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Cryo-conditioned rocky coast systems: A case study from Wilczekodden, Svalbard

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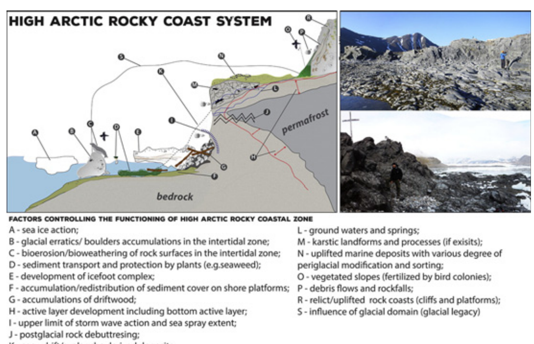
HIGHLIGHTS

- Insight into geomorphological processes operating on rocky shores in High Arctic.
- First use of SilverSHRT and TMEM tests in Svalbard rocky coast geomorphology study
- Geophysical (ERT) evidence of the impact of sea on the state of coastal permafrost
- New conceptual model of High Arctic rock coast system

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents the results of an investigation into the processes controlling development of a cryo-conditioned rock coast system in Hornsund, Svalbard. A suite of nested geomorphological and geophysical methods have been applied to characterise the functioning of rock cliffs and shore platforms influenced by lithological control and geomorphic processes driven by polar coast environments. Electrical resistivity tomography (ERT) surveys have been used to investigate permafrost control on rock coast dynamics and reveal the strong interaction with marine processes in High Arctic coastal settings. Schmidt hammer rock tests, demonstrated strong spatial control on the degree of rock weathering (rock strength) along High Arctic rock coasts. Elevation controlled geomorphic zones are identified and linked to distinct processes and mechanisms, transitioning from peak hardness values at the ice foot through the wave and storm dominated scour zones to the lowest values on the cliff tops, where the effects of periglacial weathering dominate. Observations of rock surface change using a traversing micro-erosion meter (TMEM) indicate that significant changes in erosion rates occur at the junction between the shore platform and the cliff toe, where rock erosion is facilitated by frequent wetting and drying and operation of nivation and sea ice processes (formation and melting of snow patches and icefoot complexes). The results are synthesised to propose a new conceptual model of High Arctic rock coast systems, with the aim of contributing towards a unifying concept of cold region landscape evolution and providing direction for future research regarding the state of polar rock coasts.

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1. Introduction

Since the beginning of the 21st century periglacial researchers have challenged longstanding theoretical concepts of landscape evolution in cold environments (e.g. Hall et al., 2002; André, 2003; Thorn, 2004). André (1999) argued that understanding of periglacial environments has been hidden in a 'smokescreen' of theories dominated by climate-driven geomorphic processes involving frost, snow and ice, which were disconnected from the complex processes that operate in periglacial domains. The application of paraglaciation theory in geomorphological studies has emphasized the need for a deeper appreciation of the role of non-glacial processes in present-day polar and high mountain environments (Ballantyne, 2002; Mercier, 2008; André, 2009; Slaymaker, 2011). Berthling and Etzelmüller (2011) introduced the concept of cryo-conditioning to unify interactions between cryotic surface and subsurface thermal regimes and geomorphic processes in determining cold region landscape evolution. An aspect that remains unexplored is the impact of periglacial and paraglacial processes on the evolution of Arctic coastal zones (Fig. 1) and in particular on rocky coastlines (Overduin et al., 2014). It is noteworthy that over three decades ago the lack of a consensus on the efficiency of coastal processes in high latitudes was identified by Trenhaile (1983) and still remains.

In the Arctic, sea ice extent and thickness has been declining by > 10% per decade since satellite observations began in 1979 (NASA Earth Observatory). This decrease is lengthening the period in which Arctic coastlines are vulnerable to storms and thermal erosion, potentially increasing rates of coastal erosion (Lantuit et al., 2012). In several parts of the Arctic, accelerated glacier retreat has led to the exposure of new fragile coastal systems, where evolution depends on permafrost-related processes and fluxes of sediments from paraglacially transformed landforms. All these changes are expected to impact coastal morphology, causing increased rates of erosion, extensively modifying near shore sediment and organic carbon mobilization and transport, and potentially pushing coastal systems across critical geomorphological and ecological thresholds (e.g. Fritz et al., 2017).

Up to 35% of Arctic coastlines are rock-dominated and large parts of community and scientific infrastructure are located along rocky coasts (Forbes, 2011), but few studies have focused specifically on this environment (see Hansom et al., 2014 for a comprehensive review). Previous and classic works on Arctic rock coasts systems emphasized the role of icefoot (e.g. Jahn, 1961; Dionne, 1973; Nielsen, 1979), snow cover (e.g. Ødegård et al., 1995), sea ice and frost weathering (e.g Trenhaile, 1983; Dionne and Brodeur, 1988; Fournier and Allard, 1992; Guilcher et al., 1994; Lundberg and Lauritzen, 2002; Wangensteen et al., 2007) as key controls of shore platform and cliff face geomorphology in polar settings. More recent studies carried out in Svalbard have focused on detailing the characteristics of rock coast weathering using Schmidt hammer rock tests (Strzelecki, 2011; Strzelecki, 2016). Swirad et al. (2017) analysed rock control on the geometry of northern Hornsund coastline. An important progress in understanding of Svalbard coastal systems was recently made by Kasprzak et al. (2016), who used electrical resistivity tomography (ERT) to demonstrate strong influence of the sea on the coastal permafrost base. Previously, this issue has been often overlooked in Arctic coastal studies or hidden under schemas (e.g. Lachenbruch, 1968; Gold and Lachenbruch, 1973), which cannot be universally applied for diverse Arctic coastal systems.

The overarching aim of this study is to characterise the mechanisms controlling present-day development of rocky coastal zone in High Arctic fjord environment with particular focus on the spatial changes in distribution of coastal permafrost and the degree of rock surface weathering along landforms evolving in various lithologies. In this paper we summarise the results of our recent investigations into cryo-conditioned rock coast systems in Svalbard. We have applied a combination of geomorphological and geophysical methods to identify and characterise the effects of periglacial processes operating on rocky cliffs and shore platforms and propose a new conceptual model of the functioning of High Arctic rock coast systems.

2. Regional setting

The research was undertaken along the rocky coast of Wilczekodden (76.9964°N; 15.5458°E), a small (approx. 500 × 150 m) cape located in Hornsund between the Rettkvalbogen and Isbjørnhamna embayments (Fig. 2).

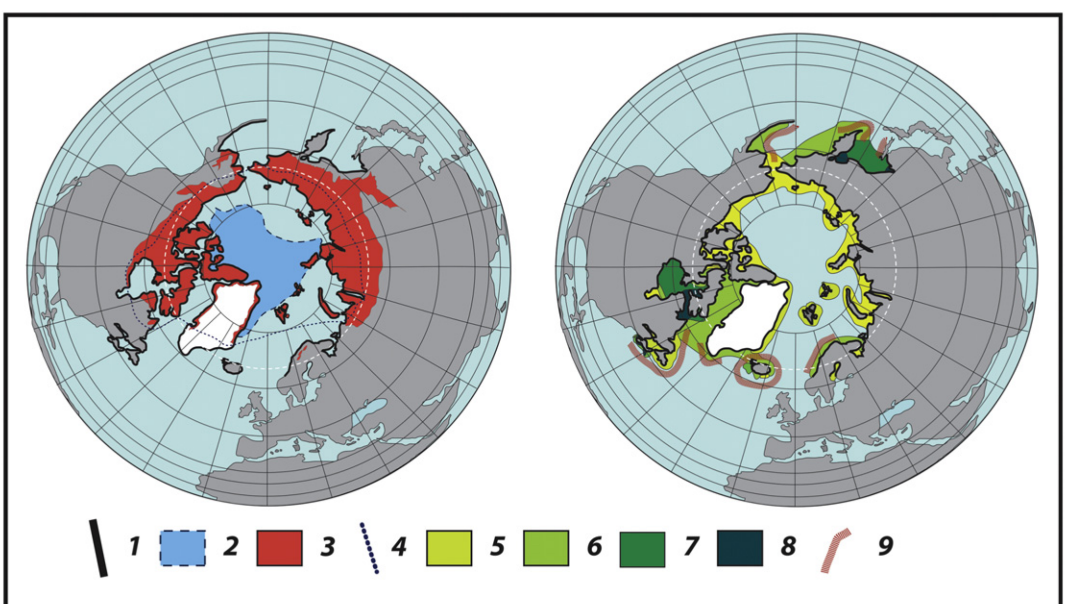

Fig. 1. Regional climatic and oceanographic factors controlling Arctic coastal geomorphology predicted to alter due to global warming and sea-level rise. 1 - cold region coasts according to Byrne and Dionne (2002) – defined as 'areas where frost and ice processes are active during a period of the year, which is sufficient to have a significant, if not permanent, impact on the near terrestrial, coastal and marine environments'; 2 – minimum arctic sea ice extent in August 2016 (source: National Snow and Ice Data Centre: http://nsidc.org/); 3 - zone of continuous permafrost (source: National Snow and Ice Data Centre: http://nsidc.org/); 4 – zone of < 60 frost-free days per year (after Davies, 1980); Spring tidal range along cold region coasts (after Davies, 1980): 5 – tides < 2 m; 6 – tides 2–4 m; 7 – tides 4–6 m; 8 – tides > 6 m; 9 – storm wave environments in cold regions (after Davies, 1980).