Two-dimensional geoelectrical monitoring in an alpine frozen moraine

Christophe Lambiel
Institute of Geography, University of Lausanne, Switzerland
Ludovic Baron
Institute of Geophysics, University of Lausanne, Switzerland

Keywords: Permafrost, moraine, geophysics, electrical resistivity tomography

Introduction

As defined by Haeberli (1979), push moraines are frozen sediments deformed by a glacier advance. In the Alps, push moraines are typically encountered in the margin of small glaciers, at altitudes comprised between 2500 and 3000 m a.s.l., in the belt of discontinuous permafrost (see for. ex. Reynard et al. 2003, Delaloye 2004). In order to better know the internal structure and the ice content and repartition of this type of landform, a monitoring of the resistivity variation has been initiated on the Col des Gentianes push moraine (Swiss Alps).

Site description and methods

The Col des Gentianes moraine is located at 2900 m a.s.l., on the orographic left side of the Tortin glacier (Fig. 1). A cable car station for ski activity was built on the northern part of the moraine at the end of the seventies. In October 2006, the road located between the building and the glacier was excavated for ski-run landscaping purposes. Massive ice layers were encountered at depths of 50 cm to 2 m. Congelation and sedimentary ice was present. Ground temperatures are recorded in a 20 m deep borehole since November 2002 (Lambiel 2006). They attest the presence of permafrost conditions in the moraine, with temperatures of -0.5°C to -1°C between 5 and 20 m depth (Fig. 2).

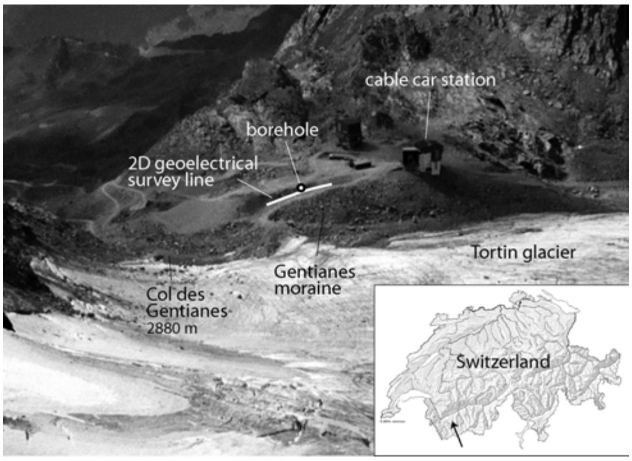

Figure 1. View of the Gentianes moraine with location of the borehole and of the 2D geoelectrical survey line.

Two-dimensional (2D) resistivity imaging is an efficient tool to characterize permafrost extension in recently deglaciated glacier forefields (e.g. Marescot et al. 2003, Kneisel 2004). To provide information on both lateral and vertical variations of the resistivity and to monitor the temporal evolution of the resistivities in the Col des Gentianes moraine, a permanent 2D electrical profile was installed on the upslope part of the road (Fig. 1). Two acquisitions were carried out on the 13th August and on the 23rd October 2007 with the Wenner-Schlumberger configuration. Data was inversed with the software RES2DINV.

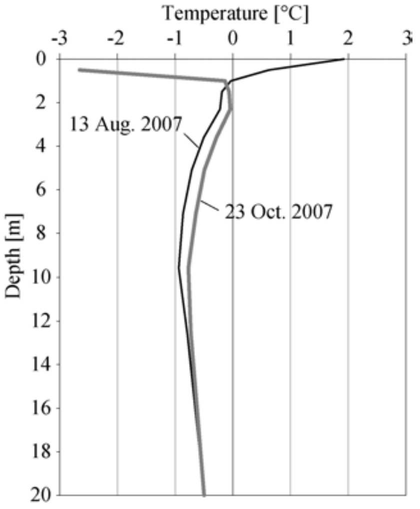

Figure 2. Thermal profiles of the moraine at the time of the two geoelectrical acquisitions.

Results and discussion

The first acquisition (13th Aug. 2007) reveals resistivities overall higher than 5 kΩm, with a clear increase towards the south (Fig. 3). Two lenses of higher resistivities (max. 150 kΩm) are clearly visible near the middle and in the south side of the profile. They probably correspond to massive ice lenses, like those which were observed in the excavation in October 2006. In the centre, resistivities are relatively low (< 6 kΩm) below 10 m depth. However, the borehole, which is located near the center of the survey line, indicates negative temperatures throughout the first 20 m of the moraine. Thus, we can conclude that the frozen material is very little resistant in places. Such low resistivities may be explained by an increase of the specific surface. This implies that the deep layers would contain a high proportion of fine-grained sediments.

The second acquisition (23rd Oct. 2007) shows a strong increase of the resistivities in the upper layers. The two resistant lenses are still visible, but the resistivities have been multiplied by 2 for the south lens and by 5 for the central one. In the northern half of the profile, at about 6 to 10 m depth, we can observe, on the contrary, a slight decrease of the resistivities.

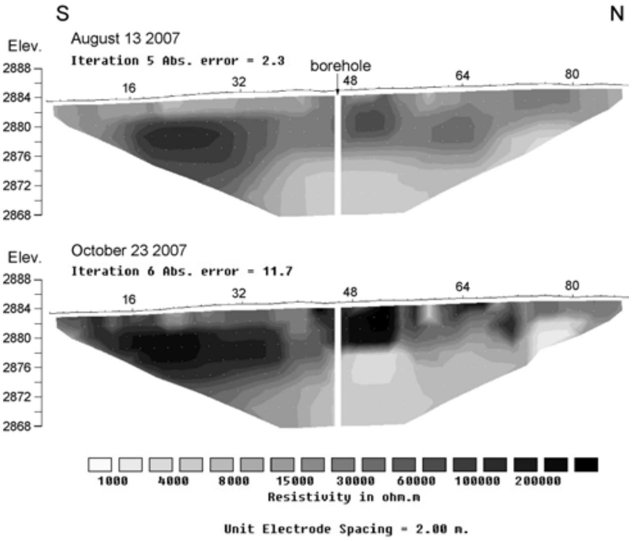

Figure 3. Two dimensional resistivity profiles on the 13th Aug. and 23rd Oct. 2007 on the Col des Gentianes moraine.

Borehole data indicates warmer temperatures between 1 and 13 m depth in October than in August (Fig. 2). At the same time, we observe a strong increase in resistivities between the two acquisitions up to 6-10 m deep. Now, below 0°C, many studies reported that decreasing temperatures provoke increasing resistivities (e.g. Hauck, 2001). Thus, the change in resistivities that we observe cannot be explained by a change in ground temperatures.

A hypothesis which could explain these different resistivities is the existence of two completely different climatic conditions during the two weeks preceding the two acquisitions. In August, the weather was very rainy, whereas October was dry and very cold at the acquisition time. As a consequence, the active layer was probably saturated with unfrozen water in August, whereas it was dry and frozen in October (Fig. 2). This led to higher resistivities at the subsurface. The strong increase in resistivities below the active layer is more difficult to understand, but we can assess that the difference in resistivity contact due to difference in surface humidity played an important role in the inversion process at greater depth.

According to the 2D resistivity imaging, the ground stratigraphy is very heterogeneous. This is not surprising, insofar as a push moraine is often a complex landform incorporating, for instance, frozen sediments and sedimentary ice from the glacier. The presence of unfrozen lenses can then not be excluded. Thus, it is possible that water could penetrate the deep layers during the rainy episode of August, which could have provoked lower resistivities.

Finally, the slight resistivity decrease at 6-10 m deep in the center of the profile may be explained by the slight warming of the ground between the two acquisitions (Fig. 2).

Conclusion

The measurements show that the internal structure of the moraine is very heterogeneous. Massive ice lenses are probably present above 10 meters depth. This assumption is supported by the observation of different ice types (sedimentary, congelation) in an excavation. An unexpected and strong increase in resistivities occurred in relatively deep layers between August and October. Totally different climatic conditions before the acquisitions and the influence of the first layer on the inversion process are probably the only way to explain such differences. However, further acquisitions and modelling of the first layer influence are necessary to validate this hypothesis.

References

Delaloye, R. 2004. *Contribution à l'étude du pergélisol de montagne en zone marginale*. Thèse. Fac. Sciences, Univ. Fribourg, Geofocus, Vol. 10, 240 p.

Haeberli, W. 1979. Holocene push-moraines in alpine permafrost. *Geografiska Annaler*, 61A/1–2, 43-48.

Hauck, C. 2001. Geophysical methods for detecting permafrost in high mountains. *Mitteilungen der VAW, ETH Zürich,* 171.

Kneisel, C. 2004. New insights into mountain permafrost occurrence and characteristics in glacier forefields at high altitude through the application of 2D resistivity imaging. *Permafrost and Periglacial Processes*, 15, 221-227.

Lambiel, C. 2006. *Le pergélisol dans les terrains sédimentaires à forte déclivité: distribution, régime thermique et instabilités*. Thèse, Université de Lausanne, Institut de Géographie, coll. "Travaux et Recherches" n° 33, 260 p.

Marescot, L., Loke, M. H., Chapellier, D., Delaloye, R., Lambiel, C. & Reynard, E. 2003. Assessing reliability of 2D resistivity imaging in mountain permafrost studies using the depth of investigation index method. *Near Surface Geophysics,* 1, 57-67.

Reynard, E., Lambiel, C., Delaloye, R., Devaud, G., Baron, L., Chapellier, D., Marescot, L. & Monnet, R. 2003. Glacier/permafrost relationships in forefields of small glaciers (Swiss Alps). *Proceedings of the Eighth International Conference on Permafrost, Zürich, Switzerland, June 2003*, 2, 947-952.