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Invited review article

Magnetostratigraphy of the Lake Baikal sediments: A unique record of 8.4 Ma of continuous sedimentation in the continental environment

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ABSTRACT

Lake Baikal sedimentary records in general and magnetostratigraphy in particular have already enormously contributed in the global context to evaluate environmental and climatic changes in the deep continental setting. The Baikal Drilling Project (BDP) has become a world leader in pioneering recovery of extremely long (several hundred meters) lacustrine sediment sequences from deep water. This has made it possible, for the first time, to obtain a continental archive with the same chronostratigraphic integrity as marine records to address critical questions of the last eight million years. It explains why the amount of publications on Lake Baikal sedimentary and magnetic records can be compared to the number of papers for the Oceanic Drilling Program.

The unique continuity of the Lake Baikal deep drilled cores — short piston cores and deep drilled cores — of 1993, 1996, and 1998 enables one to reconstruct reliably the geomagnetic polarity chrons and a number of the shorter geomagnetic events. Data from three very long cores allows a comparison to the geomagnetic polarity time scale (GPTS) and detailed records of geomagnetic events in the last 8.4 Ma. A refined age model, supported by ^{10}Be dates, provides constraints for the short geomagnetic events. Some geomagnetic events are correlated with geomagnetic excursions already discussed in the literature; others are identified for the first time and may need future confirmation.

1. Introduction

Lake Baikal is the largest lake in the world in terms of water volume. It contains 20% of the fresh surface water on Earth (23,615 km^3) with water depths up to 1642 m in the deepest part and a sedimentary infill up to 9 km. The lake occupies the central part of the largest tectonically active rift system in Eurasia, the Baikal rift (Ten Brink and Taylor, 2002). The Baikal rift system consists of a series of fault-bounded basins stretched along a ~1800 km S-W–N-E belt that frames the south-eastern margin of the Siberian craton (Logachev, 2003). The structure of the zone results from several stages of compression and extension that have affected the region from Early Paleozoic to Mesozoic times (Delvaux et al., 1995). After the final closure of the Mongol-Okhotsk Ocean in the Late Jurassic to Early Cretaceous (Kravchinsky et al., 2002), a period of relative tectonic dormancy existed from Cretaceous to Paleogene Periods (Kuzmin et al., 2010). After the Late Oligocene, the Baikal rift system reactivated forming a number of individual rift basins along the rift zone, including the south, central, and north Lake Baikal basins (Fig. 1). Smaller rift basins outside of the lake have developed north and south of Lake Baikal, mainly in E–W oriented deformation sectors defined by strike-slip faulting (Mats et al., 2000).

On the basis of the onshore geology analysis around the lake – including deep boreholes – and of multichannel reflection seismic profiles on the lake, it is generally assumed that Cenozoic rifting started by slow subsidence of the south and central Baikal basins sometime in the Late Oligocene (~30 Ma), and of the north Baikal basin in the Late Miocene (~8 Ma) (Logatchev and Florensov, 1978; Mats et al., 2000). For > 20 Ma, a series or lacustrine and fluvial sediments up to 4–5 km thick accumulated in slowly subsiding basins surrounded by subdued highlands. This period is referred to as the early rifting stage (Mats et al., 2000). From the Late Pliocene (~3.5 Ma) onward, a strong acceleration in basin subsidence and flank uplift took place. This late rifting stage resulted in an additional sedimentary infill of > 4 km, a Lake Baikal water depth of > 1 km, and flank uplifts of 1–2 km. Ongoing present day rift deformation is testified by numerous seismic events annually (Déverchère et al., 2001) and by a GPS-derived mean rate of extension of about 4 mm/yr (Calais et al., 2003).

Academician Ridge is a high ridge that separates two of Lake Baikal's three basins, the Central and North basins (Baikal Drilling Project group, 2000) (Fig. 1). The ridge is a submerged asymmetrical horst bounded by the Ushkan fault in the northwest and by the Olkhon fault in the southeast; the ridge rises for 500 m above the lake bottom in the northwest and is over 1000 m above the lake bottom in the southeast. The water depth over the ridge varies from 300 to 350 m.

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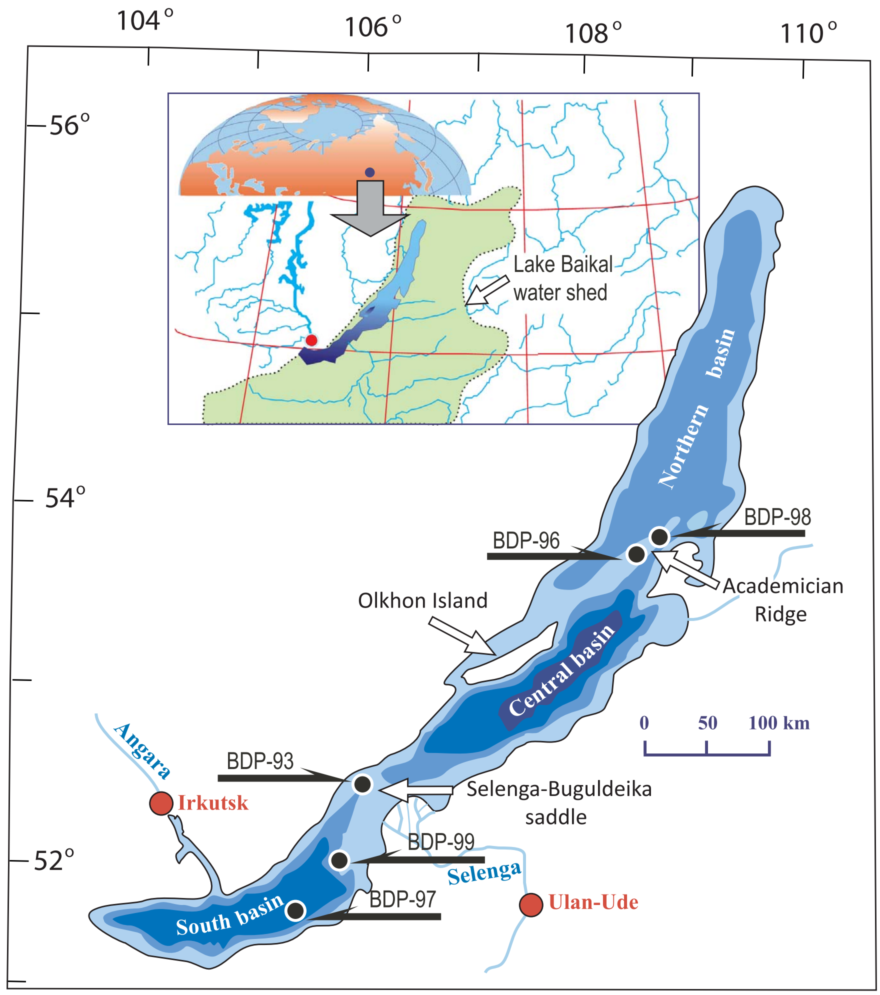

Fig. 1. Geographic position and bathimetric map of lake Baikal. Isobath interval is 500 m, and core sites are numbered. The location of the drilled sites in Lake Baikal is shown. (Modified from Kravchinsky et al. (2003).)

Table 1
Baikal Drilling Project borehole locations.

Borehole	Geographical location	Latitude, N	Longitude, E	Water depth (m)	Borehole depth/core length (m)
BDP-93	Buguldeyka isthmus	52°31′05″	106°09′11″	354	102/100
BDP-96-1	Academician Ridge	53°41′48″	108°21′06″	331/333	302/200
BDP-96-2	Academician Ridge	53°41′48″	108°21′06″	331/333	100/100
BDP-97	South basin	51°47′50″	105°29′13	1436	225/225
BDP-98	Academician Ridge	53°44′48″	108°24′34″	337	674/600
BDP-99	Posolsk Bank	52°05′23″	105°50′24″	201	350/350

Academician Ridge represents a unique sedimentary setting. The north and central basins of Lake Baikal, with depths of 900 m and 1600 m, respectively, isolate the ridge from coarse sediment input and turbidites. The Academician Ridge location is restricted to fine, continuous hemipelagic sedimentation with some coarse-grained particles deposited by ice rafting (Kuzmin et al., 2000); wind-blown sediments were also suggested to play some role in the deposition (Peck et al., 1994). Multichannel seismic profiling reveals two major seismic units in the section (Hutchinson et al., 1992; Mats et al., 2000; Colman et al., 2003). The upper unit is finely laminated and was deposited in relatively steady lacustrine conditions, whereas the lower unit contains wedge-like features indicating deposition in the river delta (Baikal Drilling Project group, 2000). Only the upper unit, which includes seismic boundaries B6–B10, was drilled and is discussed in this study.

The prolonged formation of the Lake Baikal sedimentary infill makes it possible to build a protracted magnetostratigraphic scale for the deposit of lake sediments. Although the drainage basin was glaciated during its geological past, the lake itself was never covered by permanent ice, so sedimentary input provides continues record of geomagnetic events (Peck et al., 1996; Kravchinsky et al., 2003; Prokopenko et al., 2006). Paleomagnetic investigations of Lake Baikal sediments were initiated and published in the 1970s and 1980s (Kravchinsky and Mats, 1982). This pioneering study demonstrates the feasibility of the paleomagnetic method to evaluate the age of shore sediments and deep bottom short piston cores, although little attention has been paid to the lake shore outcrops by the research community. The main purpose of the Kravchinsky and Mats (1982) study was to build a proper age model for the Pliocene and Pleistocene outcrops and to correlate them in order to shed light on the large and still undeveloped potential of the coastal geological sections for future magnetostratigraphic and geological studies. Presently, all of the magnetostratigraphy correlations on the shore need to be reevaluated. Step-wise detailed demagnetizations were not a standard procedure in the 1970s, therefore, the primary character of the magnetization is still in question.

Since the beginning of 1990s, large scale coring has been undertaken as a result of cooperation between Russian, American, Japanese,