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# Sr enrichment in mantle pyroxenes as a result of plagioclase alteration in lherzolite

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ABSTRACT

Melt impregnated plagioclase lherzolites from the Nain mélange, central Iran, contain pyroxenes enriched and chemically zoned with Sr. Pyroxenes from the lherzolite and the clinopyroxenite seams, which have been precipitated from the impregnating melt, show similar trace element geochemical characteristics, including a similar Sr anomaly. The associated plagioclase, precipitated from the impregnating melt, has been selectively altered to isotropic saussurite. Strontium concentration increases in the pyroxenes from the core to the rim and toward crosscutting saussurite trails in orthopyroxene porphyroclast cores. The highest Sr content (up to 10.8 ppm in clinopyroxene and 3.8 ppm in orthopyroxene) is found in the finer pyroxenes surrounded by thicker saussurite layers.

The Sr enrichment within pyroxenes is neither caused by metasomatism nor modified by fluids involved in hydrothermal alteration because pyroxenes are extremely depleted in fluid-mobile and light rare earth elements. Also, Sr enrichment cannot be related to the melt impregnation, since the Sr supply from the impregnating melt was consumed by plagioclase crystallization. The Sr enrichment in the pyroxene postdates the melt impregnation and is due to the relatively high-temperature (375 °C–850 °C) of saussuritization, that is, the breakdown of plagioclase. Plagioclase decomposition has released appreciable amounts of Sr to enrich adjacent pyroxenes. Saussurite shows significantly lower Sr contents than the plagioclase. Sr enrichment in peridotite pyroxenes, which is ascribed primarily to the metasomatism of slab-derived fluids, should be treated carefully, particularly when altered plagioclase is present.



## 1. Introduction

Strontium is widely used in petrology and geochronology as one of the key elements used to constrain the timing and geological process that formed or modified rocks. In spinel and garnet peridotites, Sr resides mainly in pyroxenes, especially clinopyroxenes. In plagioclase-bearing peridotite, however, Sr additionally resides in plagioclases. Strontium is a compatible element in feldspars (e.g., Bindeman and Davis, 2000) and has a relatively high partition coefficients for pyroxenes in contrast to the other common phases found in peridotite (e.g., Blundy and Dalton, 2000; Frei et al., 2009; Hart and Dunn, 1993; Johnson, 1998; Taura et al., 1998). Sr resides in crystallographic M sites of feldspars and eight-coordinated M2 sites of pyroxenes. In feldspars, the rate of Sr diffusion correlates negatively with the anorthite content (e.g., Blundy and Wood, 1991), implying that the Sr diffusion is mostly controlled by crystal chemistry. In pyroxenes, the diffusion of Sr is controlled by various factors, such as temperature, pressure, composition of pyroxene, oxygen fugacity, diffusion distance (pyroxene/source contact), presence of interconnecting melt or fluid and crystallographic direction (Freer, 1981; Sneeringer, 1981; Sneeringer et al., 1984; Van Orman et al., 2001). Sneeringer et al. (1984) showed that the diffusion of Sr in clinopyroxene is rapid enough at temperatures near the solidus of peridotite to easily maintain grain-scale homogeneity. The experiments of Sneeringer et al. (1984) have revealed that Sr is one of the most diffusive elements in pyroxenes in contrast to other trace elements.

At the same temperature, the diffusion of elements is considerably lower in the solid than that in the liquid phase (e.g., Arculus and Powell, 1986; Kogiso et al., 1997). Because of this, the chemical zonation and enrichment of elements in the pyroxenes of peridotites, such as Sr, is generally explained by the involvement of fluids or aqueous melt. The chemically zoned pyroxene is mainly derived from postmagmatic processes such as the metasomatism by slab-derived fluids and/or aqueous melt in the mantle wedge (e.g., Alibert, 1994; Bizimis et al., 2000; Grégoire et al., 2001; Pearce et al., 1984; Scambelluri et al., 2006). The source of Sr in slab-derived fluids is widely believed to be sediments and portions of the subducted oceanic crust, altered by seawater

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(e.g., Keppler, 1996). In oceanic crust, saussurite is commonly formed as a hydrothermal alteration product of plagioclases (e.g., Apted and Liou, 1983).

In this article, we present an example of relatively low-temperature Sr enrichment in pyroxenes in mantle-derived peridotites at crustal conditions. We have observed the local enrichment of Sr in fresh mantle pyroxenes (especially orthopyroxene) in plagioclase lherzolite from the Nain ophiolite, central Iran, in which plagioclase has been selectively altered under the conditions found in the crust.

## 2. Geological background

Nain mélange shows a highly tectonized ophiolite sequence (Davoudzadeh, 1972) located north of the town of Nain in Isfahan province, Iran (Fig. 1). It crops out over an area of around 480 $km^2$ and has a N-NW to S-SE trend (Fig. 1). In the mélange, ultramafics, mafics, radiolarites and limestones are strongly intermingled by tectonic processes to form what is known as the “colored mélange” (Davoudzadeh, 1972; Pirnia et al., 2013). The tectonic disruption in this zone consists mainly of numerous major and minor faults with predominantly vertical displacements. The faults mostly show the same general trend of the mélange and extend through the entire length of the zone (Fig. 1). Harzburgite and lherzolite masses have extensively been thrust up along the faults and form elongated oval shape bodies of several kilometers in length.

In the mélange, pillow lavas, basaltic flows and sedimentary rocks outcrop from Kuh-e-Zard to Nain town (Fig. 1). The mantle rocks (that are serpentinized to various degrees) mainly consist of clinopyroxene-bearing harzburgite, lherzolite, plagioclase-bearing lherzolite, dunite, and chromitite pods (Mehdipour Ghazi et al., 2010; Pirnia et al., 2010, 2013). The mantle peridotites in Nain are locally crosscut by dikes of rodingitized and unaltered gabbro, pyroxenite and wehrlite. Although tectonism has caused strong fragmentation and displacement, gradual changes in composition from lherzolite to harzburgite and then dunite can be observed in many places in the mélange. Plagioclase-bearing lherzolites are commonly found in the vicinity of shear zones and these fault-related plagioclase lherzolites display mylonite textures crosscut by frequent parallel to subparallel centimeter-thick seams of gabbro and pyroxenite (Pirnia et al., 2010).

The Nain and other ophiolites (e.g., Baft, Shahr-Babak) (Arvin and Robinson, 1994; Ghazi and Hassanipak, 2000) on the western border of Central-East-Iranian microplate (CEIM) have been widely considered to be fragments of a narrow oceanic basin which surrounded the CEIM in the Mesozoic. This has been interpreted to represent a back-arc basin related to the subduction of Neo-Tethys at a geologically active margin of the Iranian plate (Sanandaj–Sirjan zone) (e.g., McCall, 1997; Takin, 1972). This back-arc basin existed for ~45 Ma (Cenomanian to Paleocene) and closed in the early Tertiary (Davoudzadeh, 1972; Shafaii Moghadam et al., 2009). The Nain ophiolite falls into the late Cretaceous to lower Eocene interval (Davoudzadeh, 1972).

## 3. Petrography

The studied plagioclase lherzolite, found along a shear zone, contains up to 9% modal plagioclase, and shows porphyroclastic to mylonitic textures (protomylonite) (Pirnia et al., 2010). The plagioclase frequently

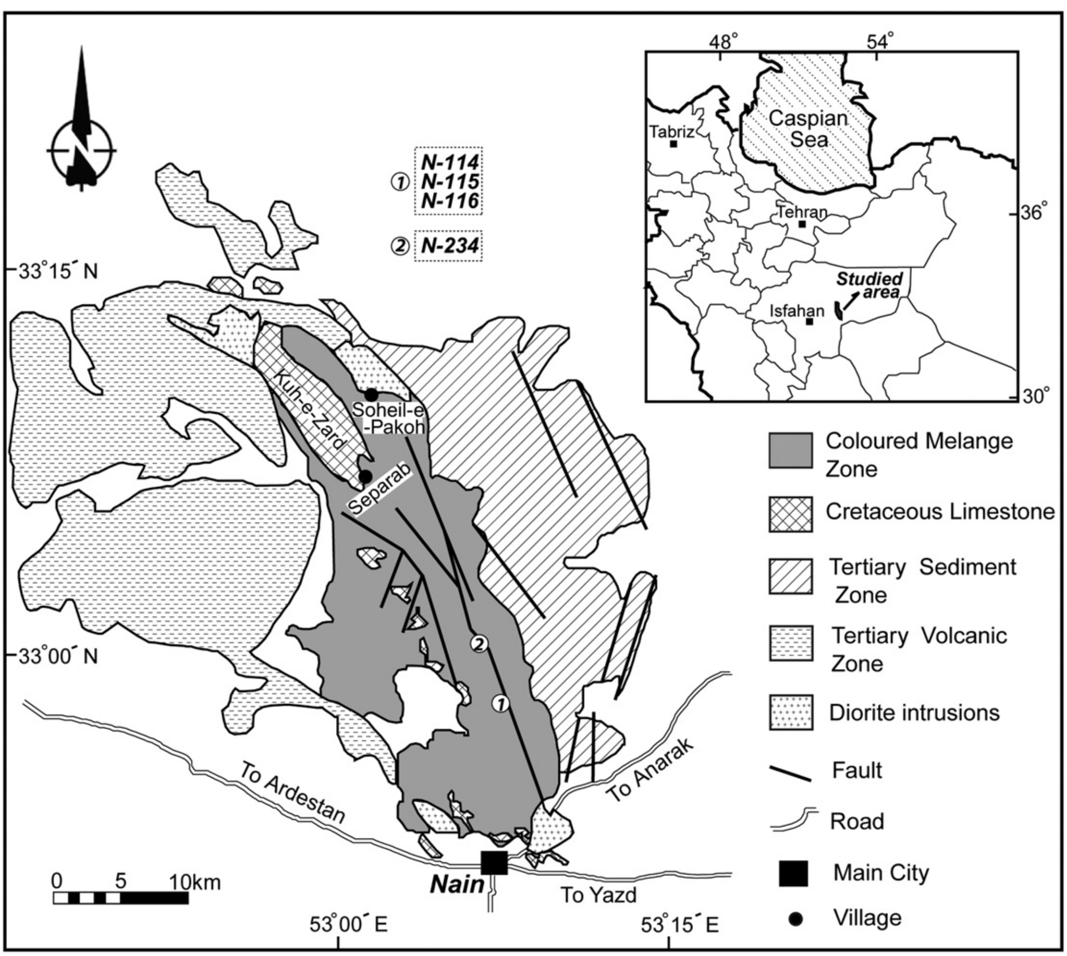


**Fig. 1.** Simplified geological map of Nain mélange (Isfahan province), central Iran (after Davoudzadeh, 1972). Sample locations are shown. Note that the colored mélange zone is a unit highly tectonized and composed of ophiolitic materials.