ASSESSMENT OF GEOTHERMAL ENERGY RELEASED FROM UMBRIA REGION (ITALY): A GEOCHEMICAL INVESTIGATION

GIULIO BEDDINI
Dipartimento di Fisica e Geologia, Università di Perugia, Piazza dell'Università, 06123 Perugia

GEOTHERMAL ENERGY IN UMBRIA REGION

The recent development of new exploitation technologies has allowed to use the geothermal energy, which derives from the internal heat of the Earth, as a source of renewable energy with a limited environmental impact respect to non-renewable energies. The increasing number of direct applications of geothermal energy has reawakened the interest on its potentialities and has extended the researches in areas considered not exploitable before. In this regard, the geothermal potentialities of Umbria region, always considered not suitable for electricity production, should be substantially reviewed in the context of direct uses of this energy.

Based on its geological-structural characteristics, it is possible to divide Umbria region into two distinct sectors: the eastern sector, where the compressive structures are better preserved and the western sector characterised by a strong crustal thinning due to an intense extensive deformation (Barchi *et al.*, 1998; Collettini *et al.*, 2000; Pauselli *et al.*, 2006).

The western sector is very interesting from a geothermal point of view because the normal faults that have dislocated the compressional structures allow the rise of deep NaCl-rich fluids with high PCO_2, and their mixing with more shallow circulating waters. The occurrence of these saline fluids is related to the presence of a deep regional aquifer at the base of Mesozoic carbonates, in which are also located the main deep geothermal reservoirs of the region. The high CO_2 content is due to the influx of deeply derived CO_2 related to a regional process of mantle degassing. This sector is also characterized by the presence of thermal springs, gas emissions, areas of diffuse soil degassing and middle-low enthalpy geothermal systems (Chiodini *et al.*, 2000, 2004; Frondini, 2008). It seems highly improbable that the heat content of thermal waters, circulating at relatively shallow depths (some tents of meters), could be caused by conductive heating only and a process of advective mixing with deep hot fluids can be hypothesized. Recent works (Frondini, 2008; Frondini *et al.*, 2012; Chiodini *et al.*, 2013) clearly showed that, in this area, deep fluids transport a significant amount of heat towards the surface causing the observed thermal anomaly of spring waters. The extent of the thermal anomaly of each spring is essentially a function of the relative proportions of deep fluids and shallow groundwater.

The geothermal prospecting was accomplished through geochemical investigations focused on fluids, both liquid phase and gases, which characterize the study area. Groundwater and gas samples were collected and analysed for the determination of the chemical and isotopic compositions. Geochemical data interpretation coupled with information from hydrogeological and geological-geophysical data allowed to estimate the reservoir temperatures, to estimate the composition of the thermal fluid, to evaluate the input of deep gas dissolved in the waters, and to reconstruct the model of local and deep circulation.

This study includes the detailed investigation of three low and middle-low enthalpy systems located in the Umbria region (Fonti di Tiberio, Parrano, and Triponzo) and the investigation of the advective heat flow in Umbria at regional scale.

RESULTS AND DISCUSSION

Local scale investigations

At local-scale three systems were investigated through a geochemical surveys. For each sampling point, temperature, conductivity, pH, Eh, silica concentration, and alkalinity were measured in field and five aliquots were collected for chemical and isotopic analysis. Aqueous speciation calculation allowed to compute for each sample the PCO_2 value, the saturation indexes with respect to relevant mineral phases, the carbon speciation, and the TDIC value. The calculations were performed with PHREEQC version 3 computer code (Parkhurst & Appelo, 2013).

The results obtained for each single system showed interesting situations in which the thermal energy resource could be exploited, considering the present technologies, for direct uses. The main results can be summarized as follow:

1) Fonti di Tiberio system: the thermal waters of this system derive from a mixing process of local infiltration water with geothermal brines (about 30%) with a similar composition to the hotter fluids present at depth in the nearby middle-enthalpy system of Torre Alfina. This process is highlighted both by chemical and isotopic analysis. These waters are characterized by temperature ranging from 26 °C (springs) to 42 °C (wells) and by a Na-Cl-(HCO_3) composition with very high Total Dissolved Solids (TDS) concentrations (4-8 g/L). The shift of the thermal waters from the Central Italy meteoric water line (Longinelli & Selmo, 2003) is a clear clue of interaction with deep hot fluids.

The equilibrium temperature of parental fluid which feeds the Fonti di Tiberio springs, estimated with ternary geoindicator (Chiodini *et al*., 1995) and silica geothermometer (Truesdell & Fournier, 1977), is about 100-120 °C with a PCO_2 up to 100 bar. This high value of partial pressure of CO_2 underline an important input of deep heavy CO_2 (inorganic), confirmed by the positive $\delta^{13}C_{ext}$ values. The thermal energy calculated for the Fonti di Tiberio thermal springs area is at least about 1.09×10^9 J/day.

2) Parrano system: the data of the Parrano thermal system highlight the presence of a deep (regional) circulation of water into the carbonate-evaporite formation of Umbria-Marche at a depth of about -2000 m. The $\delta^{18}O$ data were used in order to obtain the mean altitude of the recharge area (about 630 m a.s.l.) corresponding to the mean altitude of carbonate outcrops of Peglia Mt. from which the infiltrating waters reach the Parrano area through a deep circuit, increasing the temperature due to the geothermal gradient. This deep thermal component, which shows a $PCO_2 > 60$ bar and temperature of about 100-120 °C, rises from extensional structures in the thermal spring area mixes (about 12%) with sub-superficial waters.

The isotopic carbon analysis show that Parrano thermal spring is also affected by an input of deep heavy carbon, with $\delta^{13}C_{ext}$ value of about -1.8‰, which differs from the other cold springs in the area (from about -30‰ to about -20‰).

The thermal energy, associated to the thermal spring, is about 5×10^{10} - 5.7×10^{11} J/day confirming that Parrano area is characterized by an interesting low-middle-low geothermal system.

3) Triponzo system: this area, unlike the two systems described before, is located in the eastern sector of the region usually characterized by a relatively low average heat flow (< 50 mW/m^2, Della Vedova *et al.*, 2001).

The results indicate that thermal waters circulating in the Triponzo system have the isotopic composition of δD and $\delta^{18}O$ similar to the cold surface waters and a recharge area at a mean altitude of about 1700 m a.s.l. (corresponding to the mean altitude of Sibillini Mts.). The thermal waters showed a Ca-SO_4 composition, which highlights interaction with dolomite-evaporite rocks due to a circulation at depth. During the circulation the thermal waters have been enriched in deeply derived He and CO_2 gas components. The input of deep heavy carbon was also confirmed by the $\delta^{13}C_{ext}$ data, with values up to 7‰ heavier than surface waters, but however lower than the previous investigated systems. Geothermobarometry estimations gave temperatures at equilibrium condition ranging from 60 to 75 °C and a PCO_2 of about 0.5 bar.

The thermal energy transported by advection, associated to a thermal component flow rate of about 34±5 L/s (computed using a mass balance approach based on chlorine concentration), and released at surface through groundwater is about $3.71 \times 10^{11} \pm 0.56 \times 10^{11}$ J/day. At Triponzo the amount of thermal energy transported by groundwater is significant and locally much higher than the thermal energy transferred towards the surface by conduction. In agreement with the recent findings of Frondini *et al.* (2012) and Chiodini *et al.* (2013), the data suggest that advection is an efficient process of energy transfer in the upper crust of the Apennine region.

The main characteristics of the parental fluid for each system investigated are listed in Table 1.

Table 1 - Summary of the results obtained for thermal systems studied.

SYSTEM	PARENTAL FLUID TEMPERATURE (°C)	PARENTAL FLUID PCO_2 (bar)	THERMAL ENERGY RELEASED (J/day)
Fonti di Tiberio	100 - 120	100	1.09×10^9 J/day
Parrano	100 - 120	> 60	5×10^{10} - 5.7×10^{11}
Triponzo	65 - 75	0.5	3.71×10^{11}

Regional study

The thermal energy released from the entire region was computed based on the temperature difference between infiltrating water and water discharged from the springs connected to the several carbonate structures cropped out in the study area. This temperature difference is due to two components: *i*) the geothermal heating and *ii*) the dissipation of gravitational potential energy (Manga & Kirchner, 2004). In the calculation it was assumed that the effect of the conductive heat transfer from aquifer to the surface was negligible; this assumption is reasonable for aquifer with water table at depth higher than 100 m (Manga & Kirchner, 2004). The overall results can be summarized as follow:

1) The geothermal potential of the whole region was evaluated through the advective heat flow map (Fig. 1a) which highlights that Umbria is affected by an advective heat flux higher than the conductive heat flux estimated by Della Vedova *et al.* (2001) (< 50 mW/m^2), particularly in the western sector, characterized by values up to 4-5 times higher than the eastern area.

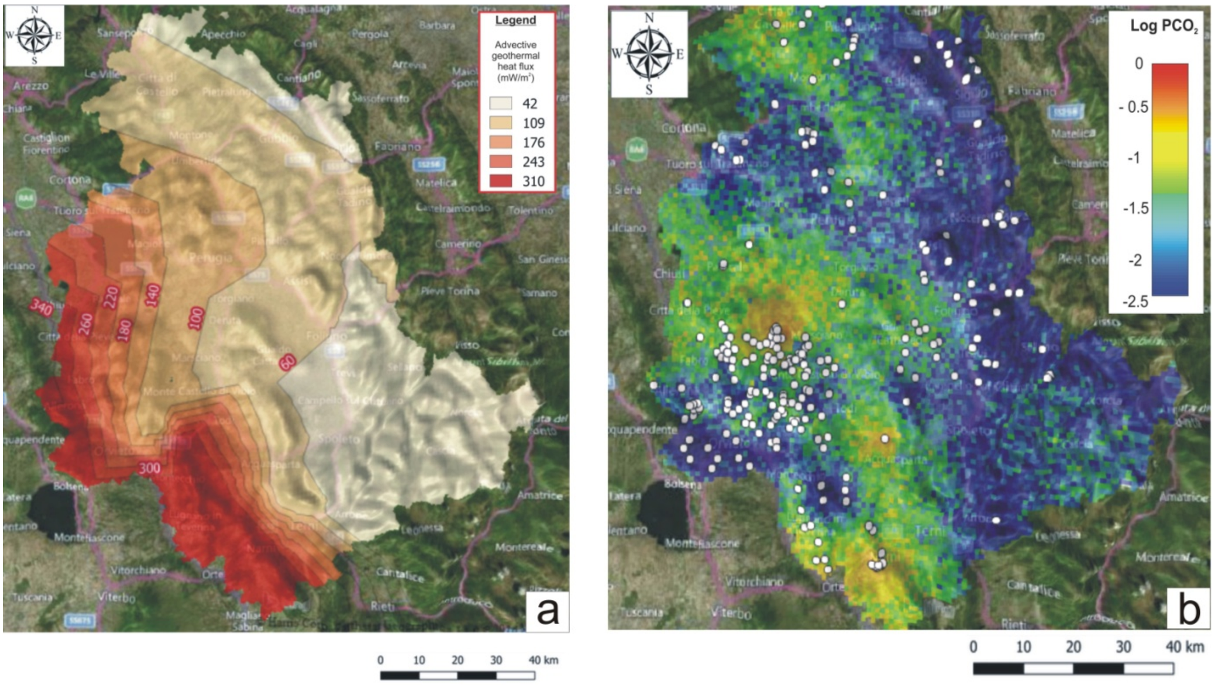

Fig. 1 - a) Advective heat flow map of Umbria region; b) Log PCO_2 anomalies map.

2) The map of PCO_2 anomalies in Fig. 1b, obtained from geostatistical elaboration through the GSLib software (Deutsch & Journel, 1998), highlights that the same area is affected by high advective heat flux and is also interested by high fluxes of CO_2 from a deep source. These anomalous CO_2 fluxes are probably connected to the Earth degassing process involving the Tyrrhenian sector of Central Italy, suggesting that heat is transported from depth by CO_2-rich fluids, as already discussed in Frondini *et al.*, 2012 and Chiodini *et al.*, 2013.

The source of this large heat flux anomaly and of the intense Earth degassing process is most probably due to a large mantle intrusion in the crust as also suggested by a marked low velocity anomaly of the seismic waves present in the subsoil of this sector of the Apennines. The top of this anomaly would be at 10-15 km of depth (Chiodini *et al.*, 2004).

The CO_2 and the thermal anomalies have a common origin, probably connected to metasomatic processes triggered by the subduction of the Adria lithosphere which causes, at relatively shallow levels, the intrusion of hotter sub-lithospheric mantle. The Fig. 1 also highlights that the western sector of the region is characterized by important PCO_2 anomalies and by a high advective heat flux respect to the eastern side, according to a general trend shown by the whole central Italy area.

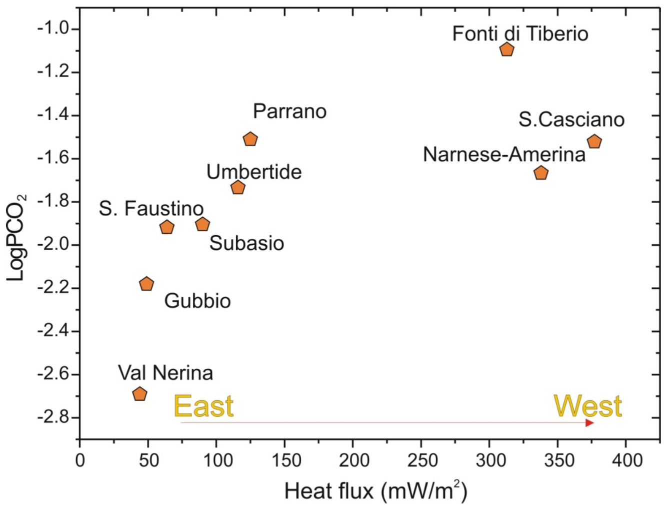

Fig. 2 - Advective heat flux versus Log PCO_2 values of the carbonate structures in Umbria and in the nearby areas.

3) The relationship among deeply derived CO_2 anomalies and high advective heat flux values, relatively to the carbonate structures of the Umbria region and nearby areas, is clearly shown also in the graph of Fig. 2, and summarized in Table 2.

4) The data obtained from each individual system investigated in this work confirm that this regional trend is also showed at local scale. The Fig. 3 shows the ternary geoindicator (Chiodini *et al.*, 1995) in which are shown the values of T-PCO_2 calculated for each investigated local system, highlighting the increment of PCO_2 proceeding from the eastern to the western sector.

In conclusion Umbria region shows *i*) locally, interesting situations with low-middle-low enthalpy geothermal systems, exploitable for direct uses like district heating, air-conditioning and thermal tourism and *ii*) regionally, a considerable amount of thermal energy, about 2.9×10^8 J/s (*i.e.*, about 300 MW), transported by groundwater.

Table 2 - Advective heat flux and mean PCO_2 values computed for each carbonate structures of Umbria and nearby areas.

STRUCTURE	**HEAT FLUX (mW/m^2)**	**Log PCO_2**
S. Casciano	377	-1.521
Narnese-Amerina	338	-1.667
Fonti di Tiberio	313	-1.094
Parrano	125	-1.511
Umbertide	116	-1.734
Subasio	90	-1.905
S. Faustino	64	-1.918
Gubbio	49	-2.181
Val Nerina	44	-2.691

Based on the present knowledge, this geothermal heat potentially represents a widely exploitable resource for several direct uses. The utilization of geothermal energy depends on the resource temperature and are described by the Lindal diagram (Lindal, 1973) which reports space heating and agricultural applications for fluids with temperature below 100 °C and industrial applications for those with temperature above 100 °C.

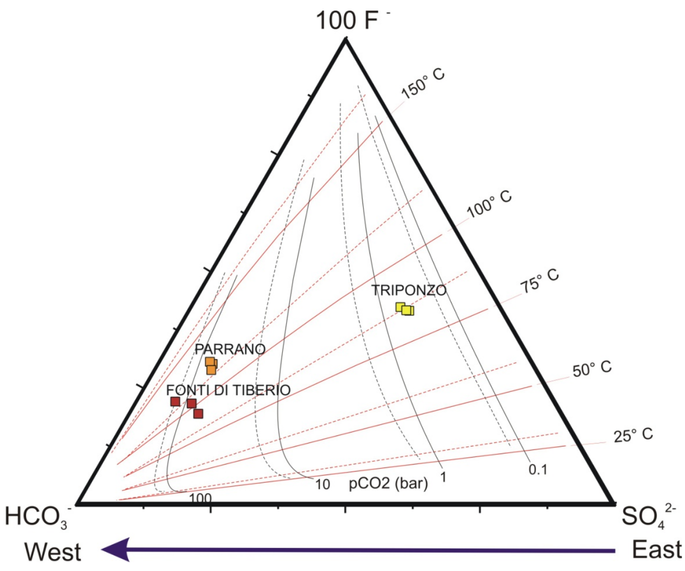

Fig. 3 - Geoindicator (Chiodini *et al.*, 1995) showing the T-PCO_2 values of the investigated systems.

Considering the temperature estimated in this PhD work and considering the activities characterizing the study area, the most common applications of the geothermal resource in Umbria could be:

1) Aquaculture and livestock farming (for temperature in the range 13-30 °C). Aquaculture or aqua farming is the raising of aquatic animals such as fish, crustaceans, molluscs, and aquatic plants. This farming activities are practised under controlled conditions and the temperatures enhances the growth rate. The use of geothermal resources in aquaculture depends on the type of aquatic animals raised, the quality of water and its composition. Also livestock farming is a rather common application. The geothermal fluid is in general used directly in the pond or pool to provide the heat required (Jóhannesson & Chatenay, 2014).

2) Swimming, bathing and balneology (for temperature in the range 30-50 °C). The geothermal resource can be used in swimming pools and Spas for thermal tourism. In Triponzo the old Spa has been renewed and opened in 2016. New feasibility studies should be carried out at Parrano and Fonti di Tiberio in order to design new Spas.

3) Agriculture. The major applications of geothermal energy in agriculture are soil warming, irrigation and, mainly, the heating of greenhouses in order to control the climate, the temperature, and relative humidity. The temperature of the water supplied to the greenhouse depends on the heating demand and ranges from 40-100 °C (Vasilevska, 2007). The water is distributed in steel pipes which could be placed under the soil, on the soil or on benches, between rows of plants or suspended in the greenhouse space (Panagiotou, 1996). In the study area the main application could be heating of greenhouses.

4) Space heating and cooling (for temperature in the range 30-150 °C). Geothermal district heating is defined as the utilization of the Earth's thermal energy for space and water heating and it can also be applied to space cooling. In the study area, space heating and cooling could either be developed for individual users or as district systems. District systems usually combine wells, gathering and distribution systems, heat central and peak load equipment to supply heating or cooling to a group of buildings. Geothermal heat pumps also play an important part for individual space heating or cooling with the use of either ground or water source heat pumps. Space cooling from geothermal can be successfully achieved with heat pumps (Jóhannesson & Chatenay, 2014).

Industrial applications deserve some specific considerations. These applications encompass a rather wide range of industrial activities requiring fluid from low to medium temperature (preheating, washing, evaporating, distillation, drying - Jóhannesson & Chatenay, 2014). However, despite of the broad range of industrial applications that may use geothermal resources, in the vicinity of the main thermal springs there are no significant industrial districts and the industrial applications seems to be less interesting with respect to other applications.

Finally, a further development of technologies and advanced focused researches could allow the use of these geothermal resources not only for direct uses but also for the production of electricity.

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