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A new concept for glacial geological investigations of surges, based on High-Arctic examples (Svalbard)

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ABSTRACT

Svalbard is a key area for the investigation of glacial surges, and almost two centuries worth of field observations exists from this region. Studies have shown that the course of a surge and the associated formation of landforms are strongly influenced by basinal factors, and that the broad range of variables involved can hamper interpretations and comparisons. Based on a review of surges in Svalbard, a new concept for glacial geological investigations has been developed that combines ice-flows, ice-front movements, and morphostratigraphy. The concept is comprised of the following four elements: 1) classification based on the configuration and characteristics of the receiving basin, 2) division of the surge cycle into six stages, 3) guidelines for morphological mapping, and 4) use of an allostratigraphic approach for interpreting ice-front movements. In this context, delineation of the active phase is critical, which include the history of terminus movements, and four main categories of receiving basins are recognized. These are (A) terrestrial basins with deformable substrates, (B) terrestrial basins with poorly deformable substrates, (C) shallow water basins, and (D) deep water basins. The ice-front movement history is reconstructed by coupling information from the proglacial moraines (syn-surge), the supraglacial moraines (post-surge), and the associated traces of meltwater to the surge stages (I–VI). This approach has revealed a critical relationship between the termination of the active phase and three morphological elements, namely, the maximum ice-front position, the maximum moraine extent and the youngest proglacial moraine, which are unique for each of the basins A–D. The concept is thus a novel and more precise approach for mapping the active phase and the active phase duration, as shown by the ~12-year long surge of Fridtjovbreen, where stage I was 30 months (inception), stage II was 54 months (ice-front advance), stage III was 12 months (stillstand), and stage IV was 48 months (retreat during active flow). The glacier has been in quiescent phase (stages V/VI) since 2002.

1. Introduction

The Svalbard archipelago is 61,000 km^2 (Fig. 1) in size and roughly 60% is covered by glacier ice, which ranges from highly active to inactive ice masses (Hagen et al., 1993; König et al., 2014), and ice-cored moraines. For almost two centuries, this region has played a major role in investigations of glacial processes and has served as a basis for paleoclimatic reconstructions, regionally and elsewhere. Here, the transition from glacial processes to products can be examined directly, both spatially and temporally, and Svalbard has also become a key area for studies of surge-type glaciers (e.g., Dowdeswell et al., 1991, 1995; Hamilton and Dowdeswell, 1996; Jiskoot et al., 2000; Murray et al., 2003b).

A surge is a distinct episode characterized by a rapid increase in the ice flow velocity that can be 10–1000 times faster than normal, and driven by intrabasinal forces (Cuffey and Paterson, 2010). A surge is associated with extensive reorganization of the ice mass and often advances of the front; many surge-type glaciers have a quasi-periodic character (Meier and Post, 1969; Raymond, 1987; Harrison and Post, 2003).

Observations on surges in Svalbard go back to the earliest scientific expeditions in the 1830s (although surge as a phenomenon was unknown at that time), via cartographic work from the late 20th century, aerial photography initiated by the Norwegian Polar Institute in 1936, to present satellite monitoring (König et al., 2014). Systematic glaciological mapping started in the 1980s (Hagen et al., 1993), and today, more than 160 glaciers are known to have surged. These surges include activity at 12–15 ice masses that experienced two or more episodes, but there has been no overall summary of

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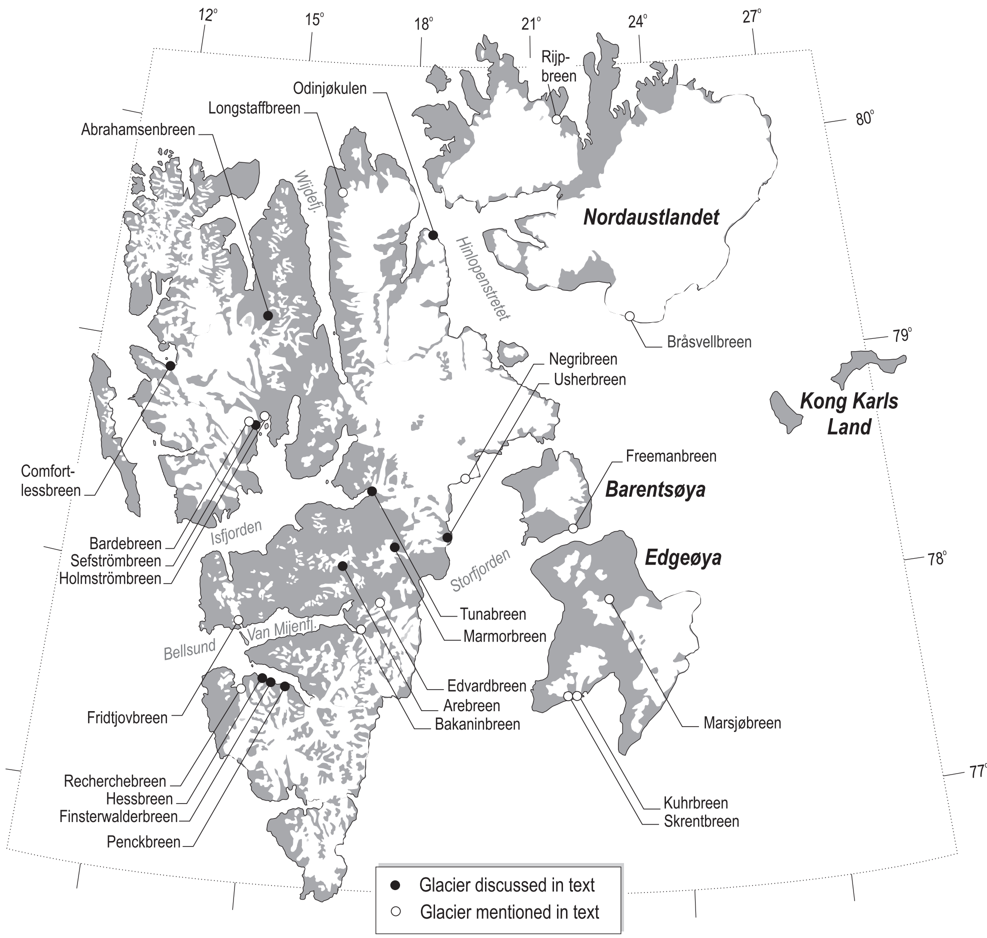

Fig. 1. The Svalbard Archipelago with location of surge-type glaciers discussed.

these data. A large portion of the information was obtained from point observations. Because the area is remote, many glaciers are difficult to access and only a small number of studies have monitored a full surge, although none have monitored a full cycle.

It was suggested early (Liestøl, 1988) that the majority of the Svalbard glaciers could be of the surge-type. Several factors have been proposed as indicators of an active or subrecent surge (Grant et al., 2009), but most of these are related to ice-flow or sediment morphology, and there are presently no unambiguous criteria for recognizing a surge in the stratigraphic record. It is unclear how this affects paleoclimatic reconstructions, however, it is generally accepted that the archipelago was covered by a Late Weichselian ice sheet extending to the shelf edge (Landvik et al., 2005; Ottesen et al., 2007).

Although a surge is primarily the result of internal rather than external factors, climate clearly plays a role, both prior to and during the active phase (Lønne, 2006; Striberger et al., 2011). The Little Ice Age (LIA) peaked late in this region, with maximum glacier extent manifesting around the turn of the 20th century (Dowdeswell et al., 1995); this is important to consider when ice-front movements from this period are discussed. It is also known that glaciers terminating in a standing body of water display dynamic shifts related to changes in the basin configuration (see review, Benn et al., 2007), superimposed on the ice-flow related changes.

Subrecent glacial landforms cover large areas in Svalbard due to low ablation during and after the LIA. However, the ongoing warming of the Arctic (Harris et al., 2009; Eldevik et al., 2014) has had a dramatic impact on the landscape, i.e., the glaciated area has been reduced by 7% in the last three decades (Nuth et al., 2013) and steep sediment surfaces are becoming increasingly unstable because of the growth of the active layer.

Surges are complex phenomena that may be studied with several approaches, and the aim of this study was to develop a comprehensive concept for surge studies that combines information on ice-flow, sediment morphology, and stratigraphic key surfaces. In this context, the recognition of the active phase is critical, and special emphasis is placed on shifts in the ice-front position. A review of surges in Svalbard formed the basis for the selection of examples that could elucidate the coupling between the receiving basins and the formation of sediment morphology in the various stages of active and passive phases. It is worth noting that the discussed basins are quite complex and that a complete interpretation of the individual cases was not the aim of this paper. The analysis was based mainly on remote sensing but has a field-based approach. Studies of the marine portion of the system represent an important part of the overall information base, but such data are not discussed here.

The concept is comprised of the following four elements: 1) a classification scheme with four main basin categories A–D, 2) subdivision of the surge cycle into six stages, 3) guidelines for morphostratigraphic mapping of moraines and meltwater traces, and 4) use of an allostratigraphic approach for interpreting ice-front movements. The sediment morphology and stratigraphic