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Late hercynian intrusives from the Southern Catalonian coastal ranges (NE Spain), and their epiplutonic to subvolcanic level of magma emplacement

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ABSTRACT. — The intrusive from the southern Catalonian Coastal Ranges form a Late-Hercynian I-type calc-alkaline association with a set of features that suggest they were emplaced in a very low-pressure, subvolcanic environment. These inferences are based on the following evidence: (i) the contact of the plutonics with their host-rock is sharp, cross-cutting and angular-to-polygonal in morphology; (ii) the plutons are roofed by their host with subhorizontal contact surfaces turning into steeply dipping ones towards the border of the plutons; (iii) the host-rock is an anchimetamorphic sedimentary sequence with well-developed contact metamorphic aureoles around the intrusions; (iv) the older plutonic units have normal equigranular textures, whereas the younger ones are mostly inequigranular and typically developed well-defined chilled margins in the contact with their host; (v) miarolitic cavities are scarce but widespread; (vi) the dyke-swarm accompanying the plutons is very well developed and in some areas is particularly dense; (vii) columnar jointing of hexagonal symmetry is present in some dykes; (viii) explosive breccias are scarce but their occurrence is regular throughout the complex.

The following conclusions are drawn from all these observations: (i) the environment of magma emplacement was subvolcanic (presence of breccias and columnar jointing) and brittle; (ii) this environment was in prominent thermal disharmony with the intruding magma; and (iii) the present-day outcrop level corresponds to the top of the complex.

Although magma venting cannot be demonstrated (no related volcanic cover is present), it cannot be rejected, since it is compatible with observed relationships and coincides in age (Stephano-Permian) with those of the well-known calc-alkaline volcanism occurring in several places of the Hercynian fold-belt.

Mineral indicators reveal that the magmas were dry and hot enough to have a deep source and to ascend close to the surface.

Key words: magma emplacement, subvolcanic environment, plutons, Late-Hercynian, calc-alkaline.

LES INTRUSIONS TARDI-HERCYNIENNES DE LA PARTIE SUD DES CHAÎNES CÔTIÈRES CATALANNES (NE DE L'ESPAGNE), ET SON NIVEAU DE MISE EN PLACE EPIPLUTONIQUE A SUBVOLCANIQUE

RESUMÉ: — Les roches intrusives de la partie Sud des Chaînes Côtières Catalannes constituent une association calco-alcaline tardi-hercynienne. Cette association présente des caractéristique typiques d'une mise en place sous conditions de pression faible, possiblement subvolcanique. Toutefois, il faut noter l'absence d'une couverture volcanique en liason. Si cette couverture volcanique a existé, elle a dû, sans doute, être démantelée par l'erosion.

Les principaux arguments appuyant cette hypothèse sont les suivants: (i) les contacts entre les plutons et leur encaissant sont très nets, recoupant les structures de ce dernier et montrant des formes angulaires; (ii) par endroits, il est possible d'observer l'encaissant formant le chapeau des plutons et reposant sur des surfaces prèsque horizontales qui deviennent brusquement inclinées vers la bordure des masses plutoniques; (iii) l'encaissant est formé par une série sédimentaire anchimetamorphique qui développe des auréoles de contact autour des intrusions; (iv) les plutons les plus anciens montrent des faciès avec des textures isogranulaires alors que les plus tardifs sont formés de faciès à texture heterogranulaire montrant des bordures figées au contact de l'encaissant; (v) la presence de cavites miarolitiques est géneralisée; (vi) il existe un cortège filonien associé très important et dans certaines zones sa distribution est particulièrement dense; (vii) certains filons montrent une prismation nette; (viii) la presence de brèches d'explosion regulièrement distribuées dans la complexe est indicative d'une pression lithostatique assez faible et inferieur à la pression des fluides.

Toutes ces relations mettent en évidence: (i) un niveau de mise en place subvolcanique (presence de brèches et de prismation); (ii) l'existence d'un fort contraste de température entre le magma ascendant et son encaissant, et (iii) un niveau d'exposition qui correspond au toit du complexe.

Tout en reconaissant qu'il n'est pas possible de démontrer l'existence d'un volcanisme local associé (absence de couverture volcanique rapportée), on ne peut pas non plus l'écarter car l'âge Stéphano-Permien des intrusions coincide avec celle du volcanisme calco-alcalin qui est dejà connue dans la Chaîne Hercynienne.

Les traceurs minéralogiques suggèrent l'existence d'un ou de plusieurs magmas d'origine profonde suffisament secs et à température élevée capable de monter à des niveaux trés superficiels.

Mots clef: mise en place, environ subvolcanique, plutons, tardi-hercynien, calco-alcalin.

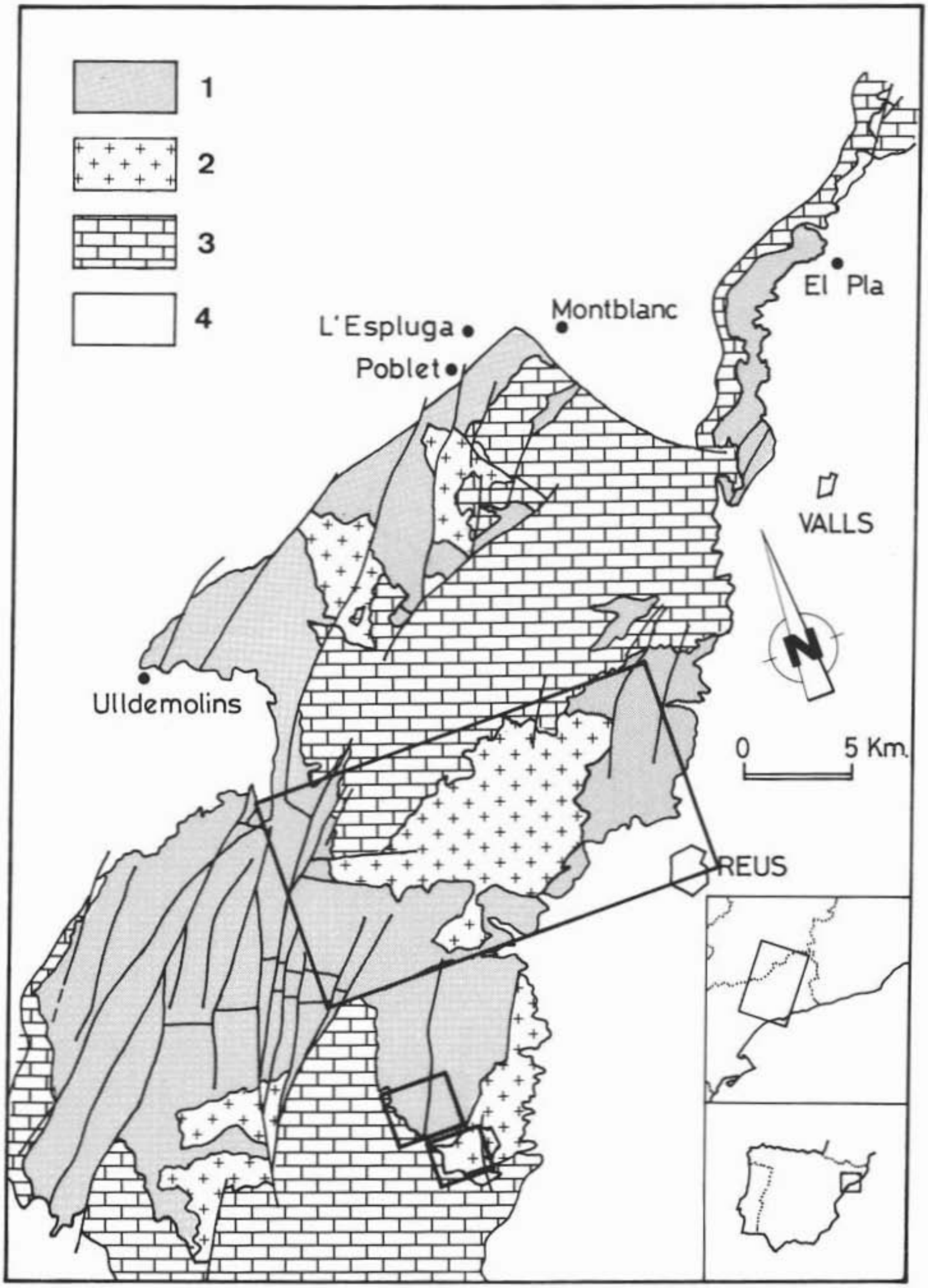

Fig. 1. — Regional map of complex showing main plutonic outcrops and position of areas mapped in Figs. 2, 5 and 8. Patterns: 1) Paleozoic sediments; 2) Plutonic rocks; 3) Mesozoic sedimentary cover; 4) Post-Mesozoic. (Simplified after MELGAREJO, 1987).

Introduction

This paper deals with the Late Hercynian intrusive complex occurring in the Southern Catalonian Coastal Ranges, including all those topics that are directly involved in their way of building-up to level of final emplacement. Chiefly, these subjectes are: the distinction among different types of intrusions present in the area, their shapes and sizes, their relationships with the wall-rock on both contact and regional scales, their relative chronology of intrusion, the structures they develop, related brecciation processes, and the textural and mineralogical indicators of their evolution.

All these observations not only confirm the high crustal level of emplacement of the Catalonian Coastal Ranges granitoids (ENRIQUE, 1984) but also clearly establish, for the first time in the area, the fact that the intrusives reached a subvolcanic level.

Consequently, the studied complex may have rooted a volcanic association of Stephano-Permian age, similar to other widespread throughout the Hercynian fold-belt, although related volcanics have never been found (for reasons outlined later). However caution must be taken when considering the actual occurrence of magma venting.

Geological setting

The complex examined here is an I-type calc-alkaline association of Late Hercynian age that occurs in the Paleozoic basement of the Southern Catalonian Coastal Ranged (Fig. 1), unconformably covered by subhorizontal to gently dipping Triassic sediments.

The Catalonian Coastal Ranges form a 250 Km-long alignment of horsts and grabens, with a NE-SW trend, parallel to the north-eastern corner of the Iberian Peninsula shoreline.

Although the nature of the host of the intrusions will be outlined here, the reader is referred to the previous works on the region (ASHAUER and TEICHMÜLLER, 1935; FONTBOTE and JULIVERT, 1982; and MELGAREJO, 1987) for more detailed information.

According to the last author, the wall-rock is a sedimentary sequence ranging from Ordovician to Carboniferous in age, the latter covering most of the area. A discordance between pre-Carboniferous and Carboniferous formations distinguishes a spatially limited basal unit with a complex structure from an overlying one characterized by NNW-SSE - trending intra-Carboniferous fold with a large radius of curvature. A subsequent brittle phase formed a dominant NE-SW - trending fracture system constituting the main dyke-bearing fracture family in the area (see later).

The outcrop of the intrusions is a roof exposition of the magma chambers. Their highest exposed stratigraphic level is anchimetamorphic Westphalian, made up of detritic, essentially turbiditic materials.

The complex consists of several plutonic bodies accompanied by a dense dyke-swarm. The plutonics have a batholithic multiple intrusion nature and are surrounded by contact metamorphic aureoles that, at least in some places in their inner parts, reach the pyroxene hornfels facies.

Volcanics related to the intrusives are lacking in the complex.

Since its age is Stephano-Permian (as evidenced by unpublished Rb-Sr isochrons, DEL MORO & SERRA), and since the Westphalian is the highest stratigraphic level outcropping in the area, erosion may be the reason for the non-presence of volanics, if they ever existed. It must be borne in mind, however, that calc-alkaline volcanics of the same age are widespread throughout the Hercynian fold-belt and that their nearest occurrence is in the Pyrenees.

Contact relationships, shape of plutons, and mechanism of magma emplacement

The plutonic masses show sharp contacts with their host rocks crosscutting the main Hercynian structures occurring in them. In detail, the contact is controlled by discontinuities in the wall-rock, such as fractures and stratigraphic surfaces, giving it an angular to polygonal morphology. Host-rock blocks engulfed by magmatic material occur in some localized contact areas.

On a larger scale the plutons are seen to be roofed by their wall-rock. Roof exposure is good along the SE and SW edges of the Alforja massif (Fig. 2). Here the sedimentary host lies above the plutonics over a gently dipping planar surface outcropping for some kilometers (Fig. 3). The rapid change of these subhorizontal contacts into steeply dipping ones is needed to explain the observed relationships between topography and contact surfaces in some areas (Fig. 4).

In the Montroig region (southernmost part of the complex), there is an arcuate structure of about 2 Km diameter consisting of and external ring of granodiorite with inequigranular texture intruded into an older tonalitic unit (Fig. 5). The interior of this ring contains a smaller arc of the older tonalite that, at the same time, encloses younger granodiorite in its central part. Contacts dip outwards about 60 to 70 degrees.

All these relationships, together with a more or less generalized lack of mineral orientation in the plutonics, indicate that the magma was emplaced in a shallow brittle environment through the action of passive mechanisms such as stoping or cauldron subsidence.

Taking into consideration that: (i) engulfed host blocks are scarce, (ii) the plutons are effectively roofed, and (iii) subhorizontal contacts rapidly turn into steeply dipping ones, it is reasonable to infer that emplacement was essentially controlled by the sinking, into underlying chambers, of large roof-rock pieces unsupported by magma, in some cauldron subsidence-related process. In such a context, piecemeal stoping must have played a subordinate role.

The arcuate structure which outcrops in the Montroig area is believed to represent a good example of block foundering. Here the inner tonalitic arc represents the outcrop of the subsided block.

Nature and composition of plutonic bodies

Lithologies forming the plutonic masses vary from gabbrodiotitic to leucogranitic. Tonalitic ones are the most widespread, granodiotites are also abundant, but leucogranites and diorites area much more restricted.

a) Chronological relationships

Contacts between plutonic indicate that the tonalite of the Borges-Vilaplana type (defined in Alforja, Fig. 2), predates granodioritic and leucogranitic units throughout the complex. The Alforja-l'Aleixar tonalite, however, is coeval to the Coll de la Batalla granodiorite (Fig. 2), as indicated by the decametric to hectometric zone of gradual transition between them. Both masses are believed to derive from the same magmatic pulse and may be related by a differentiation process. Although the gabbrodiorites may be the basic precursors of the association, their chronological relationships with the remaining plutonics have not been definitely established, due to poor contact exposures.

b) Mineralogy

Primary moscovite or any other peraluminous mineral is always lacking in biotitic granitoids, with the exception of the very occasional appearance of almandine-rich garnet in restricted volumes in the Cara del Moro leucogranitic unit (Fig. 2). The mineralogy of the leucogranites is generally simple; in some cases they have a remarkably low content of mafic phases (1% modal or less).

Hornblende commonly occurs in tonalites and diorites but is scarce in granodiorites. However, well-developed biotite pseudomorphs after hornblende are a common feature of the Coll de la Batalla granodiorite which, as mentioned above, may be comagmatic with the Alforja-l'Aleixar hornblende-rich tonalite.

Small amounts of orthopyroxene, coexisting paragenetically with other mafic phases such as biotite and/or amphibole, occur in dioritic to granodioritic rock compositions. Two groups of this mineral have been distinguished, the first consisting of a very magnesium-rich pyroxene, with large and automorphous (sometimes corroded) crystals,

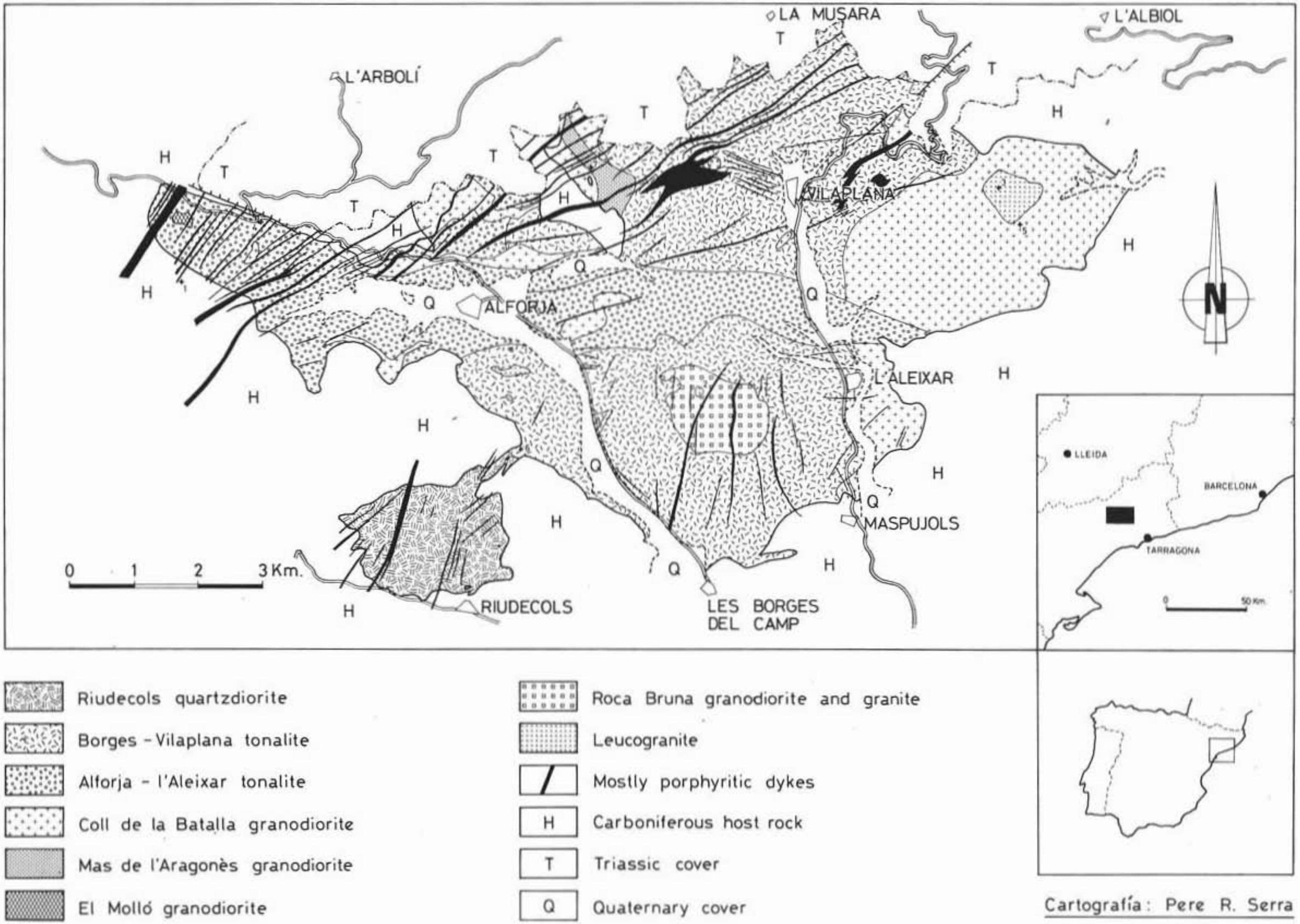

Fig. 2. — Geological map of Alforja massif.

occasionally accompanied by other high-temperature phases such as diopside, phlogopite or anorthite accompanied ; other grains, as microxenoliths (Fig. 6). The second group consists of hyperstene showing texture relationships which are believed to be formed by equilibrium crystallization from the magma.

Small amounts of cummingtonite also occur, representing a hydrous alteration

Fig. 3. — Flat, nearly horizontal plutonics (below) against their sedimentary host (above). SE edge of Alforja massif.

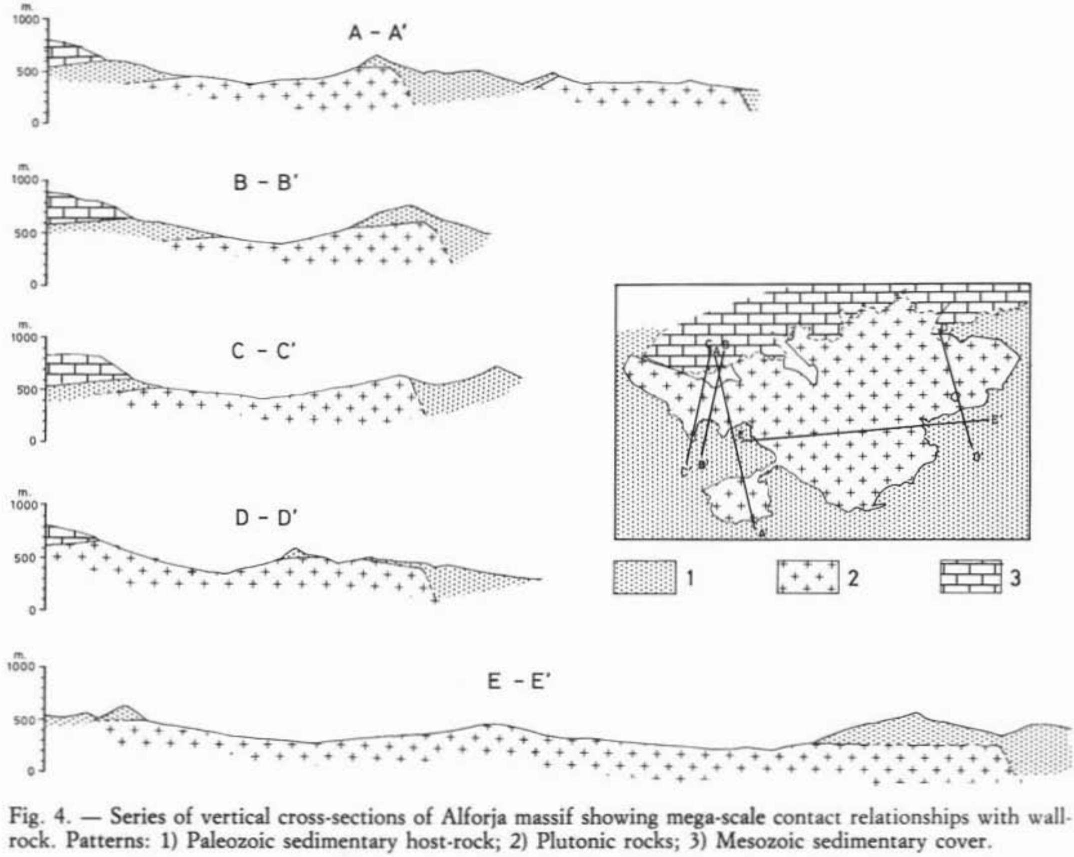

Fig. 4. — Series of vertical cross-sections of Alforja massif showing mega-scale contact relationships with wall-rock. Patterns: 1) Paleozoic sedimentary host-rock; 2) Plutonic rocks; 3) Mesozoic sedimentary cover.

product of the orthopyroxene. In some cases cummingtonite form fibrous aggregates, regarded as subsolidus reaction products with water. These fibrous aggregates may surround pyroxene crystals.

Zircon, apatite, ilmenite and allanite are the most abundant accessory phases. No primary magnetite has been found and feldspar megacrysts are lacking in the whole complex.

c) Textures

The main textures present in each plutonic unit are described in SERRA (1985) and SERRA and ENRIQUE (in press). Equigranular and inequigranular medium-grained granitoids are the two main textural groups distinguished in the complex. The dioritic units and Borges-Vilaplana tonalites belong to the first group and display normal equigranular subidiomorphic textures.

All the granodioritic units, as well as the Alforja-l'Aleixar tonalite, belong to the second group. These bodies tend to develop unambiguous porphyritic chilled margins against their host (either sedimentary or plutonic) (Fig. 7). Their inner parts are also inequigranular, but this feature may be much less evident because of grain-size increases in the groundmass. In these inner parts, quartz frequently forms large crystals with idiomorphic bipyramidal habit and, locally,

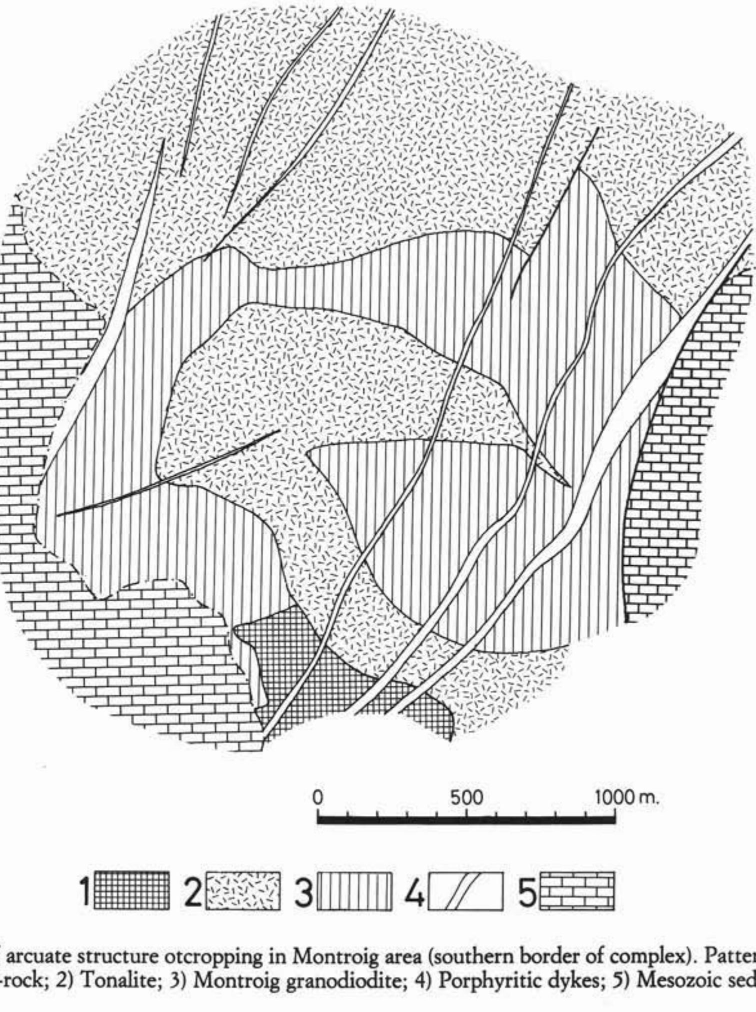

Fig. 5. — Map of arcuate structure otcropping in Montroig area (southern border of complex). Patterns: 1) Paleozoic sedimentary host-rock; 2) Tonalite; 3) Montroig granodiodite; 4) Porphyritic dykes; 5) Mesozoic sedimentary cover.

sign of corrosion. Plagioclase, biotite and hornblende also form relatively large crystals. In the Alforja-l'Aleixar tonalite hornblende presents crystals from 10 to 20 mm in diameter in a groundmass of about 1 to 5 mm. All these phases also occur as groundmass minerals, although felsic species such as alkali-feldspar, quartz and sodic plagioclase are more frequent. The inequigranularity in these rocks is sometimes not porphyritic but poikilitic; in

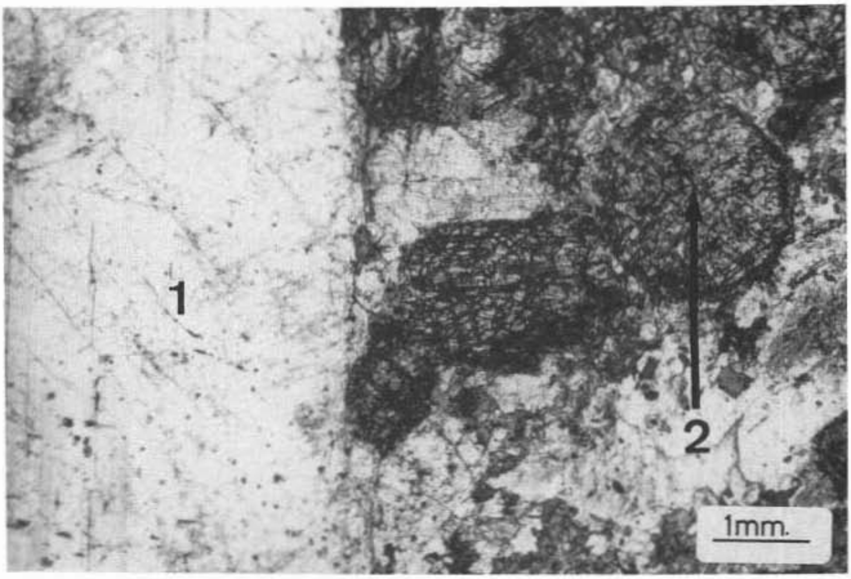

Fig. 6. — Microxenolith consisting of anorthite (1) and Mg-rich orthopyroxene (2), from a tonalite of Borges-Vilaplana type.

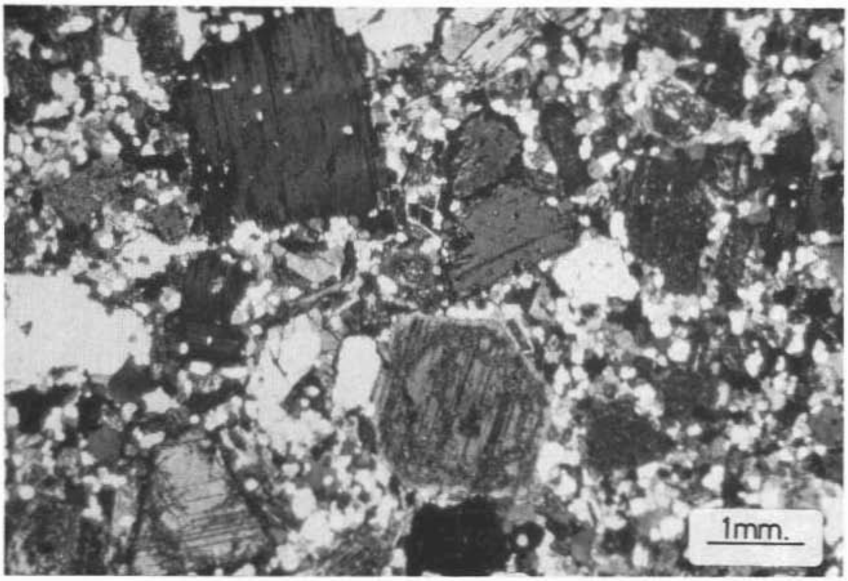

Fig. 7. — Microscopic detail of a chilled margin developed in contact of Alforja-l'Aleixar tonalite with its sedimentary host. Note openly porphyritic texture.

this case, alkali-feldspar is the only oikocrystal phase.

Miarolitic cavities are a textural feature common to almost all the igneous bodies of the complex, but they clearly predominate in the most acidic ones. They are usually filled by pegmatitic material.

The textures of the first group indicate that crystallization developed in plutonic conditions, whereas those of the second group reveal interruptions that quenched the remaining liquid in the crystallizing magma chambers, especially in their marginal parts. This quenching may have been induced not only by thermal contrasts between the magma and its host, but also by the loss of volatiles via fractures. Since chilled margins have not been found in the first group of granitoids, cooling of the environment is expected before the emplacement of the second group, if quenching was thermal. If queching was due to a loss of volatiles, it is likely that the confining pressure was low enough to permit volatile expansion in fractures or escape to the surface.

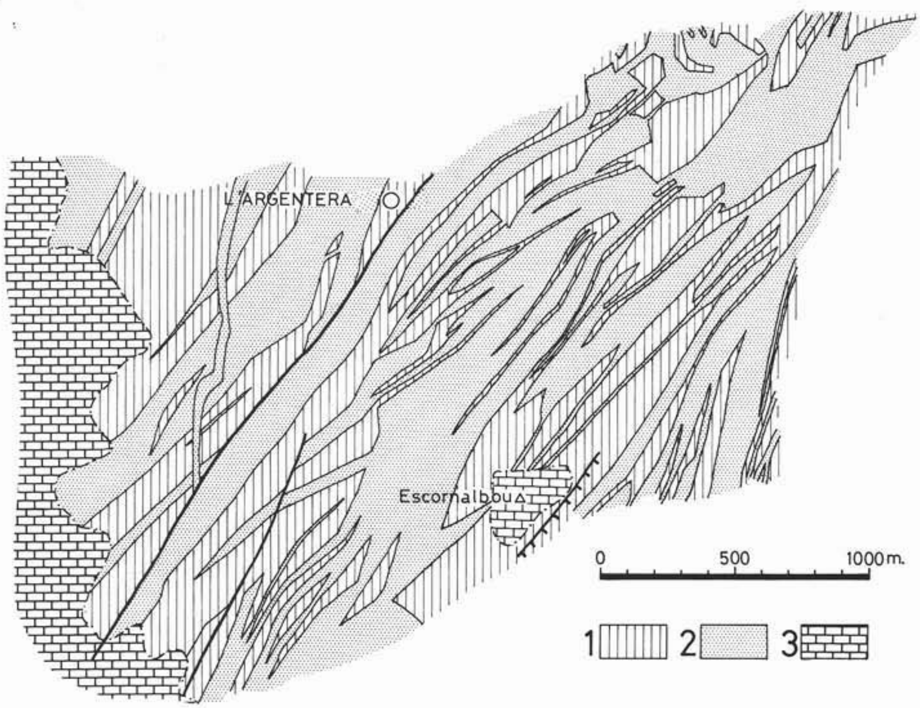

Fig. 8. — Map of dyke swarm in l'Argentera area. Porphytitic masses consist of multiple dykes of varied composition intruded into one another and covering 60% of surface. Patterns: 1) Paleozoic sedimentary host-rock; 2) Porphyritic dykes; 3) Mesozoic sedimentary cover.

The dyke swarm

Porphyritic dykes compositionally equivalent to the plutonics form a well-developed swarm in which the largest individuals have extensions of several kilometers and reach thicknesses of several hundreds of meters.

NE-SW dyke trends predominate over all other orientations. They are subparellel to the Catalonian Coastal Range alignment and are emplaced in a penetrative joint family that, according to MALGAREJO (1987), results from a brittle event corresponding to the last deformational Hercynian pulse. NW-SE-trending dykes are also important and have directions that, according to the same author, were imposed by the intra-Carboniferous folding. These dykes are usually concordant with the wall-rock stratification.

Fine-grained chilled margins and coarser porphyritic interiors characterize almost every dyke. They may show rhyolitic banding in the aphanitic margins of the acidic dykes, which may affect the thinnest ones completely.

Dike abundance in the Alforja massif (Fig. 2) is representative of the development of the swarm throughout the complex. The l'Argentera area, however, (Fig. 8) is abnormally dense and represents the highest

Fig. 9. — Columnar jointing in a porphyritic dyke (l'Argentera area).

Fig. 10. — View of southern part of Alforja breccia body in which only largest leucogranitic blocks are distinguishable.

dyke concentration of the region. Here dykes form thick NE-SW-trending composite swarms, made up of many single dykes of variable composition (from dioritic to granitic), intruding into one another and generally confining their host to thin screens between dykes. In the l'Argentera area, dykes cover 60% of the surface.

Columnar jointing of hexagonal symmetry is a very significant structure of some dykes (Fig. 9). Prisms are perpendicular to the dyke-walls and show especially good development

Fig. 11. — Detail of interior of a pebble-dyke 2 m thick in Escornalbou Castle, consisting of clasts of both igneous and sedimentary origin.

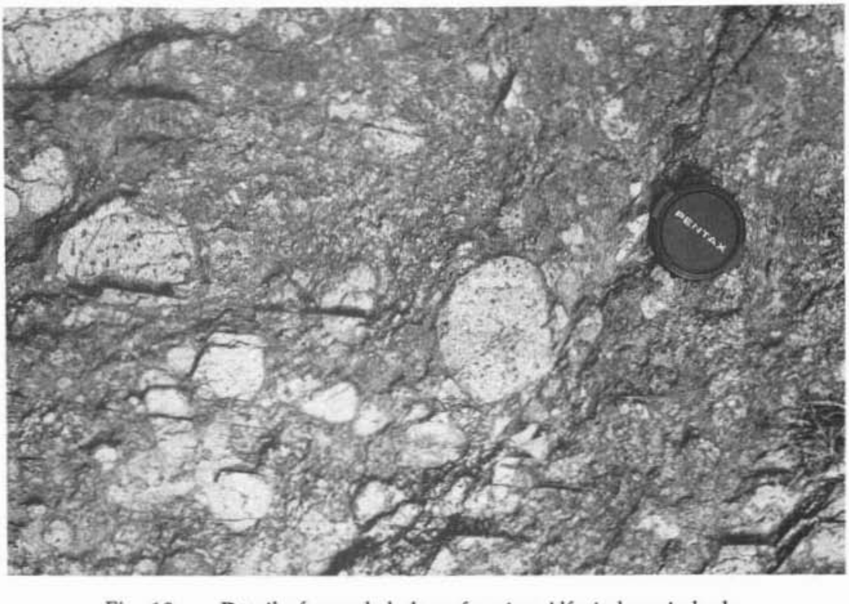

Fig. 12. — Detail of rounded clasts forming Alforja breccia body.

on the chilled margins. Columnar jointing requires such a shallow environment of formation that thermally induced stresses responsible for tensile cracking of the cooling magma are not significantly affected by the load pressure.

Breccias and explosive phenomena

As indicated in SERRA (1987), the Alforja breccia body (Fig. 10) is the best example of this kind of formation in the complex, and its origin is believed to be due to an explosive release of energy as a consequence of volatile exsolution in an epiplutonic magma chamber undergoing boiling. This is not, however, an isolated occurrence, and although breccia bodies are sparse, they have been found in several places.

A poorly exposed breccia similar to the previous one, is found along the Montroig-Vilanova d'Escornalbou road. There is another interesting breccia outcropping in the Vilanova d'Escornalbou area. It is an elliptical mass of about two hundred meters in its widest point, located at the intersection of two porphyritic dykes with another irregularly shaped porphyritic body which intrudes Paleozoic sediments. Lithologically it is formed by angular-to-rounded fragments with a matrix consisting of either igneous material or ground rock in a patchy arrangement There is a small pebble-dyke about two meters thick in Escornalbou Castle. It is also hosted by Paleozoic sediments against which it shows a sharp cross-cutting contact. The level of the outcrop is about one or two hundred meters above the inferred position of the plutonic roof. It is formed by some centimeter-sized rounded fragments of sediments, as well as by tonalite fragments belonging to the Borges-Vilaplana type, embedded in ground rock (Fig. 11).

All these breccias can also be attributed to explosive degasification of magmas in very shallow environments. A fluidized gas-solid system is invoked to explain the rounded shapes of the clasts (Fig. 12).

Summary and conclusions

High crustal levels reached by magmas may be inferred from these exposed data. Some observations indicate that this level is a subvolcanic one: (i) the sparse but regular occurrence of explosive breccias, and (ii) the development of columnar jointing in some dykes. The important energy disharmony existing between the magmas and their environment of final emplacement resulted in the development of contact metamorphic aureoles that, at least in some places, reached high grade. The chilled margins of some plutonic masses may have been by the same phenomenon if they were thermally induced.

The brittle behaviour of the host is indicated by the contact relationships. Magma emplacement may be accounted for by large block-sinking mechanisms like cauldron subsidence, whereas piecemeal stoping is considered of secondary importance.

The presence of miarolitic cavities also denotes low pressure, when gas exsolution from liquids forces the formation of bubbles.

Magma emplacement at such a high crustal level can only be explained if the magmas essentially behaved as mobile liquids with minor amounts of suspended solids. Since the presence of ortophyroxene characterizes the granitoids of the complex, it is inferred that the magmas were water-deficient, to the point that not enough water was available to hydrate all the femic components of the magma, and that their water fugacity was buffered by the assemblage of this anhydrous mineral with other hydrous ones, such as biotite and/or amphibole. To form water-deficient granitoid magmas relatively high temperatures, usually occurring at the base of the crust or in the upper mantle, are required. It is believed, therefore, that these magmas formed at such a depht and that they were hot and dry enough to ascend close to the surface.

If the magmas ever reached the surface, the dyke swarm may have provided very good magmatic vents, especially in the l'Argentera area where is is so dense.

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