ژئوشیمی ایزوتوپی و پتروژنز توده‌های نفوذی کالک‌آلکالن غنی از پتاسیم و با تفریق شدید عناصر نادر خاکی در بلوک لوت، شرق ایران

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چکیده:

گرانیتوئیدهای پورفیری دهسلم و چاه‌شلغمی در کمربند آتشفشانی- نفوذی بلوک لوت در شرق ایران مرکزی قرار گرفته‌اند و جزو گرانیتهای کمانهای آتشفشانی کالک آلکالن پتاسیم بالا تا شوشونیتی هستند. نمودار عنکبوتی نرمالیزه عناصر کمیاب نسبت به جبه اولیه نشان‌دهندهٔ غنی‌شدگی شدید عناصر (LILE) مانند Rb, Sr, Ba, Zr, Cs و تهی‌شدگی عناصر (HFSE) مانند Nb, P، Yو HREE می‌باشد. نمودار عنکبوتی نرمالیزه عناصر نادر نسبت به کندریت نشان دهنده درجه بالای تفریق REE و مقادیر بالای LREE/HREE است. با وجود ویژگیهای شوشونیتی در این توده‌های نفوذی،گرایش آداکیتی آنها در دیاگرامهای Sr/Y–Y و La/Yb–Yb قابل مشاهده می‌باشند. نسبتهای ایزوتوپی $^{87}Sr/^{86}Sr$ اولیه و εNd همراه با عناصر اصلی و کمیاب نشان می‌دهند که منشأ این توده‌های نفوذی از جبه متاسوماتیک است و گارنت فاز باقی‌مانده بوده در حالی‌که فلوگوپیت دچار ذوب شده است. این توده‌های نفوذی آلودگی کمی نسبت به پوسته داشته‌اند. به طور کلی شواهد ایزوتوپی، ژئوشیمیایی و پترولوژیکی تأییدکننده زون فرورانش در زیر بلوک لوت در ترشیاری است.

Isotope geochemistry and petrogenesis of K-rich and strongly REE fractionated calc-alkaline intrusives within the Lut Block, Eastern Iran

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Abstract

The Dehsalm and Chah Shaljami porphyritic granitoids belong to the volcanic-plutonic belt within the Lut Block, in central eastern Iran, and display geochemical features of high-K calc-alkaline to shoshonitic volcanic arc granites. Primitive mantle normalized trace element spider diagrams show strong enrichment in LILE, such as Rb, Ba, and Cs, and depletion in some HFSE, e.g. Nb, Ti, Y and HREE. Chondrite normalized plots show a very marked REE fractionation, with high values of LREE/HREE ratios. Despite their shoshonitic affinity, these rocks also display some geochemical features similar to those of adakites, as revealed by plots on the Sr/Y–Y and La/Yb–Yb diagrams. Sr and Nd isotope compositions together with major and trace element geochemistry suggest that the parental magmas resulted from melting of a metasomatized mantle source mantle, and that garnet behaved as a residual phase, whilst phlogopite underwent decomposition. Contamination by the crustal materials seems to have played only a minor role. As a whole, the petrological, geochemical and isotopic evidence agrees with a geodynamic setting characterized by a subduction zone operating under the Lut block, in the Tertiary.

Introduction

The Lut Block has been considered one of the nine structural zones of Iran since the work of Stöcklin (1968). This block is bounded to the east by the Nehbandan and associated faults, to the north by the Doruneh and related faults, and to the west by the Nayband Fault. The South Jazmourian fault, in the south of Sahand-Bazman magmatic arc, probably marks the southern limit of the block (Berberian, 1981). The present eastern border of the Lut block would have belonged to the active margin of the subducted Neotethys Ocean (Bagheri and Stampfli 2008). This ocean was closed in eastern Iran, between the Helmand and Lut plates, in Oligocene–Middle Miocene (Sengör and Natalin, 1996). Recently, adakitic affinities were identified in the Dehsalm and Chah Shaljami granitoids within the Lut block (Arjmandzadeh et al, 2010). Adakite is a petrologic term that Defant and Drummond (1990) first introduced for the volcanic intrusive rocks characterized by silica rich, high Sr/Y and La/Yb in Cenozoic arcs associated with subduction of young oceanic lithosphere (≤ 25 Ma). Usually, adakites are seen as resulting from slab melts, but some other origins have been proposed, such as assimilation-fractional crystallization (AFC) processes (Macpherson et al., 2006), melting of mantle peridotite under hydrous conditions (Stern and Hanson, 1991), partial melting of thickened lower crust (Guo et al., 2006) or delaminated mafic lower crust (Lai et al., 2007).

Although the adakitic affinities of the Dehsalm and Chah Shaljami intrusives are clear if trace element geochemistry is considered, these granitoids do not the display the sodic character which is typical of adakites. In fact, the Dehsalm and Chah Shaljami intrusives are K-rich granitoids.

The purpose of this work is to present new geochemical (both elemental and isotopic) data from Dehsalm and Chah Shaljami granitoids, aiming at establishing tighter constraints to the petrogenetic processes and reconciling the shoshonitic and adakitic affinities of those rocks.

Analytical techniques

Twenty five samples were analysed for major element contents by X-ray fluorescence (XRF) spectrometry at Ferdowsi University, Mashhad, Iran. Twenty of these samples were selected for trace element analysis by ICP-MS, in Acme laboratories, Vancouver, Canada. Sr and Nd isotopic compositions were determined, in 14 whole rock samples of the Dehsalm and Chah Shaljami granitoids, by TIMS at the Laboratório de Geologia Isotópica da Universidade de Aveiro, Portugal.

Geological setting and petrography

The Chah Shaljami and Dehsalm porphyritic granitoids belong to the Lut Block volcanic-plutonic belt of eastern Iran (Fig. 1). The Chah Shaljami complex is located 190 km to the south of Birjand, in the Lut Block volcanic-plutonic belt and corresponds to a sub-volcanic suite with a compositional range from quartz diorite to biotite granite, through quartz monzodiorite, quartz monzonite and granodiorite. The granitoids intrude Eocene volcanic of both lavic and pyroclastic natures, whose compositions vary from basaltic to andesitic. According to Rb-Sr dating, the volcanics have a 40.5±2 Ma age (Kluyver et al, 1978).

The Dehsalm intrusive complex is located about 55 km west of Nehbandan, in South Khorasan (Iran) and intruded into Eocene volcanics, sandstone and siltstone. On the basis of petrographic studies, the intrusive rocks cropping out at Dehsalm are gabbroic diorites, diorites, monzodiorites and quartz monzonites.

In both suites, the main mafic minerals are typically hornblende and biotite, but clinopyroxene and, sometimes, orthopyroxene may be observed in the least evolved rocks, especially in the Dehsalm complex.

Major and trace element geochemistry

The low molar Al_2O_3/Na_2O+K_2O+CaO ratios (<1.1) and low Rb/Sr ratios displayed by the studied rocks indicate that they are I-type granitoids, as expected in calc-alkaline intrusive suites. Consistently, the Dehsalm and Chah Shaljami intrusive rocks are classified as volcanic arc granites following the criteria proposed by Pearce et al (1984), based on trace element geochemistry.

Primitive mantle normalized trace element spider diagrams (Sun and McDonough, 1989) display strong enrichment in large ion lithophile elements (LILE), such as Rb, Ba and Cs, and other incompatible elements that behave very similarly to LILE (Th and U). The most characteristic high field strength elements (HFSE) – e.g. Nb, Zr, Y, Ti and HREE - have, compared to LILE, clearly lower normalized values; Nb and Ti, in particular, define deep negative anomalies (Fig. 2 a-b). REE patterns in chondrite normalized plots display high degrees of REE fractionation, with very strong LREE enrichment, whilst Eu has not anomalies or shows only very slight negative anomalies (Fig. 2 c-d).

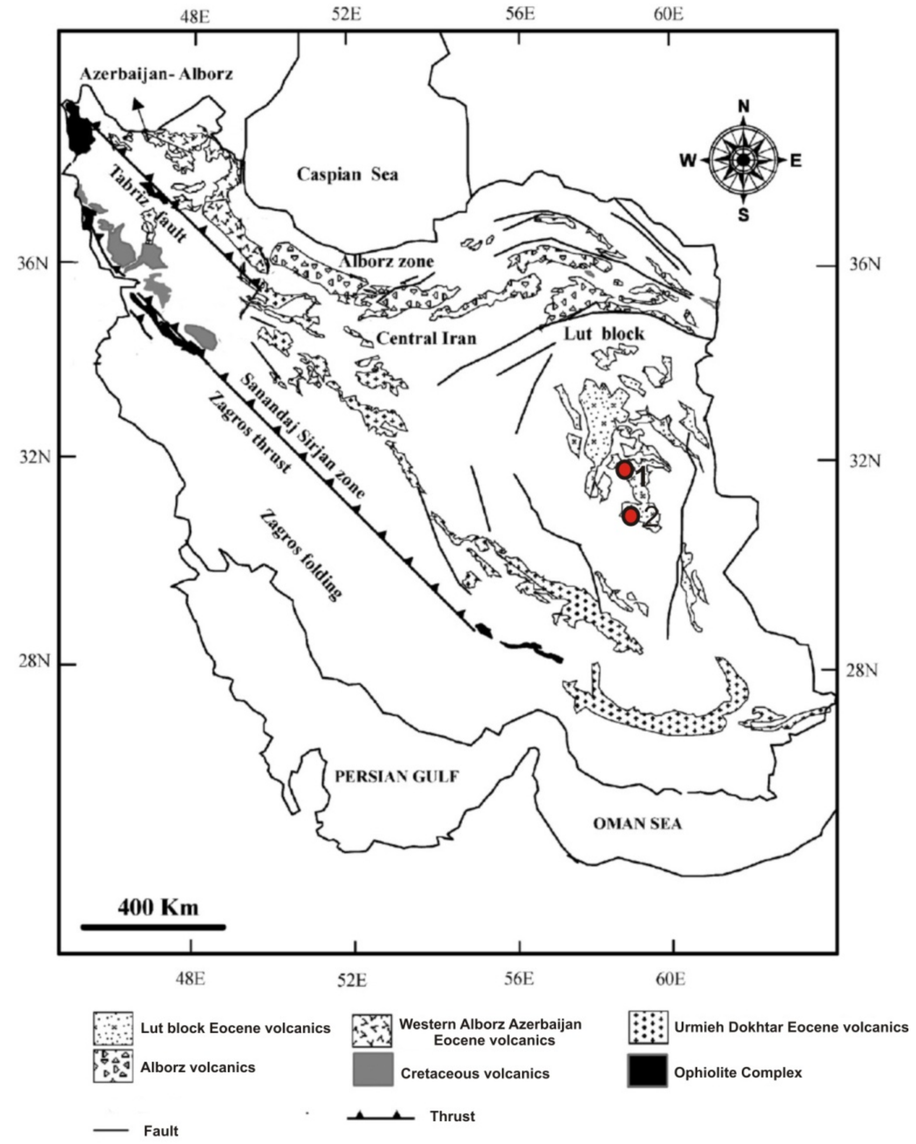

Fig. 1: Distribution of Cretaceous and Tertiary volcanic rocks and dismembered ophiolites in Iran (after Azizi and Jahangiri, 2008) and the location of Chah Shaljami (1) and Dehsalm (2) intrusive rocks.

A general LILE enrichment and negative anomalies in some HFSE (Nb, Ta and Ti) are geochemical features typical of the magmatism in subduction related belts (Wilson, 1989), such as the calc- alkaline volcanic arcs. Their high Sr and low Nb, Ta and Ti contents are thought to be due to the absence of plagioclase and presence of Fe–Ti oxides in the residue in the source area of the parental magmas (Martin, 1999).

Besides the geochemical fingerprints common to all calc-alkaline suites, the studied intrusives show some peculiar characteristics. For instance, Sr/Y and La/Yb are respectively 31.6-72.2 and 21.5-33.5 in the Dehsalm rocks, whilst the Chah Shaljami intrusive rocks display 19.7-67 and 21.4-33.7 for the same ratios, showing that both complexes have some affinities towards adakites, which become clear by plotting the data on the Sr/Y–Y and La/Yb–Yb diagrams (Kepezhinskas et al. 1997; Castillo et al 1999) (Fig. 3 a-b). However, the Dehsalm and Chah Shaljami can not be considered as typical adakites, mainly because they have high K_2O/Na_2O ratios, revealing that the studied rocks also have a shoshonitic affinity.

High Sr/Y and La/Yb ratios and low HFSE (specially, HREE) may result from melting of garnet amphibolite or eclogite facies rocks, which are expected to occur at the base of thickened (>40 km) continental crust or in subducted oceanic crust. On the other hand, garnet is also a stable phase in the subcontinental mantle lithosphere as well as in the asthenosphere (Grove et al., 2006). The low contents of Y and Yb and the high Sr/Y and La/Yb ratios can be attributed to the retention of Y and HREE in residual garnet, or to fractionation of garnet and hornblende. High Sr content may result from the absence of significant plagioclase fractionation. Hornblende and/or Fe–Ti oxides (rutile, ilmenite) are common residual minerals, thus being able to account for Ti–Nb–Ta negative anomalies in calc-alkaline rocks.

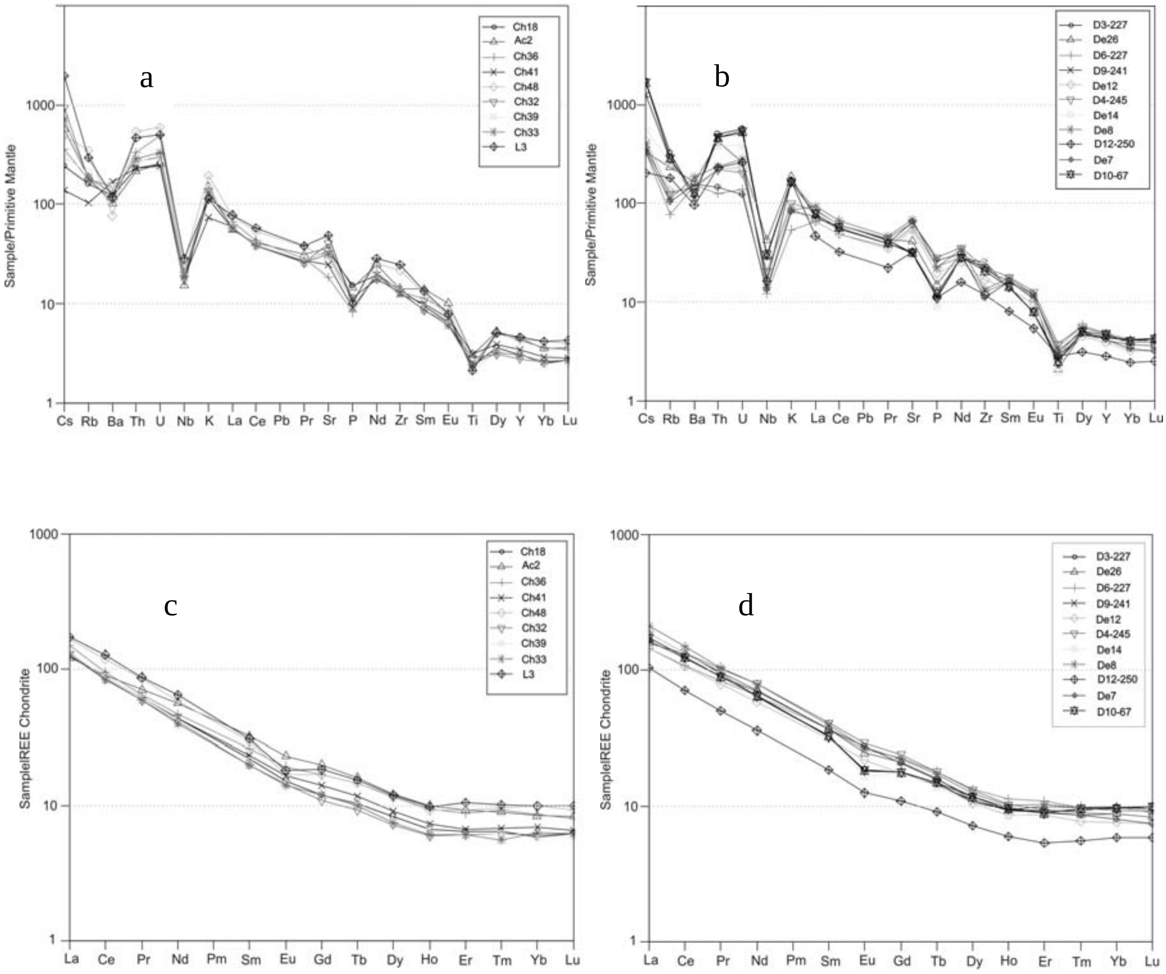

Fig. 2: a, b - Primitive mantle normalized trace element spider diagram (Sun and McDonough, 1989); c, d - REE chondrite-normalized diagram (Boynton, 1984) for Dehsalm and Chah Shaljami intrusive rocks.

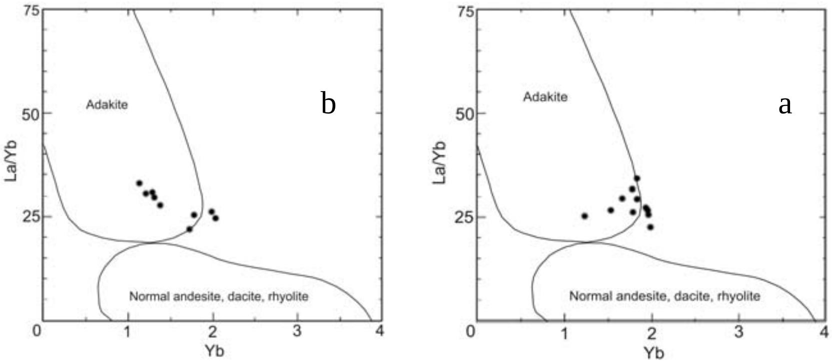

Fig. 3: Yb vs. La/Yb diagram (Defant and Drummond, 1990), used to differentiate adakitic magmas from typical calc-alkaline magmas, for intrusive rocks of: a - Dehsalm; b - Chah Shaljami

Nd-Sr isotope geochemistry

Sr and Nd isotope ratios of the Dehsalm and Chah Shaljami intrusive rocks define a tight cluster that plots slightly to the right of the mantle array, suggesting that both suites derive from very similar mantle derived parental melts. Furthermore, the position of the cluster in $\varepsilon_{Nd(i)}$ vs. $\varepsilon_{Sr(i)}$ diagram is typical of igneous rocks from convergent plate margins. On the other hand, the cluster plots outside the field of the Cenozoic subducted oceanic crust-derived adakites, which makes unlikely that the parental magmas were slab melts. Additionally, K_2O and Rb contents of the studied rocks are higher than expected in adakites. Ascent of magmas through thickened continental crust could have caused contamination by continental crust materials, which would lead to increase in Rb and K_2O. However, if such a process was extensive, correlations between SiO_2 and Sr and Nd isotopic compositions would be expected (Castillo et al., 1999). The very small changes in the values of both $\epsilon_{Nd(i)}$ (Fig. 4) and $\epsilon_{Sr(i)}$ against SiO_2, for almost all samples, precludes assimilation and fractional crystallization (AFC) as a major process (Zhong et al., 2007).

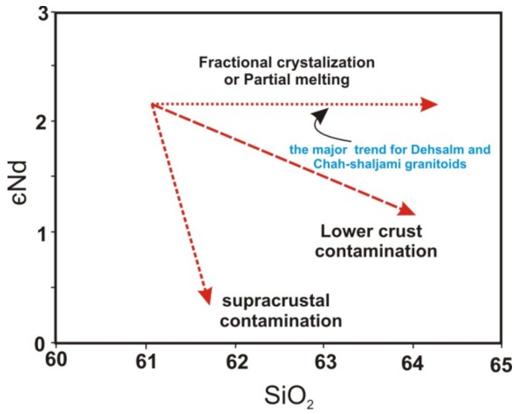

Fig. 4 Plot of $\epsilon_{Nd(i)}$ vs. SiO_2 for Dehsalm and Chah Shaljami adakitic intrusive rocks.

Therefore, considering isotope geochemistry together with major and trace element data, the Dehsalm and Chah Shaljami intrusives seem to represent mainly suites of cogenetic magmas related mainly by fractional crystallization. Only one sample, with a $\epsilon_{Nd(i)}$ value below the main trend, shows evidence of assimilation supracrustal material.

Taking into account the previous arguments, the high Rb/Sr and K_2O/Na_2O ratios in the studied rocks should be rather attributed to the source geochemistry and melting processes than to AFC processes. Amphiboles can have relatively high K and low Rb contents while phlogopite is rich in both K and Rb. Thus, extensive melting of phlogopite would account for the high concentrations in these two elements.

Conclusions

The Dehsalm and Chah Shaljami porphyritic granitoids in the Lut Block represent a continental arc setting associated with the magmatism above a subduction zone. The adakitic affinity of Dehsalm and Chah Shaljami intrusive rocks would point to derivation of the parental magmas either directly from melting in subducted ocean crust, or from melting in a zone of the mantle wedge previously enriched by metasomatism through slab melts. However, the Sr-Nd isotope signatures and the K_2O/Na_2O ratios do not fit into the first hypothesis. In contrast, melting of a metasomatized mantle source, with phlogopite decomposing into the melt and garnet remaining as a residual phase, is a likely explanation for the geochemical features of the two studied magmatic suites, namely the coexistence of adakitic and shoshonitic affinities.

In addition, the data presented in this work provide new evidence for subduction beneath the Lut block during the Tertiary.

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