Radon measurements in soil and water in the seismic Friuli area (*)(**)

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(ricevuto il 9 Giugno 1998; revisionato il 15 Febbraio 1999; approvato il 12 Marzo 1999)

Summary. — Radon concentration measurements have been related to seismic occurrence in a number of publications aiming to detect possible pre-seismic or co-seismic variations. Based on these studies, there is evidence that the radon emanation depends on the lithologic and rheologic parameters of the rock, which change in the preparatory stage of the seismic cycle. With the aim of having a better understanding of these relations, we have set up a station where both radon concentration in soil and deformation are being measured since September 1994. The station is located in the Villanova Cave (46′15′N, 13′16′E), 60 m below the surface. The experiment has recently been extended with a second radon station at the Arta Terme thermal baths, where measurements are made in water. A meteorological station controls the principal atmospheric parameters, which could influence radon variation. We present an analysis of the data recorded at the Villanova station, comprising the study of the local seismicity the results of which have been low throughout the recording period. Furthermore, in this study we show some preliminary results regarding the Arta Terme station.

PACS 91.30.Px – Phenomena related to earthquake prediction.
PACS 91.65 – Geophysical aspects of geology, mineralogy, and petrology.
PACS 92.40.Kf – Groundwater.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

Many studies exist which count radon among seismic precursors [1, 2]. On the basis of these studies is the firm belief that this gas, being the only noble radioactive gas, is sensitive to underground variations during the preparatory phase of an earthquake [3]. For this purpose numerous models [4] have been set up and also laboratory experiments carried out to attempt to correlate the emanation of radon from a rock and variations in stress that the rock undergoes [5]. In the present study, correlations in

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(*) Paper presented at the “Fourth International Conference on Rare Gas Geochemistry”, Rome, October 8-10, 1997.
(**) The authors of this paper have agreed to not receive the proofs for correction.

variations of radon emanation and measurement of deformation on the field are sought. Such measurements have been recorded since 1994 at Villanova (VLL) in a cave 60 metres deep where the annual temperature range is only 1.5 °C. In order to be able to find any correlation it is necessary to clean the radon measurements from all those effects not really tectonic, but mainly due to the variations of different atmospheric parameters [6]. After a brief discussion of the effects of such parameters we shall examine the existing correlation between variations of emanation of radon and tilt measurements. Recently a second station has been installed for the measurement of radon in water. The location of the second station was selected by finding a compromise among proximity to the first station, a detectable radon content in water and relatively high seismicity. After an accurate survey of the springs in northern Friuli, the thermal baths of Arta (ART) were chosen also for the possibility offered of having a shelter for our station.

2. – Geological and tectonic setting

The Friuli region is located on the NE border of the Adriatic plate, in the eastern part of the Southern Alps, where the overlap with Dinaric structures takes place. The Southern Alps are interpreted in global tectonics, as the result of the continuation of relative motion between the European plate and the Adriatic microplate. These movements are still active, as demonstrated by neotectonic structures and by the seismic activity [7]. The seismicity is presently limited to the upper 15 km of depth. The northward movement of the Adriatic plate in the Neogene and Quaternary involved extensive areas of the Southern Alps. This should have caused intense shortening. The most important regional features are the E-W striking South-Alpine overthrusts (mainly in the NW) and SE-NW striking Dinaric overthrusts (mainly in the SE and buried in the Friuli plane). These structures are intersected by subvertical faults, striking about N-S and often showing strike-slip motion. Both structures (overthrusts and strike-slip faults) are compatible with the actual stress field, with NNW-SSE maximum compressive stress [8].

3. – Arta station hydrogeology

The spring selected as test site for radon continuous monitoring in groundwater is located 30 km NW from the main station (Villanova) (fig. 1). An accurate study has shown that, from the geochemical point of view, the ART spring is very stable [9]. Table I gives information of the main characteristics of the spring. The main anions chemistry shows that sulphates and bicarbonates prevail. On the basis of this chemical composition, the spring may be considered as the result of a slow water-rock interaction with evaporites and carbonates (*i.e.* anhydride ($CaSO_4$), chalk ($CaSO \cdot 2H_2O$) and kieserite ($MgSO_4 \cdot H_2O$)) as main minerals. Since only limestone crops out, it can be deduced that water always mineralises at depth. The water temperature is constant at 9.7 °C, and does not vary seasonally. This suggests that the groundwater circulation is not superficial, following a slow steady-state circuit in the carbonate bedrock. It cannot be too deep, as the influences of the geothermal gradient are not observed. Alternatively the geothermal gradient may be locally reduced due to the flow of a great quantity of meteoric water. The low temperature of the spring is also justified

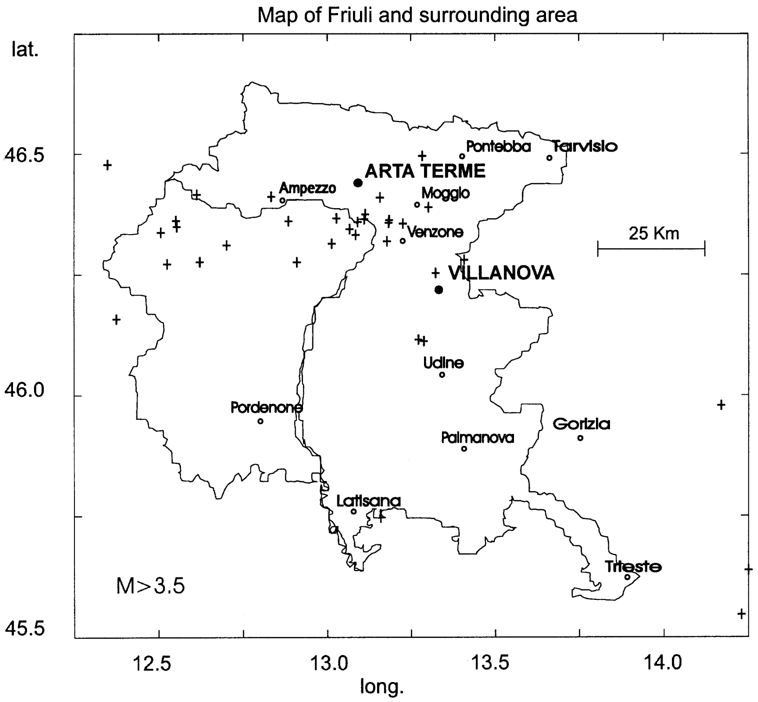

Fig. 1. – Map of Friuli and surrounding area with local seismicity: $M > 3.5$ (1976-1997).

Table I. – *Main characteristics of the Arta Terme spring, data from* [9].

Arta Terme spring			
Physical properties		Chemical properties	
		Na^{+}	0.1681 meq/l
Electric conductivity (18 °C)	1450 μs/cm	Li^{+}	0.0012 meq/l
Electric conductivity (25 °C)	1780 μs/cm	K^{+}	0.0373 meq/l
Temperature	9.8 °C	$\mathrm{Ca}^{+\,+}$	26.221 meq/l
		$\mathrm{St}^{+\,+}$	0.0628 meq/l
		$\mathrm{Mg}^{+\,+}$	9.4856 meq/l
Dissolved gas		$\mathrm{Fe}^{+\,+}$	0.0150 meq/l
		Tot.	35.991 meq/l
		$\mathrm{Cl}^{-\,-}$	0.0300 meq/l
Nitrogen and rare gas	18.2 cm^3/l	$\mathrm{SO}_4^{-\,-}$	32.6812 meq/l
Hydrogen sulphide	1.78 cm^3/l	HCO_3^{-}	3.2700 meq/l
Carbon dioxide	1.4 cm^3/l	Tot.	35.981 meq/l
		SiO	0.1265 meq/l
		$\mathrm{H}_2\mathrm{S}$	0.0801 meq/l

by the particular asset of the circuit feeding, which is at a high altitude (1700 m) on the northern slope of the valley.

4. – Measuring methods

The deformational instrumentation at VLL was installed in 1979. It includes a couple of Marussi Tiltmeters, traditional horizontal pendulums with Zöllner-type suspension, constructed at the Institute of Geodesy and Geophysics of Trieste [10]. The period of oscillation in the horizontal plane is maintained at about 90 s. The recording is digital and is accomplished with an inductive displacement transducer, reaching a resolution of about 1 ms. Next to the tiltmeters three skew horizontal Cambridge Wire strainmeters are installed in the cave. These strainmeters use an inductive displacement transducer and reach the resolution of about 1 nstrain (10^{-9}) [11]. To measure the radon exhalation from soil at VLL we have used a device built at the IFGA (Institute of Applied General Physics) of Milan [12]. Groundwater dissolved radon is measured at the ART site by a radon continuous monitoring prototype fully built up at the Fluid Geochemistry Laboratory of the Istituto Nazionale di Geofisica (ING). This device may be divided into two main parts: the first has the function of extracting radon from water (by bubbling), whereas the second measures all α-scintillations due to the decay of radon and its daughters inside the Lucas cell. The radon extraction system is linked with a drier apparatus that causes vapour condensation just before the gas flow reaches the Lucas cell. The device works continuously giving us the integrated data of α disintegrations every hour [13].

5. – Data analysis

A different radon behaviour is observed in summer periods compared to winter periods. In winter months the radon concentrations show lower average values and limited fluctuations, while in summer months the average value tends to grow slightly, and furthermore, there are fluctuations and very strong anomalies. The high-frequency oscillations are due to the presence of a 24-hour wave. The amplitude of this wave is strongly dependent on the radon average value: when the average value grows so does the wave amplitude. The presence of the 24-hour wave is identified with certainty by spectral analysis on filtered data (passing band 1 cpd–5 cpd). Inhomogeneous results were obtained by comparing the radon and pressure variation. During winter months the two parameters seem to be independent (correlation coefficient 0.03), but in the summer months the correlation increases (correlation coefficient 0.2) and better results are obtained correlating radon with time derivative of the pressure (correlation coefficient 0.4). Even if the results make it clear that the measurement of radon is affected by rainfall, it is rather difficult to quantify such an effect. A clear correlation is obtained only if the rainfalls are limited to above a certain level. Such a threshold was fixed at 30 mm/day; so therefore only 12 cases in two years of measurements reach this threshold and could be analysed.

We must now focus our attention on the relation between radon and deformation measurements. The data were collected at a fixed time of day to eliminate eventual disturbances due to daylight variations. Figure 2 shows an example of comparison of variations of radon and the East-West component of tilt. The influence of temperature on measurements of tilt is a consolidated datum. If we eliminate the contributions of

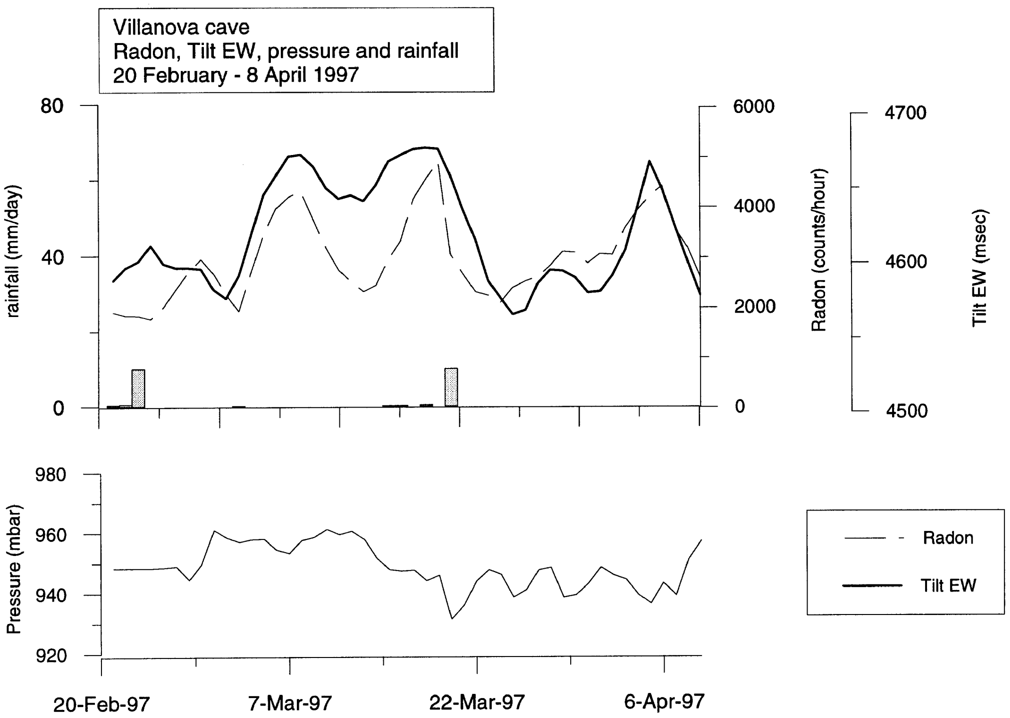

Fig. 2. – Correlation between radon and tilt EW and comparison with rainfall and atmospheric pressure (20 February-8 April 1997).

temperature on tilt by simple linear regression, the correlation with radon increases notably. Figure 3 shows, as an example, the period time 18 May-9 July 1997. Figure 4 shows the period 15 March-4 May 1995. In this case the anomaly (9 April), with duration of 72 hours, present both in radon and tilt measurements cannot be explained either by rainfalls, absent during that period, or by variations in atmospheric pressure which is constant between the days 5-12 April. From the analysis of the complete data set, 9 similar cases were found, in which neither pressure nor rain can explain the presence of maximum both in the measurements of radon and tilt. Furthermore, in all those cases there was the presence of a loop in the horizontal vector behaviour of tilt measurements. Table II shows the correlation coefficients of radon with the various measured parameters. This table shows that the best correlation is found with the North-South component of tilt. This direction is orthogonal to the fault lineaments existing in the area and coincides with the direction of the alpine compressive tectonic stress.

The measurements of radon in water at ART are still in a preliminary stage. Figure 5 shows the measurements for two periods. The sharp drop in the data was due to an interruption in the water flow. Radon seems to keep a constant average value showing daily recurrent frequency with minimum values in morning hours. It may be hypothesised that these falls are due to a possible variation of water flow, since the minimum levels coincide with the maximum water requirement from the thermal station. Alternatively the radon spectrum is driven by the temperature fluctuation (see

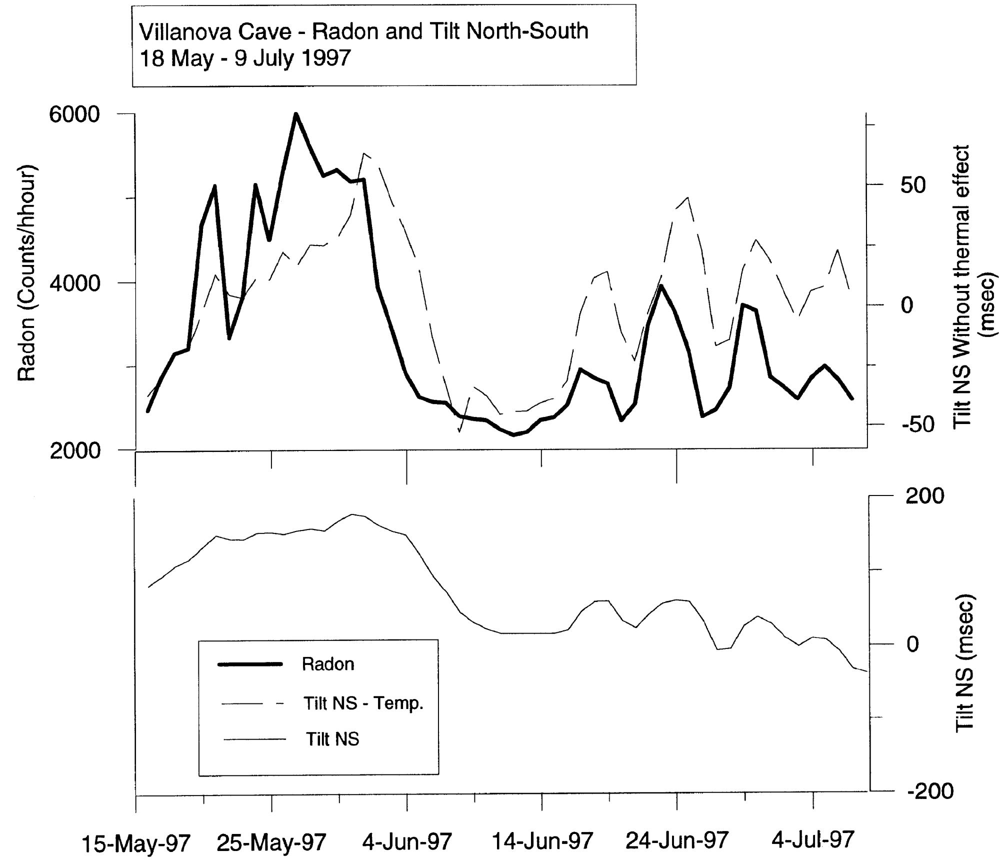

Fig. 3. – Correlation between radon and tilt NS without thermal effect (18 May-9 July 1997).

TABLE II. – *Correlation coefficients between radon and other deformational and atmospheric parameters. The mean value is calculated with the coefficients modulus.*

Villanova Cave

Time interval	14/10/94 31/12/94	01/01/95 15/03/95	15/03/95 30/04/95	01/05/95 15/06/95	16/02/96 20/04/96	24/05/96 19/06/96	09/10/96 13/11/96	01/01/97 15/02/97	20/02/97 08/04/97	18/05/97 09/07/97	Mean value
pressure	− 0.212	− 0.413	− 0.109	− **0.504**	0	− 0.386	− 0.188	0.134	− 0.134	0.305	**0.24**
temp.	0.694	0.136	0.541	0.091	0.611	− 0.525	0.297	− **0.645**	0.502	− 0.572	**0.46**
tilt NS	− **0.766**	− 0.444	− **0.627**	0.274	− **0.702**	**0.583**	− 0.402	− 0.564	− 0.683	**0.774**	**0.58**
tilt EW	0.757	0.226	0.568	− 0.061	0.657	− 0.438	0.461	0.419	**0.725**	− 0.59	**0.49**
strain 2	− 0.67	0.649	0.241	− 0.305	0.12	0.02	− 0.281	− 0.252	0.294	0.25	**0.31**
strain 3	0.625	− **0.649**	− 0.439	− 0.211	− 0.545					− 0.413	**0.48**
strain 4	− 0.749	− 0.417	− 0.284	− 0.296	− 0.236					0.286	**0.38**

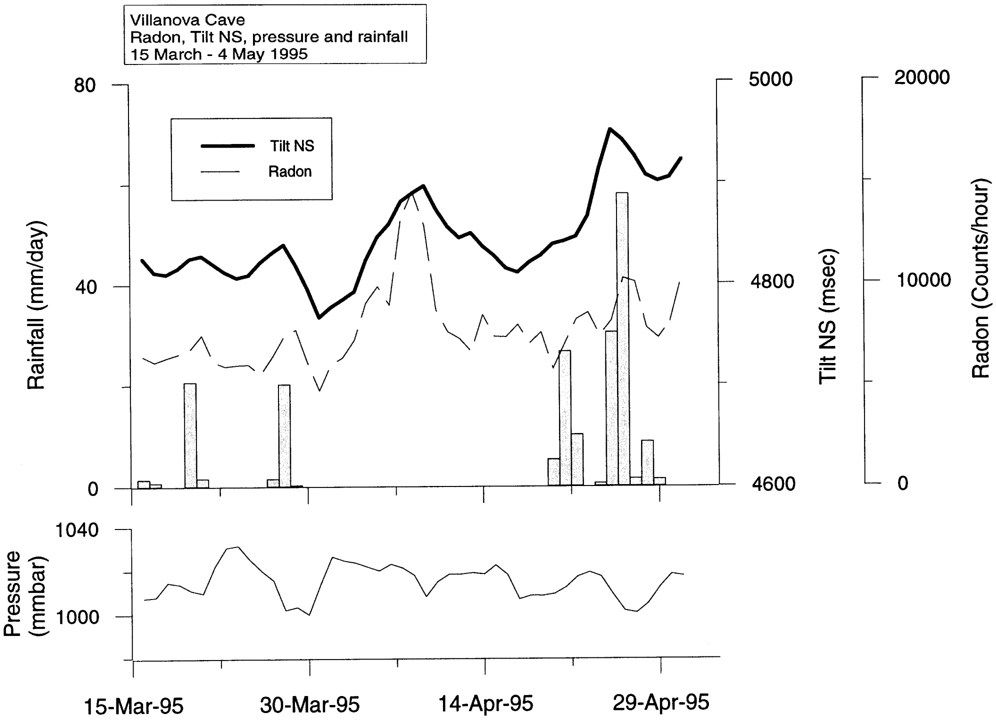

Fig. 4. – Correlation between radon and tilt NS and comparison with rainfall and atmospheric pressure (15 March-4 May 1995).

also [13]) Such behaviour is found, barring slight differences, also in the uninterrupted subsequent data recording.

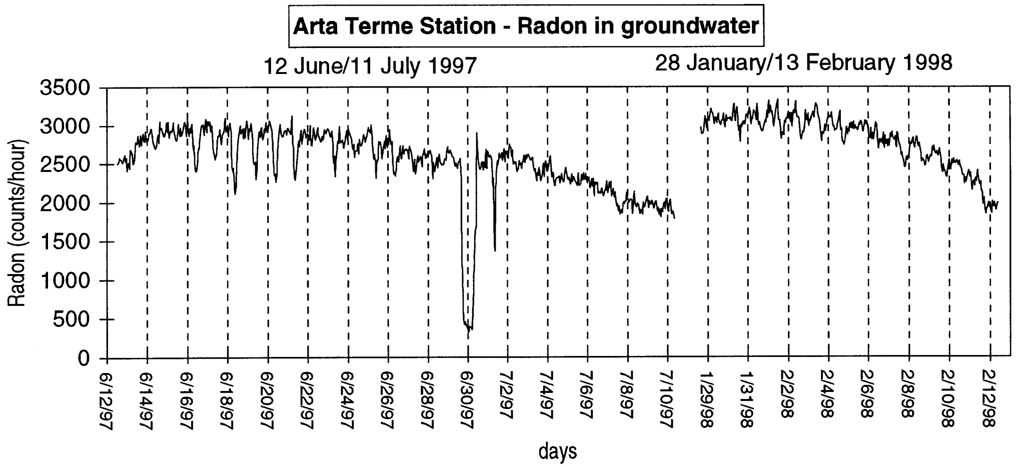

Fig. 5. – Radon concentration in water at the Arta Terme station (12 June-11 July and 28 January-13 February 1998).

6. – Conclusion

In order to consider the radon as earthquake precursor it is very important to correlate the radon measures with tilt and strain variations of tectonic origin. For a better understanding of the radon fluctuation it is necessary to measure it with all the atmospheric parameters. At VLL the pressure variations influence the radon variations particularly in summer months. Strong rainfall (>30 mm/day) is shown to lead to an abrupt increase of the signal, with following decreasing. We have found some cases of joint anomalies of radon, tilt and areal deformation that are not due to rainfall or atmospheric pressure or temperature. The best correlation coefficients are found between the radon and the North-South tilt measurements. This direction coincides with the alpine compressive tectonic stress present in the area. This suggests that the radon increasing is correlated with micro-compressive episodes without seismicity. This evidence could be argued only as hypothesis for a future work planning. The measurements at the Arta Terme station are still in the preliminary stage but we have discriminate a daily frequency component with minimum values in the morning hours.

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