

REEs geochemical characteristics of lower Cambrian phosphatic rocks in the Gorgan-Rasht Zone, northern Iran: Implications for diagenetic effects and depositional conditions



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ABSTRACT

The phosphatic rocks in the Gorgan-Rasht structural Zone (north of Iran) are widely developed within the Soltanieh Formation of Upper Neoproterozoic-Lower Cambrian age. These rocks extend in length over 60 km, vary in thickness from 2.2 m to 5 m, and lie along the boundary of the Middle Dolomite and the Upper Shale members (Lower Cambrian) of the Soltanieh Formation. In this research, the geochemical characteristics of 16 phosphatic samples using rare earth elements (REEs) within a section in the Soltanieh Formation were investigated. The entire phosphatic samples show characteristically typical hat-shaped distribution patterns of REEs, strong negative Ce anomalies ($Ce/Ce^* = 0.30-0.51$), and slightly positive Eu anomalies ($Eu/Eu^* = 1.34-1.73$). The geochemical evidence such as hat-shaped distribution patterns, MREEs enrichment relative to LREEs and HREEs, and values of Er/Nd , Y/Ho , La/Nd , and $(La/Yb)_N$ ratios together with positive correlation between pairs of $Eu/Eu^*-Ce/Ce^*$ and REEs- Ce/Ce^* and negative correlation between pair of $(Dy/Sm)_N-Ce/Ce^*$ reveal the important role of diagenetic processes in the distribution and concentration of REEs in the phosphatic rocks. This study demonstrated that the strong negative Ce anomalies and weak positive Eu anomalies are valuable indicators for determining redox conditions of diagenetic fluids existing during the development of the phosphatic rocks, and also suggest upwelling and mixing of organic-rich anoxic bottom seawaters with aerobic oxic seawaters before the development and progression of phosphatization processes in the depositional site. The geochemical parameters like Y/Ho ratio and strong positive correlation between REEs-TOC suggest that terrigenous materials along with organic matters were the principal source of REEs in the phosphatic rocks.

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1. Introduction

During recent years, geochemistry of rare earth elements (REEs) has proved to be one of the best tools for determining conditions of depositional environments and understanding of formation mechanism of sedimentary phosphatic rocks, and hence has received worldwide attention by many researchers (e.g. Elderfield and Greaves, 1982; Wright et al., 1987; Ilyin, 1998; Rao et al., 2002; Chunhua and Ruizhong, 2005; Baioumy et al., 2007; Fazio et al., 2007; Awadalla, 2010; Baioumy, 2011; Jiyan et al., 2013; Al-Hobaib et al., 2013; Khan et al., 2012, 2016; Abed et al., 2016; Xin

et al., 2016; Kechiched et al., 2016; Abou El-Anwar et al., 2017; Auer et al., 2017; Zhu and Jiang, 2017). Distribution patterns of REEs and variations of anomaly values of Eu and Ce in phosphatic sedimentary rocks are highly dependent upon various factors including conditions of the depositional environment and the degree of interaction between seawaters and land-derived detrital materials (Khan et al., 2012). Factors like weathering, diagenesis, and metamorphism can remarkably influence the concentration of REEs and their distribution patterns in phosphatic rocks (McArthur and Walsh, 1984). The results of recent researches revealed that geochemical investigations of REEs in sedimentary phosphatic rocks can furnish valuable information on paleo-seawaters and/or diagenetic fluids (e.g. Shields and Stille, 2001; Zhu et al., 2014; Muscente et al., 2014; Xin et al., 2016; Auer et al., 2017; Zhu and Jiang, 2017).

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The phosphatic sedimentary deposits in Iran were developed temporally in six discrete periods: (1) Lower Cambrian, (2) Ordovician-Silurian, (3) Upper Devonian, (4) Upper Cretaceous, (5) Paleocene, and (6) Eocene-Oligocene. Spatially, these deposits are widely spread within five structural zones: (1) Central Iran, (2) Alborz-Azarbaidjan, (3) Gorgan-Rasht, (4) Folded Zagros, and (5) Sanandaj-Sirjan (Namadmalian et al., 1998).

The Lower Cambrian phosphatic deposits in the Gorgan-Rasht Zone contain an average of 11 wt% P_2O_5 and reserves exceeding 66 million tons (Namadmalian et al., 1998), and extend over 60 km with varying thicknesses between 2.2 and 5 m. Mineralogically, the principal constituent minerals present in these deposits are calcite, fluor-apatite, dolomite, quartz, pyrite, muscovite, and illite (Abedini et al., 2012).

The Soltanieh Formation (Neoproterozoic-Lower Cambrian) is widely exposed in the Gorgan-Rasht Zone (northern Iran) and host to the phosphatic sedimentary deposits. Up to now, extensive stratigraphic, paleo-biologic, sedimentary, and geochemical (carbon stable isotopes) investigations were carried out in the Soltanieh Formation in an attempt to determine the conditions of depositional paleo-environment during the period of

Neoproterozoic-Lower Cambrian by different researchers (Hamdi et al., 1989; Brasier et al., 1990; Kimura et al., 1997). So far, comprehensive studies concerning geochemical characteristics and behavior of rare earth elements during evolution of the phosphatic rocks of the Soltanieh Formation have not been done.

The aim of this work is to study the distribution patterns of REEs, variations of Eu and Ce anomaly values, and elemental ratios as useful means for appreciating the paleo-seawater conditions and diagenetic environments during phosphatization of the Lower Cambrian phosphatic rocks of the Soltanieh Formation in the Vali-Aabad area of northern Iran.

2. Geological setting and studied section

Based upon the structural division of Iran (Nabavi, 1976), the study area is located in the central part of the Gorgan-Rasht Zone (Fig. 1). The stratigraphic units, from the oldest to the youngest, in the study area (see Fig. 2) include Neoproterozoic Kahar Formation (slaty shale, sandstone, siltstone, dolomite, and quartzite), the Neoproterozoic-Lower Cambrian Soltanieh Formation (dolomite and shale), the Cambrian Barut Formation (siltstone and shale), the

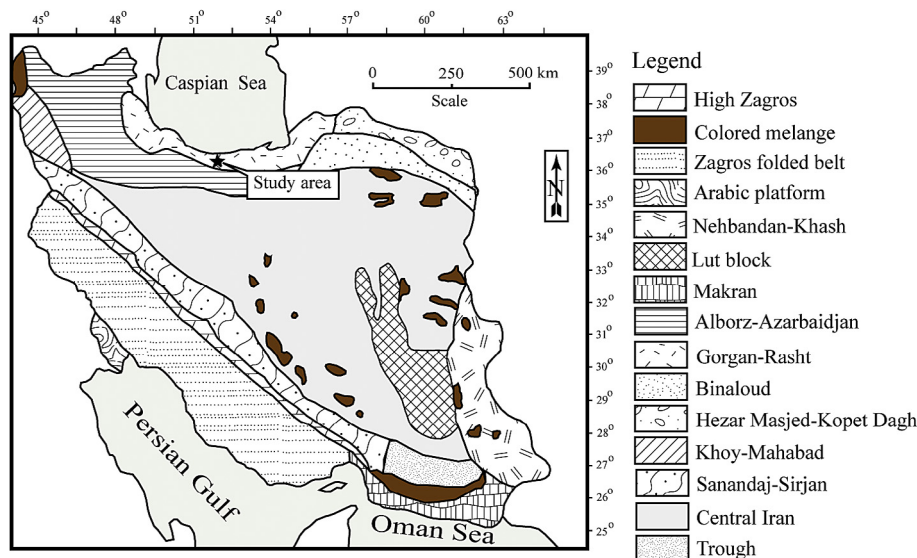


Fig. 1. Geologic map showing the divisions of structural zones of Iran (Nabavi, 1976) in which the study area lies in the Gorgan-Rasht Zone in the north of country.

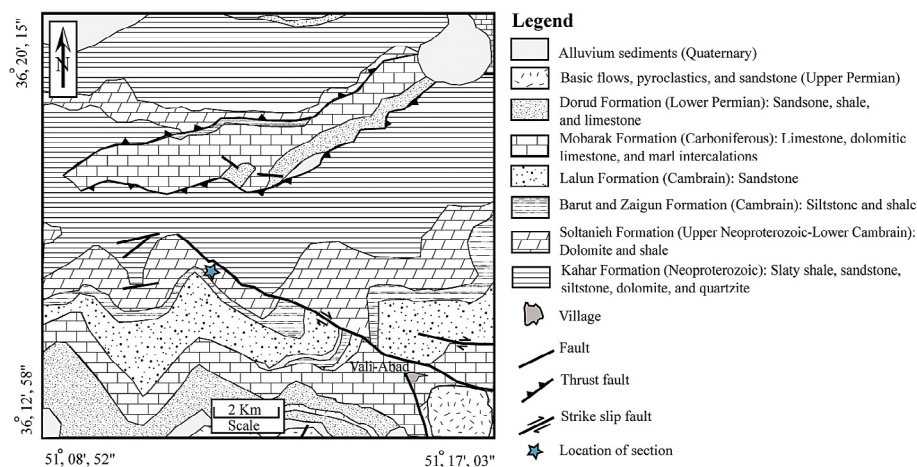


Fig. 2. Geologic map of the study area in the Gorgan-Rasht Zone in which the position of the studied selective section is marked by asterisk.

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