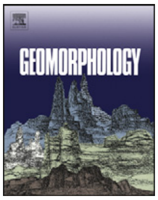
Geomorphology 248 (2015) 1–13

Contents lists available at ScienceDirect

Geomorphology

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



Understanding controls on cirque floor altitudes: Insights from Kamchatka

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ARTICLE INFO

Article history:
Received 11 April 2015
Received in revised form 2 June 2015
Accepted 1 July 2015
Available online 6 July 2015

Keywords:
Cirques
Glacier
Palaeoclimate
Climate
ELA

ABSTRACT

Glacial cirques reflect former regions of glacier initiation, and are therefore used as indicators of past climate. One specific way in which palaeoclimatic information is obtained from cirques is by analysing their elevations, on the assumption that cirque floor altitudes are a proxy for climatically controlled equilibrium-line altitudes (ELAs) during former periods of small scale (cirque-type) glaciation. However, specific controls on cirque altitudes are rarely assessed, and the validity of using cirque floor altitudes as a source of palaeoclimatic information remains open to question. In order to address this, here we analyse the distribution of 3520 ice-free cirques on the Kamchatka Peninsula (eastern Russia), and assess various controls on their floor altitudes. In addition, we analyse controls on the mid-altitudes of 503 modern glaciers, currently identifiable on the peninsula, and make comparisons with the cirque altitude data. The main study findings are that cirque floor altitudes increase steeply inland from the Pacific, suggesting that moisture availability (i.e., proximity to the coastline) played a key role in regulating the altitudes at which former (cirque-forming) glaciers were able to initiate. Other factors, such as latitude, aspect, topography, geology, and neo-tectonics seem to have played a limited (but not insignificant) role in regulating cirque floor altitudes, though south-facing cirques are typically higher than their north-facing equivalents, potentially reflecting the impact of prevailing wind directions (from the SSE) and/or variations in solar radiation on the altitudes at which former glaciers were able to initiate. Trends in glacier and cirque altitudes across the peninsula are typically comparable (i.e., values typically rise from both the north and south, inland from the Pacific coastline, and where glaciers/cirques are south-facing), yet the relationship with latitude is stronger for modern glaciers, and the relationship with distance to the coastline (and to a lesser degree with aspect) is notably weaker. These differences suggest that former glacier initiation (leading to cirque formation) was largely regulated by moisture availability (during winter months) and the control this exerted on accumulation; whilst the survival of modern glaciers is also strongly regulated by the variety of climatic and non-climatic factors that control ablation. As a result, relationships between modern glacier mid-altitudes and peninsula-wide climatic trends are more difficult to identify than when cirque floor altitudes are considered (i.e., cirque-forming glaciers were likely in climatic equilibrium, whereas modern glaciers may not be).

1. Introduction

Glacial cirques are bowl-shaped hollows formed by the erosive action of mountain glaciers (Evans and Cox, 1995; Mîndrescu and Evans, 2014). Cirques reflect former regions of glacier initiation (i.e., where topoclimatic conditions formerly allowed the development of glaciers), and, as a result, they are often used as a source of palaeoclimatic information (e.g., Anders et al., 2010; Mîndrescu et al., 2010; Bathrellos et al., 2014). One specific way in which palaeoclimatic information is obtained from a population of cirques is by analysing spatial variability in their altitudes (e.g., Linton, 1959; Davies, 1967; Derbyshire, 1963; Peterson and Robinson, 1969; Hassinen, 1998; Principato and Lee, 2014), on the assumption that cirque floor altitudes are a proxy for the climatically controlled equilibrium-line altitudes (ELAs) of former cirque glaciers (i.e., glaciers that formerly occupied, and were contained within, cirques) (see Flint, 1957; Meierding, 1982; Porter, 1989; Benn and Lehmkuhl, 2000). The analysis of cirque floor altitudes is also key to understanding the role played by glaciers in eroding and regulating mountain topography at a near global scale—as part of a test for the buzzsaw hypothesis (see Oskin and Burbank, 2005; Mitchell and Montgomery, 2006; Mitchell and Humphries, 2015). However, specific controls on cirque floor altitudes are rarely assessed, meaning that the validity of using cirque floor altitudes as a source of palaeoclimatic information or for testing the buzzsaw hypothesis remains questionable (see Peterson and Robinson, 1969; Hassinen, 1998). In light of this, the aim of the present study is to assess the relative importance of various

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http://dx.doi.org/10.1016/j.geomorph.2015.07.004
0169-555X/

controls (i.e., latitude, aspect, proximity to the coast, topography, geology, tectonics and volcanic activity) on cirque floor altitudes across the Kamchatka Peninsula (eastern Russia), in the hope that some of the information derived can be applied to cirque populations elsewhere globally. Kamchatka is well suited for this purpose, as the peninsula harbours a large cirque population; is topographically diverse; has varied, but comparatively simple, climate patterns; and is occupied by numerous modern glaciers—the altitudinal distribution of which is also studied here.

2. Study area

2.1. Topography and geology

The Kamchatka Peninsula is located in Far Eastern Russia, and separates the Sea of Okhotsk to the west from the North Pacific to the south and east. The peninsula is ~1250 km long, and is dominated by three distinct mountain regions: the Sredinny Mountains; the Vostočny Mountains; and the Eastern Volcanic plateau (EVP) (see Fig. 1).

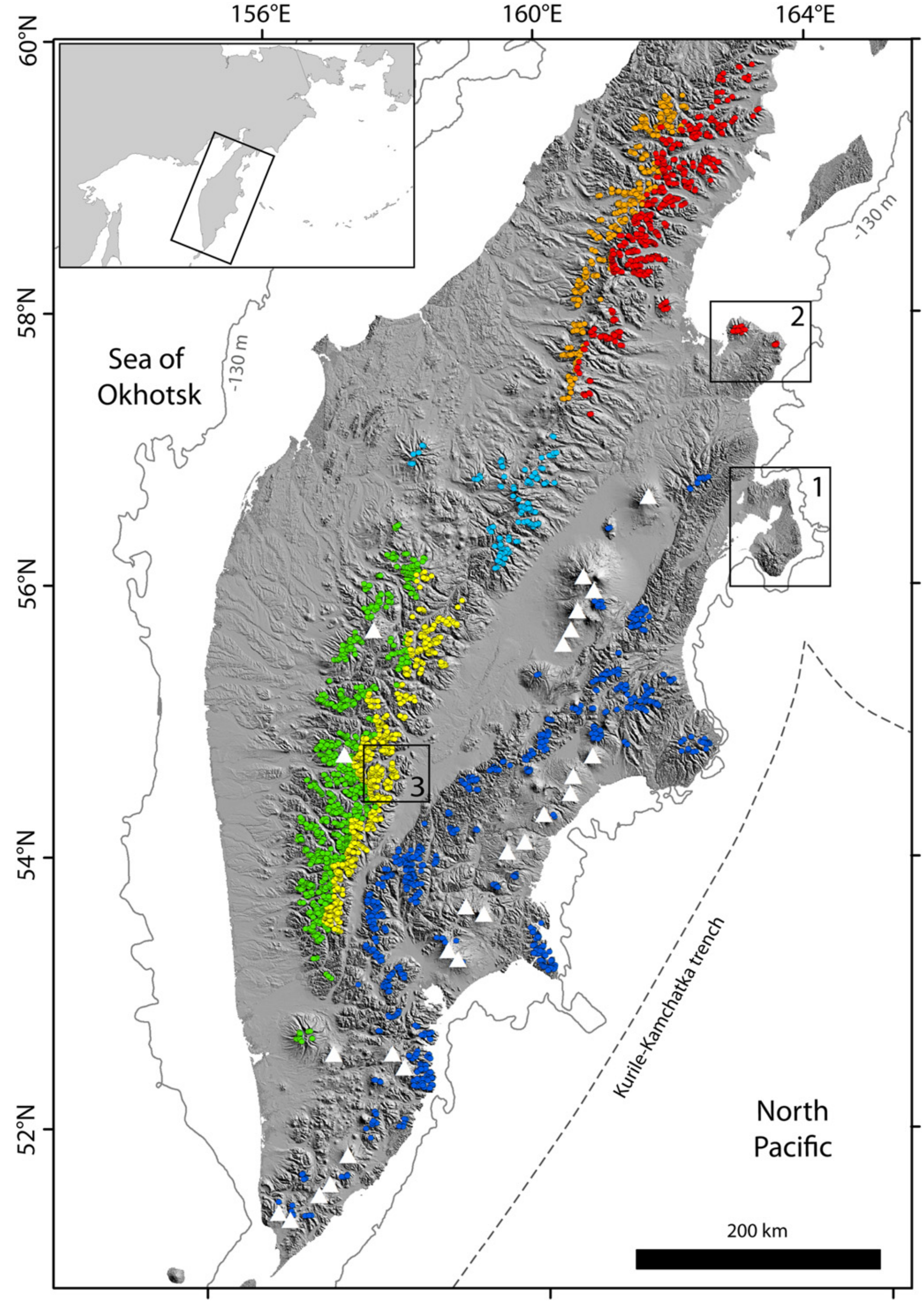

Fig. 1. Shaded relief map of the Kamchatka Peninsula. In this image, mapped cirques are shown as points, coloured according to region: NW Sredinny (orange), NE Sredinny (red), Central Sredinny (light blue), SW Sredinny (green), SE Sredinny (yellow), Vostočny and EVP (dark blue). Also shown are active volcanoes (white triangles) (from Avdeiko et al., 2007) and the LGM coastline (given a 130 m lowering of sea level relative to present). Boxed areas 1–3 are referred to in Table 6.