MICROGRANULAR ENCLAVES OF THE QUINTANA GRANODIORITE (LOS PEDROCHES BATHOLITH). PETROGENETIC SIGNIFICANCE.

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ABSTRACT

The microgranular enclaves of the Quintana granodiorite (Los Pedroches batholith, Spain) show a complete compositional series from hornblende-plagioclase diorites to porphyritic tonalites, with all transitional stages. A detailed petrographic study reveals that: (1) The fine-grained matrix of the porphyritic types crystallized from a melt quenched in a granitic host. (2) The transition from tonalites to hornblende-rich types can be interpreted in terms of magmatic differentiation of a mafic magma. (3) Correlation between several phases (biotite, hornblende and plagioclase) of the host granodiorite and enclaves can be made indicating a common origin. This correlation strongly suggests the existence of mixing between a mafic magma and a felsic one giving rise to the biotite-hornblende granodiorite of the Quintana pluton.

Key words: Microgranular enclave, Magma mixing, Los Pedroches batholith, granodiorite.

RESUMEN

Los enclaves microgranulares de la granodiorita de Quintana (Batolito de Los Pedroches, España) muestran una serie composicional completa desde dioritas con plagioclasa y hornblenda hasta tonalitas porfídicas, con todo tipo de términos transicionales. Un estudio petrográfico detallado revela que: (1) La matriz de grano fino de los enclaves porfídicos cristalizó a partir de un fundido que se congeló en contacto con un encajante granítico. (2) La transición desde tonalitas hasta enclaves ricos en hornblenda puede ser interpretada en términos de diferenciación a partir de un magma máfico. (3) Se puede establecer una correlación entre fases minerales (biotita, hornblenda y plagioclasa) de la granodiorita encajante y de los enclaves, que podría indicar un origen común para dichas fases. Esta correlación sugiere la existencia de mezcla entre un magma máfico y otro félsico, como proceso generador de la granodiorita del plutón de Quintana.

Palabras clave: Enclave microgranular, mezcla de magmas, batolito de Los Pedroches, granodiorita.

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1. INTRODUCTION

Microgranular enclaves (Didier 1973) are one of the most important petrogenetic indicators in plutonic rocks of acid and intermediate composition (Frost and Mahood, 1987; Cantagrel *et al.*, 1984; Didier, 1987; Vernon, 1983, 1984; White and Chappell, 1977; Chappell *et al.*, 1987). Many of these enclaves can be interpreted according to Vernon (1983, 1984) as "globules of mafic magma quenched in a plutonic environment". This interpretation implies the simultaneous coalescence of both mafic and felsic magmas. An alternative hypothesis (White and Chappell, 1977; Bateman *et al.*, 1963), recently revised by Chappell *et al.* (1987) considers many microgranular enclaves as restites from the partial melting zone. Metamorphic clots in S-type granites can be interpreted easily in the restite model. The problem is to apply this model to I-type granites with mafic, igneous enclaves. Textural relationships in the host granite clearly indicates that several phases (biotite, hornblende, etc.) did not crystallize from the Quintana granitic magma. They can be interpreted as restitic minerals, considering the restite model, or as xenogenous phases from a different magma (mafic) that mingled with a felsic melt considering the magma mingling hypothesis. Both processes can be involved in the genesis of granitic and granodioritic rocks. However, the distinction between the two models, restite or mixing, necessitates a detailed petrographic study.

In the Quintana pluton, the petrographic study of microgranular enclaves and host granodiorite has been made to identify, on one hand, the xenogenous or restitic phases in the granodiorite and their correlation with equivalent phases in the enclaves, and on the other hand, the nature, igneous or otherwise, of the microgranular enclaves. The aim of this paper is to show the mineral and textural relationships between granodiorite and enclaves from the Quintana pluton in order to propose a plausible petrogenetic model. Major element chemistry is also used to support the petrographic and field observations.

2. GEOLOGICAL SETTING.

The Quintana granodiorite occurs as an ovoid pluton at the NW part of the Los Pedroches batholith (Fig. 1). The batholith is mainly composed of two unrelated granitic series (García-Casco *et al.*, 1987): (1) an alumino-cafemic series of biotite hornblende granodiorites (e.g. Quintana pluton) and (2) an aluminous series of cordierite-bearing monzogranites and aplitic granites. The discrimination of the two magmatic series was made on the basis of the A-B multicationic diagrams (Debon and Le Fort, 1983). The two series are also separated in time, the granodiorites of the alumino-cafemic series being older than the minzogranites and related aplitic granites. The whole batholith was emplaced at shallow levels into metasedimentary rocks (Upper Paleozoic), previously deformed and metamorphosed (low grade) during the first phase of the Hercynian Orogeny. It is a major linear batholith, NW-SE oriented (see Fig. 1), parallel to the regional trend of Hercynian structures. Its emplacement can be related to deep seated major faults (2nd Hercynian phase, Castro 1985) acting, at depth.

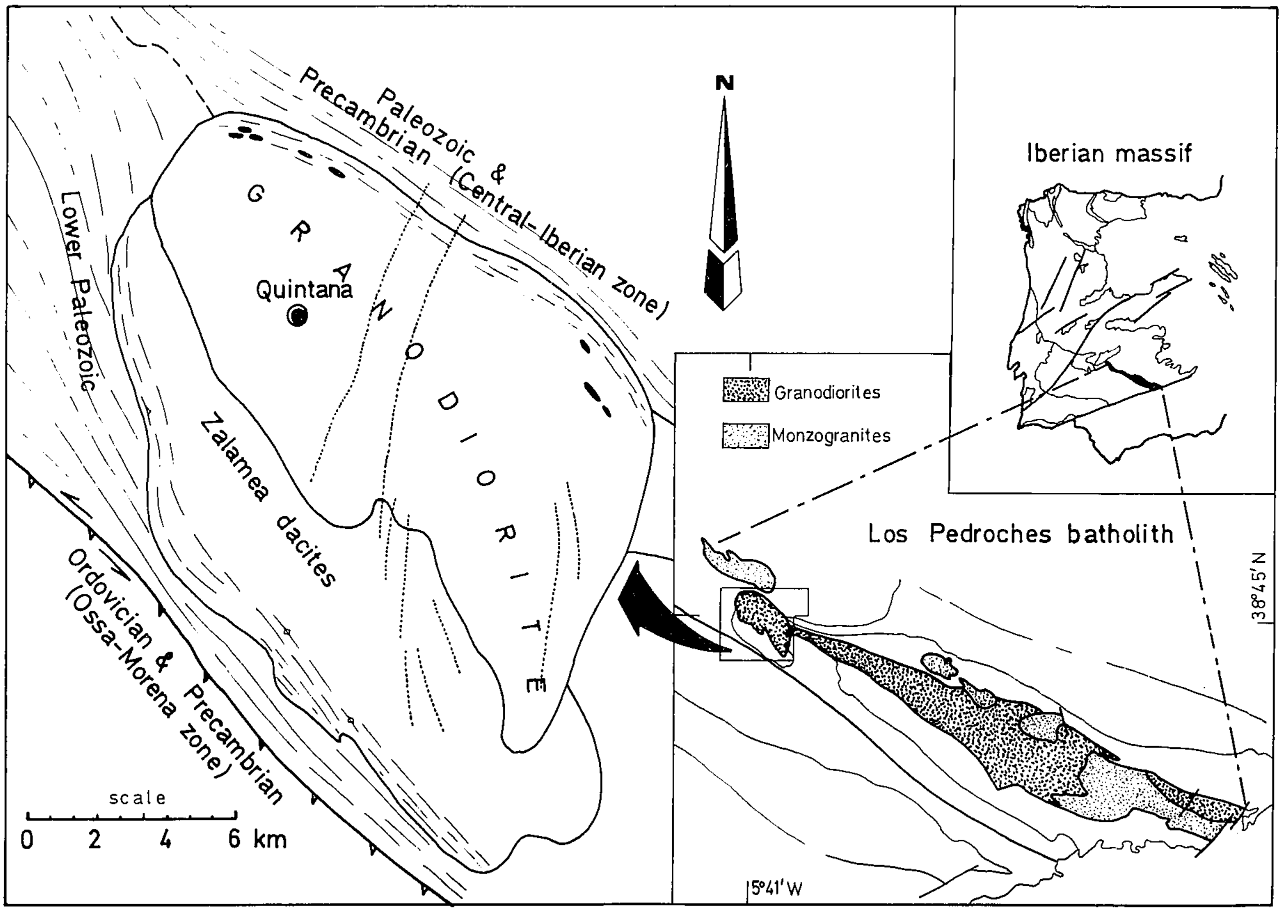


Fig. 1.-Schematic map of the Quintana pluton and its location in the Los Pedroches batholith. Note the foliation and oriented enclaves on the north border. Doted lines are prophyry dikes.

Fig. 1.-Mapa esquemático del plutón de Quintana y su localización en el batolito de Los Pedroches. Nótese la foliación y enclaves orientados del borde norte. Las líneas de puntos son diques de pórfidos.

3. FIELD RELATIONSHIPS

The Quintana pluton (Fig. 1) is mainly composed of biotite hornblende granodiorites. The host rocks are in part Precambrian (Schist-graywacke complex) and Paleozoic metasediments, previously deformed during the first deformation phase (D1) of the Hercynian Orogeny. The SW part of the pluton intruded into dacitic rocks (Zalamea dacites) probably related with the early Hercynian magmatism of the Los Pedroches batholith.

The pluton is not deformed with the exception of the NE border (see Fig. 1) in which the granodiorite contains a weak plano-linear fabric subvertical and parallel to the contact. This deformation (D2) also affects the Zalamea dacites on the SW border. The Quintana pluton is synkinematic with the second phase (D2) characterized in this region by NW-SE oriented sinistral faults as a continuation in time of the sinistral faults of the first deformation phase in the pre-Hercynian basement (Castro, 1988).

The main rock type of the pluton is a medium-grained biotite hornblende granodiorite. In spite of the local variations of the hornblende content, the granodiorite has a homogeneous mineral composition and an isotropic fabric with the exception of the NE border mentioned above. The most salient feature is the presence of microgranular enclaves of several types.

3.1. Microgranular enclaves

The microgranular enclaves are more or less homogeneously distributed within the pluton, representing generally more than 1% volume and locally more than 5% volume. Generally they show an elliptical shape or irregular with rounded contacts. In the foliated zone along the NE border, the enclaves appear deformed and oriented with the major axis horizontal and parallel to the planar fabric of the host granodiorite (Fig. 2a). These elongated enclaves do not show any internal fabric nor intracrystalline deformation, suggesting they were deformed at a magmatic stage. Both granodiorite and enclaves were magmas when they were deformed near the contacts.

A great variety of microgranular enclaves can be recognized according to mesoscopic features such as size, shape, phenocrysts, grain size, etc. In order to simplify the descriptions, and taking into account the gradual variation of the mesoscopic (and petrographic) features, all the enclaves have been grouped into three main categories: two of them are end-members and the third comprising the transitional types.

The first end-member type is constituted by fine-grained porphyritic tonalites (PT enclaves) composed of plagioclase and biotite phenocrysts, with a few hornblende aggregates, within a dark, fine-grained matrix. They appear as little blocks (0.1 to 1 m), sometimes arranged linearly resembling synplutonic dykes (Pitcher, 1979), and generally as small, rounded bodies. The contact with the host granodiorite is sharp (Fig. 2b), in places showing a very fine-grained border (Fig. 2c) like a chilled margin. They have all the features that characterize globules of tonalitic magma (Vernon, 1983, 1984).

The second end-member type is constituted by enclaves very rich in hornblende in fine-grained aggregates with minor plagioclase and biotite (HP enclaves). They are more regular in shape than the PT enclaves, ranging in size from 20 cm to 1 cm (Fig. 2d and e). The contact with the host granodiorite is always diffuse at the crystalline scale (Fig. 2d) and there are no differences in grain size from the core to the margins. Occasionally these enclaves appear disrupted conforming hornblende schlieren (Fig. 2f).

Between these two end-members, described above, there are all kind of enclaves with intermediate features. They are called transitional enclaves (TR enclaves) in this study. The most salient feature is the presence of plagioclase phenocrysts and hornblende aggregates jointly, included in a fine-grained matrix identical to that of the PT enclaves (Fig. 2g,h). The contacts with the host granodiorite are generally transitional but sharp contacts are also present.

4. PETROGRAPHY

4.1. Biotite-hornblende granodiorite.

The granodiorite is a very homogeneous, medium-grained, mesocratic rock with a typical hypidiomorphic texture. It is composed of quartz, plagioclase, K-feldspar, biotite and hornblende. The most common accesory minerals are apatite, sphene, zircon and allanite. The more salient petrographic features of each phase are described below.

4.1.1. Plagioclase.

They are subhedral to anhedral crystals showing generally a complex zoning. This is always oscillatory with the particularity that each zone is in contact to the other through an irregular surface cross-cutting the previous zoning. These surfaces are interpreted as resorbtion zones. Fig. 3 shows two typical crystals of plagioclase from the biotite hornblende granodiorite. The composition contrast on each side of the resorbtion surface is generally greater than 10% mol in anorthite (see Fig. 3). The more usual picture is the presence of at least two or three resorbtion surfaces, but crystals with more than ten surfaces have been recognized. An important observation is hornblende rich granodiorites have plagioclases more complexely zoned, with more resorbtion surfaces, than the biotite rich granodiorites. In some cases, prefferentially in the hornblende rich facies, the plagioclase growing over a resorbed surface has a dendritic texture, similar to that described by Hibbard (1981), suggesting a temperature contrast between the corroded crystal and the surrounding liquid.

4.1.2. K-feldspar.

It typically shows a perthitic texture, appearing always as interstitial and poikilitic with many inclusions of plagioclase, biotite and hornblende. It may also be intergrown with quartz.

4.1.3. Biotite.

Two different types of biotite can be distinguished. The first (Bil) occurs generally as subhedral crystals with many inclusions of apatite needles (Fig. 4a) and minor zircon. The second type of biotite (Bi2) appears in polycrystalline aggregates, without any kind of mineral inclusions and generally associated with hornblende aggregates. The existence of biotite with inclusions of acicular apatite (Bil) is a relevant feature in the granodiorite because there is no apatite in the groundmass included in other minerals with the exception of little aggregates of apatite needles included in quartz.

4.1.4. Hornblende.

There are also two different types of hornblende in the granodiorite. The most common type (Hbl) is constituted by millimetric aggregates (1-4 mm), spherical or elliptical, composed mainly of fine-grained, equigranular green hornblende. They have a nearly poligonal texture similar to that developed in a metamorphic rock by reaction in the solid state. These hornblende clots also appear in the enclaves with the same texture and similar external shape. They can be interpreted as pseudomorphs from pyroxene by complete reaction with the melt of the granodiorite. The same texture is shown by the incomplete reaction rims that characterize the Zalamea dacites (see Fig. 1), the volcanic equivalent of the Quintana granodiorite. These hornblende clots are usually rimed by an external biotite rim (Bi2), a feature also present in the Zalamea dacites. Hbl can be interpreted as xenogenous phase early crystallized in the basic magma of the enclaves and subsequently transformed and incorporated as a xenocryst by the granitoid magma. The second type of hornblende (Hb2) appears as single idiomorphic crystals with a skeletal habit. It is less abundant than Hbl in the granodiorite.

4.1.5. Apatite.

There are two types of apatite distinguished on the basis of the acicular or equant habit. Acicular apatite (Apl) is included in biotite (see Fig. 4a). In the groundmass Apl also appear in small aggregates (Fig. 4b) included in quartz. Apl is never included in hornblende and plagioclase. Apl and Bil may be xenogenous phases not crystallized in the granodioritic magma. The second type of apatite (Ap2) is more equant and appears homogeneously distributed in the groundmass. Ap2 is less abundant than Apl.

4.2. Microgranular enclaves.

The PT enclaves and many transitional types show a porphyritic texture with phenocrysts of plagioclase, quartz, biotite and hornblende aggregates interpreted as pseudomorphs of pyroxenes. The fine-grained matrix is constituted by plagioclase, biotite, quartz, hornblende (more abundant in the transitional types) and acicular apatite. This matrix is less abundant or absent in the HP enclaves. The typical HP enclaves are generally aphyric. The igneous texture is evident in all the microgranular enclaves, but it is more salient in the PT and transitional (TR) types, in which the presence of a fine-grained matrix is indicative of crystallization from a melt in conditions of rapid cooling. There are other textural evidences of undercooling and chilling that will be referred to in the following descriptions. Quartz is a late phase, it appears as large poikilitic crystals suggesting a final stage of slow crystallization. Most of the minerals appear, in more or less abundance, in most of the enclave types. For this reason the minerals will be described irrespective of each enclave-type, and finally the mineral content of each type will be presented in a general table (Fig. 5).

4.2.1. Hornblende.

Hornblende is always present in all the enclaves. It appears in three different textural types: (1) Subidiomorphic, large crystals (Hbl) associated with biotite. (2) Polycrystalline aggregates (Hb2). (3) In the matrix of porphyritic enclaves (Hb3). It is a green hornblende with identical optical properties in the three cases.

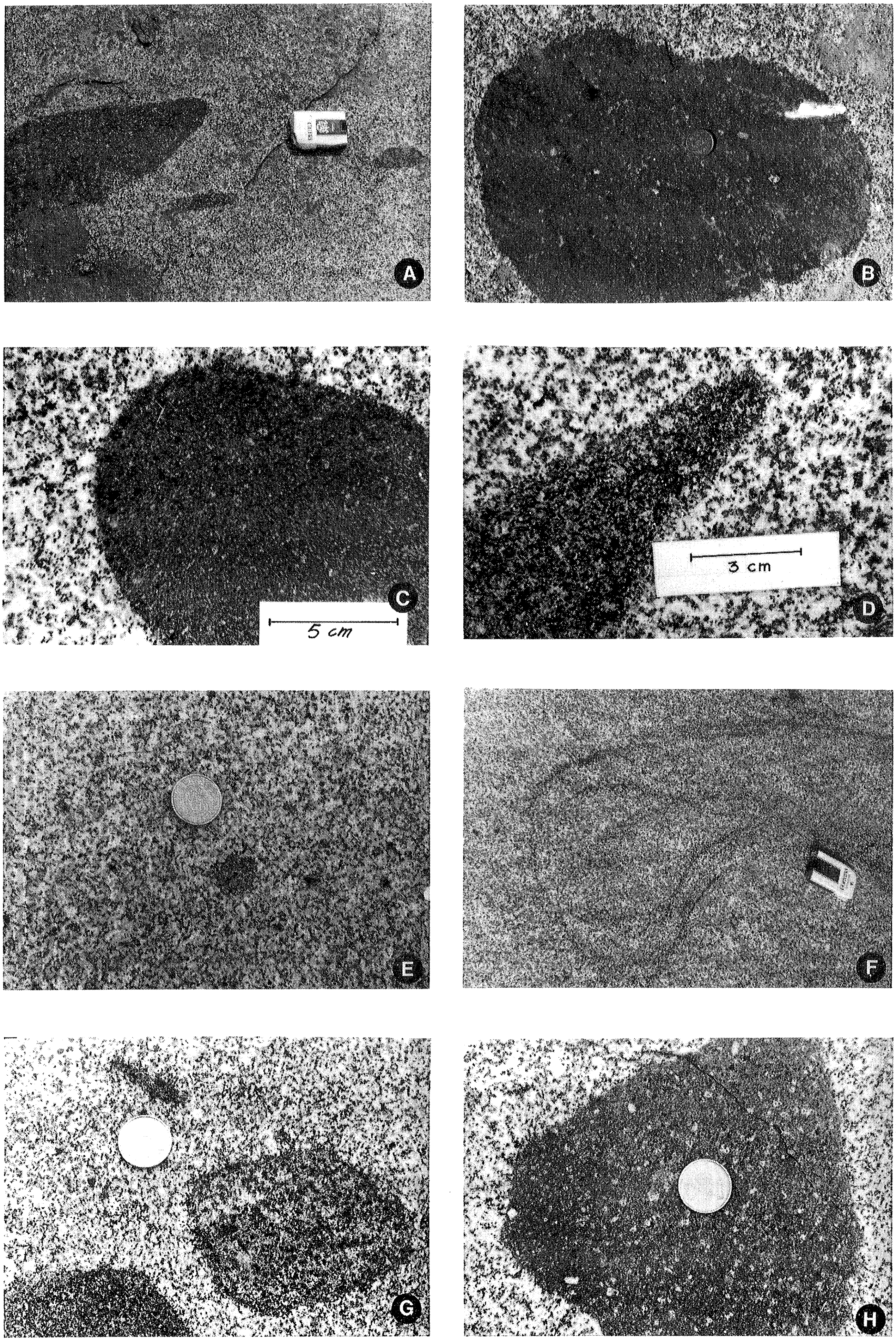
— Hbl shows reaction zones to biotite. It is characteristic of HP enclaves, scarce in the TR and absent in the PT.

— Hb2 appears in polycrystalline aggregates toge— ther with biotite. The aggregates show a regular rectangular shape suggesting the procedence from reaction of early pyroxenes (Fig. 4h). In no case, there are relicts of orthopyroxene included in these aggregates. Hb2 is more abundant in the TR enclaves. These aggregates are identical to those appearing in the host granodiorite.

— Hb3 occurs in fine-grained, single crystals for-

Fig. 2.-Mesoscopic aspects of micrligranular enclaves. A) Oriented enclaves from the north border. B) Typical aspect of PT enclaves. C) PT enclave with a slightly darker marginal zone. D) Typical aspect of HP enclaves showing diffuse contacts with the host granodiorite. E) Small HP enclaves diseminated into the granodiorite. F) HP enclave disrupted and transformed into a schliere structure. G) and H) Transitional (TR) enclaves showing the typical hornblende aggregates (G) and plagioclase phenocrysts.

Fig. 2.-Aspecto mesoscópico de los enclaves microgranulares. A) Enclaves orientados del borde norte. B) Aspecto típico de un enclave PT. C) Enclave Pt con una zona marginal ligeramente más oscura. D) Aspecto típico de los enclaves HP mostrando contacto difuso con la granodiorirta encajante. E) Pequeños enclaves HP diseminados en la granodiorita. F) Enclave HP roto y transformado en schlieren. G) y H) Enclaves transicionales mostrando los típicos agregados de hornblenda (G) y fenocristales de plagioclasa (H).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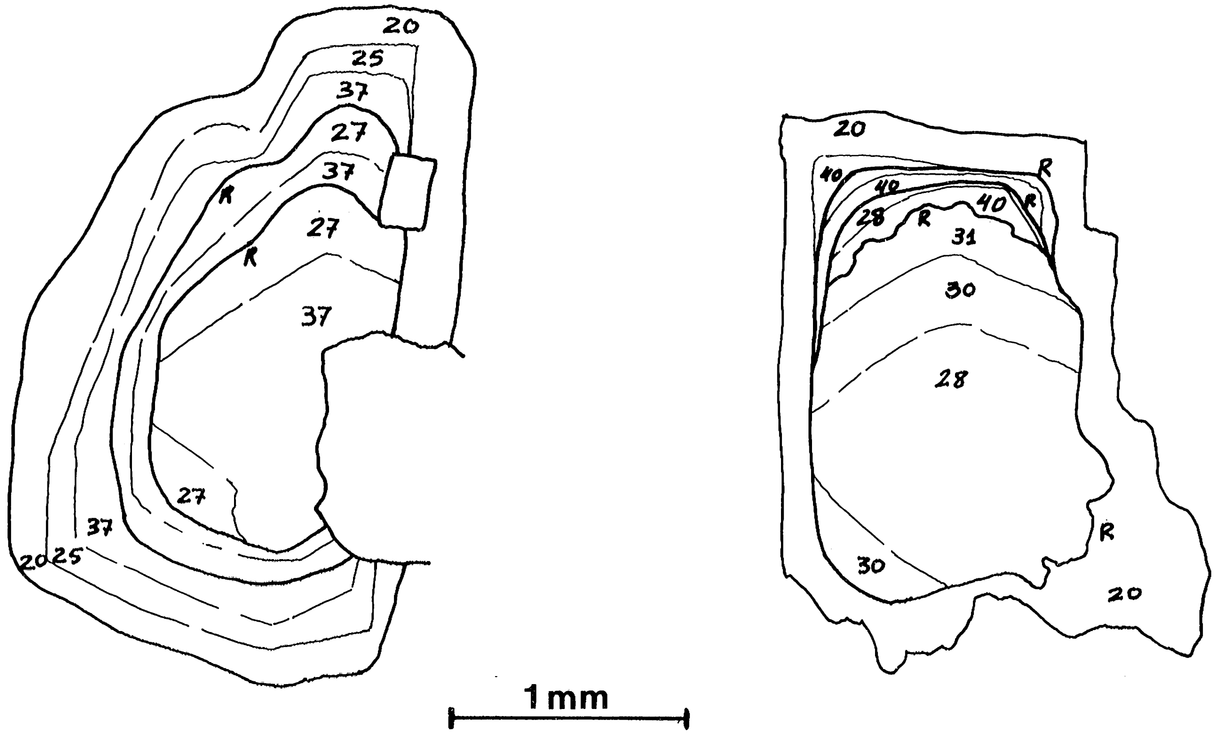


Fig. 3.-The more usual zoning pattern of plagioclases from the biotite hornblende granodiorite. The thick lines are resorbtion surfaces (r). Numbers indicate the mol% in anorthite.

Fig. 3.-Zonados más usuales de las plagioclasas de la granodiorita. Las líneas gruesas son superficies de reabsorción.

ming together with biotite, plagioclase and quartz the matrix of the PT and TR enclaves. It includes acicular apatite.

4.2.2. Plagioclase.

Three textural types of plagioclase, with differences in habit and pattern zoning, can be distinguished in the enclaves.

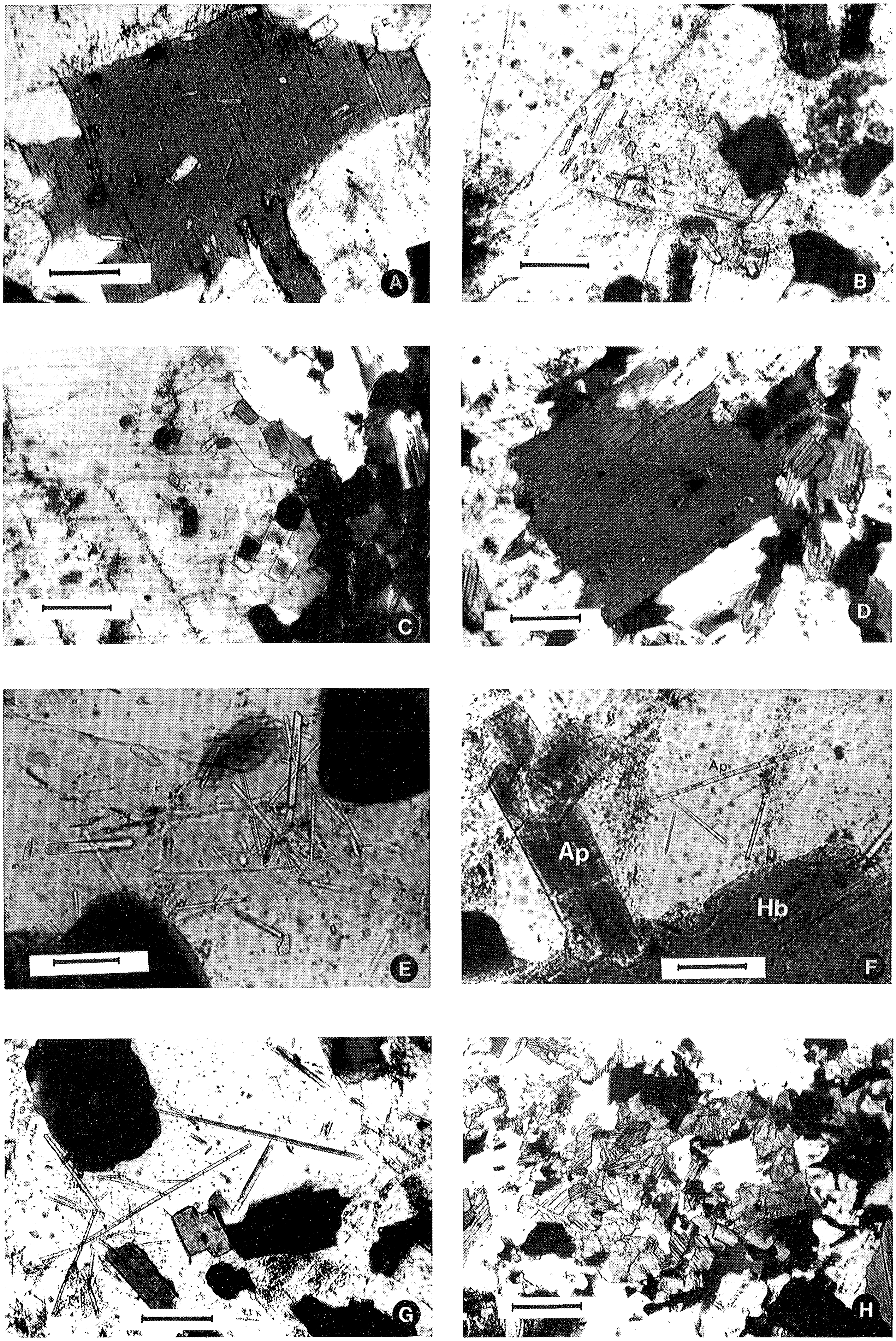
(1) Anhedral crystals, interstitial and poikilitic (PL1) including biotite, apatite and sphene. It is typical of the HP enclaves, scarcely represented in the transitional types and absent in the PT.

(2) Small crystals in the matrix of TR and PT enclaves (PL2). Very scarce in the HP enclaves. PL2 appears as tabular crystals with an idiomorphic core (An_{25} - An_{30}) and a discontinuous rim (An_{15} - An_{20}) . They have apatite inclusions preferentially in the rim zones. Some tabular crystals are aligned showing a fluidal texture contouring the plagioclase phenocrysts.

(3) Phenocrysts (PL3). They are characteistic of the PT enclaves, scarce in the transitional types and absent in the HP. They are subhedral to anhedral crystals (3 to 5 mm). The more salient feature is the presence of a big core showing oscillatory zoning and resorbtion surfaces. These cores are identical in the pattern zoning and composition to the plagioclases of the host granodiorite described above. The core is always contoured by a more or less irregular, rounded surface cross-cutting the previous zoning and resorbtion surfaces (Fig. 6). This can be interpreted as a late resorbtion surface from which a rim of more albitic plagioclase (An_{20}) appears including minerals of the fine-grained matrix, preffe-

Fig. 4.-A) Biotite with inclusions of acicular apatite in the granodiorite. B) Aggregate of acicular apatite in the granodiorite. C) Poikilitic rim of a plagioclase phenocryst of a PT enclave. Note the presence of acicular apatite just in the border. D) Biotite phenocryst in a PT enclave with many inclusions of acicular apatite (compare wit photo A). E) Acicular apatite in the matrix of a PT enclave. F) Two types of apatite, acicular and equant, appearing in a transitional enclave. G) Acicular apatites in the matrix of a transitional (TR) enclave. H) Typical aspect of the hornblende aggregates appearing in the TR enclaves. Identical aspect is shown by the hornblende aggregates appearing in the granodiorite. Scale bar 500 microns in H, 200 microns in A, B, C, D, and G, and 50 microns in E and F.

Fig. 4.-A) Biotita con inclusiones de apatito acicular en la granodiorita. B) Agregado de apatito acicular en la granodiorita. C) Borde poiquilítico de un fenocristal de plagioclasa de los enclaves PT. Nótese la presencia de apatito acicular justo en el borde. D) Fenocristal de biotita en un enclave PT con inclusiones de apatito acicular (Comparar con la foto A). E) Apatito acicular en la matriz de los enclaves PT. F) Los dos tipos de apatito, acicular y prismático, de los enclaves transicionales. G) Apatito acicular en la matriz de un enclave transicional (TR). H) Aspecto típico de los agregados de hornblenda de los enclaves TR. Estos tienen el mismo aspecto que los agregados de hornblenda de la granodiorita. Barra escala = 500 micras en H, 200 en A, B, C, D y G, y 50 en E y F.


A
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rentially acicular apatite (Fig. 4c) but also biotite and plagioclase. The cores of PL3 can be correlated with thase of the host granodiorite and thus considered as xenocrysts in the enclaves.

4.2.3. Biotite.

Biotite appears in three different textural situations.

(1) Associated with Hbl and Hb2 as a product of reaction (Bil). It includes apatite and sphene. Bil is more abundant in the HP and TR enclaves. In the HP, it also appears on the contacts with host granodiorite, but in this case free of inclusions.

(2) Forming the fine-grained matrix (Bi2) of transitional and PT enclaves, and very scarce in the HP types. Bi2 includes acicular apatite.

(3) In phenocrysts (2-3 mm) (Bi3) characterized by the presence of many inclusions of apatite needles (Fig. 4d) with identical aspect to that of the Bil in the host granodiorite. Bi3 is characteristic of the PT enclaves and can occur in some transitional types.

4.2.4. Apatite.

Two types of apatite can be distinguished in the microgranular enclaves.

(1) The first (Apl) is coloured (dark pink) with an equant habit in the HP enclaves (Fig. 4f) and acicular in the TR types (Fig. 4g). It is absent in the PT enclaves.

(2) The second type (Ap2) is transparent and always acicular in habit (Fig. 4e). Ap2 is scarce in the HP enclaves, present in the TR and a conspicuous phase in the matrix of the PT enclaves. Apl is included in Hbl and biotite of the HP enclaves; Ap2 is only included in Pll. In the TR enclaves Apl is acicular and appears included in Hb2, Bil and plagioclase. Ap2 is more abundant than Apl towards the PT enclaves, in which it is included in all the minerals of the matrix, in the biotite phenocrysts (Bl3) and in the rim zones of the plagioclase phenocrysts (Pl3). Never Ap2 is included in the hornblende aggregates (Hb2) but can be occasionally included in the single crystals of hornblende (Hb3) of the matrix. Apatite is one of the more significant phases in the PT enclaves. It typically appears as large needles homogeneously distributed in the matrix (Fig. 4e). The habit of apatite in the PT enclaves can be due to undercooling of the dioritic magma as experimentally produced by Wyllie *et al.* (1962). An important feature is the great concentration of acicular apatites near the contact of the enclave with the host granodiorite, evidencing the existence of a chilled margin 3 or 5 mm thick. This margin, apart from the apatite needle concentration, is also marked by a reduction in the grain size of the matrix.

4.2.5. K-feldspar.

Typically it appears as a late, interstitial and poikilitic, phase. Scarce or absent in the HP enclaves and absent in the PT types.

4.2.6. Quartz.

It is also an interstitial and poikilitic phase. Scarce or absent in the HP and TR enclaves, it is always present as a subordinate phase in the PT enclaves. In some of the PT enclaves there are phenocrysts of quartz with a core free of inclusions and a rim rich in inclusions of apatite, biotite and plagioclase (Pl2). These can be interpreted as xenocrysts from the host granodiorite.

4.3. Petrography interpretations.

Figure 5 shows the relative abundance of each described phase in each enclave type. From the petrographic data of microgranular enclaves and granodiorite the following points can be made:

(1) There is a continuous evolution in texture and mineral content from the HP enclaves towards the more evolved PT types.

(2) The fine-grained matrix, present in all the enclave types, is more abundant towards the PT extreme. This matrix shows all the textural features indicative of rapid cooling from a melt (i) Zoned plagioclase witn tabular habit. (ii) The homogeneous grain size of biotite, hornblende and plagioclase. (iii) The presence of acicular apatite. The HP, TR and PT enclaves show sequential textures that can be only interpreted as the result of crystallization from a melt.

(3) In the PT and TR enclaves crystallization occurred along three stages as deduced from their textures:

(i) In an early stage phenocrysts of pyroxene were developed and acumulated to produce a fractionated tonalitic liquid.

(ii) The second stage of crystallization is characterized by a rapid cooling with the development of a fine-grained matrix. This can be interpreted by chilling of the mafic magma when it intruded into the granodiorite magma probably as synplutonic dikes and pillowed masses.

(iii) If the temperature of the host granodiorite and globules (or dykes) is homogenized before the mafic magma reaches its solidus, a residual melt can be present which thereafter crystallizes slowly, together with the granodiorite, giving rise to the poikilitic quartz and the rims of the matrix plagioclase. This final, slow stage of crystallization is characteristic of synplutonic mafic dykes intruded in epizonal and subvolcanic granite reservoirs (De la Rosa and Castro 1990) and their presence in enclaves can be considered as a criteriom of mixing (Castro *et al.*, 1990).

(4) A close correlation can be made between several minerals from the enclaves and granodiorite: (i) Biotite (Bil) of the granodiorite, rich in apatite inclusions, with biotite phenocrysts (Bi3) of the PT and TR enclaves. (ii) Hornblende aggregates of the granodiorite (Hbl) with hornblende aggregates of the enclaves (Hb2). In both cases these aggregates can be interpreted as a product of reaction from pyroxene (Orthopyroxene ?). (iii) Plagioclase phenocrysts (Pl3) of PT and TR enclaves with plagioclase of the granodiorite.

The tonalitic magma of the enclaves can be consi-

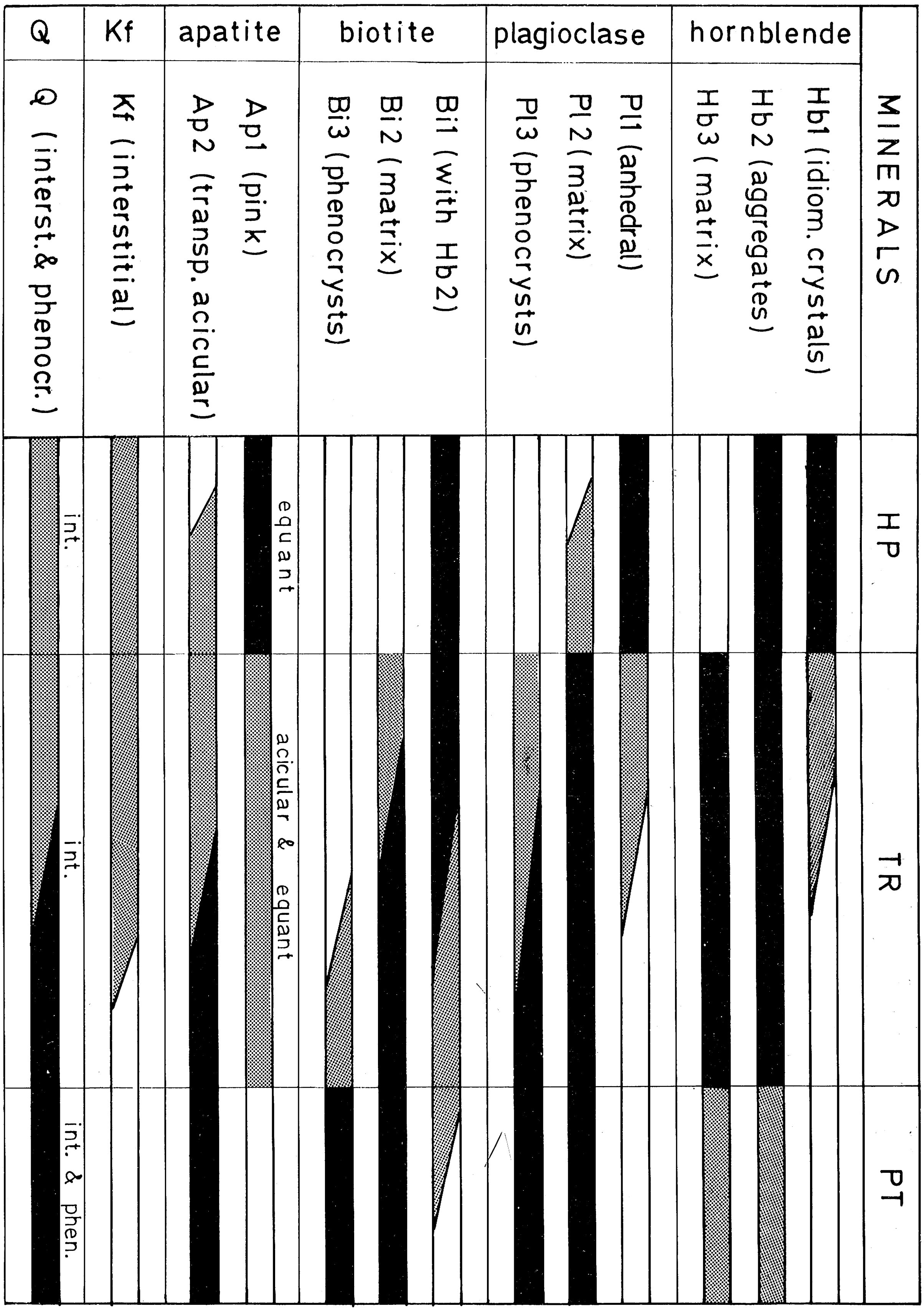

Fig. 5.-Diagramatic sketch showing the distributions of minerals in the three types of enclaves of the Quintana pluton. HP: hornblende-plagioclase enclaves, TR: transitional enclaves, PT: porphyritic tonalite enclaves. Legend, black: abundant; dashed: scarce; white: absent.

Fig. 5.-Esquema diagramático mostrando la distribución de minerales en los tres tipos de enclaves del plutón de Quintana. HP: enclaves con hornblenda-plagioclasa, TR: enclaves transicionales, PT: enclaves tonalíticos porfídicos. Leyenda, negro: abundante; punteado: escaso; blanco: ausente.

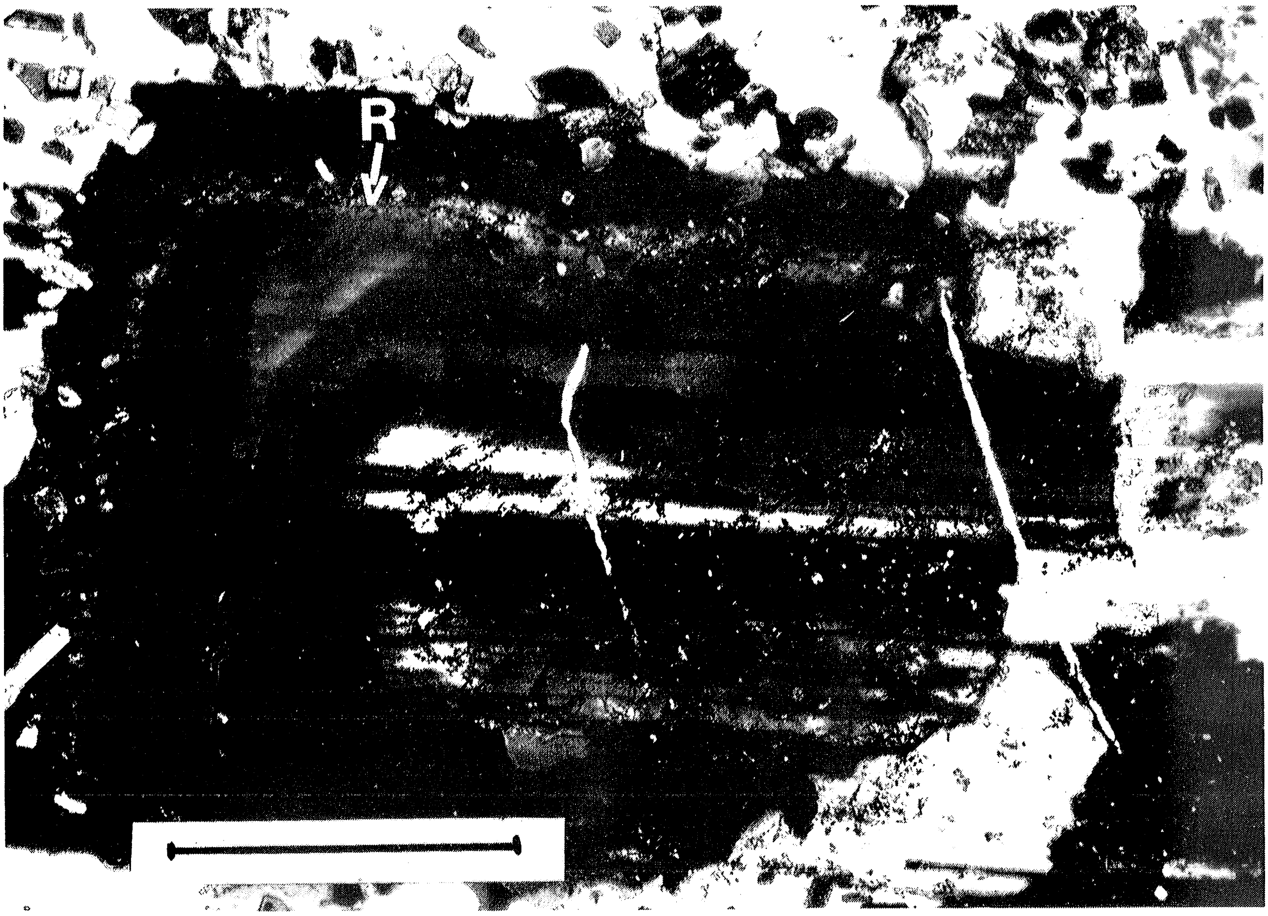

Fig. 6.-Microphotograph of a plagioclase phenocryst (xenocryst) of a PT enclave. Note the resorbtion surface (R) cross-cutting the previous zoning. Scale bar = 1 mm.

Fig. 6.-Microfotografía de un fenocristal de plagioclasa (xenocristal) de un enclave PT. Nótese la superficie de reabsorción (R) cortando la zonación previa. Barra escala = 1 mm.

dered as a hybrid so it contains xenocrysts of plagioclase and quartz, originally crystallized, in its greatest part, from the granitoid magma and captured by the tonalitic magma during intrusion in synplutonic bodies. These xenocrysts are more abundant in the more evolved compositions (PT and TR types), so they intruded as liquids with a few suspended fenocrysts (pyroxene) and thus they had more mobility and ability to capture xenocrysts from the host granitoid magma.

The HP enclaves can be considered as transformed cumulates with a high crystal content, draged by the fractioned tonalitic liquid and the hybrid granodiorite, suggesting differentiation and mixing to occur simultaneously. Occasionally they appear as enclaves inside tonalitic (PT or TR) enclaves.

The granodiorite can also be considered as a hybrid rock so it contains xenocrysts of biotite and hornblende (clots from pyroxene reaction) early crystallized in the basic magma before or during its differentiation and intrusion into the felsic magma chamber. The resorbed surfaces, repeted as an oscillatory zoning, in the plagioclases of the granodiorite can be due to repeted inputs of mafic magma in the felsic chamber. Each resorption surface means an input of basic magma with the subsequent temperature increase enough to produce resorbtion in the crystallizing plagioclase and regrowing by a more anorthitic zone due, in part, to the change in composition by diffusive mixing of the liquid close to the interface after resorbtion. An increase of more than 10% mol of anorthite after resorbtion is probably great enough to be produced by a change in the liquid composition, more than a simple homogeneization by ionic diffusion near the interface as proposed classically to explain the usual oscillatory zoning, with no resorbtion surfaces, appearing in most volcanic plagioclases. The new plagioclase growing over the resorbed surface can crystallize as dendritic, involving undercooling, so the corroded core can act as a cooler body for heterogeneous nucleation and dendritic growth.

These features of plagioclases can be considered as indicative of magma mixing as they characterize most plagioclases of granodiorite rocks clearly identified as hybrid by field, petrographical and chemical criteria (De la Rosa and Castro, 1990).

5. MAJOR ELEMENT CHEMISTRY.

Table 1 shows the chemical composition (major elements) and CIPW norms of the analyzed (XRF) samples from the granodiorite (7 samples) and microgranular enclaves (12 samples). The enclaves have been

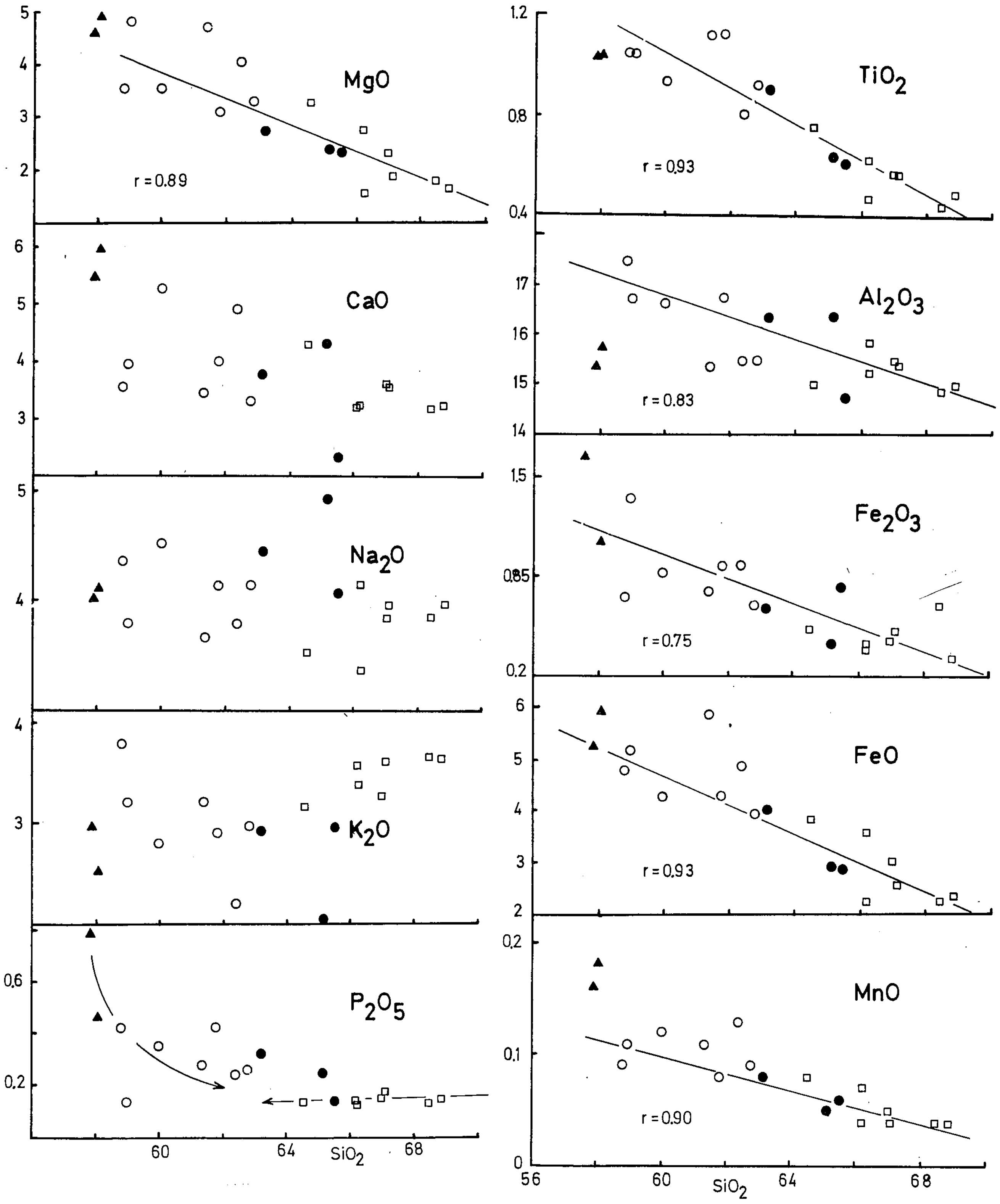

Fig. 7.-Silica-variation diagrams of the analyzed samples. Squares: granodiorites. Full circles: PT enclaves. Open circles: Transitional enclaves. Triangles: HP enclaves. Arrows in the P_2O_5 plot indicate the probable trends of mixing (strike line) and differentiation (curved line).

Fig. 7.-Diagramas de variación con la sílice de las muestras analizadas. Cuadrados: granodioritas. Círculos rellenos: enclaves PT. Círculos huecos: enclaves transicionales. Triángulos: enclaves HP. Las flechas en el diagrama P_2O_5 indican las evoluciones probables de mezcla (línea recta) y diferenciación (curva).

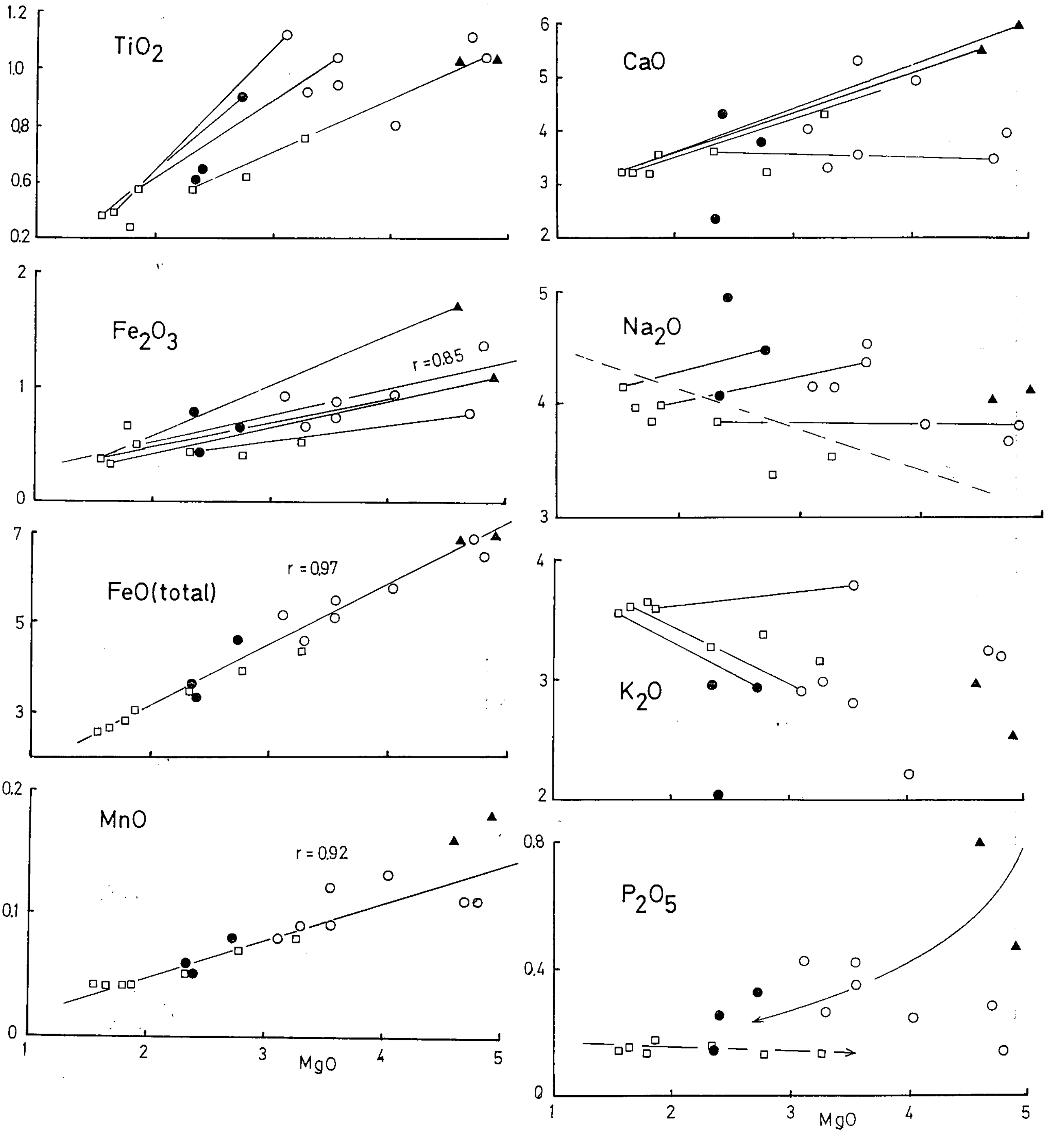

Fig. 8.-MgO-variation diagrams of the analyzed samples (Symbols like in Fig. 7). Each tie line links a pair of samples collected in the same outcrop. The two trends on the P_2O_5 plot have the same significance than in Fig. 7.

Fig. 8.-Diagramas de variación con el MgO de las muestras analizadas (Símbolos como en la Fig. 7). Cada línea de conjugación une un par de muestras cogidas en el mismo afloramiento. Las dos secuencias en el diagrama P_2O_5 tienen el mismo significado que en la Fig. 7.

TABLE 1: Chemical analysis of the Quintana granodiorite and related enclaves

GRANODIORITES

SAMPLE	GQ-1	GQ-6	GQ-7	GQ-8	GQ-17	GQ-19	GQ-21
SiO_2	66.21	67.00	66.24	64.52	67.12	68.44	68.86
TiO_2	0.47	0.57	0.62	0.75	0.57	0.44	0.49
Al_2O_3	15.82	15.44	15.19	14.95	15.32	14.82	14.95
Fe_2O_3	036	0.43	0.40	0.51	0.49	0.66	0.32
FeO	2.24	3.00	3.54	3.82	2.55	2.20	2.33
MnO	0.04	0.05	0.07	0.08	0.04	0.04	0.04
MgO	1.55	2.32	2.77	3.26	1.86	1.79	1.65
CaO	3.20	3.58	3.22	4.29	3.56	3.17	3.21
Na_2O	4.14	3.84	3.37	3.52	3.97	3.84	3.96
K_2O	3.55	3.26	3.37	3.16	3.59	3.64	3.61
P_2O_5	0.14	0.15	0.12	0.13	0.17	0.13	0.15
TOTAL	92.72	99.64	98.91	98.99	99.24	99.17	99.57

TRANSITIONAL ENCLAVES

SAMPLE	GQ-22	GQ-4	GQ-3	GQ-14	GQ-15	GQ-16	GQ-20
SiO_2	62.41	61.40	59.00	60.00	62.81	58.83	68.86
TiO_2	0.80	1.11	1.04	0.94	0.92	1.04	0.49
Al_2O_3	15.44	15.32	16.70	16.57	15.44	17.45	14.95
Fe_2O_3	0.92	0.76	1.36	0.87	0.66	0.72	0.32
FeO	4.84	5.84	5.16	4.26	3.94	4.77	2.33
MnO	0.13	0.11	0.11	0.12	0.09	0.09	0.04
MgO	4.04	4.71	4.80	3.55	3.29	3.55	1.65
CaO	4.92	3.54	3.96	5.27	4.49	4.24	3.21
Na_2O	3.79	3.66	3.79	4.52	2.97	4.36	3.96
K_2O	3.21	3.22	3.20	2.80	2.97	3.78	3.61
P_2O_5	0.24	0.28	0.14	0.35	0.26	0.42	0.15
TOTAL	92.74	99.86	99.26	99.25	99.01	99.25	99.57

	HP ENCLAVES		PT ENCLAVES		
SAMPLE	GQ-12	GQ-13	GQ-2	GQ-5	GQ-18
SiO_2	58.09	57.89	63.18	65.17	65.51
TiO_2	1.03	1.03	0.90	0.64	0.61
Al_2O_3	15.69	15.32	16.32	16.32	14.70
Fe_2O_3	1.07	1.68	0.64	0.41	0.78
FeO	5.88	5.21	3.98	2.91	2.86
MnO	0.18	0.16	0.08	0.05	0.06
MgO	4.90	4.59	2.73	2.40	2.34
CaO	5.91	5.45	3.76	4.31	3.89
Na_2O	4.10	4.01	4.46	4.93	4.07
K_2O	2.52	2.95	2.92	2.03	2.95
P_2O_5	0.46	0.79	0.32	0.25	0.14
TOTAL	99.83	99.08	99.29	99.42	97.91

grouped in the three petrographic categories: PT (porphyritic tonalites), HP (hornblende-plagioclase diorites) and TR (transitional types). These three groups can also be distinguished by: (1) The SiO_2 content, around 58%, HP; 59%-62%, TR and 63%-65%, PT. (2) The alkalis ratio (3) The MgO content, > 4.5% in HP and TR, and < 3% in PT.

Figure 7 shows the silica variation diagrams for granodiorites and enclaves. Most of the diagrams are characterized by a good rectilinear trend. It can be noted that: (1) The simple linear correlation is tighter for the samples richer in SiO_2; that is, for the granodiorites, PT enclaves and several transitional types. (2) The HP enclaves fall outside the rectilinear trend in most cases. This is especially clear in the Al_2O_3, Fe_2O_3, FeO, MnO, MgO and P_2O_5 diagrams. (3) A scattered distribution for lime and alaklis.

A very similar pattern can be deduced for the MgO variation diagrams (Fig. 8). Alkalis and lime are not well correlated. Contamination can be suggested to explain these scattered distributions of alkalis. The enrichment of SiO_2 and alkalis is nearly constant for three pairs of samples (Granodiorite and enclave) collected each one in the same outcrop. However, a late process of fluid migration can result in a similar pattern for the alkalis.

P_2O_5 and TiO_2 clearly show two trends. The change in slope from one trend to another is situated approximately on the transitional enclaves.

6. DISCUSSION.

The four points summarizing the petrography clearly suggest a combined process of differentiation and mixing to explain the observed features. This combined process can be also suggested on the basis of the chemical variations.

All the enclave types can be related by a differentiation mechanism from a mafic magma. The HP enclaves may represent crystals cummulates of pyroxene (now hornblende) with an intercumular plagioclase (Pl1). In these enclaves the presence of a residual liquid is evidenced by the existence of a fine-grained matrix with acicular apatite. This residual liquid is more important in volume towards the PT types. The existence of transitional types suggests that PT enclaves may be interpreted as differentiates from the same magma. The double trend in several variation diagrams (e.g. P_2O_5 - SiO_2, Fig. 7) also can indicate a process of differentiation relating HP and PT enclaves. The existence of a mixing process, or crystal mingling at least, is supported on the rectilinear trends of the variation diagrams (e.g. Frost and Mahood, 1987; Cantagrel *et al.,* 1984; Brown and Becker, 1986) but this process mainly relates granodiorites, PT enclaves and several transitional types.

On the other hand, mingling of crystals is strongly supported on the basis of the mineral correlations established for plagioclase, biotite and hornblende aggregates from both granodiorites and enclaves.

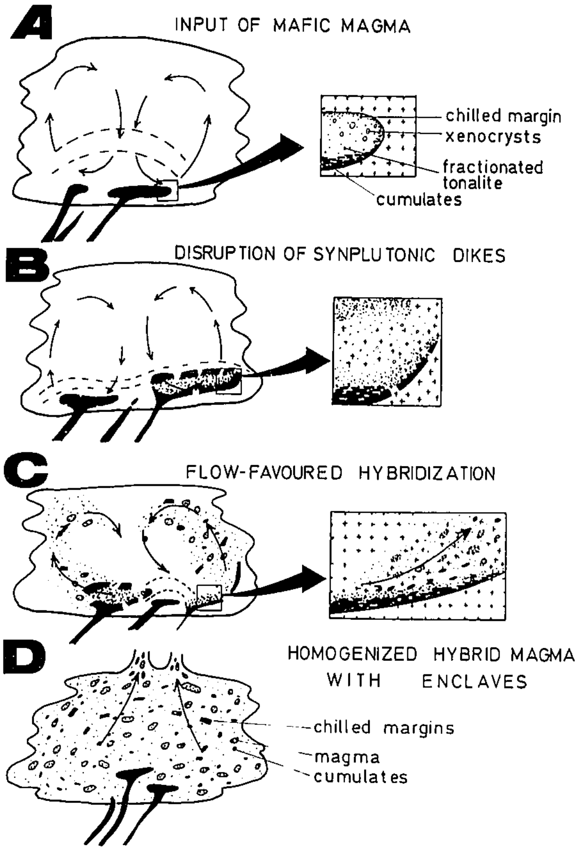

Fig. 9.-Schematic model illustrating the processes implied in the genesis of the Quintana granodiorite (see text).

Fig. 9.-Modelo esquemático ilustrando los procesos implicados en la génesis de la granodiorita de Quintana (ver texto).

A necessary condition for magma mixing is the mafic magma intruded into the felsic one. In our case the residual liquid (matrix) differentiated from the mafic magma, shows all kind of evidences revealing chilling into the felsic magma. In addition, the three stages of crystallization only can be explained by chilling and further slower crystallization.

It can be concluded that mingling of crystals (and probably diffusive mixing), between a felsic magma and a differentiating mafic one, is the process implied in the genesis of the Quintana granodiorite. Part of the biotite and most of the hornblende (from pyroxene) did not crystallize from the granodioritic magma but from a mafic one, which intruded into a felsic reservoir, giving rise to synplutonic dykes. The absence of mixing zones at the final level of emplacement and of the pure felsic end-member (the granodiorite is very homogeneous) clearly suggests that mixing occurred at depth. Ascent and emplacement are very energetic processes that can contribute to the complete homogeneization of the hybrid granodiorite.

Figure 8 shows a schematic, four stages model illustrating the processes involved in the genesis of the Quintana granodiorite. The process starts with the input of a basaltic magma into a felsic magma chamber or a partial melting zone (Fig. 9A). This induces a thermal anomally and consequently the convection of the felsic magma. At the same time the basaltic magma differentiates to a mafic tonalitic liquid and an ultramafic cumulate. The tonalitic liquid chills against the felsic one giving rise to a rigid 'shell' (chilled margin). Synplutonic bodies with rigid, chilled walls are broken by the convective magmatic flow (Fig. 9B), the two magmas being in contact at thermal equilibrium. At this stage the two magmas can mix their crystals and liquids, this process being highly favoured by magmatic flow (Fig. 9C). Non-hybridized parts of the tonalitic magma remain as enclaves together with fragments of the chilled margins and cumulates. The hybrid magma containing these enclaves can ascend via fractures giving, rise to a homogeneized hybrid granodiorite with enclaves, at epizonal levels. It can also crystallize at depth in the early felsic magma chamber or partial melting zone.

If anatexis was by a basic, mantle-derived magma, mixing is the process that can be more probably expected to occur at the partial melting zone. This explanation excludes the possibility that coalescence of basic and felsic magmas was a casual phenomenom.

Although fiel, petrographic and chemical (major elements) data, exposed in this paper, strongly support a magma mixing origin for the Quintana granodiorites, a more detailed geochemical work including trace elements and isotopes is required to confirm the petrogenesis of these granodiorites. This work and that concerning the mineral chemistry of ferromagnesian phases from both enclaves and granodiorites is under study actually.

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