken into account for the correlations between the cores and is removed from the MS data set. The greigite is probably responsible for high MS signals in some pyrite-rich horizons marked by bioturbation (Fig. 5, picture 2). The pyrites form a macroscopic network visible on large thin sections related to the benthic faunal activity (i.e. infilling of channels and chambers) (Fig. 5, picture 4). Low MS anomalies could be related to infilling of chambers and channels by hydrated iron phosphate (vivianite) in more bioturbated intervals (Fig. 5, picture 3).

The entire Holocene time window is globally characterized by low MS (20 x 10^{-6} S.I. on average) reflecting a higher proportion of diatoms in Lake Baikal sediments.

4.1.2. Grey scale record of the short cores

The Holocene period is globally characterized by high GS values, except for the uppermost centimetres of the cores where the oxidized layer occurs (60-40 units) (Fig. 6). In the Vydrino short core, GS increase from 120 and 170 units between 4.5 and 3.8 ka (60-50 cm depth) and decrease afterwards between 3.5 and 2.2 ka (48-25 cm depth) down to 100 units. In this core, maximum GS values are reached at 3.8 ka (52 cm depth) and 2.1 ka (18 cm depth), minimum values at 2.2 ka (25 cm depth) and 1.1 ka (7 cm depth). In the Posolsky core, sediment is characterized by higher GS values (120-170 units) between 4 and 3 ka (from 53 to 40 cm depth), and then the GS has lower values (100-50 units) upwards. In the Continent core, the highest GS ranging from 140 and 170 occur significantly at the base of the core and in two time periods, at approximately 6.5 ka (43 cm depth) and 4.5 ka (28 cm depth).

On the thin sections, the minimum GS values (40-80 units) in the uppermost centimetres of the cores are linked to clayey material mixed with iron oxides (e.g. Fig. 6, picture 1). The influence of iron oxides and sulfides is less visible in the GS than in the MS measurements, i.e. the background signal due to sulfides, because the GS line scan was taken outside the disturbances (i.e. bioturbations). The low GS values tend to occur in association with diatom poor sediments, whereas maximum values (120-180 units) represent the diatom-rich sediments when connected with low MS values (Fig. 6, pictures 2 and 3). Based on this relation, both records from the Southern Basin show an overall increase in GS values from approximately 4 ka followed by a decrease up to 3 ka (Fig. 6). In the Northern Basin, GS data from Continent site suggest a peak in diatom abundance ca. 4.5 ka, and earlier peaks ca. 6.5 and 9 ka, consistent with changes in MS, and in diatom/clay concentration as observed in thin sections (Fig. 6).

Fig. 5: *Magnetic susceptibility of the short cores with identification of background noise signal related to bioturbations filled with iron oxides and iron sulfide (i.e. greigite). The numbers are related to optical microscope images taken from large thin sections (140x70 mm). The shadow line represents the Late Glacial/Holocene transition with occurrence of more important magnetic mineral signal. (1) Black layers (iron oxides), (2) cubic close-packed framework typical of Fe sulfide crystal chains formed by magnetic bacteria (i.e. greigite), (3) bioturbation associated with hydrated iron phosphate (vivianite), (4) bioturbation associated with black spots (pyrite), and (5) biogenic silica (diatoms).*
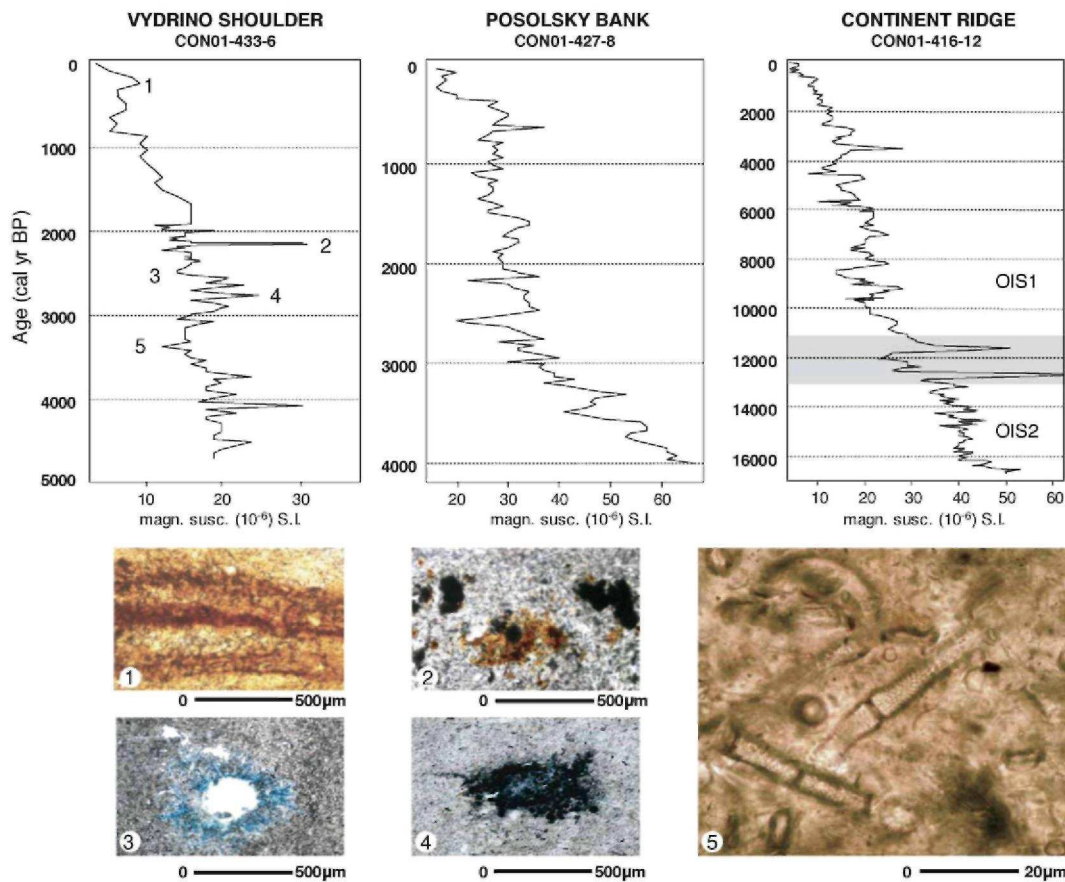
Fig. 6: *Grey density scale and magnetic susceptibility records of the short cores. Variations of GS in thin sections are mainly related to the abundance of biogenic silica (diatoms) in sediments. The high grey density values characterize the diatom-rich sediments, the low density values the clayey material. Note that in the uppermost sediments the low densities are not interpretable due to the oxidation layer. In the two cores from the Southern Basin (Vydrino and Posolsky), we observe a significant decrease trend of the GS from ca. 3.8-3.5 to 2 cal ky BP in agreement with thin-sections microscope observations. This shift corresponds to a decrease in the abundance of biogenic silica in Lake Baikal. The numbers relate to images taken from large (140x70 mm) thin sections. (1) Optical microscope view of black spots (iron oxides), (2) BSE view of clayey mud with low biogenic silica concentrations (diatoms), and (3) optical microscope view of sediment rich in biogenic silica (diatoms) around 4.8-4.5 cal ky BP.*
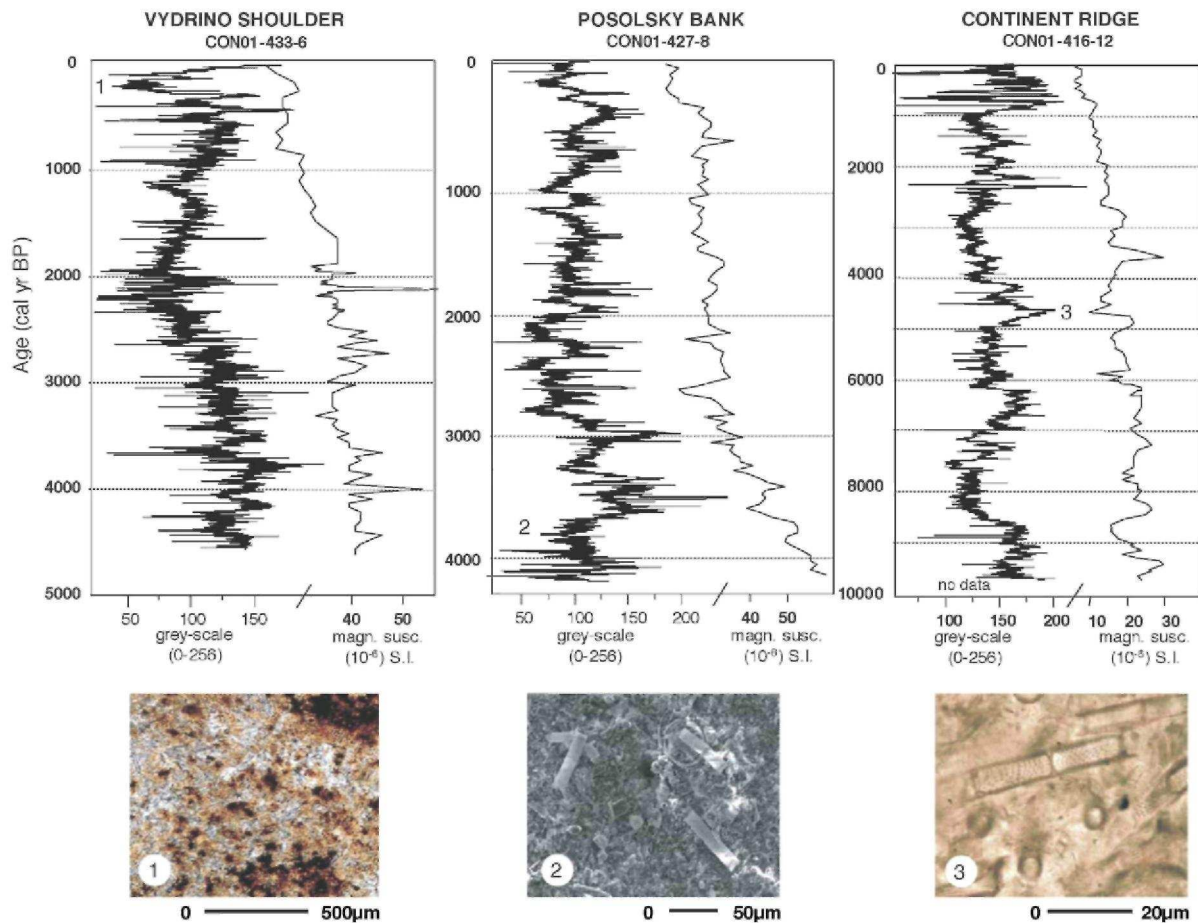

4.2. Late Glacial to Holocene record

4.2.1. Magnetic susceptibility of the hasten cores

The MS curves have been "cleaned" by removing the background signal due to greigite (three to four peaks). This has been performed by checking thin sections where highest MS peaks occur. In the Vydrino core, CON01-605-5, the MS is low (20-30×10^{-6} S.I.) throughout the core and mainly corresponds to diatom-rich sediments deposited during the Holocene (Termination I not covered, Fig. 7). In the Posolsky core, CON01-606-3, the MS curve shows a drop at 35 ka that corresponds to the Late Karginsky Interstadial correlating to MIS 3 according to Prokopenko et al. (2001b) and Swann et al., 2005-this volume. The drop is followed by a MS peak and by a progressive decrease of the MS values up to the end of Glacial Saltan (MIS 2, Prokopenko et al., 2001b). In the Continent core, CON01-603-5, the highest MS values (around 50×10^{-6} S.I.) occurs around 25 ka (120 and 100 cm depth), and the lowest values (20-30×10^{-6} S.I.) from ca. 15 ka to the present day (100 cm to the top) (Fig. 7). In the Continent core, the shift in the MS at ca. 15 ka is due to a change in detrital/biogenic supply and

underlines the boundary between OIS2 and OIS1. Based on the quality of MS record over the Termination I, the Continent site presents the best resolution, the Vydrino core ends before the Termination I, and the Posolsky Site is the most perturbed core by bioturbation processes (see Martin et al., 2005-this volume). We therefore selected the core from Continent Ridge for further high-resolution GS acquisition around Termination I.

Fig. 7: Magnetic susceptibility curves of the kasten cores versus calibrated age models (on the left side), Siberian chronostratigraphy (Karabanov et al., 1998), and (right side) SPECMAP isotopic chronology (Martinson et al., 1987). Low magnetic susceptibility values (10-20) represent interstadial epochs with more widespread biogenic lake productivity. The high magnetic susceptibility values (30-60 units) represent stadial epochs with massive clays, or more detrital supplies (60-130 units). The magnetic susceptibility record at Posolsky Bank is strongly influenced by the nearby Selenga River.
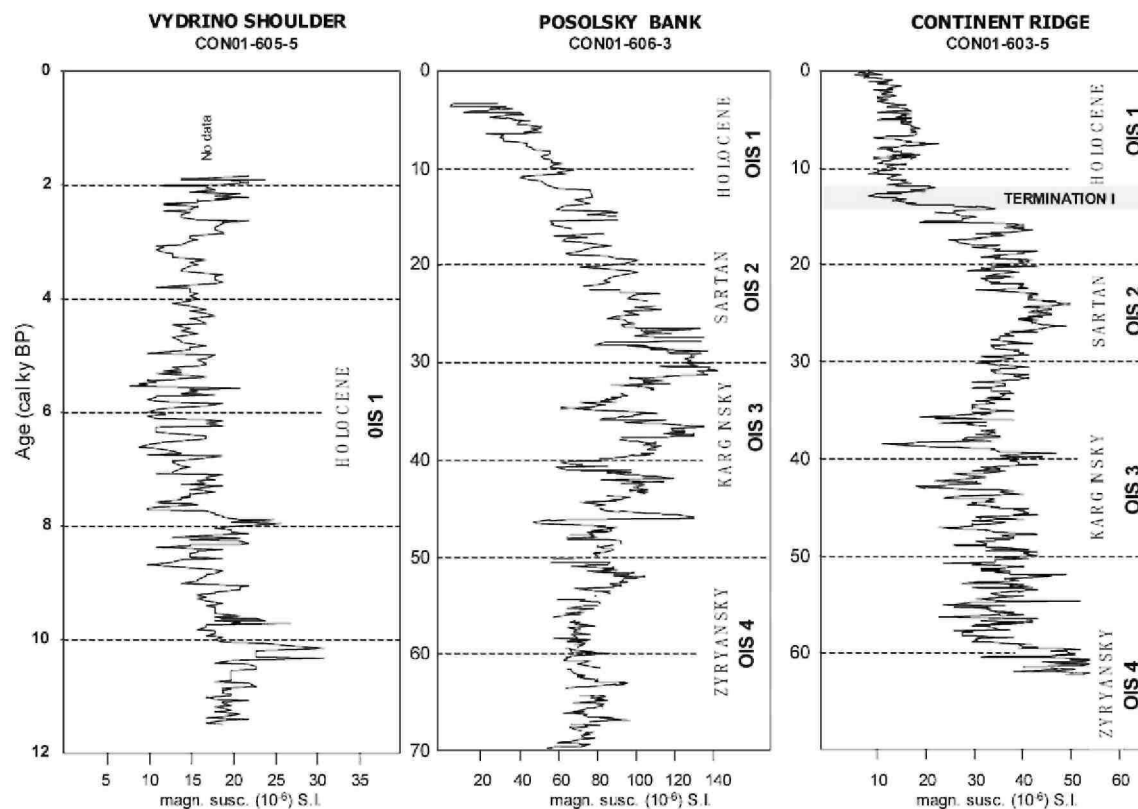
4.2.2. Grey scale record through Termination 1 in Continent Ridge

The GS from the Continent Ridge core, CON01-603-5, is presented against the MS, and the GISP 2 ice core $\delta^{18}O$ temperature proxy record (Stuiver et al., 1995) and the Eurasian pollen stratigraphy scale (Velichko et al., 2002—Fig. 8). From ca. 16 to 15 ka, GS ranges around 100-120 units (Last Glacial (LG), Oldest Dryas (OstD)), and then slowly increases up to a maximum value of 160 units in the youngest diatom-rich sediment at ca. 15.3 ka (Bölling (BO)). From ca. 15.3 to 14.2 ka (Older Dryas (OD)), GS values shift from 120 to 80 units in agreement with a lower diatom abundance as determined qualitatively in thin section. The Alleröd (AL, ca. 14 ka) is characterized by a peak of highest GS values. From ca. 13.8 to 13.2 ka, the GS values are lower (120 units) and correspond to the Intra Alleröd Cold Period (IACP) of GISP 2. Around 12.7 ka (Younger Dryas), the GS quickly drops from 110 to 80. The Preboreal/ Boreal (BO) periods (12.4-9 ka) are not visible in the data set, with GS values ranging between 90 and 110 units. From ca. 9 to 6 ka (Atlantic (AT)), the GS curve oscillates between 90 to 140 units with maximum values at around 8 ka. The Subboreal (SB) interval (6-2.5 ka) is marked by two important variations in GS with the highest GS values at ca. 6 and 4.5 ka. Note that thin sections contain evidence for laminations during the Subboreal interval: laminations consist of alternating dark clayey and light diatom-rich laminations (of a few microns). High GS peaks are reached at the beginning of the Subatlantic (SA) at ca. 3 ka. From ca. 2.5 ka to the present, GS values slowly decrease from 150 to 70 units. Minimum GS is reached in the oxidized layer at the top of the core and correlates with the dark iron-manganese oxide layers as shown in Fig. 5.

Fig. 8: Grey scale and magnetic susceptibility records of Continent Ridge for Late Glacial, Termination I, and the Holocene interval over the temperature GISP-2 proxy record. The two records are represented according to their own chronology in calendar years. Lake Baikal record is matched to GISP2 record according to GS criteria. The high GS values indicate the main increase in biogenic silica accumulation in Lake Baikal sediments. Based on the evolution over the Younger Dryas, we observe the same trends with a lag of ca. 500 years between GISP 2 and Baikal records. The lag could be either due to age model adjustment of different environments or real time response like proposed by Prokopenko et al. (1999). The high values are observed during the Bölling (BO), Alleröd (AL), Atlantic (AT), Subboreal (SB), and Subatlantic (SA) optima. The Oldest Dryas (OstD), Old Dryas (OD), and Younger Dryas (YD) are characterized by very low GS values (clayey material) lasting approximately 400 years. Since the Subatlantic optimum, the accumulation of biogenic silica decreases up to the present day. On the central part of the diagrams, we indicate the Siberian chronozones derived from European palynological records (Velichko et al., 2002). The transition between isotopic stages 1 and 2 is deduced from oxygen isotope stratigraphy from Atlantic sediments (Martinson et al., 1987). The ages are given in cal years BP.
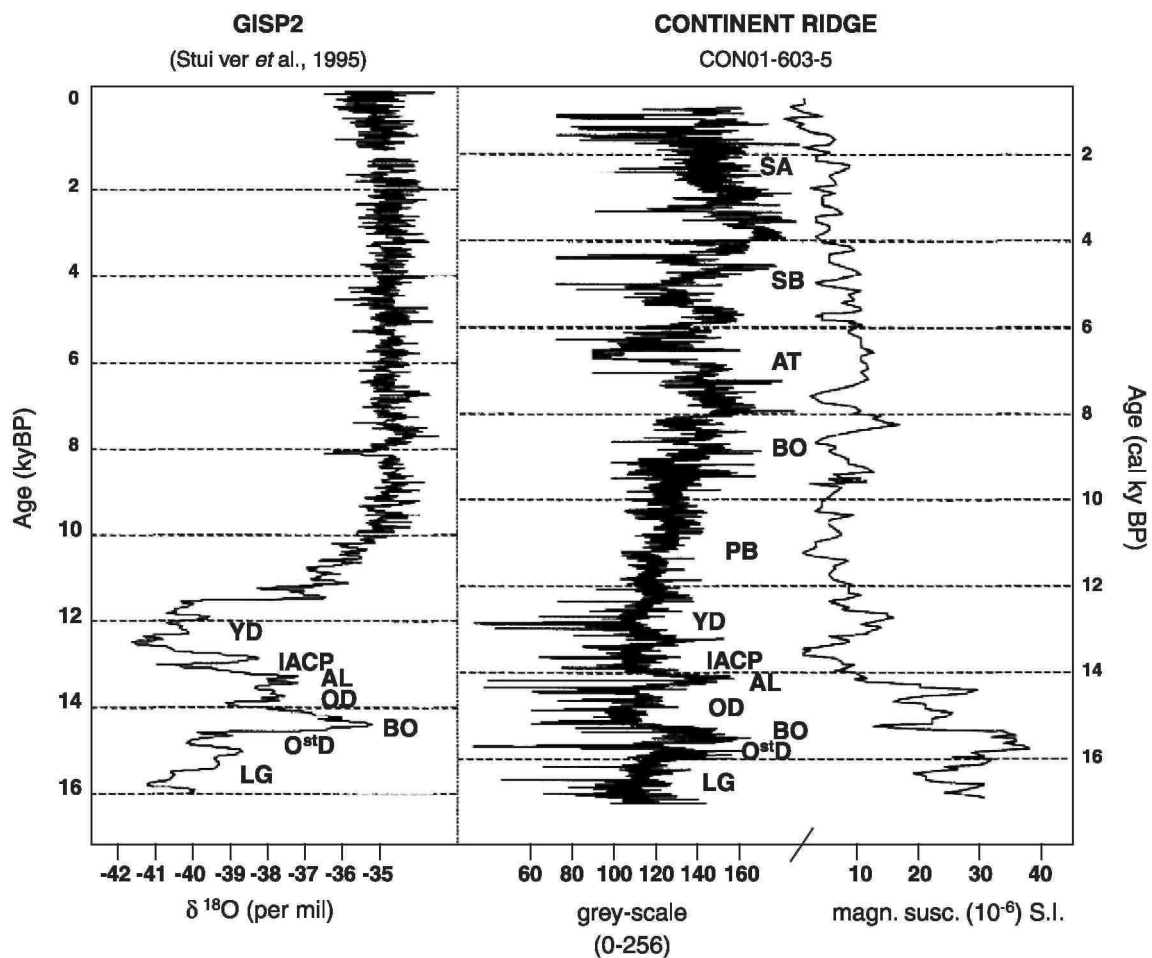
5. Discussion

GS measurement is a rapid method to derive a very-high-resolution data sets from core material, and has been successfully applied to marine sediments (Schaaf and Thurow, 1994; Nederbragt and Thurow, 2001). In Lake Baikal we apply this approach but using thin sections, that is, to our knowledge, the first time in environmental studies. Based on qualitative observations on thin sections, we interpret the GS record as an estimation of the clay/diatom ratio changes over Termination 1.

5.1. The OIS3/OIS2 transition

Mortlock and Froelich (1989) demonstrated that diatom abundance increased and reached maximum values for the OIS3 interval during the middle of the Karginsky Interstadial. This interpretation is in agreement with the lowest MS values in the core CON01-606-3, from Posolsky Bank between 35 and 30 ka (Fig. 7). Our results are consistent with the occurrence in the Karginsky Interstadial of several cold episodes in combination with high frequency fluctuations in diatoms (e.g. in BDP-93-2 core, Prokopenko et al. 2001b). The MS curve is also in good agreement with short cooling episode (i.e. Late Karginsky) as emphasized by Prokopenko et al. (2001a,b), and also with interpretation of pronounced diatom signal during OIS3 (Prokopenko et al., 2001c; Swann et al., 2005-this volume).

5.2. The Glacial Sartan (OIS2)

In Lake Baikal area, the transition to the colder Glacial stage (Sartan 25-22 ka) is characterized by a weak development of vegetation and soil layers. According to Karabanov et al. (1998), this trend during Siberian Glaciation is responsible for the increased turbidity condition (Horiuchi et al., 2000), and also for the occurrence of massive clay units in the lake, which corresponds to the increase in the MS signal in cores CON01-606-3 and CON01-603-5. The reduced solar radiation in the Northern Hemisphere (Berger and Loutre, 1991) could also explain prevailing low biogenic lake productivity at this time, which would have further accentuated the MS signal.

5.3. Termination I (OIS2/OIS1)

After the Sartan Glacial period, the deglaciation is denoted by increased diatom production, while soils became more developed in the watershed area (Horiuchi et al., 2000). A regional transition from a glacial to a post-glacial epoch (Termination 1) occurred at ca. 15 ka (Peck et al., 1994), which coincides with an increased summer insolation in the Northern Hemisphere (Berger and Loutre, 1991). Indeed, the change at ca. 15 ka corresponds to the onset of wet and warmer conditions associated with abrupt increase in precipitation and strong winds in Siberia, which in turn may have promoted deep mixing and nutrient regeneration in the lake (Bradbury et al., 1994; Chebykin et al., 2002). In the Continent core, CON01-603-5, the evolution of MS signal correlates well with the interpretation of the onset of the warming at ca. 15 ka (Fig. 7). The warming hypothesis is further supported by high grey level values that is interpreted to be representative of increased biogenic silica content over that of the occurrence of quartz grains, which also may produce high GS values. This interpretation seems to be also indicated by the MS results in Posolsky Bank which shows a continuous decrease of the detrital supply (Fig. 7). In Continent, the Younger Dryas (ca. 12.7 ka) is characterized by massive clays and low GS values and high MS (Fig. 8). According to Scholz and Hutchinson (2000), the limited influx of nutrients from alpine glacial melt waters are responsible for low lake productivity and strong oligotrophy during this period. This probably explains why GS values range around 50-100 units during the YD (i.e. decline of diatom accumulation). The visual control on thin sections confirms that the diatoms are less abundant at this level while it is less obviously demonstrated by the MS.

5.4. The Holocene (OIS1)

The early Holocene period is characterized by progressively increasing GS values since the end of the Boreal which coincides with an increase in Lake Baikal productivity (Karabanov et al., 2003). This coincides with GS interpretation of the Continent core, CON01-603-5 (Fig. 8). During this period, the influx of terrestrial debris into the Northern Basin declined (Horiuchi et al., 2000), which probably explains why the OIS2/OIS1 transition is better characterized by the GS curve in the Continent core than in Posolsky (Fig. 8). The Preboreal/Boreal periods are not significantly marked by variations of lake productivity as deduced from the GS curve.

The beginning of Atlantic period is marked by warmer condition which is accompanied by maximum aquatic production and forest expansion with extensive development of soil layers and lake productivity coincident with increased insolation (Berger and Loutre, 1991). With the development of the aquatic ecosystem, biogenic silica and organic carbon production increase significantly. This probably explains why GS values present more amplitudes during the Atlantic climate period (9-6 ka), in association with a warmer climate, increased terrestrial influx, and a more important mixing and nutrient renewal in the water column. The GS tends to demonstrate that the Atlantic period is marked by an increase in diatom content at 8 and 6 ka that mirrors the retreat of mountain glaciers which occurred at about 9.5 ka (Horiuchi et al., 2000). Nevertheless, it is important to note that according to Popovskaya (2000), a diatom increase in Lake Baikal may be accompanied by a picoplankton decrease. Therefore an increase in GS suggests an increase in diatoms, but not necessarily in productivity. The

Subboreal (6-3 ka) period is contrasted and characterized by alternating high to low GS values, corresponding to variations in diatom content. According to the literature, the Subboreal appears to be the warmest period of the Holocene in Lake Baikal, and is characterized by the highest diatom abundance (Williams and Jenkins, 1993; Carter and Colman, 1994; Bradbury et al., 1994). This is seemingly contradictory with the general Holocene climatic trend shown for Northern Eurasia and West Siberia (Khotinsky, 1984, 1989). According to our results, the Subboreal period appears to be a contrasting period with strong variations in diatom/ clay accumulation. According to published results by Karabanov et al. (1999), the highest peak of diatoms abundance is observable close to the Subboreal/ Subatlantic transition. GS results from the Continent core, CON01-603-5, show a strong influence of the biogenic silica in the sediment material during the Subboreal, at ca. 4 and 3 ka (Fig. 8).

In Lake Baikal sediments, the last ~2 ka are characterized by the lowest diatoms sedimentation rates (Qiu et al., 1993) related to enhanced recycling and regeneration of silica and low sedimentation rates (Scholz and Hutchinson, 2000). However, at the Continent site, we could not climatically interpret this time window with the GS due to the oxidized layer background noise.

Although the link between the grey scale values with the light produced by different monospecific diatoms layers (e.g. *Aulacoseira baicalensis*, *Synedra acus*) is not yet clearly understood, as well as the influence of diatom concentration on the grey scale record, our data gives evidence of decadal/centennial fluctuations of diatoms/clay ratio. While we are still investigating the relationship between the laminations and seasonal activity of the lake, it is important to note that the atmospheric changes that followed the deglaciation will have had an important impact on the air temperature and on the ice and snow cover on the lake (Livingstone, 1999). For example, Shimaraev et al. (1992) suggest that the period of no ice cover on the lake during the Sartanian glaciation (equivalent to the last glacial maximum) was approximately 60 days shorter than the present day. This is important when one considers that the snow and ice cover constitutes a significant factor that controls diatom composition and population growth in the lake (Mackay et al., 2003; 2005-this volume), in spite of secondary processes such as diatom dissolution (Battarbee et al., 2005-this issue; Ryves et al., 2003).

6. Conclusion

The core polymerization technique allows fast and high quality polishing of cut surfaces of cores that enhances the observation of laminations. The measurement of the grey scale (GS) on thin sections considerably increases the measurement resolution of the laminated feature but requires very good quality thin-section cover of the cores under study. To the best of our knowledge, this is the first time this approach is applied on core thin-section cover. After a visual control and background noise correction due to bioturbation and mineral neoformation (i.e. rearrangement of pyrite and greigite), we interpret the GS curves as a proxy for lake paleoproductivity. The Continent core gives the best resolution over Termination I, with a 20 µm resolution (i.e. approximating to an annual resolution). The minimum GS values are associated overall with the accumulation of massive clays (cold phases) and maximum values to diatom-rich sediments (wetter and warmer climates). For the last 18 ky, our results indicate an increase in diatom productivity at ca. 14.8 ka (i.e. Bölling), 14 ka (Alleröd), 8 ka (Atlantic), 6 ka (Atlantic/Subboreal transition), 4.5 ka (Subboreal), 4 ka (Subboreal/Subatlantic transition), and 3 ka (Subatlantic). Our results also suggest a lag of ~500 years with GISP 2 and that the Alleröd optimum was shorter that the Bölling (approximately 200 years compared to 400 years). In the Continent core, we note that the onset of wet and warming conditions occurs at ca. 15 ka, before Termination I. Several cold phases are recorded, the most important being at ca. 15.5 ka (Oldest Dryas), 14.5 ka (Older Dryas), 13.5 ka (Intra Alleröd Cold Period), and 12.7 ka (Younger Dryas). Successive cold episodes are observed during the Atlantic and Subboreal periods in the laminated sediment interval and should be further examined. Indeed, in this interval, grey scale acquisition indicates for the first time thin, multi-annual diatom-rich laminations in Lake Baikal sediments.

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