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Permafrost in steep sedimentary terrain: distribution, thermal regime and instabilities

PhD abstract

In the context of a warmer climate, the localisation of permafrost in steep sedimentary terrain and the measurement of terrain movements that occur in these areas is of great importance. With respect to these problems, this PhD thesis follows two different research axes. From a static point of view, the research presents a study of the permafrost distribution and characteristics in the talus slopes of the alpine periglacial belt. From a dynamic point of view, an analysis of the influence of the permafrost characteristics (ice content, permafrost temperature, etc.) and air and soil temperature variations on the creep velocities of frozen sedimentary bodies is carried out.

In order to attain this double objective, the "field" approach was favoured. To determine the distribution and the characteristics of permafrost, the traditional methods of permafrost prospecting were used, i.e. ground surface temperature measurements at the base of the snow cover (BTS), year-round ground temperature measurements and DC-resistivity prospecting. The terrain movements were measured using a differential GPS.

The permafrost distribution study was carried out on 15 talus slopes located mainly in the Mont Gelé (Verbier-Nendaz) and Arolla areas (Swiss Alps). In most cases, permafrost was found in the lower part of the talus slope, whereas the medium part was free of ice. In some cases, the upper part of the talus is also free of permafrost, whereas in other cases permafrost is present. Electrical resistivities measured in the frozen parts of the studied talus are in most cases clearly lower than those measured on rock glaciers.

Former studies have shown that internal air circulation is responsible for the negative thermal anomaly and, when it exists, the permafrost present in the lower part of talus slopes located more than 1000 m below the regional lower limit of discontinuous permafrost. The study of four low-altitude talus slopes (1400-1900 m), and notably the equipment of Dreveneuse field site (Valais Prealps) with two boreholes, surface temperature sensors and an anemometer permitted to verify and to detail the ventilation mechanism active in low altitude talus slopes. This mechanism works in the following way: in winter, the air contained in the block accumulation is warmer and lighter than the surrounding air and therefore moves upward in the talus and is expelled in its upper part. This chimney effect induces an aspiration of cold air in the interior of the lower part of talus, that causes a strong overcooling of the ground. In summer, the mechanism is reversed because the talus slope is colder than the surrounding air. Cold air is then expelled in the lower part of the slope.

Evidence of ascending ventilation in wintertime could also be found in some of the studied high-altitude talus slopes. It is probably mainly responsible for the particular configuration of the observed frozen areas. Even if the existence of a chimney effect could not be demonstrated in all cases, notably because of interstitial ice that obstructs the air circulation, indices of its presence exist in nearly all the studied talus. The absence of permafrost at altitudes favourable to its presence could be explained, for example, by the terrain warming caused by expulsion of relatively warm air.

Terrain movements were measured at about ten sites, mainly on rock glaciers, but also on a push moraine and some talus slopes. Field observations reveal that many rock glaciers display recent destabilization features (landslide scars, tilted blocks, presence of fine grained sediments at the surface, etc.) that indicate a probable recent acceleration of the creep velocities. This phenomenon, which seems to be widespread at the alpine scale, is probably linked to the permafrost warming during the last decades. The measured velocities are often higher than values usually proposed in the literature. In addition, strong inter-annual variations of the velocities were observed, which seems to depend on the mean annual ground temperature variations.