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Resistivity and induced polarization surveys for slope instability studies in the Swiss Alps

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Abstract

A geoelectrical investigation has been carried out in the Swiss Alps (near the Dent de Nendaz within the southern part of the Rhone valley in the Swiss Alps) to delineate groundwater circulation within an unstable slope. This unstable zone is characterized by a landslide area with clear scarps and hummocky ground at the bottom of the slope. Large scale apparent resistivity mapping provided information on the main pathways for water transport within the slope. Subsequently, 2D resistivity and induced polarization imaging supplied details on the region of instability located at the bottom of the slope. Polarizable units identified in the region of instability could be linked to a clay-rich unit or to local enrichment of graphite within the bedrock. Our results illustrate how low permeability clay/graphite units and permeable water-bearing units could be distinguished using a combined interpretation of resistivity and IP data in slope instability studies.

Keywords: Resistivity; Induced polarization; Slope; Instability; Water circulation; Alps; Siviez–Mischabel; Pontis

1. Introduction

Understanding groundwater circulation has been a major objective of many geological and civil engineering studies. One reason for investigating water circulation is that it can significantly increase the risk of slope instabilities that result in landslides, rockslides or mud flows (Eberhardt et al., 2005). The possibility of catastrophic mass movements needs to be considered during the planning of Alpine buildings and infrastructures (e.g. electric power lines, chalets, ski resorts, cable cars) and geotechnical and land-management activities in the lower parts of the slopes (Luino, 2005). Therefore, it is important that the geometric structure of slope instabilities be determined in order to facilitate reliable stability analyses and mitigation (Bruno and Marillier, 2000).

Most geologic materials containing water have lower electrical resistivities than their surrounding dry counterparts (Keller and Frischknecht, 1966). Consequently, cost-effective resistivity surveys can provide the important information required by engineers for hydrogeologic modelling and risk assessment. In engineering and environmental investigations, resistivity survey are used for characterizing cavities and fractures (Wang et al., 1991), permafrost (Vonder Mühll et al., 2001; Hauck et al., 2003; Marescot et al., 2003) or salt-water intrusions, waste sites and contaminant plumes (Dahlin et al., 2002a). Geoelectric techniques can also be used to map buried antiquities (Hesse et al., 1986). As water circulation paths or infiltration zones may be delineated by such surveys, resistivity techniques are well established in landslide studies (e.g. Bogoslovsky and Ogilvy, 1977; McCann and Forster, 1990; Hack, 2000). These include traditional apparent resistivity mapping and two- and three-dimensional (2D and 3D) electrical imaging methods (Mauritsch et al., 2000; Schmutz et al., 2000; Gaudio and Bottino, 2001; Susuki and Higashi, 2001; Bichler et al., 2004; Perrone et al., 2004; Lapenna et al., 2005; Lebourg et al., 2005; Friedel et al.,

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2006). These geophysical techniques supply broad-scale information on the subsurface properties. The resistivity distinction between unstable weathered material and underlying stable bedrock is possible at locations where they have different porosities, clay content, saturation and thus associated differences in resistivity. However, the distinction between shallow water-saturated silica-rich sediments, clays, metallic ores or graphite may not be possible using conventional resistivity techniques, because they are characterized by the same range of low resistivities. In these cases, the induced polarization (IP) technique may be employed, since clays, metallic ores and graphite are generally polarizable such that their IP properties differ from those in most water-saturated silica-rich sediments (Keller and Frischknecht, 1966; Telford et al., 1996). Yet, the combined use of IP and resistivity techniques has received little attention in slope instability studies.

Water-saturated sediments and polarizable materials occur within our study area (2 km^2), which is situated on an extensive slope (altitude ranging from 1700 m to 2200 m a.s.l.) near the Dent de Nendaz within the southern part of the Rhone valley in the Swiss Alps (Fig. 1). In this area, landslide scarps have been detected and an unstable region has been identified (Fig. 2). The poorly exposed geology at this location is characterized by various lithological units overlain by Quaternary sediments.

The aims of this work are to investigate how a combination of IP and resistivity techniques can be used to discriminate between low permeability units and permeable water-bearing units in slope instabilities studies and to provide new geological knowledge to identify preferential water migration paths within the slope. Two electrical resistivity techniques were employed: large-scale resistivity mapping provided information on the main structures in the subsurface (see areas outlined by dashed light blue lines in Fig. 2) and 2D electrical imaging supplied key details in critical regions (e.g. within the zone of instability outlined by a dotted red line in Fig. 2). Because clay and/or graphite was expected in some geological units, a combination of the resistivity and IP techniques was used to discriminate between water circulation zones in the bedrock and clay and/or graphite-rich units.

After briefly reviewing the geology of the study area, we introduce the field techniques and outline the results of the geophysical investigation. Based on this investigation, we present new information on the geology and hydrogeology of the survey area and highlight the advantages of combining the resistivity and IP techniques.

2. Geological setting

Our study area encompasses parts of Siviez–Mischabel and Pontis nappes, two major Alpine features. Fig. 2 shows the geology of the area as observed by geologists at a number of small to large outcrops (Monnet, 1994).

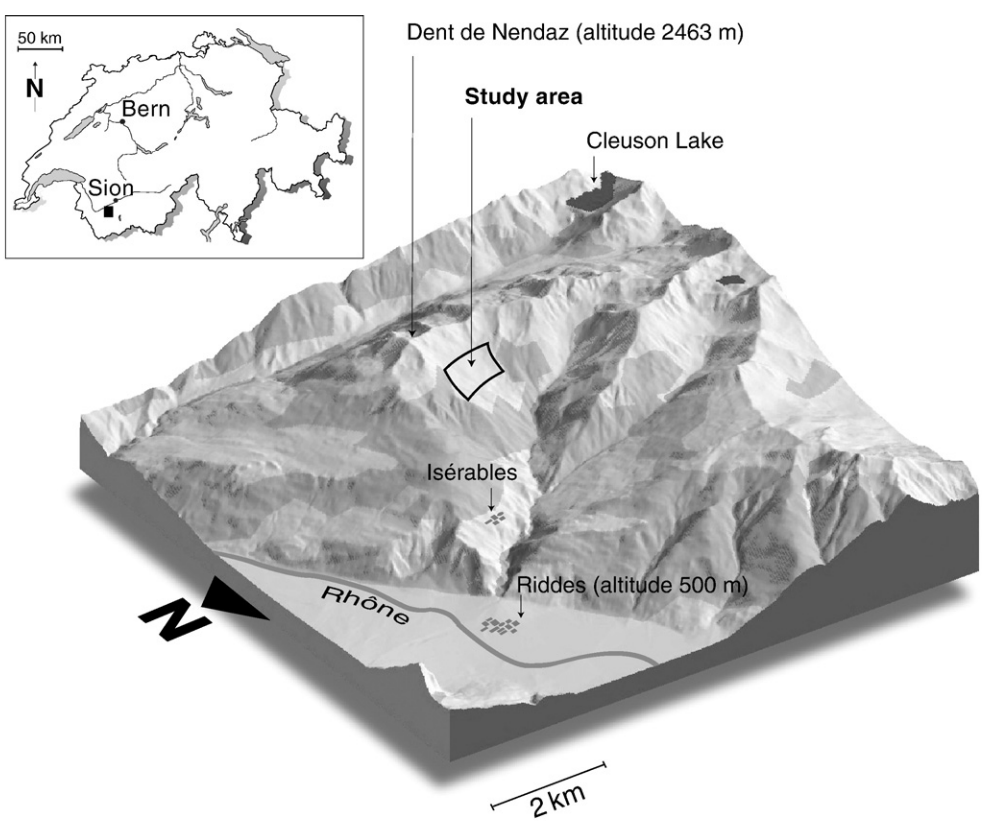

Fig. 1. Location of the survey area in the Swiss Alps. The 3D view shows the various valleys through which torrential rivers flow to the Rhone valley. Small black square on the map of Switzerland identifies the survey area. Representation of topography is modified and reproduced with permission from Swisstopo (authorization number BABA067644).