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Gas migration from two mine districts: The Tolfa (Lazio, Central Italy) and the Neves-Corvo (Baixo Alentejo, Portugal) case studies

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ABSTRACT

Detailed soil gas surveys were conducted at two mine districts to understand gas migration mechanisms from deposits buried at different depths. The Tolfa (Lazio, Central Italy) and Neves-Corvo (Baixo Alentejo, Portugal) mine districts have different characteristics: the former is relatively shallow (30–100 m) whereas the latter is at a depth of 400–500 m and covered by low-permeability metamorphic rocks. The studied gases included major (N_2, O_2, CO_2) and trace (^4He, ^{222}Rn) gases, hydrocarbons (CH_4, C_2H_6 and C_3H_8) and S compounds (H_2S, COS, SO_2). The measured concentrations (some examples of max values at Tolfa: Rn 233 Bq/L, CO_2 9.5%, CH_4 12.3 ppm, COS 3.7 ppm; and at Neves-Corvo: Rn 130 Bq/L, CO_2 24.3%, CH_4 0.1%) indicate that gases migrate preferentially through zones of brittle deformation by advective processes, as suggested by the relatively high rate of migration needed to obtain anomalies of short-lived ^{222}Rn in the soil pores. Considering the different depths of the two ore deposits, obtained results can be considered as features of near-field (Tolfa) and far-field (Neves-Corvo) gas migration.

1. Introduction

It is well known that deep-origin gas can migrate towards the surface via both pressure-driven advection, along large-scale fracture domains, and concentration-driven diffusion, along smaller-scale domains (Abu-ElSha'r and Abriola, 1997; Gascoyne and Wuschke, 1997; Thunvik and Braester, 1987). These processes can transport a deep, anomalous gas signature (in terms of composition, concentration, flux rate, etc.) to the near-surface environment where it can be studied as a proxy for subsurface processes (e.g. Voltattorni et al., 2010). Given good vertical continuity of migration pathways, the method can even be applied for mineral exploration where thick and/or low permeability sediments overlie deep buried targets (e.g. Astorri et al., 1999).

Soil gas surveys have been used to study a wide variety of different geological issues, including risk assessment such as faults, earthquakes and volcanic activity (Azzaro et al., 1998; Guerra and Lombardi, 2001; Lombardi and Voltattorni, 2010; Walia et al., 2010; Zhou et al., 2010), environmental problems like nuclear waste and anthropogenic CO_2 storage (Fritz, 2011; Harvey et al., 2012; Kharaka et al., 2010; Voltattorni et al., 2009, 2010), and resource exploration (e.g. geothermal, Phuong et al., 2012; Granieri et al., 2014). Exploration for minerals has been conducted for U deposits (Boyle, 2013; Pereira et al., 2010; Silva et al., 2014) and both base and precious metal deposits (Gao et al., 2011; Noble et al., 2013) using gas geochemistry.

Geochemical anomalies at the surface ("haloes") can be associated with buried mineral deposits (Astorri et al., 1999; Ball et al., 1990; Franklin et al., 2005; Hannington et al., 2005; Hinkle and Harms, 1978; Kelley et al., 2006; Reimer and Bowles, 1979). In areas undergoing sulphide weathering, O_2 is consumed and CO_2 formed (Hinkle et al., 1990; Reid and Rasmussen, 1990). Other species that may be associated with a mineral deposit include S gases (COS, H_2S and SO_2) derived from sulphide mineral alteration (oxidation and leaching) and hydrocarbon gases formed via thermal cracking of organic matter (where ore deposits are associated with hydrothermal activity and/or a high geothermal gradient) (Machel, 1989; Polito et al., 2002; Seewald et al., 1994; Whiticar and Suess, 1990).

Tectonic discontinuities and geothermal fluids can provide preferential pathways for gas ascending to the surface. Since the 1970s, He and Rn soil gases have been used in mineral prospecting as fault tracers where ore deposits undergo tectonic control. The study of Rn and/or He is particularly useful for detecting crustal discontinuities even when faults are buried or cut non-cohesive clastic rocks, which make surface recognition difficult using traditional field methods (Ciotoli et al., 1998, 1999; Duddridge et al., 1991; Durrance and Gregory, 1988; Lombardi and Voltattorni, 2010).

The study of gas concentrations in the unsaturated soil horizon was performed over two mine districts with different characteristics. The Tolfa ore deposit (Central Italy) is relatively shallow (30–100 m) and abandoned whereas the Neves-Corvo deposit (Portugal) is located at a depth of 400–500 m (covered by metamorphosed rocks with a low permeability) and is an active mine. Considering the different depths of the

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two deposits, the main aim of this study was to understand if the ability of soil gases to move towards the surface was related to the country rocks or to the presence of preferential pathways for movements, such as faults and fractures.

2. Materials and methods

2.1. Soil gas sampling and analysis

Shallow soil gases were sampled using a 1 m long stainless steel probe fitted with a brass valve. This system enabled soil gas to be collected and stored in metallic containers (with a vacuum of 10^{-2} atm) for both laboratory analysis and to be pumped for on-site Rn analysis. The studied gases included major (N_2, O_2, CO_2) and trace (^4He, ^{222}Rn) gases, hydrocarbons (CH_4, C_2H_6 and C_3H_8) and sulphur compounds (H_2S, COS, SO_2). Soil gas surveys were performed during the dry summer season to avoid climatic factors which may affect soil gas values (Hinkle, 1994).

Radon determination was performed in the field using an EDA Instruments RDA-200 Radon Detector. The analytical error is ±0.5 Bq/L. The determination of He was performed with a Varian Mass 4 spectrometer whose detection limit is ±100 ppb. Hydrocarbons, N_2, O_2, CO_2, and sulphur compounds were determined using a Fison Instrument GC-8000 Series gas-chromatograph. Analytical precision is ±100 ppm for CO_2, O_2 and N_2, and ±0.01 ppm for hydrocarbons and S compounds.

Two areas were investigated, one (Fig. 1) in Central Italy (Tolfa area, Lazio region) and a second (Fig. 2) in the southern part of Portugal (Neves-Corvo, Baixo Alentejo region).

The soil gas survey in the Tolfa area was performed during two stages (Pizzardi, 1998). A preliminary regional survey of 235 points was performed along a regular grid (5 samples/km^2) near the villages of Tolfa and Allumiere. The second survey was carried out at the "Roccaccia-Pozzi" area where there are many abandoned mines. A total of 156 soil gas samples were collected in this small area (around 2 km^2) to test the gas–geochemical technique in an area having known mineralized veins and mine tailings (Ferrini, 1975; Ferrini et al., 1970).

Two horizontal geochemical profiles (traverses) were sampled at the Neves-Corvo mine district, based on geological profiles (Leca et al., 1983) crossing the two main ore deposits. A total of 146 soil gas samples were collected, with spacing ranging from 50–100 m in the peripheral sectors to 25–50 m in proximity of the ore bodies.

2.2. Geospatial analysis

Different geospatial analysis techniques were applied to collected data to construct prediction maps of soil gas concentration in the two areas. Exploratory data analysis evaluates the basic characteristics of the raw data and their statistical distribution by using numerical (i.e., calculation of summary statistics and statistical distribution of

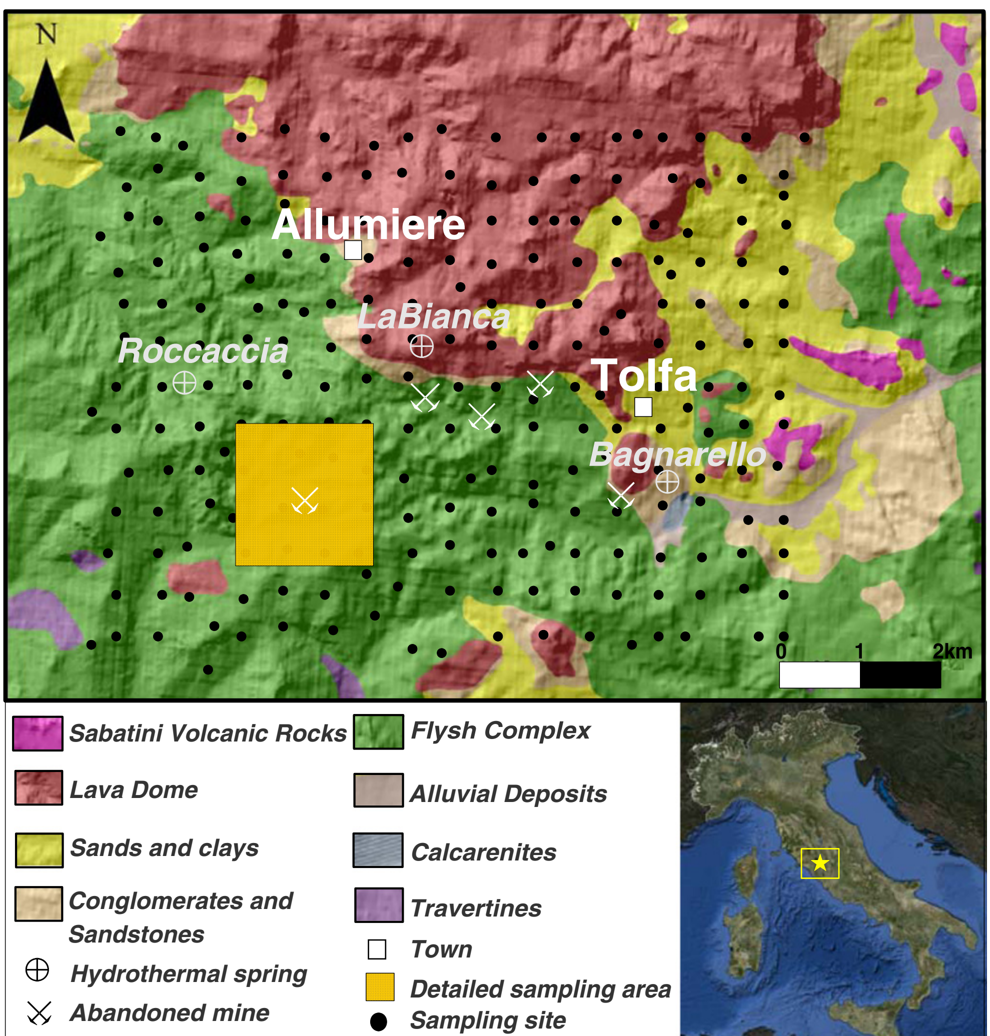

Fig. 1. Schematic geological map of the Tolfa mine district and location of sampling sites. The area is characterized by thermal alteration and by the presence of many inactive mines.