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Ephemeral skin-flows on talus affected by permafrost degradation (Corral del Veleta, Spain)

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In mountain environments, talus formed at the foot of valley sides are frequently affected by hillslope processes, such as skin-flows. The main characteristic of this type of flow is that it only causes the movement of a thin layer of soil, regolith or debris over an inclined plane parallel to the topographical surface of the talus. Some examples of this movement have already been described (Rapp, 1960; Akerman; 1984; White, 1981, Benedict, 1970; Jahn, 1967; Söderman, 1980; Lewkowicz, 1988, Harris, 1987). The causes of the formation of these movements vary, but in general they have been linked primarily with rapid snow melt and/or with degraded permafrost levels (Jahn, 1967; Nyberg, 1991; Rapp and Nyberg, 1988; Strömquist, 1985; Hall, 1985; Thorn, 1988; McRoberts and Morgenstern, 1974, Caine, 1976).
Within this context, the aims of this paper are: first, to present and describe the characteristics and temporal and geomorphological evolution of a series of skin-flows which have occurred on the talus which lies at the foot of the Corral del Veleta glacial cirque, and second, to analyze the factors that appear to have triggered them.
The Pico del Veleta mountain (3398 m a.s.l.) is one of the main summits in the Sierra Nevada Massif, a group of mountains forming part of the Cordilleras Béticas, in SE Spain (37º03´N, 3º22´W). The Corral del Veleta is a glacial cirque on the northeastern face of the Pico del Veleta, c. 600 m long in a NW-SE direction, with a head is formed by a steep wall which falls more than 250 meters to meet with a wide and irregular talus. The cirque headwall is composed of metamorphic rocks (mainly micaschist), lined up in structural steps or shelves tilted towards the NNW. One of these shelves forms the base of the cirque, on which a series of moraine ridges, tardiglacial or from the Little Ice Age, which close off the cirque towards the North (Gómez et al., 2001).
The talus is formed from abundant debris resulting from weathering (gelifraction) and hillslope dynamics (rockfall activity) which affect the headwall (Gómez et al., 2003) and is formed mainly by various talus cones which are irregular in shape and stepped as the accumulated debris covers the remains of the stepped structural shelves which were not destroyed by the glacial erosion. Although the talus debris is basically made up of blocks, it is important to point out the abundant presence of fine material, produced by the weathering of the micaschist. (Castillo and Fedeli, 2002; Gómez et al., 2003).
Field work carried out over the last ten years (1998-2008) has allowed observation of the triggering and formation in some years of various skin flows in different sectors of the talus, especially in the late summer of 2002 when four skin flows occurred. Within this timeframe monitoring and analysis of this kind of skin flow has been carried out. On the one hand, the description of the morphology, morphometry and sedimentology of each flow has been completed with the production of detailed geomorphological mapping and from sedimentological analysis. The geomorphological mapping has, in turn, allowed the observation of the geomorphological evolution of the flows from the time they occurred. On the other hand, a study has been made of the variables or factors which seem a priori to control the triggering of the skin flow landslips: the snow melt and the presence of permafrost in the detrital talus. The former has been monitored through photographic control of the snow cover at the end of the summer season, so that for each date analyzed a map was obtained of the snow cover, superimposing in turn the location of the skin flows at that date. A GIS processing of the different snow covers has also allowed a map to be produced with the areas of maximum summer snow cover, which was compared with the sites of the skin flow landslips. The existence of permafrost and its presence in the detrital slope has been detected through the monitoring of the ground temperature (BTS measurements, miniature temperature dataloggers) and geophysical

surveys (Gómez et al., 2001, 2003). However, these methods for detecting permafrost (pending more detailed surveys) have shown that the presence of permafrost or buried ice in the slope is discontinuous.

The geomorphological interpretation shows that the flows are small scale. The maximum length of the largest flow occurring during the observation period is around 50 m, and its width oscillates between 25-30 m. In general the flow only affects a layer of debris of less than 30 cm. The dislodged layer is made up of fine material and small clasts or gravel and pebble sized fragments, with a significant presence of numerous multiple flows which diverge or divide when they encounter a large block and end up forming small lobes. The interior of these is made up of fine material (clay and silt) and the lobe itself is made of small, tightly compressed fragments. Here it should also be noted that many of the flows are stopped or ended when they collide with a block of larger size, forming a series of lobes. It seems clear that many of these flows, as they are moving only a thin layer of fine material, are controlled by the presence of larger blocks which remain stable on the slope.

The location of the skin flows at the base of the snowpatches in late summer seems to be the main factor which triggers their genesis. Here, as has been observed in other areas, the absence of vegetation and the abundant water delivered by the rapid nival fusion or snow melt, stronger here as this is an area with Mediterranean climate and also linked to the presence of abundant fine material, provide the conditions needed to favor the triggering of this kind of movement.

However it was observed that some skin flows develop in sectors of the slope where the permafrost is absent and so their origin seems to be clearly related to the snow melt. In addition in these cases, the morphology of the flows once they are formed is not destroyed but rather tends to 'blur' as the years pass, although it does not completely lose its original shape: the fine material inside the lobes becomes compacted and the multiple lobes become blurred. In contrast, in other sectors of the slope, where the presence of permafrost levels or buried ice has been detected, the skin flows, once formed, change their physiognomy from year to year, which may be related to the influence of the nival dynamic along with the degradation of the permafrost and the dislodgement of the active layer.

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