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The mafic magmatic enclaves of some Northern Sardian granitoids: the existence of two different acid-basic associations.

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ABSTRACT. — Mafic magmatic enclaves associated with some representative Sardinian carboniferous granitoids are subdivided into two distinct populations: one (E1) shows chemical characters close to those of low differentiated thoelitic magmas; the other (E2 + E3) either represents evolved terms of a tholeiitic trend or is the result of a hybridization process between an iron-rich basic magma and a more acidic magma. The chemical specificities of these two enclaves groups are found within certain gabbroic complexes in Northern Sardinia (Punta Falcone). These two mafic groups may also be distinguished by their occurences inside different granitoid formations: tonalites and granodiorites (G1) for the first basic group and monzogranites (G2) and leucogranites (G3) for the second one. Thus, the mafic magmatic enclaves in granitoids from northern Sardinia belong to two distinct acid-basic associations: E1-G1 on the one hand and E2-G2 + E3-G3 on the other.

Key words: enclave-granitoid association, mingling processes.

LES ENCLAVES MAGMATIQUES MAFIQUES DE CERTAINS GRANITOIDES DE SARDAIGNE SEPTENTRIONALE: EXISTENCE DE DEUX ASSOCIATIONS ACIDE-BASIQUE DIFFERENTES.

RESUME. — Les enclaves magmatiques mafiques associées à certains granitoïdes représentatifs de Sardaigne, d'âge carbonifère, se répartissent en deux populations distinctes: l'une (E1) montre des caractères chimiques proches de magmas tholéiitiques peu différenciés; l'autre (E2 + E3) représente les termes évolués d'une lignée tholéiitique, ou est le résultat de l'hybridation de magmas basiques ferrifères et de magmas granitiques. Les spécificités chimiques de ces deux groupes d'enclaves se retrouvent dans certains complexes gabbroïques du Nord de la Sardaigne (Punta Falcone). Ces deux groupes mafiques sont également distincts par leurs occurrences au sein de formations granitiques différentes: tonalites et granodiorites (G1) pour le premier groupe basique et monzogranites (G2) et granites leucocrates (G3) pour le second. Ainsi les enclaves mafiques magmatiques des granitoïdes de Sardaigne Septentrionale appartiennent à deux associations acide-basiques distinctes: G1-E1 d'une part et G2-E2 + G3-E3 d'autre part.

Mots clés: association enclave-granitoïdes, mélange non-achevé.

Introduction

Mafic microgranular enclaves in infracrustal granitoids are considered to be of magmatic origin and to have emplaced and crystallised at about the same time as the host rock (PABST A., 1928; BATEMAN P.C et al., 1963; DIDIER J., 1964, 1973; MARRE J., 1973; WIEBE R.A., 1974, 1980; BARRIERE M., 1977; LETERRIER J., DEBON F., 1978; ORSINI J.B., 1979; VERNON R.H., 1983, 1984).

Such particular acid-basic associations result from a mingling process between two distinct magmas (LIPMAN P.V., 1963; WALKER G.P.L., SKELHORN R.R., 1966; YODER H.S., 1973; VOGEL T.A., WILBAND J.T., 1978; ORSINI J.B., 1979; BRALIA A. et al., 1981; DIDIER J., 1983, 1987). The different compositions, temperatures and viscosities of two magmatic liquids determine that the result of this mixing process is not an homogeneous

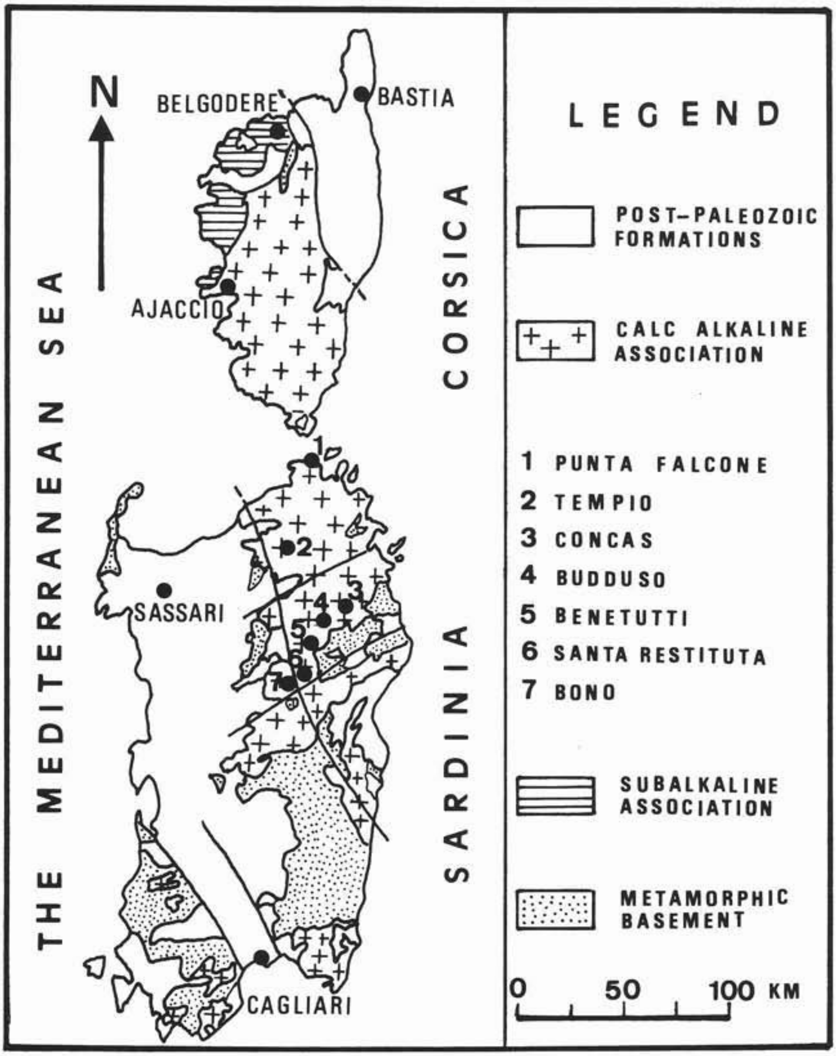

Fig. 1. — Schematic map of Hercynien Sardinian-Corsican Batholith.

liquid or rock, but generaly an enclave-granitoid association.

The proposed mechanisms for the microgranular enclave formation include rising, forcible injection and fragmentation of basic magma in an acid magma chamber (SPARKS R.J.S. et al., 1977; BLAKE S., 1984; FURMAN T., SPERA F.J., 1985), followed by convective dispersal of stratified host magma (HUPPERT H.E. et al., 1984) and the intrusion of the resulting acid-basic associations (COCIRTA C., ORSINI J.B., 1986).

The objective of this study is to verify whether one or several types of enclaves correspond with the different types of Sardinian Carboniferous granitoids. This implies retracing the evolution preceding the mingling of the basic magma at the origin of the enclaves, as well as comparing them with those which typify certain gabbroic complexes includes in the calc-alkaline association of the Sardinian-Corsican batholite. In order to resolve these problems we studied the enclaves associated with some representative granitoid massifs from the southern part of the Sardinian-Corsican batholith and the gabbros of the Punta Falcone massif by using a very large number of chemical analyses (major elements) of the enclaves, granitoids and gabbros (BRUNETON P., 1976; ORSIIN J.B., 1980; BRALIA A. et al., 1981; LE GALL B., 1985).

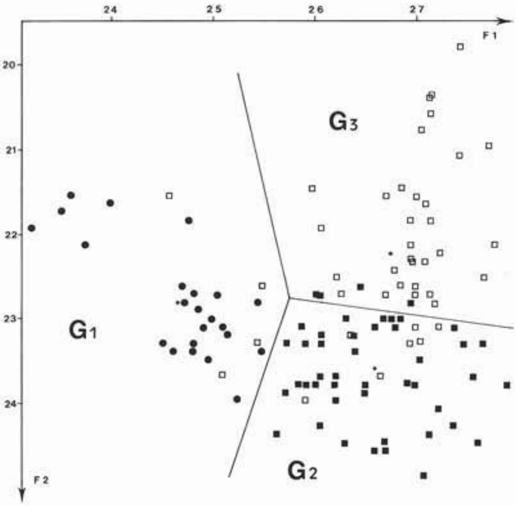

Fig. 2. — Discriminant statistical analysis applied to the Sardinian Granitoids: G1 (●), G2 (■) et G3 (□).
F1 = + 4.1 MnO + 3.3 TiO_2 + 0.4 SiO_2 + 0.2 CaO - 0.3 MgO.
F2 = + 22.1 MnO + 1.2 MgO - 0.3 SiO_2 - 1.6 CaO - 2.1 TiO_2.

Geological framework

The ensemble of granitoids which make up the Sardinian-Corsican batholith (Fig. 1) are connected whith two magmatic associations (ORSINI, 1976):

a) **the subalkaline potassic association** which is defined and developed in northwest Corsica (Balagne);
b) **the calc-alkaline association**, of greater extention, constitutes the central and southern part of the Sardinian-Corsican batholith; it extends from the Sardinia as for south as Belgodère-Ajaccio in Corsica.

Petrographically this association consists of terms ranging from tonalites to alaskites, with which basic rocks (gabbroic stocks and lopoliths, and mafic magmatic enclaves) are associated. Based on the mineralogic composition and the occurence type, three major granitic groups have been distinguished whithin the region of Goceano (GHEZZO C. et al., 1973, 1982; DI SIMPLICIO P. et al., 1974; DEL MORO A. et al., 1975; ORSINI J.B., 1976, 1980; BRALIA A. et al., 1981; LE GALL, 1985). These three groups can be chemically indentified by a discriminant statistical analysis with SiO_2, CaO, MgO, TiO_2 and MnO which reclasses into their respective group 87% of the granitoids (Fig. 2).

— **The group G1:** it consist of intrusions, generally of small size, simples or composites, homogeneous or midly differentiated. These massifs, considered to be tarditectonics, consists of tonalites and granodiorites with biotite and amphibole.

— **The group G2:** is the group the most represented in the calc-alkaline association. Its composition evolves from granodiorites with biotite +/— hornblende, to leucocratic monzonitic granites. The presence of potassic feldspar megacrystals is a dominant caracteristic of this group. The geometry of these post-tectonic intrusions within the region of Goceano is generally concentric (BRUNETON P. et al., 1977).

— **The group G3:** this group is essentially formed of siliceous leucocratic granites with biotite and garnet +/— muscovite.

The geochronological datings of the Sardinian granitoids (Rb/Sr) resultes in ages od 297 +/— 6 My for G1, 292 +/— 5 My for G2 (DEL MORO A. et al., 1975, old constants). More recently (FERRARA et al., 1978; BECCALUVA et al., 1985, new constants), the ages obtained for G1 and G2 range between 307 and 289 My. For G3, which cuts the two precceding groups, their formations have taken place around 275 +/— 4 My (COCHERIE A., 1978).

The models of genesis and deposition of the granitoids of the Sardinian-Corsican batholith and their associated basic rocks imply the existence of several types of magmas which, following the different phenomena (hydridization, differenciation) gove birth to the calc-alkaline association (BRALIA A. et al., 1981; COCHERIE A., 1984; ROSSI PH., 1986). And so the basic massifs may be the result of the fractioned intercrustal crystallization of a basic aluminous liquid generated by the partial fusion of the mantle (COCHERIE A., 1984). The most acidic terms of the granitoids (G2 and especially G3), probably originate from monzonitic magma of crustal nature, and the intermediary granodioritic rocks (G1) probably result from a hybridization of concentric structure resulting from the intrusion of three succesive injection of different nature: the tonalitic intrusion of Burgos, the intrusion of Bottida consisting of a granodiorite with amphibole and biotite, and the intrusion of Emauru which is a granodioritic nature. *The massif of Santa Restituta* consists of only one intrusion of

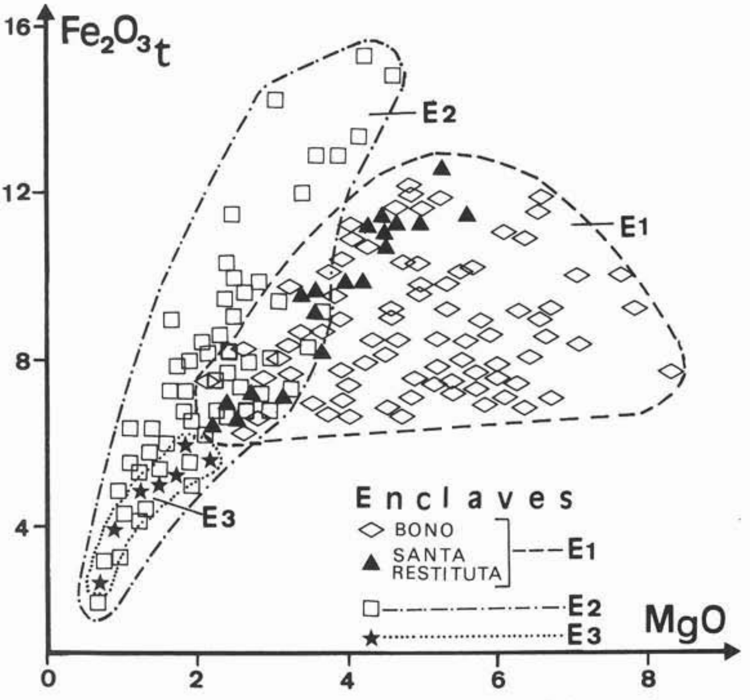

Fig. 3. — Fe_2O_3total versus MgO diagram for enclaves included in Sardinia granitoids.

primary acidic and basic magmas (BRALIA A. et al., 1981; ROSSI PH., 1986). These phenomena of formation and hybridization of the magmas which took place in the base of the earth's crust were accompanied or followed by some mingling processes resulting in the constitution of these enclave-granitoid associations.

To prove the existence of specific acidic-basic associations we have studied the enclaves included within some of the representative granitoid massifs of each of the three groups (Fig. 1).

1) **Group G1** (Bono and Santa Restituta). *The massif of Bono* presents a complex granodiorite with amphibole and biotite.

Both of these massif are very rich in mafic enclaves (E1), typified by granular and microgranular textures, and by a regular distribution within their host rocks.

2) **Group G2** (Budduso, Tempio, Benetutti). *The massif of Budduso* is represented by a zoned concentric intrusion consisting of, from the border towards the center, tonalites, granodiorites, monzogranites with megacrystals of potassic feldspar, and leucocratic granites. *The massif of Tempio* is the result of one injections of granitoids with megacrystals of potassic feldspar (granodiorites with biotite and amphibole, and

monzogranites with biotite). *The massif of Benetutti*, whose intrusions is near subsynchronous with those of Budduso massif, is made up of granodiorites and monzogranites with megacrystals of potassic feldspar and monzogranites with biotite and muscovite.

These granitoids, in comparison with those of group G1, are poorer in mafic enclaves (E2) caracterised by a microgranular texture, finer than that of the E1 enclaves, as well as by a irregular distribution inside their plutons.

3) **Group G3** (Concas). *The massif of Concas* consists essentially of leucocratic granites with garnet +/— muscovite. The mafic enclaves have a microgranular texture and are very rare.

Chemical characters of basic enclaves

The Sardinian enclaves are generaly characterised by a wide variety in chemical and quantitative mineralogical compositions inside of each massif or group of massifs (ORSINI J.B., 1976; BRALIA A. et al., 1981; COCIRTA C., ORSINI J.B., 1985). This chemical diversity explains the partial compositional overlaps (Fig. 3) between the enclaves of different massifs in inside the same group (e.g. Bono and Santa Restituta enclaves of G1 group), and between the enclaves of different groups (e.g. G1 with G2 and G2 with G3). These overlaps, shown as well by the ensemble of major elements suggest either a nearly identical composition of original basic liquids, or subsequent contamination phenomena responsible for chemical convergence. In the latter case, the original composition of the basic magmas involved in the mingling process is masked by ulterior contamination.

In order to specify the nature and possible evolution of the initial basic magmas, only the most mafic enclaves were taken into account. The selection criteria were chemical, mineralogical and textural in nature (COCIRTA C., ORSINI J.B., 1986). Employing these

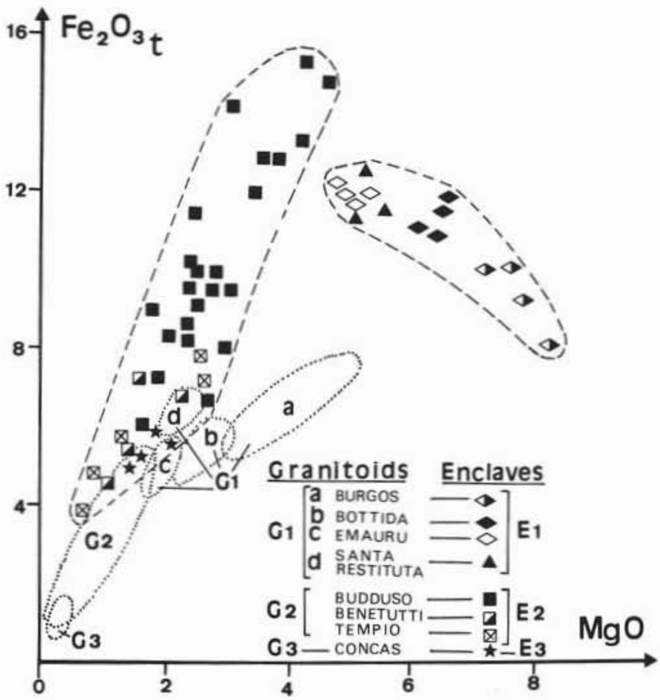

Fig. 4. — Fe_2O_3total versus MgO diagram for the most mafic enclaves and Sardinia granitoids.

criteria, all of the enclaves showing signs of certain contamination (presence of xenocrysts and/or pseudo-porphyric textures) were eliminated. The composition of the most mafic enclaves is considered to be nearly identical with that of their original basic magmas (COCIRTA C., 1986; COCIRTA C., et al., 1988). These enclaves are divided into two groups (Fig. 4 and 5).

— **The first groupe**, composed of the most mafic E1 enclaves, are included solely in G1 granitoids. This group (E1) is characterised by enrichment in Fe_2O_3total (Fig. 4) and TiO_2 (Fig. 5) and an impoverishment in MgO and CaO moving from Burgos to Bottida, Emauru and Santa Restituta enclaves. These variations are concurrent with the evolutions of the host rocks towards more acidic terms: in the same way the Burgos tonalites evolve towards Bottida, Emauru, and Santa Restituta granodiorites (Fig. 4).

— **The second group**, composed of the E2 and E3 enclaves is enclosed especially in G2 and G3 host rocks. This enclave population shows and impoverishment in Fe_2O_3total (Fig. 4), MgO, CaO et TiO_2 (Fig. 5) moving from Budduso to Tempio and Benetutti, while the silica of their host rocks increases in the same direction: granodiorites towards monzogranites and leucogranites (Fig. 4).

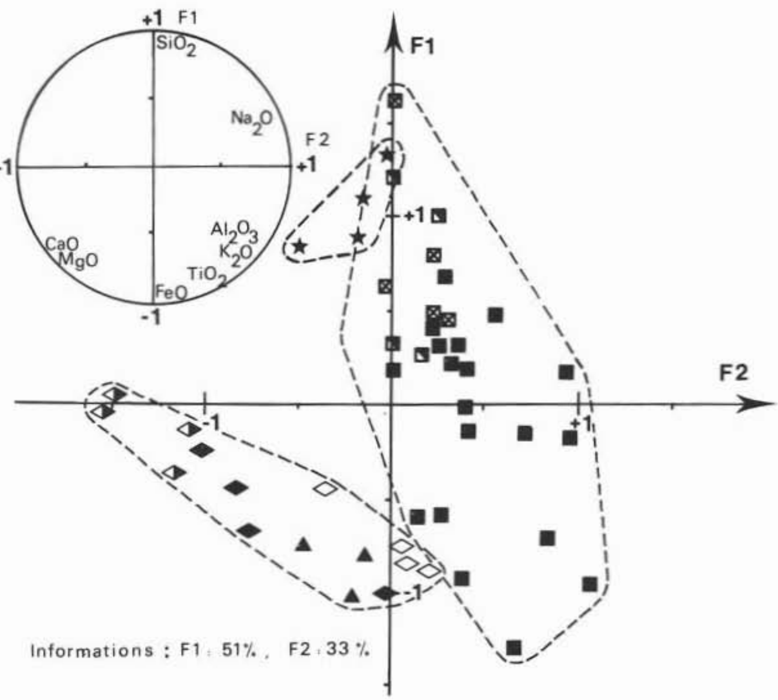

Fig. 5. — F1-F2 diagram of factor analysis applied to the most mafic enclaves of Sardinia granitoids (same symbols as in Fig. 4).

These two evolution types shown by the most mafic enclaves, probably represent inherited characters of their original basic magmas and may be rediscovered in different gabbroic bodies associated with the granitoids (COCIRTA C., ORSINI J.B., 1986; MICHON G., 1987; COCIRTA C. et al., 1988).

Chemistry of Punta Falcone gabbros Comparison with the most basic enclave composition

The granitoids of the central and southern part of the Sardinian-Corsican batholith contain some basic massifs which belong to the same Carboniferous plutonic association (BALIA A. et al., 1981; ROSSI PH., 1986). The parent magma of mafic magmatic enclaves are considered to be the same as those of these basic massif (BRALIA A. et al, 1981; COCIRTA C., ORSINI J.B., 1986; ROSSI PH., 1986).

The gabbroid body of Punta Falcone (northern Sardinia), bounded to the ESE by granodiorites and to the NNW by monzogranite and leucogranites (BRALIA A. et al., 1981), includes three complexes with different chemical characters (Fig. 6 et 7).

a) **The leucogabbroid complex** plots in the calc-alkaline field (Fig. 7) and shows an evolution which continues with the granitoid trend.

b) **The gabbroid complex** is marked by iron enrichment (Fig. 6) similar to other basic massif in Corsica (ROSSI PH., 1986) which are caracterised by a tholeiitic tendency; in the FeO_t - (FeO_t/MgO) diagram (Fig. 7) the plots of the gabbroid complex extend into the tholeiitic field.

c) **The border complex** appears to the boundary with granitoids and is composed of hybrid rocks characterised by numerous acid-basic mixing figures; on the Fe_2O_3 - MgO diagram (Fig. 6) it is situated between the calc-alkaline and tholeiitic trends or it overlaps the two areas (Fig. 7).

If the two types of variations of the most mafic enclaves of granitoids are compared with Punta Falcone gabbros evolutions (Fig. 6 and 7), some partial superpositions may be established. The compositional variations of the most basic E1 enclaves, associated with G1 granitoids, is parallel to the evolution of the gabbroid complex of Punta Falcone. Concerning the field of the E2 and E3 enclaves, belonging to G2 and G3 granitoids, it partially overlaps the border complex area of the Punta Falcone massif (Fig. 6 and 7). Because of its unusual projection into both the calc-alkaline and tholeiitic areas of the FeO_t - (FeO_t/MgO) diagram (Fig. 7), it is difficult to recognize surely the nature of the original magmas.

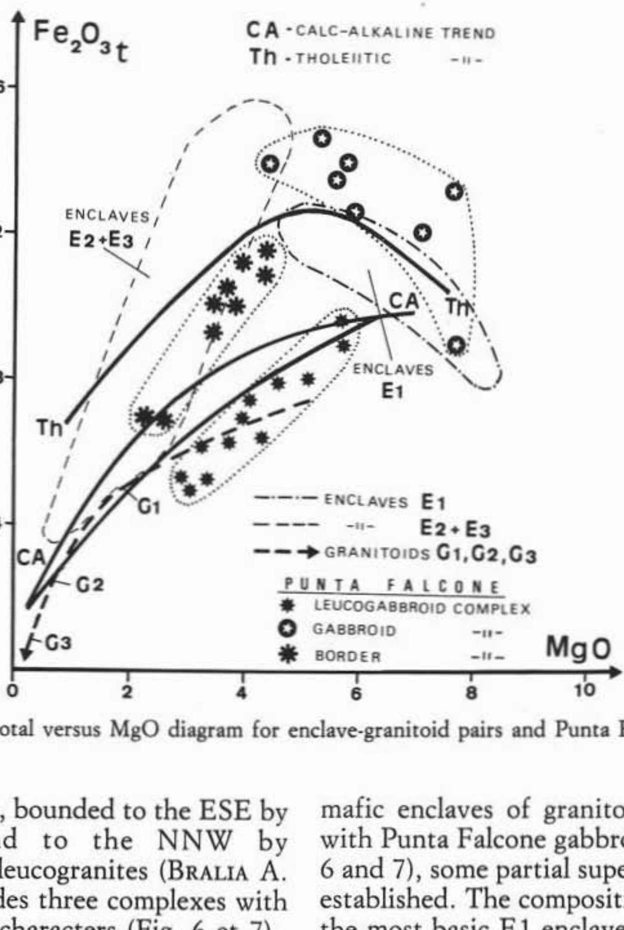

Fig. 6. — Fe_2O_3total versus MgO diagram for enclave-granitoid pairs and Punta Falcone gabbros.

Conclusions

In short, this study of the Sardinian microgranular enclaves allows us to distinguish two acid-basic associations: G1-E1 on the one hand and G2-E2 + G3-E3 on the other (Fig. 4 to 7).

1) **In the first association**, the most mafic E1 enclaves, chemically comparable to the gabbroid complex of the Punta Falcone massif, may be considered as close to the first stages of evolutions of a tholeiitic magma, before it interacts with G1 tonalitic and/or granodioritic magma.

Thus, the G1 hybrid magmas (BRALIA A. et al., 1981, COCHERIE A., 1984) have mingled with increasingly iron-rich basic magmas at different stages during their evolution.

2) **In the second association** the most mafic E2 and E3 enclaves, close to differentiated terms of the tholeiitic or calc-alkaline series and to the rocks of the border complex of the Punta Falcone massif, may represent:

a) either the most differentiated terms of the tholeiitic series, because of their overlaps on some other terms of this trend;

b) or the hybridization product between an iron-rich basic magma, because of their partial superposition on the border complex which has a hybrid character, and because of their mineralogical and textural similarities with the rocks of the same complex.

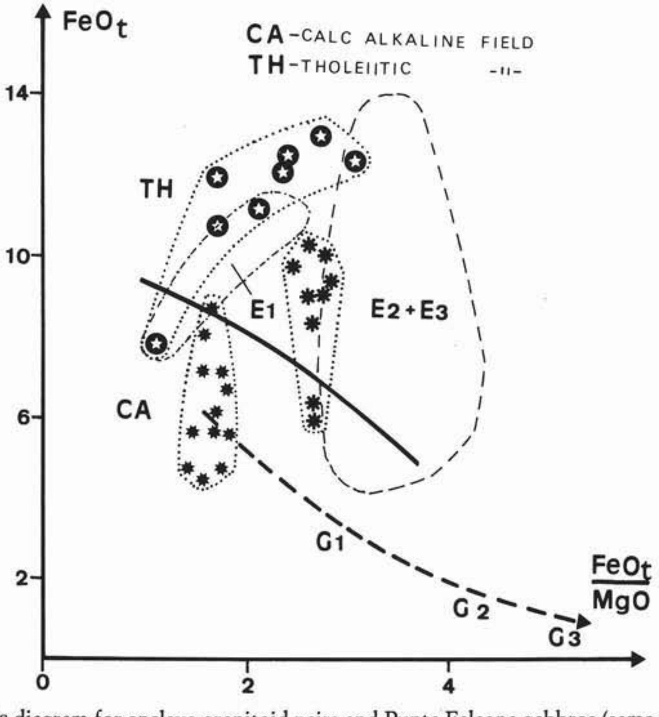

Fig. 7. — MIYASHIRO's diagram for enclave-granitoid pairs and Punta Falcone gabbros (same symbols as in Fig. 6).

Therefore the G2 monzogranitic and the G3 leucogranitic magmas mixed with more evolved or hybridized magmas.

The chemical distinction between the two enclaves groups (E1 and E2 + E3) can also be noted by their texture as well as by their repartition within the host rocks. Thus the two granulometric types, coarse for the E1 enclaves, and fine for the E2 and E3 enclaves, indicates that these rocks crystallized under different thermic constraints, connected with the temperature of the hosting magmas at the moment of mingling (COCIRTA C., 1988) and probably the level in the crust where this process took place as well. The difference of the conditions of crystallization is also indicated by the distinct repartition of the two enclaves groups inside the granitoids: homogeneous for E1, and irregular for E2 and E3. This specificity of the repartition shows a more or less magmatic stiring during the mingling of these two magmas in the different thermic environments. These textures and distribution of enclaves, which are proper to each of the two enclave populations, as well as their abundance in G1 granitoids and their scarcity in G2 and particularly in G3 granitoids, suggest that the magma mingling process at the origin of G1-E1 association took place at more important depth of the earth crust than second association (G2-E2 + G3-E3). These mingling processes probably developed inside crustal levels higher than those of the formation and/or hydridization of precursor magmas. At such crustal levels, less severe physical conditions stopped the evolution of acid-basic associations which tended, at greater depths, to complete homogeneity.

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