Quaternary Science Reviews 163 (2017) 56–71

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Reconstructing the flow pattern evolution in inner region of the Fennoscandian Ice Sheet by glacial landforms from Gausdal Vestfjell area, south-central Norway

Artūrs Putniņš*, Mona Henriksen

Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences, P.O. Box 5003, 1432 Ås, Norway

ARTICLE INFO

Article history:
Received 5 October 2016
Received in revised form
6 January 2017
Accepted 6 March 2017
Available online 21 March 2017

Keywords:
Streamlined subglacial landforms
Ribbed moraine
Fennoscandian Ice Sheet
Flow pattern reconstruction
Deglaciation
Scandinavia
LiDAR

ABSTRACT

More than 17 000 landforms from detailed LiDAR data sets have been mapped in the Gausdal Vestfjell area, south-central Norway. The spatial distribution and relationships between the identified subglacial bedforms, mainly streamlined landforms and ribbed moraine ridges, have provided new insight on the glacial dynamics and the sequence of glacial events during the last glaciation. This established evolution of the Late Weichselian ice flow pattern at this inner region of the Fennoscandian Ice Sheet is stepwise where a topography independent ice flow (Phase I) are followed by a regional (Phase II) before a strongly channelized, topography driven ice flow (Phase III). The latter phase is divided into several substages where the flow sets are becoming increasingly confined into the valleys, likely separated by colder, less active ice before down-melting of ice took place. A migrating ice divide and lowering of the ice surface seems to be the main reasons for these changes in ice flow pattern. Formation of ribbed moraine can occur both when the ice flow slows down and speeds up, forming respectively broad fields and elongated belts of ribbed moraines.

1. Introduction

The configuration of the Fennoscandian Ice Sheet (FIS) and its complex evolution in time and space during the Weichselian glaciation have been the subject of research for a long time (Böse et al., 2012; Hughes et al., 2016; Kleman and Glasser, 2007; Kleman et al., 1997; Mangerud et al., 1979, 2011; Svendsen et al., 2004). This includes the discussion on the causes of the ice divide migration (Fig. 1) and the implications of this on the ice sheet dynamics, e.g. the initiation of the Norwegian Channel Ice Stream (NCIS) (Mangerud et al., 2011). The consequence of this likely lead to an enhanced drainage of large parts of southern Norway and central Sweden and a subsequent lowering the ice surface (Svendsen et al., 2015; Sejrup et al., 2009). The study area, Gausdal Vestfjell in south-central Norway (Fig. 1), is located upstream from the NCIS (Ottesen et al., 2005) and in close proximity to the later, migrated ice divide (Vorren, 1977). Such geographical setting (an inner region of the last ice sheet) also determines that this area has been one of the last parts of the FIS to become deglaciated. Therefore, it has a high importance on reconstructing the ice sheet development, glacial dynamics and the deglaciation. Numerous scientists have emphasized the significance of glacial bedforms – streamlined terrain and ribbed moraine – as the indicators of glacial dynamics (e.g. Briner, 2007; Clark, 1993, 1997; Dunlop and Clark, 2006a, 2006b; Hättestrand, 1997; Hättestrand and Kleman, 1999; Hughes et al., 2014; Knight, 2010, 2011; Roberts and Long, 2005; Spagnolo et al., 2012, 2014; Stokes et al., 2011, 2013; Trommelen and Ross, 2010). The analysis of distribution of glacial landforms on a regional scale is the primary tool for the ice flow pattern reconstructions with the so-called flowset (*ice-flow vector* by Hughes et al. (2014)) or the palaeoglacial approach (Boulton and Hagdorn, 2006; Clark et al., 2012; Greenwood and Clark, 2009a, 2009b; Greenwood et al., 2007; Hubbard et al., 2009; Hughes et al., 2014; Kleman et al., 1997; Ross et al., 2009).

The latest development within Geographic Information Systems (GIS) and the increasing accessibility of *Light Detection and Ranging* (LiDAR) terrain data have made it possible to create a high accuracy geomorphological maps further used for glacial reconstructions, and by so it has contributed to the development of geomorphology and Quaternary geology. The extensive mapping conducted within this study provides insight on the distribution and morphostratigraphical relationships of the glacial landforms and thus reveals

* Corresponding author.
E-mail address: arturs.putnins@nmbu.no (A. Putniņš).

http://dx.doi.org/10.1016/j.quascirev.2017.03.008
0277-3791/

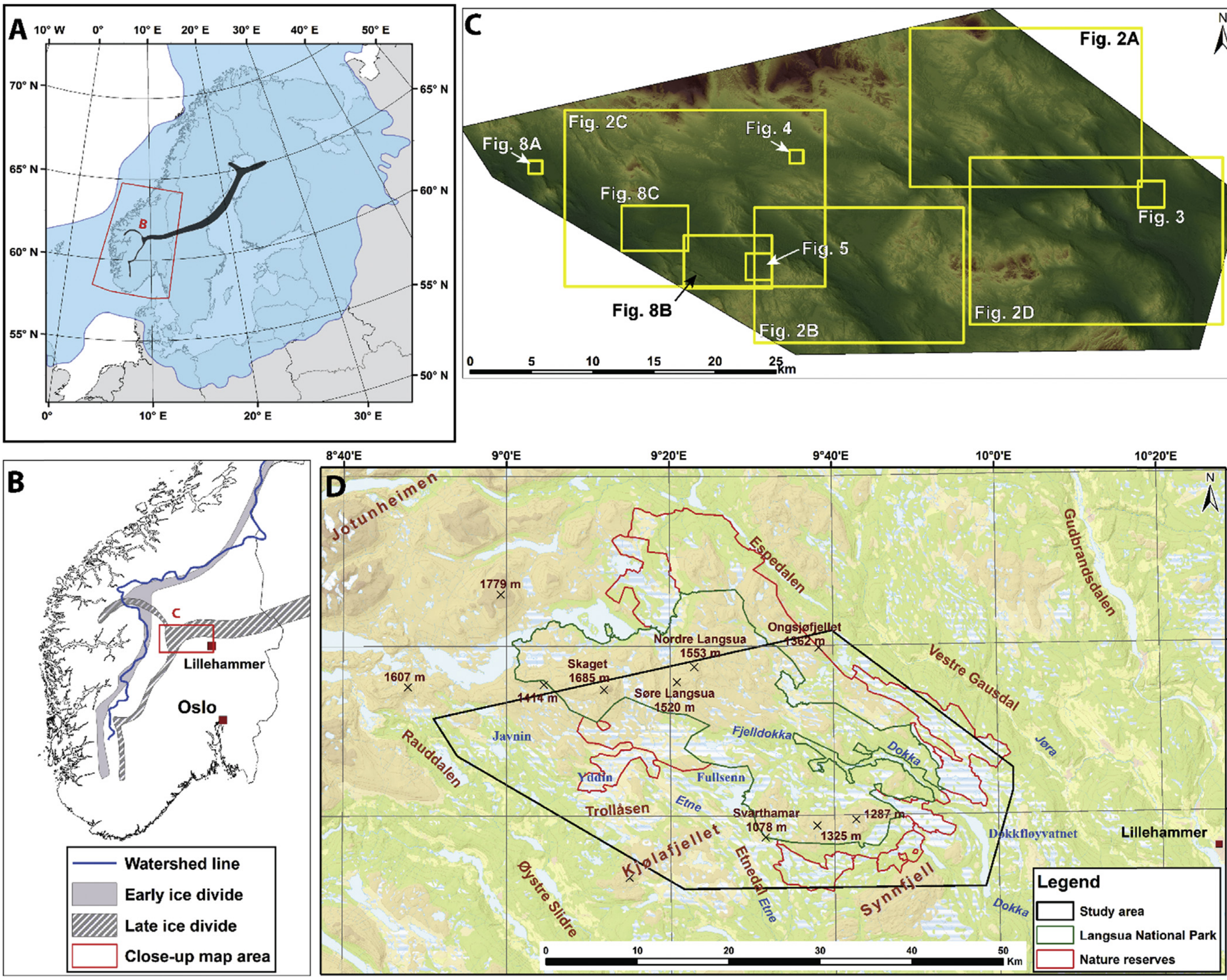

Fig. 1. A. The Fennoscandian Ice Sheet at its maximum position during the Late Weichselian (according to Svendsen et al., 2004) with ice divide in dark (according to Kleman et al., 1997). **B.** Overview map of southern Norway with watershed and ice divide locations (according to Vorren, 1977). **C.** Overview map with locations of other map figures. **D.** Map of Gausdal Vestfjell with outlines of the study area and the protected Langsua National Park and nature reserve areas. Some additional location names are shown in Figs. 2 and 7.

new information on the glacial dynamics during the last glaciation. Based on the identified ice flow patterns, a detailed reconstruction of glacial events from the Late Weichselian and deglaciation in the Gausdal Vestfjell area are established.

2. Study area

Gausdal Vestfjell is located in Oppland County, south-central Norway, situated c. 50 km W of Lillehammer and 50 km SE of the Jotunheimen mountain region (Fig. 1). Jotunheimen is the highest part of the Scandinavian Mountains, which has functioned as one of the primary accumulation areas during the buildup of the FIS prior to the LGM (Mangerud et al., 2011). The study area shows a diverse and relatively complex topography (Fig. 1C). In general, it can be described as an undulating upland plateau, gently sloping towards the SE. The plateau is surrounded by several topographic highs, a W-E oriented mountain ridge in the N (highest peak Skaget 1685 m a.s.l.), the Kjølafjellet ridge in the SW, and the Synnfjell ridge in the SE. Within the plateau area itself, several elevated areas (1100 up to 1325 m a.s.l.) exist. Low-lying areas are commonly occupied by several natural or dammed water bodies that are linked by rivers (Fig. 1D). The two largest ones, the Fjelldokka and Etne rivers, emerge from the foothill of the northern ridge and flow towards the SE, continuing into deep glacial eroded valleys. The western border of the study area is drawn at the upper valley slope of the Rauddalen and Øystre Slidre valleys, while the eastern is along the Vestre Gausdal valley. Almost two thirds of the study area is located within the Langsua National Park and adjacent nature reserves (Fig. 1D) having different degrees of nature protection status limiting the possibilities for excavations.

2.1. Bedrock

The bedrock in the study area is mainly composed of metamorphosed sedimentary rocks of Precambrian to Ordovician age in nappes emplaced during the Caledonian orogeny (Heim et al., 1977). The northern and central part of the area consists of metamorphosed arkose, greywacke sandstone, and conglomerate of Late Precambrian age, and quartzite of Middle to Late Ordovician age belonging to the Jotun-Valdres Nappes Complex. In the southern and southeastern part, slate, sandstone and limestone of Cambrian to Middle Ordovician age form the Synnfjell Nappe (Heim et al.,