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Waterborne and on-land electrical surveys to suggest the geological evolution of a glacial lake in NW Italy

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ABSTRACT

Geophysical surveys on and around the Candia Lake, located NE of Turin (NW Italy), in the internal depression of the Ivrea Morainic Amphitheater (IMA) right frontal sector, are reported in this paper. The surveys were intended to obtain a geophysical characterization of the lakebed, to investigate the interconnection paths between surface water and groundwater and to be used as a first general survey for suggesting the geological processes which lead to the actual morphology.

An extensive waterborne continuous vertical electrical sounding (CVES) survey consisting of 15 profiles, with a total length of about 19 km of acquisition, was carried out on the lake surface. The processing of the acquired profiles with a laterally constrained inversion (LCI) approach lead to the reconstruction of the lakebed sediment distribution, down to 10 m depth. Self potential (SP) data recorded on the lake surface have also been analyzed. Moreover, to verify the areal distribution of the deposits, three electrical resistivity tomographies (ERTs) were carried out on land near the northern and southern shores of the lake. The combination of the geophysical survey results with hydrogeological information and geological observations and interpretations allowed the characterization of the submerged deposits, the probable identification of the main areas of groundwater recharge and the preliminary reconstruction of the lake genesis.

1. Introduction

The geological characterization of the bottom sediments of a lake is essential to determine the hydrogeological properties of the deposits and to investigate the interconnecting relationship between surface water and groundwater. However, geological analysis in water-covered areas is difficult and expensive with traditional survey techniques. Direct investigations (e.g. logs or cores) are often neither cost-effective nor reasonably quick and adequate in number to cover the whole surface of a basin and to obtain a reliable correlation of data over a wide area.

Geophysical methods can therefore be very useful to investigate sediments which are entirely located beneath a water-covered area. They can be indeed profitably used not only as a validation of the results of direct techniques, but also as a tool for planning future surveys. Among the available geophysical methods the use of non-seismic methods to study shallow inland water is relatively recent. A review of the existing methods and case histories can be found in the Special Issue of Near Surface Geophysics on Waterborne Geophysics (Butler, 2009; Sambuelli and Butler, 2009).

Among the electrical techniques used for waterborne surveys, continuous vertical electrical soundings (CVESs) have gained greater attention. The possibility of using multichannel resistivity meters makes it possible to simultaneously perform several resistivity measurements, in a fast and cost-effective way. CVESs have been applied in water-covered areas for different purposes and using different electrode configurations. In this respect there is a wide scientific literature. Bradbury and Taylor (1984) used the CVES acquisitions with floating electrodes, together with seismic refraction profiles, to study the hydrogeological properties of the bottom sediments of Lake Michigan (USA). Loke and Lane (2004) examined three different acquisition strategies in an aquatic environment. Their study found that the presence of a water layer between electrodes and sediments reduces the depth of investigation. Kwon et al. (2005) compared acquisitions from floating and water bottom electrodes, in order to find both the minimum electrode spacing and the thickness of the water layer allowing for the best results using different electrode configurations. Allen and Merrick (2007), in a study focused on the inversion of geoelectric data for hydrogeological purposes, demonstrated that using a floating array with exponentially spaced potential electrodes provides the maximum

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resolution with depth. Mitchell et al. (2008), with a combination of stationary and towed electrodes floating on the lake surface, used continuous resistivity profiling to identify heterogeneities which control seepage at Mirror Lake (USA). Another case study with hydrogeological purposes is reported in Kelly et al. (2009). The authors investigated the capability of towed electrical cable to map a known aquifer recharge zone and to provide the hydrogeological information and electrical properties of the sediments. Befus et al. (2012) carried out some resistivity profiles to delineate groundwater–lake interactions with floating equi-spaced electrodes. Geological characterization of sediments can be deduced from electrical measures as demonstrated by Rucker et al. (2011) carrying out an electrical continuous survey with floating electrodes set on a cable dragged by a boat through the whole length of the Panama Canal. Such data have been used to detail the geological mapping of the region in submerged areas to support the project of dredging and widening of the canal. All of these previous studies agree that submerged electrodes allow better penetration in the lakebed sediments, while the selection of the electrode array is closely related to the purposes of the survey (i.e. depth of investigation and resolution required); in this respect an optimum a-priori choice does not exist. However, the use of floating electrodes seems preferable, since it is faster and less expensive than submerged ones from the acquisition point of view. With the floating cable arrangement, exponentially spaced electrodes appear to provide the best resolution with depth.

Most multichannel resistivity meters also allow for a contemporary acquisition of self potential (SP) data; these could be potentially related to water paths since it is known that, roughly, water sources generate positive SP anomalies and the opposite occurs with water sinks. Recent literature works have underlined the potentiality of the SP method from waterborne acquisition for mapping groundwater–surfacewater exchanges (Grangeia and Matias, 2012). Ishido and Pritchett (1999) carried out the numerical simulation of electrokinetic potentials associated with subsurface fluid flow, using SP data which have actually been observed in real geothermal fields. They demonstrated that a positive self-potential anomaly is present above the upflow region while large negative anomalies appear in the peripheral areas where meteoric water flows downward. Goto et al. (2012) analyzed the implications of self-potential distribution caused by groundwater flow in a mountain slope. They observed positive SP anomalies related to local springs and SP decreasing pattern mainly related to vertical infiltration flow in the slope body. Other examples of studies that confirm these correlations between water flow and SP anomalies can be found in Trique et al. (2002) and Thompson et al. (2012).

We discuss the results of a survey conducted with the CVES method on the Candia Lake, located NE of Turin (NW Italy). The main objective of the study was to obtain a first assessment on the characterization of the sediments of the basin, in order to define the nature, composition,

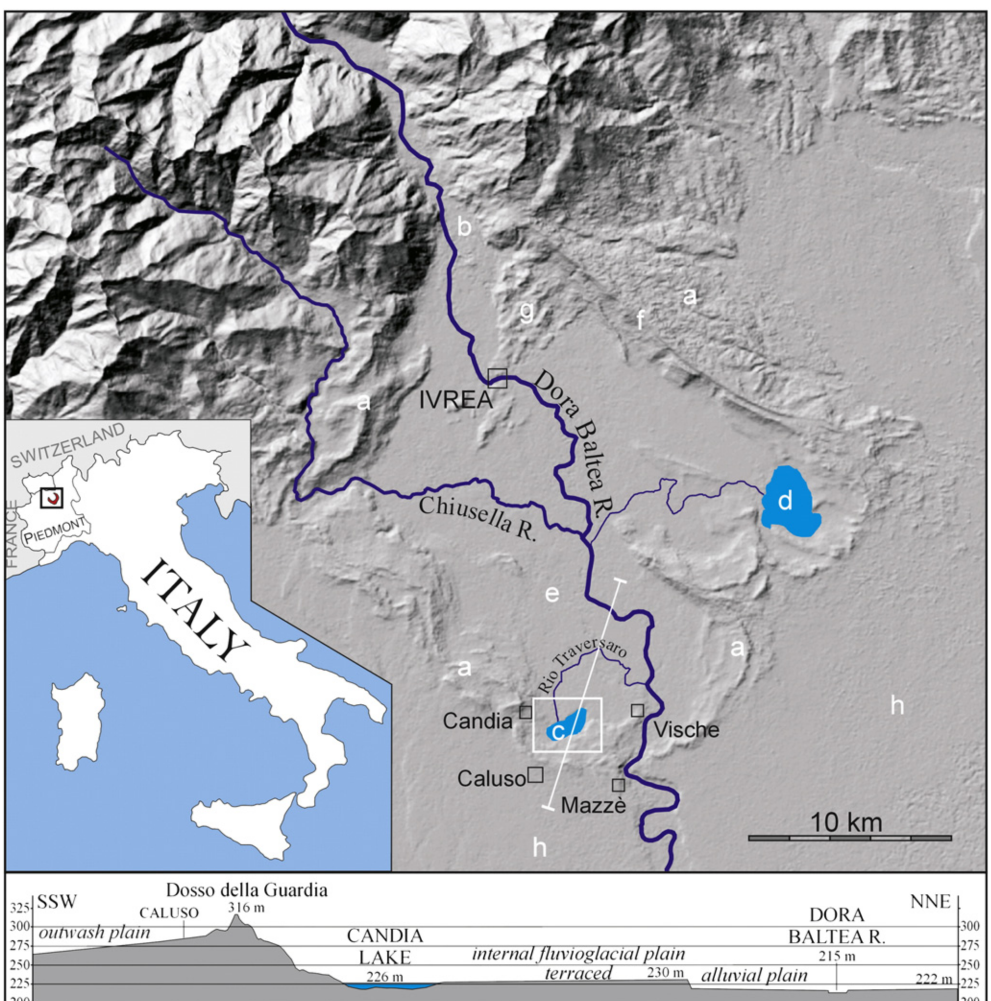

Fig. 1. Digital terrain model of the Ivrea Morainic Amphitheater (IMA) (a) at the Dora Baltea Valley outlet (b), where the study area develops (white box). Candia Lake (c) and the Viverone Lake (d) fill up two depressions on high terraces of the internal plain (e). The remarkable 16 km long Serra d'Ivrea moraine (f) in the left lateral sector, the Colli d'Ivrea abrasion reliefs (g) and the outer outwash (proglacial) plain (h) are pointed out too. The Candia Lake location and the considerable difference in altitude between the internal and the outer fluvioglacial plains are shown in the bottom topographical profile (white trace in the map).