Groundwater argon content on the occasion of strong earthquakes in a seismogenetic area of Kamchatka (Russia) (*)(**)

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Summary. — Since 1988 the argon content in underground water has been measured at the Morosnaya well, in the Kamchatka peninsula, with a sampling frequency of three days. In the same well other gases and ions dissolved in water are measured, together with flow rate, *p*H and temperature. The most active seismogenetic area in Kamchatka is that located offshore, along the south-eastern coast of the peninsula. The strongest earthquakes in this area occurred on March 2, 1992 ($M = 7.1$), November 13, 1993 ($M = 7.0$) and June 21, 1996 ($M = 7.1$), within a distance of 200 km from the well. The focal depth of the earthquakes of 1992 and 1993 was 20 and 40 km, respectively. The earthquake which occurred in 1996 was very shallow; a focal depth of few kilometres was estimated. No anomalies in the argon or other dissolved gas concentration were observed on the occasion of 1992 and 1993 earthquakes; on the other hand, a very clear preseismic anomaly appeared in the concentration of argon and nitrogen on the occasion of the 1996 earthquake. The behaviour of the ion content was opposite; no anomaly on the occasion of the last earthquake and clear preseismic anomalies on the occasion of the two former earthquakes appeared. A possible explanation of the quoted behaviour of dissolved gases and ions in groundwater according to the different focal depth of the subsequent earthquakes is presented.

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PACS 92.40.Kf – Groundwater.
PACS 91.30.Bi – Seismic sources (mechanisms, magnitude, moment frequency spectrum).
PACS 01.30.Cc – Conference proceedings.

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1. – Introduction

A frequent and strong seismic activity occurs normally in the Kamchatka Peninsula located in the Far East of Russia. This activity seems to be characterized by the alternation of relatively quiet time intervals and time intervals when very strong earthquakes occur.

In the period 1977-1986 only earthquakes with magnitudes less than 6.0 occurred; by contrast, during the last ten years many seismic events with $M > 6.0$ took place. One of the most active seismogenetic areas is that located offshore, along the south-eastern coast of the Peninsula (fig. 1). Here, the hypocentral depths range from a few kilometres to 500 km, depending on the position of the earthquakes with respect to the subduction zone.

Here we present the behaviour of the groundwater argon content with respect to that of some other dissolved gases and ions on the occasion of the strongest earthquakes occurring in this seismogenetic area during the last ten years.

2. – Earthquakes and the hydrogeochemical station

The strongest earthquakes during the last ten years in the quoted area occurred on March 2, 1992 ($M = 7.1$), November 13, 1993 ($M = 7.0$) and June 21, 1996 ($M = 7.1$). The epicentres of these earthquakes are indicated in fig. 1. The focal depth of the 1992 and 1993 earthquakes was of 20 and 40 km, respectively. The earthquake that occurred in 1996 was very shallow; a focal depth of few kilometres was estimated. Moreover, after this earthquake a strong seismic crisis ($4.0 \leq M \leq 6.0$) happened for more than two months.

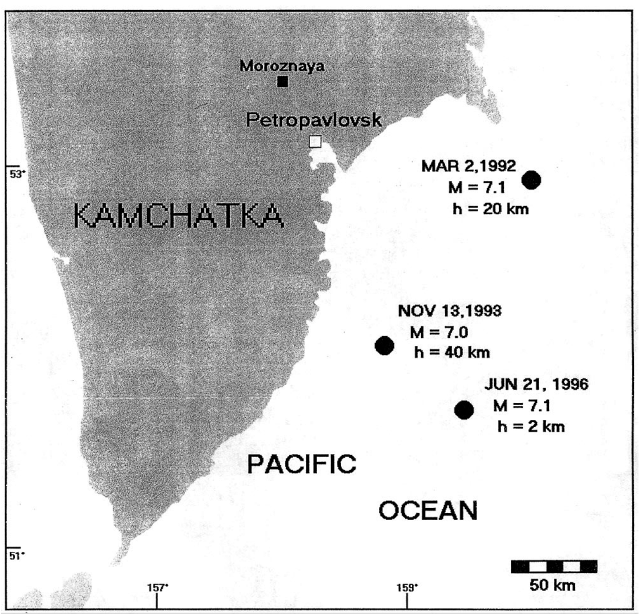

Fig. 1. – Map showing the location of the Morosnaya well and the three earthquakes that occurred from 1987 to 1996 with $M \geqslant 7.0$ within a distance of 200 km from the well.

In 1983 the Morosnaya well was drilled ($\varphi = 53° 12.5'$ N and $\lambda = 158° 18.7'$ E) as shown in fig. 1. Its depth is of about 600 m and it was drilled through tufaceous rocks. The flowing water is characterized by a mean temperature of 16 °C and a mean pH value of 8.5. For some years the well was normally used for water supply to the little neighbouring village Morosnaya. In the last years the civil use was interrupted and now the well is only a hydrogeochemical station.

Since 1988 the groundwater argon concentration in the Morosnaya well has been measured, with a sampling frequency of three days. At the same station the concentration of other gases and ions melted in the water has been measured with the same sampling frequency, together with flow rate, pH and temperature [1, 2]. The concentration of dissolved gases after thermovacuum degassing is measured by means of gas chromatography; that of melted ions is measured according to the different constituents of the compound, by means of the potential method, flame photometry, photoelectric spectophotometry and other standard methods.

The three strongest earthquakes we considered happened within a distance of 200 km from the Morosnaya station, the 1996 earthquake being the furthest from the station.

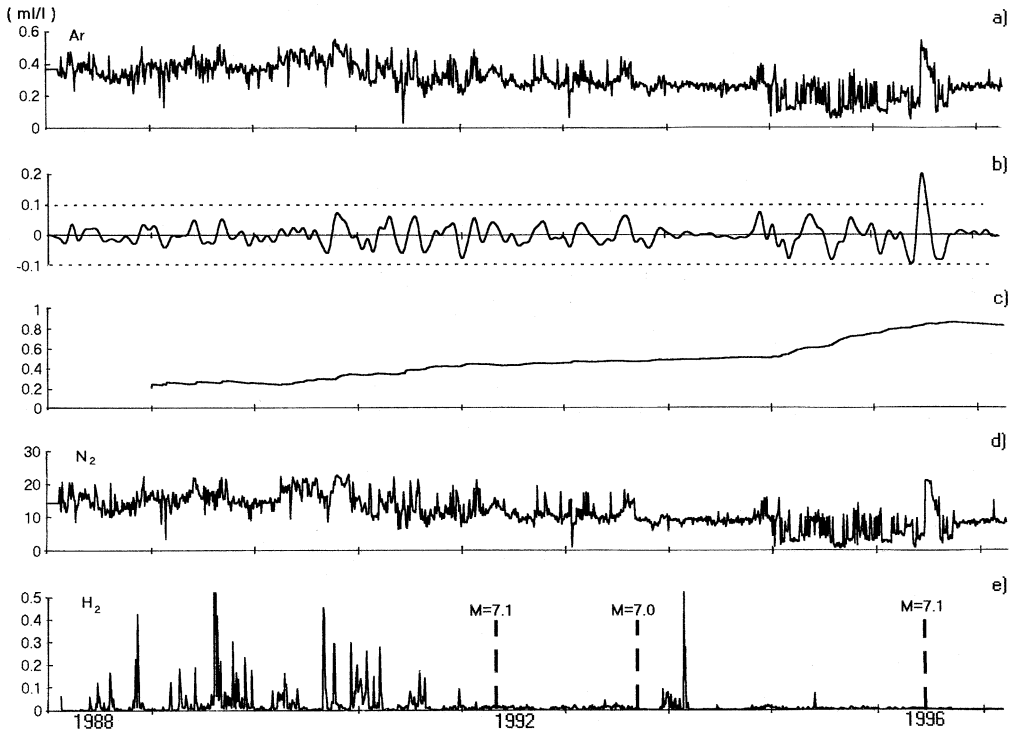

Fig. 2. – a) Time-series of the argon content at the Morosnaya well. b) FFT filter smoothing with a window of 30 days on the data set resulting from the difference between plot a) and a first smoothing with a window of 180 days. The dotted lines represent the $\pm 3\sigma$ level. c) Cumulative variance of the time-series of the argon content. d) Time-series of the N_2 content. e) Time-series of the H_2 content. The Ar, N_2 and H_2 contents are in ml/l.

3. – Results

We used for statistical and mathematical analysis the STATGRAPHICS software package by the Statistical Graphics Corporation.

The argon content in groundwater at the Morosnaya well from January 1988 to April 1997 is shown in the plot a) of fig. 2. In the same figure two other plots are shown, that is plot b) and plot c). Plot b) represents the FFT filter smoothing with a window of 30 days made on the data set resulting from the difference between the raw Argon content data and a first smoothing with a window of 180 days. The $\pm 3\sigma$ level is indicated by horizontal dotted lines. Plot c) represents the cumulative variance of the time series of the argon content, starting from a first data set of 365 days. The occurrence of the three quoted earthquakes is also shown in fig. 2. On the occasion of 1992 and 1993 earthquakes no anomaly seems to appear in the plots reported in fig. 2; however, on the occasion of the earthquake that occurred in June 1996, an anomaly over the $+3\sigma$ level appears in the trend of plot b) and a preseismic phase exists with a duration of 5 days with respect to the $+3\sigma$ level. The variance in plot c) shows an anomalous increase starting from about a year and a half before the same earthquake.

The nitrogen content, that has been sampled from January 1988 in the groundwater of the Morosnaya well, shows the same behaviour as the argon content that has been described previously. The time-series of the N_2 content is reported in the plot d) of

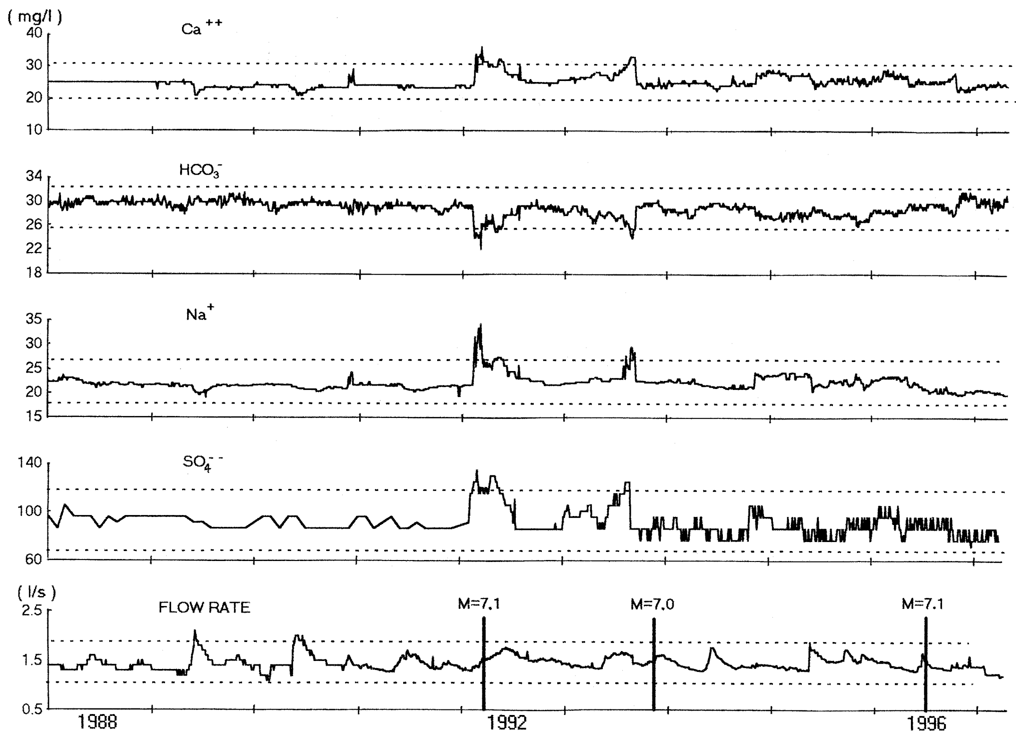

Fig. 3. – Time-series of Ca^{++}, HCO_3^-, Na^+, SO_4^{--} contents and flow rate at the Morosnaya well. In each plot the dotted lines represent the $\pm 3\sigma$ level. The ions contents are in mg/l; the flow rate in l/s.

fig. 2. By contrast, the other dissolved gases (CO_2, H_2, CH_4, C_2H_6 and C_3H_8) that are sampled at the same station and over the same time interval have never shown any anomaly during the last ten years. As an example the trend of the H_2 content is shown in the plot *e* of fig. 2.

The dissolved ion content in the groundwater of the Morosnaya well and its flow rate from January 1988 to April 1997 are shown in fig. 3. The $\pm 3\sigma$ level is indicated over each plot by horizontal dotted lines. The occurrence of the quoted three earthquakes is also shown. On the occasion of the 1996 earthquake no anomaly appears in the plots reported in fig. 3. However, anomalies over the $\pm 3\sigma$ level do appear in the ion content on the occasion of the 1992 and 1993 earthquakes. The onset over the $\pm 3\sigma$ level of the precursory phase starts from 20 to 90 days before the forhcoming earthquake. The flow rate trend does not show any anomalous behaviour for any of the three earthquakes.

4. – Discussion

The anomalies we presented cannot be directly related to the "near-field" processes preceding earthquakes in the focal zone, since these anomalies were recorded at a site at a considerable distance (> 100 km) from the epicentres. Therefore, these anomalies appear to be due to the readjustment of stresses induced by strong "near-field" processes [3, 4]. The absence of contemporary anomalies in the flow rate seems to indicate that no relevant further water-supply happened in the water-bearing stratum connected with the Morosnaya well on the occasion of the anomalies in the gas or ion content. So, the delivery of gases, vapours and pore solutions, which are squeezed out of the rock into the water-bearing stratum due to microfracturing processes and/or changes in the existing cracks during the induced preseismic stress readjustment, could be the possible origin of the quoted anomalies [5-7].

The different behaviour of both the argon and nitrogen content and the ion content on the occasion of the 1992 and 1993 earthquakes with respect to that in 1996 does not seem justifiable on the basis of the different distances of the epicentres from the Morosnaya well. The different behaviour could be related to the different focal depth of the earthquakes. In fact, in the first two cases, the induced preseismic stress readjustment involves probably the lowest part of the water-bearing stratum, that is the zone where the temperature is higher, and its shallow part in the last case, that is where the temperature is lower. So, the solubility of ions in groundwaters was better on the occasion of 1992 and 1993 earthquakes compared to that of 1996; on the other hand, the solubility of gases in groundwater was better in this last case than for the previous two earthquakes. Of course, the kind of ions or gases that are delivered depends on the mineralogical composition of the rocks. The duration and the amplitude of the preseismic anomalies depends on the propagation of the stress from the hypocentre to the measurement site and on the "sensitivity" that the tectonic structures near the Morosnaya well have towards the stress itself. So, both the duration and the amplitude are rightly unpredictable from case to case.

5. – Conclusion

The results we presented seem to indicate that the focal depth of a forthcoming crustal earthquake could influence the appearance of anomalies in the content of dissolved gases or ions in groundwater. This influence could be a general rule, not just a peculiarity of the seismogenetic area we consider. More results are necessary both to confirm the particular effect, and to decide how general it is.

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