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On the origin of the gabbro-tonalite-monzogranite association from Toledo area (Hercynian Iberian belt)

by *L. Barbero*[1], *C. Villaseca*[1] *and P. Andonaegui*[1]

Abstract

In the central region of the Hercynian Iberian belt, in the plutono-migmatitic complex of Toledo, several plutonic bodies outcrop ranging from gabbros to monzogranites in composition. They were syntectonically emplaced at middle crustal levels which were undergoing high grade metamorphism and subsequent migmatization. This anatectic event culminated with the intrusion of peraluminous granitoids. Monzogranite bodies appear with bands and enclaves of gabbroic to tonalitic rocks. Exceptionally the gabbroic rocks outcrop as small sills.

Geochemically, two different associations with calc-alkaline characteristics have been distinguished. The first comprises the gabbroic sills which range in composition from olivine norites to two pyroxene gabbros. It defines a differentiation trend that is essentially controlled by olivine and plagioclase fractionation. The second group consists of several varieties of amphibole gabbro, tonalites and more or less porphyritic granodiorites and monzogranites, exhibiting straight and curved lines on variation diagrams. Based on the field relationships, petrographic features and the available geochemical data (major, trace, rare earth elements, and Sr isotopes), we suggest that the gabbros are genetically unrelated to the more acid types. Fractional crystallization of an intermediate parental magma could be the origin of the tonalite-monzogranite members.

The main contribution of the basic magmas, the transfer of heat, did induce and/or support different periods of crustal melting.

Keywords: Calc-alkaline granites, intermediate rocks, Hercynian Iberian belt.

1. Introduction

The plutono-migmatitic complex of Toledo (CPMT) is a part of the axial zone of the Hercynian Iberian belt (the Central Hercynian zone of JULIVERT et al., 1974). In this region a complex group of igneous rocks intrudes a pre-Ordovician metamorphic complex of augen orthogneisses, pelitic and semipelitic paragneisses, leucogneisses, quartzites, amphibolites and marbles. The main tectonometamorphic regional phase of Hercynian age is an isoclinal folding corresponding to the F2 of the orogenesis (APARICIO, 1971; MARTÍN ESCORZA and LÓPEZ MARTÍNEZ, 1978). It causes a strong strain-slip foliation and some local shear-bands, usually of constant 130–140 strike and dipping to the east.

In this metamorphic series, different plutonic rocks ranging in composition from gabbros to monzogranites, intruded syntectonically and a little later. A Rb–Sr isochron for granitic rocks indicates an age of emplacement of 340 ± 25 Ma which coincides with the age of F2 of the Hercynian belt of this axial zone (SERRANO PINTO et al., 1987). The metamorphic peak in the CPMT is estimated to be around 800 °C (± 50) and 5 kb (± 1.5).

Most of these rocks, particularly the pelitic varieties, are variably migmatized giving rise to several types of metatexites, diatexites and anatexites.

The migmatization event begins during F2 but continues later being affected by a new tectonic event not so strongly penetrative but with similar orientations (F3). The leucosome varieties are composed of different peraluminous granitoids, usually segregated as pods, veins, dikes and small massifs. Nebulitic and heterogeneous para-autochthonous granitoids varying from very peraluminous granodiorites to tonalites (with similar characteristics to the Australian S-type granites) were also generated during this anatectic event.

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Little previous work has been undertaken in this area. Aparicio (1971) did not distinguish between basic-acid syntectonic rocks and the para-autochthonous peraluminous granitoids. All were grouped in a migmatitic facies of the so called Toledo migmatitic unit. More recently, some deformed tonalitic-monzogranitic plutons and some of the later peraluminous granitoids have been distinguished by Andonaegui and Villaseca (1988). These authors made a preliminary study of the petrographic and geochemical aspects of these rocks. The coronitic textures displayed by some of the small gabbroic sills scattered in the area were described by Barbero and Villaseca (1988), who subsequently studied the geochemical evolution of one of them (Barbero and Villaseca, 1989).

The early publications did not consider the whole complex magmatic association represented by this syntectonic plutonism. The close time-space relationship of the intrusions was not explained.

In our work in the studied zone of the CPMT (Fig. 1) we distinguished several magmatic groups summarized as follows:

G1 Olivine and pyroxene gabbros
G2 Amphibole gabbros
G3 Tonalite to monzogranite granitoids, being the most abundant variably porphyritic granodioritic types.

As intrusions in the aforementioned plutonic rocks mainly after the metamorphic peak and migmatization:

G4 Heterogeneous and xenolite-rich granitoids
G5 Peraluminous leucogranites

The main granitoid massifs of the area are more or less porphyritic granodiorite plutonic

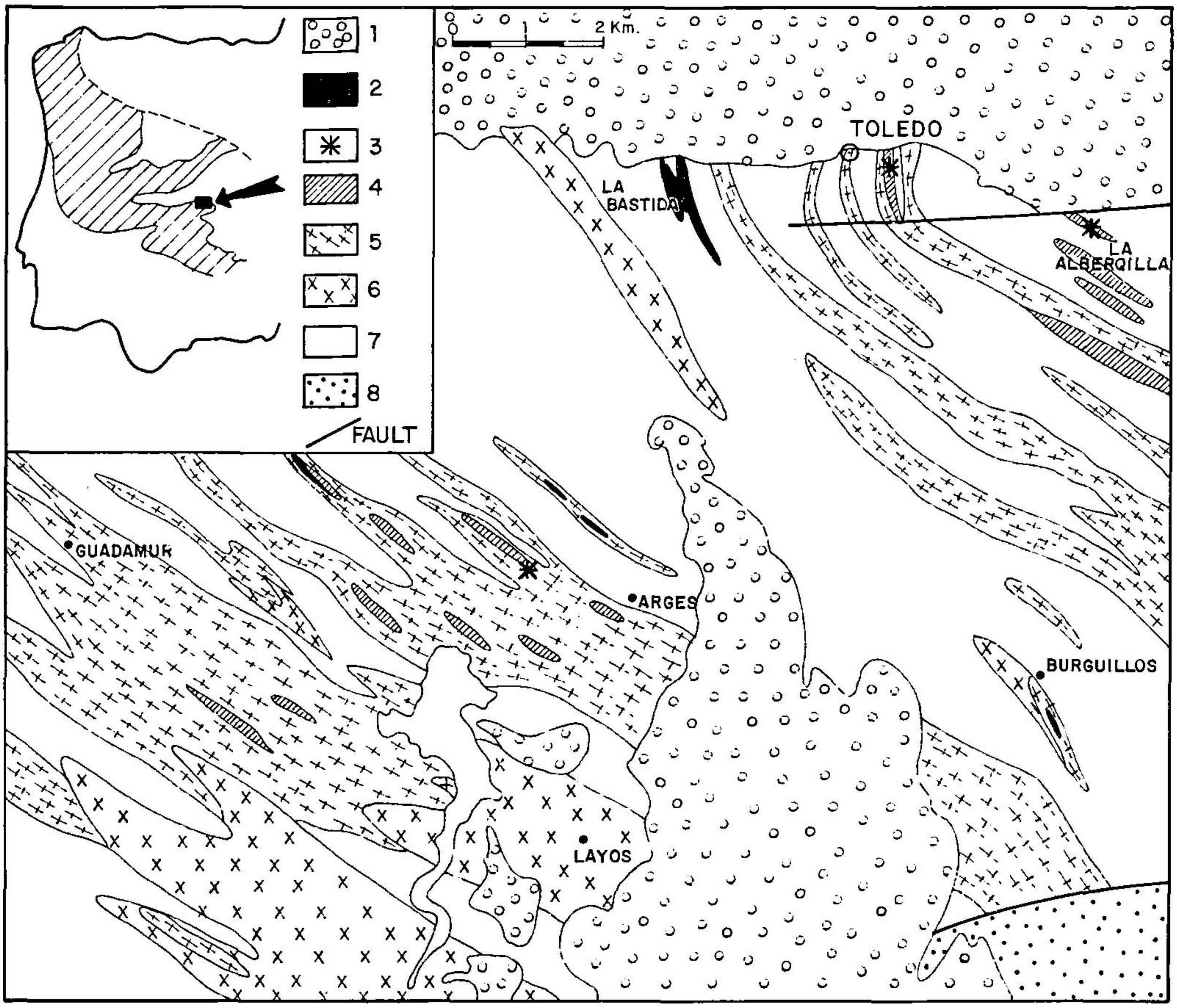

Fig. 1 Geological sketch of the syntectonic plutonic bodies of Toledo area. 1. sedimentary rocks. 2. olivine-pyroxene gabbros. 3. amphibole gabbros. 4. tonalites. 5. porphyritic granodiorites and monzogranites. 6. peraluminous granites. 7. migmatites. 8. low-grade metamorphic terranes. Inset map shows the situation in the Hercynian Iberian belt.

bodies (G3) (Fig. 1) with lesser intermediate rocks included.

The present work deals with some petrographic, geochemical and petrogenetic constraints on the G1-G2-G3 syntectonic association, and considers the possible genetical relationship between gabbroic rock and the spatial and age associated intermediate-acid types. Some possible petrogenetical models on the origin of the intermediate rocks are also presented.

2. Field relations

Within the early plutonic association of the CPMT two groups of basic rocks have been distinguished:

1. Pyroxene gabbros, norites and gabbronorites (G1) which are usually included and scattered in the larger volumes of G3 granitoids. They appear as small bodies or megaenclaves a few meters in size. Contacts with the host granites are sharp and there is no obvious mingling between them.

Sporadically, they appear as independent units between the migmatized metamorphic series, as in the case of La Bastida sill (Fig. 1). This basic sill comprises mainly olivine norites, olivine gabbronorites and gabbronorites. In the inner parts of the sill, a weak igneous layering can locally be observed consisting of a sequence of olivine melanorites (near to troctolites fields in modal analyses), olivine gabbros and gabbronorites, suggesting crystal fractionation processes. The border facies of this body exhibit a foliate fabric parallel to the F2 regional direction. This tectonic fabric diminishes toward the inner part of the body which is completely massive. Occasionally, the La Bastida gabbros are intruded by later veins and dikes of G5 leucogranites. Olivine-pyroxene gabbros only appear in this sill. Olivine bearing varieties are absent in the monzogranitic bodies.

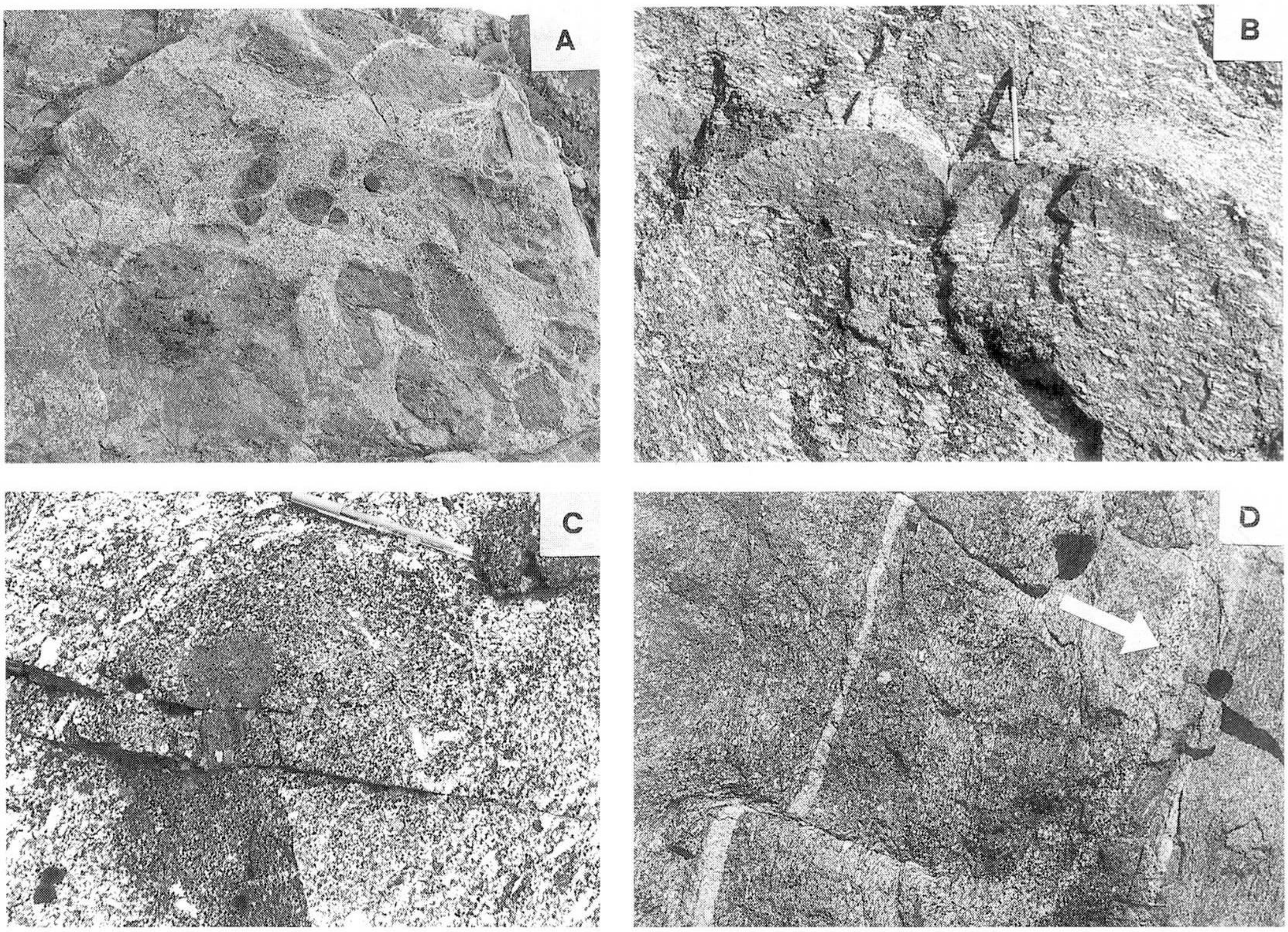

Fig. 2 A) G2 gabbros enclaves in G3 granitoids with some leucocratic reaction rims at their borders. B) Porphyritic monzogranites with microgranular enclave. The enclave has scarce host-granites K-feldspar phenocrysts included. C) Tonalitic enclave within an hybrid zone included in the host-granite. D) General aspect of G3 monzogranites with feldspar phenocrysts rich bands (see arrow). Also a leucocratic leucosome is shown.

2. Amphibole gabbros (G2) always appear related to G3 granitoids and we have never seen them as independent units (Fig. 1). In the contacts between G2 gabbros and G3 granitoids some pillow-like enclaves of G2 gabbros with leucocratic reaction rims are developed (Fig. 2A). This kind of contact attests to the relative contemporaneity between both lithological groups. In the thicker bands of these G2 gabbros, small veins and pods of leucocratic amphibole-bearing pegmatites are locally found.

The main group of this early plutonism, associated to both types of gabbros (G1 and G2), comprises the G3 granitoids. They vary from tonalites and granodiorites to more or less porphyritic monzogranites. Tonalites appear as bodies and bands usually less than 20 meters in extent, included or interlayered with the granodiorites and monzogranites, as well as widespread centrimetric enclaves (20–30 cm). These enclaves are usually flattened and are orientated with the fabric of the host monzogranites (Fig. 2B). In some outcrops it is possible to see these enclaves as small marginal fragments of the larger bodies of more basic magma, captured by the granitic magma. The microgranular enclaves are conspicuous in all the G3 monzogranite plutons of the CPMT studied area. Some enclaves have petrographic features of hybrid rocks such as:

1. K-feldspar phenocryst of the host monzogranites in the interior of the intermediate enclaves and 2. tonalitic enclaves surrounded by an irregular zone, more acid than the enclaves but darker than the monzogranites and with a gradual transition with respect to the host porphyritic monzogranite (Fig. 2C).

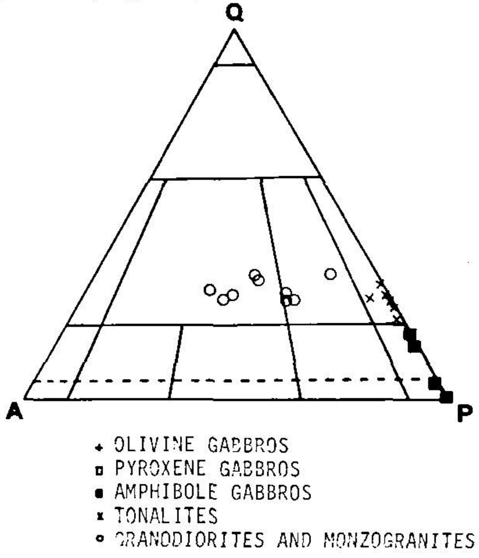

Fig. 3 QAP plot of the typical members of the gabbro-tonalite-monzogranite association of the CPMT. Some amphibole gabbros and all the olivine and pyroxene gabbros plot in the plagioclase corner.

G3 granodiorites and monzogranites are variably porphyritic with K-feldspar phenocrysts strongly orientated in the F2 regional direction. The groundmass of these granites is variably deformed. There are also some strongly porphyritic narrow zones and some biotitic schlieren (Fig. 2D). In addition to the microgranular enclaves but in lesser amount, mica-rich enclaves and metamorphic xenoliths (but not migmatitic varieties) are also found.

All these granitoidic rocks have undergone some migmatization. Small leucosomes concordant with the structure of the rocks can be observed. In some cases, these leucosomes cross-cut the foliation of the rock or have an irregular shape suggesting that the migmatization process is in part synchronous with or later than the F2 tectonometamorphic phase of the area.

3. Petrography

Fig. 3 shows a QAP modal plot of typical members of the various rock groups.

The G1 olivine gabbros range from olivine melanorites to olivine gabbros. The olivine always is rimmed by different coronitic textures caused by the Hercynian regional metamorphism imposed subsequently on these rocks (Barbero and Villaseca, 1988). Igneous paragenesis are still recognizable in some samples and consist of zoned plagioclase (An$_{85}$–An$_{65}$), olivine (Fo$_{75}$–Fo$_{65}$), orthopyroxene (En$_{75}$–En$_{70}$), clinopyroxene, ilmenite, spinel, apatite, zircon and accessory sulphides (calcopyrite and pyrrotite). The original igneous textures of these rocks are ophitic with plagioclase and olivine enclosed by orthopyroxene oikocrystals and intergranular varieties.

Although granoblastic metamorphic textures are widespread, pyroxene gabbro (G1) igneous paragenesis are still recognizable. Zoned plagioclase (An$_{55}$–An$_{50}$), orthopyroxene (En$_{65}$) and clinopyroxene (diopside) are the major phases of these rocks (Barbero and Villaseca, 1988).

Variable amounts of coronitic orthopyroxene, spinel, pargasitic amphibole, clinopyroxene and biotite (from phlogopite to high-Mg biotite) (Fig. 4), appear as metamorphic phases in both olivine and pyroxene gabbros.

Amphibole gabbros vary from gabbros s.s. to quartz-gabbros. Their paragenesis consists of plagioclase (An$_{55-50}$), Mg-hornblende and biotite (Fig. 4). As minor phases, quartz, two pyroxenes, apatite, zircon and sulphides can be present. Mg-hornblende is the most abundant mafic mineral. It appears as large interstitial crystals with respect to the plagioclase and also as large oikocrystals enclosing zoned plagioclase thus forming subophitic textures. Biotite is weakly orientated and interstitial to plagioclase and it can form the main mafic phase in the quartz-gabbro varieties. Some large biotite crystals enclose plagioclase, apatite and opaque minerals. Interstitial clinopyroxene (Wo_{45}–En_{34}–Fs_{21}) (Fig. 4) and rare orthopyroxene (En_{62}) within hornblende are occasionally present.

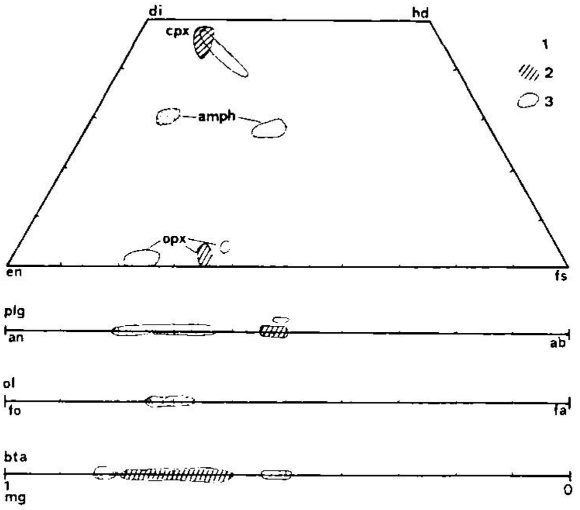

Fig. 4 Compositional variation of clinopyroxene, amphibole, orthopyroxene, plagioclase, olivine and biotite of the gabbroic rocks of the CPMT. 1. G1 olivine gabbros. 2. G1 pyroxene gabbros. 3. G2 amphibole gabbros. mg in biotite line is Mg / (Fe + Mg).

The G3 group comprise tonalites, granodiorites and monzogranites. The main mineral phases of these rocks are quartz, plagioclase, K-feldspar and biotite, while apatite, zircon and opaque minerals occur as minor phases (see Tab. 3).

In tonalites K-feldspar is scarce (see QAP plot, Fig. 3). Secondary pale-green amphibole can also appear in the quartz-poor varieties ($Q < 18\%$). The quartz content of tonalites is between 14–25%, and biotite is the main mafic mineral present except for some sporadical garnet. In the more evolved G3 granitoids (granodiorites and monzogranites), cordierite, sillimanite, garnet and scarce spinel, dumortierite and tourmaline can also occur as minor phases.

Plagioclase in G3 rocks is euhedral or subeuhedral and includes small crystals of quartz, biotite and apatite. In the intermediate rocks it is andesine in composition, but varying from An_{48} (core) to An_{41} (rim) when it is zoned. In the non-porphyritic granodiorites its composition varies from An_{39} (core) to An_{35} (rim) and in the porphyritic granites from An_{31} (core) to An_{29} (rim). Thus, there is an almost continuous variation in the plagioclase composition in the whole G3 group.

K-feldspar is especially abundant in the monzogranite types and in composition shows little variation over the whole group, being $Or_{85-90}Ab_{10-15}$.

Biotite crystals are weakly orientated defining the planar fabric of the rocks, and have very little compositional variation being more iron and aluminum-rich in the granites.

Garnet composition changes from Alm_{73}–Pyr_{18}–Sp_5–$Gros_3$–$Andr_1$ in the tonalites to Alm_{77}–Pyr_{14}–Sp_6–$Gros_1$–$Andr_2$ in the granites.

All the aluminous minerals (garnet, cordierite, mica, sillimanite, etc.) have obviously recrystallized in the F2–F3 metamorphism and there is a suspicion (that will be investigated in the future) that some of them have been indeed generated after the emplacement of the granites.

4. Geochemistry

4.1. ANALYTICAL PROCEDURES

Major and trace-elements have been analysed by x-ray fluorescence, using a Phillips PW 1510 spectrometer, following the procedure described by BRÄNDLE and CERQUEIRA (1972). Na_2O and K_2O were determined by flame spectrometry, P_2O_5 by calorimetric method, H_2O by Pendfield method and FeO by classical titrimetric procedure. REE were determined by Emission-Plasma technique (ICP) in C.N.R.S. Nancy (France), with a precision within the 5–10% range (GOVINDARAJU, 1982 in LETERRIER, 1985). Sr-isotopes were analysed by Rb-Sr spectrometry at laboratory no. 10 C.N.R.S. University of Clermont-Ferrand (France).

4.2. RESULTS

30 samples of the gabbro-tonalite-monzogranite association from CPMT have been analysed. On the basis of chemical and modal criteria they can be separated into five groups (Tab. 1): olivine gabbros (n = 6), pyroxene gabbros (n = 5), amphibole gabbros (n = 5), tonalites (n = 7) and granodiorites-monzogranites (n = 7). In general, they are poorer in silica than Le Maître's average (LE MAÎTRE, 1976). Two tonalite samples correspond to microgranular enclaves (no. 17–19, Tab. 1).

All the basic rocks are silica-saturated (except no. 12, with 1.7 Ne in the norm) and metalumi-

Tab. 1 Major and trace element contents of Toledo igneous rocks: 1 to 6 olivine norites (Go) from La Bastida sill; 7 to 10 pyroxene norites and gabbronorites (Gp) from La Bastida, Alberquilla and Argés region; 12 to 16 amphibole gabbros (Ga) from Toledo City and Argés; 17 to 23 tonalites (To) from Argés and Alberquilla region; 24 to 30 granodiorites and more or less pophyritic monzogranites (Gt and Gtp) from Argés and Toledo City.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Go	Go	Go	Go	Go	Go	Gp	Gp	Gp	Gp	Gp	Ga	Ga	Ga	Ga	Ga
SiO_2	46.82	46.84	47.20	47.25	48.04	48.05	49.72	50.02	52.09	52.60	54.62	48.48	50.19	51.81	52.09	52.77
TiO_2	0.88	1.01	1.03	1.02	0.91	1.02	1.58	1.12	1.26	1.25	1.67	1.62	1.91	1.52	2.28	1.57
Al_2O_3	11.04	12.71	12.09	12.92	12.67	13.55	15.58	17.59	16.12	16.81	16.99	20.09	18.38	18.76	17.67	18.37
Fe_2O_3	3.60	1.27	2.24	2.60	2.65	2.23	1.37	1.63	1.58	1.66	1.09	1.80	1.26	1.20	5.13	1.39
FeO	7.78	9.06	8.91	9.17	8.14	8.18	8.21	7.15	7.14	7.02	8.62	6.61	7.56	6.72	4.47	6.48
MgO	20.75	15.78	18.58	15.85	16.26	16.44	6.68	7.79	8.03	8.27	4.42	5.19	4.94	4.95	4.23	4.32
MnO	0.17	0.16	0.17	0.17	0.16	0.16	0.16	0.15	0.13	0.13	0.14	0.12	0.15	0.10	0.13	0.11
CaO	5.82	6.99	6.61	6.98	6.58	6.97	9.44	8.26	7.35	7.58	6.40	8.74	8.00	7.27	6.99	7.31
Na_2O	1.41	2.20	1.75	2.08	1.98	1.56	2.83	2.08	2.82	2.79	2.97	3.11	3.02	3.11	2.55	3.03
K_2O	0.89	0.97	0.93	0.87	0.93	1.01	1.44	2.06	1.75	1.66	1.63	2.53	2.22	2.82	2.18	2.81
P_2O_5	0.14	0.11	0.13	0.13	0.12	0.14	0.22	0.18	0.18	0.16	0.31	0.59	0.43	0.32	0.88	0.33
H_2O	0.90	1.20	1.29	1.08	1.58	1.11	1.29	1.79	0.81	1.10	1.25	1.55	1.30	1.36	1.64	1.42
TOTAL	100.20	98.30	100.93	100.12	100.02	100.42	98.52	99.52	99.24	99.37	100.11	100.57	99.39	99.94	100.24	99.91
Ba	243	210	248	320	212	271	459	311	440	416	661	1600	786	1607	1356	1444
Cr	580	734	472	364	564	597	124	371	412	413	375	37	157	168	230	186
Ga	12	15	14	20	16	13	21	17	21	21	20	20	19	22	18	19
La	12	5	2	20	29	12	38	15	22	9	41	25	34	26	75	33
Nb	--	1	4	4	1	4	--	11	11	2	27	25	10	25	40	20
Ni	434	394	379	78	358	312	32	75	63	56	20	1	10	19	17	20
Rb	27	24	25	105	23	29	48	105	46	49	51	50	57	63	61	66
Sr	220	249	245	403	265	271	373	401	279	278	305	1246	578	606	532	581
Th	8	7	6	10	6	6	8	1	9	6	6	1	4	5	10	1
Y	23	25	25	20	23	26	30	22	53	31	31	35	50	35	41	28
Zr	125	116	125	136	121	127	149	138	154	154	190	196	141	141	319	158
Sample	87075	87078	87213	87080	87214	87076	87079	87088	87099	87096	87200	87109	87092	87198	87112	87197

nous. The olivine gabbros display a high MgO content (15–20%) and high Al_2O_3/CaO ratio. The quartzdiorite-monzogranite rocks are silica-oversaturated and define an alumino-cafemic trend after DEBON and LE FORT (1983).

On the SiO_2-alkalies diagram, all the rocks plot close to the alkaline-subalkaline boundary line, reflecting their high K_2O content. This is particularly the case for the amphibole gabbros (Fig. 6). The calc-alkaline character of all these rocks is shown in an AFM projection and in the R1-R2 diagram (Fig. 5).

On chondrite normalized trace-element patterns (not shown), all these rocks display negative anomalies in Ba, Nb, Sr and Ti, similar to other orogenic granitoids (THOMPSON et al., 1984). Except for P an Nb, these rocks show geochemical features of magmatic rocks in a mature continental area (BROWN et al., 1984) as is the case for this Hercynian zone.

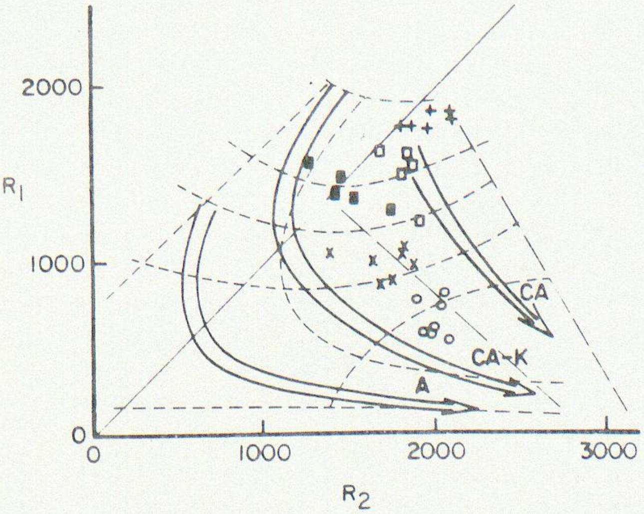

Fig. 5 R1-R2 diagram (LA ROCHE et. al., 1980) with granitic fields after BATCHELOR and BOWDEN (1984). CA = calcalkaline. – Ca–K = calcalkaline K_2O-rich. A = Alkaline. Symbols as Fig. 3.

Tab. 1 Continuation

	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	To	To	To	To	To	To	To	Gt	Gt	Gt	GtP	GtP	GtP	GtP
SiO_2	55.52	56.18	56.20	57.64	57.68	58.81	59.14	61.25	62.41	64.26	64.86	65.79	65.79	67.18
TiO_2	1.39	1.63	1.71	1.78	1.33	1.33	1.59	1.49	1.34	1.14	1.26	1.16	1.23	1.00
Al_2O_3	18.78	18.96	17.61	18.54	17.26	17.38	17.01	16.47	16.28	16.12	15.19	15.81	15.67	14.85
Fe_2O_3	0.02	0.04	1.09	0.53	1.31	1.24	0.84	0.64	0.32	0.71	0.53	0.43	0.51	0.29
FeO	6.64	6.81	6.51	6.18	4.79	4.95	5.71	5.31	5.32	4.28	4.57	4.10	4.03	3.76
MgO	4.11	3.32	3.59	3.09	2.90	2.68	3.12	1.92	3.24	1.99	1.74	1.33	1.47	1.30
MnO	0.08	0.09	0.11	0.10	0.05	0.07	0.10	0.08	0.08	0.08	0.06	0.05	0.05	0.06
CaO	4.58	4.57	5.41	4.89	3.92	4.06	4.58	3.66	3.28	3.02	2.27	2.14	2.28	1.87
Na_2O	3.56	3.10	2.64	2.94	3.49	3.26	3.07	2.82	2.95	2.58	2.86	2.98	2.87	3.24
K_2O	3.63	3.36	3.08	3.09	2.87	3.52	3.21	4.34	3.78	5.00	4.90	5.37	5.31	4.76
P_2O_5	0.94	0.60	0.47	0.50	0.34	0.57	0.55	0.55	0.53	0.44	0.40	0.43	0.35	0.43
H_2O	1.23	1.84	1.24	1.20	1.19	1.37	1.30	0.95	0.99	0.60	0.92	0.82	0.90	0.79
TOTAL	100.48	100.50	99.66	100.48	97.13	99.24	100.22	99.48	100.52	100.22	99.56	100.41	100.46	99.53
Ba	534	1694	1217	1364	1105	922	1150	1004	842	949	731	905	1018	574
Cr	154	167	334	104	192	183	428	405	102	77	174	196	385	158
Ga	27	25	18	20	27	27	21	22	23	26	27	25	22	23
La	45	55	19	21	16	84	24	99	68	85	101	111	117	106
Nb	28	31	2	32	21	23	15	16	30	20	26	15	24	25
Ni	5	2	17	1	28	18	16	20	4	3	9	15	17	23
Rb	269	181	125	153	166	123	138	179	226	202	260	237	226	247
Sr	386	596	491	568	473	468	479	359	287	320	237	284	288	157
Th	13	2	13	3	12	25	10	29	23	24	46	76	37	67
Y	21	11	13	9	15	30	17	26	18	30	32	20	22	33
Zr	239	186	124	278	203	326	139	358	272	303	326	423	437	375
Sample	76915	76913	87091	81927	87097	87100	85735	81920	76912	81921	81922	81913	81912	76905

On Harker diagrams (Fig. 6) two clearly defined variation trends can be seen. The first ranging from Mg-rich and olivine-bearing gabbros to pyroxene gabbros, with a small compositional gap between, particularly shown by Al_2O_3, MgO, CaO and Ni. It has a high slope, always positive, except for MgO, FeO_t and Ni. The second trend includes amphibole gabbros, tonalites and more or less porphyritic granodiorites-monzogranites. Sometimes, it defines straight variation lines (MgO, CaO), although in others they are curved (Al_2O_3, P_2O_5, TiO_2 and Sr). As can be observed in Fig. 6, the G2–G3 line defines a strongly contrasting trend compared to those of the anhydrous gabbros G1. Although the amphibole gabbro varieties plot at the end of the Mg-rich gabbros in some variation diagrams, the high LILE contents of these rocks make it difficult to include them in the Mg-rich serie.

Finally, depending on the REE content (Tab. 2), these rocks can be put into two groups. The first group is composed by gabbroic (G1, G2) rocks with the less fractionated spectra (La/Yb close to 9), showing small Eu negative anomalies (Fig. 7). The second group comprises the tonalite-granite interlayered plutons (G3) which show higher variation in REE total contents and more REE fractionation (La/Yb = 22–56). They vary from low-REE with low positive anomalies (tonalites) to high-REE and more pronounced Eu negative anomalies (granodiorites-monzogranites). The slight positive Eu-anomaly of intermediate rocks could suggest cumuli of plagioclase.

5. Petrogenetic constraints

The Mg-rich gabbro's trend (G1 types) could be explained by a fractional crystallization process, with olivine and minor plagioclase accumulation in the olivine melagabbros. On binary and log-

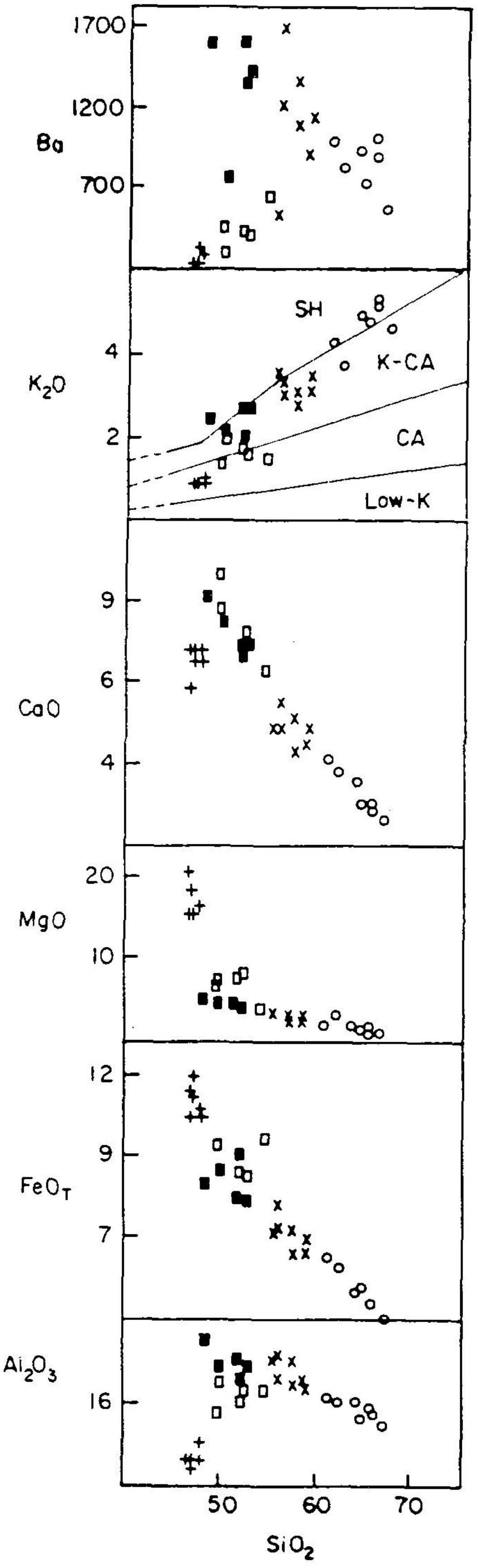

Fig. 6 Harker diagrams with SiO_2 as differentiation index. *Fields in SiO_2–K_2O diagram after* Rickwood (1989). Symbols as Fig. 3.

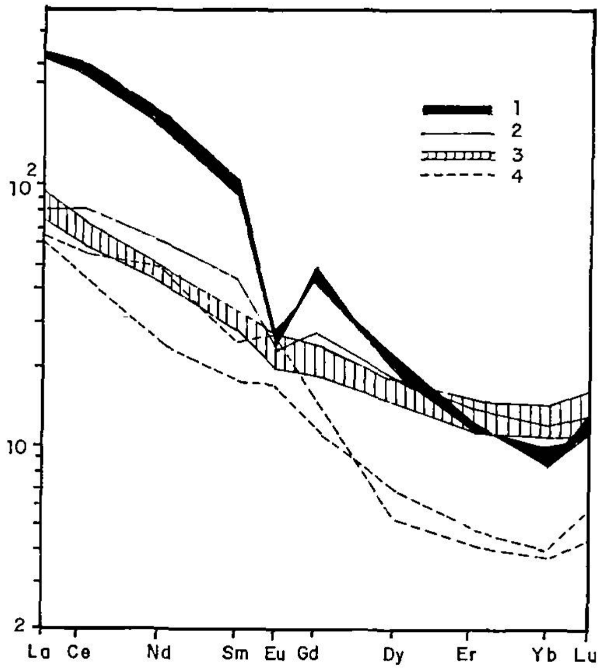

Fig. 7 Chondrite-normalized (Masuda et. al., 1973) REE patterns. 1 granodiorites and monzogranites (n = 3). 2 amphibole gabbro. 3 pyroxene gabbros (n = 3). 4 tonalites (n = 2).

log trace-elements diagrams (Fig. 8) and on the Fe + Mg/K–Si/K diagram of Pearce (1968) (see Barbero and Villaseca, 1989, Fig.5), all these rocks plot on olivine control lines, suggesting fractional crystallization trends as discussed in detail by Barbero and Villaseca (op. cit.). The more Mg-rich gabbros seem to be essentially petrogenetically unrelated to the other plutonic bodies intruded more or less at the same time.

Concerning the genetical relationships of the pyroxene and amphibole gabbro-tonalite-monzogranite sequence that defines the more complex association of the area, we consider the origin of these rocks under the following headings.

5.1. CRYSTAL FRACTIONATION FROM A BASIC PARENTAL MAGMA

In some geochemical diagrams there is a linear relationship between olivine-pyroxene gabbros of the group G1 and tonalites of G3 group (e.g. Fig. 8). This feature could suggest a possible genetic relation through olivine ± plagioclase fractionation comparable to the way which gives rise to the G1 group.

As it can be observed in the Harker diagrams (Fig. 6), there are some distinct changes of the slope in the G1 gabbros-tonalites line. This could indicate that, if a fractional crystallization pro-

Tab. 2 REE contents of Toledo igneous rocks. Abbreviations and index numbers as Tab. 1.

			9	14	19	20	24	27	30
	Gp	Gp	Gp	Ga	To	To	Gt	Gtp	Gtp
La	28.34	25.47	21.83	25.84	19.02	20.51	98.83	100.78	105.98
Ce	57.98	56.43	50.76	66.82	36.34	46.10	218.20	223.59	245.91
Nd	26.07	26.00	22.64	37.68	15.20	29.62	99.64	111.45	116.67
Sm	6.26	6.82	5.51	8.73	3.60	4.97	17.42	18.28	20.01
Eu	1.86	2.02	1.53	1.82	1.26	1.97	2.18	1.77	1.50
Gd	5.65	6.54	5.09	7.37	3.18	4.08	11.05	13.11	12.14
Dy	5.28	6.16	5.95	6.27	2.32	1.79	6.27	6.30	7.39
Er	3.30	3.00	2.70	3.12	1.10	0.91	2.66	2.86	2.98
Yb	2.88	3.11	2.53	2.70	0.87	0.80	1.78	2.18	1.88
Lu	0.49	0.53	0.40	0.43	0.19	0.15	0.45	0.36	0.33
Sample	89080	89082	87099	87198	87091	81927	81920	81922	76905

cess exists, there is a change in the fractionating mineral phases. Initially, olivine ± plagioclase fractionation operates in the genesis of the more basic members of G1 group (BARBERO and VILLASECA, 1989) but subsequently it would seem that mainly pyroxene ± plagioclase fractionation was the main mechanism to generate tonalitic liquids from pyroxene gabbros. This pyroxene ± plagioclase participation can be elucidated by plotting the composition of the mineral phases in the Harker diagrams. The pyroxene gabbros-tonalites variation line is inside the olivine-pyroxene-plagioclase triangle, indicating that there is an additional phase (pyroxene) that has an important participation in the process.

Some problems appear when the trace-elements are considered. In particular, the pyroxene gabbros show a marked variation in some incompatible element ratios (e.g. Th/Rb, Zr/Rb) contrasting with more limited variations in the tonalitic types which are typical of closed system fractional crystallization process (MINSTER and ALLEGRE, 1978). Also, the REE-patterns of the gabbros show very different LREE/HREE fractionation and higher contents with respect to the tonalitic varieties, contrasting with pyroxene-plagioclase fractionation process which generates more REE-rich derived liquids with appreciable negative Eu-anomaly.

Initial Sr-isotopes ratio of tonalitic rocks are approximately 0.707 (see Fig. 9); this is possibly too high for a fractionated liquid from the Mg-rich gabbros.

Concerning the amphibole gabbros (G2) as a hypothetical basic parental magma in a fractionating magma chamber evolving to more acid types, there are other problems. Thus, although there are straight and curved lines on the binary variation diagrams (Fig. 6), such a process seems to have some geochemical and geological constraints that make it difficult to be considered as the main petrogenetic mechanism. On Sr, Ba, Ni versus Rb bilogarithmic diagrams (Fig. 8) a fractional crystallization trend is observed between tonalites and monzogranitic rocks (COCHERIE, 1985). However, the amphibole gabbros are not aligned with this fractional evolutive trend and it is also noticed that these gabbros have the same Ni–Cr contents as the more acid types. Moreover, the clearly different ratios of Zr/Rb of these gabbros compared to the more constant values shown by the tonalites-monzogranites, is more consistent with other magmatic processes as discussed by MINSTER and ALLEGRE (1978) in their CH/CM–CH plots.

The simultaneous intrusion of gabbros and G3 granitoids seem to have no evolutionary geochemical trends easily related to closed system crystal fractionation. This chemical conclusion is supported by field observations since this kind of process cannot be justified in the light of the relative areal ratios between the basic rocks and the much more widespread acid types. As has been noticed by other authors (POLI et al., 1989) it is necessary to separate a large volume of mafic types (not found in the area) to obtain the high proportion of acid and intermediate rocks observed in the CPMT.

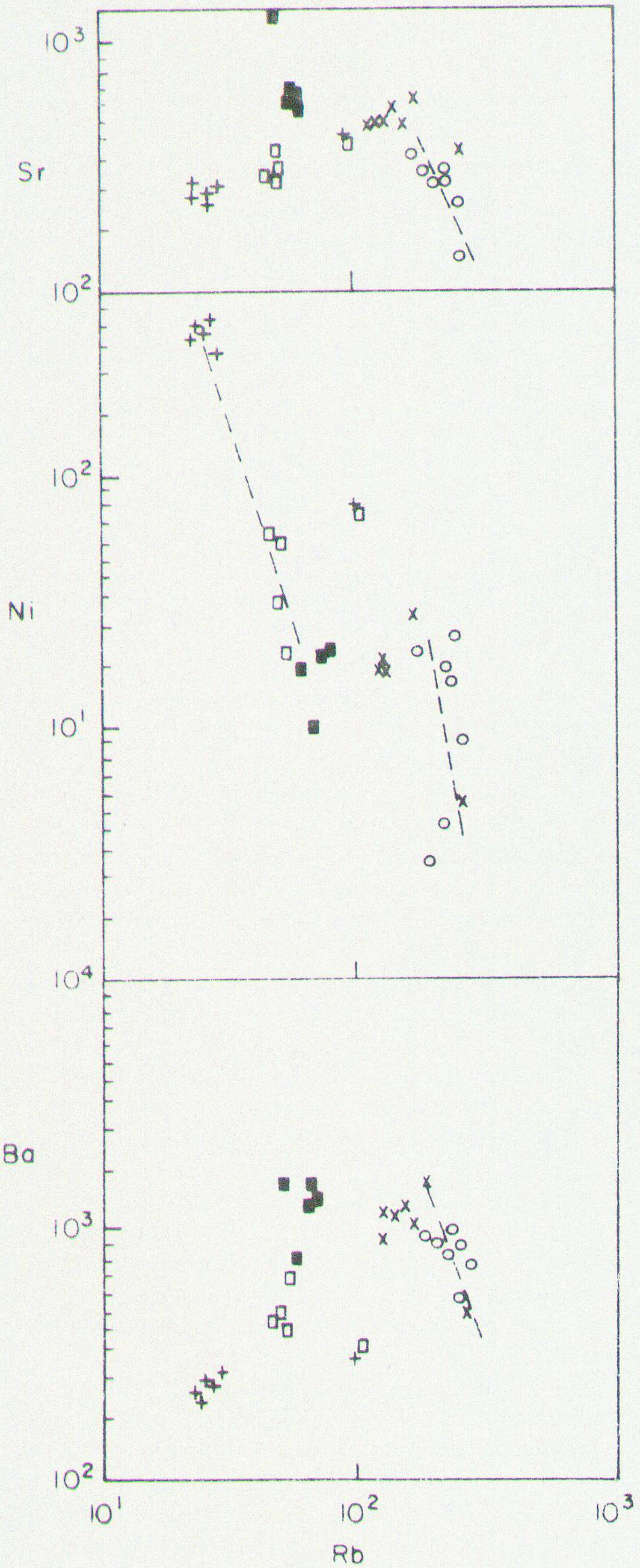

Fig. 8 Log-log diagrams of compatible-incompatible elements (Cocherie, 1985). Mg-rich gabbros and some intermediate-acid rocks follow different fractionation trends. Amphibole gabbros are not aligned with either of the two fractionation trends. Symbols as Fig. 3.

5.2. MIXING PROCESS BETWEEN BASIC AND ACID MAGMAS TO OBTAIN AN INTERMEDIATE TYPE

In outcrop, G1 and especially G2 gabbros appear locally mingled with granitic rocks along their contacts. The basic enclaves are mainly limited to the contacts of these rocks and there are no petrographic features indicating mixing between them (xenocrysts, mineral disequilibria, etc.). The geochemical data do not support mixing between these simultaneous magmas even though they occasionally mingle at the emplacement level.

Langmuir et al. (1978) showed that one of the characteristics that must be produced by a mixing process is the linearity between the mixing poles and the hybrid components in all the variation diagrams. On Harker diagrams it is observed that this association does not plot as straight lines for all the components and this remark is especially clear for the G1 gabbros usually disconnected to the G2 gabbros–G3 granitoids that plot in more straight trends (Fig. 7). It could be suggested that there is no single mixing process and that more than one mixing line occurs between several poles. When some more complex geochemical mixing tests are made (element ratio plots) only a few show hyperbolic curves with corresponding straight trends in the companion diagrams. Following Langmuir et al. (op. cit.) this would indicate that mixing processes are not the only explanation of these features.

It can be observed in Fig. 7 that in their REE contents the amphibole gabbros show spectra between those of the intermediate and acid rocks, and with different degrees of REE-fractionation, the intermediate rocks being the lowest REE types. Thus, the higher REE content

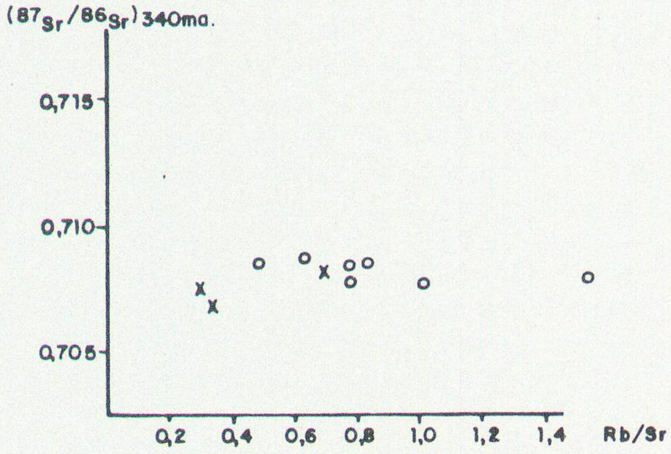

Fig. 9 Initial Sr-isotopes (at 340 Ma) versus elements ratio diagram of tonalitic-granitic rocks (G3). The I_{Sr} average is 0.707 ± 0.0005. Symbols as Fig. 3. See text for explanation.

of the gabbros could not explain the lanthanide content of the intermediate rocks in hypothetical magmatic mixing process with granitic rocks.

5.3. CRYSTAL FRACTIONATION OF AN INTERMEDIATE PARENTAL MAGMA

As has been previously noticed, there are several features that indicate such a kind of process. The fact that several gradual, transitional and slightly interlayered petrographic types outcrop all together; and also their clear mineral fractionation, indicated by biotite segregation (schlierens) and K-feldspar phenocrysts defining porphyritic zones, are geological evidence for an effective crystal fractionation process. Furthermore, there are geochemical continuities between intermediate and acid rocks defining regular or curved trends in the binary variation diagrams. There are also fractionation trends on compatible versus incompatible element plots (Fig. 8).

The isotopic data of this G3 granitoids reinforce the hypothesis of origin from a single parental magma. On $(^{87}Sr/^{86}Sr)_{340\ Ma}$ versus Rb/Sr plot (Fig. 9) these rocks display very little variation in the initial Sr-isotope values supporting a co-genetic origin for this series. Fractional crystallization and not another magmatic mixing or other open system mechanism seems to be the differentiation process.

As a first hypothesis we suggest that most of the tonalitic rocks could represent the less evolved liquids of a series, probably with some cumular fraction, as suggested by the REE patterns, while the granodiorites and monzogranites would be subsequently derived liquids. The theoretical parental magma would be tonalitic-granodioritic in composition. As shown in Tab. 1, the La content of some intermediate types could fit well the actual compositional gap in lathanides content, and this type of rocks must be close to the supposed parental magma.

This petrogenetic scheme has been tested using the least squares mixing program given by McBirney (1984). In our model we have calculated the proportions of the phases to be subtracted or added to a theoretical parental magma, tonalitic in composition, to obtain the tonalitic and monzogranitic end-members. Mineral compositions were those of microprobe analysis (Tab. 3). The theoretical parental magma would belong to the high-SiO_2 tonalitic sub-group (samples 21, 22, 23) because some low-SiO_2 tonalites (samples 19 and 20) display a slightly positive Eu-anomaly. Thus, we think that a possible parental magma would have a composition between samples 21 and 23. An average composition of these rocks has been taken as L_0 (Tab. 3).

Addition of 40% of minerals in the following proportions: 40% biotite, 57% plagioclase and 3% apatite to this tonalitic parental magma (L_0) yields a low-SiO_2 tonalitic composition with the sum of the squares of the residuals (SSR) about 0.44 (Tab. 3).

Tab. 3 Mineral and rock composition used in the mixing calculations. (1) Biotite average from high-SiO_2 tonalites (n = 4). (2) Plagioclase from high-SiO_2 tonalites (n = 2). (3) Apatite (Deer et. al., 1966). (4) Biotite average from granodiorites (n = 2). (5) Plagioclase average from granodiorites (n = 4). (6) K-feldspar from granodiorites (n = 1). (7) L_0. (8) Average low-SiO_2 tonalites (samples 17 to 19). (9) Average granodiorite (samples 24 to 26). (10) average porphyritic monzogranite (samples 27 to 30).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
SiO_2	37.51	59.32	-----	36.17	58.01	63.73	9.07	56.28	62.54	65.87
TiO_2	3.91	----	-----	5.55	0.02	0.03	1.59	1.58	1.32	1.16
Al_2O_3	16.38	25.63	-----	18.91	26.14	19.21	16.99	18.59	16.26	15.37
FeO_t	22.31	-----	-----	20.59	0.06	0.02	6.46	6.73	5.46	4.51
MnO	-----	-----	0.07	0.16	0.01	0.01	0.10	0.09	0.08	0.05
MgO	10.15	-----	0.01	8.51	0.01	-----	3.12	3.69	2.38	1.46
CaO	0.16	7.65	56.44	-----	7.60	0.05	4.84	4.88	3.31	2.14
Na_2O	0.13	6.90	-----	0.11	6.73	1.61	3.07	3.12	2.78	2.98
K_2O	9.45	0.19	-----	10.00	0.41	14.35	3.21	3.37	4.36	5.08
P_2O_5	-----	-----	42.50	-----	-----	-----	0.55	0.67	0.51	0.39

Removing of 25% of minerals in the following proportions: 32% biotite, 67% plagioclase and 1% apatite and adding 8% K-feldspar to L_0 yields the average granodiorite with SSR values about 0.05.

Finally, removing 18% of minerals with proportions of 44% biotite, 50% plagioclase and 6% apatite and adding 7% K-feldspar to the average granodiorite (Tab. 3) yields the average porphyritic monzogranites composition with SSR round 0.58.

Although we strongly prefer the above crystal fractionation hypothesis we note that tonalitic microgranular enclaves are widespread in the granitic rocks, some of them appearing like petrographic mixing types (gradual composition of enclaves, K-feldspar xenocrysts into the microgranular enclaves). Thus, some intermediate rocks, mainly the minor volumes disrupted in the granitoid magma, have undergone a combined process of crystal fractionation and magmatic mixing.

6. Summary

The scarcity of gabbro compared to the large volumes of the granitoid plutons is an initial objection to a direct derivation of the acid types from the gabbroic rocks. The sharp contacts, the absence of intermediate varieties between them, and the lack of petrographical features indicative of mixing support this view. Furthermore, geochemical data are also coincident with this lack of a clear genetical relationship, that will be investigated with more detail in the future. Thus, a crystal fractionation process starting with the gabbros outcropping in the area could not originate the whole association. Most of the geochemical plots and bilogarithmic trace-element diagrams do not show such an evolutionary trend.

In the absence of mixing lines in most of the Harker diagrams and element ratio plots, a magmatic mixing process between gabbro and granite is considered most unlikely. The REE data are particularly difficult to reconcile with such a process.

Thus, the more or less simultaneous gabbro intrusions of this area seem to be genetically unrelated to the large tonalite-granite plutons (G3). On the contrary, this intermediate-acid group seems to be related by a crystal fractionation mechanism to a theoretical parental magma of intermediate composition. This mechanism would explain some of the intermediate rocks as less evolved magmas with varied cumular fractions, and the granodiorites and monzogranites as derived liquids. There could be local magmatic mixing (in a closed differentiating magma chamber) between the intermediate and acid liquids as indicated by the hybrid characteristics of some bands and enclaves within the host-granite.

In summary, it is possible to suppose that G1 anhydrous gabbros an G2 amphibole gabbros did not evolve toward granitic rocks, at least to those they are associated with. The main petrogenetical contribution of the gabbroic rocks could be to participate in crustal melting and in generating the G3 granitoid magmas. When rising to their emplacement levels, these granites drag the basic intrusive bodies with them causing some brecciation, mingling and perhaps limited mixing. It is worth mentioning the importance of this early basic-acid magmatism in increasing the metamorphic gradient of the Hercynian belt in this region, one of the highest in the Hercynian Iberian belt. The subsequent mobilization of anatectic peraluminous magmas must be enhanced by the voluminous intrusion of this basic-acid magmatism at catazonal levels (approximately 25% of the lithological units of the region). This scheme coincides with other recent studies which also indicate the importance of the mantle derived thermal flow in the beginning of crustal melting process in this intracontinental Hercynian collisional belt (FRANCO and GARCIA DE FIGUEROLA, 1986; WICKHAM, 1987; PITCHER, 1987, BORIANI et al., 1988).

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