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Anomalous pattern of geochemical data recorded in the seismically active site of Pieschi (Southern Italy)

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Abstract
This work explores three years of geochemical signals recorded by Pieschi station (Southern Italy). The measuring station is located in a thermal spring located in the Southern Apennines Chain, one of the most seismically active areas of the Mediterranean region. The spring is located close to a geophysical monitoring network installed in 2001 by IMAA-CNR. The probe is able to record temperature and water conductivity with a sampling rate of 10 min. From November 2001 to February 2005 several anomalous variations of water conductivity were recorded. Correlation analysis with selected local earthquakes was carried out to identify events inducing strain effects in the investigated area.

Key words *earthquakes – geochemical signals – time series*

1. Introduction

Deep seated fluids have been widely investigated to monitor possible crustal strains possibly linked to earthquakes (*e.g.*, Wakita *et al.*, 1988). Basilicata Region (Southern Italy) experimented several strong seismic events in the past (Gruppo di Lavoro CPTI, 1999). The abundance of thermal spring sources and gas emissions in Basilicata evidence intense local faulting and enhanced characteristics of crustal permeability induced by tectonic activity. Most suitable local deep seated fluids useful for geodynamic monitoring were described by Balderer and Martinelli (1995) and by Martinelli and Albarello (1997). Among them Pieschi thermal spring is characterized by absence of anthropic noise and by clues of possible sensitivity to seismic events in the past (Martinelli, 2004).

Pieschi spring source (fig. 1) is located in the municipality of Tito (Basilicata region) and is characterized by a flow rate of about 5 l/s and *T*°=20°. Acquifer is fed by the local Mount Pieschi carbonatic rock which belong to the Campanian platform. Intense local faulting allows water infiltration up to 1 km depth while a hydraulic head is responsible for water outflow. Sodium carbonate geochemical character and the about absence of Tritium (<1.3 T.U.) are consistent with a long path feeding circuit and with long residence time of water into the reservoir estimable in > 40 years. The constancy of

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Fig. 1. Thermal spring where Pieschi station has been installed.

flow rate allowed the exploitation of thermal waters in a local resort, due also to relatively high H_2S concentration. Long residence time and constancy in flow rate inhibit the short term effects of rain in water parameters. The meanwhile some chemico-physical characteristics of Pieschi spring changed during the 1857, $M_e=6.9$ earthquake (Martinelli, 2004), thus the possible sensitivity of local fluid to crustal deformative processes and relatively high signal/noise characteristics induced us to monitor Pieschi spring.

2. Seismological setting

The Southern Apennines are a fold-and-thrust belt built on from late Oligocene to Pleistocene. The chain is mainly composed of Mesozoic-Cenozoic sedimentary cover from the Ligurian oceanic crust and the western passive margin of the Adriatic Plate, and of the Neogene-Pleistocene piggyback basin and foredeep deposits of the active margin. Recent shortening occurred at the belt front deforming Pleistocene sediments and volcanics whereas widely documented extension is still active along the Apennines axis. Major extensional features are located along the Tyrrhenian side of the chain. The belt is also affected by Plio-Quaternary strike-slip faults (Schiattarella, 1998, and references therein).

From the Tyrrhenian Sea to the Adriatic (Apulian) Foreland, and from the top to the bottom of the wedge, the following tectonic units are observed (Pescatore *et al.*, 1999, and references therein): 1) Jurassic to Oligocene polydeformed ophiolitic units, unconformably covered by syntectonic deposits, Early Miocene in age (Ligurian units); 2) a carbonate platform unit (Campania-Lucania platform), whose age ranges from Late Triassic to Early Miocene; 3) several units mainly composed by deep-sea sediments, ranging from Early Triassic to Lower-Middle Miocene; 4) a frontal imbricate fan made up of Cretaceous to Lower Miocene deep-sea marls, shales and sandstones, covered by Middle to Upper Miocene syntectonic deposits; 5) Pliocene to Pleistocene foredeep clastic deposits; 6) the Apulian carbonate platform, which has been partly incorporated at the base of the orogenic wedge, forming toward east the less deformed foreland area.

The most ancient rocks of the Lagonegro pre-orogenic successions are present in the investigated area. They are composed of shallow-water siliciclastic sediments, organogenic limestones and, towards the top, of deep-sea deposits (Monte Facito Fm, Lower-Middle Triassic). The overlying pelagic succession is characterised by Upper Triassic to Jurassic carbonate and siliceous sediments (Calcari con Selce and Scisti Silicei Fms). During Early Cretaceous times, turbiditic sedimentation took place (Galestri Fm), followed by Late Cretaceous-Oligocene calcareous-clastic and clayey sedimentation (Pescatore *et al.*, 1999).

From the seismological point of view, the Campano-Lucano sector of the Southern Apennines Chain is one of the most active areas of the Mediterranean region. In particular in February 1826 an earthquake, reaching up to VIII degree on the MCS scale (Alessio *et al.*, 1995), hit the village of Tito where the geochemical station of geophysical monitoring network is located (Colangelo *et al.*, 2004) installed by IMAA-CNR (fig. 2). One of the most historically important events, the December 16, 1857 (I=XI MCS) normal-faulting earthquake (Mallet, 1862), occurred close to Marsico Nuovo village in Val d'Agri. On November 23, 1980 (M_s=6.9), a large normal-faulting earthquake occurred in the nearby Irpinia area. Seismic activity occurred after the 1980 event consisting of medium intensity events (M<5.5) located close to the border between Campania and Basilicata regions (Alessio *et al.*, 1995). The May 5, 1990 (M_D=5.0, ING-National Institute of Geophysics) and the May 26, 1991 (M_D=4.7) earthquakes took place to the north of Potenza town (Tertulliani *et al.*, 1992). These events were generated by a strike-slip fault system with WE direction, perpendicularly oriented toward the Apennines Chain (Ekström, 1994), located in such a way as to limit toward north and south two great seismogenetic faults that caused the 1857 Val d'Agri and 1980 Irpinia earthquakes respectively.

On April 18, 2002 a seismic sequence occurred along the northern side of the Pergola-Melandro Basin. The M_w=4.4 main shock occurred at a depth of 9 km, and was followed by a small number of $1.4 \leq M_d \leq 3.4$ aftershocks. The distribution of the earthquakes belonging to this sequence is concentrated within 3 km distance from the main shock. The mean depths of the shocks range between 4 and 15 km, and the CMT solution for the main shock suggests a prevailing normal faulting mechanism with NE-SW direction of extension (see Cucci *et al.*, 2004 for further details).

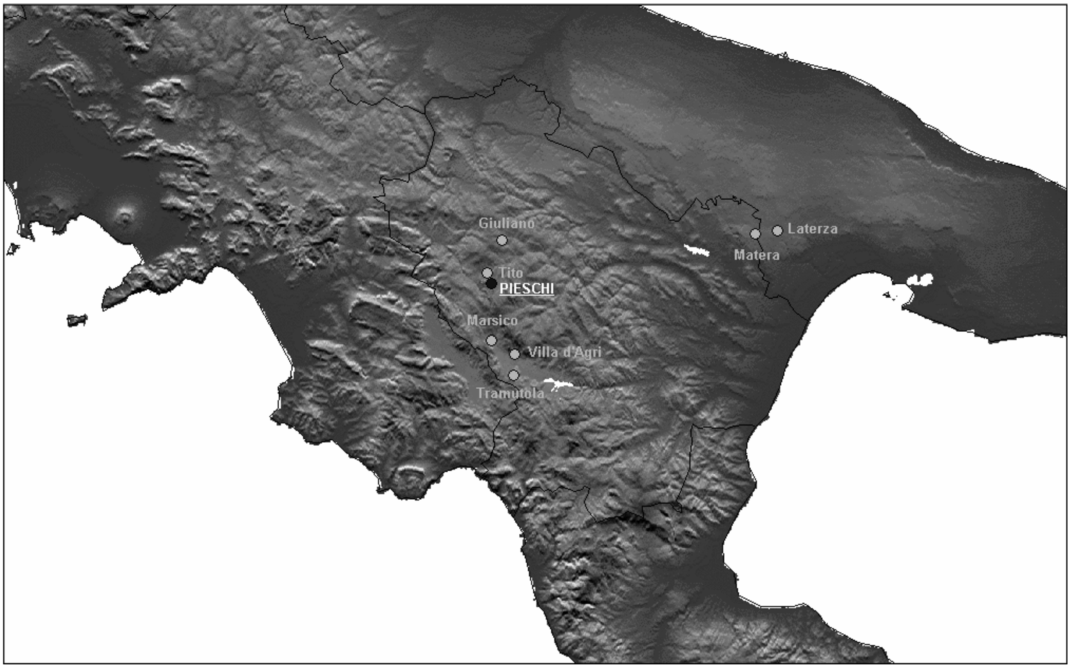

Fig. 2. Location of Pieschi geochemical station.

3. The monitoring station

The monitoring station is constituted by Greenspan EC-250 equipment able to continuously monitor and record temperature and electric conductivity of waters. In particular the magnetic based toroidal sensor of monitoring equipment allows the collection of reliable data over time since it is not affected by possible scales effect due to plastic material protection. The monitoring station is equipped with a car battery able to supply electric energy for several months. A slight seasonal effect in temperature is to be accounted for since water parameters are collected at a depth of about 30 cm. The pool of the spring source is protected by local natural morphologic features able to inhibit possible rain effects. Presented here are data collected in the period November 2001-January 2005. Short data missing periods are due to maintenance activities during battery change-over. The sampling rate was adjusted to one datum every ten minutes.

4. Results and discussion

During the past three years some anomalies in geochemical signals recorded at Pieschi site have been recorded. The anomalous signals were correlated with the seismic activity (fig. 3) extracted using the Dobrolovsky method (Dobrolovsky, 1992). The anomalous patterns observed in the time series are the following:

1) Time interval 1, from November 2001 to September 2002. At the beginning the temporal

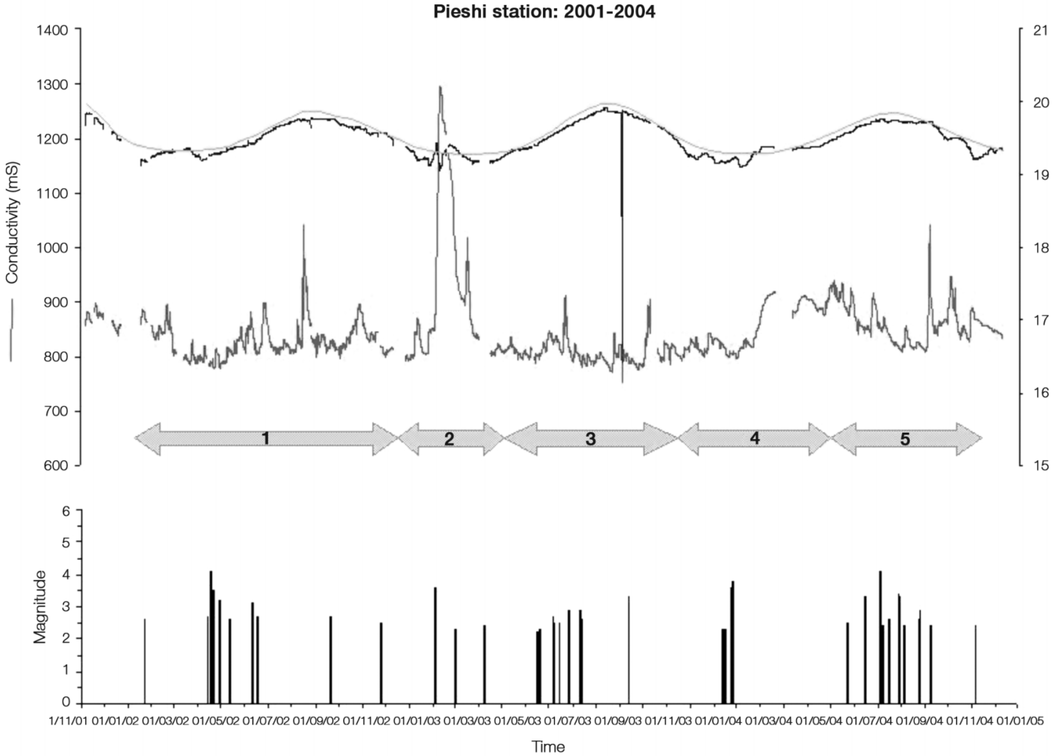

Fig. 3. Water temperature and water conductivity recorded at Pieschi station (top) and local seismicity occurred in the investigated area (bottom) during the observation period.

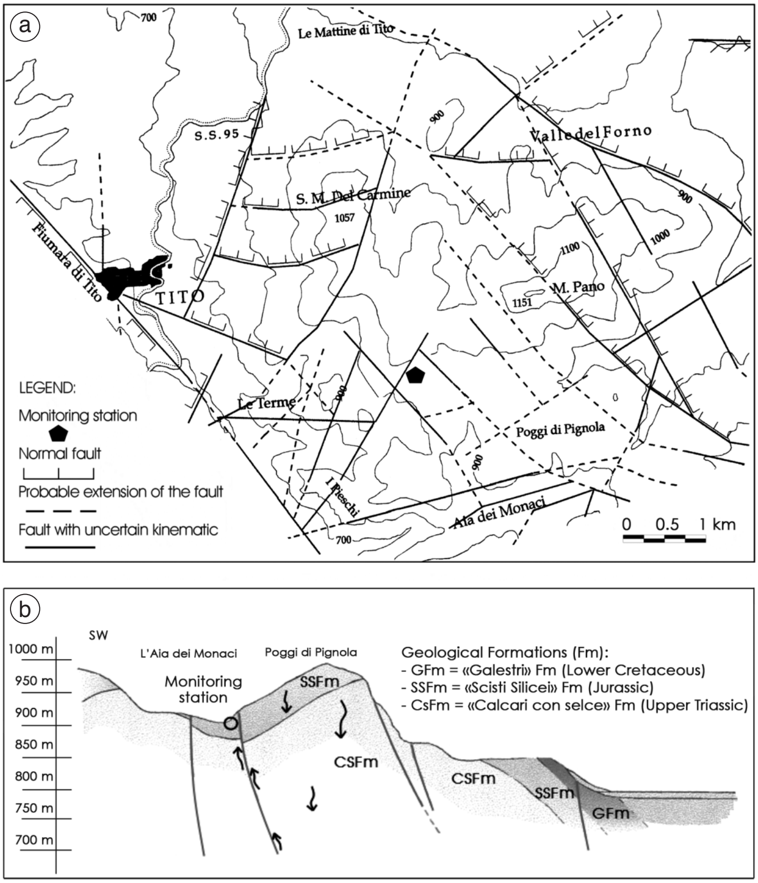

Fig. 4a,b. a) Tectonic map of the investigated area; and b) geological section of the geothermal area of Pieschi (Coviello, 1999, modified).

and epicentral distribution of the sismicity occurred during this period was characterized by a clusterization (fig. 3). The epicentres, indicated in fig. 4a,b by the symbol ☆ are quite far from the station; therefore the strongest variation in geochemical signals could be associated with the earthquake (indicated by the arrow) that occurred after the seismic cluster, whose epicentre is not included in the area of the previous seismic cluster, and whose depth is about 4.1 km (from INGV), the most superficial event. During this period significant variations were observed in self-potential data recorded by the Tito IMAA monitoring network (Telesca and Lapenna, 2004).

2) Time interval 2, from October 2002 to May 2003. During this time interval the water conductivity was characterized by the strongest variation that occurred throughout the observation period (fig. 3). The sharp increase is of about 350 μS/cm (resolution 0.1 μS/cm) and at the same time a strong variation in the thermal water temperature was recorded at about 0.30°C (resolution 0.01°C). The cyan line, superimposed on the water temperature, represents the typical annual excursion. Corresponding to the seismic events the deviation of the temperature from the cyclic component is very clear. The epicentres of the earthquakes (as indicated in fig. 4a,b by the

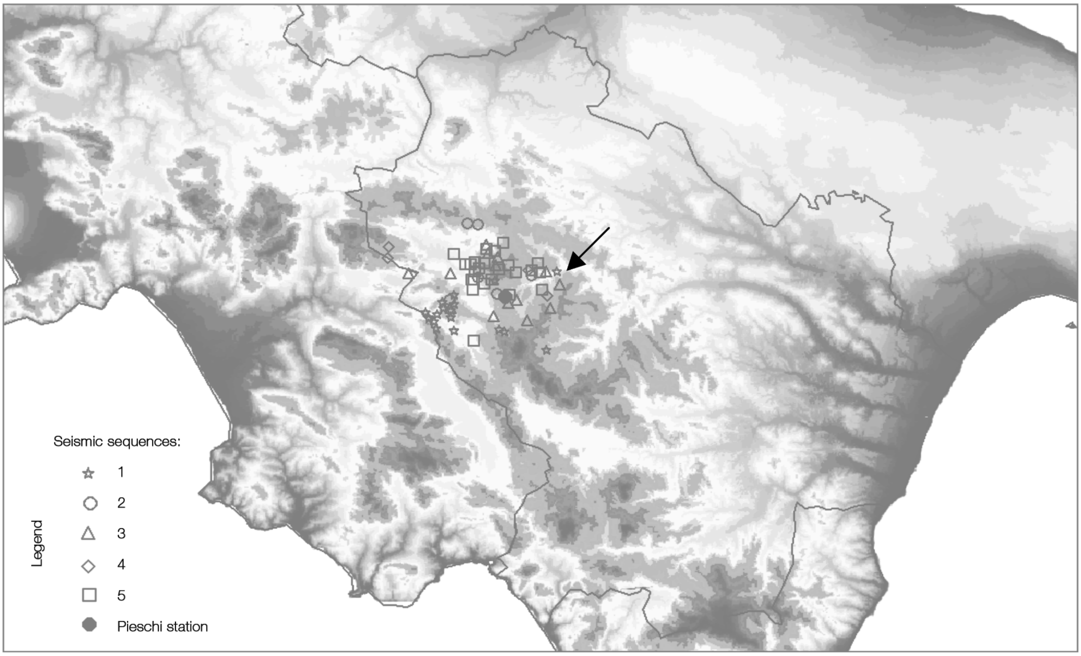

Fig. 5. Epicentral distribution of the earthquakes occurring in the investigated area: the symbol ☆ labels the events occurring from November 2001 to September 2002; the symbol ○ labels the events occurring from October 2002 to May 2003; the symbol △ labels the earthquakes occurring from June 2003 to December 2003; the symbol ◇ indicates the earthquakes occurring from January 2004 to June 2004; and the symbol □ indicates the events occurring from July 2004 to January 2005.

symbol ○) that occurred during this time interval are very close to the geochemical station. This suggests a very close connection between the anomalous value in the water conductivity and the faults system of investigated area (fig. 4a,b).

3) Time interval 3, from June 2003 to December 2003. During this time interval, the water conductivity was characterized by some sharp variations, as that indicated in fig. 3 by the arrow, but not strong as in the previous time intervals. Close to the monitoring station a cluster of seismic events, indicated in fig. 5 by the symbol △, occurred. Therefore a close link could be supposed between the occurrence of this seismic cluster and the sharp variation of the signal.

4) Time interval 4, form January 2004 to June 2004. During this period no anomalous values in the signal were recorded (fig. 3) and the low seismic activity occurred far from the station (fig. 5 symbol ◇).

5) Time interval 5, from July 2004 to January 2005. A few sharp increases in the signal could be observed (fig. 3), very probably linked with seismic events, indicated in fig. 5 by the symbol □.

4. Conclusions

Significant anomalous patterns in hydrogeochemical signals recorded in thermal water of Pieschi station have been related to the occurrence of seismic events, whose epicentres are located close to the station. These fluctuations can be attributed to crustal deformation processes though not all local seismic events were preceded or followed by the detection of anomalous pattern. The results presented in this paper are still preliminary and similar investigations performed over other geochemical data sets, measured in seismic areas have to be performed to contribute to the earthquake prediction problem.

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