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Geodynamic evolution of the genetic setting of the pre-Alpine orthoderived rocks from the Mulhacen Complex (Betic Cordilleras, SE Spain)

Evolución geodinámica del ambiente de génesis de las rocas ortoderivadas prealpinas del Complejo del Mulhacén (Cordilleras Béticas, SE España)

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RESUMEN

Se ha realizado un estudio petrológico, geoquímico y geocronológico de las rocas ortoderivadas originadas entre el final de la orogenia Hercínica y el comienzo de la Alpina. Los resultados nos permiten deducir una evolución en el contexto geodinámico de génesis de los magmas originarios de estas rocas, que pasa desde: Un ambiente sin-colisional al final del ciclo Hercínico a un contexto de rifting en el Triásico, el cual evolucionó gradualmente hasta un ambiente de dorsal oceánica a lo largo del Jurásico.

Key words: *Orthogneisses, ophiolites, isotope geochemistry, Mulhacén Complex, Betic Cordillera.*

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Introduction and geological setting

The Mulhacén Complex forms part of the Internal Zone of the Betic Cordilleras (SE Spain) and crops out in the central-eastern part of this zone as a series of tectonic windows below the Alpujárride and Maláguide Complexes and above the Veleta Complex (Fig. 1). The Mulhacén Complex is formed by a pile of thrust nappes of continental crust origin (Caldera below and Sabinas above), composed of Paleozoic basement and Mesozoic cover series, between which a Jurassic-Cretaceous nappe of oceanic floor provenance is tectonically intercalated (Fig. 2). Overlying these ophiolitic and continental nappes occurs a discontinuous, volcano-sedimentary formation of continental and evaporitic origin, named the Soportújar Formation (Puga et al, 1984), which was deposited between the eo-Alpine (upper Cretaceous) and the meso-Alpine (Oligocene) metamorphic events (Puga *et al.*, 1996).

The aim of this paper is to elucidate the geodynamic evolution of the Mulhacén Complex between the end of the Hercynian Orogeny and the beginning of the Alpine Orogeny, based mainly on the genetic

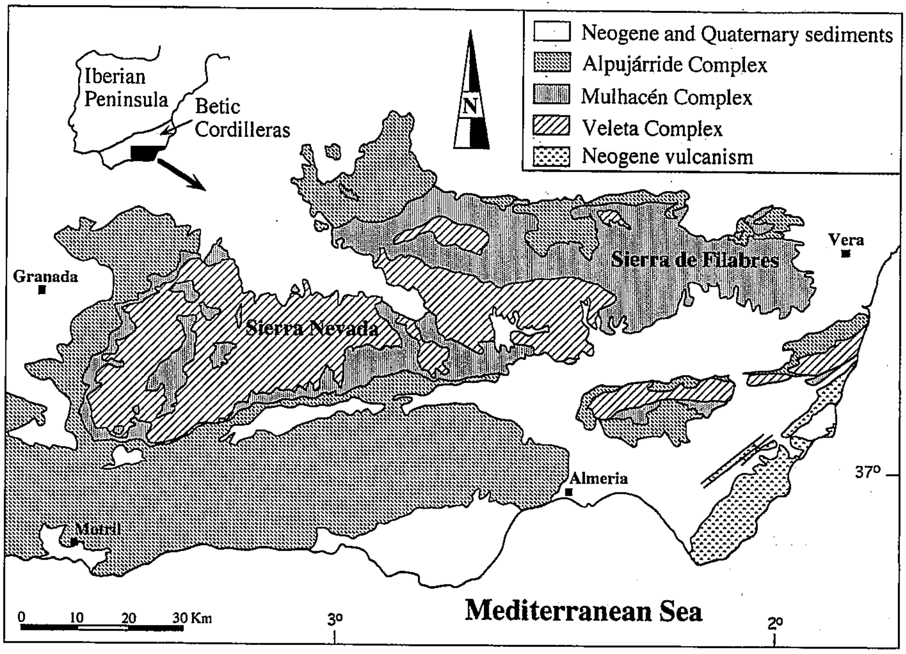

Fig. 1.- Geological sketch map of the central-eastern sector of the Betic Cordilleras showing the limits between the Veleta, Mulhacén and Alpujárride Complexes

Fig. 1.- Mapa geológico sintético del sector centro-oriental de las Cordilleras Béticas, mostrando los límites entre los Complejos del Veleta, Mulhacén y Alpujárride.

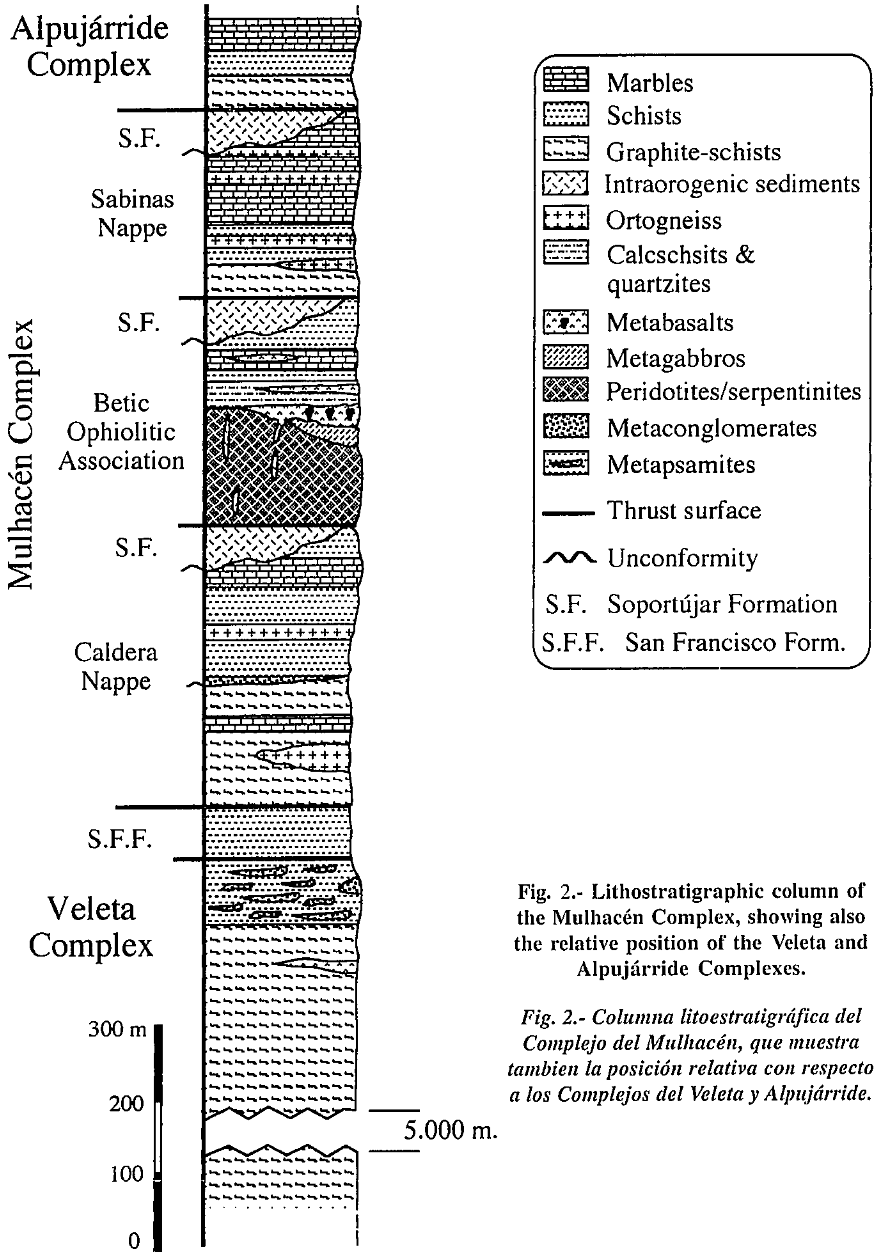

Fig. 2.- Lithostratigraphic column of the Mulhacén Complex, showing also the relative position of the Veleta and Alpujárride Complexes.

Fig. 2.- Columna litoestratigráfica del Complejo del Mulhacén, que muestra tambien la posición relativa con respecto a los Complejos del Veleta y Alpujárride.

environment of its orthoderived rocks, originated throughout this period, deduced from their Nd isotopic signature, their trace element composition and radiometric ages.

Petrology and geochemistry

Intercalated at different levels within the nappes of continental crust provenance (Caldera and Sabinas) appear igneous rocks of granitic s.l. composition, transformed into orthogneisses and locally to meta-granites as a consequence of the polyphase Alpine metamorphism. These orthoderived rocks mainly form either lens-shaped outcrops up to several kms long, derived from plutonic bodies intruded into the graphite-bearing micaschists of the basements (type 1), or banded orthogneisses derived from acidic to intermediate volcanic rocks, making up centimetric-to-metric layers intercalated mainly within the metasediments of the covers (type 2).

These two groups of rocks are also different from a geochemical point of view, as shown in Figs. 3 and 4. The meta-granites and orthogneisses corresponding to type 1 show a lower REE content, higher fractionation index $(La/Yb)_N$ and higher negative Europium anomaly than the orthogneisses from type 2 (Fig. 3). The Nd isotopic signature of these gneisses (e^{i}Nd = -6.5) indicates a clear crustal origin for the granitic magmas from type 1, and a crustal origin with variable mantel influence for those from type 2 (e^{i}Nd = -2 to +4). The relationship between Rb and Y+Nb in these rocks (Fig. 4) indicates that the tectonic setting in which the type 1 magmas were developed is syn-collisional, while the type 2 magmas would have formed in a within-plate environment.

The ophiolitic nappe is made up of all the elements of a dismembered ophiolitic sequence, known as the Betic Ophiolitic Association (Puga, 1990). It is composed of metres-to-km sized lenses of basic, ultramafic and sedimentary rocks, affected by ocean-floor and orogenic polyphasic metamorphism. In spite of the deformation and metamorphism that attain eclogite facies, the basic rocks partly retain their igneous textures (cumulitic, variolitic, porphyric) and the pillow and flow structures in the volcanic sequence (Puga *et al.*, 1989, 1995). Some meta-basalts also locally preserve a high-gradient brown amphibole filling millimetric veins, typical of ocean-floor metamorphism and generally overgrown by different types of amphiboles that developed during the orogenic metamorphism. The plutonic sequence is made up of meta-gabbros, with cumulitic levels, in which the igneous paragenesis (Ol, An ± Cpx) is locally preserved as relics in the variously amphibolitized eclogites (Morten *et al.*, 1987; Puga, 1990). The ultramafic sequence is formed by serpentinized lherzolites showing gradual transition towards secondary modal harzburgites. The latter are constituted by brown Ol and Opx (frequently with pseudo-spinifex textures), which developed during the orogenic HP metamorphism from serpentine formed in the original oceanic environment (Bodinier *et al.*, 1993). The ultramafic rocks contain abundant boudinated dykes of dolerites, with different degrees of transformation in rodingites, formed by grossularite and diopside, which were later locally transformed in the almandine-omphacite eclogitic paragenesis. The CaO-enrichment of the basic dykes, characterizing the rodingitization process, was coetaneous and complementary with the CaO-leaching originated by the Cpx-breakdown of their hosted lherzolites during the oceanic serpentinization (Puga *et al.*, 1993).

Fig. 5 shows the REE patterns, normalized to chondrites, of the different types of rocks forming part of the ophiolitic nappe. The similitude between the REE average patterns corresponding to basic rocks, constituting the volcanic and plutonic sequences, and those of the dolerite dykes forming part of the ultramafic sequence, in spite of the interelement mobilization due to the rodingitization process, suggests a common mantel source for their originating magmas. The N-MORB and V-shaped REE patterns of the serpentinized ultramafites might

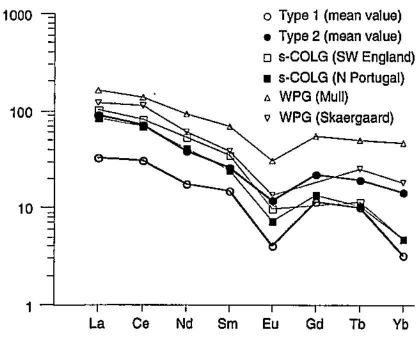

Fig. 3.- **Chondrite-normalized REE patterns of mean values of type 1 meta-granites and ortogneisses and type 2 ortogneisses, compared with granitoids from known geodynamic setting in:** *et al.,* **(1984) and Albuquerque, (1978).**

Fig. 3.- Diagrama de los valores medios de REE, normalizadas a condritos, de los metagranitos y ortogneises del tipo 1 y de los ortogneises del tipo 2, comparados con granitoides de situaciones geodinámicas conocidas in Pearce et al. (1984) y Albuquerque (1978).

correspond to the residual protoliths, after extraction of a reduced degree of melting that would have originated the associated LREE enriched basic rocks. The pyroxenite REE pattern corresponds to scarce centimetric veins with mantel Cpx relics contained in the serpentinites. Fig. 6 shows the geochemical affinity of the basic, variously rodingitized rocks from the ophiolitic nappe with E-MORB type magmas currently erupting in the mid-oceanic ridges, and their notable differences with basalts originated in other tectonic settings, such as continental crust within plate, island arcs or oceanic islands. Moreover, the Nd isotopic signature of these magmas, ranging from e^{i}Nd = +6.5 to +9.8, indicates a mantle origin with some crustal influence for the lower values and an oceanic-floor tectonic setting for the upper values. The lower e^{i}Nd values correspond to meta-gabbros containing Al-silicate xenocrysts resulting from the assimilation of basement micaschists (Puga *et al.,* 1989; Gomez-Pugnaire & Muñoz, 1990).

Radiometric ages

The type 1 orthogneisses from Sierra de Filabres have been dated by Sm/Nd to the upper Carboniferous (Nieto, 1996) and by Rb/Sr to the lower Permian (Andriessen *et al.,* 1991), while the type 2 from Sierra Nevada and Sierra de Filabres have been dated by Rb/Sr to the middle Triassic (Puga, 1976; Andriessen *et al.,* 1991).

The ophiolitic metagabbros from Sierra de Filabres, containing pseudomorphs after chiastolite xenocrysts indicative of crustal assimilation, have been dated by Ar/Ar to the Triassic-Jurassic boundary (Puga *et al.,* 1995). Other meta-gabbros and meta-basalts from Sierra de Filabres have been dated by Rb/Sr and K/Ar as middle and upper Jurassic (Hebeda *et al.,* 1980; Portugal *et al.,* 1988; Puga *et al.,* 1991, 1995), while the brown amphibole filling veins in metabasalts, formed during the oceanic-floor metamorphism, has been dated by Ar/Ar to the upper Jurassic (Puga *et al.,* 1991, 1995). These basic rocks, dated up to the upper Jurassic, are overlain by metasediments, from the ophiolitic sedimentary sequence, which locally contain remains of Cretaceous foraminefers (Tendero *et al.,* 1993).

Conclusions

The preceding geochronological and geochemical data corresponding to the orthoderived acidic, basic and ultramafic rocks, forming part of the different nappes

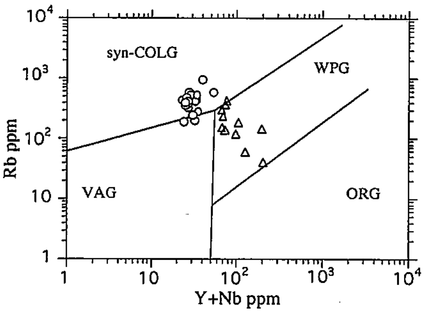

Fig. 4.- **Diagram Rb vs. Y+Nb for the geodynamic classification of granitoid rocks (Pearce et al, 1984). Symbols:** ***circles*** **= type 1 meta-granites and ortogneisses;** ***triangles*** **= type 2 ortogneisses**

Fig. 4.- DiagMma Rb vs. Y+Nb para la clasificación geodinámica de las rocas granitoides (Pearce et al., 1984). Símbolos: Círculos= metagranitos y ortogneises tipo 1; triangulos= ortogneises tipo 2.

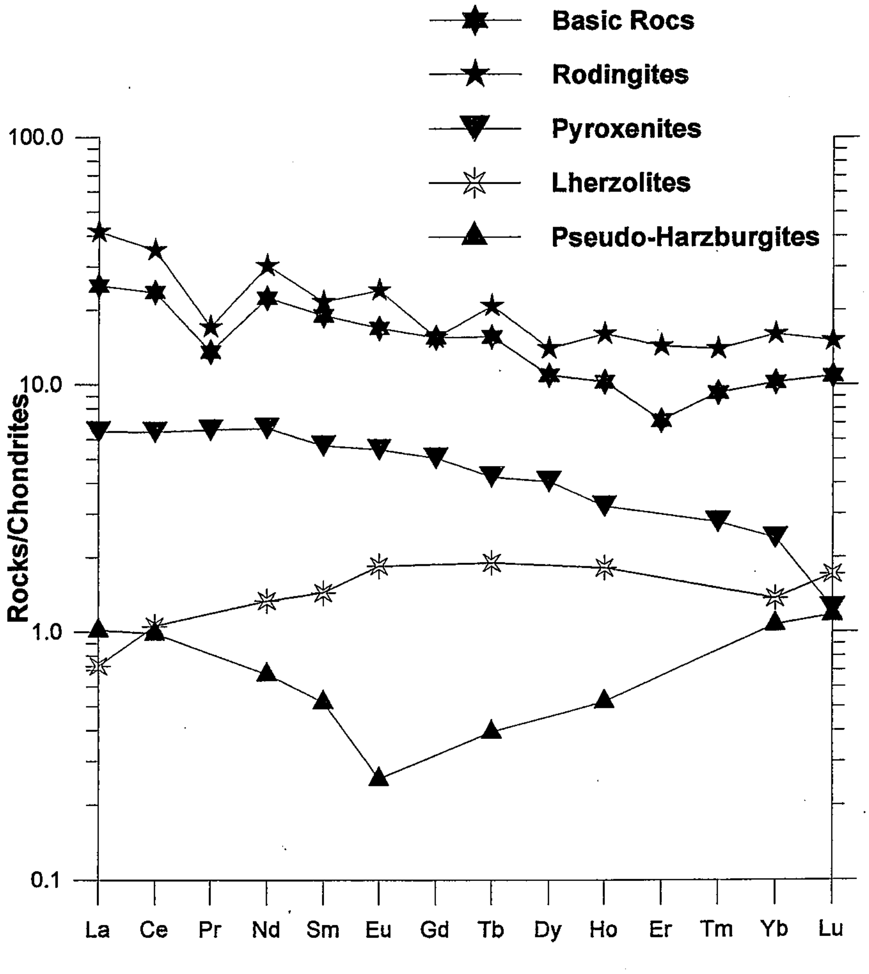

Fig. 5.- **Chondrite-normalized REE average patterns of basic rocks, rodingites, pyroxenites, lherzolites and pseudo-harzburgites forming the ophiolitic nappe.**

Fig. 5.- Valores medios de REE normalizados a condritos de rocas básicas, rodingitas, piroxenitas, lherzolitas y pseudo-harzburgitas, constituyentes del manto ofiolítico.

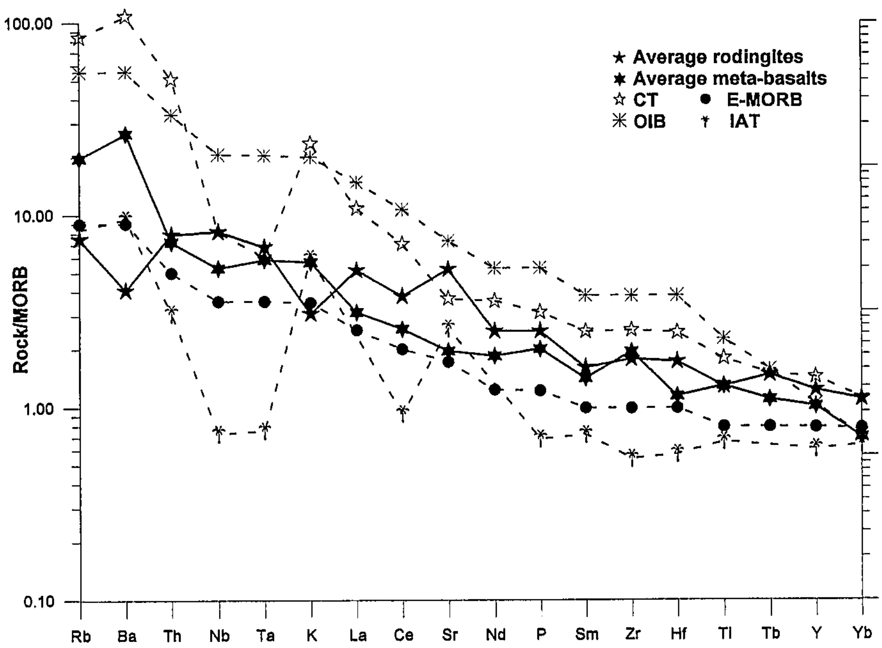

Fig. 6.- Spidergram of trace elements normalized to N-MORB for the average meta-basalts and rodingites, compared with continental tholeiites from Columbia River <u>in</u> Govindaraju (1984), E-MORB and OIB <u>in</u> Sun and McDonough (1989), and IAT <u>in</u> Pearce (1982).

Fig. 6.- Diagrama de elementos tMza normalizados a N-MORB para valores medios de metabasaltos y rodingitas, comparados con Toleitas continentales de Columbia River in Govindaraju (1984), E-MORB y OIB in Sun y McDonough (1989), y con IAT in Pearce (1982).

constituting the Mulhacén Complex, allow us to deduce the following evolution in the geodynamic environment of their precursor magmas : a) Type 1 granitic magmas would have originated in a syn-collisional context at the end of the Hercynian Orogeny, while type 2 acidic vulcanism developed in a post-collisional within-plate environment, below an increasing influence of mantel material indicating crustal thinning preceding, or accompanying, a rifting tectonic setting during the Triassic. Some intrusive basic rocks dated to the Triassic-Jurassic boundary could have intruded into the thinned continental crust during the rifting environment, assimilating some of the pelitic rocks it passed through. Finally, the tectonic setting evolved throughout the Jurassic to a drifting environment, causing the accretion of the oceanic floor from which the basic and ultramafic rocks forming the ophiolitic nappe derive.

Acknowledgements

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