Silvia Duca : “Design of an experimental procedure and set up for the detection of ice segregation phenomena in rock by acoustic emissions” THESIS SUMMARY

Large slope failures in steep alpine bedrock present a significant geological hazard in many high mountain areas throughout the world. An increased number of periglacial rock falls have been identified in recent decades as a consequence of climate changes. Referring to the Matterhorn site field observations (Italy), a simplified heat-transfer numerical model has been computed, in order to perform a comparative analysis between temperature spatial-temporal distribution and microseismic activity: it showed that the hypocentres seemed to be localized close to the permafrost boundary. Ice segregation has been interpreted as one of the mechanisms involved in high mountain bedrock degradation and its associated instability.
In order to deepen the study of ice segregation phenomenon and resultingcrack growth in hard, intact rock, a down scaled physical simulation of this frost weathering mechanism has been designed and set up, to monitor the microfracture activity in rock specimens under fixed temperature gradient; upsizing of physical modeling experiments and monitoring natural unweathered bedrock, would provide valuable insights into permafrost landscape evolution and engineering geology.
A coupled thermo-hydro-mechanical model (FEM code CODE_BRIGHT), which incorporates the thermodynamics of ice-water mixtures, has been used in order to predict the timing and depth of a potential macrocrack originating perpendicular to the water flow from ice segregation processes.
Observing the computed trend of the liquid water saturation degree, it was possible to recognize a range between -3!C and 0!C, in which considerable amount of water remains unfrozen, although the subfreezing temperature: this layer is defined “frozen fringe”. The computed liquid flux has demonstrated how the accumulation of freezing pore water drives the ice segregation process: the unfrozen pore water is drawn into the frozen fringe, and here the flux reaches the maximum value equal to 3.25E-07 Kg $m^{-2}s^{-2}$. Finally it was possible to deduce that freezing at fixed temperature gradient allowed the localization of increasing porosity below the zero-isotherm depth, which should therefore be the preferential place for the ice lenses formation.
Moreover, thermal numerical analyses have also been performed with the FEM code ABAQUS: they highlight how steady temperature gradients play a fundamental role in crack propagation and permit to choose the temperature interval that would maximize the frost cracking mechanism in the rock sample.
According to the results obtained with the numerical model, the temperature interval that would maximize the frost cracking mechanism in the rock sample, has been chosen: -12°C on the lower surface, +3°C on the upper surface.
Due to the complexity of the phenomena involved, a pilot trial has been necessary in order to test the methodology and to identify the difficulties connected with the application of thermal cycles to a saturated rock sample, monitoring microcrack activities. Experimental laboratory prototype have been modeled and set up, the Arolla gneiss samples have been characterized and thermally microcracked to be comparable with the material which characterizes the Matterhorn at 3835 m a.s.l.
A sensitive point of the laboratory procedure was to monitor with acoustic emission techniques the microcracks propagation induced by ice growth. As a matter of fact, conventional measures of frost damage do not provide enough information about the magnitude, timing and location of frost-induced deterioration. Monitoring AE has been considered a suitable investigation tool for studying frost weathering experimentally, because it permits continuous, non-destructive determination of the approximate location of microfracture events caused by ice growth in rocks.
In order to obtain an accurate location of AE events, ultrasonic measurements have been carried out in different thermal regime within the sample, obtaining wave velocity values for temperatures above and below the freezing point. The importance of a correct receiver array distribution has been examined in

detail, and an optimum array geometry has been chosen, following a procedure that would minimize source location errors.

Finally two long-term freezing tests have been carried out: the first was aimed to reproduce the ice lens growth mechanism due to the onset of ice segregation processes at the interface active layer-permafrost table, building up a physical model. During three months of testing, microcracks propagated horizontally through the gneiss sample, resulting in a continuous and thick macro-crack near the base of the artificial active layer of the simulated permafrost. The fracture was more or less horizontal, flat and parallel or sub-parallel to the cooling surfaces (i.e. the -2°C isotherm): fractures depth was located in the layer between approximately 2.5 and 6 cm in depth, and the ice-lens growth was inferred within an approximate temperature range of -0.5°C to -2.5°C. Thus, the experimental results provided strong support for the segregation ice model of frost weathering.

During the second trial, acoustic emission monitoring system has been installed, to study the processes operating in evolving fault zone due to the ice lens growth. Localizing recorded events, a 40 mm thick band (i.e. between 4.5 and 8 cm deep) have been identified, where most of the hypocenters were concentrated. This layer matches roughly with the frozen fringe, where unidirectional steady heat transfer and water transport, induce fracture propagation by slow-continuous freezing and fixed temperature gradient.