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Jesús RUIZ-FERNÁNDEZ [1*] & Marc OLIVA [2]

GEOMORPHOLOGICAL PROCESSES IN THE ALA ARCHA NATIONAL PARK (KYRGYZSTAN, TIAN SHAN RANGE)

Abstract: Ruiz-Fernández J. & Oliva M., *Geomorphological processes in the Ala Archa National Park (Kyrgyzstan, Tian Shan Range).* (IT ISSN 0391-9838, 2019).

The Ala Archa National Park includes a wide range of geomorphological processes and landforms from the lowlands to the highest peaks. Here, we examine the distribution of geomorphological processes and landforms in the central part of the Tian Shan mountain range, Kyrgyzstan. Late Pleistocene glaciers shaped the landscape of the highest lands and left a moraine complex (M1) at the foot of the Ala Archa area at an elevation of 1580 m. The process of deglaciation followed different stages that favoured the individualization of glaciers within their respective valleys, with several moraine complexes (M2 and M3) distributed at elevations between 1680 and 3900 m. Today, debris-covered glaciers and rock glaciers constituted the lowest parts of the current glaciers, with their fronts located between 3350 and 3670 m. All these glacial features are being intensely reshaped by periglacial, alluvial and mass wasting processes on the steep slopes of this valley. The wide variety of landforms and sedimentary records existing in the area allows inferring a sequence of several environmental and climatic stages since the Late Pleistocene. Finally, the distribution of present-day geomorphological processes and active landforms identified in the Ala Archa National Park allowed establishing four morphodynamic belts: montane forests (<2000 m), subnival (2000-2800 m), nival (2800-3200 m), cryonival (>3200 m, excluding glaciated areas), and glacial (>3350 m between the glacier fronts and the highest peaks).

Key words: Tian Shan, Ala Archa National Park, Geomorphology, Quaternary.

INTRODUCTION

National Parks stand as protected areas which aim at preserving both the geomorphology and geology (geodiversity) as well as wildlife (biodiversity) (Gray, 2011). In the context of mid-latitude mountains, many of these protected natural spaces correspond to high mountain areas, whose ecosystems and cultural and historical heritage must be preserved for future generations (Panizza & Piacente, 2003; Gómez-Ortiz & *alii*, 2013).

In certain mountainous countries of Central Asia, the number of protected natural spaces – especially of National Parks – is still scarce, particularly when the large extent of this mountainous sector, as well as its great natural heritage are taken into account. However, in line with an important effort aimed at openness and modernisation, some countries from this region are changing lately their policies regarding nature protection, instituting new protected natural spaces at a fast pace. This is the case of Kyrgyzstan, where there are 13 National Parks (5 of them very recently instituted, between 2009 and 2016), in addition to many other protected areas under forms such as Nature Reserve, Nature Monument, etc. Nevertheless, in many cases, the listing under the form of National Park has been linked – especially in the past – more to recreation and leisure activities due to their being close to major population centres than to the real protection of their geoecological heritage (Shokirov & *alii*, 2014). This is the case of the Ala Archa National Park, whose geodiversity has barely been studied so far, and has only been analysed through thematic approaches (e.g. Aizen & *alii*, 2007a; Zaginaev & *alii*, 2016) or marginally within the context of broader works (e.g. Koppes & *alii*, 2008; Xu & *alii*, 2010).

With the aim of complementing the existing partial knowledge up to now on the geomorphology of the Ala Archa National Park and enhancing the need to preserve its geoecological heritage, this article focuses on the study of the distribution of the existing geomorphological landforms and processes in this National Park, as well as its past and current dynamics, which allows us to infer the environmental and climatic conditions that shaped the configuration of this Central Asia high mountain landscape.

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STUDY AREA

The study area is located in the Tian Shan or Tien Shan Mountain Range, a great range in Central Asia which, together with other close ones such as Karakorum, Hindu Kush, Pamir and Kunlun, made up an important mountain knot which connect the western spurs of Himalaya (fig. 1). All these ranges have risen as a result of the convergence of the Indian and Eurasian continental plates (Yin & Harrison, 2000). The Tian Shan range, whose highest peaks are over 7000 m (Pico Poveda or Jenglish Chokusu being the highest summit with 7439 m), consists of individual minor mountain ranges, with raised and sunken blocks (horst-graben) which single out large valleys, some of which are taken up by great lakes of tectonic origin (e.g. Issyk-Kul). This range spreads over Kyrgyzstan, Kazakhstan and China along 2500 km, flanked South by Taklamakan Desert (Tarim Basin) and North by Kazakhstan plains and steppes.

Within this range, the study area is located on the Kyrgyz Alatau or Kyrgyz Range, and in particular on the Ala Archa valley (Kyrgyzstan), declared National Park in 1976 (74° 24′ E – 74° 34′ E; 42° 25′ N – 42° 40′ N). It is an mountainous sector whose highest summit is Semenova Peak (4895 m) and which in 2003 comprised a glacier area of 3630 ha (Aizen & *alii*, 2007a). The Tian Shan climate is conditioned by its marked continental characteristics (~2000 km away from the ocean in any direction), and low winter temperatures due to the influence of the Siberian High. The Ala Archa area receives >1000 mm/yr precipitation, concentrated on spring and summer months (almost 50% of the yearly precipitation is registered between the months of April and June (Aizen & *alii*, 2007a; Koppes & *alii*, 2008), due to the humidity derived from the westerly circulation and the convective rains of the warm season. In the Ala Archa valley, the average yearly temperature at 760 m is 10.6 °C, with monthly average temperatures between -4 and 24 °C. For the entire Tian Shan range, yearly average temperature ranges from 2.1 °C at ~2000 m and -7.1 °C at ~4000 m (Xu & *alii*, 2010).

These climatic conditions allow the development of vegetation dominated by trees such as *Picea schrenkiana* and *Juniperus semiglobosa*, and by herbaceous (steppe) and bush species. Local lithology consists mainly of granites, granitoids, schist and sedimentary rocks (Koppes & *alii*, 2008; Przhiyalgovskii & Lavrushina, 2017). Finally, it is worth mentioning that the Ala Archa area is drained by the homonymous river and two tributaries, the rivers Adygene and Aksay (fig. 1).

METHODOLOGY

This contribution studies the geomorphological setting of the Ala Archa National Park. Fieldwork comprised detailed observation of landforms and sediment records, as well as taking photographs and GPS measuring of the landforms to ascertain heights, lengths, widths, etc. Fieldwork was carried out in August 2017, when the snow free terrain enabled optimal observation of the geomorphological features. These observations were completed with a vertical profile where the main morphogenetic environments existing in the area are gathered. Data were supported by

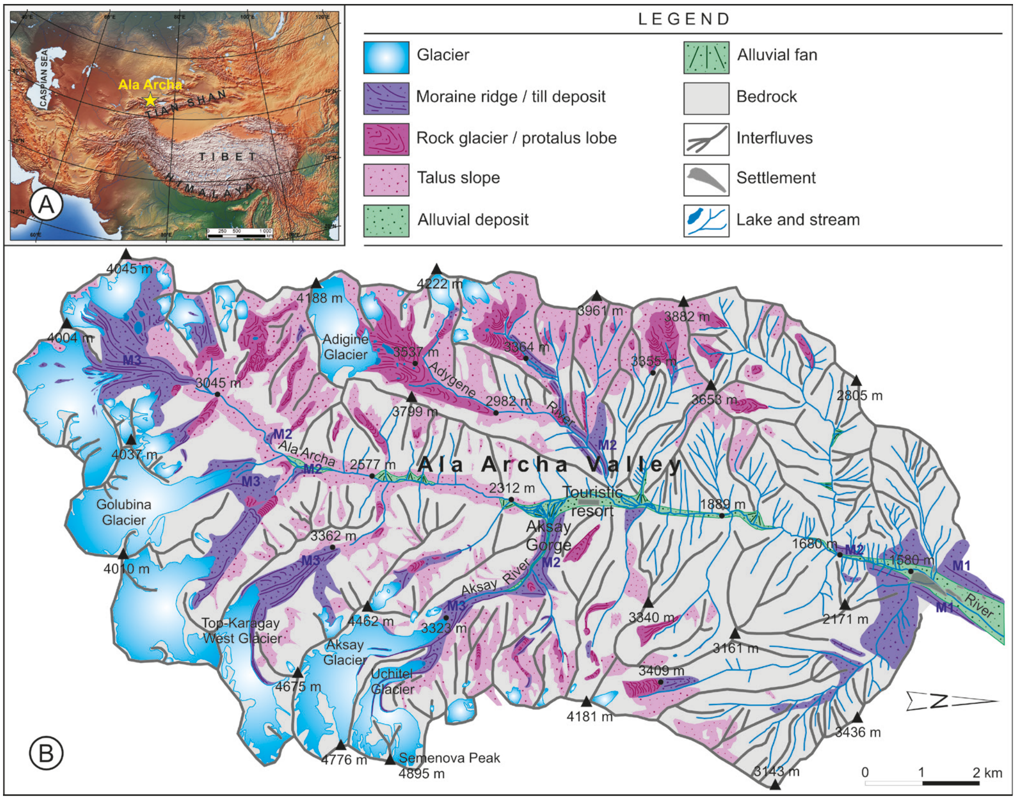

FIG. 1 - (A) Location map of the Ala Archa area within the Tian Shan range and Central Asia, and (B) geomorphological sketch of the study area.

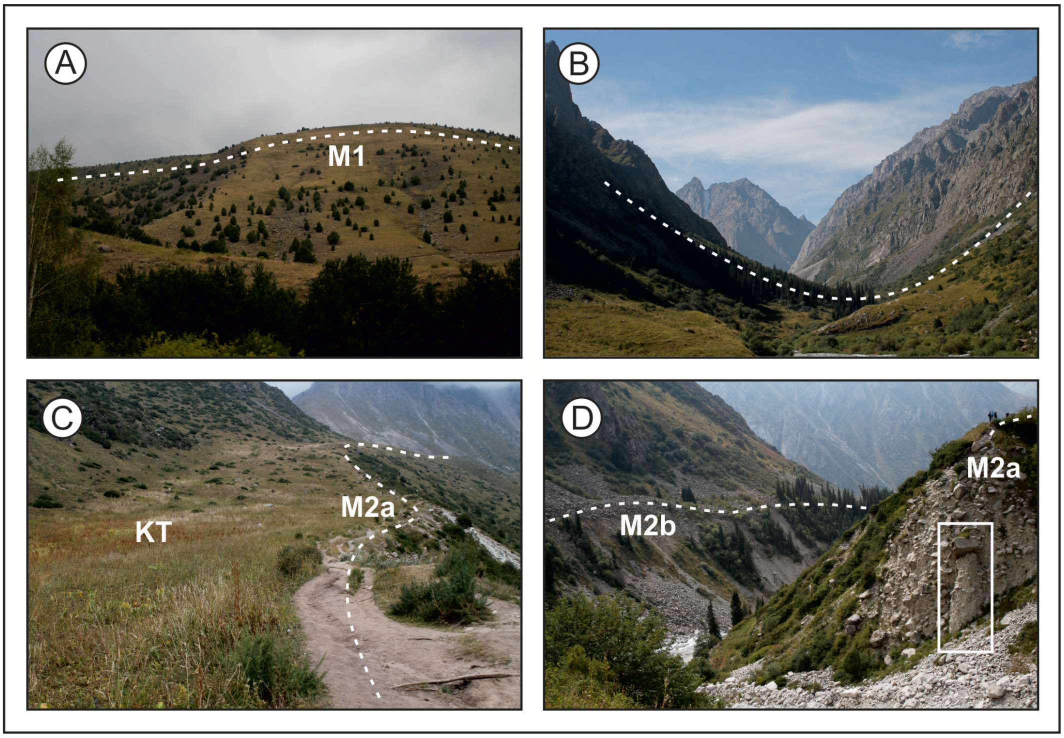

FIG. 2 - Examples of glacial landforms in the study area. (A) Terminal moraine (M1) at the entrance of the Ala Archa National Park. (B) Glacial trough with U-shaped cross profile in the intermediate sector of the valley. (C and D) Internal moraine complexes (M2a and M2b) with associated kame terrace (KT) and ephemeral features such as a fairy chimney, generated in till (see white box).

the images of this sector from Google Earth image repository, in particular from the years 2003, 2006, 2012, 2013, 2014, 2015 and 2017, which were used as the basis for areas calculations and the execution of the geomorphological skecht included in fig. 1.

RESULTS

The Ala Archa area constitutes a high-altitude mountain environment, whose current landscape has been significantly shaped by Quaternary and present-day glaciers. Postglacial periglacial dynamics and nival processes have also had a great imprint in the landscape of the highest elevations. Within formerly glaciated sectors, periglacial belt has retreated to higher altitudes at the same time that the glacial belt has shrunk compared to the Maximum Ice Extent (MIE) of the Last Glaciation. In turn, the abundance of unconsolidated sediments and the wide vertical gradient between the high summits (~4800 m) and piedmont areas (~1500 m) have enhanced the reshaping of glacial landforms through fluvial, torrential and slope processes (tab. 1). The following sections elaborate on both the processes (past and current) and the landforms identified in the study area according to their morphogenesis.

Glacial processes and landforms

In the Ala Archa National Park we have identified three main generations of moraines (figs 2, 3):

EXTERNAL VALLEY MORAINES (M1) - The terminal moraines are found at 1580 m, at the entrance of the Ala Archa National Park through the valley floor, a topographic area of very gentle slope (~5°) (fig. 2A). The moraine complex is very large, consisting of two major moraine ridges located on both margins of the valley, as well as other minor ones, all of them reshaped by slope, fluvial and torrential processes. The lengths of the major moraine ridges range from 1.4 km in the case of the shortest one to 2.1 km in the longest one, while the widths range between 170 and 430 m. These moraines consist on heterometric blocks of 0.5-3 m of diameter which appear scattered on the surface, drawing a clear contact with the non-glaciated area during the Last Glaciation, where blocks do not appear. In both cases, these moraines are located 110-140 m above the current river course (1470 m), although on their distal section their height gradually diminishes downriver. This moraine complex is located 25 km away from the current glacier front and 28 km from its head.

Upriver the terminal moraine complex, the main valley has a clear U-shaped profile, which keeps up to the head with a distance of 0.8-1.4 km between both slopes (fig. 2B), reaching the furthest distance in the intermediate sectors of the valley. The secondary major valleys have equally transversal U-shaped profiles, getting narrower at higher levels (distance between both slopes raging between 0.6 and 1.2 km).

INTERNAL VALLEY MORAINES (M2) - The internal moraine complexes are located at higher elevations than the former, both along the main valley, as well as the front section and the side slopes of tributary valleys, at elevations ranging between 1680 and 2700 (fig. 1). Indeed, the slopes of the Ala Archa valley are covered in till in several sections of their lower and middle areas, as it happens in the surrounding areas of the touristic resort located at the entrance of the Ala Archa, as well as along the trekking track

TABLE 1 - Geomorphological landforms identified in the Ala Archa National Park.

Morphogenetic system	Landforms and deposits	Main characteristics, distribution and dimensions
Glacial landforms	Moraines	Ridges and arches of glacial origin with lengths of 100 to 2100 m, widths between 50 to 430 m, and heights between 4 to 140 m. They are located along the main valley and the tributary valleys.
	Till deposits	Sedimentary accumulations of glacial origin without defined morphology and with variable extension. They are located in intermediate and low sectors of the main valley and several tributary valleys.
	Erratic blocks	Boulders of granites and granodiorites of 0.5-5 m of diameter, located in flat areas of the slopes and bedrock plateaus.
	Glacial troughs	Valleys with U-shaped profiles generated by glacial erosion located along the main valley and the tributary valleys. The distance of both slopes ranged between 0.6 and 1.4 km. The maximum length is 21 km in the case of the Ala Archa main valley.
	Roches mountonnées	Convex features of decametric dimensions generated by glacial erosion on bedrock areas. Rocky sectors close to the present-day glaciers.
	Kame terraces	Flat areas of decametric/hectometric dimensions generated between slopes and morainic ridges, in the distal and intermediate sectors of the valleys. They are integrated by fine-grained size sediments of lacustrine origin.
	Glaciers	In Ala Archa there are 48 glaciers (10 valley glaciers and 38 cirque glaciers) which cover an area of 3586 ha. The biggest glacier (Golubina Glacier) has an area of 550 ha, while the smaller glaciers have areas from ca. 0.5 to 1.5 ha. Present-day glacier fronts are located between 3350 and 3670 m of altitude.
	Proglacial lakes	These lakes are dammed by moraine ridges. They are ephemeral landforms, generated recurrently in many cases glacial lake outburst floods (GLOFs).
Periglacial and slope landforms	Rock glaciers	Permafrost-related landforms composed by arcuate ridges and furrows. They are preferably located at the bottom of glacial cirques, connecting with present-day glaciers, moraines or talus slopes. They present different degree of activity depending on their location, and their dimensions are very variable (~70-0.5 ha).
	Protalus lobes	Permafrost-related features of small dimensions (0.3-2 ha) located at the foot of the slopes, connecting talus cones with the bottom of glacial cirques and valleys.
	Talus slopes	Deposits of coarse sediments at the foot of the cliffs. The rocks surfaces show a transition from poor (in highest areas) to high vegetation colonization (in moderate altitude areas).
	Patterned ground features	Landforms of centimetre size (sorted-circles and stripes) formed in areas with fine-grained sediments and gentle to moderate slopes (4-21°).
	Snow avalanche channels	The steep slopes of this valley favor the existence of channels of hundreds of metres through which snow and sediments are transferred downslope.
	Solifluction landforms	Solifluction processes mobilizing slope sediments affected by frost shattering. Several morphologies such as turf- and stone-banked lobes and terracettes (0.1-0.5 m height, 1-5 m long) were observed along the steep slopes.
	Rockfalls	Large accumulations of angular and heterometric blocks fallen from the scarps and sloping rocky outcrops.
	Landslides	Erosive scars and convex accumulations of debris (decametric to hectometric dimensions) located in the middle and lower parts of the slopes. While above the timberline they are fully active, below this level they are usually inactive.
	Debris flows	They are composed by erosive channels in the middle and proximal areas and by accumulations of coarse and fine-grained sediments in the distal sectors. They constitute an efficient system of transport of sediments along the slopes from the upper morphodynamic belts to those below. Highly variably size, from some meters to hundreds of metres.
Alluvial landforms	Anastomosed bed	In areas of greater bed width, the Ala Archa river has variable number of wandering channels, separated by deposits of boulders (maximum diameter of 1-2 m), cobbles and pebbles with abundant fine matrix.
	Grooves and gullies	Channels generated by retrogressive erosion in areas of unconsolidated sediments of the slopes (mainly on morainic deposits). They have variable dimensions and constitute landforms in constant evolution.
	Alluvial fans	The reworked moraine and slope sediments transported down-valleys by mass wasting processes form fan-shaped deposits of decametric to hectometric dimensions. They are composed mainly of coarse material, being frequent boulders of more than 1 m of diameter. They are located in the contact area between the main valley and the tributary valleys. The dynamics of some alluvial fans are conditioned by the unleashing of GLOFs.

that climbs towards the head of the valley. Additionally, in the contact between some tributary valleys and the main one, moraine arches and lateral moraines have been identified, with some examples of intermediate moraines. This is the case, for instance, of the moraine complex located at the bottom of the main valley at 1680 m and 24 km away from the head. In this area some remains of an intermediate moraine are preserved, thus showing the coalescence of the tributary valley with the main one, as well as a morainic arch very blurred as a result of post-glacial fluvial erosion (fig. 1). Within the secondary glacial valleys there are other moraine complexes of different thickness and volume, such as the originated on the right and left slopes of the Aksay gorge between ca. 2370 and 2700 m (M2a and M2b; fig. 2C, 2D), which also generated a kame terrace.

HIGH MOUNTAIN MORAINES (M3) - Above 2800 m up to 3900 m (in the case of the highest deglaciated cirques of the Ala Archa valley NE sector) several generations of recent and currently active moraines develop (figs 1 and 3A). Between 2 and 3 external moraines have been identified, completely disconnected from the glacier front by hundreds of metres (300-1200 m), as well as 2-3 internal moraines which progressively lose thickness and are generally in contact with glacial ice (e.g. M3a and M3b in fig. 3A). Both features correspond to moraine ridges connected with the slopes, and consisting of coarse sediments (essentially boulders and cobbles of granites and granodiorites), as well as abundant fine-grained size particles. In every case there is an almost total lack of vegetation and they are subjected to an intense remobilisation and readjustment of their sediments through very active slope dynamics, mainly driven by mudflows and debris flows. This is particularly intense in proglacial environments, with dead ice already disconnected from the glacier and covered by debris.

PRESENT-DAY GLACIERS - There are 48 subsisting glaciers in the Ala Archa valley (Bolch, 2015), which in 2017 covered a total surface of 3586 ha, 1.2% less glacial extension according to 2003 data calculated by Aizen & *alii* (2007a). Out of them, 10 are valley glaciers (fully developed in some cases, unclear in others), while the rest are cirque glaciers. The biggest glacier of the Ala Archa valley is Golubina Glacier, which had an area of 550 ha in 2017, and 580 ha in the year 2003 according to Aizen & *alii* (2007a). The seven largest glaciers of the Ala Archa valley occupy in 2017 an area of 2908 ha (81% of the glaciated surface in this National Park). On the contrary, nine glaciers have a very limited surface, from ca. 0.5 to 1.5 ha. The glacier fronts are currently located between 3350 and 3670 m. The front of the glacial tongues is usually covered by debris, creating debris-covered glaciers in their final sections (e.g. Top-Karagay West Glacier). In these sectors ice ablation is intense, often leaving sectors of dead ice disconnected from the existing glacier and covered by till (fig. 3B). In a dozen cases the debris cover of the current glacier fronts in the Ala Archa National Park has evolved to the point of generating glacier-derived rock glaciers (e.g. Adigine Glacier in fig. 1). Additionally, in these environments some pro-glacial lakes have formed, dammed by morainic ridges. Some of these lakes have recently generated glacial lake outburst floods (GLOFs) and related large debris flows (e.g. the Aksay catchment; Zaginaev & *alii*, 2016).

On the other hand, melting waters coming from glaciers feed proglacial streams that rework glacigenic deposits left by previous glacial stages, as well as the newly deglaciated areas.

Periglacial and slope processes and landforms

The steep gradient of the valley hillsides (with a gradient higher than 30-40°) enhances slope processes such as landslides and rockfalls (tab. 1). In the lower areas of the Ala Archa valley these kind of mass movements (landslides, rockfalls, debris flows, mudflows) are inactive or show a limited activity, favoured by the development of the forest. However, above the timberline, rapid mass movements are frequent and active, since unconsolidated glacial and periglacial sediments have plentiful erosion scars and associated deposits, fresh and devoid of vegetation.

Present-day cryogenic processes are active from approximately 2000 m to glaciated areas. Seasonal frost regime exists in this environment, which shows negative monthly mean air temperatures between November and March. However, its impact on present-day landscape dynamics is very limited, with the existence of inactive to very weakly active landforms (see tab. 1). Around 2000 m, the environment is subjected to certain degree by snow dynamics, namely by the existence of snow avalanche tracks (or debris flow channels occasionally used as avalanche tracks). During the cold season and from higher levels, snow avalanches break into the forest belt hundreds of metres in the slope (fig. 4A). However, the snow avalanche tracks, covered in herbaceous and even bushy vegetation, barely

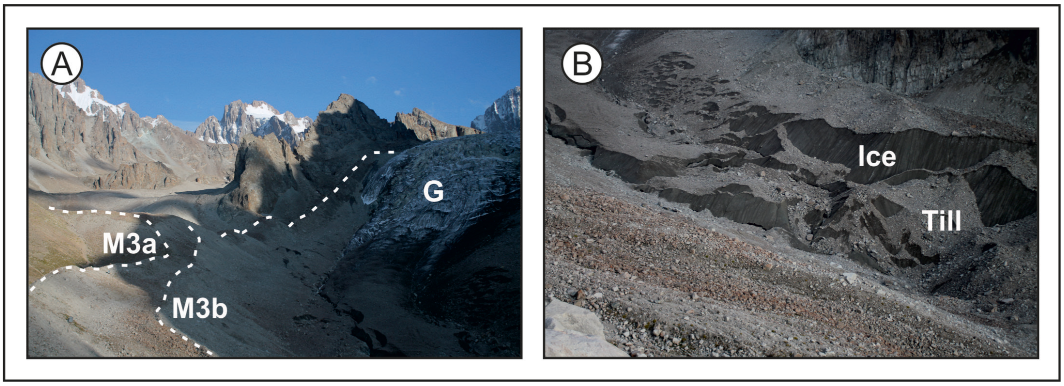

FIG. 3 - Glacial features of the Aksay Glacier. (A) High mountain moraines (M3a and M3b), and (B) debris-covered dead ice.

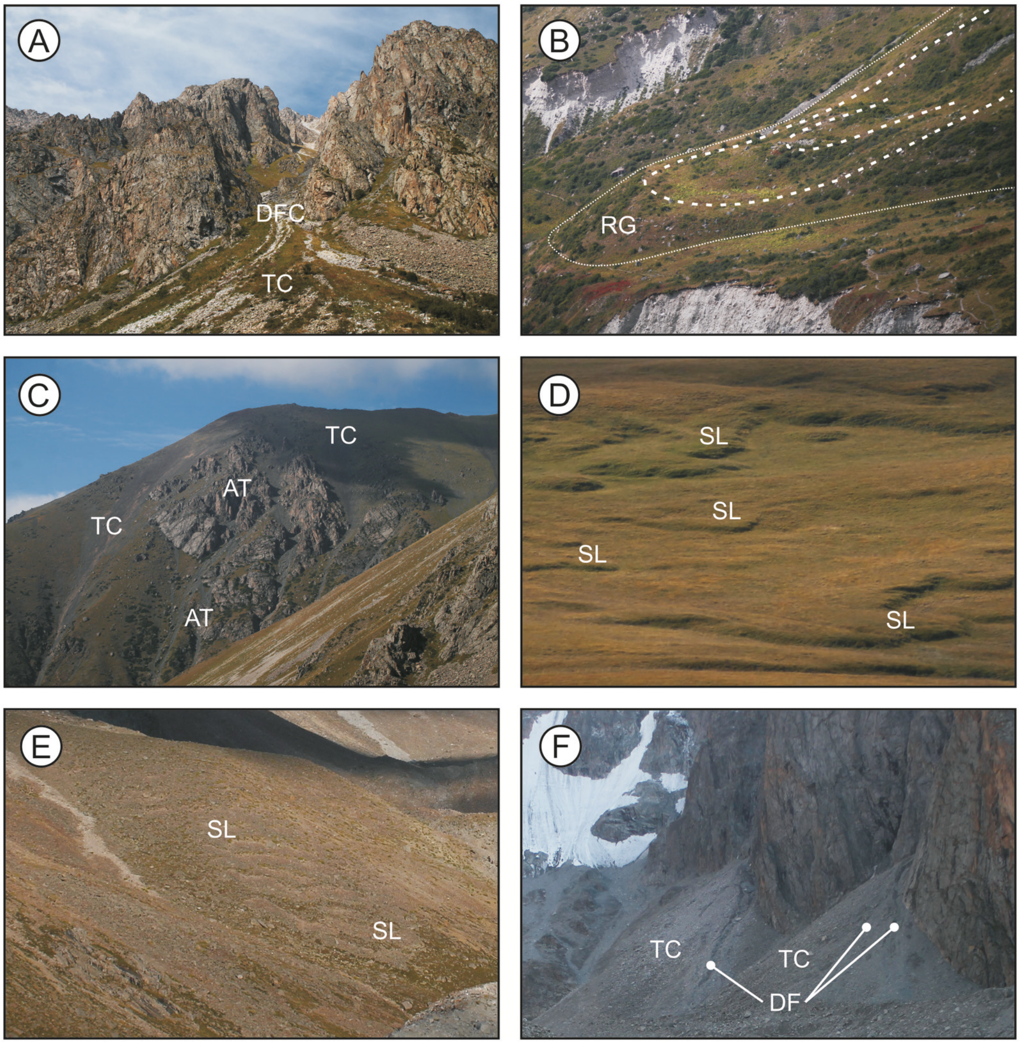

FIG. 4 - Examples of periglacial landforms in middle (A and B) and high mountain environments (C, D, E and F). Abbreviations: debris flow channel (DFC), avalanche track (AT), talus cone (TC), relict rock glacier (RG), solifluction features (SL), and debris flows (DF).

have current associated deposits, and there is no trace in them of intense recent activity. On the valley floors, talus slopes are inactive. Several relict rock glaciers have also been identified, totally covered by vegetation, in the slopes of the main valley and other tributary valleys. Their fronts are at altitudes between 2620 and 2730 m (fig. 4B).

Below 2400-2500 m, the activity of talus slopes is very weak as shown by the high degree of bush colonisation (even tree colonisation in some cases). Although the degree of activity depends on the slope, the altitude and the existence of acutely weathered vertical walls productive in sediments. At these elevations, the proximal and middle sections of the talus slopes are those showing higher activity, linked to the track of snow avalanches, debris flows and rockfalls from higher sectors (figs 4A, 4C). Above these altitudes, geomorphological dynamics of talus slopes increase.

From 2500-2700 m solifluction is active in fine-grained sediment slopes, both on lower areas covered by herbaceous vegetation (fig. 4D) and on higher parts, within deglaciated cirques and non-glaciated areas of the highest cirques of the Ala Archa valley (fig. 4E). Here, solifluction lobes develop on the unstable slopes of recent moraines and slope deposits, devoid of vegetation.

Between 3000 m and the highest sectors of the Ala Archa valley non-glaciated areas it is possible to find active talus slopes, mostly devoid of vegetation (fig. 4F). There, sediments are mobilised by several processes (snow avalanches, debris flows, solifluction, water runoff, etc.). In high sectors, sediment readjustment in recent and currently active moraines generates abundant rapid mass movements, such as debris flows, landslides and rockfalls. Similarly, unconsolidated sediments of glacial origin are redistributed downslope through other processes such as water runoff and solifluction (tab. 1), as revealed by the existence of turf- and stone-banked lobes and terracettes (Matsuoka, 2001; Matsuoka & *alii*, 2005; Oliva & *alii*, 2009; Oliva & Gómez-Ortiz, 2011). Thus, this is a very dynamic and unstable environment, due to the prevailing morphoclimatic conditions along with the marked steep gradient of the slopes. Steep slopes do not favor the formation of patterned ground features, but for some tiered ledges in the slopes and in flat summit areas of some interfluves.

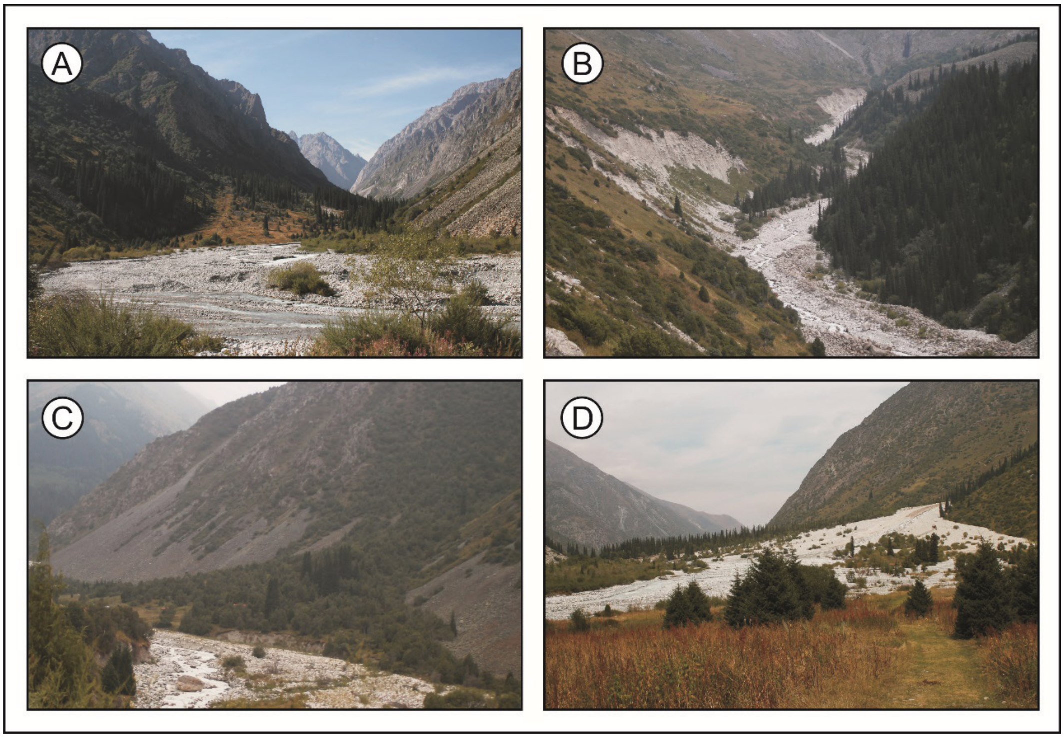

FIG. 5 - Examples of alluvial landforms. (A) Anastomosed bed, (B) basal erosion generated in sediments of glacial origin and related mass wasting processes, and (C and D) relict and present-day alluvial fans.

In addition, above 3000 m there are abundant rock glaciers and protalus lobes with different degrees of activity (fig. 1). While the lower ones are colonised by plant communities, most of these features are completely devoid of vegetation and show very fresh morphologies (i.e. very marked ridges and furrows). The dimensions of these landforms vary significantly, with surfaces ranging between ~70 ha for the most extensive rock glaciers and 0.3 ha of some protalus lobes. Above 3000 m there is a transition from an environment defined by the existence of seasonal frozen ground to another defined by the existence of permafrost. However, permafrost and seasonal frozen ground processes may also coexist in the same altitudinal interval, depending on microclimatic conditions constrained mainly by local topographic factors (slope, aspect, sediment grain-size).

Alluvial processes and landforms

The Ala Archa river has a high energy and particle mobilization capacity, and, therefore, able to mobilize boulders of 1-2 m in diameter, as seen in numerous sectors of the present-day alluvial deposits, completely devoid of vegetation. The water flow carry an abundant load of suspended fine particles (glacial flour), which gives water a milky colour. Downriver the National Park, by the main villages the river goes through, river gravels are used as filling material for building purposes. In the sectors within the National Park where the valley is wider, the Ala Archa river presents an anastomosed bed, creating a variable number of wandering channels (fig. 5A).

On the other hand, undercutting generated in deposits of glacial origin by the river courses has increased in some cases due to GLOFs action. This erosion in the bottom parts of glacial deposit edges has caused the creation of grooves and gullies through retrogressive erosion, as it happens in the lateral moraines at both sides of Askay Gorge, in the section flows between 2370 and 2540 m. This also contributes to trigger rapid mass movements (fig. 5B).

The intense erosion and sediment mobilisation has created numerous alluvial fans at the convergence of the tributary valleys with the Ala Archa main valley (fig. 1; tab. 1). Many alluvial fans are inactive (fig. 5C), but in other cases they are fully active. Among them, there is a large fan located between 2250 and 2320 m at the bottom of the main valley at the convergence with Askay Gorge (fig. 5D). This fan has a fully active sector whose dimensions are ca. 460 m at its maximum length and 437 m at its maximum width, with an area of 9 ha. However, most of the area of this alluvial fan is inactive, with the exception of some parts that have channels which would sporadically become active when GLOFs coming from the frontal sector of Askay Glacier are triggered (Zaginaev & *alii*, 2016). This area, located above the present-day river course and colonised by vegetation, reaches larger dimensions than the former one (1310 m wide by 760 maximum length, with 28 ha of surface).

DISCUSSION

Past geomorphological dynamics

The glacial evidence remaining in the Ala Archa valley have allowed us to establish three main moraines generations: (I) M1 – external valley moraines; (ii) M2 – internal valley moraines, and (iii) M3 – high mountain moraines.

M1 constitutes the largest moraine complex in terms of volume of all the existing in the Ala Archa valley. Its front is located 1580 m in the surroundings of the entrance of the National Park at the bottom of the valley. Despite this moraine complex being remodelled by fluvial and torrential dynamics as well as slope processes, the moraine ridge retains perfectly its morphology, which suggests that it might belong to the MIE of the Last Glaciation. On the other hand, the M2 moraine complexes are widely spread along the main valley and the tributary valleys slopes, within altitudes from 1680 to 2700 m. They constitute relict landforms covered by herbaceous communities, bushes and even trees, and they are frequently affected by rapid mass movements and water runoff, generating grooves and gullies by means of retrogressive erosion. The existence of successive moraine complexes with the aforementioned characteristics to gradually higher levels, show that a progressive disconnection between the great glacier channelled from its head and its tributary glaciers occurred, as well as a gradual regression of the glacial tongues (which over time became individualised), interrupted by pulses of interspersed glacial advances.

The high mountain moraines (M3, >2800 m) are typified by their closeness to present-day glacier fronts, at distances between 300 and 1200 m, and their scarce or non-existent plant colonisation. Despite the intense paraglacial activity that occurs in them nowadays, they still present well defined morainic ridges, which suggests recent formation. Among M3 moraines, the most external ones would be linked to recent glacial stages, such as the Little Ice Age (LIA), whereas more internal moraines, located near the present-day glacier fronts, are of recent and present-day formation. This interpretation is reinforced by the results from both datings of Cosmic-Ray Exposure (CRE) based on isotope ^{10}Be performed in moraines of the Aksay Gorge of the Ala Archa area at 3180 and 3246 m, resulting in 0.54 and 0.24 ka respectively (Koppes & *alii*, 2008; Xu & *alii*, 2010). These data match with the work of Aizen & *alii* (2007a), according to which, since the end of the LIA to the beginning of the 20th century, the Ala Archa glaciers retreated an average of ~1 km; their fronts retreated from 2800 m to higher than 3100 m. On the other hand, Solomina & *alii* (2004) reach similar conclusions from aerial photographs, historical information and lichenometry, establishing for the whole of the Tian Shan range an average shrinking rate of the glaciers since LIA maximum of 989 ±540 m, with an increase of glacier fronts altitude of 151 ±105 m.

Regarding the timing of deglaciation, only two datings have been carried out in the Ala Archa valley (Koppes & *alii*, 2008; Xu & *alii*, 2010). Thus, from a geochronological perspective, there is an important knowledge gap in this valley. In other sectors of the Tian Shan range, absolute dates are also scarce in number, as well heterogeneous in the techniques employed (CRE, Optical Stimulating Luminescence, Electron Spin Resonance, ^{14}C and lichenometry). These dates suggest the existence of old stages of glacier advance, ranging from 471 to 418 ka, and, therefore, within the Marine Isotope Stage 12 (MIS-12), from 134 to 219 ka (MIS-6) and from 72 to 108 ka (MIS-5) (Zhou & *alii*, 2001; Zhang & *alii*, 2006; Koppes & *alii*, 2008; Zhao & *alii*, 2009, 2015; Xu & *alii*, 2010). Geochronological data obtained by several authors suggest that the MIE of the Last Glaciation in these mountains predates the LGM, with a reported age of 58-71 ka (MIS-4) in the eastern and central parts of the Tian Shan range, and between 30 and 56 ka (MIS-3) in the western sector (Koppes & *alii*, 2008; Narama & *alii*, 2009; Zech, 2012; Zhao & *alii*, 2009; 2015; Xu & *alii*, 2010). However, for Li & *alii* (2014), who recalculated all CRE ages published in previous works on this range using CRONUS Earth 2.2 calculator, the MIE took place across the Tian Shan range during MIS-4 (56-77 ka), with glacier advances as well during MIS-3 both in the eastern and western sectors of the Tian Shan range, within an age range from 37 to 53 ka (Li & *alii*, 2014). Synchronous glacial advances with the LGM have also been dated (17-28 ka, MIS-2; Narama & *alii*, 2007; Koppes & *alii*, 2008; Kong & *alii*, 2009, Xu & *alii*, 2010; Zech, 2012; Li & *alii*, 2014; Zhao & *alii*, 2015), as well as with the Late Glacial (~11-14.1 ka, MIS-1; Abramwski & *alii*, 2006; Zech, 2012; Li & *alii*, 2014), the Early Holocene (~9 ka, Kong & *alii*, 2009), the Neoglacial (3-7.6 ka; Yi & *alii*, 2004; Koppes & *alii*, 2008; Xu & *alii*, 2010; Zhao & *alii*, 2015) and the LIA (0.2-05 ka) (Chen, 1989; Yi & *alii*, 2004; Zhao & *alii*, 2009, 2015; Koppes & *alii*, 2008; Xu & *alii*, 2010; Stroeven & *alii*, 2013; Li & *alii*, 2014).

In other close ranges, such as the Pamir, ages obtained for the main stages of glacial evolution are different. For instance, in Waqia valley, located in the Chinese Pamir, Hedrick & *alii* (2017) have identified glacial advances between 103 and 208 ka (MIS-6/older to MIS-5; moraine complexes 1 and 2); new glacier advances occurred at ~55 ka and between 15 and 30 ka (MIS-4 to late MIS-2; moraine complexes 3 and 4), as well as between 8-15 and 2.1 ka (MIS-1; moraine complexes 5 and 6). In Muksu catchment (Northern Pamir), Grin & *alii* (2016) detected a massive deglaciation stage in 17.5 ka, that is, towards the end of LGM (MIS-2), through the use of CRE (^{10}Be). On the other hand, Narama (2002) dates by ^{14}C several moraines of Raigorodskogo Glacier, located also in the Pamir range, thus showing the existence of moraine formation stages during the Late Holocene, similar to those detected in the Tian Shan range between 1.5-3.2 ka, 0.3 ka (LIA), and during the 20th century, when three generation of recent and present-day moraines were formed, composed by fresh sediments and devoid of vegetation.

In addition to landforms and deposits of glacial origin, in the Ala Archa National Park there are abundant relict mass movements preserved (rockfalls, landslides, debris flows), particularly under the timberline. Many of these landforms, developed in the lateral slopes of the main valley and in some of the tributary ones, are possibly of paraglacial origin, due to the debutressing of rock slopes occurring after the gradual glacial retreat. But the deglaciation of lower and intermediate parts of the Ala Archa valley throughout the Pleistocene and Holocene had also other implications, favouring the gradual rise of the morphodynamic belts located below the glaciated area, until they reached the present-day evelation. As a result of this altitude rise of active processes and landforms derived from nival and periglacial dynamics, many periglacial landforms

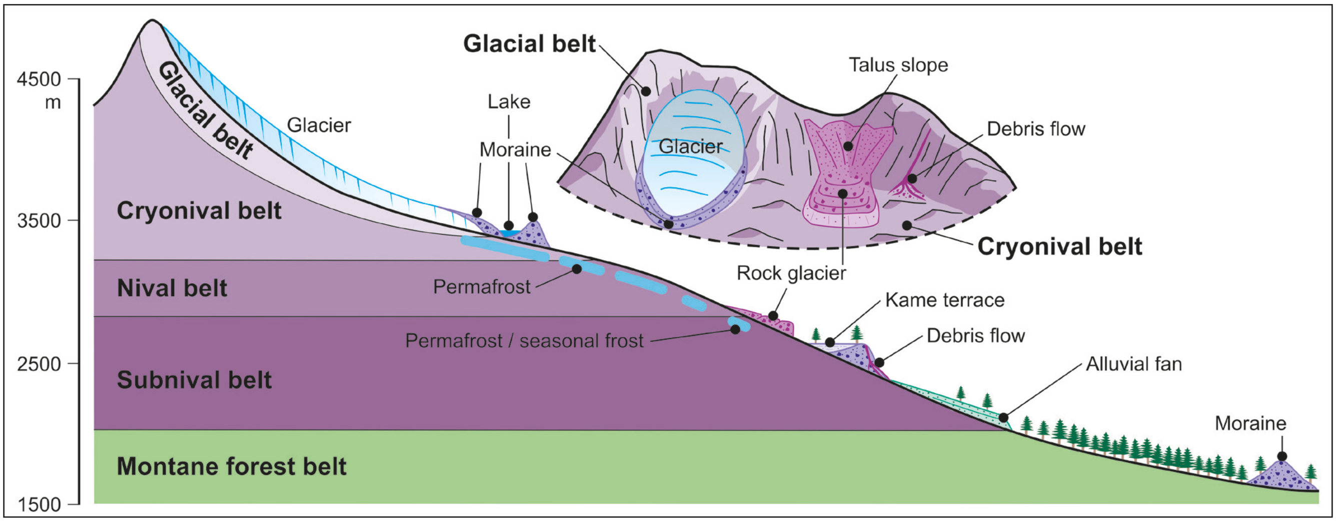

FIG. 6 - Sketch with the distribution of the five morphodynamic belts and the main geomorphological features identified in the study area.

at lower altitudes are currently relict, or they show very weakened dynamics.

This is the case of several rock glaciers identified below 2700-2800 m, which are usually fully vegetated. Currently, sporadic permafrost can exist in the Tian Shan range above 2700-2800 m (depending on topography, slope, geomorphological context, etc.) although above 3200-3300 m it becomes widely present (Marchenko & *alii*, 2007; Zhao & *alii*, 2010; Bolch & Gorbunov, 2014; Duishonakunov, 2014). However, it is estimated that during LIA, permafrost altitude distribution was 200-300 m lower than today (Marchenko & *alii*, 2007). Thus, relict landforms inherited from colder stages such as LIA are relatively common in the subnival belt, even though active rock glaciers are far more numerous that relict ones; as it occurs for instance in Ile and Kungöj Alatau (northern Tian Shan range), where 429 active and 75 inactive rock glaciers and 422 active and 108 inactive rock glaciers have been identified respectively (Gorbunov & *alii*, 1998; Bolch & Gorbunov, 2014).

From the glacier fronts can trigger sudden events marked by high intensity flow energies, such as GLOFs, which cause major changes in the topography of the courses, as they mobilise great amounts of debris and may result in human casualties and significant damage to infrastructures in environments located far away from the source area (Richardson & Reynolds, 2000). In the Ala Archa National Park, GLOFs triggering is a recurring process over time, as shown by Zaginaev & *alii* (2016), focused on the large alluvial fan generated in the Aksay Gorge between 2200 and 2320 m. In this alluvial fan, which has undergone at least 15 post-LIA event since 1885 as a result of paraglacial readjustment (Oliva & Ruiz-Fernández, 2015), erosion grooves and gullies can be clearly noticed, framed by *levées* generated by the triggering of former GLOFs. GLOFs triggering and their associated debris flows coming from the Kyrgyz Tian Shan have caused major material losses and even casualties in Bishkek, the capital of Kyrgyzstan (Zaginaev & *alii*, 2016).

Present-day geomorphological dynamics

The active processes and the associate landforms identified in the Ala Archa National Park enable us to establish five morphodynamic belts (fig. 6):

MONTANE FOREST BELT (<2000 m) - Dominant geomorphological dynamics are related to fluvial and torrential processes: undercutting in slopes, retrogressive erosion, sediment mobilisation through several mechanisms (suspension, saltation, etc.), deposition in river bars and alluvial fans, formation of anastomosed areas, etc. However, slope dynamics are weak, with well-developed soils favouring a dense vegetation cover, including the presence of coniferous forests.

SUBNIVAL BELT (~2000-2800 m) - Its upper limit matches with the present-day timberline. This level includes geomorphological dynamics related mainly to fluvial, torrential and snow processes, as well as rapid and slow mass movements. Prevailing processes are water runoff, surface formations saturation, which favors solifluction and creep, etc. Some of the existing alluvial fans in this belt are affected recurrently by GLOFs, which in the Ala Archa valley are able to carry boulders larger than 1 m of diameter (Zaginaev & *alii*, 2016). Debris and energy transference from higher morphodynamic levels is frequent, so, in addition to the GLOFs, gravitational processes, such as snow avalanches, landslides and debris flows, are also frequent, leaving grooves and gullies generated in the higher areas of this morphogenetic environment.

NIVAL BELT (~2800-3200 m) - The magnitude of cold-climate geomorphological processes increases in this elevation belt characterized by widespread snow processes, in addition to frost shattering, solifluction and rapid mass movements such as debris flows. In this environment it is possible to find landforms such as rock glaciers and protalus lobes which, in contrast, present less fresh forms or suggest less activity than in the immediate upper level. Despite the fact that little evidence is available from boreholes monitoring permafrost temperatures (Zhao & *alii*, 2010), geomorphic evidence suggests that sporadic permafrost occurs in the Tian Shan range between 2700 and 3200 m. Marchenko & *alii* (2007) point out that in the northern and eastern sectors of the Tian Shan range, sporadic permafrost develops in the same elevation range. According to Duishonakunov (2014) there can be patches of permafrost in North-facing slopes between 2700 and 3000 m. On the other hand, according to Marchenko & *alii* (2007), in northern and eastern parts of the Tian Shan range permafrost is discontinuous between 3200 and 3500 m, and continuous above this level. Similarly, Zhao & *alii* (2010) locate the discontinuous permafrost limit in that sector between 3200 and 3600 m. For his part, Duishonakunov (2014) points out that permafrost is widely represented above 3300 m in the Inner Tien Shan. According to him, the thickness of permafrost can vary from 20-25 m at the altitude of 3000 m to more than 200 m at 4000 m, depending on orientation, slope, and materials characteristics. The active layer depth also varies significantly depending on the same factors, there being significant intra-annual differences (50 to 300 cm depth at 3659 m in the Tian Shan Meteorological Station; Duishonakunov, 2014). In the Lenin Peak, located in the close range of the Pamir, permafrost is distributed starting at 3400-3500 m (Oliva & Ruiz-Fernández, 2018), although there is a 300-500 m of difference in the altitude in that permafrost appears between South and North slopes (Gravis & *alii*, 2003).

From the second half of 20th century, permafrost in the Tian Shan range went through a warming period which is still ongoing. Thus, by means of geothermal observations and modelling of the thermal regime it can be ascertained that over the last 30 years there has been an increase in the Tian Shan range (Bolshaya and Malaya Almatinka river basins) permafrost temperature from 0.3°C to 0.6°C, together with an increase of the active layer of 23% in contrast with data from 1970s (Marchenko & *alii*, 2007).

CRYONIVAL BELT (~3200-4800 m, except glacial areas) - It is an extremely dynamic environment in which processes such as frost shattering and nivation effectively interact with all sorts of rapid and slow mass movements that remobilise sediments (fig. 6). Cryoturbation is also present, and there is a great distribution of active landforms linked to the presence of permafrost (glacier-derived rock glaciers, talus-derived rock glaciers and protalus lobes; Humlum, 1996, 2000; Johnson & *alii*, 2007). Some previous works have brought to light that active rock glaciers are a kind of landform widely distributed in the northern sector of the Tian Shan range, particularly between 3000 and 3800 m (Bolch & Gorbunov, 2014). These same authors point out the existence of large active rock glaciers (≥ 100 ha) of glacial origin which reach low levels where, outside their tongues, there is no permafrost. Thus, their development is conditioned by their interaction with polythermal glaciers, with an intense weathering, and triggered by rockfalls generated by seismic activity (Bolch & Gorbunov, 2014). The study site is located in an area in which significant Quaternary tectonic activity has been documented (Thompson & *alii*, 2002), which has also triggered massive rockfalls related with large seismic events in nearby ranges such as the Pamir range (Reznichenko & *alii*, 2017; Oliva & Ruiz-Fernández, 2018). In addition, some of the recently deglaciated environments are strongly influenced by intense paraglacial activity that favours the mobilization of sediments from unstable landforms (Oliva & *alii*, 2019). This is particularly intense in the foreland of the major glaciers in the Ala Archa National Park, as shown by the presence of debris flows, mudflows, etc. in the unconsolidated slopes surrounding the present-day glacier fronts.

GLACIAL BELT (>3350 m from the lowest glacier fronts to the summits) - In the Ala Archa valley 48 glaciers subsist, out of which ten are alpine glaciers and only five of them show well-developed glacier tongues. The rest are cirque glaciers, which in some cases show very reduced dimensions (some ≤ 1 ha) with very small accumulation areas, and in process of disappearance. According to Xu & *alii* (2010), the modern Equilibrium Line Altitude (ELA) of the glaciers of the Kyrgyz Range, where the Ala Archa valley lies, is located at a mean altitude of 3870 m.

The Ala Archa glaciers have also undergone an important retreat since the last decades of the 20th century. From 1963 to 2003 the glaciated surface in the Ala Archa valley shifted from 42.8 to 36.3 km^2, thus shrinking in a 15.7% (Aizen & *alii*, 2007a). This recent regression has been brought to light by other authors in nearby mountain ranges. Khromova & *alii* (2006) studied 44 active glaciers both in wet and dry areas of the E and W sector of the Pamir range, ascertaining the existence of a substantial reduction of the glacier surface and a retreat of their fronts since 1970. Despite finding an increase of precipitation in winter in the wet sector of this region and in summer in the dry one, it has been proved insufficient to compensate ice ablation during summer (Khromova & *alii*, 2006), so the glaciated area decreased in a 7.8% in 1978-1990, and an 11.6% during 1990-2001. Central Asia glaciers high sensitivity to summer temperature and precipitation had already been brought to light by Glazyrin & *alii* (2002). According to Aizen & *alii* (2007b), an increase of the mean summer air temperature of 1°C must correspond in this geographical area to an annual precipitation increase of 100 mm so that the ELA remains at the same level. In contrast, in other Central Asia close mountainous areas, the glaciers retreat trend has been inverted, precisely due to an increase in summer precipitations, as well as due to a decrease in net radiance (Kok & *alii*, 2018). This study has linked the existence of an almost zero or positive mass balance of diverse glaciers of the Karakorum and the Pamir mountain ranges, with an increase of the irrigation intensity in the lowlands surrounding this mountainous region, thus causing the aforementioned summer precipitation and net radiance changes. Other studies have revealed the important melt-reducing effect exerted by the supra-glacial debris (together with the mentioned changes of precipitation and temperature) in the glacier mass balance of the central and northeastern parts of the Karakorum range (Groos & *alii*, 2017).

The response of the Ala Archa glaciers to the recent warming trend has driven large changes in their mass balances, which in some cases has favoured dramatic environmental responses. Depending of subglacial topography, some glaciers affected by glacial retreat have generated new lakes (e.g. Golubina and Aksay glaciers in past decades, and Adigine and Uchitel glaciers currently), and exposed new ice free terrain. In some cases, this process may trigger GLOFs events (Aizen & *alii*, 2007a; Zaginaev & *alii*, 2016). The collapse of the front of the Golubina Glacier in 1917 resulted in the damming of the river, which towards the end of the summer of the same year managed to drain the lake thus formed, triggering a GLOF and doubling the water flow of the Ala Archa river from 15 to 30 m^3/s (Aizen & *alii*, 2007a). In the present-day context of accelerated retreat of the glaciers of this sector of the Tian Shan range, the generated lakes at the front of several glaciers in the Ala Archa valley, such as Adigine and Uchitel glaciers, which are moraine-dammed lakes, might trigger new GLOFs in the years to come. But the flow of the Ala Archa river has not only increased due to these sudden events, which can pose a risk for communities located downriver. The speeding glacier retreat has also contributed to increasing the river flow, and, therefore, its energy and its capacity for particles mobilisation.

CONCLUSIONS

This work studies the distribution of geomorphological processes and landforms in the Ala Archa National Park, located in the central part of the Tian Shan range. This space has been strongly modelled by Quaternary glaciers. At present, three generations of moraines are preserved: (i) M1- external valley moraines, located at ~1580 m and related to the MIE of the Last Glaciation; (ii) M2- internal valley moraines, scattered between 1680 and 2700 m, and (iii) M3- high mountain moraines, located above 2800 m and related to recent (LIA) and present-day glacial stages.

The calendar of deglaciation is still little known, both in the Ala Archa and in the whole of the Tian Shan range. Absolute dates until now are scarce in number and in spatial representation, as well as heterogeneous in the methodology employed. Therefore, one of the priorities of future studies focused on the Tian Shan glacial evolution in general, and in the Ala Archa area in particular, must be to establish a robust chronological framework of glacial evolution. Accordingly, our future work will aim at reconstructing the glacial evolution of the Ala Archa valley, providing the glacial stages identified in this work with an absolute chronology. During the fieldwork campaign carried out in August of 2017 in this National Park, ten samples of erratic bocks and glacial thresholds were obtained in Askay Gorge to be dated through CRE, currently under laboratory analysis.

On the other hand, regarding the current geomorphological dynamics, in middle altitude sectors, fluvial and torrential processes prevail, as well as those related to slope dynamics. However, deglaciated areas at higher altitudes are under cryogenic dynamics which becomes more intense to gradually higher levels. Landforms related to the presence of permafrost, such as rock glaciers and protalus lobes are abundant and fully active, especially from 3200 m upwards. Finally, in the highest sectors, cryogenic dynamics are replaced by those of glaciated environments, with 48 glaciers currently subsisting in the Ala Archa valley, extending over an area of 3586 ha. Out of these, ten are of the alpine type, while the rest are cirque glaciers which have a very reduced extent, and have next to no accumulation area, so they will foreseeably disappear in the future decades, if the present-day trend of mass loss they are subjected to carries on. The detected staggering of the landforms and related active processes allows to distinguish five morphodynamic belts in the Ala Archa National Park: montane forest belt (<2000 m), (ii) subnival belt (~2000-2800 m), (iii) nival belt (~2800-3200 m), (iv) cryonival belt (~3200-4800 m, outside glaciated areas), and (v) glacial belt (>3350 m).

This study on the distribution of the processes and associate landforms in the Ala Archa National Park will contribute to a better understanding of the geomorphological and environmental values of this protected natural space in Kyrgyzstan. This is a must to carry out suitable actions of land use planning and management in this National Park, especially in the present context of touristic development which is taking place in this Central Asia country. In order to avoid problems such as overcrowding or an irreparable impact on the ecosystems of both this and other surrounding protected natural spaces, their management must be rooted in a proper understanding of their natural and cultural worth.

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