IL NUOVO CIMENTO VOL. 22 C, N. 3-4 Maggio-Agosto 1999

Gas-water partition and gas channelling along Rn-He-CO_2 bearing faults (*)(**)

G. ETIOPE and M. GUERRA
ING, Istituto Nazionale di Geofisica - via di Vigna Murata 605, 00143 Roma, Italy

(ricevuto il 9 Giugno 1998; approvato il 21 Dicembre 1998)

Summary. — The amount and distribution of radon (^{222}Rn) and helium (^{4}He) at the Earth's surface are controlled not only by type and depth of the source, permeability of geological formations and hydrogeological setting, but also by disequilibria processes occurring during upward gas migration. In order to evaluate the latter processes, in this work we discuss Rn and He data collected during surveys performed simultaneously in different types of natural occurrence (*i.e.* soil-air, groundwater, gas vent and soil-atmosphere exhalation flux) located along faults bearing pressurised CO_2 (Siena basin, Central Italy). The obtained results emphasize the effects of gas-water partition and gas channelling processes induced by faults on Rn and He distribution in near-surface environment; accordingly they suggest that the analysis of a single "sub-system" of the geologic environment (*e.g.*, groundwater analysis only) may provide data not representative of gas occurrence or abundance in the investigated site.

PACS 91.25.Ey – Interactions between exterior sources and interior properties.
PACS 91.30.Tb – Volcano seismology.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

Gas-geochemical analyses in ground and groundwater are increasingly recognised as a fundamental task for geological and environmental characterisation. The amount and distribution of surface discharges of rare gases such as radon (^{222}Rn) and helium (^{4}He) may be controlled not only by type and depth of the source, permeability of geological formations and hydrogeological setting, but also by disequilibria processes occurring during upward gas migration (*e.g.*, gas exolution due to pressure decrease). Therefore, field gas data can be prone to misinterpretation if the boundary conditions of the observed system and the possible interactions among phases (gas, water, rock) are not properly considered. In this work we discuss an integrated approach encompassing the study of radon, helium and CO_2 concentrations in different types of

(*) 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.

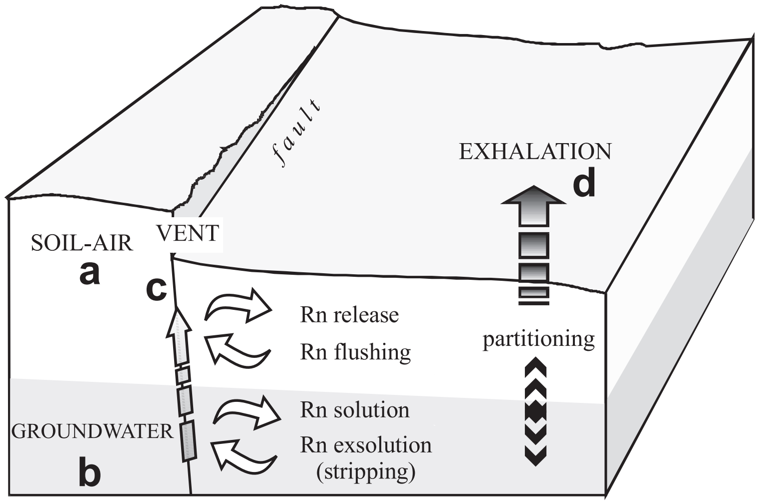

Fig. 1. – Block diagram showing the different types of gas occurrence (subsystems) that have been considered in this work: a) soil gas, b) groundwater, c) gas vents and d) exhalation flux to the atmosphere. Whereas possible, at any sampled point the concentration of Rn, He, and CO_2 in the different subsystems was measured (within few square meters) to study gas-water partition processes.

natural occurrence, *i.e.* soil gas, groundwater, gas vents and exhalation flux to the atmosphere (fig. 1). This communication outlines the main results of gas surveys undertaken from 1993 to 1995 within the framework of PEGASUS (Project on the Effects of GAS in Underground Storage facilities for radioactive wastes) European project [1]. The surveys were performed in the northern sector of the Siena basin (Tuscany, Central Italy), in correspondence with two important tectonic faults, Linea d'Arbia (LA) and Rapolano fault (RF), along which many discharges of CO_2-rich waters from a low-enthalpy geothermal reservoir occur.

2. – Methodology

Soil-gas was sampled at 0.7 m below the ground by portable hollow steel probes [1]. Exhalation flux was measured by closed chamber method [2]. Free gas from vents and bubbling pools was collected through an inverted funnel and driven into gas-tight vessels. In all gas samples ^{222}Rn was determined in the field by an α scintillation counter (EDA RDA 200). Dissolved Rn was previously extracted by air stripping. Samples for dissolved helium and CO_2 analyses were collected by admitting water into a gas-tight 500 cm^3 glass vessel equipped with vacuum stopcocks. The determination of He and CO_2 was performed in laboratory within 10 days after sampling by quadrupole mass spectrometry. Test sites were selected along faults bearing pressurised gas (CO_2) from low-enthalpy geothermal reservoirs in the Siena basin.

3. – Results and discussion

Data show that, in the same site, low concentrations of radon or helium in water co-exist with high concentrations in the ground, and low Rn in soil-air can occur in correspondence with Rn-rich gas vents. As an example, fig. 2 shows the scatterplot of CO_2 exhalation *vs.* Rn concentration in soil gas collected in correspondence with gas vents. A logarithmic inverse dependence highlights the depletion of Rn in soil pores within the CO_2 vent area. Figure 3 shows a direct dependence of helium concentration in gaseous phase, discharged at vents, with CO_2 flux, consistently with the channelling effect. The enrichment of trace gas in the channel/vent is more effective as much as the flux of the carrier (CO_2) increases, in spite of the large amount of discharged CO_2 that should dilute and minimise the rare-gas signal. Figure 4 shows the inverse relationship between He in groundwater and He concentration in the free phase of vents, as evidence of the channel-induced partitioning effects. The stripping effect that causes the enrichment of rare gas in the ascending gas column and the "draining" of the surrounding volume of rock and soil acts also below the water level.

Gas stripping is clearly related to the strength of carrier flux; however, geometric, thermodynamic and hydrologic conditions of the system (*e.g.*, partial pressure gradient

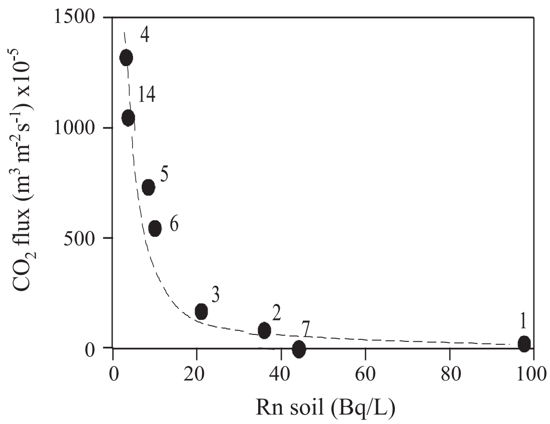

Fig. 2. – Scatterplot of CO_2 exhalation *vs.* Rn concentration in soil gas collected in correspondence with gas vent. A logarithmic inverse dependence highlights the depletion of Rn in soil pores within the CO_2 vent area.

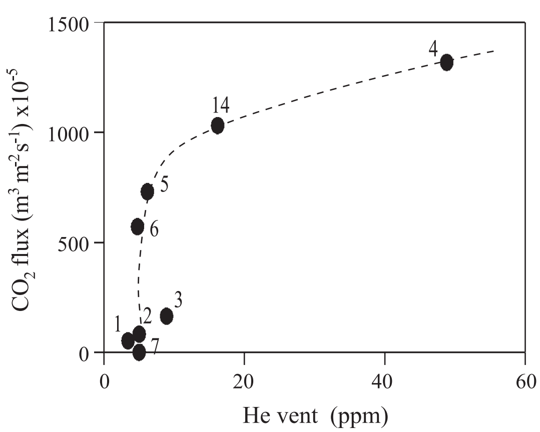

Fig. 3. – Helium concentration in gaseous phase discharged at vents. A direct dependence with CO_2 flux is consistent with the channelling effect.

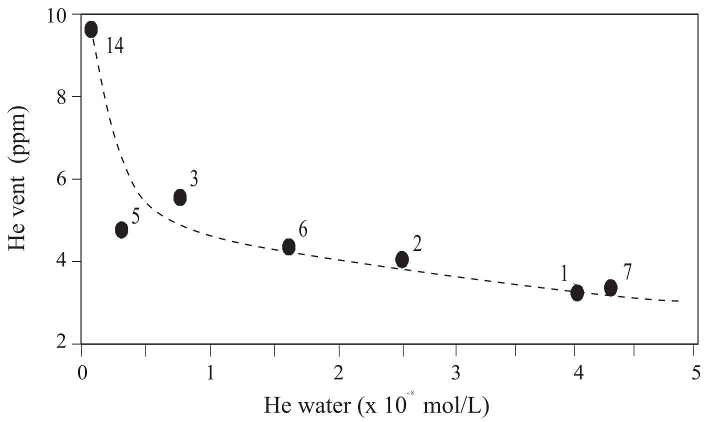

Fig. 4. – The inverse relationship between He in groundwater and He concentration in the free phase of vents gives evidence of the channel-induced partitioning effects.

between dissolved gas, gas in vent and in the surrounding environment; the ratio between water volume and stripping-gas volume; groundwater flow rate) could also control underground stripping processes; probing studies should quantify the relative effects.

4. – Conclusion

The observed results suggest that the analysis of a single "subsystem" of the geologic environment (*e.g.*, groundwater analysis only) may provide data not representative of gas occurrence and abundance in the investigated site. Integrated data, including all possible types of subsystems in the studied areas, are indeed recommended for a reliable use of gas geochemistry in any application, *i.e.* natural resource exploration, earthquake precursor studies or radiation protection zoning.

* * *

Field investigations were partly undertaken in the framework of a EU project (contract No. FI2W-CT91-0064). Analyses were performed at the Earth Science Department of the University of Rome "La Sapienza". The authors wish to thank Prof. S. LOMBARDI, co-ordinator of the research project.

REFERENCES

[1] LOMBARDI S., ETIOPE G., GUERRA M., CIOTOLI G., GRAINGER P., DUDDRIDGE G. A., GERA F., CHIANTORE V., PENSIERI R., GRINDROD P. and IMPEY M., *The refinement of soil gas analysis as a geological investigative technique,* Final Report EC contract no. FI2W-CT91-0064, 4th R&D programme on *Management and Storage of Radioactive Waste* (1990-1994), Part A, Task 4: *Disposal of Radioactive Waste*, Official publication of the European Communities no. EUR 16929 EN (1994).

[2] ETIOPE G. and LOMBARDI S., *Levels of* CO_2 *leakage in relation to geology*, in *Plant Responses to Elevated* CO_2. *Evidence from Natural Springs*, edited by A. RASCHI. *et al.* (Cambridge University Press) 1997, pp. 21-33.