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Rapid Communication

Huge Ice-age lakes in Russia

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ABSTRACT: During an early phase of the Last Ice Age (Weichselian, Valdaian), about 90 000 yr ago, an ice sheet formed over the shallow Barents and Kara seas. The ice front advanced on to mainland Russia and blocked the north-flowing rivers (Yenissei, Ob, Pechora, Dvina and others) that supply most of the freshwater to the Arctic Ocean. The result was that large ice-dammed lakes were formed between the ice sheet in the north and the continental water divides to the south. Here we present reconstructions and calculations of the areas and volumes of these lakes. The lake on the West Siberian Plain was nearly twice as large as the largest lake on Earth today. The well-mapped Lake Komi in northeast Europe and a postulated lake in the White Sea Basin would also rank before the present-day third largest lake. The lakes overflowed towards the south and thus the drainage of much of the Eurasian continent was reversed. The result was a major change in the water balance on the continent, decreased freshwater supply to the Arctic Ocean, and increased freshwater flow to the Aral, Caspian, Black and Baltic seas. A sudden outburst of the lakes' water to the Arctic Ocean when the ice sheet thinned is postulated. Copyright © 2001 John Wiley & Sons, Ltd.

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KEYWORDS: northern Russia; Siberia; Arctic Ocean; Caspian Sea; ice-dammed lakes; Early Weichselian; Barents Ice Sheet; Kara Ice Sheet.

Introduction

The idea that an ice sheet centred over the Barents and Kara seas dammed large lakes in northern Russia and thus diverted the continental drainage, dates back to the 1970s (Kvasov, 1979; Grosswald, 1980), but the extent and age of these ice sheets and lakes have been controversial. Until recently it was commonly thought that large ice-dammed lakes flooded the lowlands of northern Russia during the Last Glacial Maximum (LGM) about 20 ka (Grosswald, 1998). However, extensive recent investigations have shown that the LGM Barents–Kara Ice Sheet did not reach far enough south to impound these rivers (Forman *et al.*, 1999; Svendsen *et al.*, 1999; Gataullin *et al.*, 2001). Only during more extensive (and thus older) glaciations were these rivers blocked and diverted to the south.

Lake Komi, northeast Europe

Shorelines from an ice-dammed lake, named Lake Komi (Plate 1), have been mapped using aerial photographs for hundreds of kilometres in the Pechora Lowland, although the shorelines are far from being continuous (Astakhov *et al.*, 1999). Their elevation ranges from 90 m a.s.l. in the south to 110 m in the north, reflecting a larger glacio-isostatic depression near the ice margin than farther south. Around the city of Usinsk, where the shoreline deposits are exploited for construction purposes, sand pits show typical beach and shoreface sedimentary facies (Mangerud *et al.*, 2001). Numerous radiocarbon dates from deposits post-dating the shoreline have yielded ages in the range 25–40 ka, showing that the lake is older (Mangerud *et al.*, 1999). We have obtained 28 optically stimulated luminescence (OSL) dates on shoreline sand from various sites. Within the range of one standard deviation, 21 samples yielded ages 80–100 ka, the mean being 90 ka (Mangerud *et al.*, 2001). Lake Komi is thus correlated with marine oxygen isotope stage 5b and the Rederstall Stadial of western Europe. Detailed investigation of Lake Komi, based on fieldwork every summer since 1993 (Astakhov *et al.*, 1999; Mangerud *et al.*, 1999; 2001) forms the basis for this study. It is surprising that 90 000-year-old

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shorelines are so well preserved on the surface. This apparently is not the case to the east and west of the Pechora Lowland, where lakes are reconstructed mainly from extrapolation of the Lake Komi results. These areas have not been examined in the field in this study.

Lake in the White Sea Basin

The Timan Ridge forms a barrier between the Pechora Lowland and the White Sea Basin. Older sediments in most of the White Sea Basin have been obliterated by an advance of the Scandinavian Ice Sheet during the LGM (Larsen *et al.*, 1999)(Plate 1). However, shorelines of Lake Komi can be traced on aerial photographs along a low pass through the Timan Ridge into the White Sea Basin, which implies that a counterpart of Lake Komi existed there (Astakhov *et al.*, 1999). The most likely outlet of Lake Komi is identified as the outlet of this western counterpart across the water divide between the White Sea and the Baltic Sea basins, well inside the LGM ice-sheet limit (Maslenikova and Mangerud, 2001). Glaciolacustrine sediments in similar chronostratigraphical positions as the Lake Komi sediments have been described at various sites west of the Timan Ridge (Devyatova and Loseva, 1964; Houmark-Nielsen *et al.*, 2001). However, these authors postulated that only small ice-dammed lakes of this age existed, either because an ice sheet filled most of the White Sea Basin (Devyatova and Loseva, 1964), or because the ice sheet was limited to the eastern part and did not block the entire basin (Houmark-Nielsen *et al.*, 2001). We propose that Lake Komi extended through the mentioned pass into a corresponding lake in the White Sea Basin, and we have calculated an area and volume (Table 1) assuming that the Barents–Kara Ice Sheet blocked the neck of the White Sea and did not expand farther south. This assumed ice limit results in a calculated lake area and volume that may be at the high end.

Table 1 Areas and volumes of lakes. Areas and volumes of the ice-dammed lakes in Eurasia and of the Aral and Caspian seas as estimated in this paper. For comparison are included corresponding numbers for the largest ice-dammed lake in North America, Lake Agassiz (Leverington *et al.*, 2000; Teller *et al.*, in press) and for the three largest lakes on Earth today (Herdendorf, 1984).

	Lake level (m a.s.l.)	Area (10^3 km^2)	Volume (10^3 km^3)
Ice-dammed lakes, Eurasia:			
Lake Komi	90–110	76	2.4
Lake in White Sea Basin	100	218	15
Lake on West Siberian Plain	60	613	15
Sum Eurasian ice-dammed lakes		907	32.4
Increase of Aral and Caspian seas:			
Aral Sea, between 53 and 57 m a.s.l.	57	17	0.4
Caspian Sea, between −28 and +26 m a.s.l.	26	424	34
Caspian Sea, between −28 m and 0 m	0	259	15
Ice-dammed Lake Agassiz:			
Upper Campbell level, 9.9–9.5 ka		263	23
Herman level, 11.5–11 ka		134	11
Lake Agassiz merged with Lake Ojibway		841	163
Largest lakes on Earth today:			
Caspian Sea		374	78
Lake Superior		82	12
Lake Victoria		68	2.7

Lake on the West Siberian Plain and in the Aral Sea Basin

To the east of the Pechora Lowland the ice margin that formed Lake Komi is mapped around the northern tip of the Ural Mountains (Astakhov *et al.*, 1999; Mangerud *et al.*, 2001), which separates the West Siberian Plain from the Pechora Lowland (Plate 1). The ice margin can be traced by end moraines and other marginal features across the West Siberian Plain to the foothills of the Putorana Plateau on the east bank of the Yennissei River (Eurasian Ice Sheet Project Members, 2001) and farther eastwards to the Taimyr Peninsula, where it again is dated (Alexanderson *et al.*, 2001). Even though there are some uncertainties in the position of this limit, the ice front must have blocked the entire West Siberian drainage basin at this time. In this area old shorelines or lake sediments are much more difficult to discover because of a subdued topography and a thick cover of loess and other younger sediments. An exception is the Yenissei River valley where glaciolacustrine sediments 30–40 m thick are mapped at about 60 m a.s.l. for hundreds of kilometres (Astakhov and Isayeva, 1988). Radiocarbon dates show these sediments to be older than 50 ka (Kind, 1974). Glaciolacustrine sediments are also known along the lower Ob River, close to the Polar Urals, where a shoreline has been detected in aerial photographs along the 60 m a.s.l. contour. No OSL or other finite dates exist from such sediments in the West Siberian Plain, but based on their stratigraphical position and geographical extent, it is likely that they date from an early phase of the Last Ice Age (the Weichselian).

The lowest water divide between the West Siberian Plain and the Aral Sea is the floor of the Turgay Valley, presently at 126 m a.s.l. (Plate 1). However, the valley is filled with wind-blown sand and other sediments, which are radiocarbon-dated in correct stratigraphical order from 29 ka at 75 m depth to 19 ka at 34 m and 11 ka at 4 m depth. The bedrock threshold is only 40 m a.s.l., and is covered by fluvial gravel of northern origin, reflecting an overflow directed to the south well before 29 ka (Astakhov, 1992).

The level of the Aral Sea was about 53 m a.s.l. during most of the last century. The dry Uzboy channel, presently at 57 m a.s.l., served as an outlet to the Caspian Sea as late as 5000 yr ago (Boomer *et al.*, 2000). Possibly lower passages existed in earlier times, but they were probably higher than the 40 m bedrock threshold in the Turgay Valley. Therefore the outlet of the ice-dammed lake in West Siberia probably was

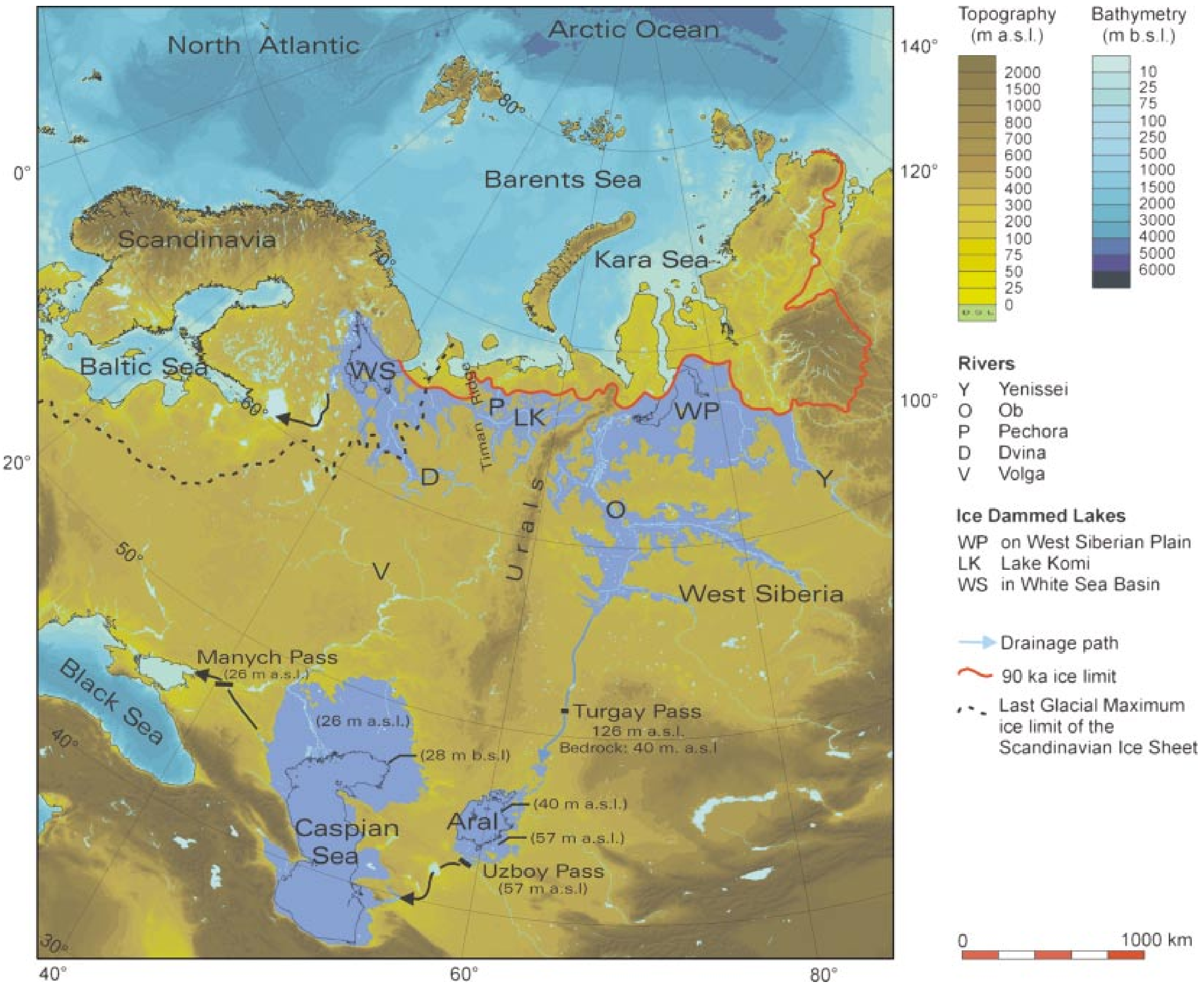

Plate 1 Reconstructed ice-dammed lakes on northern Eurasia. Three major lakes are considered—in the White Sea Basin (WS), Lake Komi (LK) and on the West Siberian Plain (WP). Also shown are the extensions of the Aral and Caspian seas when they overflowed the Uzboy Pass and the Manych Pass, 57 and 26 m a.s.l., respectively. (The Aral Sea is shown at present-day level 40 m a.s.l., not at the pre-1960 level, 53 m a.s.l. used in our calculations). The southern limit of the 90 ka Barents–Kara Ice Sheet is shown according to Eurasian Ice Sheet Project Members (2001), except in the White Sea Basin where we conclude it blocked the entrance.

from the Aral to the Caspian Sea, implying that the lake was some 3000 km long, although very narrow for a long distance between the West Siberian Plain and the Aral Sea depression (Plate 1). In Table 1 we have presented separate estimates for the water bodies on the West Siberian Plain and in the Aral Sea depression.

The Caspian Sea

An overflow from the Aral Sea should have influenced the Caspian Sea level, which is presently at −28 m. Sediments of the last major transgression (the Early Khvalyn) have yielded radiocarbon dates in the range 7–16 kyr BP and Th/U ages 6–31 ka (Svitoch and Yanina, 1997). This transgression was probably partly caused by an influx of meltwater from the last (LGM) Scandinavian Ice Sheet. The outlet was over the Manych Pass, which is now at 26 m a.s.l. in valley about 400 km long between the Caspian and Black (Azov) Sea depressions. Below the Early Khvalyn strata the Manych Valley is blocked by 35 m of periglacial loess, fan-alluvial and limnic silts (Popov, 1983). The loess is TL dated in the range 28–80 ka (Svitoch and Yanina, 1997). The top of the underlying marine formation is located below sea-level and shows a westward migration of brackish Caspian fauna. These latter strata are interpreted either as a regressive series of the Late Khazar (Eemian) Sea (Svitoch *et al.*, 1998) or as sediments of a separate Girkan transgression of Early Weichselian age (Popov, 1983). This highstand may have resulted from the proglacial drainage system discussed above. Our calculations (Table 1) provide two alternatives; one is an increase from the present −28 m lake-level to the 0 m level and the other to the +26 m level.

Area and volume estimates

For estimating the areas and volumes (Table 1) of the lakes discussed we have used a digital elevation model (GLOBE Task Team, 1999) combined with an Arctic Ocean bathymetric grid model (Jakobsson *et al.*, 2000a). The combined data set was re-projected to Lambert's Equal Area projection before the calculations were carried out. This means that we have filled up the lakes to the estimated lake surface level and calculated the areas and volumes based on the present-day surface topography. Thus we neglect erosion and deposition after the lakes disappeared, which we consider to be a minor source of error.

If we use the present river discharge (Gordeev *et al.*, 1996) (Table 2), the lakes on the West Siberian Plain and the Pechora Lowland would have been filled in less than 20 yr, and the one in the White Sea Basin in less than 50 yr. Ice-age climate was much drier than the present, but the lakes were also fed by meltwater from the ice sheet north of the present drainage area. It therefore seems likely that they were filled within a few hundred years.

Environmental implications

A comparison of the ice-dammed lakes in Eurasia with the largest lakes on Earth today and with two phases of the largest ice-dammed lake in North America, Lake Agassiz (Leverington *et al.*, 2000) (Fig. 1 and Table 1) may give some hints as to their environmental impact. The Upper Campbell level represents the largest phase of Lake Agassiz and the Herman beach level represents the lake that catastrophically emptied into the North Atlantic about 11 ka. Modelling and empirical data indicate that this latter re-routing influenced the oceanography of the North Atlantic (Licciardi *et al.*, 1999), and it is even suggested that it caused the Younger Dryas climatic event (Broecker *et al.*, 1989). Lake Agassiz also had a regional climatic impact on the surrounding areas (Hostetler *et al.*, 2000). As seen from Table 1, the areas of the reconstructed lakes in Eurasia were several times larger than Lake Agassiz during these phases. The volumes were also larger, but the difference was not as large because the lakes in Eurasia were much shallower than Lake Agassiz. During its last phase Lake Agassiz merged with Lake Ojibway and formed an even larger lake (Table 1) (Teller, personal communication, 2001, Teller *et al.*, in press). The impact of the Eurasian lakes is still unknown, and will certainly be more difficult to clarify as the lakes are so much older than Lake Agassiz.

Table 2 Russian rivers draining into the Arctic Ocean, according to Gordeev *et al.* (1996)

	Area (10^3 km^2)	Annual discharge (km^3)
Dvina	357	110
Pechora	324	131
Total to the Barents Sea	1386	463
Ob	2545	429
Yenissei	2594	620
Total to the Kara Sea	6589	1478
Total from Eurasia to the Arctic Ocean	13 054	2960

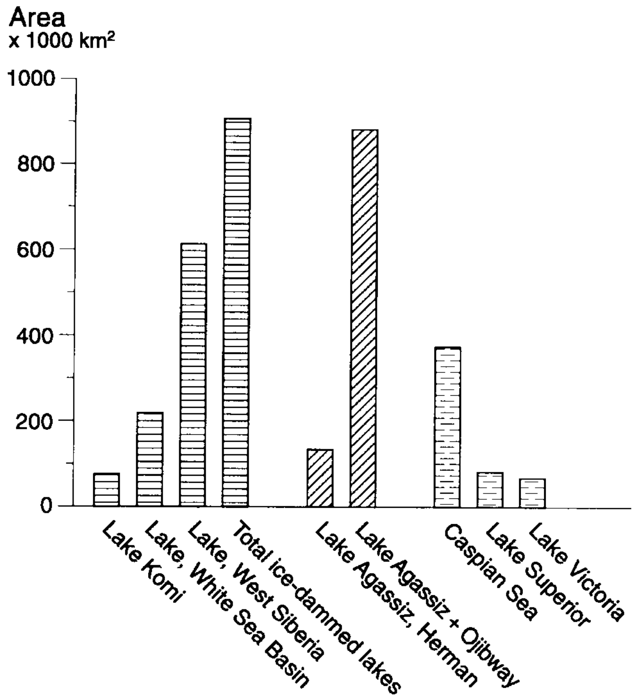

Figure 1 The area of the ice-dammed lakes in northern Russia compared with stages of the ice-dammed Lake Agassiz in North America and the three largest lakes on Earth today

In recent models even a small change in the freshwater budget of the Arctic Ocean is important for global climate simulations (Rahmstorf and Ganopolsky, 1999). It is also a robust feature of most climate models that the climate responds to changes in the freshwater influx to the North Atlantic (Stocker and Marchal, 2001). We assume that a sudden outburst of freshwater from the ice-dammed lakes influenced sea-ice formation, climate and oceanic circulation in the Arctic Ocean and thereby also large areas beyond this ocean. The lack of well-dated sediment cores from the Arctic Ocean makes a search for evidence of the damming and subsequent outbursts difficult. However, manganese content and sediment colour in sediment cores from the central Arctic Ocean suggest large-scale variations in freshwater supply and ocean ventilation during glacial–interglacial cycles (Jakobsson *et al.*, 2000b). A damming of the major rivers in European Russia and West Siberia would enhance the difference in manganese content between glacial–interglacial sediments by shutting off a major part of the manganese source for the Arctic Ocean.

Interestingly, this experiment of nature was a larger version of the damming and reversal of the north-flowing rivers that was planned by the Soviet Union in order to irrigate the dry southern steppes. This plan was heavily criticised by natural scientists both in the Soviet Union and in the west, owing to its possible impact on the Arctic Ocean and the global climate (Semter, 1984; Cattle, 1985).

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