Genesis of granitoids by interaction between mantle peridotites and hydrothermal fluids in oceanic spreading setting in the Oman Ophiolite

Génesis de granitoides por interacción entre peridotitas del manto y fluidos hidrotermales en un contexto de expansión oceánica en la Ofiolita de Omán

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RESUMEN

Los granitos potásicos que afloran en las ofiolítas supra-subducción son atribuidos a la fusión de metasedimentos durante el inicio de la obducción o durante procesos petrogenéticos relacionados con la subducción. En este artículo, presentamos nuevos datos de campo, petrológicos y geoquímicos (elementos mayores, trazas e isótopos), que apoyan la opinión de que parte de estos granitoides pueden haber sido formados a partir de un manto empobrecido afectado por procesos hidrotermales de muy alta temperatura en un ambiente de expansión de litosfera oceánica.

Palabras clave: *Granitoides, fluidos hidrotermales,Ofiolita de Oman*

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Introduction

Granitoids are commonly found in the mantle section of supra-subduction ophiolites, including the Oman ophiolite (Allemann and Peters, 1972; Boudier *et al.*, 1988; Briqueu *et al.*, 1991; Peters and Kamber, 1994; Cox *et al.*, 1999). These granitoids, especially the potassic types, when occuring in deep levels of ophiolites, are almost systematically attributed to an «exotic» meta-sedimentary source and to igneous processes related to subduction and/or obduction rather than to accretion. This scenario certainly accounts for the genesis of part of ophiolitic granitoids such as the Al-rich granitoids forming the Khawr Fakkan massif at the northermost end of Oman ophiolite, which according to petrological and isotopic data seem to derive from the underlying metamorphic sole (Briqueu et *al.*, 1991; Cox *et al.*, 1999).

The main objective in the present paper is to determine if a metasedimentary source satisfactorily accounts for the formation of *all* potassic granitoids observed in the Oman Ophiolite. A second question addressed in this paper concerns the petrological and geophysical conditions leading to the genesis of granitoids in the sub-oceanic mantle.

Previous studies of Oman granitoids have focused on a specific structural level or on a given area. In the frame of a systematic field, petrological and geochemical survey of intrusive lithologies in the Oman mantle section

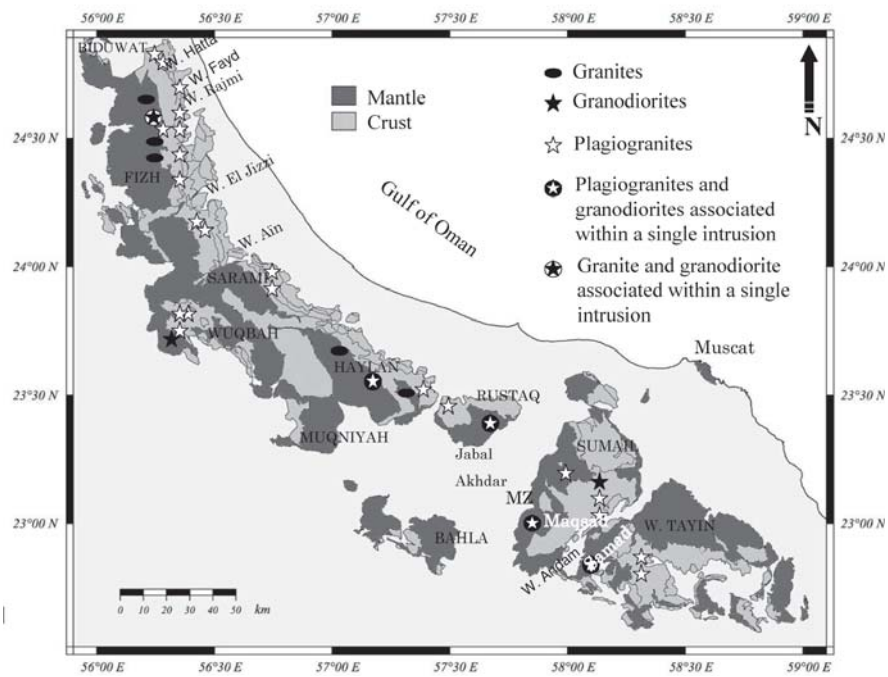

Fig. 1.- Geographical and geological distribution of the different granitoid types from the Oman Ophiolite.

Fig. 1.- Distribución geográfica y geológica de los diferentes tipos de granitoides en la Ofiolita de Omán.

(Ceuleneer *et al.*, 1996; Benoit *et al.*, 1999; Python and Ceuleneer, 2003), we have sampled numerous occurrences of granitoids in the different massifs of the Oman range, from Wadi Tayin in the Southeast to Wadi Hatta in the Northwest (Fig. 1). The synthetic map presented in figure 1 is based on this comprehensive survey and on the observation of hundreds of thin sections.

Based on this petrographic study and on electron microprobe data, we have selected 33 samples representative of the various kinds of mantle and crustal granitoids for a bulk rock geochemical study (major elements, trace elements, and Nd-Sr isotopes on a selection of 16 samples). We compare our data to the ones collected by Cox *et al.* (1999) on granitoids from the Khawr Fakkan massif and show that melting of the metasedimentary metamorphic sole alone cannot account for the diversity of field relations and geochemical compositions of granitoids exposed in the Oman mantle. We bring new pieces of evidence supporting the hypothesis that part of them derive from a mantle source affected by a deep and very high-temperature hydrothermal alteration according to experimental data and theoretical models (McCollom and Shock, 1998; Koepke *et al.*, 2004).

Petrography and field relations

According to the classification of Streckeisen (1976) the granitoids included in the present study range in composition from tonalites-trondhjemites (plagiogranites) to granodiorites and granites *s. str.* (potassic granitoids). Granites *s. str.*, appear to be restricted to the northern part of the ophiolite, but occurrences of granodiorites are ubiquitous although their abundance decreases southward. In some areas, granitoids from different families can be associated within a single intrusion (Fig. 1).

Granitoids belonging to the potassic family are not of frequent occurrence in the Oman Ophiolite, apart from the Khawr Fakkan area, where they are exceptionally abundant (Alleman and Peters, 1972; Cox *et al.*, 1999), only a dozen of occurrences have been documented (Lippard *et al.*, 1986; Beurrier, 1987; Python and Ceuleneer, 2003). They range in volume and shape from small lense-shaped pods to swarms of metre-thick dykes.

A main result of our survey is that potassic granitoids are restricted to the mantle section of the ophiolite. All these granitoids have essentially dunitic, more rarely pyroxenitic or wehrlitic wall rocks (Fig. 1). Contact relationships between the potassic granitoids and their host are never clear cut. Dykes always show reactional features at the contacts, and the modal composition of their host peridotite is affected on distances of at least several decimetres away from the intrusion. The most common case is the development of dunitic wall rocks resulting from the preferential depletion in orthopyroxene of the host harzburgite. These relations are even more diffuse in the case of pods which may be surrounded by well developed dunitic walls «impregnated» with interstitial pargasitic amphiboles.

Mantle granitoids, whatever their lithological nature, are, as a rule, spatially associated to major fault zones. These fault zones present evidence for high temperature ductile deformation (mylonites). This is the case of the Muqbariah shear zone (MZ), in the Maqsad area, that is hundred metres thick and can be followed along tens of kilometres along strike (Beurrier, 1987; Amri *et al.*, 1996). There, and in other occurrences where the deformation is less developed, emplacement of the granitoids appear to be contemporaneous with the deformation event. Most of them are foliated and transposed into parallelism with the shear zones, but some individual dykes or lenses have escaped to deformation.

In contrast, plagiogranites occurring at the upper crustal are ubiquitous all along the Oman range, they form plugs of a few tens to hundred metres in size, and are localized at the transition between the isotropic gabbros and the sheeted dyke complex (Amri *et al.*, 1996).

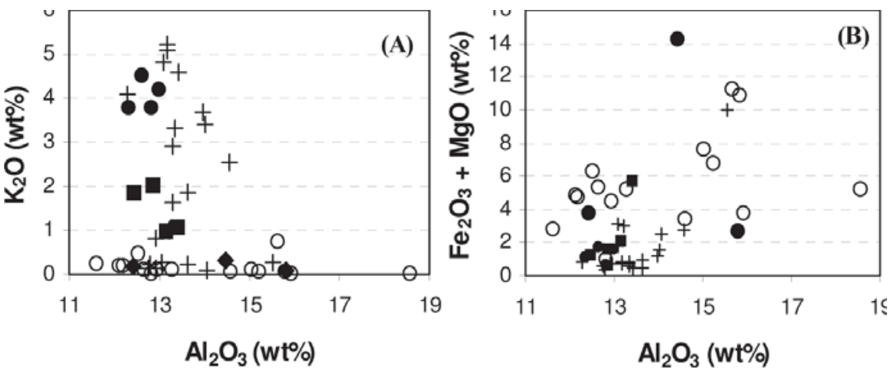

Fig. 2.- K_2O *vs.* Al_2O_3 diagram (A) and Fe_2O_3T+MgO *vs.* Al_2O_3 diagram (B) of the Oman granitoids compared with those coming from Khawr Fakkan area. Symbols for Oman granitoids: Dots = mantle granites; full squares = mantle granodiorites; full diamond = mantle plagiogranites; circles = crustal plagiogranites. Crosses = symbol for Khawr Fakkan granitoids.

Fig.2.- Diagrama K_2O vs. Al_2O_3 (A) y Fe_2O_3T+MgO vs. Al_2O_3 (B) de los granitoides de Omán comparados con los del área de Khawr Fakkan. Símbolos para los granitoides de Oman: Puntos = granitos mantélicos; cuadrados llenos = granodioritas mantélicas; rombos llenos = plagiogranitos mantélicos; circulos = plagiogranitos corticales. Cruces = símbolo de los grantoides de Khawr Fakkan.

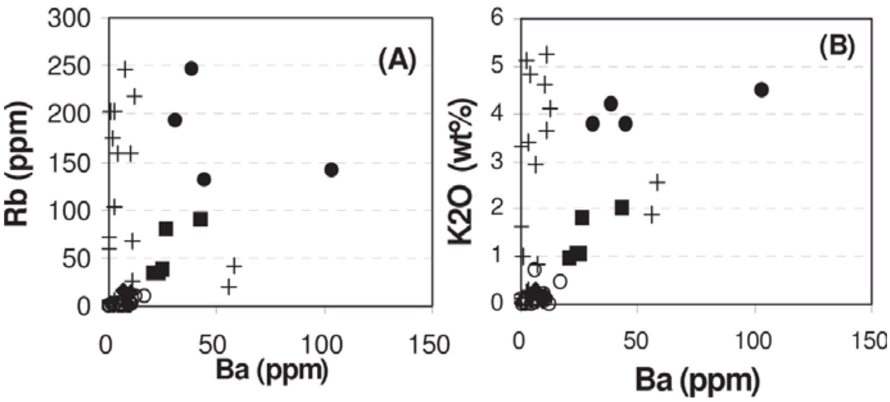

Fig. 3.- Rb *vs.* Ba (A) and K_2O *vs.* Ba (B) of the Oman granitoids compared with those from Khawr Fakkan area. Symbols as in Fig. 2.

Fig. 3.- Rb vs. Ba (A) y K_2O vs. Ba (B) de los granitoides de Oman comparados con los del área de Khawr Fakkan . Símbolos como en la Fig. 2.

Major and trace compositions

Major elements were analysed by XRF in (CRPG) Nancy. Trace elements data were obtained in Toulouse, by ICP-MS after fusion with lithium borates. The results of major, trace element and Sr-Nd analyses are available to the request.

In terms of major elements, our potassic granitoids (mantle granites and granodiorites) differ significantly from the Khawr Fakkan granitoids described by Cox *et al*. (1999). They are richer in silica and, for a given K_2O or Fe_2O_3+MgO content, are poorer in Al_2O_3 (Fig. 2). Another important fact is that Rb and K_2O content in our granites show a well correlation to Ba content which is not present in the Khawr Fakkan granitoids (Fig. 3). These alkalic elements were likely introduced in the mantle section, from which our granitoids derive, together with Ba-containing hydrothermal fluids.

An interesting observation is that the variations in the trace element composition of our samples are not only a function of the lithology but they depend also critically on the nature of their wall rock. This is mainly clear for REE concentrations normalized to chondrite values that present clearly different patterns in granitoids from mantle or from crustal outcrops (Fig. 4)

Crustal plagiogranites, originated from fractional crystallisation of MORB type magmas, have higher REE_N contents, and they show perfectly flat $HREE_N$ patterns, while their $LREE_N$ patterns decrease slightly towards $La_{N,}$ except in some more evolved samples. In contrast, the $HREE_N$ concentrations in mantle granitoids are globally lower than for crustal lithologies and they present a strong enrichment in $LREE_{N,}$ originating REE_N patterns typical of hydrothermally altered depleted mantle sources.

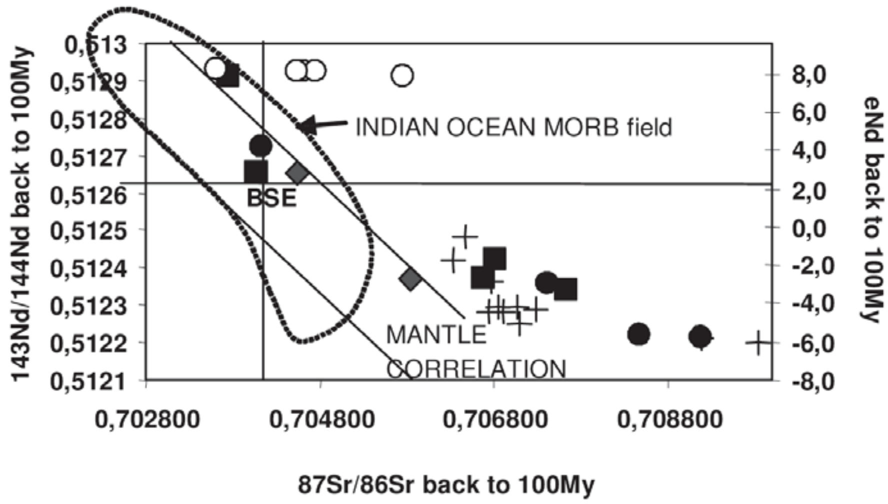

Fig. 5.- ^{143}Nd/ ^{144}Nd and εNd *vs.* ^{87}Sr/^{86}Sr diagram, with calculated ratios at 100My, for Oman granitoids, compared with those from Khawr Fakkan and the MORB field from Indian Ocean (dotted field). Symbols as in figure 2.

Fig. 5.- Diagrama ^{143}Nd/ ^{144}Nd y εNd vs. ^{87}Sr/^{86}Sr, con relaciones calculadas para 100My, de los granitoides de Oman, comparados con los de Khawr Fakkan y con el campo de los MORB del Océano Indico (Campo punteado). Símbolos como en la figura 2.

Sr and Nd isotopic composition

We performed Nd and Sr isotopic ratio measurements on a TRITON T1 mass spectrometer (Brest) in static mode.

In order to compare the isotopic signatures with the ones from actual MORBs from the Indian Ocean (Engel and Ficher, 1975), we have used the εNd notation, calculated at 100My. ^{87}Sr/^{86}Sr was also corrected from 100My ^{87}Rb decay (Fig. 5). Age of about 95-100My is considered as the age of the genesis of the Oman Ophiolite (Tilton *et al*., 1981).

Figure 5 shows: large isotopic variability within all the samples, some of our granitoid samples have upper- mantle like Nd and Sr isotopic composition, while other have been shifted to higher radiogenic Sr values. This element was most probably introduced in the mantle by hydrothermal fluids. For most of these granitoids we propose a simple two-component mixing model to explain their isotopic signature: depleted mantle source and hydrothermal fluids contribution. Finally, the isotopic signature of the granitoids with lower εNd and higher ^{87}Sr/^{86}Sr, might also be explained by a complementary input to the mantle source of previously subducted terrigenous sediments.

Discussion

The potassic granitoids described in this paper occur as small pods and dykes scattered in the mantle section of the Oman Ophiolite, frequently associated to ductile shear zones parallel to the azimuth of the former spreading center. A depleted mantle source is supported for them by several geochemical characteristics including: a) their lower Al_2O_3 content, and better correlation of K and Rb with Ba content, relative to granitoids derived from a metasedimentary source; b) a typical REE_N pattern with marked depletion in HREE, with respect to crustal plagiogranites, and enrichment in $LREE_{N,}$ indicative of a hydrothermally transformed mantle source, and c) their Nd-Sr isotopic signatures plotting in part along the mantle array, despite a probable increase of ^{87}Sr/^{86}Sr ratio due to incorporation of radiogenic Sr to the mantle source by hydrothermal fluids.

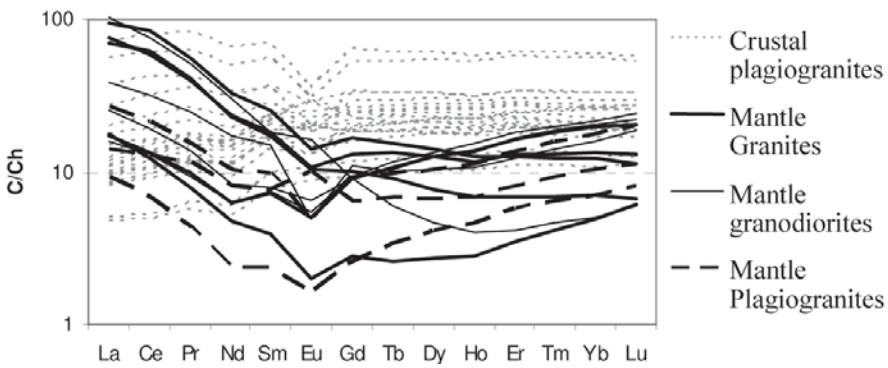

Fig. 4.- REE concentrations normalized to chondrite for the Oman granitoids, showing the marked pattern differences between crustal plagiogranites and mantle granitoids.

Fig. 4.- Concentraciones de REE de los granitoides de Oman normalizadas al condrito, mostrando las marcadas diferencias entre las tendencias de los plagiogranitos corticales y los granitoides del manto.

The source of silica for these granitoids is to be looked for in the incongruent melting of ortho-pyroxene induced by alkalic-rich aqueous fluids, as suggested by the systematic occurrence of dunitic wall rocks around these granitoids. The great scatter in the K_2O/SiO_2 ratio that characterizes our suite of hydrothermal granitoids (lithologies ranging from potassic granites *s. str.* to tonalites) reflects variations in the proportion of fluids and of silicic partial melts dependent on local conditions specific for the genesis of each individual pod.

Conclusions

All granitoids cropping out in the Oman Ophiolite mantle section, including the K-poor, plagiogranitic, end-members, contrast markedly in terms of trace element and isotopic compositions with the more classic crustal plagiogranites, which derive from MORB magmas (Figs. 4 and 5), pointing to different conditions of genesis and melt sources between them.

The formation of Al-poor granitoids in the shallow mantle can be viewed as the deepest and hotest (T° likely in the range of 800°C-900°C) expression of hydrothermal alteration of the oceanic lithosphere, making possible a subsequent, localized partial melting of the mantle source. The absence of potassic granitoids at crustal level may reflect the low probability for the rare silicic melts formed in the mantle of reaching the crust. Mantle ophiolitic granitoids should not be considered systematically as deriving from an «exotic» metasedimentary source, instead, in our opinion, some of them must represent a new «hydrothermal» type to be included among the various kinds of granitoids generated during oceanic accretion.

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