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Subglacial decoupling at the sediment/bedrock interface: a new mechanism for rapid flowing ice

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Abstract

On millennial or even centennial time scales, the activity of rapid flowing ice can affect climate variability and global sea level through release of meltwater into the ocean and positive feedback loops to the climate system. At the surge-type glacier Brúarjökull, an outlet of the Vatnajökull ice cap, eastern Iceland, extremely rapid ice flow was sustained by overpressurized water causing decoupling beneath a thick sediment sequence that was coupled to the glacier. This newly discovered mechanism has far reaching consequences for our understanding of fast-flowing ice and its integration with sediment discharge and meltwater release.

1. Introduction

Interest in fast ice flow behaviour is stimulated by recent events along the periphery of contemporary ice sheets, where interior collapse subsequent to ice shelf disintegration is suddenly a realistic possibility (De Angelis and Skvarca, 2003). In the present state of rapid global environmental changes there is a growing wish to understand the causal mechanisms behind ice sheet instability and its contribution to global sea level rise (Alley and Bindschadler, 2001; Clark et al., 2002; Domack et al., 2005). Fast flowing ice streams and surging glaciers exert a strong control on the discharge of the Antarctic and Greenland ice sheets acting as regulators on their configuration and stability (Dowdeswell et al., 2004; Rignot and Kanagaratnam, 2006). Consensus in the literature dictates that mechanisms behind ice flow variability and distribution of meltwater are linked to subglacial processes influencing basal motion and not to ice-mechanical processes (Boulton and Hindmarsh, 1987; Fischer and Clarke, 2001). An important issue is, however, to identify and quantify the different hydro-mechanical processes beneath the ice and in particular the significance of deep-seated sediment deformation as it is directly linked to predictions of ice sheet stability (Clarke, 2005). Surge-type glaciers provide an opportunity to probe this problem as they experience major fluctuations in velocity between phases of active surging and quiescence. Between surge events as the glacier ice retreats—a landform association and sediment succession re-emerges imprinted with vital information on subglacial driving processes.

2. Setting

Brúarjökull, a northern outlet of the Vatnajökull ice cap in eastern Iceland, has experienced major velocity fluctuations switching between active winter surging of some 3 months duration and quiescent phases lasting from 70 to 90 years (Todtmann, 1960; Thorarinsson, 1969; Raymond,

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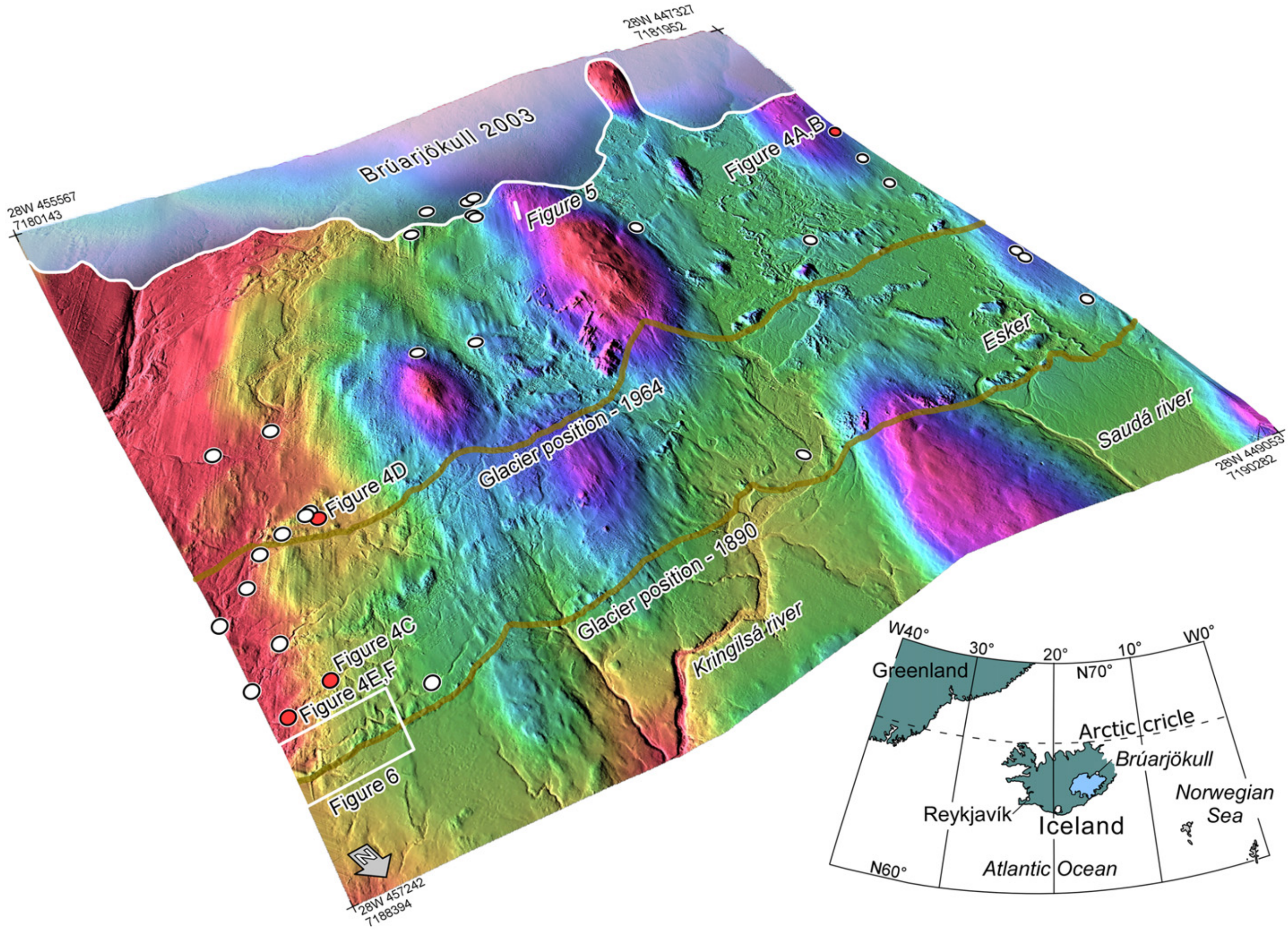

Fig. 1. The forefield of the surge-type glacier Brúarjökull, eastern Iceland. Terrain-Shaded Relief (TSR) draped over a digital elevation model based on a 3 m grid generated from ortho-rectified 1:15,000 aerial photographs recorded in 2003. Dots mark localities used for detailed sedimentological and stratigraphical studies.

1987). During the most recent surges initiated in 1890 and 1963 the glacier advanced respectively, 10 and 8 km affecting an area of roughly 1400 km^2 (Fig. 1). Recent surges in 1890 and 1963 were documented in the field and the meltwater discharge was described prior and subsequent to surges (Thoroddsen, 1914; Thorarinsson, 1969). The peak velocity was at least 125 m/day over a period of almost three months (Thorarinsson, 1969), which exceeds even the fastest ice streams in Antarctica and Greenland (Echelmeyer and Harrison, 1990; Joughin et al., 2002). Basaltic rocks overlain by $\leqslant$6 m unlithified sediments comprise the subglacial lithologies around the fringe of Brúarjökull.

Oblique 1964 aerial photographs of the surging Brúarjökull testify that it was heavily crevassed and disintegrated as internal ice deformation was unable to compensate sufficiently for extreme lateral extension during the active phase. In the succeeding quiescent phase, the glacier retreated passively as seen from consecutive aerial photographs and satellite imagery recorded in 1964, 1988, 1993, 2002 and 2003. Measurements of ice displacement between 2003 and 2005 show negligible glacier movement, while the glacier front retreated up to 250 m/year and the surface lowered 6–7 m/year (Fig. 2). Therefore, the glacier experiences no forward movement during the quiescent phase and except for stagnation features all processes related to depositional landforms and subglacial deformation are restricted to the surge phase. Effectively, the glacier in the present quiescence state behaves like a dead-ice body.

3. Earlier models for fast ice flow

Rapid ice flow velocities reached either by ice streams or surging glaciers, have hitherto been explained by two modes of basal motion largely dependent on ice/bed coupling (Fischer and Clarke, 2001). Decoupling of a glacier from its bed enables fast ice flow through enhanced basal sliding across the ice/bed interface or very shallow subglacial deformation, i.e. the basal sliding model in Fig. 3A (Engelhardt and Kamb, 1998). Alternatively, fast ice flow is sustained by deformation of water-saturated subglacial sediment that is strongly coupled to the glacier,