Geomorphology 208 (2014) 34–49

Contents lists available at ScienceDirect

Geomorphology

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

A field-based model of permafrost-controlled rockslide deformation in northern Norway

Lars H. Blikra [a,b], Hanne H. Christiansen [c,d,*]

[a] Åknes/Tafjord Early Warning Centre, Stranda, Norway
[b] Sogn & Fjordane University College, Sogndal, Norway
[c] Geology Department, The University Centre in Svalbard, UNIS, P.O. Box 156, 9170 Longyearbyen, Norway
[d] Center for Permafrost, CENPERM, Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark

ARTICLE INFO

Article history:
Received 7 April 2012
Received in revised form 13 November 2013
Accepted 19 November 2013
Available online 26 November 2013

Keywords:
Permafrost
Jettan rockslide
Geohazard
Ground thermal regime
Deformation monitoring
Snow

ABSTRACT

Knowledge about the detailed processes linked to the existence of permafrost in rockslide fractures is sparse. Large parts of the Jettan rockslide are located right below the discontinuous permafrost limit in the arctic part of the alpine landscape of northern Norway. Combining four years of meteorological and rockslide deformation data with temperature measurements from different parts of open fractures, shallow bedrock boreholes and air, as well as daily snow cover observations, allows a detailed identification of the key processes involved. These field data are the basis for the development of a permafrost controlled rockslide model. Seasonally, the deformation has a very distinctive pattern with high deformation starting abruptly right after snowmelt in May, and lasting until snow isolation in winter. Then there is a gradual transition to medium deformation as the ground is cooled further for another 1–2 months. Finally, the winter period, when maximum snow occurs in the fractures, is characterized by limited or almost no deformation. The primary controlling deformation process is meltwater percolation into fractures in summer with significant refreezing, ice formation and temperature increase in the lower part of the fractures from −1 °C to 0 °C. Sporadic permafrost exists below the discontinuous permafrost limit, and may extend into open fractures and sliding planes. Another primary process is the significant cold air accumulation in fractures in early winter, due to the Balch effect, which significantly cools the fracture and surrounding rock promoting permafrost development. Finally, the cold air effect is stopped by snow isolation once enough snow has accumulated in the fracture by late winter. The deformation itself is thought to be controlled by changing shear strength of the brecciated sliding planes due to either changing ice temperatures and/or variations in water infiltration to the unsaturated sliding zones. The overall system is very locally controlled driving itself, and the effect of a future climate change can thus be of minor importance.

1. Introduction

Rockslides pose a significant geohazard in the cold, periglacial fjord landscapes of northern Norway. The Jettan rockslide at Nordnes at 69°30′N (Fig. 1) may cause serious consequences to the inhabited fjord areas due to its potential of generating destructive tsunamis (Kristensen and Blikra, 2011). A clear seasonal deformation pattern has been identified for the Jettan rockslide, which has been demonstrated not to be controlled by rainfall and snowmelt alone (Nordvik et al., 2010).

Large parts of the north Norwegian fjord landscapes are located in the arctic zone with altitudinal permafrost. The permafrost regional limit descends from ca. 990 m a.s.l. in the west, to 550 m in the interior in the eastern part of northern Norway (Christiansen et al., 2010). This means that the Jettan rockslide area, extending from 400 to 800 m a.s.l., is located at the regional modern permafrost limit. However, the irregular topography of the rockslide area, with deep open fractures, a complex fracture geometry and snow accumulation pattern, creates special local terrain and subsurface conditions. This complex topographic setting strongly suggests that permafrost can be locally present, which can affect the rockslide deformation. Studies of processes and driving mechanisms of rockslides in such environments are very limited.

The seasonal deformation of large landslides is mainly thought to be controlled by rainfall causing increased water pressure (e.g. Crosta and Agliardi, 2003; Sartori et al., 2003; Hong et al., 2005), a factor assumed also as fundamental for several rockslide events in Norway (Bjerrum and Jørstad, 1968). Snowmelt is also thought to be an important factor increasing the water level in fractures and thus controlling displacements, as assumed to be the case for the Rio Colorado Rockslide in Chile (Casassa and Marangunic, 1993), the rockslope at Affliction Creek in British Colombia (Bovis, 1990) and documented displacements based on the monitoring data from the Åknes rockslide in western

* Corresponding author at: Geology Department, The University Centre in Svalbard, UNIS, P.O. Box 156, 9170 Longyearbyen, Norway. Tel.: +47 79023320; fax: +47 79023301.

E-mail address: hanne.christiansen@unis.no (H.H. Christiansen).

0169-555X/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geomorph.2013.11.014

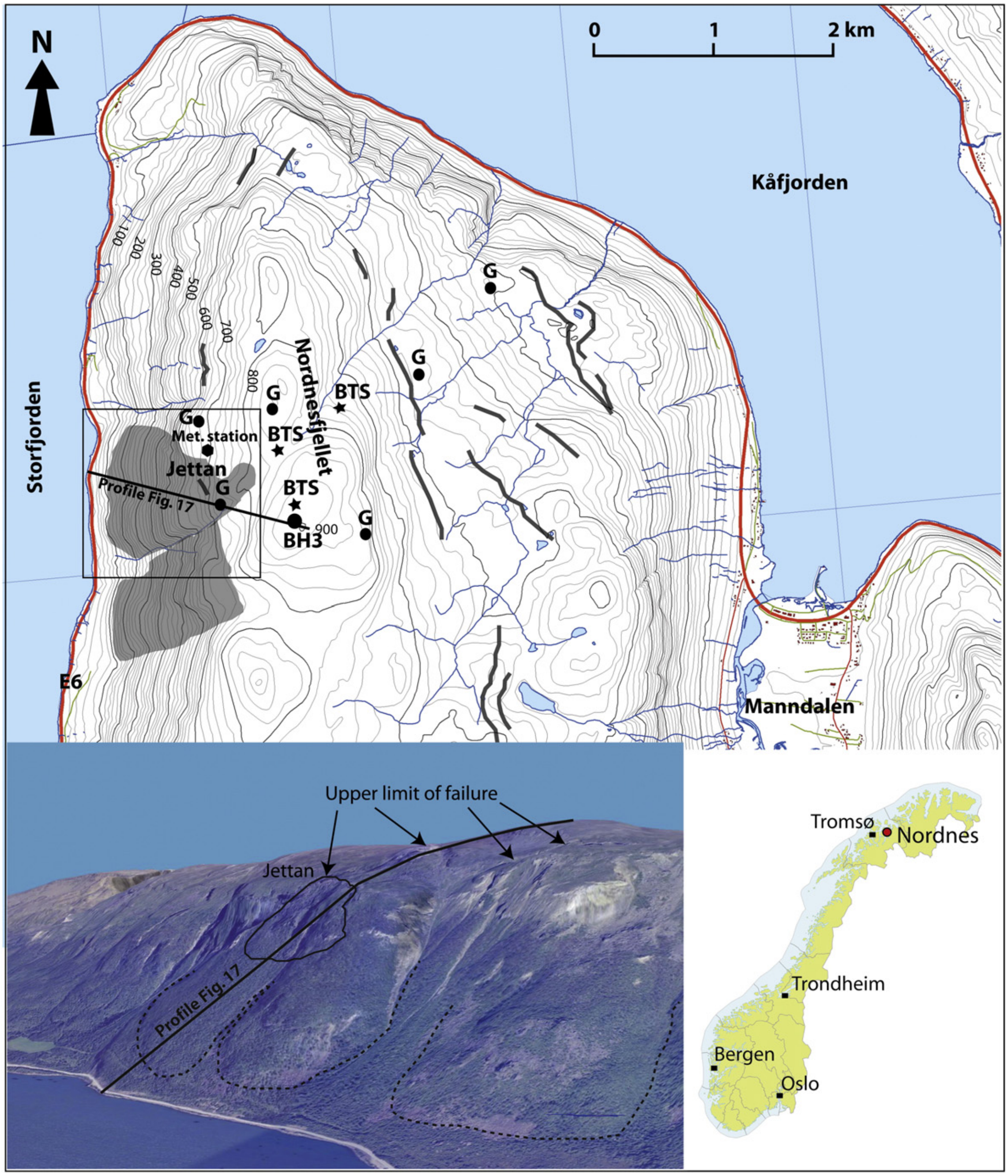

Fig. 1. Location of the Nordnes area in Norway, and the Nordnesfjellet mountain plateau with location of the Jettan unstable rockslide. Positions of the meteorological station at 699 m a.s.l. and the uppermost 2.3 m deep borehole (BH3) at 900 m a.s.l. are shown together with locations of ground surface temperature (G) and bottom temperature of snow (BTS) recordings. Black lines show the positions of Younger Dryas marginal moraines (modified from www.ngu.no/kartogdata). Location of the geomorphological map in Fig. 2 is marked with the frame. The lower 3D image shows the uppermost backscarp and the large frontal "lobes" of the instabilities consisting of highly fractured bedrock (stippled lines). The active moving area is indicated by the solid line. Location of profile in Fig. 17 is shown.

Norway (Grøneng et al., 2011). Alternatively, Watson et al. (2006) interpreted the cyclic deformation of the Checkerboard Creek landslide in British Colombia as being controlled by a thermal response of the rock mass due to seasonal temperature variations. However, detailed process understanding is lacking, and the displacements in all other previously investigated sites can also be linked to the variations in water pressure.

Even though permafrost and its potential influence on landslides have been assumed to be important (e.g. Davies et al., 2001; Harris et al., 2001; Geertsema et al., 2006; Gruber and Haeberli, 2007; Sosio et al., 2008; Huggel et al., 2010), detailed field studies on the subject are still sparse. However, the slide scar of the Felik landslide in the Aosta valley in Italy has been observed to have fractures completely filled by ice down to more than 30 m depth (Bottino et al., 2002). The review of recent large slope failures in ice and rocks in Alaska, New Zealand and the European Alps (Huggel et al., 2010) indicates that periods of high air temperatures, melting of snow and ice and rapid thaw reduce the overall slope strength. Also, studies of periglacial landforms such as rock glacier dynamics provide some background for the state of knowledge concerning the seasonal dynamics in landforms characterized by open fractures and large pore spaces. A clear seasonal rhythm has been identified in the European Alps for rock glacier movement rates. The highest velocities were recorded mainly between summer and early winter; while the lowest velocities were generally observed in spring or early summer (Delaloye et al., 2010). To some