PROCEEDINGS

25TH SALT WATER INTRUSION MEETING

17-22 JUNE 2018

GDAŃSK POLAND

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PREFACE:

Welcome to the 25th Salt Water Intrusion Meeting (SWIM), being held from 17 to 22 June 2018 in Gdańsk, Poland. It is our great honor and pleasure to celebrate with you a round anniversary of the SWIM conferences, the first one of which was held in Hannover, Germany, 50 years ago. SWIM was born as an initiative of scientists from Germany, the Netherlands and Denmark concerned about increased groundwater salinity caused by abstraction of fresh groundwater adjacent to the sea. Over the years the scope of the meetings extended to cover a wider range of theoretical and applied research topics related to coastal aquifers, including management practices, protection of groundwater resources, submarine groundwater discharge, methodology of field investigations and modeling techniques. Groundwater salinity originating from processes other than seawater encroachment was also considered. The first meetings have been organized, mostly on biennial basis, in different European countries, with an increasing number of participants.

In 2008 SWIM merged with SWICA (Saltwater Intrusion and Coastal Aquifers) conferences. Starting from that year every second SWIM is held outside Europe - the most recent one took place in Cairns, Australia in 2016, as a joint event with Asia-Pacific Coastal Aquifer Management Meeting (APCAMM), which is an initiative with similar aims as SWIM, but focused on a specific region.

The continuous success of SWIM stems from the fact that a significant proportion of the world's population lives on the shores of oceans and seas. It is estimated that about 30% of the people on Earth inhabit the first 100 km from the coast, and they increasingly depend on groundwater supply.

Many communities and whole nations have to cope with rising demand for water due to economic development and population growth, which in turn causes over-exploitation of water resources and deterioration of their quality. The problem is amplified by expected changes in precipitation patterns and sea level rise. Such challenges require close cooperation between scientists, engineers, water resource managers and policy makers. In this regard SWIM conferences provide a forum bringing together participants from academia, private consulting firms, local, state, and national government agencies, and giving them a possibility to interact in an informal and relaxed environment.

The proceedings book of 25th SWIM contains over 130 papers and abstracts submitted by participants from more than 20 countries. Besides European and American countries, having been the mainstay of SWIM for a long time, there are attendees from Middle East, Africa, Asia and Pacific region, which reflects the global relevance of SWIM themes. Presentations have been grouped around several topics: case studies of saltwater intrusion, approaches to coastal aquifer management, submarine groundwater discharge, application of geophysical methods, geochemistry, hydrogeology of islands and modeling studies, including numerical, analytical and physical models.

This is the third SWIM organized in Poland, after the one held in 1990 in Sopot (close to Gdańsk) and another one in 2000 in Międzyzdroje on Wolin Island near Szczecin. Despite relatively low salinity of the Baltic sea, saltwater intrusion has been extensively studied in the Baltic countries, in hydrogeological settings varying from sandy spits to deltaic areas to crystalline bedrock islands. The whole Tri-city agglomeration of Gdańsk, Sopot and Gdynia relies almost exclusively on groundwater resources, from Quarternary, Tertiary and Cretaceous unconsolidated aquifers. A large proportion of water is obtained from wells located in close vicinity of the sea, which were particularly vulnerable to increasing salinity in 1980's. Since that time, great political, social and economic changes occurred in Poland and the whole Eastern Europe - regular SWIM participants have certainly noted the effects. The transformation also modified groundwater usage patterns, reducing the abstraction for both industrial and domestic purposes. Consequently, gradual freshening of groundwater is observed in Gdańsk aquifers. On the other hand, submarine groundwater discharge is increasingly studied as a potentially important process leading to contamination of the Baltic sea, particularly by nutrients originating from agricultural practices, at least at the local scale. These issues are reflected in several contributions submitted to the conference.

The 25th SWIM is organized by several institutions: Gdańsk University of Technology, Polish Geological Institute - National Research Institute, University of Nicolas Copernicus in Toruń and three institutes of the Polish Academy of Sciences: Institute of Hydraulic Engineering in Gdańsk, Institute of Oceanology in Sopot and Institute of Geophysics in Warsaw.

We owe sincere gratitude to our sponsor, KGHM Polska Miedź company. The support from the members of the Advisory Committee and the Scientific Committee is highly appreciated. Special thanks are to Christian Langevin, Frans Schaars and Mark Bakker, who volunteered to organize a pre-conference short course on groundwater modeling in coastal aquifers.

Last but not least we would like to thank all SWIM participants. This conference is for you and would not be possible without your support. We do hope that you will enjoy scientific discussions, exchange experiences and develop new ideas, at the same time discovering beautiful nature and rich cultural heritage of the Gdańsk region.

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Deep geoelectrical investigation to bound a coastal thermal outflow area

Enzo Rizzo[1], L.E. Zuffianò[2], F. Santaloia[2] and **M. Polemio**[2]
[1] CNR-IMAA, National Research Council – Institute of Methodology for Environmental Analysis, C.da S. Loja, 85050 Tito Scalo, Italy
[2] CNR-IRPI, National Research Council – Research Institute for Hydrogeological Protection Via Amendola 122 I, 70126 Bari, Italy

ABSTRACT

The coastal carbonate Apulian aquifers, located in southern Italy, feed several coastal fresh springs and constitute the main local source of high quality water. The Santa Cesarea Terme cave system is almost unique case of hypogenic coastal spring caves, located along the Adriatic Sea coastline and hosting spring coastal outflow of mixed groundwater (from 22°C to 33°C) mainly of thermal groundwater due to infiltration offshore, in the sea bottom, and pure fresh groundwater due rainfall infiltration.

Thermal springs and the outflow system are strictly controlled by both the discontinuity network and the karst processes involving the foreland environment. Detailed geoelectrical prospecting were carried out to bound the upflow continental area of this system, considering the geoelectrical effects of deep water mixing with different salinity and temperature close the Adriatic coast.

INTRODUCTION

The sulphurous and thermal waters of Santa Cesarea Thermal springs are known from ancient times (e.g. Aristotle in IV century BC). They flow out along a well-defined, 500 m-long, coastal sector of the Salento peninsula, which is part of the Apulia carbonate platform, (i.e. the foreland of the Apennines-Dinarides orogeny; Ricchetti et al. 1988), consisting of Jurassic-Cretaceous limestone and dolostone, over 5 km-thick in the study area. This succession rests above Late Triassic evaporites (Burano Fm), and is unconformably overlain by Cenozoic calcareous successions with stratigraphic lacunae.

The thermal water of Santa Cesarea Terme area origins offshore with the infiltration of fresh seawater, flowing down to several hundreds of meters below the sea level, almost directly into the deeply fractures Apulian carbonate platform (Santaloia et al 2016). The seawater flows downward along steeply inclined faulted zones and interacts with different rocks that are geothermally heated at least at 80-85 °C. Thereafter, this sulphurous water is driven upwards crossing the coastal transition zone of the seawater intrusion by density difference phenomena. Then, it outflows through the coastal springs of the Santa Cesarea Terme system, mixing itself with the continental pure fresh groundwater and the seawater. The whole flow system of thermal water should be considered a convective cell process.

Detailed geoelectrical prospecting were carried out to bound the upflow continental area of this cell, considering the geoelectrical effects of deep water mixing with different salinity and temperature close the Adriatic coast.

METHODS

In the investigated area, n. 6 high-resolution Electrical Resistivity Tomographies (ERTs) were performed, as shown in Figure 1.

The ERT method consists in the determination of the apparent resistivity parameter (Ohm*m), through combined measurements of electric current intensity, injected in the subsoil by means of a pair of electrodes fixed in the ground, and drop of potential measured on two different electrodes. The acquired data are memorized and subsequently elaborated by ad hoc software, in order to obtain the electrical resistivity distribution. In the last decade, the use of ERT was very intensive for the investigation of complex geological areas (geothermal areas, volcanoes, etc.). In particular, the geoelectrical technique of surface tomography along a profile consists in the realization of an extreme detail image of the areal behavior of the electrical resistivity along the plane of the vertical section passing through the chosen profile. The high resolution obtained by this technique makes it possible to discriminate much more effectively the resistivity contrasts existing in the subsoil, thus providing more reliable information on the subsoil: geological discontinuity (Caputo et al. 2003; Rizzo et al. 2004), groundwater, landslide systems (Lapenna et al. 2003; Perrone et al. 2004), buried archaeological finds (Rizzo et al. 2004).

The instrumentation used was the Syscal R2 with a 48-channel multi-electrode system and an electrode spacing of 20 m. Each profile was long 940 m and the investigation depth was about 180 m. The used geoelectrical methodology was the Wenner-Schlumberger (WS), which allows to obtain a high S/N ratio and good information on vertical structures (i.e. faults) and horizontal layers (i.e. geological stratigraphy). The apparent resistivity data were processed by the RES2DINV software (Loke 2001) to obtain in real time tomographic subsurface images of the electrical resistivity pattern. The 2D inversion routine applies a Gauss-Newton least squares method (Loke and Barker 1996), based on the finite-difference model of the subsurface, automatically adjusted in an iterative process. The Root Mean Squared (RMS) error provides a measurement of the quality of the inversion process.

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The Santa Cesarea Terme area is located along the south-eastern coast of the Salento peninsula, a carbonate platform defined by a wide, WNW–ESE trending, antiform structure, dissected by a series of extensional and strike-slip faults (Tozzi 1993).

As shown in the geological map of Figure 1, the Upper Cretaceous Altamura Limestone represents the calcareous bedrock at Santa Cesarea Terme, consisting of well-bedded, peritidal limestone and dolomitic limestone. Locally the Late Eocene-Early Oligocene coral reef limestone, belonging to the Castro Limestone, overlays the Cretaceous formation through a marked angular unconformity (Figure 1; Bosellini et al. 1999; Bossio et al. 2005). Both Altamura Limestone and Castro Limestone are unconformable overlain by the bentonic foraminifer-bearing Oligocene calcarenite (Porto Badisco Calcarenites). The youngest formation cropping out at Santa Cesarea Terme is the Salento Calcarenites (Pleistocene), consisting of massive to poorly bedded, weakly cemented calcarenites, related to a slope environment, as testified by the presence of slumpings and submarine slides. The offshore equivalent of the Salento Calcarenites are well imaged in the seismic lines and form a series of prograding units settled during a forced regression (Aiello and Budillon 2004). In the studied area, groundwater flow within a deep aquifer that occurs within the intensely fissured and karstified Altamura Limestone, Castro Limestone and Porto Badisco Calcarenites (Romanazzi et al. 2015, De Giorgio et al. 2018). These units have the same hydrogeological characteristics and play an important common role in the groundwater circulation. The borehole n. 4 (VIGOR well, Abate et al. 2015) has crossed the rocky succession of the deep aquifer. As shown by the rock coring, this succession is composed primarily of white fine and medium grained micritic limestones (L in Figure 1c), locally interbedded with dolomitic limestone and dolomite (L/DL in Figure 1c i.e. 135-145 m, 285-290 m and 295-300 m below the ground level). Biogenic structures, as biostromal rudists (rb in Figure 1), have been found between 200 m and 215 m below the ground level. Many karst forms (microcavities, karst fractures, calcitic concretions, etc.) have been intercepted even at considerable depths. They seem to decrease starting from 230 m from the ground level (about -115 m a.s.l.). Moreover, it is important to note that the evolution of hypogenic karst forms should have been strongly influenced by the fluctuations of the karstic base level. This level has been linked to the sea-level oscillations occuring during the Quaternary. Morever, in the coastal study area, the development of the karst cavity should have been is also influenced by the fluctuation of the zone of dispersion where the seawater mix with the fresh groundwater (De Waele and Piccinni, 2008).

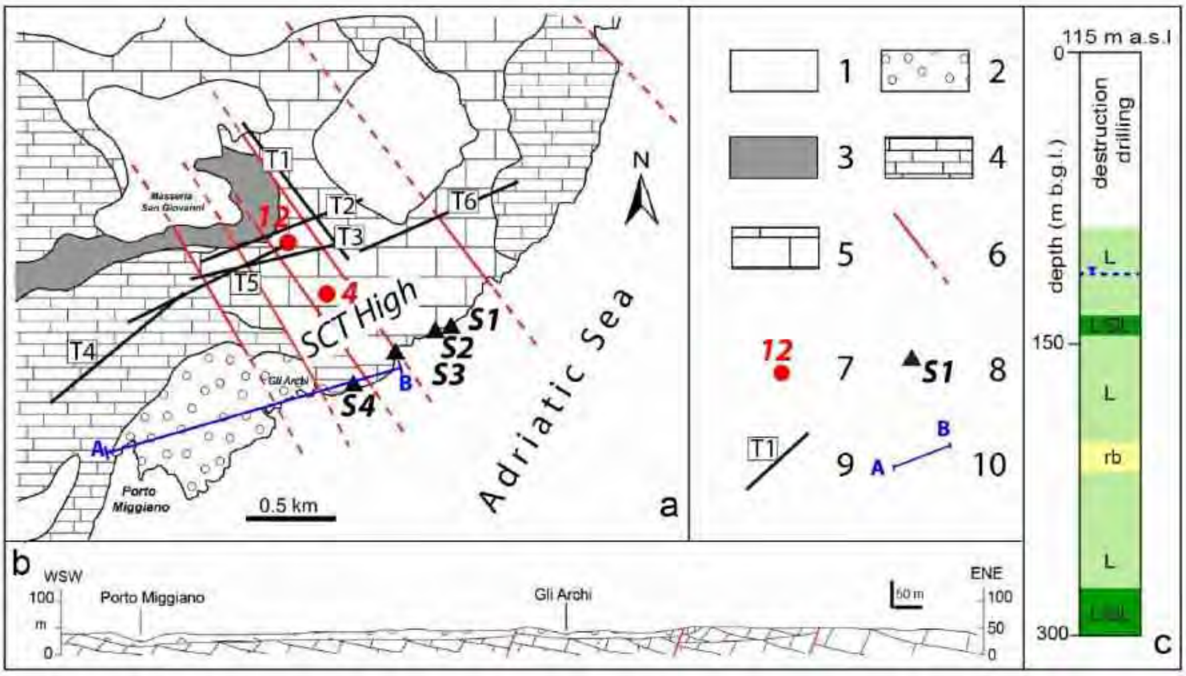

Figure 1. a) Simplified geological map. Legend: 1) red clays, 2) Salento Calcarenites, 3) Porto Badisco Calcarenites, 4) Castro Limestone, 5) Altamura Limestone, 6) fault (a-transtensional, b-normal, dashed when inferred), 7) borehole 12, 8) thermal spring, 9) total Electrical Resistivity Tomography (ERT) data profile, 10) trace of the geological section; b) geological section; c) stratigraphic column of borehole 4. Legend: L=Limestone, L/DL=Limestone and dolomitic limestone, rb= Microcrystalline limestone with traces of macrofossils.

RESULTS

The Figure 2 shows the total ERT profile obtained from the elaboration of the apparent electrical resistivity data coming from the profiles T3, T4, T5 and T6 in figure 1. Along the profile two empty data are well showed (white triangle), due to a lack of an overlap of the performed measurement. In general, the ERT image shows high electrical resistivity values (>500 Ohm*m). In details, the ERT image highlights two electrical resistivity distribution zones: the western one, from the starting point to around 1000 m, and the eastern one, from 1000 m to the end of the profile. The western zone shows a heterogeneity resistivity distribution with lateral and vertical variation. In details, between 700 m to 1000 m some vertical high electrical resistivity structures were recognized, while the first part of the profile shows horizontal electrical resistivity layers with low values (<500 Ohm*m).

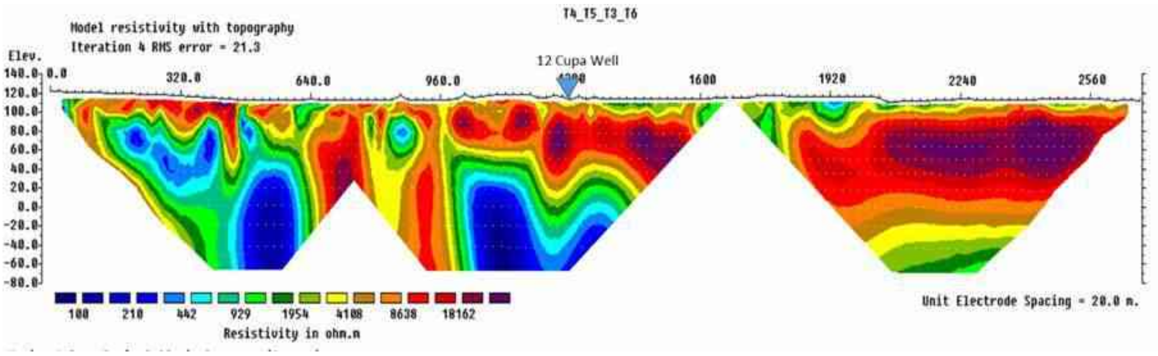

Figure 2. The total GRT profile inverted from the T4, T5, T3, and T6 data profile. The position of the GRTs profile is showed on Figure 1.

The eastern electrical resistivity zone displays a horizontal layer (>2000 Ohm*m) that increases in thickness going to the East (from 20 m to -80 m asl); below this layer, between 1000 m to around 1500 m a relative low resistivity layer (< 400 Ohm*m) is well defined.

DISCUSSION AND CONCLUSIONS

The complex electrical resistivity distribution could be interpreted from the geological point of view combining the geological knowledge of the area with the hydrogeological conceptualization. The geological formations (calcareous rocks) present in the area have very similar electrical characteristics (high resistivity values). However, the presence of some elements of erosion or fracturing and porosity variation due to the fault system assumes an important effect on the electrical resistivity heterogeneity. Therefore, some relatively lower resistivity values of the rocks are well defined, at least for the superficial parts on the western investigated zone, that should be associated to filled karst structures. Furthermore, in depth, their variability may depend on the presence of water circulations with salt characteristics and/or higher temperatures, as described by Archie's law. The thermal well (12, Cupa Well) shows thermal water at 0 m a.s.l., therefore the presence of a saline or heat fluid safely affects the resistivity distribution (i.e. water with high salt content or a high temperature produces a lowering of the resistivity values). Finally, the strong lateral variation (vertical structures) should be associated to the main fault system which delimited the deep geothermal zone well, as hypothesized on the basis of some well data.

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Contact Information: Maurizio Polemio, Consiglio Nazionale delle Ricerche, Research Institute for Hydrogeological Protection (CNR-IRPI), Via Amendola 122 I, 70126 Bari, Italy, Phone: +39-080-5929584, Email: m.polemio@ba.irpi.cnr.it

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