Tectonic setting of the Monte Castelo Gabbro (Ordenes Complex, NW Iberian Massif)

El gabbro de Monte Castelo (Complejo de Ordenes, NW del Macizo Ibérico): geoquímica y contexto tectónico.

P. Andonaegui [1], J. González del Tánago [1], R. Arenas [1], J. Abati[1], J. R. Martínez Catalán [2], M. Peinado [2] y F. Díaz García [3]

[1] Departamento de Petrología y Geoquímica, Universidad Complutense, 28040-Madrid, Spain.
[2] Departamento de Geología, Universidad de Salamanca, 37008-Salamanca, Spain.
[3] Departamento de Geología, Universidad de Oviedo, 33005-Oviedo, Spain.

RESUMEN

En el Complejo de Ordenes (NW del Macizo Ibérico) la unidad tectonoestratigráfica superior está constituida por una potente secuencia metasedimentaria (Serie de Ordenes), intruida por ortogneises y gabros. El Gabro de Monte Castelo se localiza en la parte inferior de la Serie de Ordenes, en él se han distinguido tres tipos composicionales: 1) gabronoritas olivínicas (Pl+Cpx+Opx+Ol +Hbl), 2) gabronoritas anfibólicas (Pl+Cpx+Opx+Hbl±Bt), y 3) gabronoritas biotíticas (Pl+Cpx+Opx+Bt). Las características geoquímicas, tanto de elementos mayores como trazas, indican que el Gabro de Monte Castelo es de carácter toleítico, con rasgos químicos que presentan afinidad con tipos toleíticos generados en arcos-islas. Por otro lado, los datos de geocronología de U-Pb indican que una parte de la evolución tectonotermal de la Serie de Ordenes tuvo lugar en el Cámbrico superior – Ordovicico inferior, y demuestran también que la intrusión del gabro de Monte Castelo (499±2 Ma, U-Pb en circones) fue seguida de un episodio metamórfico que alcanzó las facies de las granulitas (493 – 498 Ma, U-Pb en monacitas). Estos datos afianzan la hipótesis de la generación del gabro en una zona de subducción insular , ya que un contexto acrecionario es el más propicio para integrar de forma contemporánea magmatismo, metamorfismo y fuerte deformación.

Key words: *arc-related gabbros, geochemistry, Variscan suture, Ordenes Complex, NW Iberian Massif.*

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Introduction

The Ordenes Complex is the largest of the allochthonous complexes containing the Variscan suture in the NW of the Iberian Massif. Its uppermost tectonostratigraphic unit is an intricate lithological ensemble located in the hangingwall to the suture, and overlying ophiolitic units. It consists of a thick metasedimentary sequence, the Ordenes Series, intruded by granitoids and gabbros, and affected by low to high-grade metamorphism of the intermediate-pressure (IP) type. The structural position of this element suggests it is a terrane which collided in Devonian times to develop the Variscan belt, during the closure of the Rheic ocean (Martínez Catalán et al., 1997). The arc option for the upper allochthonous units has been mainly based on the terrigenous, flyschoid character of the Ordenes Series, and on the existence of an important Paleozoic bimodal magmatism, but these criteria fit equally well the outer part of a stable continental margin. New U-Pb data have confirmed a magmatic and metamorphic event close to the Cambrian-Ordovician boundary (493-500 Ma; Abati et al., 1999). The new data furnish the age of the mafic and felsic magmatism (large bodies of metagabbros and granitic orthogneisses), and also the chronology of an early event with penetrative deformation and intermediate-pressure metamorphism which reached the granulite facies in the lower parts of the Ordenes Series. These data support the arc option, because an accretionary setting appears as the more significative possibility to integrate the nearly contemporary magmatism, metamorphism and strong deformation.

In an attempt to fill the lack of reliable geochemical data for IP unit, this paper focus on the geochemistry and petrologic characteristics of the Monte Castelo Gabbro, the largest of the Gabbro bodies intrusive in the Ordenes Series . The ensemble of data obtained in this gabbro will be used to discuss the tectonic setting of the magmatism, as a key point to clarify the origin and Paleozoic evolution of the upper colliding element in the European Variscan Belt.

Field and mineralogical aspects of the monte castelo gabbro

The large, rounded, Monte Castelo Gabbro outcrops in the western part of the Ordenes Complex, intruded into the lowermost exposed section of the Ordenes Series (Fig. 1). This is a massive metagabbronorite, fine to medium grained, with variable textures from granular to intergranular and ophitic; most of the gabbro has been preserved from deformation. There, the igneous mineral assemblages consist of plagioclase, clinopyroxene, orthopyroxene, olivine, amphibole and biotite, with ilmenite, sphene, spinel and zircon as possible accessory minerals; quartz rarely appears as a primary mineral. Pegmatoid veins constituted by plagioclase, pyroxene, amphi-

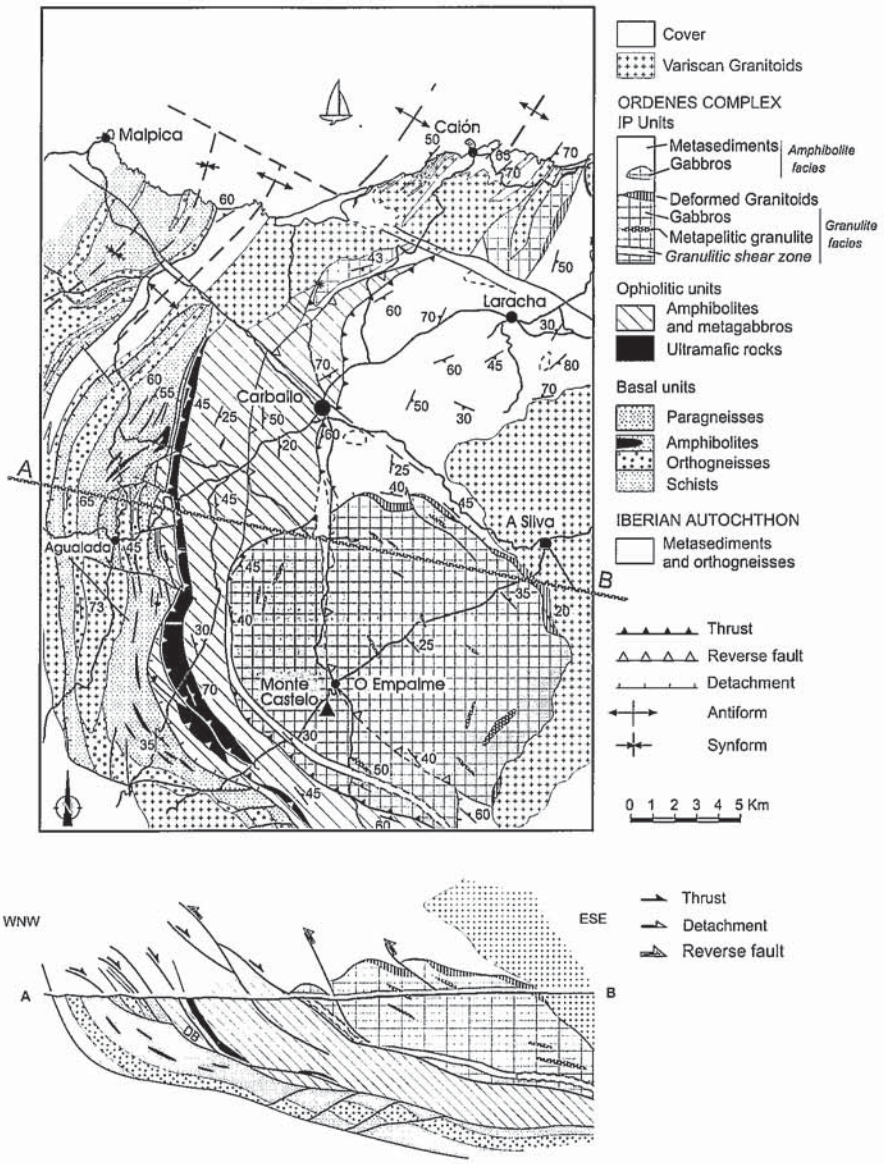

Fig. 1.- Geological map and cross-section of the NW sector of the Ordenes Complex showing the structural position of the Monte Castelo Gabbro.

Fig. 1.- Mapa y corte geológico del sector NW del Complejo de Ordenes en los que se muestra la posición estructural del Gabro de Monte Castelo.

bole, minor ilmenite and occasional quartz are rather common. The firts minerals to crystallize were olivine and plagioclase followed by piroxenes, cumulate types with plagioclase and olivine as cumulus phases have been occasionally observed.

Three major compositional types have been distinguished in the Monte Castelo Gabbro: 1) olivine gabbronorites (Pl+Cpx+Opx+Ol+Hbl); 2) amphibole gabbronorites (Pl+Cpx+Opx+Hbl±Bt); 3) biotite gabbronorites (Pl + Cpx + Opx + Bt). The samples with olivine can content up to 12.4% of this mineral, whereas the biotite content does not exceed 4.1%; the proportion of amphibole can be occasionally high, but generally is lower than 10-12%. Clinopyroxene values range from 14.3 to 30.9%, whereas those of orthopyroxene range between 2.1 and 13.2%. A very limited presence of quartz (< 1%) was detected in two of the counted samples.

Petrography and mineral chemistry

Plagioclase is the dominant mineral in all the gabbro types, reaching the highest modal content in the biotite gabbronorites (64.8% – 51.6% modal). Hypidiomorphic tabular crystals with polysynthetic twinning and weak optic zoning are the more common form. The analyzed plagioclases range in composition from An_{51} to An_{74}, with very low orthoclase content (< 2 mol%). Highest An contents were observed in the olivine gabbronorites (up to 74 mol%), while the biotite gabbronorites show the lowest An values (average An content of 52 mol%). Plagioclase crystals generally exhibit a continuous normal zoning, usually not very pronounced, although some analysed crystals show discontinuous zoning characterized by middle areas with the highest An content.

A similar modal content in **clinopyroxene** characterizes the three gabbronorite types. Clinopyroxene crystals exhibit an interstitial character, with frequent exsolutions of orthopyroxene parallel or oblique to the exfoliation. Marginal or symplectitic replacement by brown hornblende or by secondary blue-green amphiboles is a common feature. According to the classification of Morimoto (1988), the analyzed clinopyroxenes are diopsides or augites, with a rather high $Mg/(Mg+Fe^{2+})$ (MF) ratio (MF = 0.76–0.81). The MF ratio in clinopyroxenes is higher than in orthopyroxenes with a positive correlation between both, wich can be considered indicative of an early crystallization of the monoclinic pyroxenes.

Modal contents in **orthopyroxene** are rather variable, but significantly lower than those of clinopyroxene. Orthopyroxene crystals show an interstitial character; in the olivine gabbronorites it is also characteristic the presence of a generation of fine orthopyroxene crystals surrounding the olivine grains. All the analyzed orthopyroxenes in the Monte Castelo Gabbro are enstatites (En = 58-77 mol%;), with MF ratios slightly lower than clinopyroxenes (MF = 0.59–0.77).

A relatively low **olivine** content characterizes the olivine gabbronorites. Fresh and undeformed gabbros show hypidiomorphic olivine crystals, only replaced by opaque minerals in fracture zones and brown amphiboles in the rim areas. The composition of the analyzed olivines ranges between Fo = 56-73 mol%. Their MF values is lower than in clinopyroxenes and show a clear positive correlation with that of the orthopyroxenes.

Two types of **amphiboles** have been found in the Monte Castelo Gabbro: 1) primary large and hypidiomorphic brown amphiboles; 2) secondary blue-green amphiboles growing after the ig-

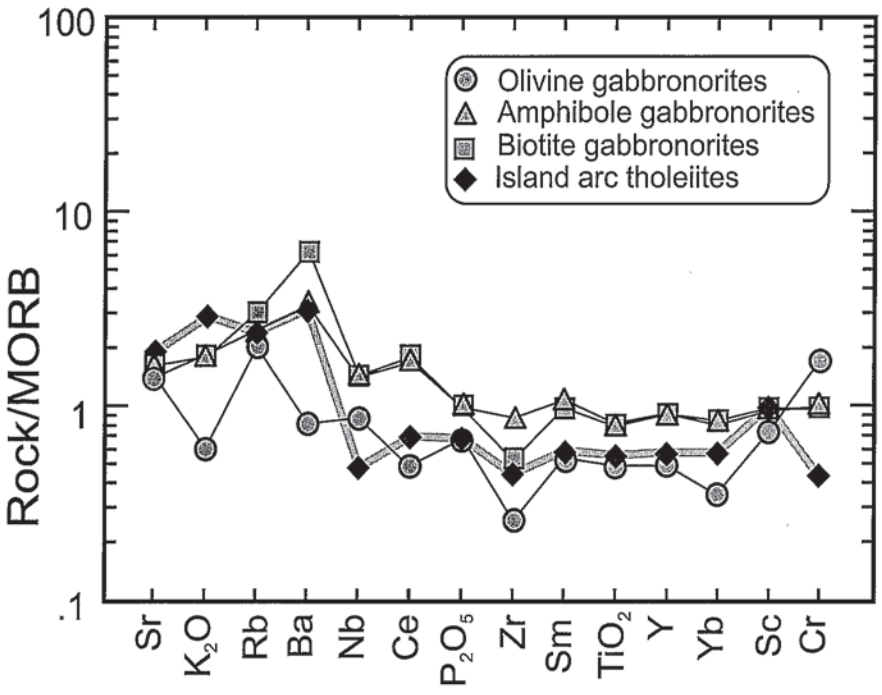

Fig. 2.- N-MORB normalized multi-element diagram. The composition of the gabbroic rocks of the Monte Castelo massif is also compared with tholeiitic basalt type generated in island arc setting.

Fig. 2.- Diagrama normalizado a N-MORB. Se compara la composición de los gabros de Monte Castelo con tipos basálticos generados en arco-islas.

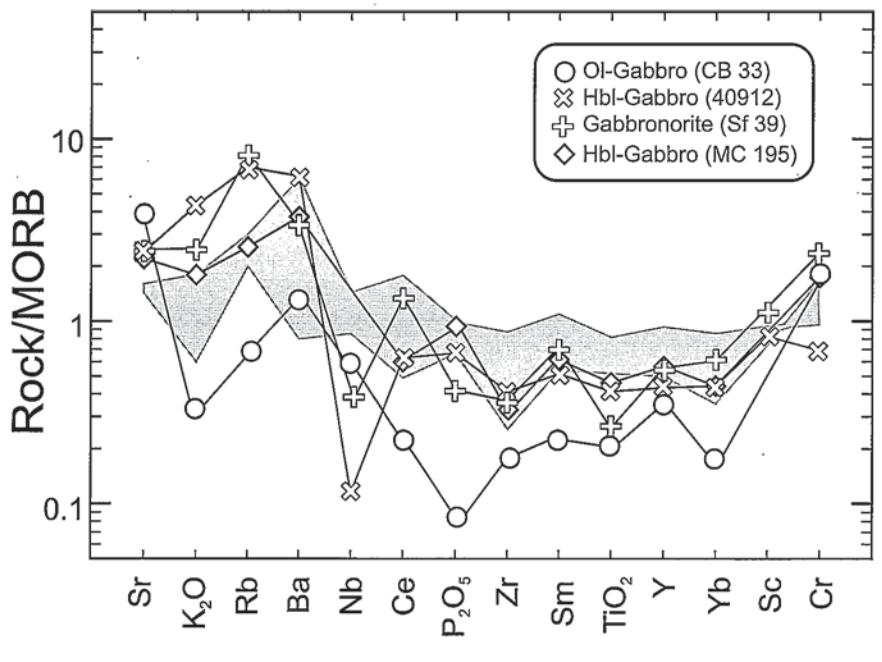

Fig. 3.- N-MORB multi-element diagram showing the composition of the Monte Castelo gabbroic types (shaded area), and other gabbroic rocks generated in magmatic arc setting. Comparative samples O = CB33 in Lucassen and Franz (1994); X = 40912 in Whalen (1985); + = Sf39 in De Bari (1994); à= MC195 in Lapierre et al. (1992) .

Fig. 3.- Diagrama normalizado a N-MORB en el que se compara la composición de los tipos gabroicos de Monte Castelo (zona sombreada), con otras rocas gabroideas generadas en arcos-islas. Muestras utilizadas para la comparación: O = CB33 en Lucassen and Franz (1994); X = 40912 en Whalen (1985); + = Sf39 en De Bari (1994); à= MC195 en Lapierre et al. (1992) .

neous mafic minerals. Brown amphiboles exhibit an interstitial character in relation to the plagioclase crystals, and generally sorrounded other mafic minerals. Its modal content is rather variable, ranging from 31 % to less than 1 % in olivine gabbronorites and hornblende gabbronorites. The compositions of the analyzed brown amphiboles are characteristic of pargasites with high TiO_2 contents (TiO_2 = 2.5-4.1 %), which is considered indicative of a high temperature of crystallization (Otten, 1984; Heltz, 1973). The MF ratio ranges between 0.63 and 0.74, with higher values in olivine gabbronorites. The secondary blue-green amphiboles are classified as tremolites and actinolites with low TiO_2 contents, and rather high FeO, MgO and Al_2O_3 values.

Biotite gabbronorites and hornblende gabbronorites are characterized by accessory **biotite** contents. Biotite crystals exhibit a tabular hypidiomorphic shape. Their chemical composition is characterized by a solid solution between the three major end-members phlogopite, Fe-eastonite and Ti-biotite. The high TiO_2 contents (TiO_2 up to 5.4 %; Ti-biotite up to 30 mol%) are indicative of elevated temperatures of crystallization, probably similar to those of the brown amphiboles.

Accesory Fe-Ti oxides are anhedral **ilmenites** with textural relationships indicatives of a previous to simultaneous crystallization in relation to plagioclase. The analyzed Fe-Ti oxides show high contents in ilmenite end-member (Ilm = 86-94 mol%), with minor but significative values of rutile and pyrophanite molecules.

Geochemistry and tectonic setting

The analyzed gabbronorites show a rather limited compositional range in SiO_2 (46.42-52.21 %), Al_2O_3 (15.81-19.25 %), CaO (8.10-12.69 %), Na_2O (1.73-3.04 %), K_2O (0.01-0.32 %) and TiO_2 (0.44-1.93 %), and more variable contents in MgO (6.60-12.14 %) and FeO (2.87-8.91 %). The magnesium number (M number = 100 x MgO/(MgO+FeO_t)) ranges from 31 to 54. According with their very low K_2O contents, the analyzed gabbronorites show a tholeiitic affinity in the SiO_2-K_2O diagram of Peccerillo and Taylor (1976). This general pattern of the Monte Castelo massif is also confirmed in the AFM diagram, where all the samples plot in the tholeiitic field of Irvine and Baragar (1971).

In the three types of gabbronorites occurring in the Monte Castelo massif,

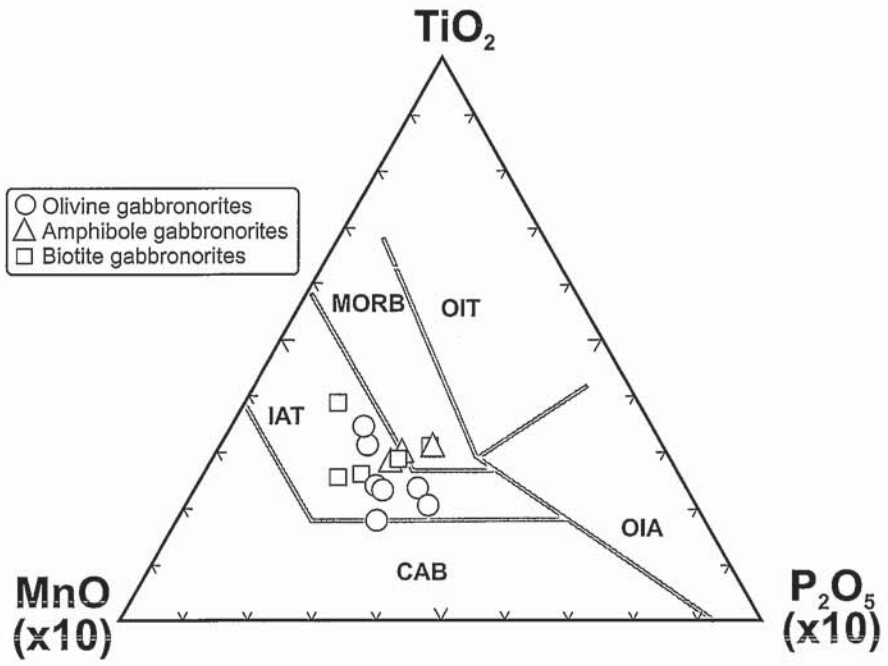

Fig. 4.- TiO_2- MnO(x10)- P_2O_5(x10) plot (Mullen, 1983). The diagram shows fields for ocean ridge basalts (MORB), ocean-island tholeiites (OIT), ocean-island basalts (OIA), island-arc tholeiites (IAT) and calc-alkaline basalts (CAB).

Fig. 4.- Diagrarma TiO_2- MnO(x10)- P_2O_5(x10) (Mullen, 1983), en él se muestran los campos en los que se proyectan: basaltos de dorsal oceánica (MORB), toleitas de islas oceánicas (OIT), basaltos de islas oceánicas (OIA), toleitas de arco-islas (IAT) y basaltos calco-alcalinos (CAB).

the average values of some elements with significative petrogenetic interest have been normalized to the composition of a characteristic N-MORB (Pearce, 1982). The diagrams show a general pattern with low enrichment in LIL elements (Sr, K, Rb, Ba), as well as values close to one or slightly depleted in HFS and REE. The olivine gabbronorites exhibit a general depletion in Zr, Ti and Y, which has been considered characteristic of many tholeiitic magmas generated in island arcs (Wilson, 1989; Lapierre et al., 1992). The composition of the gabbronorites has been also compared with the average values proposed by Pearce (1982) for the island-arc tholeiites, This comparision shows that the compositions of the Monte Castelo Gabbronorites are finally very similar to those of the island arc tholeiites. (Fig.2)

The Monte Castelo Gabbronorites have been also compared (Fig.3) with other gabbroic rocks, generated either in an island-arc (Whalen, 1985) or in more general magmatic-arc settings (Lapierre et al., 1992, De Bari, 1994; Lucassen and Franz, 1994). The compositions of Monte Castelo Gabbronorites are very similar to those reported from differents magmatic-arc settings, showing multi-element diagrams with comparable general patterns and anomalies. Specially, Monte Castelo Gabbronorites are most closely resemble the magmatic series of Guanajuato (Lapierre et al., 1992) because both rocks series have Nb contents abnormally high for arc tholeiites (in the range of N-MORB). Such high Nb contents have usually explained by being related to immature stages of arc development.

Finally, in order to expand the comparison of Monte Castelo Gabbronorites with other basaltic compositions generated in different tectonic settings, all analyzed samples were also plotted using the $MnO\text{-}TiO_2\text{-}P_2O_5$ diagram of Mullen (1983) (Fig. 4). This plot is effective in discriminating between most of the basaltic types, with the important exception of within-plate basalts, which in any case are basaltic compositions, which are very different from the studied gabbronorites. The majority of analyzed samples plot in the island arc tholeiites field, which confirms the tectonic setting deduced for the Monte Castelo Gabbronorites based on multi-element diagrams.

Conclusion

According to their petrographic characteristics, mineralogical composition and general geochemical pattern, we conclude that the Monte Castelo Gabbronorites show a close similarity with tholeiitic basalts generated in island arc settings. Variations of major elements suggest that the gabbronorites were originated from a magma with the composition of a tholeiitic basalt, through a process of fractional crystallization where olivine, orthopyroxene, clinopyroxene and plagioclase were the more important developed phases. The olivine gabbronorites are the less evolved lithologies (higher contents in MgO and Cr), whereas the amphibolic and biotitic gabbronorites represent progressively more differentiated compositional types. Similar variations in major, trace and REE elements to those characteristic of the Monte Castelo Gabbronorites have been also reported in other gabbroic rocks assigned to island arc-settings; this is the case of the gabbros of the Sierra de Fiambalá, in Argentina (De Bari, 1994), of those studied in the Guanajuato region, in Mexico (Lapierre et al., 1992), and also of the gabbroic rocks outcropping in the northern cordillera of Chile (Lucassen and Franz, 1994), the latter generated in an extensional back-arc setting.

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