TITOLO TESI
Thermal anomalies of the Verona Province and sustainable uses of hot water resources
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Cycle: XVIII

Abstract
In the present year non-invasive microtremor survey is applied for the preliminary characterization of Caldiero thermal district, in the eastern Po Plain (Italy), a thermal resource known since the Roman times for the presence of warm springs. The purpose of work was to try out the possibility of the microtremor passive technique for the preliminary characterization of a thermal basin, in terms of resonance properties between the alluvial deposit covers and the rocky bedrock with 103 HVSR single station measurements collected and analyzed in the studied area. HVSR information is integrated with the data relative to 21 deep wells. At the same time, after having contacted the management company of the thermal areas, it is possible to lead a water sampling campaign, supported by C.N.R. of Pisa, work in progress. The HVSR technique together with other geophysical surveys and more detailed analysis of the cold waters in Lessini Mountains and hot of the Lake Garda area and plain, will allow significant knowledge of the territory. In particular chemical and isotope analysis and hydrogeology research are providing important information regarding the basin water recharge spas, travel times and routes taken by these underground waters in the Verona area.

Second-year activity

Introduction
The preliminary research allowed to define areas of thermal springs divided into four main districts including Sirmione area. Now it is possible to distinguish "hot areas" characterized by homogeneous geological conditions, instead the chemical and isotopic study is in progress. In this year I favoured, in particular, Caldiero area, being an ancient area of thermal tradition.
In the report I will describe in a first step the geological and geophysical research and the geochemical research in a second step, dividing the study in thermal districts.

Method used in the first district and results: geological and geophysical research
The first district is focused mainly in the neighbourhood of Caldiero, but also brings together the towns of Belfiore, Colognola ai Colli, Lavagno, S. Martino Buon Albergo, S. Bonifacio, Zevio, Ronco all'Adige and Arcole. These thermal wells have not been studied in detail due to time constraints.
After analyzing the geology of the area with a geological relief and controlled the stratigraphic wells present in the territory, a 103 HVSR single station measurements were collected. I use the HVSR technique (also known as Nakamura’s technique; Nakamura 1989) because it consists in the passive recording of natural microtremors (seismic noise) by the use of three component broad band receivers. The tool is a tromograph (Tromino of Micromed Company). The method aims to identify the subsoil resonance frequency $F_o$, assumed as the maximum peak of the ratio between the horizontal and vertical components of motion (Field and Jacob 1993). HVSR technique proved to be an efficient tool for estimating the fundamental frequency response $F_o$ of soft deposits, e.g. bedrock and sediments (Field and Jacob 1995).
The measurements, after to be calibrated on the stratigraphy of 21 of 125 wells tested, enable us to define the deep of bedrock and fractured rock. The final result is a bedrock map. It is possible to see in the figure of left, figure 1. In fact, bedrock depth estimation, in previous studies, is in very good agreement with the HVSR results. In the right it can be seen as resonance frequency values decrease toward south direction as attended due to the deepening of the bedrock. The abrupt difference in resonance frequency behavior seems in good correlation with the fault system of the area (figure 2).
Geological and Hydrogeological Studies in other districts

The second district, based on its hydrogeological conditions, includes the towns of Sant’Ambrogio of V.Ila, where I started a study with HVSR method similar to Caldiero that I have not yet finished, San Pietro in Cariano, Pescantina. The third district is to the western, where there are warm water wells in the moraines of the municipalities of Pastrengo, Lazise, Bardolino, Peschiera and Castelnuovo. Sirmione is the fourth district outside the province of Verona. Every district has different temperatures and different geological conditions as it has been shown in previous studies (Berlusconi and al. 2013; Castellaccio and Zorzin 2012). We can see, for example, that the temperature of groundwater is decreasing from west (68°C measured in Sirmione well) to the east (42°C - Sant’Ambrogio of V.Ila well and about 30°C in Caldiero well).

Geochemical research: Collected samples and laboratory analysis

In all districts, during this year, were collected 47 samples, 37 samples of waters of cold springs in Lessini mountains, 9 samples of hot waters wells and 1 sample of lake Garda’s water for chemical and isotopic analysis in CNR-Pisa during November month. Some parameters were measured on site using a multiparametric probe.

The hydrochemical surveys on the stable isotopes of Caldiero oxygen thermal waters, previously obtained by Sighinolfi and al. 1982, present at an altitude of 1,000 ÷ 1,500 m, the approximate altitude of infiltration of storm water recharge. This result will be verified with further isotopic analysis, however crossing the isotopic data with the geological and structural framework of the Verona-Trento area, appears likely that the recharge area of the "geothermal reservoir" uniting the northern portions of Lessinia and Monte Baldo, to include the Small Dolomites mountain range and probably the area which continues further north towards Trento, how it necessary to consider. This situation would testify, on one hand the vast extent of the hydrothermal system and, secondly, the existence of complex hydrogeological phenomena. Finally another consideration, but by no means less important which should be defined, will be the travel time of these waters. Chemical waters’ analysis are going to complete in C.N.R. of Pisa and then we could choose more appropriate samples respect e.g. latitude values of temperature, precipitation and rocks’ typologies crossed. In the Laboratories of the C.N.R. the investigated isotopes will be: oxygen, deuterium, strontium, tritium and perhaps others isotopes.

Program next year

It is also interesting that, in a research of Insubria University and CNR IAMC Napoli, a morphobathymetric map of Punta San Vigilio-Sirmione shows a lot of pockmarks in the depth. Over the coming months we will take water and gas samples from these pockmarks, with a contribute of Coast Guard of the Lake Garda, to see if they match with the emergence of hot water from the Bojola spring into the Lake Garda near Sirmione.
In this campaign of investigation will be involved researchers and professors at the University of Insubria and Naples who kindly help us to complete what they had started with the study of morphotettonic in this area (Berlusconi and al. 2013; Sileo and al. 2008) and could give a positive contribution to the study of the geochemical research.

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**References**

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DE VECCHI G., 1960 *Relazione idrogeologica – mineraria relativa al permesso di ricerca per acque termominerali denominato ‘San Francesco’ Comuni di Sirmione e Rivoltella (Bs). Relazione tecnica*


FORLANI E., 1977. Indagine idrogeologica sull’area termale di Sirmione. Relazione tecnica

FORLANI E., 1981. Studio idrogeologico sul bacino termale di Sirmione. Relazione Tecnica


VUILLEMIN E., 1978. Prospezione geofisica integrativa sull’area termale di Sirmione. Relazione Tecnica
SUMMARY OF ACTIVITY IN THIS YEAR

Courses:
F.GHERARDI, G.MAGRI, M.PENNISI: “Corso di Idrogeologia Isotopica”, Centro Nazionale Ricerche di Pisa
M.FLORIS: “Corso Gis Base e Avanzato”, Dipartimento di Geoscienze, Università degli Studi di Padova
G.DE RUBEIS: “ArcGis Online: le soluzioni Gis sul Web a disposizione di tutti” C.I.R.GEO. Università di Padova

Communications:
No communications

Posters:
“GEOTHERMALISM IN THE PROVINCE OF VERONA Lake Garda and Verona Province case studies” S.G.I. 10-12sept 2014 Milano Laura Agostini Department of Geosciences – University of Padua, Padua (Italy), Collareda M., Castellaccio E., Dal Degan D. Geologists of Vicenza (Italy) and Verona, Antonio Galgaro, Jacopo Boaga, Institute for Geosciences and Earth Resources, IGG-CNR Padua, Italy
“AN ACQUEDUCT FOR GUARANI” S.G.I. Milano 10-12sept 2014 Milano P. Bruttì Environmental Engineer of Verona; L. Agostini Department of Geosciences – University of Padua; E. Agnelli Architect, Free Professional of Verona; M. Righetti, Associate Professor - D.I.C.A.M. , University of Trento; Rocio Dosserich Pastoral Social Caritas Camiri, Camiri, Bolivia, Stefania Croce Caritas of Verona

Publications:
Agostini L., Boaga J., Galgaro A., Ninfo A. “HVSR technique in near surface thermal-basin characterization: the example of the Caldiero district (North-East Italy)” 2014 Envr. Earth Sc. - Resubmitted after revision under review

Teaching activities:

Other:
Workshop: “Ricerca di Idrocarburi e gestione del gas metano in Pianura Padana: aspetti di rischio sismico e criticità energetiche e amministrative”, Dipartimento di Ingegneria, Università di Brescia - 7 maggio Brescia