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Subglacial sediment, proglacial lake-level and topographic controls on ice extent and lobe geometries during the Last Glacial Maximum in NW Russia

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ABSTRACT

Investigations in sections along the rivers Severnaya Dvina and Vaga, and morphological mapping based on a new digital elevation model and Landsat imagery, allow for a reinterpretation of the extent of the Scandinavian Ice Sheet during the Last Glacial Maximum (LGM). The reconstruction provides a much better link between stratigraphical and morphological expression of glaciation than previous proposals. Most striking is the configuration of long, low-gradient ice-lobes (ice-streams) extending for some 300–400 km up the wide and smooth river valleys. Their extremely low surface gradients are evidenced by glacial trimlines that formed along the sides of the ice-lobes in contact with the gentle valley slopes. In the main valleys, end moraines marking terminal positions are present, whereas drumlins are rare in the peripheral areas of the ice sheet but found in some tributary valleys at somewhat higher elevations. Large drumlin fields, however, are found farther up-ice. The glacial sediment succession is composed of waterlain sediments and tills. The sediments provide evidence of distal ice damming, glacier overriding and retreat, and finally distally glaciolacustrine sedimentation and lake drainage. The diamicton unit associated with the LGM shows evidence of basal coupling, although more striking is the abundant evidence for ice–bed decoupling. These include *in situ* waterlain sediments within tills, and clastic sills running along the till/substrate contact showing lift-off. These features indicate that the weight of the glacier lobes was, to a large extent, carried by pore-water pressure in subglacial sediments, and that subglacial shear and erosion were moderate. Thus, fast ice flow in the lobes is envisaged. The balance between glacier weight and pore-water pressure was probably maintained over time by the buoyancy effect of glaciers advancing into proglacial lakes. Subglacial lakes may have formed by capture of proglacial lakes during glacial advance. The combination of low-gradient ice and decoupled beds indicate that glacier advance and extent was largely controlled by lake levels and topographic thresholds. This is taken to indicate that steeper-gradient ice much farther upstream was providing the gravitational push. A presumably abrupt change in ice-surface profile is supported by the mapped distribution of glacial bedforms. The model presented herein potentially has wide applicability for large parts of northern Russia as the topographic setting and glacier advance in lakes across fine-grained low-permeable sediments provide very similar conditions.

1. Introduction

During recent years there has been substantial progress in understanding the Weichselian ice-sheet history of northern Russia (e.g. Svendsen et al., 2004; Larsen et al., 2006a) and associated ice-dammed lakes (e.g. Mangerud et al., 2004; Lyså et al., 2011).

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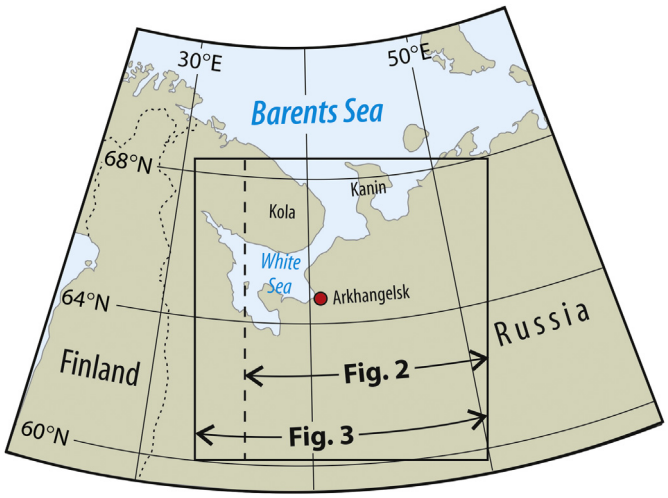

Fig. 1. Map showing the study area. Areas covered by Figs. 2 and 3 are framed.

Despite this, there are still unsolved issues in terms of glacial and lake history. Even reconstructions of ice-sheet distribution and their proglacial lakes belonging to the Last Glacial Maximum (LGM), from which there is relatively good stratigraphical and morphological control, are hampered with uncertainty. In the Arkhangelsk region of NW Russia (Fig. 1), this is expressed as widely different interpretations of the LGM extent of the ice sheet (e.g. Krasnov, 1974; Larsen et al., 1999; Lavrov and Potapenko, 2005; Demidov et al., 2006). The conflicting ice-sheet interpretations (Fig. 2) reflect the complexity of such reconstructions in a very low-relief landscape. Moreover, glaciers advanced and retreated in huge proglacial lakes (Kvasov, 1979; Astakhov, 2004, 2006; Mangerud et al., 2004; Svendsen et al., 2004; Larsen et al., 2006a; Lyså et al., 2011) leaving behind subdued morphological expressions of their ice-marginal positions. This paper is based on detailed studies of proglacial and subglacial sediments deposited in the ice-marginal lakes and linking these with new morphological evidence of the ice-sheet extent.

The study area is south of the city of Arkhangelsk where lobes of the Scandinavian Ice Sheet (SIS) occupied the wide valleys of the rivers Dvina and Vaga, damming large proglacial lakes during the last glaciation (Fig. 2). The bedrock is composed of sedimentary rocks, mainly Palaeozoic sandstones, siltstones and limestones

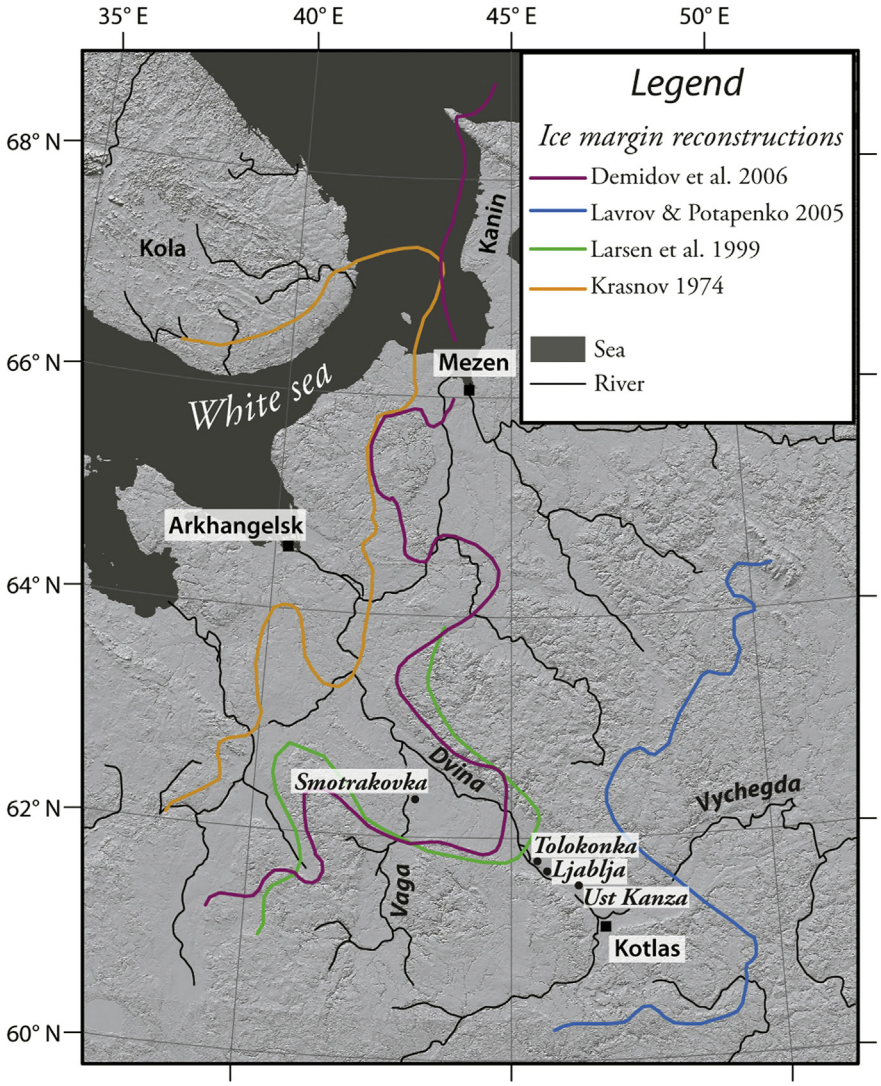

Fig. 2. Map showing locations of the four river sections described in the text, and their locations relative to four different published reconstructions of the LGM ice-marginal positions of the Scandinavian Ice Sheet.