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Late Quaternary Sedimentation History of the Lena Delta

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ABSTRACT. The Lena River draining to the Siberian Arctic is considered to be the main sediment source for the Laptev Sea. Nevertheless, the delta of the Lena River occupying an area of 28,000 km² is a poorly studied and very complicated region of Land-Ocean-Interactions in the Arctic. To understand the sedimentation and environmental history of the Lena delta different geological and geophysical approaches were applied. To identify sedimentary and permafrost structures within the Lena delta sampling of sedimentary sequences by shallow coring and through natural exposures, ground penetrating radar and shallow seismic studies have been carried out. Age determinations are based on radiocarbon and OSL dating.
Mineralogy and geochemistry of the sediments show that the Late Quaternary conditions of accumulation and deposition in the Delta area are of purely fluvial nature and any marine ingression can be excluded. A radio-echo sound (RES) system proved to be a valuable technique for mapping subsurface structures on land and lake sediments. The 100 MHz radar signal penetrated the permafrost down to 80 m at maximum showing periglacial features like ice wedges and ice layers. Seismic surveys complemented lake sediment profiling to characterize the geometry of basin fills, changes in lake sedimentation, and to identify the permafrost table below talik zones. Sediment drilling is used to verify the geophysical profiling.

KEY WORDS: Lena Delta, permafrost, Late Quaternary environment, fluvial sediments, lake sediments, Arctic Siberia.

Introduction

Studies of Arctic delta processes, delta morphology and facies development are relatively limited compared to the extensive literature on low-latitude deltas. Whereas the development on all deltas is governed by the interaction of sediment supply, the stability of the receiving basin and wave and tide processes, an additional primary factor in Arctic delta settings like the Lena Delta is the influence of climate, i.e. ice. The effects of ice are reflected in the sedimentary facies of the delta on sediment processes at the river mouth. Patterned ground formed by thermal contraction and present in sediments original as ice wedges or preserved as small, v-shaped sand wedges provides the most direct sedimentological indicator of the arctic climate and is widely spread in the Lena Delta plain. However, winter ice and permafrost also govern the stratigraphic development of interchannel and channel-mouth deposits. Ice cover confines flow at primary channel mouths, promoting the bypassing of sediments across the delta front during peak discharge in spring. Permafrost minimizes consolidation subsidence and accommodation near the shore, further enhancing sediment bypass. Storms limit the seaward extent of bar development and promote a distinctive pattern of upstream and lateral island growth. And despite a low tidal range and relatively low wave conditions, the Lena Delta is not prograding seaward but rather is undergoing transgressiv shoreface erosion (Rachold et al., in press). During the last two decades scientists studied geomorphology, cryolithology, hydrology, paleogeography, tectonics, permafrost, the greenhouse gas flux, Quaternary geology etc. in the area (Korotaev, 1986; Galabala, 1987; Kunitsky, 1989; Grigoriev, 1993; Fukuda, 1993; Alabyan, 1995; Rachold, 1996; Are, 1999). But although the Lena Delta is the main connection between interfering continental and marine processes within the Laptev Sea the sedimentation history of the Lena Delta, its importance as a fossil accumulation area, age relations between the main fluvial terraces, as well as the processes that control the lateral extension, are poorly understood.

Methods and material studied

According to Grigoriev (1993) the Lena Delta area can be subdivided into three major geomorphological terraces. While the main part of the eastern Lena Delta is assumed to be an actual "active" delta (first terrace) the western part consists of mainly sandy deposits (Arga Island, second terrace) and Ice Complexes (ice-rich silty peat accumulations, third terrace) of different age and origin (Rachold et al., 1999). Sedimentation and permafrost conditions in the western and in the eastern part reflect different phases of fluvial deposition depending on climatic, tectonic and/or glacial controls during the Holocene and the Late Pleistocene. Geological sampling and geophysical surveys have been conducted both on land and on lakes at representative sedimentation sites in the delta area (Fig. 1). To identify sedimentary and permafrost structures within the Lena delta sampling on land was done by permafrost drilling to recover

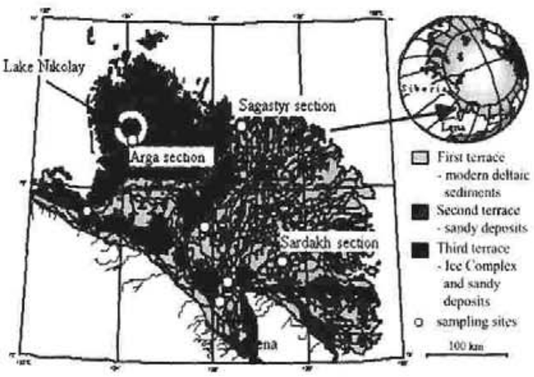

Fig. 1. Geomorphological overview and sampling sites of the Lena Delta. Locations described in the text are highlighted by name.

Arga section	^{14}C AMS ages
m below surface	
(active layer) 0.60	-825 +/-25BP
3.20	56510 +4250/-2760BP

Arga section	OSL ages
m below surface	
1.25	13100 ±1100BP
1.75	12000 ±1100BP
2.50	13300 ±1500BP
3.90	13400 ±1100BP

Tab. 1. ^{14}C-AMS and OSL ages of sandy deposits of the second terrace (Arga Island), western Lena Delta.

frozen sediment cores, through natural exposures, and by applying radio-echo sounding (RES) completed by theodolite surveys. On lakes studies of sedimentary sequences have been carried out by shallow seismic, RES measurements and lake sediment drilling. Age determinations of the deposits are based on radiocarbon and OSL dating. For a detailed description about sedimentological, geochemical, hydrochemical, and geophysical methods applied on the sediments see Schwamborn (in press).

Results and discussion

In the easternmost part of the delta, where modern sedimentation is taking place (first terrace deposits), samples of thawed natural exposures and frozen flood plain deposits (max. depth 9.25 m) were retrieved. The alluvial facies of the sediments changes from peaty sands at the bottom to silty-sandy peats towards the surface (highest TC content: 18 weight%). Grain size distribution and sorting of sedimentary sequences at Sardakh in the delta plain

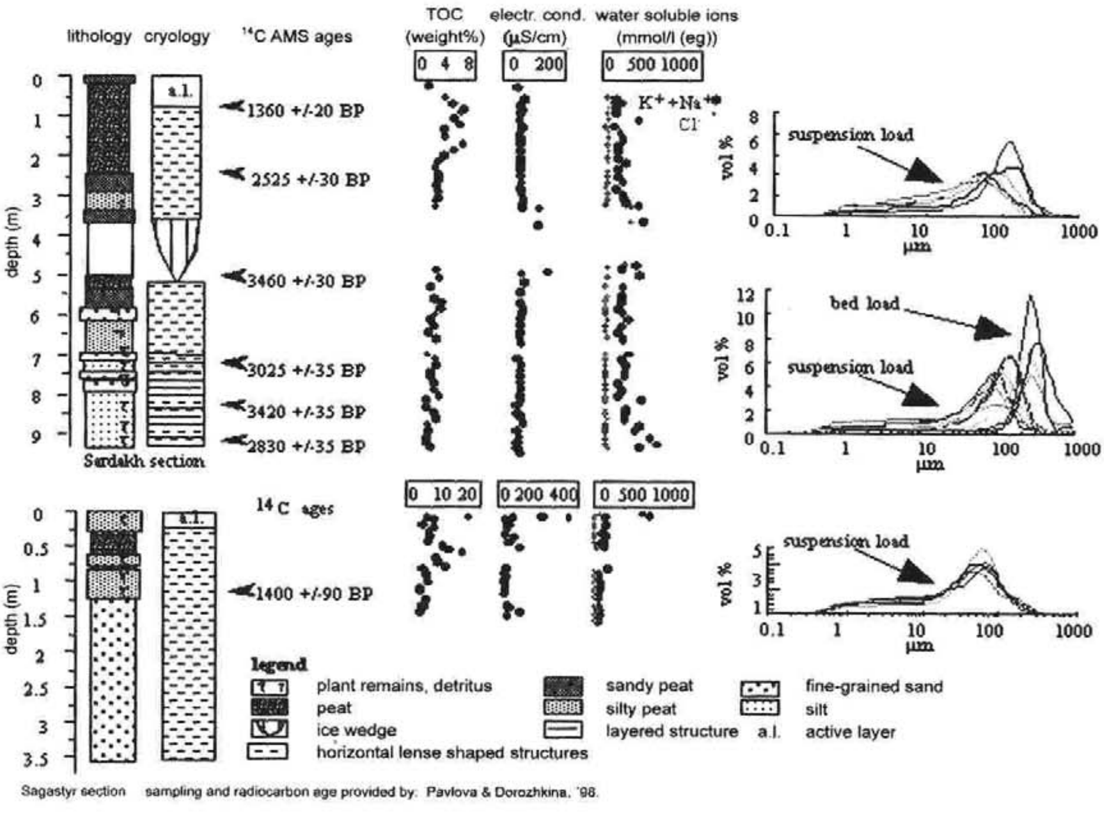

Fig. 2. Sediment profiles of Sardakh and Sagastyr sections (first terrace) and analytical results.

and Sagastyr at the delta rim indicate the general development from river bedload to suspension load bedding towards the top. The hydrochemistry of the permafrost shows low overall electrical conductivity and documents that Holocene conditions of accumulation and deposition are controlled merely by fluvial processes and apart from marine aerosols (i.e. $K^+ + Na^+$, Cl^-) on top of the Sagastyr section any marine influence on modern delta sedimentation can be excluded. Based on ^{14}C-AMS radiocarbon dating a late Holocene origin of the deposits (< 3500 years BP) could be determined. Inversions of age determinations indicate that the fluvial sediments are highly reworked (Fig. 2).

The same sedimentological investigations were performed on samples collected from sandy sections of the western Lena Delta representing the second fluvial terrace (Arga Island). The outcrop conditions show a sedimentary nature indicating pure bedload sedimentation. The sandy sediments in a section of about 4 m are horizontally bedded in a mm-cm scale and have a good sorting in the fine sand fraction. This has been confirmed by laser particle sizing. Electrical conductivity as a measure of total anion and cation content of the pore water remains unconspicuous (47 µS/cm) which supports a fluvial origin of the deposits. According to OSL and ^{14}C-AMS age determinations, which have been conducted for the first time in the area, the deposits have a Late Pleistocene age (14,500 to 10,900 years BP). The high accumulation rate is associated with a fluvial environment under upper flow regime (Table 1). Since the ^{14}C-AMS value for 3.20 m below the surface is deduced from detrital material it proved to be not reliable for dating the deposition time. The ^{14}C-AMS age of the active layer shows modern contamination. The surface sediments here are object to eolian transport, a fact that can be observed in the area at various wind originated deposits.

Geophysical investigations carried out by a radio-echo sound (RES) system suggest that the fluvial layering continues at least down to about 80 m. This was the maximum penetration depth of the electro-magnetic waves (Schwamborn, in press). For the upper 20 to 40 m the RES records indicate that the sediments are deformed by ice wedge growth of Holocene age as deduced from measurements of the $\delta^{18}O$ value of the stable isotope fraction in the ice (Meyer, pers. comm. 2000).

In order to understand the origin and ages of the numerous lakes, that are part of the sandy second terrace of the western Lena Delta, lake sediment profiling has been carried out at Lake Nikolay, the largest lake in the Lena Delta. The lake sediments have been surveyed with a sediment echo sounder for high resolution shallow seismic records (1.5–11.5 kHz). It was possible to characterize the geometry of basin fills, thickness, and changes of lake sedimentation as well as to identify the permafrost table below the talik zone (Schwamborn, 1999). Lake sediments have been drilled in a length of 3.3 m. The upper 0.9 m consist of organic rich, silty sand (max. TC content: 3.9 weight%) and can be regarded as the original lake sedimentation. The lower 2.4 m consist of pure fine sand that is comparable to the sandy area around the lake (Fig. 3). This material is regarded to have been slided into the lake basin when the lake depression was created. ^{14}C-AMS datings reveal in a correct depth to time function an age of about 7090 years BP for Lake Nikolay. This calculates for a low sedimentation rate of 12.8 cm per 1000 years. The beginning of lake sedimentation coincides with the onset of the regional Holocene climatic optimum (MacDonald et al., 2000) which may have resulted in thermokarst processes promoting lake development in the sandy environment. The oldest ^{14}C-AMS age (12,480 ± 60 years BP) dates material below the lake sediments. This sediment is regarded to represent the old surface before the onset of the lake development. The value matches well with the OSL ages measured for the Arga section as described above.

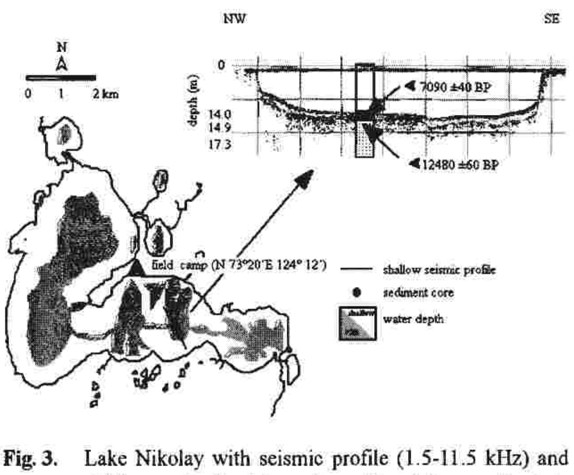

Fig. 3. Lake Nikolay with seismic profile (1.5-11.5 kHz) and drilling results. For lake sediment description see the text.

Conclusions

The Lena Delta is located in an area where there are controversial hypotheses upon the extent of the late Weichselian aged ice sheet. One view favours a panarctic ice glaciation covering the entire Arctic margin of the continent and explaining the lake occurrence in the Lena Delta (i.e Lake Nikolay) as glacier erosion forms connected with glacial furrows (Grosswald, 1998). The other side regards the deposits in western Lena Delta to be local outwash plains derived from local snow glaciers in the Chekanovsky ridges south of the Lena Delta (Galabala, 1997). In contrast, our research shows that the lake depressions (i.e. Lake Nikolay) are of typical thermokarst type which is still being active. To proceed in this debate provenance studies for the Pre-Holocene aged sediments of western Lena Delta locations using the heavy mineral fraction are in progress. This includes those sites which have not been mentioned in this paper expressively.

Acknowledgements

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An Arid Event at the Younger Dryas Time Window in the NE Tibet - Qinghai Plateau: Evidence from Qinghai Lake

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ABSTRACT. A multi-proxy approach was applied to the study of two sediment cores extracted from two subbasins centers of the large closed-basin Qinghai Lake. Results suggest that before the abrupt onset of a warm and wetter climatic regime of the early-Holocene, an arid event occurred around 10,700–10,000 ^{14}C years BP. A decrease in catchment inflow due probably to a reduction of rainfall marked the beginning of the arid period. Enhanced summer evaporation may also be responsible for the formation of a nearly desiccated carbonate playa in the entire lake. The arid event at Qinghai Lake is interpreted as a Younger Dryas equivalent although a return to cold conditions is not evident. Abrupt changes in hydro-climatic conditions across the late glacial-to-Holocene transition in Qinghai Lake may reflect oscillations in monsoon moist to the NE Tibet-Qinghai Plateau.

KEY WORDS: Qinghai Lake, Tibet-Qinghai Plateau, sediment cores, Younger Dryas arid event, carbonate stratigraphy.

Introduction

Younger Dryas (YD) climatic reversal, originally recognized about century ago in paleoclimatic records from northwest Europe, is for now still a subject of scientific interest, including its causes and geographic distribution. To have better understanding on the subject may help us to improve our knowledge on how various components of the biosphere, atmosphere, ocean, and cryosphere interact on short time scales. In the past decade, investigations on paleoclimatic records in China relevant to this scientific issue have been carried out. The investigated proxy records include those from lake sediment cores (Kelts et al., 1989; Lister et al., 1991; Gasse et al., 1991; Gasse and van Campo, 1994; Yu and Kelts, 2000), ice cores (Thompson et al., 1989; Thompson et al., 1997), loess and paleosol sections (An et al., 1991; Zhou et al., 1993), as well as marine cores (Kudrass et al., 1991). A consistent explanation on the climate conditions at the YD time window from these studies is however elusive. This paper presents results from investigation on two sediment cores from subbasin centres in Qinghai Lake to examine paleoclimatic conditions at the YD time window on the NE Tibet-Qinghai Plateau.

Qinghai Lake lies on the northeast corner of Tibet-Qinghai Plateau at an elevation of 3193.7 m a.s.l. It has a size of about 4600 km^2 and a maximum depth of 26.5 m, the largest water body now in China. The lake today is at the outer margin of the