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The continuous automatic monitoring network installed in Tuscany (Italy) since late 2002, to study earthquake precursory phenomena

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Since late 2002, a continuous automatic monitoring network (CAMN) was designed, built and installed in Tuscany (Italy), in order to investigate and define the geochemical response of the aquifers to the local seismic activity. The purpose of the investigation was to identify eventual earthquake precursors. The CAMN is constituted by two groups of five measurement stations each. A first group has been installed in the Serchio and Magra graben (Garfagnana and Lunigiana Valleys, Northern Tuscany), while the second one, in the area of Mt. Amiata (Southern Tuscany), an extinct volcano. Garfagnana, Lunigiana and Mt. Amiata regions belong to the inner zone of the Northern Apennine fold-and-thrust belt. This zone has been involved in the post-collision extensional tectonics since the Upper Miocene-Pliocene. Such tectonic activity has produced horst and graben structures oriented from N-S to NW-SE that are transferred by NE-SW system. Both Garfagnana (Serchio graben) and Lunigiana (Magra graben) belong to the most inner sector of the belt where the seismic sources, responsible for the strongest earthquakes of the northern Apennine, are located (e.g. the M=6.5 earthquake of September 1920). The extensional processes in southern Tuscany have been accompanied by magmatic activity since the Upper Miocene, developing effusive and intrusive products traditionally attributed to the so-called Tuscan Magmatic Province. Mt. Amiata, whose magmatic activity ceased about 0.3 M.y. ago, belongs to the extensive Tyrrhenian sector that is characterized by high heat flow and crustal thinning. The whole zone is characterized by wide-spread but moderate seismicity (the maximum recorded magnitude has been 5.1 with epicentre in Piancastagnaio, 1919). The extensional regime in both the Garfagnana-Lunigiana and Mt. Amiata area is confirmed by the focal mechanisms of recent earthquakes. An essential phase of the monitoring activities has been the selection of suitable sites for the installation of monitoring stations. This has been carried out on the basis of: i) hydrogeologic and structural studies in order to assess the underground fluid circulation regime; ii) a detailed geochemical study of all the natural manifestations present in the selected territories, such as cold and hot springs and gas emission zones; iii) logistical aspects. Therefore, a detailed hydrogeochemical study was performed in 2002. A total of 150 water points were sampled in Garfagnana/Lunigiana area (N-W Tuscany) and analysed. Based on the results of this multidisciplinary study, five water points suitable for the installation of the monitoring stations, were selected. They are: Bagni di Lucca (Bernabò spring), Gallicano (Capriz spring) and Pieve Fosciana (Prà di Lama spring) in Garfagnana, Equi Terme (main spring feeding the swimming pool of the thermal resort) and Villafranca in Lunigiana (well feeding the public swimming pool). In the Amiata area, in the preliminary campaign, 69 water points were sampled and analyzed and five sites were selected. They are Piancastagnaio, Santa Fiora, Pian dei Renai and Bagnore, which are fed by the volcanic aquifer, and Bagno Vignoni borehole, which is fed by the evaporite carbonate aquifer. The installation and start-up process of the monitoring systems in the Garfagnana-Lunigiana area begun in November 2002; in the Monte Amiata region it begun in June 2003. From the day of installation, a periodic water sampling and manual measurement of the main physical and physicochemical parameters have been carried out on a monthly basis. Such activity has the double function of performing a cross-check of the monitoring instrumentation, and carrying out additional chemical and isotopic analysis.
The continuous automatic monitoring stations operate with flowing water (about 5 litres per minute) and record the following parameters: temperature (T), pH, electrical conductivity (EC), redox potential (ORP) and the content of CO2 and CH4 dissolved in water. Data are acquired once per second; the average value, median value and variance of the samples collected over a period of 5 min are recorded in a local removable non-volatile memory (Compact Flash card). Data can be downloaded both onsite and in remote, via a GSM/GPRS modem connected to the embedded PC.

The results of seven years of continuous monitoring can be summarised as follows: i) the monitoring stations made it possible to detect even small variations of the measured parameters, with respect to equivalent commercial devices; ii) acquired data made it possible to identify the groundwater circulation patterns; iii) in most locations, the observed trend of the acquired parameters is consistent with the periodic manual sampling results, and confirms the mixture of different water types that the hydrogeochemical model has determined. The absence of seismic events with a sufficient energy precluded the possibility to locate anomalies, with two exception: Equi Terme and Bagno Vignoni sites. At the Equi Terme station an anomalous increase in the dissolved CO2 content was observed twelve days before a M=3.7 earthquake occurred at a distance of 3 km north of the monitoring station. At the Bagno Vignoni station an anomalous decrease in the temperature and electrical conductivity signal was observed nine days before a M=3.3 earthquake occurred at a distance of 12 km est of the monitoring station.
The CAMN resulted as being a suitable tool in order to investigate the anomalous variations of the physical, physicochemical and chemical parameters of aquifer systems as earthquake precursors.