NEW ASPECTS AND CONSIDERATIONS ON THE ASSIMILATION OF CORDIERITE-BEARING ROCKS

J.M. Ugidos (*)

ABSTRACT

The presence of cordieritites (rocks with high percentages of cordierite and probably restitic in origin) as enclaves in cordierite-bearing biotite granitic rocks is an important point in favour of a xenogenic origin for this mineral and a basic feature in an alternative hypothesis of the interpretation of cordierite-bearing granites as of S (s.s.) origin. It is concluded that the assimilation of restitic rocks (cordieritites and possible similar rocks: garnet cordieritites and garnetites) may account for the presence of these minerals (and also of andalusite and sillimanite) in igneous rocks (intrusives and equivalent effusives, originally independent of anatectic processes affecting metasedimentary rocks) that thus acquire an S appearance.

Key words: Biotite granites, Cordierite-bearing granites, Cordieritites, Assimilation.

RESUMEN

La presencia de cordieritas (rocas con elevados porcentajes de cordierita y de probable origen restítico) en forma de enclaves en granitos biotíticos cordieríticos constituye un importante dato en favor del origen xenógeno de dicho mineral y es un aspecto básico en una hipótesis alternativa a la interpretación que tipifica como de origen S (s.s.) a granitos con cordierita. Se concluye que la asimilación de rocas restíticas (cordieritas y posibles rocas similares: cordieritas granatíferas y granatitas) puede explicar la presencia de estos minerales (también de andalucita y sillimanita) en rocas ígneas (intrusivas y equivalentes efusivos, originalmente independientes de procesos anatécticos que afectan a materiales metasedimentarios) que adquieren así apariencia S.

Palabras clave: Granitos biotíticos, Granitos cordieríticos, Cordieritas, Asimilación.

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INTRODUCTION

The significance of prismatic cordierite in granitic rocks is a much debated aspect and of particular importance in the interpretation of an S or I origin (Chappell and White, 1974) for igneous rocks bearing this mineral. Generally, the commonest interpretation is that favouring both a magmatic origin for cordierite and an as S (s.str.) character for the granites (see White et al., 1986 for an overview of the problem). An alternative point of view has been formulated for many hercynian granites in the Iberian Massif (see discussion in Ugidos, 1985a, b, 1986) mainly based on the study of associated high grade metamorphic rocks.

In the author's opinion, the difference between the different interpretations to a large extent arises as a consequence of the different types of host rocks in the areas or regions under consideration. Accordingly, if intrusion levels of the granitic rocks are at low or medium grade metamorphism and the granites are very differentiated, the interpretation given is an mentioned above: a magmatic (or residual) origin for the cordierite and an S (s.str.) character for the granites. However, this is not the more general situation and in levels of medium to high metamorphic grade the host rocks show very different characteristics that are highly suggestive of the second interpretation based on the presence of the hornfels of pyroxene hornfels facies (Cord + Kfeldspar ± And ±

(*) Departamento de Geología, Facultad de Ciencias. 37008 Salamanca (Spain).

Sill), migmatitic hornfelses and migmatites surrounding intrusive granites (Ugidos, ops. cit.).

In previous works reference has been made to the possibility of late granites of the Iberian Massif having acquired an S mineralogy from the assimilation of restites left behind by the migration of other earlier granitic melts (Ugidos, 1985b, 1986).

New data regarding these rocks obtained from drill cores have allowed us to broaden our knowledge and to describe them as cordieritites, with the double petrographic and genetic meaning proposed by Gordillo (1979) (see also Schreyer *et al.*, 1979): a high content in cordierite and a restitic nature. These kinds of rocks are of special importance in the interpretation of many of the cordieritic rocks in the Iberian Massif and elsewhere.

GEOLOGICAL CONTEXT OF THE CORDIERITITES

The cordieritite outcrop, discovered by García de Figuerola and Franco, is completely embedded in porphyritic biotite granites, although observational difficulties have hindered precision concerning its real extension and relationship with granite. The outcrop is close to the contact between biotite granites and leucogranites (see geological map of García de Figuerola and Franco *in* Vargas *et al.*, 1982) and both are within a medium-high grade metamorphic context in which hornfelses of pyroxene hornfels facies, gneisses and migmatites are frequent (García de Figuerola and Franco 1975; García de Figuerola *et al.*, 1983). The vertical extension of the cordieritites has not been determined but from the drill core information the outcrop is thought to be continuous down to at least 10.5 m, the maximum depth reached, without cutting the lower contact with the granite. All drill cores also point to a very homogeneous nature for the cordieritites. On the other hand, in the area surrounding the cordieritites the granite shows a great abundance of cordierite prisms similar to those in the cordieritite and relatively abundant muscovite. This is the only locality where the granite bears cordierite and appreciable amounts of muscovite, although in neighbouring areas cordierite and muscovite-bearing biotite granites can be found, together with leucogranites bordering much wider extensions of biotite and amphibole-bearing biotite granites (Franco, 1980; Hernández *et al.*, 1982; Fernández *et al.*, 1982).

Close to the cordieritites, a split granite tor (1,5 maximum diameter) shows numerous cordierite prisms on its surface while inside it is lacking in this mineral. This structure is similar to those formed by schlieren associated with enclaves in granites but in this case the schlieren-like structure is developed outside the enclave, which points to the fluidity of the rock (*in* Didier, 1973).

The author interprets this structure as the result of disgregation of the cordieritite enclave and of the differential displacement of the cordierite prisms (disposed along the flow lines) due to the rate of shear strain produced in the magma upon entering into contact with the enclave. At the same time the sinking of the cordieritite block created flow patterns with a circular trend (as is the general case of a solid moving through a fluid) that were recorded by the cordierite as mentioned. The process implies the absence or scarcity of phenocrysts in the magma (high fluidity); i.e., the composition of the granite at some points where no interaction with the enclave can be appreciated is virtually that of the melt.

The disgregation of the cordieritite into independent crystals is favoured by the increase in volume and differential dilations of each crystal (thermal anisotropy of the minerals) owing to heating by the magma. Other factors, such as the presence of restitic felsic minerals may have contributed to the process by interstitial melting or dissolution.

The biotite granite in which the cordieritite enclave is found is associated with biotite and amphibole-bearing biotite granites that generally show I-type characteristics (absence of aluminous minerals and of relicts of migmatites; abundance of basic and microgranular enclaves; presence of amphibole, allanite and sphene).

PETROGRAPHIC CHARACTERISTICS

The cordieritites have a cordierite content in the 60-80% range and variable proportions of quartz, andalusite, tourmaline and laminae of chloritized biotite. Such cordieritites are isotropic rocks without relicts of a possible earlier foliation.

— Cordierite: totally pinitized, as pseudomorphs with the original euhedral-subhedral configuration and sizes ranging from a few milimeters to a maximum of 3.5-4 centimeters.

— Quartz: predominantly in the form of irregular interstitial crystals among the other minerals.

— Andalusite: euhedral-subhedral; sizes of 5-7 mm are reached. It does not show pleochroism and inclusions are rare. Alteration to sericite wholly or partially pseudomorphizing the original crystals is a common finding.

— Muscovite and aggregates of muscovite + quartz: their textural relationships point to a secondary origin, although it has not been possible to establish from what mineral(s) they come from.

— Apatite: generally equigranular crystals, euhedral-subhedral, with sizes ranging around 0.2 mm, frequently included in the previous minerals.

— Tourmaline in fibrous-radial aggregates; chlorite pseudomorphizing biotite and few opaque minerals are the commonest accessories. The impregnation of metallic oxides disperse or concentrated in microfissures is also of certain importance.

The original mineral association prior to the alteration processes, probably due to interaction with fluids from the host granite, is impossible to establish but in any case the presence of prismatic cordierite and andalusite and, in particular, the high content in the former is of great interest.

The characteristics of the cordieritites are similar to those reported by Gordillo in Argentina (op. cit., see also Schreyer *et al.,* op. cit.) with high cordierite contents (up to 70-90%), interpreted as being restitic. The volume of these cordieritites is much greater (up to 10 m thick and hundreds of meters of lateral extension); the cordierite is unaltered, the rocks show sillimanite instead of andalusite and, like those studied in the present paper, are related to cordierite —bearing biotitic granites (Gordillo, *op. cit.;* Schreyer *et al., op. cit.*). The similarity between both cases is noteworthy and the restitic interpretation also seems the most appropriate for the present case, especially when taking into account the nearby presence of leucogranites (in turn with small percentages of cordierite and andalusite); (Franco, *op. cit.*). Leucogranites and cordieritites may thus represent melt and residue, respectively, developed from metasedimentary rocks relatively rich in a pelitic component that were subject to anatectic conditions.

DISCUSSION AND INFERENCES

The data point to interaction between a fluid granitic magma and a macroenclave of cordieritite resulting in the incorporation of cordierite prisms to the first step in the development of some schlieren-like structures. This implies a low degree of crystallization in the magma and hence a long later history until complete solidification occurred during which cordierite and andalusite remained in disequilibrium in the granitic magma. Accordingly, these minerals could have been included in orthomagmatic mineral phases and/or may have reacted with the magma during its crystallization. In the first case, the textural appearance is also orthomagmatic (andalusite included in plagioclase, for example). In the second, the possibility exists of chemical zoning of the cordierite, of dissolution of Al and Fe+Mg and of magmatic crystallization of muscovite (partly depending on aH_2O) with a strong celadonitic component at low pressures (Anderson and Rowley, 1981). Pseudoperitectic reactions between cordierite/ andalusite and the magma together with reactions in subsolidus conditions can finally produce secondary pinite and muscovite as a result of the increase in aH_2O in the final crystallization stages.

The result of these processes was the production of biotite-muscovite granites bearing cordierite (pinite) that were present not only in the outcrop under discussion but also in nearby areas where a gradual transition between biotite granites and cordierite-bearing granites rich in restitic enclaves and with a high content in normative corundum have been observed (2%, Franco, *op. cit.*).

Evidently, an assimilation process is not the only possibility in the genesis of cordierite-bearing granites. However, in the case of those studied here the biotitic and biotitic-amphibolic granites have low normative corundum contents (0 to $< 1\%$) and show no correlation between SiO_2-MgO+FeO, Ca-FeO+MgO, Al_2O_3-FeO+MgO (chemical data from Franco, *op. cit.*), suggesting that the cordierite is not the result of differentiation processes.

Low assimilation percentages of cordieritites have pronounced repercussions in the compositional characteristics (chemical and modal) of the resulting granites. Simple calculations show that an assimilation of 5% of cordieritite (60-80% of cordierite) leads to a relative increase of more than 2% in Al_2O_3 in the granite composition and adds 3-4% of modal cordierite to it. Accordingly, a granite magma of I origin drastically changes its original characteristics even if the assimilation percentage is a low as 5%, acquiring S-type characteristics. Another possible effect is the inhibition of amphibole crystallization in I-type magmas due to the excess of Al added.

The mechanism proposed to account for the structure defined by the cordierite prisms is evidently a particular case and its very nature restricts the presence of this mineral to the neighbourhood of the enclave or at least to its trajectory during sinking.

In the general case of magma-restitic host rock interaction, it seems logical to accept the presence of multiple enclaves, specially in the roof zone of the granite, whose sinking in the magma would leave behind numerous cordierite tails until total disgregation is reached or until the fluidity of the magma prevents sinking from continuing. The enclaves would not be expected to reach the same depth and in view of its isolated nature the case studied here probably corresponds to a large block sunken to a considerable depth.

If the number of blocks is large and they are situated close to each other, the creation of structures such as that mentioned above would be hindered by the complexity of the flow patterns produced by the set of enclaves and the dispersion of cordierite would therefore not adopt defined structures. The depth of the assimilation process to a large extent depends on the fluidity of the magma and on the volume of the enclave. In this sense, one would expect to find chemical and modal variations (depending on erosion) in a granite body that has undergone the process mentioned and also gradual transitions to facies in which the assimilation intensity has been less pronounced or null.

One problem that is very difficult to solve owing to the total alteration of the cordierite is to determine the PT conditions prevailing in the genesis of cordieritites. The presence of andalusite indicates low-pressure conditions but it is difficult to accept that cordierite + andalusite could represent the original restitic paragenesis left behind by granite melts. As far as the author is aware, no cases have been reported in which andalusite has such an origin. More probably, both minerals would have formed an earlier restitic paragenesis that was later modified by a thermal effect of the granitic intrusions. The following data are in favour of such an interpretation: abundance of relicts of Biot+Sill/ Fibr in the regional migmatitic structures and the transformation of this association into cordierite ± andalusite in rocks close to the contact with granitic bodies that intruded during metamorphic stages at lower pressure (Ugidos, 1985a). This interpretation dispenses with the problem of explaining the presence of andalusite as a restitic phase in an anatectic process.

The data provided here and those reported previously (Ugidos, 1985a, b, 1986) in most cases strongly suggest a non-magmatic origin for the cordierite and andalusite (specially in late granites with respect to syntectonic metamorphism) and that they were incorporated by assimilation to the granites (s.lat.) and their differentiation products (aplites, pegmatites, granites).

As mentioned in the introduction, White *et al.*, (*op. cit.*) hold the opposite point of view in their review on criteria concerning S granites considering among other aspects, that the presence of cordierite (accepted as being primary in the granitic magma) is an indication of a strongly peraluminous character of the magma and hence an S character of the granite presenting this mineral.

Regardless of whether a primary origin is possible or not, the findings point to the idea that it is not the only way in which a granite can acquire S mineralogy and is therefore not an inequivocal criterion for such an origin. It should be noted that the amount of other types of components (residual migmatitic structures, for example) may be very low or even absent (cordieritites are isotropic). In these cases, the disperse presence of cordierite and/or garnet, regardless of possible metamorphic structures and polymineral aggregates, is not a sufficiently meaningful criterion to interpret their origin as magmatic. Accordingly, the plotting of the granite composition with these characteristics in a primary filed of the AFM triangle might not be correct since it is based, or at least partially so, on the acceptance of the primary origin of the cordierite (see for example Clarke, 1981). The same kind of risk is inherent to the experimental use of natural compositions (cordierite-bearing) accepted as primary melts (see for example Clemens and Wall, 1981).

One of the classic difficulties in accepting quantitatively significant assimilation processes is that of the thermal contribution necessary to produce the digestion of the country rock. Although this difficulty can be considerably reduced depending on the temporal evolution of the metamorphism with respect to the possible intrusions from deep levels (Ugidos, 1986), there is no doubt that the assimilation of a restitic rock similar to cordieritite is a predominantly mechanical problem and hence the thermal problem would be minimum or even nonexistent.

Finally, it is of interest that the presence of cordieritites suggests, depending on the PTX conditions, the possible development of garnet cordieritites, garnetites and rocks with more complex mineral associations through the same sequence of processes. The assimilation of these rocks (restites with original mineralogies or modified later on) would give rise to other granite types whose origin is not necessarily S.

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REFERENCES

Chappell, B.W. and White, A.J.R. (1974): Two contrasting granite types. *Pacific Geol.,* 8, 173-174.

Clarke, D.B. (1981): The mineralogy of peraluminous granites: a review. *Can. Mineral.,* 19, 3-17.

Clemens, J.D. and Wall, V.J. (1981): Origin and crystallization of some peraluminous (S-type) granitic magmas. *Canad. Mineral.,* 19, 111-131.

Didier, J. (1973): Granites and their enclaves. *Developments in Petrology,* 3, 393 pp. Elsevier, Sci. Pub. Comp. Amsterdam.

Fernández, J., Olivé, A., Carreras, F., Hernández, A., Aguilar, M.J. and Capote, R. (1982): *Mapa Geológico de España. E.:1/50.000, 2.ª Serie. Hoja n.º 505 (15-20) Mirueña de los Infantes.* 77 págs. Inst. Geol. Min. España. Madrid.

Franco, M.P. (1980): *Estudio petrológico de las formaciones metamórficas y plutónicas al norte de la Depresión del Corneja-Amblés Sierra de Ávila.* Tesis Doct. Univ. Salamanca, 273 p.

García de Figuerola, L.C. and Franco, M.P. (1975): Las formaciones infraordovícicas y el borde de las granodioritas al este de Guijuelo (Salamanca). *Estudios Geol.,* 21, 487-500.

García de Figuerola, L.C., Franco, M.P. and Castro, A. (1983): Características petrológicas del complejo laminar pegmatoide (Serie del Álamo) de las provincias de Salamanca y Ávila. *Stvd. Geol. Salmant. Univ. Salamanca,* 19, 33-77.

Gordillo, C.E. (1979): Observaciones sobre la petrología de las rocas cordieríticas de la Sierra de Córdoba. *Bol. Acad. Nac. Ciencias Argentina,* 53, 3-44.

Hernández, A., Carreras, F., Fernández, J., Olivé, A., Aguilar, J.M. and Capote, R. (1982): *Mapa Geológico de España. E.:1/50.000, 2.ª Serie. Hoja n.º 506 (16-20). Cardeñosa.* 68 págs. Inst. Geol. Min. España. Madrid.

Schreyer, W., Gordillo, C.E. and Werding, G. (1979): A new sodian-beryllian cordierite from Soto, Argentina, and the relationship between distortion index, Be content, and state of hydration. *Contrib. Mineral. Petrol.,* 70, 421-428.

Ugidos, J.M. (in press.): Características del metamorfismo de baja presión en zonas centro-occidentales españolas y su significado en relación con minerales alumínicos en los granitos. *IX Reun. Geol. Oeste Penins.* Porto.

Ugidos, J.M. (in press.): Cordierita, andalucita y sillimanita en las rocas graníticas. ¿Fases magmáticas o residuales?. *IX Reun. Geol. Oeste Penins.* Porto.

Ugidos, J.M. (in press.): Asimilación en los granitos hercínicos: aspectos básicos e implicaciones. In: Geología de los granitoides y rocas asociadas del Macizo Hespérico. Salamanca. *Libro Hom. L.C. García de Figuerola.* Ed. Rueda, Madrid.

Vargas, I., Peón, A., García de Figuerola, L.C. and Franco, M.P. (1982): *Mapa Geológico de España. E.: 1/50.000 2.ª Serie. Hoja n.º 504 (14-20).* Alba de Tormes. 44 págs. Inst. Geol. Min. España, Madrid.

White, A.J.R., Clemens, J.D., Holloway, J.R., Silver, L.T., Chappell, B.W. and Wall, V.J. (1986): S-type granites and their probable absence in southwestern North America. *Geology,* 14, 115-118.

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