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The spatial pattern of beryllium and its possible origin using compositional data analysis on a high-density topsoil data set from the Campania Region (Italy)

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ABSTRACT

This study demonstrates the spatial distribution of Be and its possible sources by using the high density Campanian topsoil dataset. A combination of univariate and multivariate statistical analysis with multifractal methods were performed on the raw-, and compositionally transformed data set to recognize the spatial patterns of Be and its background values. Specific groups of elements were chosen based on the compositional clr-biplot to implement multiple sequential binary partitions which were used in the calculation of balances. Balances enabled us to reveal the dominance and relation between specific groups of elements. Ratio maps based on balances were also made to better understand the compositional behaviour of Be in a multidimensional space. Index of chemical weathering (CIA) was calculated to explore the advancement of pedogenetic processes which might govern the Be distribution. Enrichment Factor (EF) was used to discover the possible anthropogenic contamination of Be. In addition, different thematic maps (e.g. fault zones, bauxite mineralization spots, hydrothermal springs, pyroclastic and carbonatic rocks distribution) were involved to support and verify our interpretation.

Beryllium distribution is influenced by multiple geogenic factors. We proved that Be anomaly in topsoils is not only influenced by the presence of volcanoclastic deposits but the advancement of pedogenetic processes (e.g. chemical weathering, rubification) is equally or even more important. We pointed out that Be anomaly is mainly concentrated in topsoils developed over the oldest pyroclastic deposits in Roccamonfina and over carbonatic massifs where pedogenesis is more advanced. The distribution of pyroclastic deposits in the Campania Region was also demonstrated independently by using different balances (groups of elements). Some high Be anomaly can be interpreted as local peculiarities associated with bauxite mineralization and the presence of fault zones along which hydrothermal deposits and springs are particularly rich in Be. Finally, Be background values reflect geogenic origin and exceed the intervention limit for residential area in the vast majority of the Campania Region, hence decision-makers should take into consideration the local geological conditions when determining intervention limits.

1. Introduction

The spatial and statistical distribution of geochemical elements has long been in the focus of environmental geochemistry, mineral exploration and soil science. Different graphical and statistical techniques (e.g. classification using box-plots or cumulative probability) (Tennant and White, 1959; Sinclair, 1976, 1983; Kürzl, 1988; Reimann et al., 2008) have been elaborated to study the elemental distribution at different scales. Various interpolation methods (e.g. Kriging, Multifractal Inverse Distance Weighted) have been introduced to obtain continuous elemental concentration maps and to study the trend and change in the spatial distribution (Cheng et al., 1994; Reimann et al., 2012; Gosar et al., 2016; Birke et al., 2017). Spatial pattern recognition and background/anomaly separation by using various fractal methods (e.g. Concentration-Area) was given particular attention in mineral exploration, environmental health-risk analysis and regional topsoil studies (Cheng et al., 1994; Cheng, 1999a; b; Agterberg, 2001; Lima et al., 2003; Fabian et al., 2014; Albanese et al., 2015; Zuo et al., 2015). Spatially weighted singularity mapping (Xiao et al., 2017) and local neighbourhood analysis (Zhang et al., 2007; Carranza, 2009; Xie et al.,

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2008) have been also successfully applied in spatial feature recognition. Recently, Jordan et al. (2018) has introduced digital image processing techniques including numerical differential analysis in the identification of spatial pattern of Ni using the regional scale GEMAS (Geochemical Mapping of Agricultural and Grazing Land Soil) topsoil data set (Reimann et al., 2014).

However, geochemical data has long been considered as compositional data meaning that the ratio between elements carries more important information than the absolute values (Aitchison, 1986; Pawlowsky-Glahn et al., 2015). Compositional data are vectors of strictly positive real components belonging to the D dimensional simplex space (Aitchison, 1986). Several log-ratio transformations have been elaborated to study the data structure and treat them in the Euclidean space where classical multivariate analysis tools can be applied (Aitchison, 1986; Pawlowsky-Glahn and Buccianti, 2011). Even a single element can be regarded as a part of a composition; hence its spatial analysis is more meaningful after using one of the log-transformations (McKinley et al., 2016; Birke et al., 2017). Buccianti et al. (2015) were the first who used multivariate compositional data analysis on the Campanian topsoil data set followed by several regional studies (Buccianti et al., 2017; Thiombane et al., 2017; Rezza et al., 2018; Minolfi et al., 2018).

In this paper, we investigate the spatial distribution of Be, which a potentially harmful carcinogenic element is and we explain its possible origin in topsoils using high density Campanian topsoil data set. We applied a combination of univariate and multivariate statistical analysis (e.g. clr-biplot) with fractal methods on raw-, and compositionally transformed data set to recognize the spatial patterns of Be and its background values. Ratio maps were also made by using specific group of elements (balances) to study their compositional behaviour and dominance with respect to Be and its other indicator elements. Finally, after revealing the reasons of Be anomalies, in the last chapter we made suggestion for the modification of intervention limit of Be fixed by Italian environmental Law taking into consideration the local geological conditions.

2. Study area

The Campania Region is located in the south-western part of Italy (Fig. 1). Morphologically, it can be divided into two main parts. The NW-SE trending Apennine Mts evolved during the Cretaceous-Tertiary Alpine orogeny (Fig. 1). It consists of NE vergent thrust-sheets as a result of the NE-SW compression induced by the continuous subduction of the Adriatic and Ionian microplates (Bonardi et al., 2009; Vitale and Ciarcia, 2013). The Apennine Mts is made up of Mesozoic carbonate rocks and mainly Tertiary siliciclastic rocks deposited in different tectonic settings. The highest mountains (1800–2000 m) are built up by carbonate rocks and they have the steepest slopes with debris-flow deposits. The mountainous areas are encircled by moderately high hilly regions where siliciclastic rocks (siltstones, sandstones and conglomerates) prevail (Fig. 1) and landslides frequently occur along mud-rich sediments (Di Crescenzo et al., 2007).

The western part of the Campania Region is a Pliocene-Quaternary structural depression (Campania Plain) including alluvial plains of the Volturno and Sele River (Fig. 1). This is an actively subsiding area induced by the roll-back mechanism of the subducting Adriatic lithosphere which was responsible for the formation of the Tyrrhenian back-arc basin (Bonardi et al., 2009; Vitale and Ciarcia, 2013). The structural

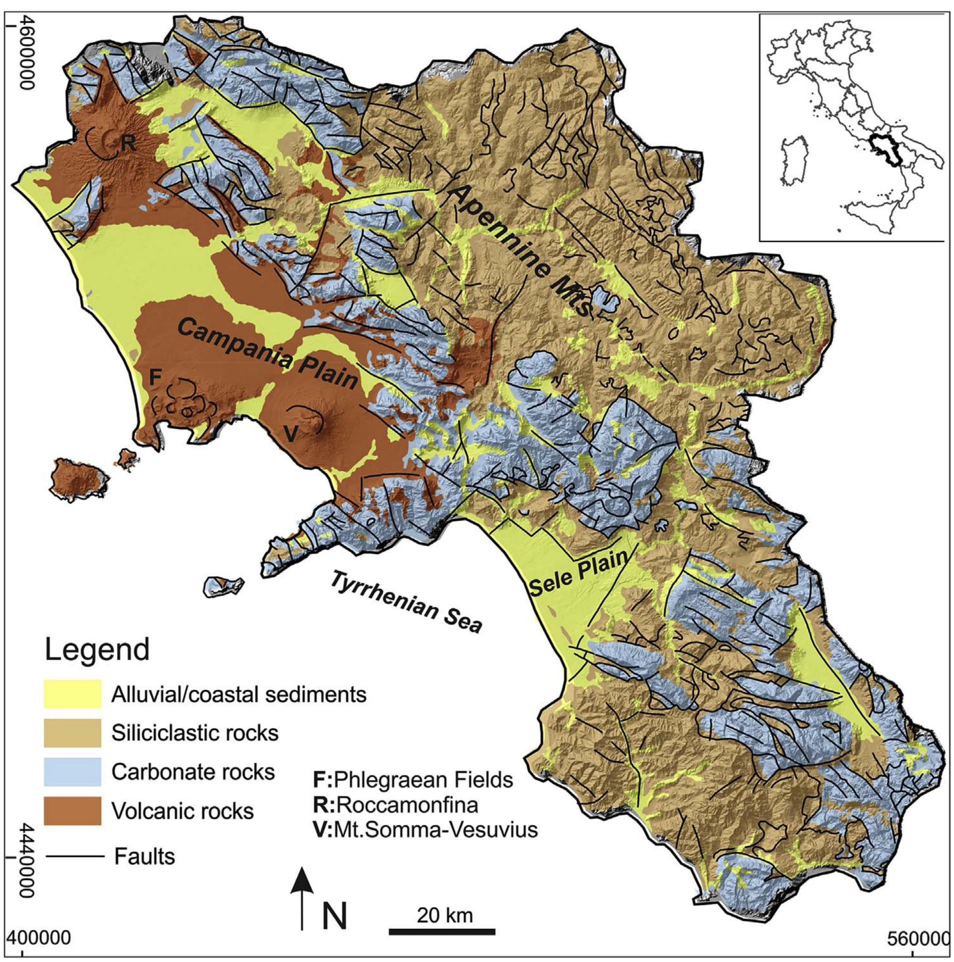

Fig. 1. The geological map of the Campania Region (after Lima et al., 2003).