Geomorphology 295 (2017) 662–679

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Rise and fall of a small ice-dammed lake - Role of deglaciation processes and morphology

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ARTICLE INFO

Article history:
Received 10 January 2017
Received in revised form 17 July 2017
Accepted 6 August 2017
Available online 9 August 2017

Keywords:
Svalbard
Nordenskiöldbreen
Gilbert delta
Stacking pattern
Glacier dam retreat
Basin floor morphology
Fluvio-deltaic terraces

ABSTRACT

A small ice-dammed lake, which developed along the margin of Nordenskiöldbreen on the northern coast of Adolfbukta, (central Spitsbergen, Svalbard) has been studied by a combination of facies analysis, ground penetrating radar, analysis of photos and satellite imagery, and by surface mapping by Unmanned Aerial Vehicle (drone). The lake existed between the years 1990–2012 and occupied two partial depressions in the bedrock, separated by a bedrock ridge for the dominant period of its history. Whereas the eastern depression was almost completely infilled due to direct fluvial input, the western depression revealed only thin sedimentary cover and was dotted from the eastern depression by an outflow of surficial waters. Gilbert delta deposits with typical tripartite zones of topset, foreset and bottomset were recognised in the eastern depression. Topset was comprised by deposits of a braided river. Foreset is formed by deposits of sediment gravity flows (turbidity currents and debris flows). Bottomset is represented by alternating suspension deposits and deposits of hyperpycnal underflows (low-density turbidity currents). The ruling factors of the evolution of the delta were glacier retreat, bedrock morphology, both affecting the relative lake level, and the rate of sediment delivery. Glacier retreat over stepped and inclined bedrock morphology led to delta prograding and downstepping. The recognised fluvio-deltaic terraces revealed four lake level falls followed by fluvial downcutting, erosion and redeposition of the older deltaic/lake deposits, the shifting of the lake's position towards the damming glacier and the transition of the sediment input in the same direction. The termination of the lake was a result of further glacier retreat and the opening of subglacial drainage.

1. Introduction

Landscape and environmental changes of the glacial realm are commonly well recorded in the deposits of glacial lakes. Special attention has been devoted to the deposits of ice-dammed lakes because of catastrophic floods (Knight, 2003; Russell, 2007, 2009), effects of meltwater release on subglacial (Shaw, 2002) and proglacial environments (Magilligan et al., 2002), or spectacular ice-dam failures (Teller, 1995; Fisher et al., 2002). The presence and drainage of subglacial and proglacial lakes also have wider implications for terrestrial ice sheet stability, and marine processes including thermohaline circulation (Clark et al., 2001; Teller et al., 2002).

Ice-dammed lakes develop during both ice-sheet advance and retreat; however, they are typically connected with the ice-sheet decay (Donnelly and Harris, 1989; Johnsen and Brennand, 2006; Winsemann et al., 2004). Recent deglaciation processes in the polar realm give rise to the formation of such lakes. Small and closed lake basins are commonly characterised by rapid lake-level fluctuations. In this paper, we will document the sedimentary history of a small ice-dammed lake (78°40.44′N, 16°54.48′E) that existed from 1990 to 2012 at Nordenskiöldbreen (Svalbard). The lake was filled by a coarse-grained Gilbert delta complex, with the feeding stream sediment delivery oriented constantly towards the damming glacier. The first brief and rather general information about the existence of the study deposits was provided by Stacke et al. (2013).

Deltaic successions play an important role in the sedimentary infill of ice-dammed lakes (Clemmensen and Houmark-Nielsen, 1981; Martini, 1990; Aitken, 1995). Alluvial deltas are complex depositional systems and their stratigraphy is often used to infer changes in the water level, the energy of the basin and the sediment supply (Giosan and Bhattacharya, 2005). The studied case is an excellent field example of a delta system, controlled by rapid base-level changes, glacier retreat and bedrock morphology (the role of subsidence, compaction, waves or tides is neglected) and so should be included in the sequence

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http://dx.doi.org/10.1016/j.geomorph.2017.08.019
0169-555X/

stratigraphic interpretation of complex glacigenic sedimentary environments, which are still undervalued compared with most other sedimentary environments.

2. The study area and locality

Nordenskiöldbreen glacier represents one of several joined ice tongues which descend into Adolfbukta (Fig. 1). The middle part of the glacier calved into the sea bay after the climax of the Little Ice Age (LIA) (Rachlewicz et al., 2007). Nordenskiöldbreen is classified as a tidewater outlet glacier with a polythermal regime (Evans et al., 2012; Hambrey and Glasser, 2012; Ewertowski et al., 2016; Rachlewicz et al., 2007). The lateral margins of the glacier terminate in the terrestrial realm, on the northern and southern coast of Adolfbukta (Fig. 1). Nordenskiöldbreen glacier retreated rapidly from the end of the 19th century until the 1960s of the 20th century. Glacier retreat significantly decreased since then, which is explained by the shallowing of the bay in the front of the glacier snout (Rachlewicz et al., 2007). Zones of both the basal debris-rich ice and the upper clean coarse crystal ice can be observed along the vertical walls of the Nordenskiöldbreen; the zone of the basal debris-rich ice is up to 2.5 m thick and the total glacier thickness along its north-western margin is about 10 m.

The LIA-proglacial zone is located on the hillside of the mountain ridge and declines towards Nordenskiöldbreen glacier and the coast of the bay along the northern side of the Adolfbukta. Outcrops of metamorphic rock dominate in the proximal part of the proglacial zone due to significant dynamics of the relief. The bedrock is predominantly formed by Precambrian mica schists, marbles and amphibolites (Dallmann et al., 2004). Thin and discontinuous sediments cover the basement here, which was reshaped into rouches moutonnées with polished and scratched surfaces. The proglacial zone is poured through by streams of meltout water. These streams are incised into the basement; their directions are governed by the basement structures (Figs. 1, 2). Channels are relatively straight; the braiding style is only local. Some streams are oriented towards the glacier due to the basement tilt (generally between 2° and 5°).

The studied area is located on the margin of Nordenskiöldbreen on the northern coast of Adolfbukta (Figs. 1, 2). Large glacially abraded elevations of basement here are broken up by significant fractures, along which tight and relatively deep gorges were formed. The gorges are perpendicular to the north-eastern margin of the glacier. Two of these gorges, separated by a rock ridge (Fig. 2), played a crucial role in the formation of the studied lake. The eastern depression is narrow and prolonged in the NNW-SSE direction. The western depression is more open and less elongate in the NW-SE direction. The glacier terminates both depressions on the surface on their E-SSE sides (Fig. 2). The barrier of the glacier is oriented in the NNE-SSW direction. Evidence that the lake occupied both depressions is given by preserved deposits and

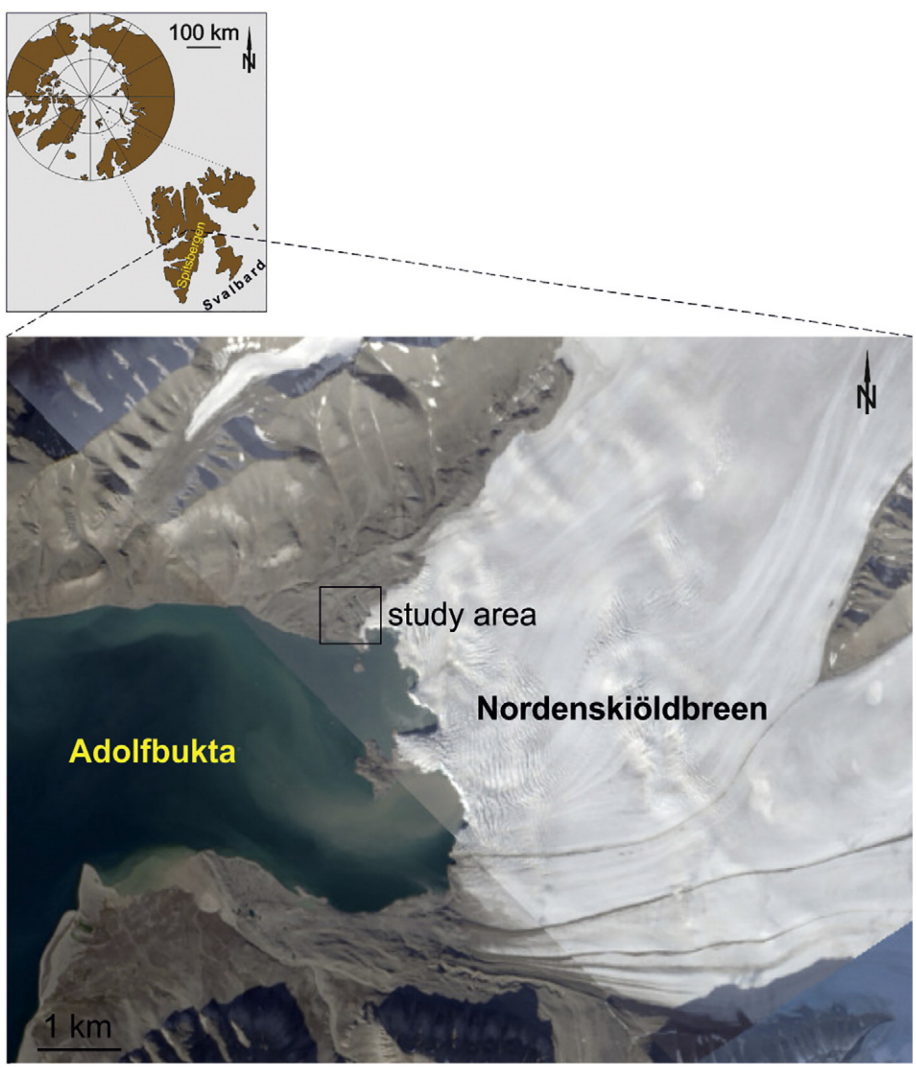

Fig. 1. Geographic location of the area under study. Source of map - http://toposvalbard.npolar.no/.