Radon groundwater anomalies related to the Umbria-Marche, September 26, 1997, earthquakes

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RESUMEN

Desde mayo de 1996, se han realizado mediciones de radón en agua freática, así como de otros parámetros (pH, conductividad eléctrica, presión de los gases disueltos y temperatura). Se han analizado las correlaciones entre las posibles variaciones del radón y los mecanismos de deformación de las rocas, así como entre los fenómenos de difusión del radón y la geoquímica del agua freática. El análisis de las series de tiempo ha mostrado fuertes anomalías en pH, concentraciones de radón y presión de gases disueltos, los cuales muestran una alta correlación con la secuencia sísmica Umbria-Marche, del 1997-1998. Este fenómeno puede ser causado por una fase de compresión transitoria que produce un cambio en el contenido del dióxido de carbono en el agua freática. Además las anomalías en conductividad eléctrica se correlacionan con eventos sísmicos locales, lo que sugiere la ocurrencia de variaciones en la dinámica del agua freática.

PALABRAS CLAVE: Radón, anomalías de radón y hidrogeoquímiquas, terremoto.

ABSTRACT

From May 1996, measurements of the radon content in groundwater and other parameters (pH, electrical conductivity, pressure of dissolved gases and groundwater temperature) were conducted at the Gran Sasso underground laboratory of the National Institute for Nuclear Physics, Italy, using multiparametric equipment. We have analyzed the correlations between radon variations and the stress-strain processes in the rock, and the radon diffusion processes related to groundwater geochemistry. Time series analysis showed strong anomalies in pH, radon concentrations and pressure of dissolved gases, which highly correlate with the Umbria-Marche seismic sequence of 1997-1998. This may be caused by a transient compression phase producing a change of carbon dioxide content in groundwater. Spike-like anomalies of electrical conductivity correlate with local seismic events thus suggesting variations in groundwater dynamics.

KEY WORDS: Radon, radon and hydrogeochemical anomalies, earthquake.

INTRODUCTION

The radon groundwater monitoring is a useful tool to study the possible link between the radon variations and deformation phenomena of tectonic interest. Space-temporal variations of this noble gas have been justified with the stress changes in the rocks associated with the seismicity. Crustal gas-fluxes along active faults or the radon transport from its origin to the surface through the microfractures as possible sources have been identified by Hauksson (1981), Wakita *et al.* (1991) and Heinicke *et al.* (1995). Nevertheless, radon diffusion processes are also related to groundwater geochemistry and non-tectonic environmental factors (Shapiro *et al.,* 1984).

To better define the geochemical and geophysical properties of the Gran Sasso aquifer (central Apennines, Italy) (Figure 1) and its radon variation source(s), we have planned and performed measurements with an automatic multiparametric equipment (pH, electrical conductivity, pressure of dissolved gases, groundwater temperature and radon concentration) (Plastino and Bella, 2001). The monitoring activity at the underground laboratory of Gran Sasso of the National Institute for Nuclear Physics started in May, 1996 with a sampling period of twelve hours. The data recorded during the period from May, 1996 to June, 1999 have emphasized the characteristics of a shallow aquifer with low mineralized groundwater and high dynamics behaviour due to high permeability of Cretaceous limestones. During these years, some anomalies in geophysical and geochemical groundwater parameters have been recorded showing a high correlation with tectonic deformation processes related to the Umbria-Marche seismic sequence and local seismicity (Plastino and Bella, 2001).

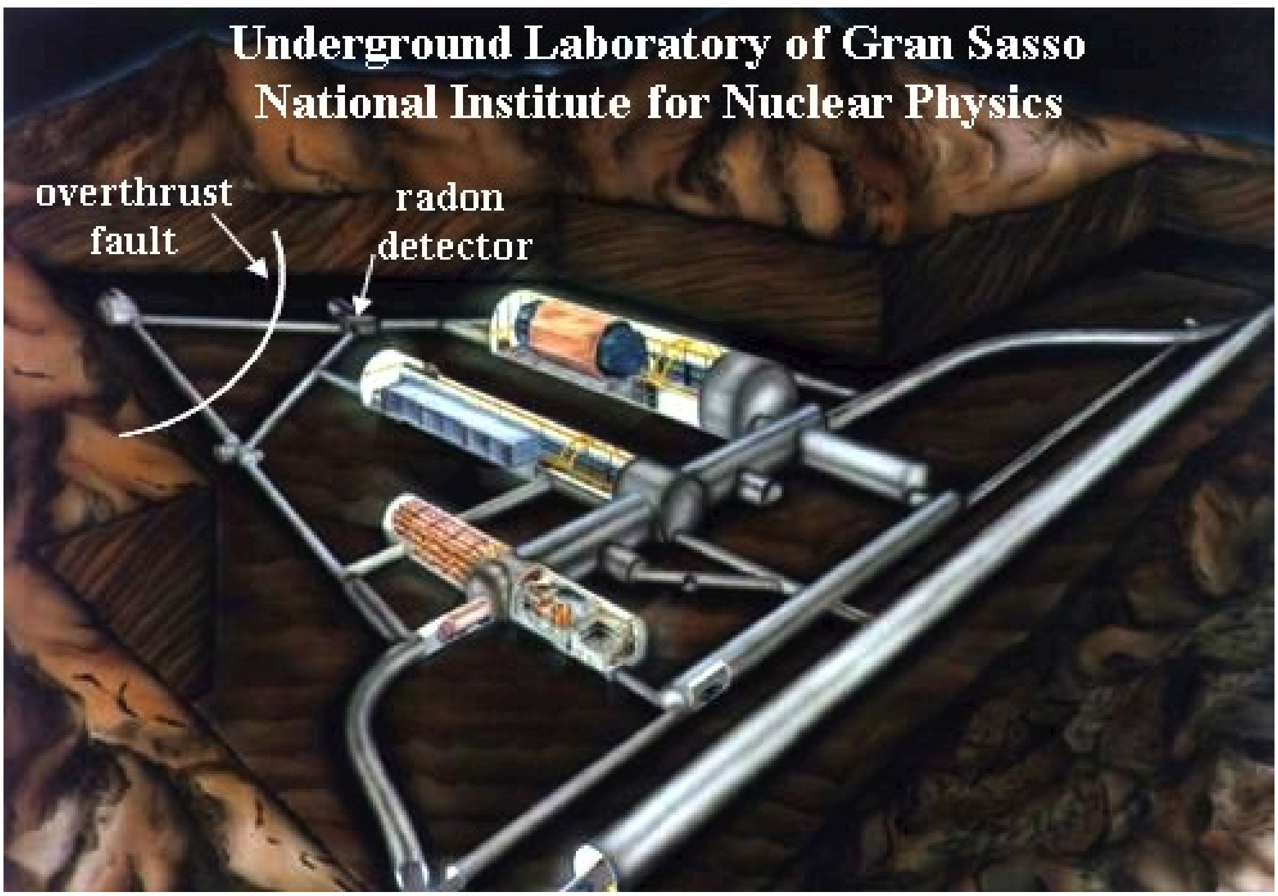

Fig. 1. The schematic view of the underground laboratory of Gran Sasso and the measurement site.

RESULTS

The automatic multiparametric equipment is made of stainless steel with pneumatic valves and it consists of a system for groundwater geochemical analysis and extraction of dissolved gases and of a detection system for alpha radioactivity due to the dacay of radon and its daughters (^{218}Po, ^{214}Po) (Plastino and Bella, 2001). The groundwater analyzed flows in a tube introduced into the rock down to a depth of about three meters. After performing an *in situ* test we have selected a sampling period of twelve hours.

The trends of the geochemical parameters monitored during the period from May, 1996 to June, 1999 are shown in Figure 2. The data of the groundwater temperature from July, 1997 to September, 1997 are not supplied because of a breakdown between the thermocouple output and analogic input channel. From the analysis of raw data may be observed: *a)* the groundwater temperature is characterized by a mean deviation of 0.2 °C; *b)* the electrical conductivity has a small range of variablity of the order of 0.2 mS/m but two spike-like events occurred in October-November 1996 and August-September 1997, respectively; *c)* during the period from January, 1997 to August, 1997, pH increased of 0.4 pH units and then decreased to its initial value in November, 1997; *d)* a spike-like event of the radon content in groundwater in November, 1996 occurred. Furthermore, the mean radon value from May, 1997 to September, 1997 decreased and then increased from 15^{th} September, 1997 to November, 1997.

The trend of the setting parameters monitored during the period from May, 1996 to June, 1999 are shown in Figure 3. The environmental temperature shows a periodic component with T=180 days and some spikes due to ventilation activity inside the underground laboratory. The background and ^{241}Am counting monitored before each measurement seem to point out a good stability and reliability of the detecting system, respectively. The pressure of gases monitored in the counting cell showed two abrupt rises: the first in July, 1997 (~1.5 kPa) and the second in September, 1997 (~2 kPa). Then, the pressure value decreased to the initial value in September, 1998.

DISCUSSION

The correlation between groundwater geochemistry variations and strain processes of the rock has been estimated with a parametric time series approach by means of an autoregressive linear model to describe the residual time series filtered from meteo-climatic and stratum parameters (Box and Jenkins, 1976). The spike-like anomalies are identified when the modulus of the white noise series obtained is greater than three times the standard deviation.

The seismic analysis is based on information from the National Institute for Geophysics and Volcanology catalogue which is complete since 1985 for magnitude M>3.3. From the distribution analysis recorded instrumental seismicity during the period from May, 1996 to June, 1999 in an area of 150 km around the measurement site, it can be observed that an inner radius of 10 km was affected by very low seismicity while the bordering areas were affected by higher seismicity (INGV, 1996/1999). A very important seismic sequence occurred in central Italy in 1997, known as the Umbria-Marche sequence. This started with a foreshock of magnitude 4.5 on September 4 and followed by two strong events on September 26 of magnitudes 5.6 and 5.8 respectively, which occurred within a nine hour interval (INGV, 1996/1999).

In order to correlate the spike-like geochemical anomalies with seismic activity, we estimated the ε deformation parameter as a function of the earthquake magnitude and the epicentral distance (Dobrovolsky *et al.,* 1979) during the period from May, 1996 to June, 1999 in an area of 150 km around the measurement site, using the National Institute for Geophysics and Volcanology catalogue (INGV, 1996/1999). We first selected the seismic events and clusters assuming a lower limit for ε of $0.1\cdot10^{-8}$. The residual time series of the geochemical parameters and ε deformation parameters during the period from May, 1996 to June, 1999 are shown in Figure 4. Fifteen spike-like anomalies in the electrical conductivity, twenty-six in the pH and ten in radon series have been detected. Also, a comparison between earthquakes time series (ε parameter) and alert periods suggested by the occurrence of these spike-like anomalies is reported in Figure 4.

The electrical conductivity spike-like anomalies are probably related to two seismic sequence occurred in October-November 1996 and August, 1998 in two different seismogenetic structures located at about 25 km in NW-W direction with respect to the measurement site. Also, the radon spike-like anomalies recorded in November, 1996 seem to be related to the former seismic sequence. These anomalies are probably due to changes in groundwater dynamics, i.e. variations in the velocity of liquid-phase fluids, related to strain processes associated to earthquakes (Andrews, 1977).

Furthermore, we focussed our analysis on the potential correlation between long time geochemical variations (pH and radon) and the seismic activity, probably related to the starting process of the Umbria-Marche seismic sequence. In particular, this sequence was preceded by two stages identified by means of the RTL(x,t) prognostic parameter calculated at the tested space-time point (x,t) resulting from the multiplication of the following functions: the epicentral R(x,t), the temporal T(x,t) and the earthquake source size L(x,t) (Di Giovambattista and Tyupkin, 2000). A quiescent stage started on early September, 1996. The RTL parameter reached its minimal value on March 3, 1997. After this date, the quiescent stage was replaced by a period of foreshock activities that included the Massa Martana earthquake, occurred on May 12, 1997, (M=4.5), located at about 37 km away from Umbria-Marche main shock. The RTL parameter seems to be related with the long time pH and radon variations. This phenomenology can be explained by the occurrence of a transient compression phase producing a change of the carbon dioxide content in groundwater. The carbon dioxide variation causes the pH and radon trend observed and the absence of electrical conductivity variations recorded before the Umbria-Marche seismic sequence, because it changes the chemical properties of the $CaCO_3$-CO_2-H_2O system and the properties of the radon transport dynamics in groundwater. Therefore, the pH and radon spike-like anomalies recorded during the September, 1997, are probably related to the Umbria-Marche main shock.

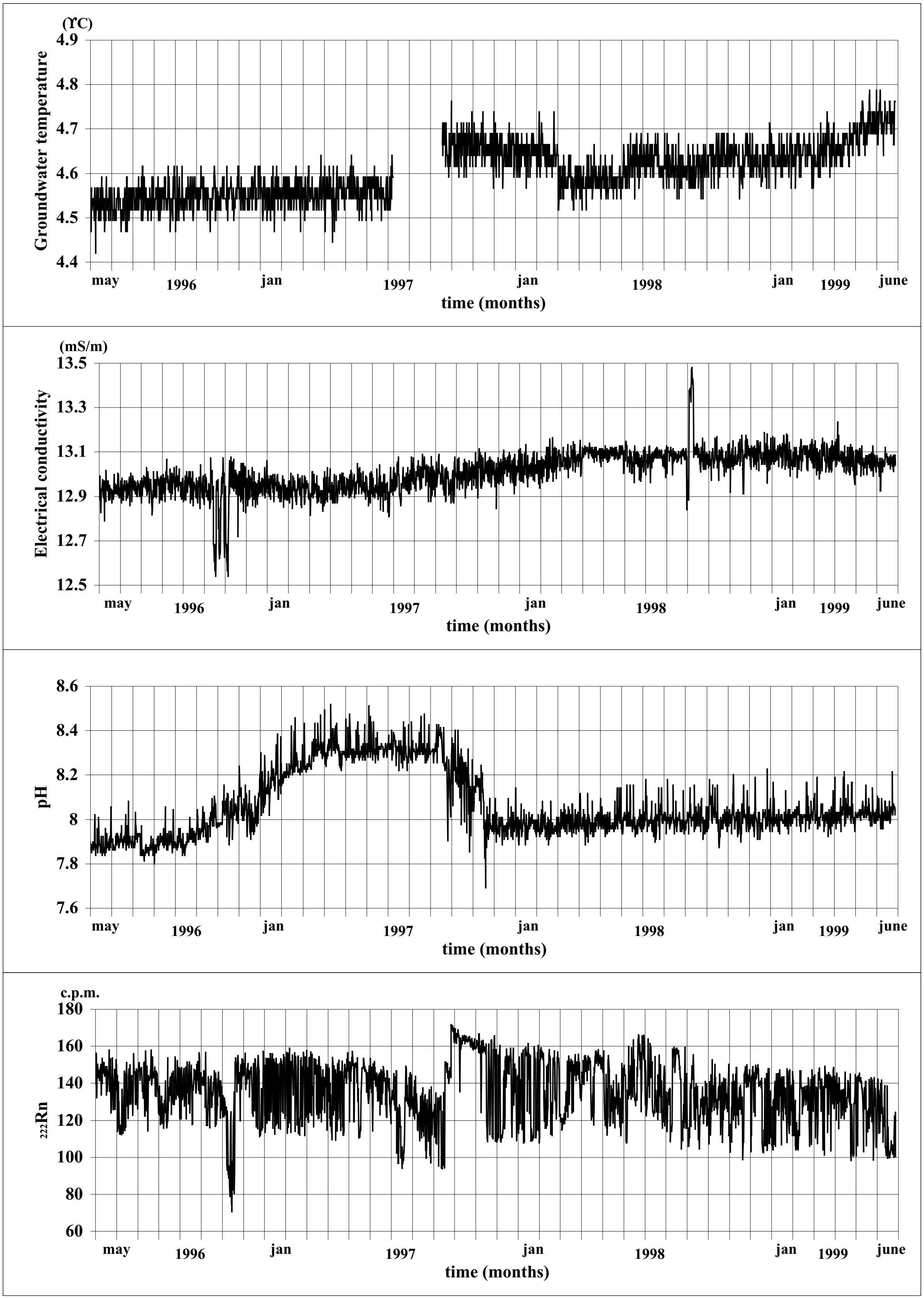

Fig. 2. The trends of the groundwater temperature, electrical conductivity, pH and ^{222}Rn monitored during the period from May, 1996 to June, 1999.

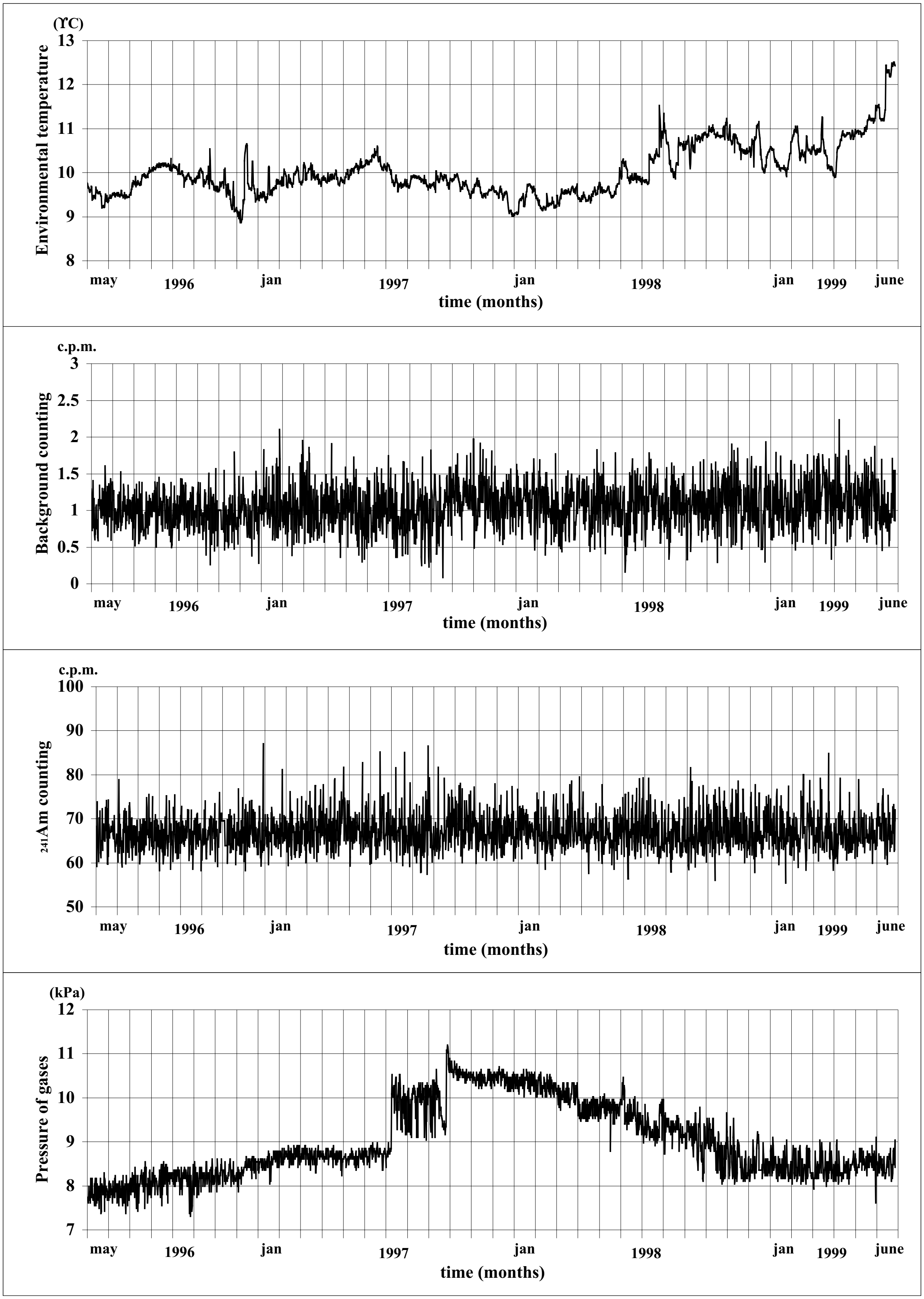

Fig. 3. The trends of the environmental temperature, background counting, ^{241}Am counting and pressure of gases monitored during the period from May, 1996 to June, 1999.

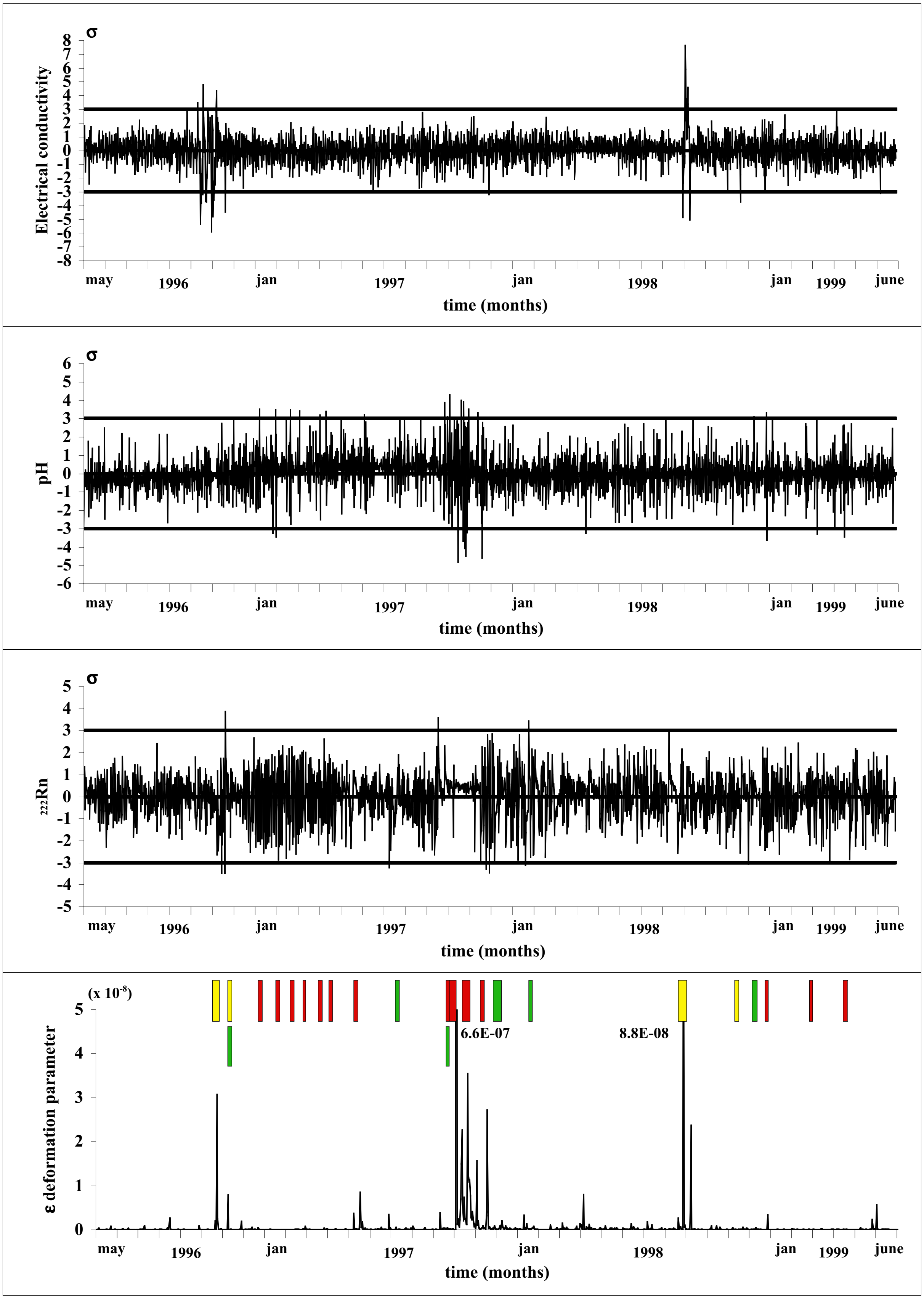

Fig. 4. The residual time series of the electrical conductivity, pH, ^{222}Rn and the ε deformation parameter during the period from May, 1996 to June, 1999. The estimated 3σ, i.e. the thresholds used to identify the anomalies, are also indicated.

CONCLUSIONS

The automatic multiparametric equipment has shown a good reliability and stability during the monitoring period.

The geochemical parameters monitored at the underground laboratory of Gran Sasso have pointed out a shallow aquifer behaviour with high dynamics typical for karst units. The spike-like anomalies observed in the electrical conductivity and radon concentrations are highly correlated to deformation processes due to local earthquakes. Also, the long term variation in pH and radon are likely linked with the RTL parameter of the Umbria-Marche seismic sequence and probably related to the occurrence of transient compression phases that change the equilibrium factors of the hydrogeochemical system by means of different concentrations of carbon dioxide.

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