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State and evolution of the Bérard rock glacier (Southern French Alps) after its collapse in 2006: insights from geophysical, geodetic and thermal datasets

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In the French Alps, the summer 2006 has been marked by the sudden collapse of the Bérard rockglacier, a rare event, exceptional by the quasi complete destabilization of the landform. This case raises questions on the evolution of mountain permafrost under warming conditions, especially those ice-rich debris accumulations located close to the altitudinal and/or latitudinal limits of permafrost and that may be experiencing morphogenetic crisis. The Bérard site (2500-2900 m asl; 44°26' N. – 6°40' E.) is located in the Parpaillon range, near the Southern limits of the Alpine permafrost and under Mediterranean climatic conditions.
The objectives of our study are to analyse the present state of the Bérard rock glacier (collapsed and non-collapsed mass) and its evolution after the major movements of summer 2006 that mobilized 1.5 millions m3 of material. In this purpose, electrical resistivity and seismic refraction tomographies were repeated along two profiles in summers 2007 and 2009, GPS survey of 40 points was initiated in summer 2007 and a thermal monitoring, composed of 6 miniature temperature dataloggers and an automatic weather station was installed on the site on summer 2007.
First, the combination of the thermal and geodetic data allows us to distinguish three areas:
1) the unstable but non-collapsed upper part of the rock glacier, characterized by creeping signs and which displays surface velocity between 0.1 and 0.6 m/yr and WEqT (Winter Equilibrium Temperature) values > - 2°C in 2008 and 2009;
2) the highly unstable but non-collapsed median part, characterized by destabilization signs like wide fractures and which displays surface velocity up to 8 m/yr (no ground temperature available);
3) the collapsed mass, characterized by strong morphological changes (rapid downwasting of ice/debris packets) just after the deposition but no visible signs of evolution since 2007 and which displays surface velocity below 0.1 m/yr and WEqT around 0°C.
The electrical resistivity tomographies confirmed partly the observations made on open cuts just after the collapse, but don't reveal the 1-2-m thick layer of quasi pure ice (suspected to be a relict of Little Ice Age) observed in the detachment cut in 2006 and 2007. Similarly to measurement on other peebly rock glaciers, the resistivity of the internal structure of the Bérard rockglacier ranges from 0.2 to 25 kOhm.m. These low values may reflect the presence of warm permafrost or permafrost at the melting point. The seismic data indicate a seismic interface on average at 3-4 m depth with mean velocity Vp of the ice-rich level around 1800-2000m/s.
The collapse of the Bérard rock glacier in 2006 may be representative of the consequences of mountain permafrost degradation under warming climate. Nevertheless, a first assessment of the possible triggering chain of factors (climatic conditions of the last decades, meteorological events –storms and heavy rains– during summer 2006, geological and topographic contexts) shows the high complexity of such events and the further need to study and monitor mountain permafrost, especially in populated regions where its degradation may generate hazardous situations.