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Late Quaternary environmental dynamics in Lenin Peak area (Pamir Mountains, Kyrgyzstan)

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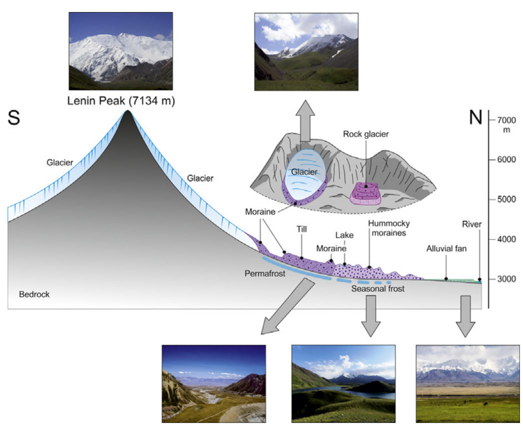
HIGHLIGHTS

- We examine landscape dynamics in the northern Lenin Peak area, Kyrgyzstan.
- There is a wide range of glacial and periglacial processes and landforms.
- Permafrost is widespread at 3400–3500 m, with seasonal frozen ground in lower areas.
- Geomorphic evidence suggests several glacial stages since the Last Glaciation.

GRAPHICAL ABSTRACT



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ABSTRACT

The Pamir Mountains include peaks exceeding 7000 m, such as Lenin Peak (7134 m) in the northern Zaalai Range. Here, we examine the distribution of soils and geomorphological processes and landforms in its northern slope, from the highest glaciated environments until Alai valley floor. We present the first geomorphological map of the study area as well as an accurate description the main geomorphological units in order to reconstruct landscape dynamics in the area from Quaternary cold stages until present-day. Five main units are distributed: (1) valley floor (2900–3040 m), an area that must have been ice-free during Quaternary glaciations and is currently being reshaped by glaciofluvial processes, with a large alluvial fan reworked by aeolian activity; (2) hummocky terrain (3040–3500 m) including two moraine systems left by a piedmont glacier during the Last Glaciation as well as hilly deposits originated by a catastrophic rockfall event; (3) U-shaped glacial valley (3500–3800 m), including some moraine ridges as well as a sedimentary cover composed of glacial till that is being eroded by fluvial and mass-wasting processes; (4) high mountain valleys (up to 4600–4800 m) adjacent to the main valley floor with small cirque and alpine glaciers and widespread periglacial processes in ice-free environments; (5) glaciers flowing from the Lenin Peak summit until the foot of the mountain, where they form a debris-covered (surge-type) glacier. The existence of abundant glacial, periglacial and rockfall deposits (moraines, till, erratic boulders) allows inferring five different environmental stages since the Last Glaciation. The latest glacial advances took place during the 20th century and the Little Ice Age and deposited two moraine systems near the glacial front. The occurrence of active rock glaciers and protalus lobes indicates that the limit of permafrost conditions is now located at 3400–3500 m, with seasonal frozen ground in lower areas.

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1. Introduction

The high mountain ranges of Central Asia, including Pamir Mountains, constitute a natural boundary in terms of geography, climate and ecological dynamics. The high elevation, compactness and extension of these mountains, together with the scarce mountain passes and the long distance to the sea, control the climate of the region and impose a wide climatic spectrum within the mountain systems and in surrounding areas. Tectonics and climate conditioned human colonization of these lands as well as the subsequent evolution of societies over millennia, compelling substantial differences in the lifestyle of communities settled at short distances (Glantz, 2011; Caves et al., 2016).

Central Asian high mountain ranges play a crucial role in the global climate system and small variations in regional atmospheric circulation patterns can led to important changes in mountain environmental dynamics. However, our current understanding of geomorphological processes prevailing in some of these mountain systems differs substantially from one another. Certain areas with more tourist pressure and with an easier access have been intensely examined from a geomorphological perspective, such as surroundings of Himalaya's highest peaks (e.g. Benn et al., 2012). Some other areas have also received more attention to better understand singular environmental dynamics, such as the so-called 'Karakoram anomaly', with intense scientific debate on the magnitude and causes of the recent glacial advances recorded in this region (Kapnick et al., 2014; Forsythe et al., 2017) within the present-day context of global warming (IPCC, 2013). Over the last two decades, geomorphological research in these mountain ranges turned to the study of natural hazards affecting local communities through a wide range of processes such as floods, landslides, snow and rock avalanches or glacial lake outburst floods (GLOFs) (Hewitt, 2009; Janský et al., 2009, 2010; Hewitt and Liu, 2010; Bolch et al., 2011; Round et al., 2017; Nie et al., 2018), glacier mass balances (Bolch et al., 2012; Lin et al., 2017) and its impact on runoff (Sorg et al., 2012), distribution and thermal state of permafrost (Zhao et al., 2010; Gruber et al., 2017), relationship between deglaciation and soil formation (Srinivas et al., 2011; Stres et al., 2014) as well as the establishment of the chronological framework of past glacial events (Seong et al., 2007; Owen and Dortch, 2014; Eugster et al., 2016).

However, in other Central Asian mountain ranges such as the Pamir Mountains, geomorphological processes have been much less examined, namely in Lenin Peak (7134 m) area, where this research focuses. For the entire Pamirs, early research on landscape evolution was firstly addressed through basic geomorphological mapping of the main features together with glaciological and geomorphological observations (Zabirov, 1955; Bazhev et al., 1971; Velichko and Lebedeva, 1973; Grosswald and Orlankin, 1979; Sidorov, 1979). Recently, similar issues to those examined in other high Asian mountains have been assessed, such as natural hazards, particularly GLOFs (Yerokhin, 2003; Schneider et al., 2004; Mergili and Schneider, 2011), hydrological modelling and river flow regimes (Chevallier et al., 2014; Pohl et al., 2015, 2017), landscape development and tectonic influence (Strecker et al., 2003; Fuchs et al., 2015), soil degradation and erosion processes (Golosov et al., 2015) and reconstruction of past stages of glacial retreat through terrestrial cosmogenic dating (Zech et al., 2005a, 2005b; Wang et al., 2011; Röhringer et al., 2012; Schoenbohm et al., 2014; Grin et al., 2016; Hedrick et al., 2017). However, some topics remain clearly understudied, such as frozen ground conditions, namely permafrost distribution and active layer dynamics which is only based on very scarce number of boreholes and mostly inferred from geomorphological observations (Zhao et al., 2010).

In Lenin Peak area, most of these topics have not been addressed, such as the role of glacial and periglacial processes on past and recent landscape dynamics. Some very general geomorphological issues were described in Czech language by Sekyra (1964, 1965, 1967) and, more recently, Reznichenko et al. (2017) focusing on the large hummocky deposits distributed across the Alai Valley – namely in the Achik-Tash catchment – remarked the need to reconsider their origin, highlighting the combined action of glacial processes and rock avalanches in their formation. However, until now no studies have examined the spatial distribution of processes and landforms of glacial and periglacial origin in this catchment as well as the role of frozen ground conditions, which is crucial to better understand past and present-day environmental dynamics in Lenin Peak area. Therefore, with the purpose of providing new knowledge on the geomorphological evolution in the area, we will give answer to the following issues:

- Introduce a geomorphological map of Lenin Peak area.
- Examine the arrangement of geomorphological features existing in the area and its relationship with Alpine soils.
- Infer the spatial distribution of permanently frozen ground based on geomorphic evidence.
- Discuss the processes and landforms observed in Lenin Peak area and compare them with the spatio-temporal sequence of environmental events occurred in the area since the last glaciation as well as in other surrounding mountain regions.

2. Study area

The Pamir Mountains include peaks exceeding 7000 m in the core of the central Asian mountain systems. They are located at the junction of the Himalayas with other large mountain ranges such as the Karakoram, Tian Shan, Kunlun and Hindu Kush. Administratively, they are distributed between Kyrgyzstan (W, N), China (E), Afghanistan (S), and Tajikistan (S, W).

The southern slope of the Pamir Mountains constitutes one of the largest centers of glaciation in Central Asia and includes some of the longest glaciers outside the Polar Regions, such as the Fedchenko glacier, which flows downslope along 77 km. There are ca. 10,000 glaciers in the Pamir Mountains, with a total glaciated area estimated to be around 12,100 km^2 (Khromova et al., 2006; Hoelzle et al., 2017). The Zaalai (or Trans-Alai) Range is the northernmost range of the Pamirs and includes several heavily glaciated mountains, with a glaciated surface of ca. 760 and 710 km^2 for the northern and southern slopes, respectively (Zabirov, 1955). Lenin Peak is its highest peak and divides Tajikistan (S) from Kyrgyzstan (N). This research focuses on the headwaters of the catchment located in its northern slope, from the highest lands until the Alai valley floor, a wide semi-arid intermontane basin running *E*-W at elevations between ca. 2500 and 3500 m where the Kyzyl-Suu River flows (Fig. 1).

The complex relief of the Pamir Mountains include several well-individualized massifs separated from each other by tectonic dynamics, high altitude valleys and high plateaus, as well as large rivers, endorheic basins and saline lakes. This dynamic terrain imposes substantial differences in terms of precipitation and temperatures, and therefore on prevailing environmental dynamics. In general, the Pamir Mountains are characterized by an extremely dry and cold climate. Precipitations range from 100 to 600 mm between the Eastern and Western Pamirs, mostly concentrated during winter and spring seasons (Zhang and Kang, 2017), with the moisture brought by the westerlies (Böhner, 2006). A relative close high-altitude meteorological station at Karakul lake (3929 m), located in the southern side of the Zaalai Range, reports a Mean Annual Air Temperature (MAAT) of −3.9 °C, ranging from average monthly temperatures of −18.1 °C in January and 8.5 °C in July, with a highly variable mean annual precipitation of 82 mm (Heinecke et al., 2017). Similarly, in the Alai Range, at the Abramov Glacier Meteorological Station (3837 m) the MAAT is −4.2 °C with a higher annual precipitation of 1000 mm (Pertziger, 1996).

Present-day geomorphological dynamics in the study area is manly conditioned by glacial and periglacial processes, although the impact of catastrophic rock falls in the study area have been also recently examined by Reznichenko et al. (2017). The high solar radiation enhances ablation rates and determines the level of the Equilibrium Line Altitudes (ELAs) at elevations where MAAT are well-below freezing, generally