

Contact metamorphism in synkinematic two-mica granites produced by younger granitic intrusions, Galicia, N.W. Spain

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Abstract

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The thermal effects produced by relatively late granitoids on older synkinematic two-mica granites were studied. Both groups of granitoids are of late-Hercynian age and form part of the large Galician granite area in the N.W. of the Hesperian Massif.

The thermometamorphic effects observed in the synkinematic two-mica granites consist of a complete recrystallization with progressive breakdown of biotite and muscovite and formation of andalusite, sillimanite, corundum, spinel, cordierite, quartz, plagioclase, K-feldspar and opaque minerals.

Breakdown reactions of biotite and muscovite in the presence of quartz and under oxidizing conditions are proposed to explain the appearance of some of the newly formed minerals.

Introduction

Study of the late-Hercynian granitoids of Galicia revealed that several postkinematic and late-synkinematic plutons caused contact aureoles in pre-existing granitic rocks, leading to the neof ormation of the Al-rich minerals sillimanite, andalusite, corundum and spinel.

The presence in granitic rocks of the last two minerals is rather exceptional (Clarke 1981) and raises petrological problems which have not yet been satisfactorily explained. References to spinel and/or corundum-bearing granites are scarce: Brammall & Harwood (1923) reported the presence of hercynite in the Dartmoor granite of Cornwall; Scharbert (1966) recorded spinel from Austrian Moldavia; Lisitsin & Yurkuna (1974)

cited a Zn-rich spinel (gahnite) from late-Hercynian leucogranites of eastern Siberia; Wilson (1975) mentioned the presence of sapphire in the Land's End granite of Cornwall and Propach & Gillesen (1984) studied late-Hercynian hercynite-bearing granites of the Bavarian Forest. In northern Galicia the presence of these minerals is recorded in the granite of the El Barquero Massif by Arce et al. (1977) and Cuesta (1981). More common are references to the presence of corundum or spinel in granite pegmatites and aplites, like those of Colorado, U.S.A. (Finlay 1907), the area west of the Sea of Azov (Bazhenova 1955), the Yosemite National Park, U.S.A. (Rose 1957), the Hebrides, Great-Britain (Knorring & Dearnley 1960), the Bohemian Massif, Czechoslovakia (Němec 1973), the Himalaya (Foord 1977), and the

South Mountain batholith, U.S.A. (Farley 1979).

The massifs that produce contact metamorphism in the synkinematic two-mica granites are postkinematic granitoids, with the exception of the La Ruña Massif, a late syn-kinematic pluton (Arps 1970) with features intermediate between those of the synkinematic and postkinematic granitoids.

For a general picture of the regional geology and granitoids of Galicia the reader is referred to Capdevila & Floor (1970), Den Tex & Floor (1971), Den Tex (1977, 1981a, b), Barrera et al. (1982, 1984), Corretge (1983) and Gil Ibarra et al. (1983).

Petrological features of the postkinematic granitoids

Seven granitoid massifs causing contact metamorphism in the surrounding synkinematic two-mica granites have been found. These massifs are listed in Table 1 and their locations are shown in Fig. 1.

Table 1 presents petrological and mineralogical characteristics of the granitoid bodies and the range in SiO₂ contents.

As shown by Table 1, the range in mineralogical and geochemical variation of the postkinematic granitoids is relatively wide. The compositional variation of the massifs is reflected by the intensity of the contact metamorphism that they cause. There is a clear relation between the degree of metamorphism produced by a given pluton and its degree of differentiation.

Petrological features of the contact-metamorphosed granites

The extensive belts of syn-kinematic two-mica granites intruded by the postkinematic massifs are less variable petrologically and geochemically than the latter. As a rule their texture is equigranular (fine-, medium- and coarse-grained), but porphyritic facies with megacrysts of K-feldspar with a mean length from 1 to 3 cm are not infrequent.

The main minerals in these syn-kinematic granites are quartz, K-feldspar, plagioclase (albite-oligoclase, exceptionally andesine), biotite and muscovite. Sillimanite, garnet, andalusite, apatite, zircon, monazite and opaque minerals are found as accessory minerals.

The relative proportion of biotite to muscovite is variable and there are facies rich in biotite and poor in muscovite as well as leucocratic facies with muscovite as the only mica. Sillimanite and andalusite, if present, are only found in minor amounts. Mostly they have been partially or completely replaced by muscovite, a mineral that is often overgrowing them as large flakes. The sillimanite appears as fibrolite or as small short prisms enclosed in muscovite and, occasionally, in feldspar or quartz. Andalusite is scarcer than sillimanite. It forms stout subhedral to anhedral crystals in muscovite. Barrera et al. (1984) observed that the synkinematic two-mica granites can be geochemically characterized as strongly peraluminous (mean index of peraluminosity = 1.29; mean content of normative corundum = 3.55%) with a mean D.I. of 87.92 (the highest of the three granitic groups

Table 1. Some petrological and geochemical data of postkinematic granite massifs causing contact metamorphism in surrounding synkinematic two-mica granites

Massif	Type of rock	Mineralogy	SiO ₂ content
Estaca de Bares	Granite-Granodiorite	Q-Kf-Plag (An ₃₀₋₅₀)-Bi±Hbl±Cpx	64.0-67.0
Porriño	Granite	Q-Kf-Plag (An ₁₀₋₅₀)-Bi±Hbl	67.2-77.6
Ribadavia	Granite	Q-Kf-Plag (An ₁₀₋₃₀)-Bi±Ms	68.5-73.5
Traba	Granite	Q-Kf-Plag (An ₁₀₋₂₃)-Bi	70.5-76.5
Orense	Granite	Q-Kf-Plag (An ₁₀₋₃₀)-Bi±Ms	70.1-75.1
La Ruña	Granite	Q-Kf-Plag (An ₁₀₋₃₀)-Bi-Ms	71.0-73.5
Lovios	Granite	Q-Kf-Plag (An ₈₋₂₇)-Bi±Ms	71.1-75.6

Q = Quartz; Kf = Potassium feldspar; Plag = Plagioclase; Bi = Biotite; Ms = Muscovite; Hbl = Hornblende; Cpx = Clinopyroxene

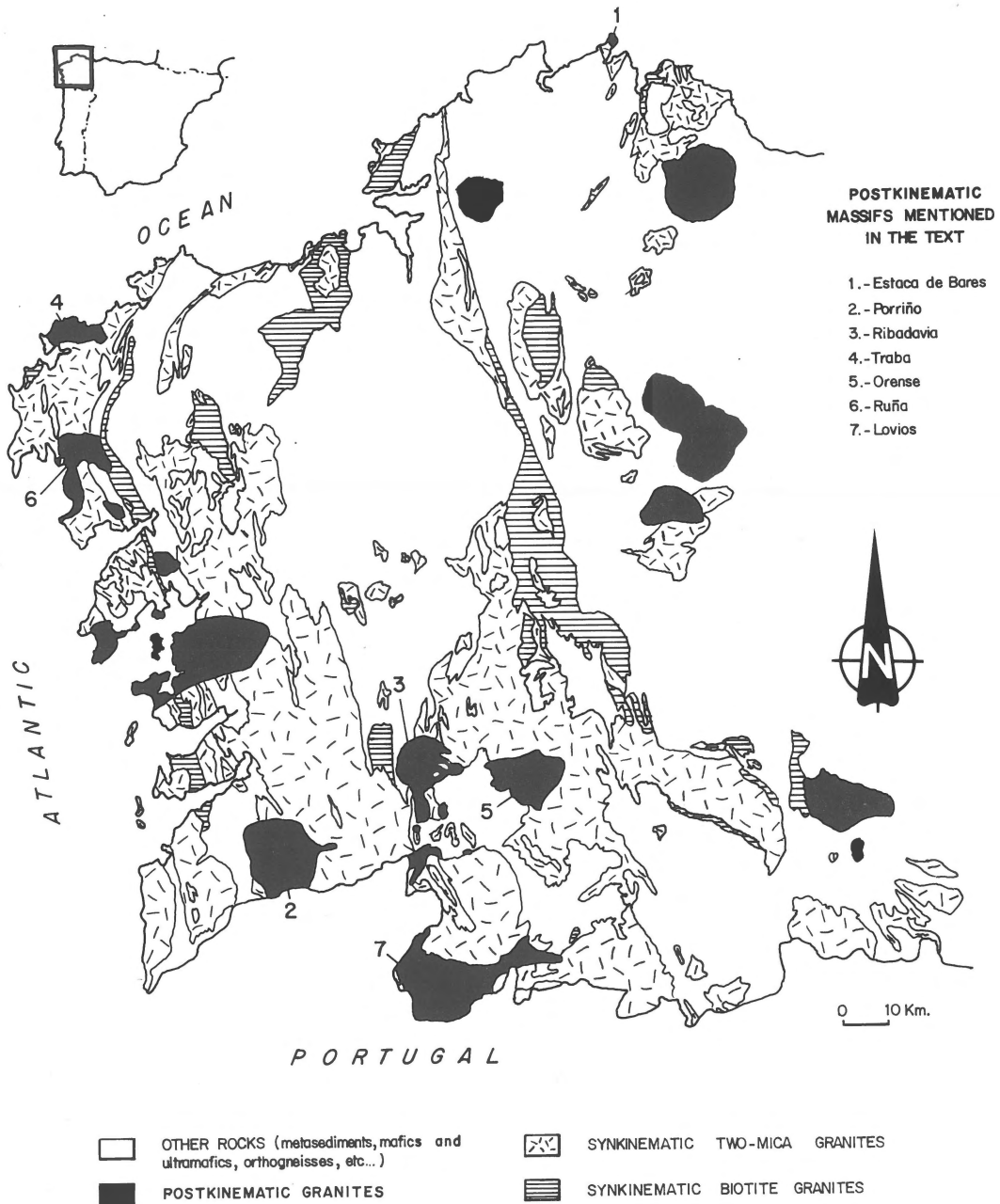


Fig. 1. Location of synkinematic and postkinematic granites in Galicia. Based on sheets nos 1 (1984), 7 (1984), 8 (1982), 16/26 (1985) and 17/27 (in prep.) of the Geological Map of Spain 1:200 000 (I.G.M.E.) and data of the authors.

distinguished by these authors) and a mean content of Ca of less than 0.70%. These values are not exceptional because they are the same as those found for the great majority of the two-mica granites from other European Hercynian massifs.

It must be stressed that the peraluminosity of the synkinematic two-mica granites of Galicia cannot be invoked to explain the presence of spinel and corundum.

Textural and mineralogical changes in the contact-metamorphosed granites

The changes observed in the peraluminous synkinematic two-mica granites around the postkinematic massifs are both textural and mineralogical. Textural changes are inconspicuous and have so far been overlooked in Galicia. Apparent grain size and gross deformational structures are still preserved in the vicinity of the contacts with the massifs of postkinematic granites. A more or less complete transformation of the biotite flakes into fine-grained pseudomorphic aggregates of newly formed minerals (mainly andalusite and sillimanite, Fig. 2) can sometimes be observed with a pocket lens. This microtextural change and a decrease in the content of larger muscovite flakes are the most important clues for the recognition in the field of the thermal metamorphism.

The decrease in muscovite content may lead to confusion regarding the classification of the contact-metamorphosed granite.

The width of the contact aureoles is variable. In

the examples studied, the mean width is less than 1 km; an exception is the aureole around the Estaca de Bares Massif, that reaches a width of about 2 km.

The most obvious mineralogical phenomenon resulting from the contact metamorphism is the breakdown of the muscovite and biotite. The breakdown of biotite is especially conspicuous due to the concentration of oxides and Al-silicates in the replacement aggregates. Noticeable is the presence in all aureoles, except that around the La Ruña Massif, of both andalusite and sillimanite. Outside the aureoles their coexistence has been very rarely observed in the synkinematic two-mica granites. The quantities of andalusite and/or sillimanite in almost all aureoles greatly surpasses the minute amounts of these minerals that are sometimes present in the synkinematic two-mica granites outside the aureoles. In some cases the Al-silicates must be considered essential minerals, e.g. sillimanite in the granite around the Porriño Massif and andalusite in the granite around the Orense Massif.

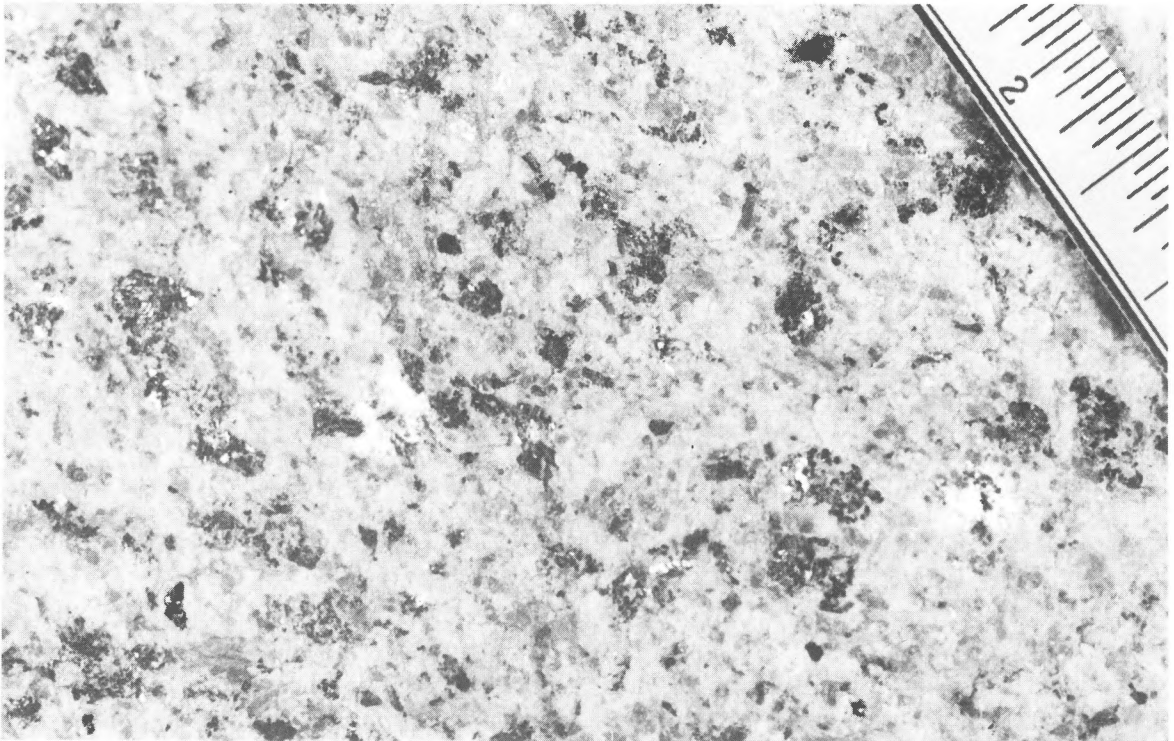


Fig. 2. Clusters of tiny biotite specks resulting from the breakdown of the original biotite flakes. Carballino Granite from the contact aureole of the Orense Granite.

Table 2. Newly formed minerals in contact-metamorphosed two-mica granites.

Younger massifs	Enveloping massifs	Newly formed minerals									
Estaca de Bares	Amoa-El Barquero	A	S	Sp	C	Cd	Q	Plag	Kf	Op	Ms
Porriño	La Cañiza-Puente Caldelas	A	S			(Cd)	Q	Plag		Op	Ms
Ribadavia	Carballino-Cortegada	A	S	Sp		(Cd)	Q	Plag		Op	Ms
Traba	Lage-Dumbría	A	S	Sp		(Cd)	Q	Plag	Kf	Op	Ms
Orense	Allariz; Orense-Carballino	A	S			(Cd)	Q	Plag		Op	Ms
La Ruña	Dumbría-Barbanza		S			(Cd)	Q	Plag			Ms
Lovios	Baltar	A	S			(Cd)	Q	Plag		Op	Ms

A = Andalusite; S = Sillimanite; Sp = Spinel; C = Corundum; Cd = Cordierite; Q = Quartz; Plag = Plagioclase; Kf = Potassium feldspar; Op = Opaques; Ms = Muscovite

Table 2 presents the newly formed minerals in the aureoles in the synkinematic two-mica granites around the postkinematic granites.

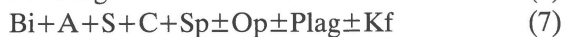
From a comparison of Tables 1 and 2 it can be seen that there is a tendency for the high-temperature Al-minerals (corundum, spinel) to appear in aureoles around less differentiated massifs with probably high initial emplacement temperatures. This is exemplified by the presence of both spinel and corundum in the aureole of the most basic of the postkinematic granitoids, viz. the Estaca de Bares Massif.

The appearance of cordierite as a contact mineral has been deduced from the occurrence of microcrystalline aggregates of a light green mica (+ biotite) or from phyllosilicates similar to those found as pinnitization products of cordierite. The circumstance that these aggregates are commonly found on a substratum of recrystallized biotite supports this supposition.

On a mesoscopic scale some granites still exhibit a more or less well-developed foliation, but on a microscopic scale quartz and K-feldspar have recrystallized completely into markedly allotriomorphic textures with well-developed triple junctions and strain-free crystals.

There exists a considerable variation regarding the mineral assemblages found in the aggregates replacing the biotite.

The most important assemblages are



(See Table 2 for the abbreviations).

Moreover, the above-listed minerals of the aggregates are rather frequently intermingled with microcrystalline micaceous material, presumably alteration products of cordierite.

In almost all of these assemblages K-feldspar is lacking and quartz and muscovite are invariably present as additional minerals. The muscovite appears in many cases as late poikiloblasts. The first four of the above-mentioned assemblages are the most common. They are characterized by the presence of andalusite and/or sillimanite in combination with opaques and/or plagioclase. The assemblage (7) has been found only in the aureole around the Estaca de Bares Massif.

Petrographically the newly formed minerals have the following characteristics:

– Quartz forms equigranular recrystallization mosaics. Subordinate amounts of quartz replace feldspar, in particular K-feldspar, which shows characteristic net-like systems of quartz veinlets that roughly follow the cleavage planes.

– Biotite always has strikingly reddish colours. In the great majority of the recrystallized biotite flakes a substratum of quartz, plagioclase and possibly cordierite is formed, in which the Al-silicates are found (Fig. 3a). Tiny crystals of opaque minerals have been formed as by-products of the breakdown of the biotite.

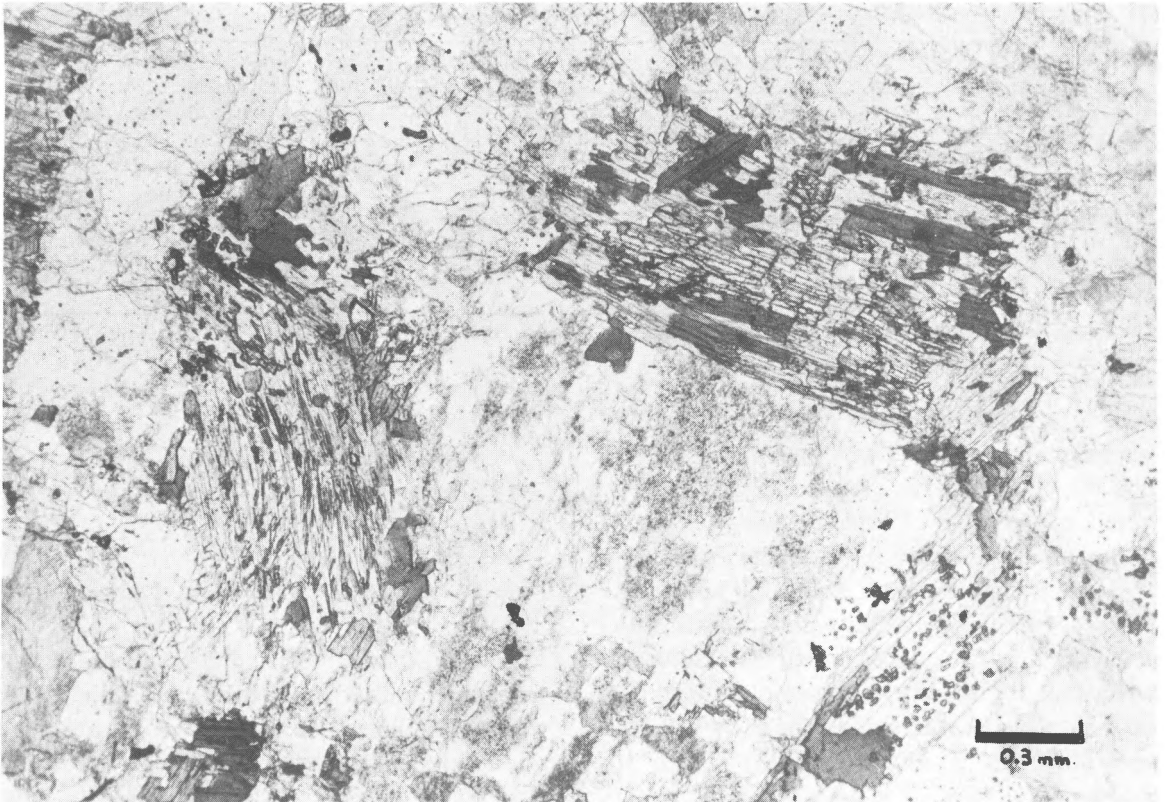


Fig. 3a. Aggregates of andalusite, sillimanite and biotite replacing the original biotite crystals. Carballino Granite from the contact aureole of the Orense Granite.

– Andalusite replacing biotite forms euhedral to subhedral prisms of variable size. It is frequently accompanied by fine-grained opaque minerals (Fig. 3b). The andalusite is commonly overgrown and replaced by muscovite. Only in very few instances andalusite is found associated with quartz or feldspars outside the aggregates that replace biotite.

– Sillimanite is the only Al-silicate found in all the contact aureoles. It appears as fibrolite and as euhedral prisms (up to 0.1 mm wide). Both forms sometimes coexist in the same sample. Mostly sillimanite is associated with biotite (Fig. 3b). Only in a few cases have bundle-shaped felty aggregates of sillimanite been observed outside the recrystallized biotite.

– Spinel is very rare. It shows greenish tinges and possibly is hercynite. The mineral appears in tiny anhedral grains (≤ 0.1 mm) associated with

sillimanite and/or andalusite in the aggregates resulting from the breakdown of biotite (Fig. 3c).

– Corundum has been found only in a few samples from the aureole around the Estaca de Bares Massif. It forms tiny anhedral crystals in the aggregates resulting from the breakdown of biotite. It appears associated with sillimanite and spinel and sometimes encloses the latter mineral (Fig. 3d).

Discussion

The principal petrological problem discussed in this paper concerns the thermal metamorphic origin of corundum and spinel in synkinematic two-mica granites in the vicinity of massifs of postkinematic granites and the increase in the

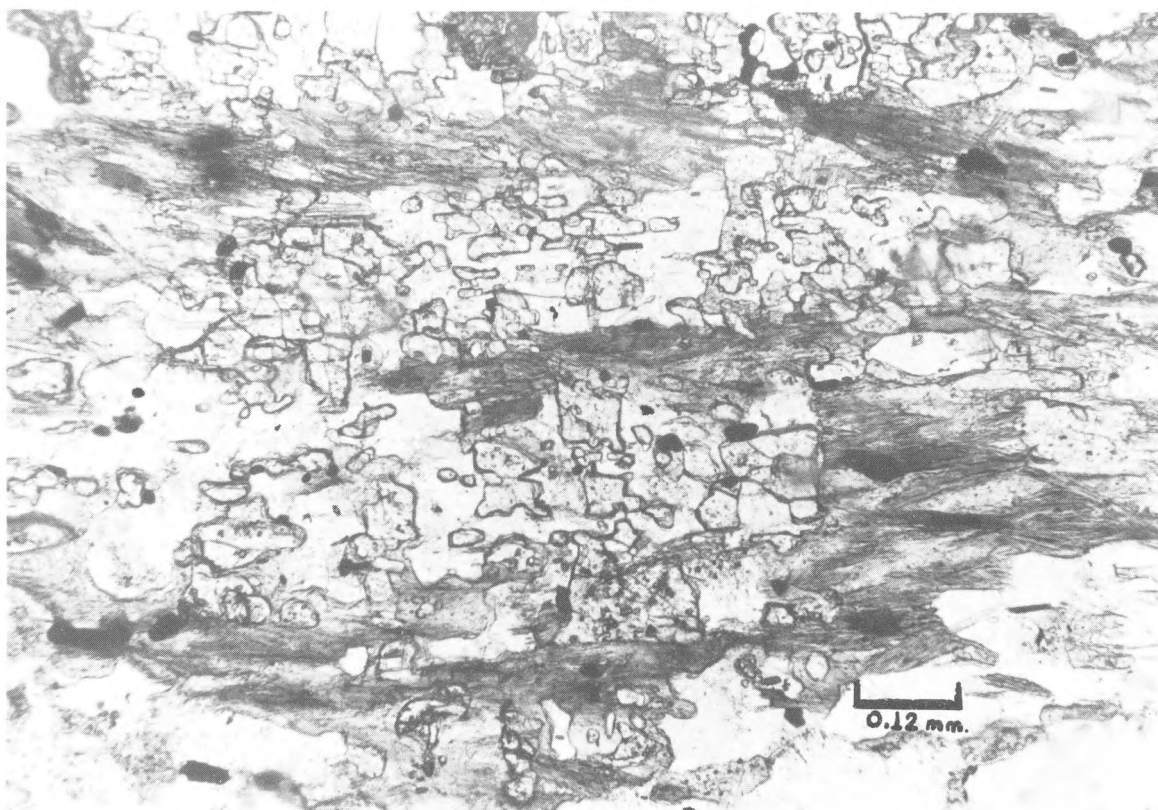


Fig. 3b. Aggregate of andalusite (colourless, high relief), sillimanite (fibrous, mainly enclosed by biotite), tiny grains of opaques and partly chloritized biotite (matrix of fibrous sillimanite). Amoa-El Barquero Granite from the contact aureole of the Estaca de Bares Granite.

amount of sillimanite and andalusite towards the younger intrusions. These features have never been described before and previous hypotheses to explain the origin of the above-mentioned minerals in granitic rocks do not envisage thermal metamorphism, with but one exception known to the authors. Klein (1965) has recorded the presence of andalusite, sillimanite and fresh cordierite in a member of the Series of 'Older Granites' (the Feital Granite) and in granitic components of banded, migmatite-like rocks near the contact with a member of the Series of 'Younger Granites' (Guarda Granite of Oen 1970) of northern Portugal. The presence of sillimanite, andalusite and cordierite is ascribed to contact metamorphism caused by the younger granite; the contact-metamorphosed older granites show many textural features similar to those in the Galician granites described in this paper.

Both in Galicia and Portugal there is strong evidence for a contact-metamorphic origin of the observed textural and mineralogical changes in the synkinematic two-mica granites towards the younger massifs, because they are only found in the contact zones around the younger plutons.

In summary, these changes are:

- A strong increase in the amount of sillimanite and andalusite towards the postkinematic granites.
 - The appearance of spinel and corundum restricted to these zones.
 - The appearance of typical quartz and feldspar recrystallization textures and breakdown aggregates of biotite with anhydrous Al-rich minerals.
- The above changes are typical of metamorphic and not of magmatic processes. The nature of the breakdown products of biotite indicates conditions of high temperature and low pressure contact metamorphism.

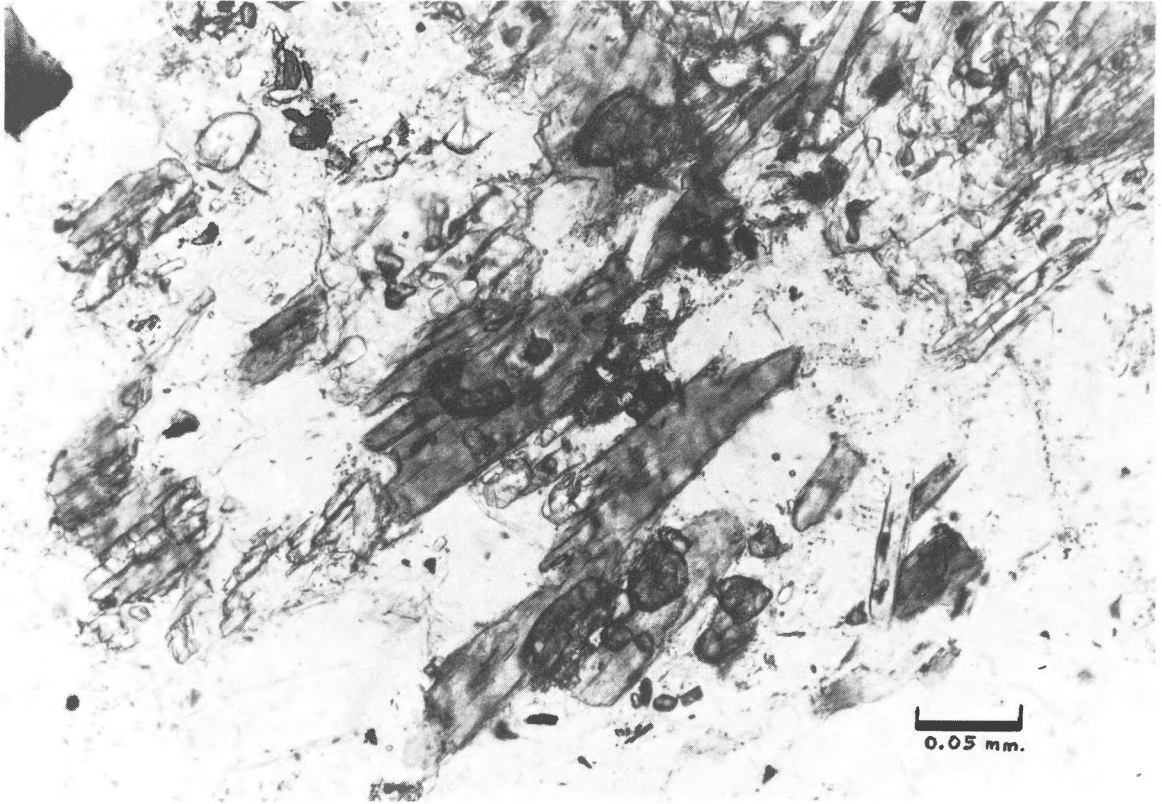
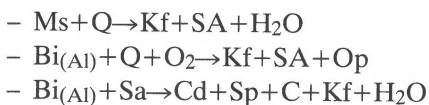


Fig. 3c. Spinel (small grains with high relief) is enclosed by biotite. The biotite is accompanied by andalusite (colourless, high relief) and sillimanite (slender, needle-like prisms). Amoa-El Barquero Granite from the contact aureole of the Estaca de Bares Granite.

The relation between petrological composition of the younger granitoids and intensity of the transformations in the aureoles supports the hypothesis of contact metamorphism as the cause of the phenomena described in this paper.

The changes found in the aureole involve the breakdown of the micas. It is envisaged that with fast reaction rates microdomains have been formed where silica had no access and where phases like spinel and corundum, that are unstable in the presence of quartz, could crystallize. The schematic reactions that possibly played a role in the metamorphic transformations are:



$\text{Bi}_{(\text{Al})}$ = Aluminium-rich biotite; SA = aluminosilicate; the other abbreviations are the same as in Table 2.

The above reactions suggest the formation of considerable amounts of K-feldspar. Actually, this is not observed. This deficiency of K-feldspar could only in part be explained by the K being consumed in the formation of retrograde muscovite.

With regard to the alternative hypothesis of a magmatic origin of the corundum and spinel, experimental and thermodynamic data make such an origin improbable (Carr 1968; Dimitriadis 1978).

Conclusion

Several of the postkinematic granites of Galicia induced contact metamorphism in peraluminous



Fig. 3d. Corundum (high relief) in partly chloritized biotite (greyish). The two biggest crystals enclose spinel (dark grey, almost opaque in photograph). Note the presence of minute crystals of an opaque mineral and tiny needles of sillimanite. Amoa-El Barquero Granite from the contact aureole of the Estaca de Bares Granite.

synkinematic two-mica granites. The mineralogy and mineral assemblages found in the contact aureoles indicate that at least in some of them conditions typical of the pyroxene-hornfels facies were reached. The observed mineral assemblages are sometimes characteristically silica-deficient. This is in striking contrast with the strongly oversaturated nature of the metamorphosed granites. This contradiction, which is also observed in some pelitic hornfels with corundum and spinel, may be explained by high rates of reaction of the transformations involved and by the low chemical mobility of the components. Probably these factors must be held responsible for the presence of microdomains undersaturated in silica at the spots where the dehydration reactions of the micas took place.

The conditions of contact metamorphism seem to have exceeded the upper temperature stability

limit of muscovite in the presence of quartz and possibly even of that of muscovite alone; part of the corundum is probably formed by the breakdown of muscovite under silica-deficient conditions.

Contact metamorphism thus provides a possible explanation for the presence of andalusite, sillimanite, corundum and/or spinel in granitic rocks.

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