TITOLO TESI
Geothermal districts of the Verona Province and sustainable uses of hot water resources
Ph.D. candidate: LAURA AGOSTINI, Geoscienze course
Tutor: Prof. ANTONIO GALGARO
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Abstract
The study area extends along the southern boundary of the central-eastern pre-Alps. The research is mainly focused in the analyses of the thermal districts of the Verona Province. A geological, geophysical and geochemical research is being performed in the area characterized by different temperatures and hydrogeological conditions in the thermal districts. The aim of study consists on the characterization of the thermal reservoirs in relations with the uses of the resource. For these purposes two groundwater sampling campaign have been conducted in the autumn 2014 and summer-autumn 2015, with the support by C.N.R. IGG of Pisa. The geophysical surveys also helped to provide useful information for better understanding of certain analyzed areas. Furthermore geochemical and isotope analysis have provided fundamental information regarding the hydro-thermal circulation, in the studied geothermal districts. The data of this research can be used as input parameters in geothermal modeling to draw a geothermal map of the research area. This research will provide many information about thermal resources aimed at promoting the rational use of geothermal energy.

Third-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 thermal anomalies in the study area characterized by homogeneous geological, chemical and isotopic conditions. The Caldiero area is being studied in details with further investigations respect the others thermal areas.

In the report I will describe the geological, geophysical and geochemical research delving into the study of detail undertaken in the area of Caldiero and Sirmione/Lake of Garda. In figure the study area and the geological situation divided into three paleogeographic areas (Cau and Fanti, 2010). The presence of thermal water can also be considered among the evidence of the tectonic, and sometimes seismic, activity of the structural overview at regional level.

Geological and Hydrogeological Studies in the geothermal districts
The first district is focused mainly in the neighbourhood of Caldiero Village, but also brings together the villages of Belfiore, Colognola ai Colli, Lavagno, S. Martino Buon Albergo, S. Bonifacio, Zevio, Ronco all'Adige and Arcole. The research activity has been focused on the Caldiero area because it appears to be the most representative sector both from the geothermal point of view that the use of thermal resource. After analyzing the geology of the area with a geological relief and controlled the stratigraphic wells present in the territory. The measurements, after to be were calibrated on the stratigraphy of 21 of 125 wells tested, enable us to define the deep of bedrock and fractured rock (see Geomorphological map below). The final result is a bedrock map. In fact, bedrock depth estimation, in previous studies, is in very good agreement with the microtremor investigations results. 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 also with a statistical approach (see Trevisani S. and al., submitted; Agostini and al., 2015). These results, in Caldiero
area, shows as critic data scrubbing, joined to rigorous statistical approach for data interpolation, are mandatory to assure meaningful structural interpretation from microtremor HVSR survey.

The second geothermal district, based on its hydrogeological conditions, includes the towns of Sant’Ambrogio di V.lla, where a study similar to Caldiero was performed, San Pietro in Cariano, Pescantina. The third district is to the western, where there are hot water wells in the moraines of the municipalities of Pastrengo, Lazise, Bardolino, Peschiera and Castelnuovo. Sirmione village is the fourth district, located in the Brescia province. Every district has different temperatures and different geological conditions as it has been shown in previous studies (Berlusconi and al., 2013). In the research, the data obtained by some geothermometers (Gunnarsson and Arnorsson, 2000 and Verma e Santoyo, 1998) compared with the geological context suggest an Eastern reservoir of about two thousand deep, while a North Western one, which is part of the thermal area of Sant’Ambrogio di V.lla – Cola’ di Lazise, can reach about two/three thousand deep; Sirmione instead own reservoir at about 4,000 meters deep.

Analysis of the $\delta^{18}$O and $\delta^2$H cold/warm springs and wells indicated the rainwater recharge infiltration altitude at approximately over 1.500m in height. Cross-checking the isotopic data with the geological and structural overview of recharge area seems to include the northern portion of Lessinia/ M.te Baldo and the mountains of Trento, a wide area which is characterized by a high permeability due to the strong tectonic deformation.

Geochemical sampling campaign and laboratory analysis
In particular geological, geophysical and geochemical research is being performed in four “thermal” districts characterized by different temperatures and hydrogeological conditions. The first district is mainly focused in the Caldiero village, where the temperature of the spring and well is about 26°C. The second district is situated in the north–western part of Verona Province, where temperature up to 40°C are measured. The third district is located close to the south-eastern border of the Lake Garda and it is represented by warm waters (temperature in the range 18-25°C) which are tapped by some wells.

Sirmione, at south coast of the Lake of Garda, is the fourth district and shows the highest temperatures (about 65°C) in the studied area, despite being located at the bottom of the lake 20 m depth.

Geochemical studies of thermal fluids develop in three steps:
1) Sampling;
2) Analysis;
3) Data interpretation

Last year for sampling in all districts were collected 47 samples, 37 samples of water 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 autumn. In this year more of 100 samples were collected, about ten in the Trento Province and five in the Brescia Province respectively in the winter and summer seasons.

Some parameters as pH, salinity, temperature and conductivity were measured on site using a multiparametric probe of Hanna Instruments. Chemical waters’ analysis are going to complete in C.N.R. IGG 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 are being: oxygen, deuterium, strontium, tritium and sulfur isotopes.

In the Piper Diagram is highlight the different chemical species of the waters. Sirmione water differs from other waters of the Verona Province. Even though furthermore investigation are being carried out, the produced data seem to provide new insight into the framework of thermal groundwater flow. Crossing the geochemical data with the geo-
structural framework, it appears likely that a significant recharging of the geothermal resource, at least for the Sirmione district, more than 50 km N-NW from the study area. These results suggest extent of the hydrothermal system and the existence of a complex hydrogeological framework.

In thermal water salinity depends on different factors and it tends to increase as long as the fluids flow underground, whilst its chemical composition is influenced by the rock types with which the water comes in contact. The waters with low temperature (until 14°C) are cold springs or cold wells. The chemical classification is calcium-magnesium bicarbonate for the typology of crossing carbonate rocks. In eastern zone like Caldiero, the warm waters are characterized by calcium alkaline bicarbonate. The western zone (villages of Sant’Ambrogio of Valpolicella, Pescantina and Lazise) shows waters rich in calcium-sulfate or sodium with higher temperatures. Now in laboratories of CNR-IGG UOS Padua and Canada strontium and sulfur isotopes analysis are in working. By means of the few analysis performed and based on the historical ones I can assume different types of thermal groundwater. The first type, a carbonate reservoir, is contained in the pre-Quaternary rock substrate rocks of the plain and the deep sub-alpine and alpine layers, where there is intense hydrothermal fluid movement with little or no connections with the cold surface water systems. A clastic type reservoir is made of Quaternary sediments melted in the plain whose hot fluid concentration is related to the dispersals and to the landfill of the deeper rock hydrothermal system.

Research in Lake of Garda
Between January and March a further research was carried out by a group of people composed by Speleosub Group of Veneto Region, researchers of Pisa CNR-IGG, Insubria and Padua University with a contribute of Coast Guard of Salò. We took water and gas samples from the bottom of the lake to see if they match with the emergence of hot water from the Bojola spring into the Lake Garda near Sirmione. This investigation was based on a previous study by Insubria University and CNR Garda near Sirmione which a morphobathymetric map of Punta San Virgilio-Sirmione shows a lot of pockmarks in the depth (Berlusconi and al., 2013). In this campaign of investigation 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 morfotettonic in this area (Berlusconi and al. 2013; Sileo and al. 2008) and could give a positive contribution to the study of the geochemical research.

Conclusions
A new geological and geochemical approach was carried out in order to improve the knowledge of the characteristics of thermal resources of geothermal districts Verona. These studies have led to the definition of conceptual models of hydrothermal circulation and to distinguish various sectors for their particular characteristics. After analyzing approximately 1000 wells in the province of Verona, I considered 24 important sites for sampling water both hot and cold. These samples are used to define the origin of such water, and then the traffic routes. To create a model of movement it’s necessary to make isotopic analysis. The samples taken are only 6 because some owners of spas do not agree to give permission to analyze their water.

The thermal area of Caldiero has been studied with rigorous statistical analysis of temporal correlation between precipitation and changes in hydraulic conditions at the spa wells, allowing to provide, with the support of the geochemical data and passive seismic surveys, new insights about local thermal groundwater flow path. In particular, though further investigations are being carried out and the data interpretation is ongoing, it appears likely that a significant recharge of the geothermal resource originates some tens of km to the North of the studied thermal area, on the pre-alpine zone. The geothermal mapping of the Italian territory for that type of thermal area shows a potential huge and easily available, which include the areas between Sirmione and the Adige Valley and the wide area around Caldiero. The low enthalpy of Verona province thermal area is therefore a possible important source of energy for public environments.
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SUMMARY OF ACTIVITY IN THIS YEAR

Courses:


Communications:
No communications

Posters:
“The thermal water of the Verona area, North-East Italy” IAH Congress 13-18 September 2015 Rome (Italy)
Agostini Laura1, Galgaro Antonio1, Doveri Marco2, Lelli Matteo2, Michetti Alessandro Maria1, Livio Franz1, Terrana Silvia3, Visintainer Paola1, Paoli Marco1, Santuliana Ernesto1, Saverio Cocco1, Fiaccavento Piero1
1Department of Geosciences – University of Padova Via G. Gradenigo, 6 - 35131 Padova, Italy
2Institute of Geosciences and Georesources, CNR, Area della Ricerca, Via G. Moruzzi 1, I-56124 Pisa, Italy
3 Dipartimento di Scienza e Alta Tecnologia Università dell'Insubria Via Valleggio, 11, 22100 Como, Italy
4 Servizio Geologico Provincia Autonoma di Trento Via Roma, 50 38122 Trento, Italy
5 Geologist Salò – Brescia, Italy

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)” 2015 Envir. Earth Sc.
Trevisani S., Agostini L., Galgaro A., Boaga J. “Mapping bedrock surface morphology using low-cost passive seismic surveys and integrated geostatistical” analysis” to be submitted.

Teaching activities:
No teaching

Other:


GeoTHERM expo & congress 2015 5-6 March 2015 Exhibition Center Offenburgh, Offenburgh (Germany)