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PROJECT 276
Paleozoic of the Tethys

The Hercynian intrusive rocks of the Catalonian Coastal Ranges (NE Spain)

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ABSTRACT

The hercynian outcrops of the Catalonian Coastal Ranges (NE Spain) consist mainly of Lower Permian-Upper Carboniferous, post-tectonic, epizonal granitoid intrusions which form a typical plutonic calc-alkaline suite ranging from mafic hornblende gabbros and ultramafic olivine hornblendites through tonalites and granodiorites to leucogranites. This suite displays major and trace-element characteristics and Sr isotope ratios similar to volcanic arc and post-collision magmatism and is therefore believed to have formed above subducted oceanic lithosphere and to have been modified by contamination with melts from the crust.

Key words: Hercynian plutonism. Catalonian Coastal Ranges. calc-alkaline magmatism.

RESUMEN

Los afloramientos hercinianos de las Cadenas Costeras Catalanas (NE de España) están constituídos principalmente por granitoides intrusivos, epizonales, postectónicos de edad carbonífera superior-pérmica, los cuales representan a una serie calcoalcalina típica que comprende desde gabros hornbléndicos y rocas ultramáficas de tipo hornblendítico olivínico, hasta tonalitas, granodioritas y leucogranitos. Esta serie presenta unas características, en sus elementos mayores y trazas y en sus relaciones isotópicas iniciales del Sr, similares en parte a las de los magmatismos de arcos volcánicos y en parte a los de post-colisión, por lo que probablemente debe haberse formado por encima de una litosfera oceánica en subducción, pudiendo haber sido más o menos modificada por contaminación con fundidos procedentes de la corteza continental.

Palabras clave: Plutonismo hercinianoo. Cadenas Costeras Catalanas. Magmatismo calcoalcalino.

INTRODUCTION

The Catalonian Coastal Ranges consist of two, N60E-trending low altitude mountain alignments, approximately parallel to the north-eastern coast of the Iberian Peninsula (Littoral and Pre-littoral Ranges), and an elongated graben, filled with Neogen sediments and alkali basalt volcanics, between them (Prelittoral Depression).

From a structural point of view these ranges represent the emerged north-western margin of the Catalonian-Balearic Basin (Santanach, 1986) formed by Neogen tensional tectonics. The subsequent rifting caused the uplift of different crustal blocks allowing extensive Paleozoic terrains to outcrop once the Mesozoic-Tertiary cover was removed.

The Paleozoic materials of the Catalonian Coastal Ranges consist of two principal groups of rocks: a) Supracrustal, mainly sedimentary, ranging from Cambro-Ordovician to Lower Carboniferous, deformed and regionally metamorphosed during the Hercynian Orogeny, and, b) Plutonic and hypabyssal, mainly acidic and intermediate in composition which form a granite batholith which outcrops over an area of more than 1500 Km^2.

All granitic rocks are pre-Triassic. Most of them are clearly post-tectonic and younger than the regional metamorphism and, therefore, are considered to be late-Hercynian. However, there are also some small peraluminous leucogranitic and pegmatitic perianatectic

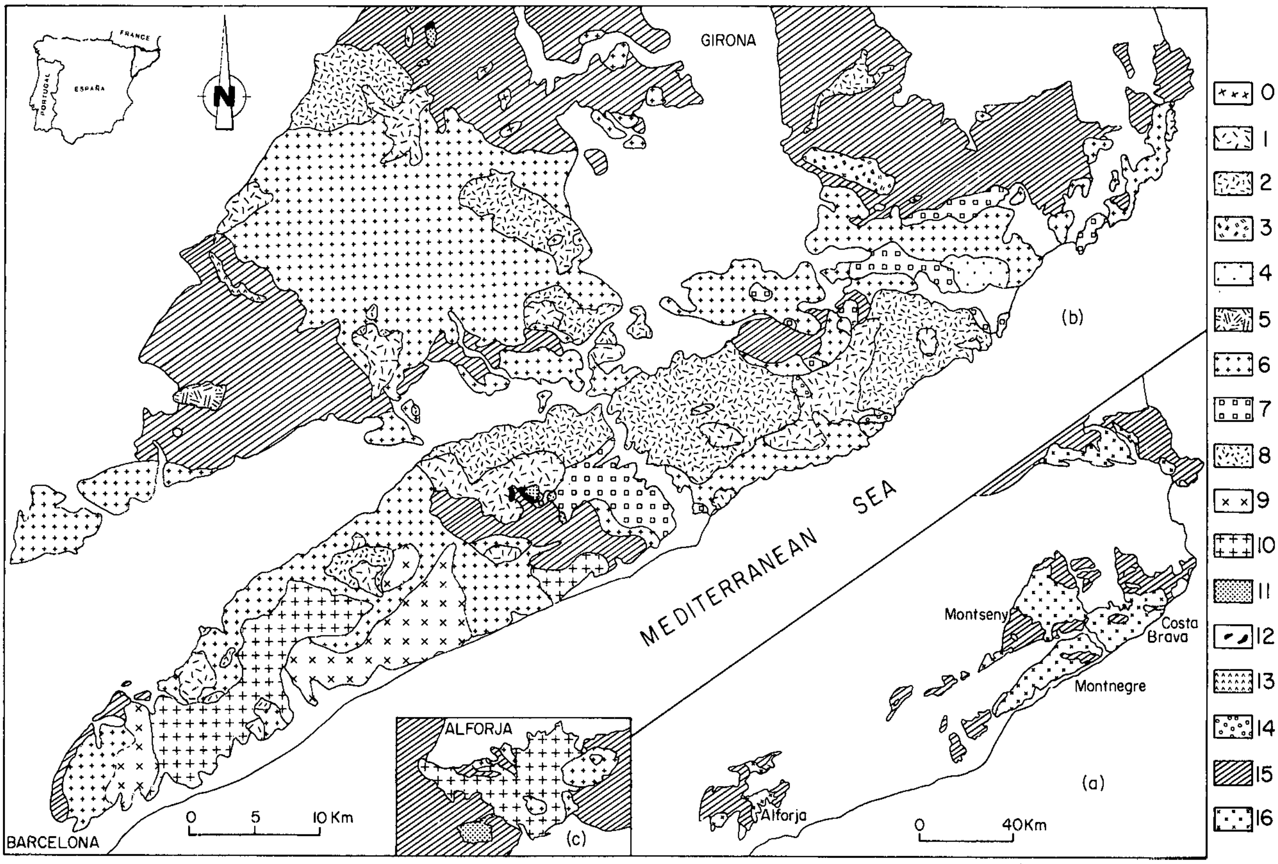


Figure 1.- Geological setting of the Catalonian Coastal Batholith and location of the main plutonic rocks. a) main Hercynian outcrops in the Catalonian Coastal Ranges; b) the Montnegre, Costa Brava and Montseny-Guilleries massifs; c) the Alforja massif. LEGEND, 0: Syn-metamorphic muscovite leucogranites and pegmatites from the Montseny-Guilleries massif; 1: Fine- to medium-grained biotite leucogranites (sometimes with accessory muscovite); 2: Coarse-grained biotite leucogranites; 3: Medium-grained muscovite leucogranites; 4: Fine-grained two mica leucogranites; 5: Porphyroid biotite granite (K-feldspar megacrysts-bearing) (grading to porphyroid microgranite); 6: Medium-grained biotite granodiorites; 7: Porphyroid biotite granodiorites (K-feldspar megacrysts-bearing); 8: Inequigranular biotite granodiorites; 9: Hornblende-bearing biotite granodiorites; 10: Hornblende biotite tonalites and granodiorites; 11: Biotite hornblende (+/- pyroxene) quartzdiorites, diorites and quartz gabbros, and hornblende gabbros (bojites); 12: Olivine hornblendites («cortlandtites»); 13: Granite porphyries; 14: Felsites, porphyritic microgranites and porphyritic aplites.- 15: Paleozoic sedimentary and metamorphic rocks; 16: Plutonic rocks.

bodies emplaced during high-grade regional metamorphism stages.

Thus, the Paleozoic terrains of the Catalonian Coastal Ranges form a set of, more or less, scattered Hercynian remnants scarcely modified by the Alpine Orogeny, although their isolation in the post-Hercynian materials hinders their correct assembly into the Hercynian Belt and, consequently, the interpretation of associated metamorphism and magmatism. However, there are some geological features that are shared with other neighbouring Hercynian fragments, particularly with the Hercynian Pyrenees, Monthoumet and Montagne Noire (Julivert, 1981) : a) All these massifs are, at present, located to the north of the Iberian-Armorican arc (Julivert, 1981); b) the pre- and syn-orogenic Carboniferous sequences are similar (Julivert and Martínez, 1980); c) the main tectonic structures face the south (Ashauer and Teichmüller, 1935; Julivert and Martinez, 1980; Casas, 1986); d) There are abundant late-orogenic calc-alkaline granitic intrusions with similar petrologic and geochemical characteristics, and a relative scarcity of early peraluminous leucogranites.

It is, therefore, believed that the Catalonian Coastal Ranges and Pyrenees may represent a relatively external fragment of the southern branch of the European Hercynian belt, possibly in an equivalent location to that of the westernmost part of the West-Asturian-Leonese zone in the Iberian Massif (Julivert, 1981).

Despite this, from a plutonic point of view the existence of important differences between the zone of the Catalonian Coastal Ranges and that of Western Asturias-Leon must be taken into consideration: a) the great scarcity of peraluminous leucogranites in the Catalonian Coastal Ranges Batholith in contrast to their abundance in the Iberian Massif; b) the higher calcium oxide/alkalis ratios in the Catalonian Coastal Ranges plutonics in relation to those of most of the late-Hercynian calc-akaline plutonics from the Iberian Massif (Enrique, 1985; Enrique et al, 1987).

THE CATALONIAN COASTAL BATHOLITH: GENERAL FEATURES.

A discontinuously outcropping granitic batholith 200 Km long forms most of the Hercynian Catalonian Coastal terrains (Fig.1). Geographically, the batholith may be divided into two areas: The first and main area extends continuously from Barcelona to the NE forming the granitic massifs of Montnegre and Costa Brava in the Littoral chain, and Montseny-Guilleries in the Pre-littoral chain. Some small peripheral stocks, intruded into paleozoic meta-sedimentary rocks (e.g. Gavarres, Tagamanent, etc.), and several isolated outcrops (due to tertiary faulting and sedimentary covering) (e.g. La Garriga, Caldes de Montbui, Capellades, etc.) may be regarded as belonging to the same area. The second area, which is much more restricted, includes a group of medium-sized plutons situated in the southernmost part of the Pre-littoral chain (e.g. Alforja, Prades, Riudecanyes, Marsà, etc). In addition to plutonics, hypabyssal rocks form dense linear dyke swarms which are concentrated in determined zones, probably related to some underlying elongated plutonic intrusions. Typical examples of these dyke swarms are: a) The southern part of the Montnegre massif; b) the Alforja and Riudecanyes (Tarragona) zones; c) the Susqueda (Montseny-Guilleries) zone; d) Tossa - s'Agaró (Costa Brava) zone, etc.

The Catalonian Coastal Batholith is composed of numerous individual plutons, the composition of which ranges from ultramafic to acidic rocks although the majority of these are granodiorites, monzogranites and tonalites. A large variety of textures are also well displayed.

Many plutons have very characteristic compositions and textures and show sharp contacts with the enclosing rocks, which allows a separate and coherent description for each one. In some cases, however, the limits between different petrographic types or intrusive units are not well-defined.

For these reasons a combined criterion based on composition, textures and mode of occurrence was chosen for the following descriptions.

Considering the fact that the aim of this work is to update the information available concerning the Catalonian Coastal Batholith, more emphasis has been given to the petrological features than to the geochemistry.

PETROLOGY AND OCCURRENCE OF THE PLUTONIC ROCKS

The plutonics, which are the main and best known members of the batholith, are first described followed by the minor intrusions.

The general order of descriptions, in each case, is from the most basic terms to the most acidic ones. The nomenclature used in this work has been mainly those of Streckeisen (1976) (modal) and of De la Roche et al. (1980) (chemical). The most basic rocks consist of hornblendites which form small bodies associated with gabbros and diorites (and/or quartz diorites). Only two ultramafic outcrops have been found to date: Orsavinyà (Montnegre massif, Enrique 1981, 1983, 1984, 1985, Galán, 1987, Enrique & Galán, 1989), and Susqueda (Montseny - Guilleries massif, Enrique, 1988).

Ultramafic to intermediate plutonic rocks from the Orsavinyà complex

The Orsavinyà complex is formed by a group of small and irregular plutonic bodies of quartz diorites, hornblende gabbros (bojites), and olivinic hornblendites (cortlandtites).

Can Caselles and Can Montsant hornblendites

These are coarse-grained rocks (up to 3 cm in grain size) consisting predominantly of amphibole and olivine with small amounts of clino- and orthopyroxene, phlogopite, spinel and opaque ores. Their mineral composition has been described by Galán (1987) and Enrique and Galán (1989). There are several types of amphiboles. The most prominent type forms large, euhedral grains, colourless or slightly brownish in colour in thin sections, often including poikilitically numerous olivine crystals covered with networks of black fractures. This amphibole, which is considered to be a primary magmatic mineral, has a variable composition ranging from tschermakite and magnesio-hornblende in the cores to actinolite and magnesio-

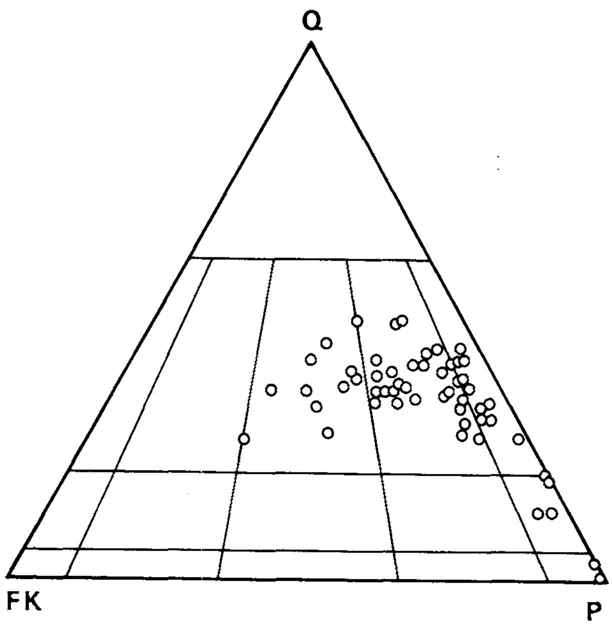


Figure 2.- Plot on the QAP diagram (Streckeisen, 1976) of plutonic rocks of the Montnegre massif (numeric data are in Table I and II).

Table I.- Modal analyses of mafic and ultramafic rocks of the Montnegre massif. CDT (1-1): olivine hornblendite («cortlandtite»); g-1 (1-3): hornblende gabbro (bojite); g-2 (1-4): leuco-hornblende gabbro (pyroxene leucobojite); QD-1 (1-6): quartz diorite; Qg-1 (4-1): biotite hornblende quartz gabbro; Emi-1 (7-2): microgranular enclave from tonalites.
Numbers in brackets as in Table-V.

	CTD	g-1	g-2	QD-1	Qg-1	Emi-1
Q	-	0.50	2.78	9.70	11.96	7.90
Pl	-	51.10	71.33	62.10	50.67	50.30
Fk	-	0.30	-	2.00	-	3.30
Mo	-	-	-	-	-	-
Bi	-	-	-	13.00	17.24	17.90
Ho	74.30	47.70	18.32	3.80	19.52	14.50
Clpx	0.60	-	6.97	1.80	-	-
Opx	-	-	-	5.40	-	-
Ol	16.90	-	-	-	-	-
Ap	-	-	-	0.68	-	0.43
Zr	-	-	0.05	0.39	-	0.16
Opc	4.00	0.40	0.35	1.12	0.44	0.16
Sp	2.40	-	-	-	-	-
Phl	1.80	-	-	-	-	-

cummingtonite in the rims. Secondary fibrous amphiboles of actinolite and magnesio-cummingtonite form a substantial part of the rock. Olivine is found as rounded inclusions in amphibole oikocrysts. Pyroxenes, chromiferous endiopside and orthopyroxene are only present in very small amounts although many fibrous amphiboles seem to have their origin in secondary subsolidus replacements. Phlogopite often replaces olivine and orthopyroxene and has a heterogeneous distribution in the rock. A deep green aluminous spinel, pleonast in composition, is an important mineral in these rocks since (in an ultramafic paragenesis) it is indicative of medium- to high-pressure conditions of crystallization (O'Hara, 1967, etc). It is found in groups of small anhedral grains and as euhedral inclusions in olivine. In some outcrops hornblendite occurs as irregular and angular masses cut by aplite veins, which suggests that hornblendite emplacement predates the granitoid intrusions. In contrast, the passage from hornblendites to hornblende gabbros is somewhat ambiguous. Occasionally, contacts between them are sharp but, in some cases there seems to be a gradational transition between the two rocks through the following types: a) olivinic hornblendite, with spinel, phlogopite and pyroxene, but without plagioclase (cortlandtites); b) plagioclase hornblendite, with phlogopite but without olivine or spinel; c) hornblende melagabbro (melabojite); d) hornblende gabbro.

Can Rec, Can Caselles and Can Montsant hornblende gabbros

These rocks form a group of small stocks intruded into the Silurian and Devonian limestones and into the pelitic rocks and are partly surrounded by granites. The contact metamorphism of the country rocks has produced calc-silicate and pelitic hornfelses (with diopside, andradite, idocrase, etc., and andalusite, respectively), which belongs, at least, to the hornblendic hornfels facies.

The hornblende gabbros consist of very calcic plagioclase (bytownite) and amphibole, as essential minerals. In addition, they have very small amounts of quartz and opaque ores (sometimes pyrrhotite). There are usually two kinds of amphibole in these rocks, both of which are anhedral. The largest amphiboles (1-2 cm), are colourless or slightly brown in thin sections and usually include several euhedral plagioclase crystals giving the rock an ophitic-like or sub-ophitic appearance. The other amphiboles are light green and exhibit an interstitial arrangement.

This mineral composition corresponds to that of the bojites (Hatch et al, 1972; Hughes, 1982; Le Maître, 1989), in which pyroxenes are absent or only present in small amounts. There are many varieties of

Table-II.- Modal analyses of the granitoids of the Montnegre massif. MH: Baldiri melatonalites; H: Sant Mateu tonalites and granodiorites; h: Llavaneres granodiorites; B: Orrius granodiorites; FK: coarse-grained granodiorites (Tordera); GB: coarse-grained northern Montnegre granites; Gb: medium-grained northern Montnegre granites; M: southern Montnegre leucogranites.

	MH-1	MH-2	H-1	H-2	H-3	H-4	H-5	H-6	H-7	H-8
Q	16.15	23.80	26.73	33.40	29.86	21.68	31.24	25.92	30.93	30.13
Pl	44.00	46.20	48.66	44.20	52.02	49.17	41.92	56.52	46.40	48.93
Fk	1.25	2.50	6.93	3.90	6.57	8.55	2.67	4.24	5.10	4.23
Mo	-	-	-	-	-	-	-	-	-	-
Bi	26.30	23.00	14.70	17.40	9.98	14.25	15.72	11.03	14.46	14.36
Ho	10.20	3.90	3.03	0.40	1.03	3.65	5.72	0.25	1.86	1.60
Ap	0.65	0.20	0.16	0.30	0.16	0.18	0.15	0.17	0.36	0.13
Zr	0.05	0.10	0.03	0.09	-	0.03	0.11	-	0.06	0.03
Opc	0.60	0.10	0.23	0.20	-	0.03	0.19	0.07	0.10	0.03
SEC	0.45	0.10	0.16	0.09	0.19	2.40	2.00	12.07	0.66	0.53

	H-9	H-10	H-11	H-12	H-13	H-14	H-15	h-1	h-2	h-3
Q	30.06	21.37	24.42	30.08	24.73	24.46	32.73	37.89	39.42	33.60
Pl	47.50	52.49	59.42	45.78	55.60	50.96	43.76	43.54	48.67	39.09
Fk	7.73	6.85	7.35	4.81	4.20	4.93	5.00	6.06	2.91	10.52
Mo	-	-	-	-	-	-	-	-	-	-
Bi	12.80	17.26	7.73	16.94	14.03	13.53	14.33	10.60	6.67	14.42
Ho	1.33	1.06	0.74	1.13	0.70	0.03	2.13	0.47	1.18	0.46
Ap	0.16	0.32	0.10	0.18	0.13	0.23	0.26	0.43	0.13	0.65
Zr	-	0.03	-	0.03	0.03	0.03	0.06	-	0.04	0.19
Opc	0.13	0.03	-	0.06	0.13	0.06	0.16	0.06	0.17	0.37
SEC	0.26	0.57	0.47	0.87	0.42	0.69	1.33	1.12	0.80	0.32

	h-4	h-5	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8
Q	25.69	23.64	36.59	42.61	41.20	33.60	32.00	29.80	31.65	33.44
Pl	49.75	49.44	42.02	36.39	35.00	38.20	40.43	39.46	47.45	37.24
Fk	4.02	7.59	8.10	9.18	10.40	14.56	14.70	19.90	14.45	17.62
Mo	-	-	0.02	-	-	-	-	-	-	-
Bi	18.12	15.92	11.83	9.76	10.90	12.40	12.43	10.33	5.00	10.92
Ho	0.77	2.69	-	-	-	-	-	-	-	-
Ap	0.32	0.20	0.25	0.36	0.20	0.30	0.06	0.10	0.10	0.33
Zr	0.22	0.04	0.05	0.07	0.10	0.13	0.06	0.03	-	0.03
Opc	0.19	0.04	-	-	-	0.03	-	-	0.05	-
SEC	0.87	0.36	1.11	0.90	1.10	0.76	0.26	0.36	0.30	0.37

	B-9	B-10	B-11	B-12	B-13	B-14	FK-1	FK-2	FK-3	GB-1
Q	31.60	29.49	37.50	31.33	30.56	28.93	32.44	32.34	38.56	45.37
Pl	43.03	46.81	45.07	41.80	38.06	41.90	43.14	33.89	38.25	31.76
Fk	7.03	8.40	9.78	16.46	18.70	16.33	14.26	23.66	17.32	17.18
Mo	-	-	-	-	-	-	-	-	-	0.09
Bi	17.53	14.95	6.91	9.56	13.30	12.33	9.00	7.66	4.92	4.37
Ho	-	-	-	-	-	-	0.05	0.05	-	-
Ap	0.33	0.12	0.06	0.16	0.13	0.10	0.30	0.26	0.16	0.15
Zr	0.13	-	0.03	0.06	0.03	0.03	0.15	0.05	0.13	0.03
Opc	0.03	-	0.03	0.01	0.03	-	0.10	-	-	-
SEC	0.29	0.20	0.55	0.50	0.09	0.50	0.55	1.68	0.64	1.10

	GB-2	Gb-1	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8
Q	25.54	30.18	38.55	37.32	33.94	42.15	34.15	25.46	30.06	34.86
Pl	36.97	32.88	28.00	35.95	25.00	29.90	30.93	26.26	38.81	36.43
Fk	31.23	30.23	27.60	22.37	36.77	24.35	32.08	47.43	17.16	21.90
Mo	4.33	-	0.10	-	-	-	0.09	0.03	-	0.06
Bi	-	6.18	4.85	3.67	3.86	3.70	2.63	0.70	12.59	5.30
Ho	-	-	-	0.06	-	-	-	-	-	-
Ap	0.23	0.22	0.10	-	0.03	-	-	-	0.13	0.13
Zr	0.09	0.17	-	-	0.10	-	-	-	0.06	0.03
Opc	0.14	0.13	-	-	-	-	-	-	-	0.03
SEC	1.46	-	0.80	0.56	0.26	-	-	0.10	0.50	1.23

hornblende gabbros depending on their plagioclase content, ranging from hornblende melagabbros to clinopyroxene-hornblende leucogabbros. Occasionally, a more or less layered structure may be seen, suggesting some degree of crystal settling processes.

The most acidic terms contain biotite which is more abundant as the quartz content increases.

Can Camps, Can Vilà and Can Font Rodona quartz diorites

Medium- to fine-grained quartz diorites form some small intrusive bodies situated very close to the hornblende gabbros. They consist predominantly of inequigranular, strongly zoned plagioclases (showing conspicuous oscillatory zoning) with a calcium-rich andesine average composition. Biotite and hornblende are the principal mafic constituents, but ortopyroxene (hyperstene) and clinopyroxene are also present in some bodies (e.g. Can Camps stock, Enrique, 1983) (Table-I, Fig.3). Quartz diorites are usually separated from the hornblende gabbros by a heterogeneous mingling zone consisting of swarms of rounded fine-grained quartz dioritic enclaves engulfed by a granodioritic to tonalitic medium-grained matrix. The enclaves range in size from a few centimeters to some meters and contain biotite and hornblende in variable amounts.

Quartz dioritic enclaves and granodioritic magma show evidence of crystal exchanges in the magmatic state, giving rise to hybrid rocks, sometimes with blurred contacts.

The distribution of enclaves is also irregular and for this reason there are zones where these rocks are predominant and zones where they are scarce.

Contacts between hornblende gabbros and quartz diorites/ granodiorites *mélange* have not been directly observed but the existence of some enclaves of these gabbros in the quartz dioritic material near the deduced contacts suggests an older (or synchronous) age of emplacement.

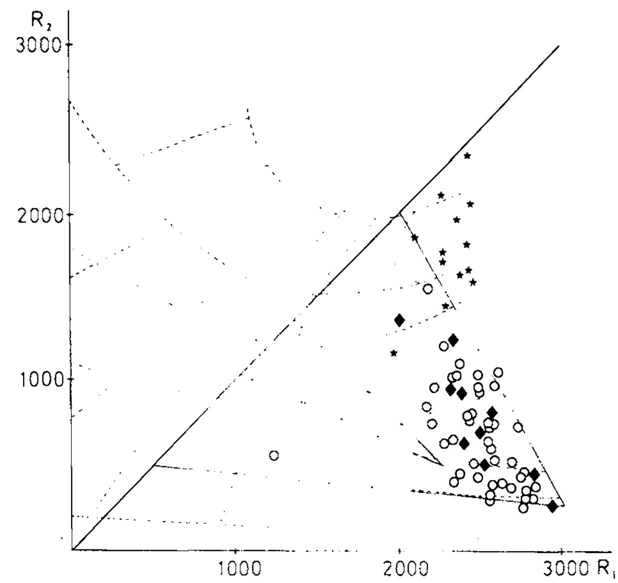


Figure 3.- Plot on the R_1R_2 diagram (De la Roche et al, 1980; Batchelor and Bowden, 1985) of rocks from the Catalonian Coastal Batholith illustrating the distribution of the samples along the «pre-collision» field (Cordilleran-type plutonics), both for plutonics (open circles) and hypabyssal calc-alkaline (rhombs) rocks. Stars represent samples of the intermediate-mafic- ultramafic complexes. (The open circle displaced to the left of the main trend is a K-feldspar megacrysts cumulate).

Ultramafic to intermediate plutonic rocks from the Susqueda complex

Beside the Susqueda dam lies the largest basic massif of the Catalonian Coastal Ranges Batholith which is composed mainly of dioritic and gabbroic rocks (Ashauer and Teichmüller, 1935, San Miguel de la Cámara, 1936, Van der Sijp, 1951), although some small ultramafic masses are also present (Enrique, 1988). The complex is intruded into an infra-Caradocian pelitic series intensely affected by the Hercynian metamorphism (Van der Sijp, 1951, Durán, 1985). The morphology of the complex is considerably modified by the intrusion of a dense network of granodioritic porphyries which frequently leaves plutonic and metamorphic rocks reduced to screens between the dykes.

Susqueda hornblendites

In addition to the plagioclase-rich rocks, the Susqueda complex contains small bodies with terms that are progressively more mafic in which plagioclase may even be absent, giving rise to hornblende melagabbros, plagioclase hornblendites, hornblendites «*sensu stricto*», and pyroxene-bearing olivinic hornblendites

Table III.- Trace element analyses of plutonic rocks of the Catalonian Coastal Batholith. Numbers as in Table V.

	2-1	2-2	2-3	2-4	2-5	2-7	2-8	2-9	6-1	7-4
Y	10	12	16	11	29	33	19	23	12	28
Zr	42	59	54	37	120	49	54	48	137	85
Nb	5	6	5	4	12	6	4	4	10	10
Rb	13	5	24	26	85	40	25	58	178	83
Sr	80	61	92	198	246	134	198	181	246	234
Ba	79	64	166	99	546	197	132	163	1005	298
Pb	1	4	5	3	9	8	7	12	64	15
Th	2	7	2	2	10	6	1	4	3	4

	14-1	14-4	15-1	20-2	20-3	20-4	20-5	21-1	21-2	25-4
Y	28	27	19	49	41	34	41	58	35	20
Zr	163	122	136	65	77	71	65	75	62	156
Nb	13	14	14	16	12	12	11	18	13	9
Rb	141	128	150	207	160	172	197	210	161	67
Sr	156	125	170	16	36	25	25	25	29	285
Ba	667	579	557	nd	318	nd	95	87	107	595
Pb	27	21	26	39	4	30	34	35	4	16
Th	14	17	10	24	17	21	17	25	10	9

(cortlandtites) (Enrique, 1988). The mineral and textural features of these rocks are very similar to those of the Orsavinyá complex in the Montnegre massif. Susqueda cortlandtites consist of large anhedral poikilitic, equant, amphibole crystals (1-3 cm) which include numerous subhedral olivine crystals (0.5-2 mm). Other noticeable minerals of these rocks are orthopyroxene (analogous in morphology and size to amphiboles, and often replaced by secondary fibrous amphiboles), and, in smaller amounts, phlogopite, green spinel and opaque ores. Olivine and plagioclase are not found together, which suggest that these minerals are incompatible in this particular hornblendite composition environment. Spinel is almost exclusively found in olivinic varieties whereas phlogopite is also present in *«sensu stricto»* (without plagioclase or olivine) hornblendites.

Susqueda quartz diorites, diorites and hornblende gabbros.

These form a group of medium- to fine-grained rocks consisting mainly of plagioclase and mafic minerals, hornblende or biotite or both. Some quartz, K-feldspar and clinopyroxene may also be present. The relative proportions of biotite and hornblende, the anorthite content of plagioclase and, the textures are very variable. Rock types, rich in plagioclase range from biotite quartz diorites to hornblende gabbros (bojites). The latter rocks are generally characterized by anhedral brown amphiboles, sometimes including poikilitically plagioclase crystals. Euhedral amphiboles occur locally and, in these cases, they often lie on primary magmatic surfaces without any preferential orientation.

Some degree of layering may be observed in some outcrops showing alternate zones with more or less mafic minerals.

The contacts with the metamorphic country rocks are very intricate and, locally, the border diorite facies shows evidence of magmatic contamination giving rise to the crystallization of significant amounts of garnet as a consequence of pelitic assimilation.

Quartz gabbros and quartz diorites unrelated to ultramafic outcrops

In addition to quartz diorites which are closely associated with hornblende gabbros and cortlandtitic rocks there are several small masses of these rocks

Table IV.- REE analyses of plutonic rocks of the Montnegre massif. Numbers as in Table V. LaN, CeN, ..., etc.: chondrite-normalized values (chondrite standards from Wakita et al, 1971, in: Henderson, 1984). EuN*: Europium interpolated values.

	24-1	17-5	17-2	8-4	8-1	13-2	4-1	1-4	18-3	1-6	1-1	1-3
La	22.88	22.78	25.41	31.01	28.86	42.84	21.06	9.29	34.73	32.72	9.68	8.44
Ce	49.15	46.61	50.31	60.25	55.51	83.33	46.07	20.61	66.20	64.56	20.11	17.49
Nd	24.01	21.56	23.83	27.47	25.32	38.44	21.99	12.08	27.19	31.97	9.60	9.73
Sm	5.97	5.10	5.31	5.43	5.04	7.61	4.85	2.69	5.44	6.13	2.56	2.35
Eu	0.82	0.66	0.76	1.09	1.08	1.21	1.23	0.75	0.70	1.21	0.53	0.71
Gd	5.07	4.50	4.33	4.46	3.98	5.71	4.25	2.32	4.71	4.89	2.37	2.47
Dy	5.68	4.27	3.85	4.49	3.71	4.60	4.67	2.31	4.82	4.64	1.97	2.46
Er	3.01	2.39	2.04	2.42	1.99	2.23	2.57	1.09	2.66	2.34	1.08	1.27
Yb	3.43	2.92	2.38	2.58	2.11	2.28	2.77	1.10	3.00	2.45	1.06	1.25
Lu	0.52	0.47	0.41	0.42	0.33	0.35	0.47	0.22	0.45	0.36	0.22	0.18
Y	38.67	29.97	25.91	29.51	23.91	27.80	30.19	14.19	33.03	29.39	12.35	15.24
LaN	67.29	67.00	74.74	91.21	84.88	126	61.94	27.32	102.15	96.24	28.47	24.82
CeN	54.01	51.22	55.29	66.21	61.00	91.57	50.63	22.65	72.75	70.95	22.10	19.22
NdN	37.52	33.69	37.23	42.92	39.56	60.06	34.36	18.88	42.48	49.95	15.00	15.20
SmN	30.62	26.15	27.23	27.85	25.85	39.03	24.87	13.79	27.90	31.44	13.13	12.05
EuN	11.23	9.04	10.41	14.93	14.79	16.58	16.85	10.27	9.59	16.58	7.26	9.73
GdN	19.50	17.31	16.65	17.15	15.31	21.96	16.35	8.92	18.12	18.81	9.12	9.50
DyN	18.93	14.23	12.83	14.97	12.37	15.33	15.57	7.70	16.07	15.47	6.57	8.20
ErN	15.05	11.95	10.20	12.10	9.95	11.15	12.85	5.45	13.30	11.70	5.40	6.35
YbN	15.59	13.27	10.82	11.73	9.59	10.36	12.59	5.00	13.64	11.14	4.82	5.68
LuN	15.29	13.82	12.06	12.35	9.71	10.29	13.82	6.47	13.24	10.59	6.47	5.29
EuN/EuN*	0.45	0.42	0.47	0.66	0.72	0.54	0.82	0.90	0.42	0.66	0.65	0.90
CeN/YbN	3.46	3.86	5.11	5.65	6.36	8.84	4.02	4.53	5.33	6.37	4.59	3.38
LaN/YbN	4.32	5.05	6.91	7.78	8.85	12.16	4.92	5.46	7.49	8.64	5.91	4.37

scattered throughout the batholith. Three principal types may be distinguished: 1) Amphibole-rich (sometimes containing accessory pyroxene) small, fine- to medium-grained, quartz diorite and quartz gabbro intrusions. Riudecols quartz diorite (Tarragona), Can Capa quartz gabbro (Montnegre massif) and Vallcàrcara quartz diorites (Montseny massif) may be considered typical examples.

2) Small masses (decametric to hectometric) of highly biotitic fine-grained quartz diorites (sometimes melatonalites), closely associated with biotite granodiorites. Amphiboles are very subordinated to biotite and may even be absent in these quartz- diorites. They frequently show signs of magmatic co-existence with granodiorites. Of these signs mechanical hybridization is possibly the most widespread. The most typical examples occur in the Costa Brava massif: 1) Llafranc (Palafrugell), 2) La Fosca (Palamós) and 3) Can Samada (Tossa). 3) Quartz diorite/quartz gabbro microgranular enclaves from granodiorites and tonalites.

Riudecols orthopyroxene-bearing biotite hornblende quartz diorite

The Riudecols quartz diorite constitutes a fairly homogeneous, fine- to medium-grained intrusion of 3.5 Km^2 which are peripheral to the Alforja plutonic complex (Serra, 1985). The main mafic minerals present are pleochroic green hornblende, cummingtonitic amphibole and biotite.

Orthopyroxene, often replaced by pale green, non-pleochroic and polisynthetically twinned cummingtonitic amphibole, characterizes these rocks.

Can Capa hornblende-biotite quartz gabbro

This forms a small outcrop, less than 1 Km^2 in area, in a peripheral position of a biotite granodiorite intrusion (Enrique, 1984a, 1985). It consists of subhedral zoned plagioclase, anhedral biotite and hornblende, and interstitial quartz. K-feldspar is absent. Because of their richness in mafic minerals and high anorthite content (67 normative wt. per cent) of their plagioclase these rocks must be classified as quartz gabbros (Streckeisen, 1976, Le Maître, 1989) (Fig. 2) or gabbro-diorites (if the chemical R_1R_2 classification is used, De la Roche et al, 1980) (Fig. 3). (Table-I, num. Qg-1; Table-V, num. 4-1). These rocks are the most basic members recognized in the plutonic superunit of southern Montnegre.

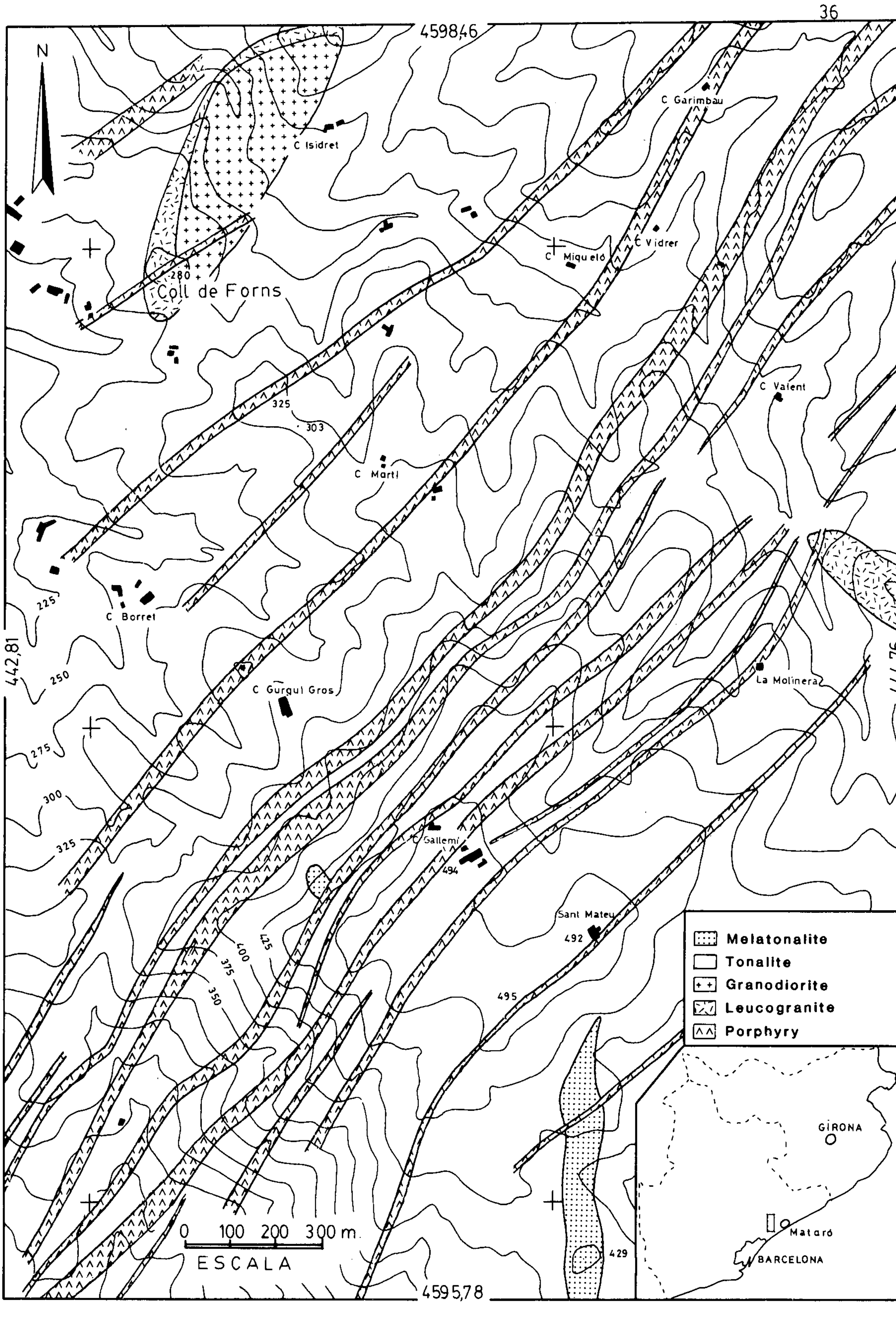


Figure 4.- Detailed map of the dyke swarm of Sant Mateu area (Southern Montnegre) which consists mainly of granite and granodiorite porphyries.

Table V.- Major element analyses of samples of the Catalonian Coastal Batholith. 1 Orsavinyà complex (N-MTN), 1-1 and 1-2: olivine hornblendites («cortlandtites»), 1-3: hornblende gabbro (bojite), 1-4: clinopyroxene leuco-hornblende gabbro, 1-5: mela-hornblende gabbro; 1-6: Can Camps quartz diorite; 2: Susqueda complex (GUI), 2-1: olivine hornblendite («cortlandtite»), 2-2: hornblendite *s.s.*, 2-3: mela-hornblende gabbro; 2-4 and 2-6 to 2-9: hornblende gabbros; 2-5: biotite quartz diorite; 3-1 Riudecols quartz diorite (*); 4-1: Can Capa biotite hornblende quartz gabbro; 5-1: La Fosca biotite quartz diorite; 6-1: Can Samada biotite quartz diorite; 7-1 to 7-3: microgranular enclaves from granodiorites and tonalites (S-MTN); 8-1 to 8-3: Sant Mateu tonalites and granodiorites; 8-4: Baldiri melatonalite; 8-5: leucotonalite; 9-1, 9-2: Borges-Vilaplana tonalites and granodiorites (*); 9-3: Riudecanyes tonalite (**); 10-1: Coll de la Batalla granodiorite (*); 11: Alforja tonalites and granodiorites (*); 12: Llavaneres granodiorites; 13: Orrius granodiorites; 14: tabular biotite granodiorites, 14-1 Susqueda (GUI), 14-2: S'Alguer (CB), 14-3: Tordera, 14-4: Tossa; 15-1: S'Agaró megacrysts-bearing granodiorite; 15-2: K-feldspar megacrysts cumulate of Calella de Palafrugell; 16-1: Roca Bruna leucogranite (*); 17: S-MTN leucogranites, 17-1 to 17-4: Céllecs pluton; 17-5: Mont Cabrer pluton; 17-6: Corredor pluton; 18: N-MTN, 18-1: porphyritic facies, 18-2: coarse-grained facies, 18-3: fine-grained facies; 19 and 20: CB leucogranites, 19-1: S'Alguer; 20-1: coarse-grained facies, 20-2: miarolitic facies, 20-3 and 20-5: fine-grained facies, 20-2: porphyritic fine-grained facies; 21-1: CB porphyritic microaplite, 21-2: CB porphyritic felsite, 21-3: S-MTN spherulitic felsite; 23-1: N-MTN leucogranite porphyry; 24-1: S-MTN granite porphyry; 25-1: S-MTN granodiorite porphyry; 25-2: S-MTN K-feldspar megacrysts granodiorite porphyry; 25-3: AL granodiorite porphyry GUI: Guilleries; N-MTN: Northern Montnegre; S-MTN: Southern Montnegre; CB: Costa Brava; AL: Alforja; (*): Serra (1985); (**): Enrique (1987a).

	1-1	1-2	1-3	1-4	1-5	1-6	2-1	2-2	2-3	2-4
SIO2	44.49	46.39	47.50	49.09	49.60	58.66	40.70	45.62	47.21	48.32
TIO2	0.48	0.35	0.53	0.32	0.53	0.97	0.43	0.37	0.48	0.41
AL2O3	7.38	7.57	20.24	19.38	12.45	17.76	8.79	8.20	11.09	19.21
FE2O3*	14.10	15.26	7.58	5.44	9.12	6.62	12.84	12.13	9.96	8.38
MNO	0.16	0.24	0.10	0.10	0.13	0.10	0.18	0.18	0.16	0.13
MGO	25.15	22.20	7.67	5.91	12.20	3.23	24.16	21.93	15.76	8.41
CAO	3.16	3.23	12.56	15.66	11.34	6.26	4.60	5.66	9.14	9.25
NA2O	0.56	0.48	1.46	1.46	0.69	3.20	0.61	0.85	1.01	1.39
K2O	0.51	0.26	0.68	0.77	1.60	2.66	0.23	0.11	0.69	0.94
L.I.	2.31	2.04	1.78	1.81	2.47	0.89	5.00	2.91	2.41	1.69
P2O5	-	-	-	--	--	-	0.03	0.05	0.04	0.04
TOTAL	98.31	98.00	100.10	99.94	100.13	100.35	97.57	98.01	97.95	98.17
R1	2279	2466	2282	2425	2441	1958	2107	2396	2361	2283
R2	1730	1595	2121	2349	2063	1178	1863	1854	1977	1784

	2-5	2-6	2-7	2-8	2-9	3-1	4-1	5-1	6-1	7-1
SIO2	59.79	49.68	49.99	50.00	52.02	57.33	53.44	60.45	60.92	55.57
TIO2	0.75	1.90	0.74	0.65	0.69	1.13	1.02	0.89	0.88	0.84
AL2O3	17.37	19.45	14.52	19.94	19.07	17.73	18.00	17.37	17.02	17.60
FE2O3*	6.74	11.44	9.86	8.87	8.98	6.98	9.08	5.59	6.22	9.11
MNO	0.15	0.15	0.16	0.13	0.13	0.13	0.14	0.09	0.10	0.17
MGO	3.16	4.00	11.43	7.10	6.42	3.32	4.86	3.95	2.63	3.49
CAO	5.58	8.29	8.82	10.14	9.13	6.56	9.10	4.59	3.62	5.36
NA2O	2.63	1.25	1.77	1.40	1.33	2.94	2.02	2.25	2.11	2.71
K2O	2.00	1.04	1.22	0.75	1.42	1.18	1.67	3.00	4.04	2.81
L.I.	1.61	1.14	2.11	1.18	1.25	2.01	1.52	1.14	1.65	1.47
P2O5	0.19	0.24	0.11	0.08	0.03	-	--	0.24	0.16	--
TOTAL	99.97	98.58	100.73	100.24	100.47	99.31	100.85	99.56	99.35	99.13
R1	2392	2286	2149	2418	2417	2294	2197	2362	2185	1832
R2	1095	1467	1795	1828	1669	1214	1568	1028	852	1092

	7-2	7-3	7-4	8-1	8-2	8-3	8-4	8-5	9-1	9-2
SIO2	56.09	54.56	54.14	63.57	64.79	64.53	60.91	65.43	63.20	61.55
TIO2	0.90	0.86	0.62	0.63	0.48	0.65	0.75	0.30	0.72	0.77
AL2O3	18.26	17.98	17.98	16.87	16.75	16.37	17.46	19.08	15.42	16.26
FE2O3*	8.01	8.45	6.72	4.80	4.67	5.07	6.40	1.83	5.05	5.68
MNO	0.16	0.18	0.22	0.07	0.16	0.10	0.10	0.04	0.08	0.10
MGO	3.85	3.90	4.08	1.85	2.08	2.05	2.45	0.50	2.96	3.17
CAO	6.99	6.64	7.06	5.10	5.16	4.63	6.02	6.01	5.58	5.37
NA2O	3.35	3.25	4.01	2.82	2.71	2.81	2.75	3.65	2.70	2.85
K2O	2.13	2.59	1.60	2.63	2.64	2.79	2.29	1.73	2.67	2.53
L.I.	1.13	1.94	1.55	0.60	0.72	0.74	0.75	0.63	1.24	0.93
P2O5	-	-	0.11	-	-	-	-	0.02	-	-
TOTAL	100.87	100.35	98.09	98.94	100.16	99.74	99.88	99.22	99.62	99.21
R1	1824	1640	1623	2480	2605	2503	2365	2603	2481	2333
R2	1297	1257	1310	968	984	918	1108	1042	1046	1051

	9-3	10-1	11-1	11-2	12-1	12-2	13-1	13-2	13-3	13-4
SIO2	64.64	67.82	61.90	65.38	66.57	66.18	67.32	67.60	67.82	69.16
TIO2	0.63	0.48	0.59	0.48	0.55	0.70	0.50	0.52	0.58	0.54
AL2O3	15.59	14.92	16.78	15.85	15.90	16.10	15.53	15.75	15.53	15.20
FE2O3*	5.43	3.40	6.39	3.90	4.34	4.61	4.05	3.78	4.23	3.55
MNO	0.10	0.05	0.07	0.07	0.09	0.08	0.05	0.04	0.08	0.07
MGO	2.34	0.91	2.02	1.86	1.68	1.65	1.41	1.65	1.51	1.20
CAO	4.23	2.75	5.03	3.73	3.66	3.96	3.37	3.49	3.54	3.52
NA2O	2.52	3.32	3.07	2.86	2.99	2.93	2.92	3.04	2.92	2.86
K2O	3.66	4.08	2.78	3.44	3.53	2.84	3.36	3.13	3.56	3.17
L.I.	1.14	0.92	0.94	1.54	0.81	0.74	0.99	0.70	0.63	0.53
P2O5	-	-	-	-	-	-	-	-	-	--
TOTAL	100.28	98.65	99.57	99.11	100.12	99.79	99.50	99.70	100.40	99.80
R1	2402	2286	2207	2424	2423	2569	2546	2582	2526	2746
R2	875	632	968	802	787	821	735	764	758	734

	14-1	14-2	14-3	14-4	15-1	15-2	16-1	17-1	17-2	17-3
SIO2	67.26	64.46	70.33	71.60	69.85	63.31	76.67	72.93	74.84	75.42
TIO2	0.35	0.58	0.40	0.29	0.37	0.33	0.10	0.28	0.12	0.14
AL2O3	16.03	16.81	15.07	14.26	15.33	18.96	12.52	14.30	13.55	13.62
FE2O3*	3.42	4.91	2.76	2.73	3.28	2.91	0.67	2.18	1.33	1.35
MNO	0.04	0.07	0.07	0.07	0.04	0.16	0.02	0.06	0.04	0.04
MGO	0.84	1.25	1.02	0.58	0.79	0.57	0.12	0.62	0.19	0.38
CAO	2.75	3.41	2.86	2.01	2.55	1.57	0.92	2.37	1.67	1.66
NA2O	3.30	3.63	3.43	3.54	3.45	3.41	3.12	3.29	3.16	3.24
K2O	3.78	2.84	3.52	3.62	3.34	7.22	5.12	4.03	4.64	4.65
L.I.	1.15	0.69	0.66	0.69	0.64	0.80	0.29	0.59	0.43	0.49
P2O5	0.13	0.22	0.10	0.08	0.17	0.23	-	-	-	-
TOTAL	99.05	98.87	100.22	99.47	99.81	99.47	99.55	100.65	99.97	100.99
R1	2329	2202	2563	2589	2554	1237	2781	2684	2740	2747
R2	650	757	652	524	613	568	350	565	454	464

	17-4	17-5	17-6	18-1	18-2	18-3	19-1	20-1	20-2	20-3
SIO2	75.53	75.26	75.64	72.28	72.44	73.36	71.65	73.74	75.69	76.13
TIO2	0.08	0.10	0.10	0.23	0.22	0.19	0.06	0.17	0.05	0.10
AL2O3	13.11	13.05	13.76	14.61	14.45	14.47	14.61	13.23	12.77	12.59
FE2O3*	0.93	1.19	1.38	2.06	2.34	2.11	1.47	1.74	1.12	1.16
MNO	0.05	0.05	0.05	0.05	0.06	0.06	0.03	0.07	0.05	0.01
MGO	0.16	0.14	0.22	0.54	0.47	0.40	0.17	0.05	0.01	0.01
CAO	1.00	1.19	1.11	1.23	1.88	1.10	0.98	1.20	0.39	0.01
NA2O	3.32	2.90	3.64	4.05	3.97	3.90	3.35	3.78	3.64	3.17
K2O	4.85	4.79	4.59	4.02	3.84	4.12	5.16	4.11	5.00	4.90
L.I.	0.56	0.40	0.39	0.74	0.77	0.49	0.63	0.49	0.49	0.85
P2O5	-	-	0.03	-	-	0.07	0.18	0.04	0.01	0.01
TOTAL	99.59	99.07	100.91	99.81	100.44	100.27	98.29	98.62	99.22	98.94
R1	2691	2829	2634	2378	2452	2479	2337	2559	2549	2767
R2	372	390	400	445	508	421	400	390	293	249

	20-4	20-5	21-1	21-2	22-1	23-1	24-1	25-1	25-2	25-3
SIO2	76.61	77.00	76.19	77.18	75.32	73.32	71.68	68.35	68.18	66.50
TIO2	0.09	0.06	0.08	0.04	0.12	0.11	0.16	0.47	0.49	0.60
AL2O3	13.07	12.81	12.95	13.21	13.11	13.14	14.37	15.61	15.93	15.45
FE2O3*	1.09	0.98	0.29	0.85	1.21	1.62	2.34	3.29	3.37	4.30
MNO	0.04	0.04	0.01	0.01	0.02	0.06	0.06	0.06	0.12	0.07
MGO	0.01	0.01	0.01	0.01	0.20	0.50	0.69	1.21	1.18	1.89
CAO	0.56	0.47	0.45	0.02	0.93	1.45	1.82	3.23	3.57	2.40
NA2O	3.41	3.41	4.24	3.14	3.45	2.46	3.47	3.31	3.11	2.71
K2O	4.62	4.54	4.25	4.60	4.43	4.84	4.20	3.27	3.35	4.06
L.I.	0.46	0.55	0.50	0.97	0.45	2.11	1.08	0.79	1.07	1.69
P2O5	0.01	-	0.02	0.01	0.03	0.05	--	-	-	-
TOTAL	99.97	99.87	98.99	100.04	99.27	99.66	99.87	99.59	100.37	99.67
R1	2781	2829	2565	2927	2721	2834	2496	2517	2556	2394
R2	317	302	303	262	367	438	511	712	753	654

	25-4	26-1	26-2	27-1	28-1
SIO2	67.81	63.22	62.57	56.30	55.09
TIO2	0.45	0.76	0.78	0.74	0.85
AL2O3	16.10	16.79	16.41	17.30	17.27
FE2O3*	3.21	5.45	5.86	7.01	7.24
MNO	0.07	0.09	0.12	0.10	0.12
MGO	1.34	2.17	2.42	5.10	5.17
CAO	1.67	4.69	5.02	6.13	7.18
NA2O	4.54	2.77	2.72	2.34	3.06
K2O	2.67	2.87	2.98	1.64	1.61
L.I.	1.61	0.94	1.30	3.08	2.95
P2O5	0.13	-	-	-	-
TOTAL	99.60	99.75	100.18	99.74	100.54
R1	2187	2399	2337	2340	2002
R2	561	939	979	1248	1363

Vallcàrcara hornblende-biotite quartz diorites

They were first described by Alonso et al (1976). They form two small stocks intruded into pelitic and calcareous materials of Devonian, Silurian and Ordovician ages which are highly metamorphosed near the contact giving rise to magnetite-rich skarns.

These rocks bear a resemblance to Can Capa quartz gabbros previously described. They mainly contain subhedral zoned plagioclase, hornblende, biotite, quartz and, sometimes, accessory pyroxene.

Both the diorites and their metamorphic envelope are cut by numerous porphyritic microgranites (granite porphyries).

Llafranc quartz diorite

The Llafranc quartz diorite forms a fairly homogeneous, dark grey, fine-grained, biotite-rich rock mass in which hornblende is also present in smaller amounts.

It is located in the southern coast of Llafranc which is mainly composed of paleozoic metamorphic rocks (mostly pelitic and semipelitic hornfelses) and biotite granodiorite. The granodiorite intrudes into the quartz diorite along rectilinear veins, which suggests a relatively rigid behaviour of the latter.

In other cases the granodiorite forms small curved seams and small rounded bodies. Near the contacts the granodiorite is often contaminated by the quartz diorite showing an appreciable increase in their biotite content.

Little coarse-grained quartzite xenoliths with more or less irregular morphologies and surrounded by a reaction hornblende-rich border are frequently found in the quartz diorite. These enclaves may apparently be considered to be quartz-vein resisters proceeding from the country rock hornfelses which have been isolated by magmatic assimilation processes (cf. Didier, 1973).

La Fosca quartz diorite

This quartz diorite is located in the northern coast of La Fosca beach (Palamós). The rocks of this outcrop have similar characteristics to those of Llafranc (see above) although they have more complex relationships with the host rocks.

Most of the quartz diorite body is extensively broken and injected by heterogeneous coarse-grained granodiorite and tonalite, offering a densely packed enclave swarm appearance in places. The relationships between the host granodiorite/tonalite and the quartz diorite suggest that the two rocks coexisted in the magmatic state. The main evidence in this respect are based on the following observations: a) The granodiorite/tonalite intrudes the quartz diorite through many sinuous and complex veins dispersing it in a bunch of more or less separated fragments.

b) These fragments appear to have been rapidly rounded, which suggests strong corrosion by the granodiorite magma. The corrosion of the quartz diorite is due to the scattering of the crystals situated on the contact surface and is probably caused by the existence of a small proportion of intergranular melt in the quartz diorites. This melt proportion might be lower than in coeval granodioritic magma.

c) Numerous crystals of quartz and some of plagioclase (with features similar to those in granodiorites) are found included in the quartz diorite. These minerals have different habits away from the contacts. For this reason, it is believed that they are xenocrysts which have been introduced into a plastic quartz diorite body during magmatic emplacement of the overall unit.

d) Some quartz diorite fragments seem to have been plastically deformed by magmatic movements on contact.

e) Quartz diorite and granodiorite display the same planar fluidality.

The scattering of biotite crystals from the quartz diorite into the granodiorites is very conspicuous in the first corrosion stages, giving rise to schlieren structures, but in the later stages, subsequent homogeneization produces a more mafic hybrid granitoid.

The ductile behaviour of quartz diorites in relation to granodiorites contrasts strikingly with the subsequent brittle, rectilinear fractures occupied by aplitic dykes proceeding from a potassic-feldspar megacryst granite intruded into both the quartz diorite and granodiorite after they had completely solidified (Enrique, 1986).

Can Samada quartz diorites.

These quartz diorites form a strongly weathered outcrop which are very micaceous and cut by several veins of K-feldspar-bearing biotite granodiorite. They are also located close to the contact with hornblende-biotite granodiorites (Enrique et al, 1983).

Quartz diorite/quartz gabbro microgranular enclaves in granodiorites and tonalites.

Most of the microgranular enclaves within granodiorites and tonalites have quartz dioritic to quartz-gabbroic compositions (Table-I, Emi-1) even though they display a great variety in size, grain-size, textures and mineral proportions.

Their abundance with respect to the enclosing rocks is variable and depends mainly on the host granitoid composition (more abundant in tonalitic and granodioritic rocks, and very scarce in leucogranites), but it is also conditioned by their situation in the magmatic body.

The following are some examples of mafic enclave-rich granitoids: 1) Sant Mateu and Llavaneres tonalites and granodiorites (Montnegre massif). 2) S'Agaró K-feldspar megacryst granodiorites (Costa Brava). 3) Granodiorite porphyry dykes, mostly in Southern Montnegre.

The size of enclaves ranges from a few centimeters up to a meter, whereas the morphology is irregular but generally with rounded outlines.

There is a total gradation from slightly modified, fine-grained, often porphyritic, enclaves (normally the largest ones, showing sharp contacts with the granitoid) to very transformed enclaves either by mechanical hybridism (crystal exchange and mixing of the interstitial melt) or by metasomatism, showing blurred contacts.

Microgranular enclaves contain very occasionally other enclaves of miscellaneous origins (hornfelsic, surmicaceous, vein-quartz resisters, etc.). These double enclaves are mostly found in the s'Agaró K-feldspar megacrysts granodiorite.

Microgranular enclaves consist mainly of plagioclase and biotite. Quartz and K-feldspar are present in smaller amounts. The enclaves found in hornblende biotite tonalites contain abundant hornblende whereas this mineral is scarce or may even be absent in the enclaves of biotite granodiorites.

Textures are very characteristic, the mafic minerals usually with euhedral habits, being poikilitically enclosed by large anhedral quartz and feldspar grains (San Miguel de la Cámara, 1936, Enrique, 1985).

Tonalites

The most basic rocks of the Catalonian Coastal Batholith involved in kilometric-sized intrusions have tonalitic compositions.

However, classification of these rocks is problematic since this depends on the criterion used, either mineral or chemical.

This is due to the presence of biotite which is the predominant mafic mineral (the potassium of which cannot be used to form potassic feldspars) and to the high anorthite content of plagioclase (factor not taken into account in mineral classifications). For these reasons, the same rock may be classified as granodiorite in the QAP modal diagram (Streckeisen, 1976) or as a tonalite in the R_1R_2 chemical diagram (De la Roche et al., 1980) (Figs.2 and 3). The rocks classified as tonalites in both diagrams belong to intrusions which are mineralogically and texturally very uniform.

Despite this, the scattering of samples overlaps the granodioritic field of the QAP diagram.

The main examples of tonalites are: 1) Sant Mateu hornblende biotite tonalites and granodiorites (Southern Montnegre) (Enrique 1978, 1979, 1981, 1984a, 1985, cf., amphibolic granite or adamellite by Montoto, 1967). 2) Borges-Vilaplana and Riudecanyes orthopyroxene-bearing hornblende biotite tonalites and granodiorites (Tarragona) (Serra, 1985, Enrique, 1987a). 3) Small bodies (decametric to hectometric in size) of melatonalites, associated with the Sant Mateu tonalites (Baldiri hornblende biotite melatonalites) (Enrique, 1984a, 1985). 4) Small vein-like bodies of biotite leucotonalites (decimetric to metric) widespread throughout the Sant Mateu intrusion (Enrique, 1987b).

Sant Mateu hornblende-biotite tonalites and granodiorites

These rocks (with a K-feldspar content under 7 %) cover a large area in a continuous outcrop, elongated from SW to NE, in the southern part of Montnegre. They are light grey in colour and medium- to coarse-grained, and the occurrence of some large euhedral hornblende crystals (1-2 cm long) gives a heterogranular appearance to the rock. Biotite forms prismatic, subhedral crystals with pseudo-hexagonal habits, often attaining 1 cm in length. Plagioclase tends to be euhedral, whereas K-feldspar (orthose and microcline) which is very often interstitial, forms poikilitic plates with very irregular borders and includes small euhedral crystals of plagioclase and biotite. The rock consists mainly of strongly oscillatory and patchy zoned plagioclase. The anorthite content of plagioclase is high, ranging from labradorite (in some crystal cores) to oligoclase, although Ca-rich andesine is the most frequent composition. Synneusis of several plagioclase crystals may sometimes be observed. Quartz is abundant in the form of anhedral, interstitial, polycrystalline aggregates and generally shows an undulatory extinction.

A large number of melanocratic enclaves are contained in these rocks. Most of them are microgranular and of quartz dioritic composition (cf., above) and some of them are metamorphic. These enclaves, which are mainly pelitic, are very rich in biotite and plagioclase, and display a relict or a mimetic foliation which is sometimes folded. They do not contain any hornblende but may have some Al-rich metamorphic minerals such as corundum and deep green spinel which are indicative of pyroxene hornfels facies conditions.

A complete sequence from pelitic hornfelses to migmatitic rocks (formed by induced anatexis) and surmicaceous enclaves may be found, the latter representing the restites in the most evolved states (Didier, 1973). Some other interesting enclaves are present in very small amounts including amphibolic-garnetiferous rocks and orthopyroxene xenocrysts (Enrique, 1985)

Baldiri hornblende-biotite melatonalites

These form various small bodies associated with the Sant Mateu tonalites with which they seem to have coexisted in the magmatic state because: a) They show smooth sinuous contacts, b) They are both reciprocally enclosed as enclaves, and, c) a narrow hybrid zone between them is sometimes present (Enrique, 1978, 1984a, 1985). They are dark grey rocks displaying a porphyritic appearance with a fine- to medium-grained groundmass. This groundmass consists chiefly of subhedral zoned plagioclase and interstitial quartz, in addition to biotite and hornblende which are present in smaller amounts.

Hornblende phenocrysts are often pseudomorphosed by a microgranular aggregate of biotite. Plagioclase phenocrysts frequently have well-defined labradorite cores, a middle zone with intense oscillatory zoning and an andesine-oligoclase border zone. Rim plagioclase usually replenishes inner cavities formed by magmatic embayment (patchy zoning) or by rapid growth of the phenocrysts, resembling the plagioclases of andesites.

These rocks have a high modal mafic content (approx. 37%, Table-II, MH-1).

Biotite leucotonalites

These rocks occur as white irregular veins or small lens-shaped bodies with blurred contacts in the Sant Mateu tonalites (Enrique, 1987b). They contain a large proportion of euhedral and zoned plagioclases amongst which there are anhedral quartz grains. Biotite, in smaller grains, and some interstitial K-feldspar are also present. Hornblende is absent. The mode of occurrence of these leucotonalites suggests a possible origin by filter pressing processes.

Borges-Vilaplana and Riudecanyes orthopyroxene-bearing hornblende biotite tonalites and granodiorites.

Like the rest of the Batholith, Southern Catalonian Coastal Ranges granitoids (Serra, 1985) consist of numerous successive separated plutons assembled into plutonic complexes. Some of the principal units are formed by rather uniform hornblende biotite tonalites and granodiorites. The most important ones are the Borges-Vilaplana and Riudecanyes units.

The rock-types of these intrusions are light grey, medium-grained (3-4 mm), and relatively mafic-rich (approx. 19% colour index). Euhedral, usually strongly oscillatory and patchy zoned plagioclase is the main component.

The average plagioclase composition is calcium-rich (high-andesine) sometimes with labradorite or even bytownite compositions (An_{75}) at cores. There is abundant anhedral quartz.

K-feldspar is only present in small amounts and forms anhedral, interstitial plates. Biotite is abundant and has a prismatic subhedral habit.

As with the Riudecols quartz diorite described above, two amphibole varieties are present: a) euhedral, inclusion-rich, intense green pleochroic hornblende, and, b) slightly pleochroic, pale green and polisyntetically twinned cummingtonitic amphibole.

Orthopyroxene is also present as sparse, brown, non-pleochroic (bronzite- hypersthene) crystals. This orthopyroxene is 0.5 to 1 cm in size, has prismatic to rounded morphology and is often rimmed by cummingtonitic amphibole.

Other accessories include apatite, zircon, ilmenite and allanite (the latter occurring as relatively frequent euhedral 0.1 to 0.5 cm crystals, and, more rarely, forming euhedral, large, 2-3 cm long, crystals clustered in aplitic segregations). These tonalites seem to be the oldest plutonic units of the tonalites-granodiorites-leucogranites group in this area.

The mode of emplacement was determined by a brittle behaviour of the country rocks which consist of pelites, graywackes, sandstones and conglomerates (probably of Namurian age, Sáez, 1982, Serra, 1985). The contacts with the host rocks are sharp, normally without noticeable development of piecemeal stoping.

Moreover, sub-horizontal contact surfaces at the top of intrusions suggest passive sinking of large blocks (Serra and Enrique, 1989). These tonalites always contain oval or rounded microgranular enclaves which consist mainly of euhedral biotite, hornblende and plagioclase. These minerals are normally included in poikilitic plates of quartz and, more rarely, of K-feldspar. Large prismatic crystals of hornblende often give these enclaves a porphyritic appearance.

Some small angular hornfels xenoliths (containing cordierite porphyroblasts) and lens-shaped «surmicaceous» enclaves (containing cordierite and sometimes sillimanite) are also present.

Granodiorites

Granodiorites are the most abundant plutonic rocks of the Catalonian Coastal Batholith (Ashauer and Teichmüller, 1935; Van der Sijp, 1951; Fontboté and Julivert, 1952; Montoto, 1967; Vaquer, 1972; Viladevall, 1975; etc.). Although these rocks show only small differences in mineral and chemical composition they exhibit a large variety of textural types.

The granodiorites may form small stocks and large plutonic bodies extending over 200 Km^2 in area. The widest outcrops are located in the central part of the batholith (Montseny-Guilleries and Montnegre massifs) where they represent more than 60% of the total amount of plutonic rocks.

From a petrographical point of view it is possible to distinguish two principal groups (Enrique , 1984): **1)** ***Granodiorites with prismatic biotites*** in which the biotite (the whole or a part of it) forms large euhedral, prismatic (often corroded) crystals up to 1 cm long. Euhedral plagioclase displaying intense normal, oscillatory and patchy zoning is the most abundant mineral in these rocks. K-feldspar is usually found as an interstitial phase.

This group of granodiorites may be divided into three main subgroups:

a) Orthopyroxene-bearing biotite granodiorites. The main example is the Coll de la Batalla granodiorite (Alforja plutonic complex, Tarragona).

b) Amphibole-bearing granodiorites, the characteristics of which are very similar to those of the hornblende-biotite tonalites and there may be gradational transitions between them. Their mafic mineral content is about 15-16%. The most typical examples of these rocks are: the Alforja-L'Aleixar granodiorites (and tonalites) (Tarragona; Serra,1985) and the Llavaneres granodiorite (Montnegre massif; Enrique, 1984).

c) Biotite granodiorites (without either amphibole or orthopyroxene). The main facies of this type are equigranular rocks which form very extensive outcrops in the Montnegre and Montseny-Guilleries massifs. They also make up most of the isolated outcrops located in the central part of the Pre-Littoral Range (e.g. La Garriga, Caldes de Montbui, Capellades, etc., outcrops). Their mafic content averages approx. 12% (ranging from 7 to 18%). Other textural facies may be found locally in more restricted outcrops some examples of which include the inequigranular facies of Serra Ameia and Can Cosí (Montnegre massif, Fig.1, no.8). **2) Granodiorites with tabular or flaky biotites.** The biotite of these granodiorites has generally tabular or flaky morphologies. Only exceptionally is it present in the form of long prisms. The quartz tends to form globular grains and the K-feldspar usually appears as grains of early crystallization (both euhedral and anhedral). They comprise two subgroups:

a) Biotite granodiorites without K-feldspar megacrysts. (e.g. Santa Fe-Viladrau, Sant Feliu de Buxalleu-L'Esparra, Lloret de Mar and Romanyà-Platja d'Aro, biotite granodiorites *b) K-feldspar megacrysts-bearing biotite granodiorites.* These rocks form a very distinctive group which is restricted to the north-easternmost part of the batholith (e.g. Calella de Palafrugell, Palamós, s'Agaró, Llagostera, etc., outcrops) (San Miguel de la Cámara, 1936; Marcet Riba, 1947; Montoto, 1967; Gállego et al, 1983, etc.). The most typical example is the s'Agaró granodiorite.

Coll de la Batalla orthopyroxene-bearing biotite granodiorites

These rocks have been described by Serra (1985). They outcrop over an area of approx. 10 Km^2. The inner facies of this intrusion consist of granular medium-grained rocks whereas the outer facies near the walls with the enclosing rocks are highly inequigranular showing a fine-grained groundmass.

Biotite is found both as prismatic and tabular crystals. It may also be found replacing ancient hornblende crystals in the form of small-grained rectangular aggregates. Quartz is present both as first generation euhedral bipyramidal crystals and as late anhedral grains. Orthopyroxene is fairly frequently found in these rocks although it is generally sparselly distributed.

Alforja-L'Aleixar hornblende-bearing biotite granodiorites (and tonalites)

These rocks form an E-W elongated intrusion which is synchronous with the Coll de la Batalla granodiorites and younger than the Borges-Vilaplana tonalites (see above). They are characterized by the presence of conspicuous euhedral hornblende crystals (approx. 1 cm in length). They have a chilled, very inequigranular facies with a somewhat more leucocratic composition close to the contact with the carboniferous rocks.

Llavaneres hornblende-bearing biotite granodiorite.

This forms a wide outcrop in the coastal slope of the Montnegre massif, between Mataró and Arenys de Mar. It bears a striking resemblance to the Sant Mateu tonalite, also in their abundance in microgranular enclaves. It differs mostly in its significantly lower hornblende and K-feldspar content.

Orrius biotite granodiorite

It may be regarded as the most representative type of these granodiorites. It intrudes into the Sant Mateu tonalite and the Llavaneres granodiorite.

It is distributed in several isolated outcrops. The paleozoic materials are sharply intruded by this granodiorite. Large stoped and rotated hornfels xenolithic blocks may sometimes be found near the contacts, but in most cases only minor piecemeal stoping is observed. It is finer-grained (3-4 mm) than the hornblende biotite tonalite and the dark microgranular enclaves are usually relatively scarce and small (5-15 cm). There are some metamorphic enclaves which sometimes contain sillimanite.

Biotite granodiorites without K-feldspar megacrysts. Santa Fe-Viladrau, Sant Feliu de Buxalleu-L'Esparra, Lloret de Mar and Romanyà-Platja d'Aro, biotite granodiorites

These rocks extend broadly over the Montseny-Guilleries and Costa Brava massifs showing several mineral and textural varieties.

As far as mineral composition is concerned, they range from biotite-poor facies (which often grade to monzogranite compositions) to biotite- and plagioclase-rich facies (rarely with accessory hornblende) close to tonalites in composition (Cala Pedrosa, Cala S'Alguer, Romanyà, etc., in the Costa Brava massif). The plagioclase crystals have complex oscillatory zoning which is sometimes distorted by biotite or other mineral inclusions (Enrique 1985). The K-feldspar may be interstitial (including euhedral plagioclase and biotite) although it is normally found with subhedral morphologies and few inclusions.

Texturally, these rocks range from medium-grained equigranular rocks (the most frequent facies) (e.g. Sta. Fe, Lloret, etc.) to rocks in which the potassic feldspars and the quartz have a larger development giving the rock a coarse-grained heterogranular appearance (e.g. Tossa, Tordera, etc., outcrops). These terms constitute an intermediate step towards the megacrysts-bearing granodiorites described below.

Their internal structure is generally not very conspicuous but it may sometimes be well defined due to the planar orientation of the biotites (e.g. Romanyà, S'Alguer, etc.). Some facies frequently show «schlieren structures» (e.g. Tossa). Biotite-rich, fine-grained, quartzdioritic, microgranular enclaves are common. The enclaves have often a porphyritic appearance due to the presence of larger plagioclase crystals.

The enclaves included in the most basic granodioritic facies may contain hornblende.

As a result of piecemeal stoping xenoliths are particularly abundant in the zones located close to the contacts with the country rocks (e.g. Cala Pedrosa in the Costa Brava massif, Enrique, 1981; 1986). There, numerous hornfels fragments of the country rocks (metric to centimetric in size) are included without any preferential orientation in the granodiorites.

S'Agaró K-feldspar megacrysts-bearing biotite granodiorite.

The most striking feature of this granodiorite is the occurrence of very large phenocrysts (megacrysts) of K-feldspar, usually twinned on the Carlsbad Law. These megacrysts range from 2 to 5 cm although, exceptionally, they may reach 10 cm . The megacrysts are embedded in a medium- to coarse-grained (3-10 mm) granular matrix which consists of globular-shaped quartz, euhedral strongly zoned plagioclase, tabular biotite and anhedral interstitial K-feldspar. Megacrysts normally account for about 7-8% of the rock. There are, however, some localities in which the megacrysts are highly accumulated giving rise to aggregates of densely packed crystals (Calahorra, pers. com., 1988). In these cases the matrix is relegated to interstitial positions and the rock approaches syenitic composition (Table-V, no.15-2). In the s'Agaró outcrops the granodiorite contains a large number of quartz dioritic microgranular enclaves. These enclaves are relatively large (5-50 cm), generally with rounded morphology, fine-grained and very dark-coloured which also display a diversity of hybridation and assimilation relationships with the enclosing granodiorite. The granodiorite also contains xenoliths of diverse origins (pelitic and calc- silicate hornfelses, quartzites, anatectically induced migmatitic metapelites, surmicaceous enclaves, etc.) although these xenoliths are present in small amounts and sparsely distributed. Biotitic «schlieren» are also frequently found in these rocks.

Granites

The most acidic plutonic rocks in the Batholith of the Catalonian Coastal Ranges have monzogranitic compositions. They generally plot in central positions of the QAP triangle (Streckeisen, 1976), and only rarely approximate syenogranitic compositions (e.g. Rocabruna leucogranites, Serra, 1985). Their mafic content, variable within each intrusion, is usually under 5% and thus the leucocratic types are the most widespread.

From a textural point of view these granites are exceedingly varied. They range from aplitic (or even finer grained) to pegmatitic, frequently with gradational changes. Sometimes they vary from equigranular plutonic types to strongly inequigranular porphyrytic rocks with a subvolcanic appearance. Graphic and micrographic textures are common.

The monzogranites of the Catalonian Coastal Ranges have an unequal geographical distribution. The largest outcrops are located in the northern part of the batholith to the north of the parallel defined by the Montnegre summit.

Besides their higher K-feldspar/plagioclase ratios and their lower biotite content regarding the granodiorites, the monzogranites display an increase in their quartz content and an important decrease in the anorthite content of the plagioclase.

Biotite is generally the only micaceous mineral in these rocks but, in highly differentiated facies appreciable amounts of muscovite and some accessory garnet may also be present.

The main examples are the following:

Roca Bruna and Cara del Moro leucogranits (Alforja massif) (Serra, 1985) .

These rocks form small stocks (under 1Km^2) associated with the hornblende biotite granodiorites and tonalites of the Alforja pluton to which they are usually related through gradational transitions.

The plagioclase displays normal-type zonation not very conspicuous. The K-feldspar is highly perthitic with verydeveloped elongated vein perthites. The biotite forms small euhedral crystals with tabular or flaky habits. Hornblende is a rare accessory.

Céllecs, Corredor and Mont Cabrer-Burriac leucogranites (Montnegre massif) (Enrique, 1978, 1981, 1984, 1985)

These leucogranites form small plutons ranging normally from 2 to 6 Km^{2}in area. They are white in colour and show a large diversity in grain-size. In the deepest zones there are often coarse-grained facies which sometimes tend to be granodioritic in composition as prismatic biotites begin to appear.

In contrast, finer-grained facies which often contain small amounts of muscovite and accessory anhedral Mn-rich garnet predominate in the upper zones.

In the uppermost zones of the Céllecs intrusion there are several decametric-sized bodies of pegmatites (approx. 1-4 cm in grain size) which grade transitionally to the leucogranites.

The plagioclases of these leucogranites are subhedral and slightly zoned (both normal and oscillatory). The potassic feldspars are generally anhedral and display well developed vein perthites, and sometimes are strongly zoned (e.g. Corredor outcrops in the Montnegre massif; Enrique, 1985).

The biotites have generally tabular habits and are normally present in amounts not exceeding 5% and may sometimes be completely absent.

These leucogranites always postdate the Sant Mateu hornblende biotite tonalite and, apparently, also the Orrius granodiorite (as may be deduced from the granodioritic enclaves included in the Céllecs leucogranites, and from the finer leucogranitic facies found sometimes close to the contacts with the granodiorites).

The Mont Cabrer-Burriac intrusion seems to have a tabular morphology which is about 100 m thick and appears to be interbedded between a granodioritic intrusion (below) (Cabrera granodiorite) and the Sant Mateu hornblende biotite tonalite (above and around). In the zone of contact with the tonalite, the leucogranites often develop an aplitic facies (e.g. Cabrils outcrops).

The emplacement mechanism of of this group of leucogranites seems to be determined by the sinking of large blocks of rigid country rocks (generally the tonalites and granodiorites previously solidified) into an underlying magma chamber with the subsequent filling of the cavities produced with leucogranitic magma (stoping- cauldron subsidence, Enrique, 1985).

The contacts with the enclosing rocks are very sharp and piecemeal stoping is almost absent. Microgranular enclaves and metamorphic enclaves are exceedingly scarce and small (1-3 cm).

Montnegre biotite granites and leucogranites.

These rocks have been described by Enrique (1984a,1985). They extend along the northern part of the Montnegre massif for more than 75 Km². They are pinkish in colour and generally have a granular texture which ranges from very coarse-grained (8-12 mm) (e.g. Hostalric outcrops) to medium-grained facies (2-3 mm) (e.g. Roca Rossa outcrops) without any significant changes in chemical composition. Medium-grained facies are generally miarolitic. Gradual but rapid transitions (completed in a few cm) from coarse-grained granite to porphyrytic microgranite have been observed locally. In these cases there is a development of very fine-grained groundmass which includes bipyramidal quartz, plagioclases and K-feldspar phenocrysts. The chemical compositions of these two very different textural facies are indistinguishable.

The K-feldspar usually displays poorly developed perthites. The plagioclase is subhedral (in the coarse-grained facies) or anhedral (in the fine-grained facies) and exhibits slightly normal zoning (ranging from andesine to oligoclase in composition). Rhythmic zoning is rare.

Biotite, which amounts to approx. 7%, has flaky to tabular habits wth a corroded appearance.

An unusual feature of these granites is their abundance in rounded dark microgranular enclaves with a melagranodioritic composition. The enclaves are often abnormally large, from 30 to 50 cm in diameter, and attaining sometimes a length of 100 cm (e.g., Font d'en Roca and Can Xifrè outcrops, Sant Celoni). These enclave swarms are sometimes associated with the porphyritic facies. The enclaves may display a well defined «hybrid» rim intermediate in composition between that of the core of the enclave and that of the enclosing granite (Enrique, 1985).

Costa Brava granites and leucogranites (Lloret-Sant Felíu de Guíxols).

These rocks form a large outcrop of about 200 Km² which in some aspects may be considered to be a northeasternwards prolongation of the Montnegre granites. Pinkish varieties are the most widespread. The overall outcrop is formed by several adjacent intrusions which differ mainly in their textural features (aplitic granites, pegmatitic granites, porphyrytic granites; Llopis et al., 1953).

From a textural point of view two main groups may be distinguished:

1) Granular facies which comprise two subgroups:

a) Coarse-grained leucogranites. These granites are very weathered and form extensive outcrops. They consist mainly of quartz, K-feldspar and sodic plagioclase (average oligoclase).

When they are unaltered the K-feldspars are usually pink in colour whereas the plagioclases are white but, sometimes, both feldspars are pink. Xenomorphic textures with highly perthitic potassic feldspars and only slightly zoned plagioclases twinned on the Albite Law, are frequent.

b) Fine-grained leucogranites. They form important independent outcrops associated with the coarse-grained facies. They generally have a very small biotite content and occasionally some accessory garnet may also be present (e.g. Tossa outcrops). They very often have miarolitic cavities.

2) Inequigranular facies. Many medium- and fine-grained Costa Brava leucogranites are inequigranular in texture. In these cases the rocks consist of a matrix which includes a variable number of phenocrysts (mostly quartz or feldspars). The grains which compose the matrix range from medium-grained (with a normal plutonic appearance) to microscopic-sized (analogous to the matrix of the porphyries). The phenocrysts may be very abundant or very scarce. Furthermore, the size of the phenocrysts may decrease until reaching the groundmass grain-size. The kind of phenocrysts is also variable. Some of these rocks contain only phenocrysts of quartz which are more or less affected by magmatic corrosion and become more anhedral as the grain-size of the groundmass increases. Other rocks contain, in addition to quartz, orthoclase and plagioclase (and sometimes biotite) phenocrysts.

In the outermost facies of the intrusions the groundmass is sometimes micrographic.

The combination of these variable textural parameters gives rise to a large number of possible petrographic types (and names) without significant changes in chemical composition. Examples of these include porphyritic leucogranites (medium-sized groundmass), porphyritic aplites (fine-grained aplitic-like groundmass), leucogranite porphyries (or porphyritic micro-leucogranites, after Hatch et al, 1972, terminology) and felsites (San Miguel de la Cámara, 1936) (very fine-grained aphanitic groundmass almost lacking phenocrysts, also called aphyric microleucogranites, Hatch et al. 1972).

The distribution of these petrographic types is mainly determined by their relative position within the intrusion and by the size and morphology of this intrusion. Thus, when very fine-grained facies exist they are located in the zone of contact with the enclosing rocks whereas the coarsest-grained facies (aplitic or leucogranitic plutonic-like types) tend to be located in the innermost parts of the intrusions.

These texturally very heterogeneous leucogranitic bodies (mainly porphyritic aplites and aphyric or porphyritic microgranites) form some kilometric composite intrusions near the village of Tossa (Costa Brava massif) (e.g. Cala Bona-Puig Ventós and Rampugut-Borrasar outcrops) which are termed globally «felsites» in previous works on the zone (Llopis et al, 1953; Enrique, 1984b, etc.).

HYPABYSSAL SHEET INTRUSIONS: DYKES AND SILLS

The batholith of the Catalonian Coastal Ranges is intruded by a prominent system of different kinds of dyke-rocks which fill up several swarms of closely spaced parallel fractures trending mostly in a NE-SW direction.

The compositions of the main dykes are closely allied to each of plutonic types of the batholith described above.

The dominant compositions are granodioritic and granitic though leucogranitic, tonalitic, dioritic and gabbrodioritic (Fig.3) (or diabasic) are also sometimes found. By contrast, aplitic and pegmatitic dykes and veins, although relatively numerous in the vicinity of plutonic contacts, are volumetrically restricted.

The plutonic rocks may also form dyke or sill-like apophyses which penetrate into the country rocks near the contacts and are generally associated with magmatic stoping processes.

(e.g. granodiorites intruding into pelitic hornfelses and leucogranites intruding into granodiorites at Cala Pedrosa, Enrique, 1981, 1986; dykes of granodiorites intruding into tonalites, in the Montnegre massif, Enrique, 1978, 1985; etc.).

The dimensions of the dykes are exceedingly varied ranging from a few cm to more than 100 m in width, and from a few meters up to 5 or 6 Km in length.

The dykes tend to be concentrated heterogeneously in different parts of the batholith.

Some of the more prominent dyke swarms are located in the following areas: a) In the southernmost Catalonian Coastal Ranges plutons (Tarragona) (Serra, 1985; Serra and Enrique, 1989); b) in the southern Montnegre (Almera, 1914; Enrique, 1984a, 1985) (e.g. the Sant Mateu zone, Fig. 4); c) in the Susqueda surroundings (Guilleries massif) (San Miguel de la Cámara, 1936; San Miguel Arribas, 1966; Durán, 1985); d) in the northern Costa Brava massif.

Moreover, a small number of different types of intrusion breccias suggests a shallow level of magma emplacement (e.g. Alforja plutonic autobrecciated body, Serra, 1987; Serra and Enrique, 1989; and granite porphyry autobrecciated bodies of Susqueda, Rebollo and López, per. com., 1983).

In addition to these hypabyssal rocks closely related to plutonic major intrusions, there are other dyke-rocks which are well developed in some areas although their relationships with the plutonics are at present poorly understood. Amongst these the most noticeable are the lamprophyres with a calc-alkaline affinity (spessartites of San Miguel de la Cámara, 1936; Llopis et al. 1953; San Miguel Arribas, 1952, etc.) intruded in the form of vertical dykes, and those of alkaline affinity (camptonites of San Miguel de la Cámara, 1936). The latter may be observed as sub-horizontal sills cutting at about 90° the espessartitic lamprophyres at Aiguablava outcrops (San Miguel de la Cámara, 1936).

K-Ar dating of the camptonite types gives middle Mesozoic ages (Chessex et al. 1967) and thus they are highly unlikely to be related to the plutonic tardi-Hercynian events. This is not so clear in the case of the vertical espessartites which might represent the latest magmatic activity of the batholith.

Felsites

These rocks have very acidic compositions which are more or less equivalent to leucogranites. They are generally pale green in colour and often display well defined flow banding structures.

In these cases they are indistinguishable from rhyolites in hand-specimen.

They form dykes of varying width and sometimes stocks with irregular shapes. The thinnest veins (centimetric) display aphanitic textures with rare and small phenocrysts.

More developed intrusions have more variable textures from the margins (aphanitic and aphyric) to the centre (porphyritic or aplitic). They occasionally have micrographic (granophyre) or spherulitic textures (San Miguel de la Cámara, 1936).

They occur sparsely throughout the batholith but they are more widespread in the central zone of the Costa Brava (Lloret-Sant Feliu de Guíxols). (See Costa Brava granites described above).

Leucogranite porphyries

They appear principally in the central Costa Brava zone (Blanes, Lloret, Tossa, Sant Felíu) generally associated with the leucogranites. They are also relatively abundant in the northern Montnegre but they are scarce in the rest of the batholith. Their groundmass is normally microgranular but sometimes it may be micrographic or spherulitic. They frequently have chilled felsitic margins.

Granite and granodiorite porphyries

These dyke-rocks are very abundant in all the batholith although they are mostly developed in the Alforja and Riudecanyes zones (Serra, 1985), in the southern Montnegre (Enrique, 1984a, 1985, Fig.4) and in the Guilleries massif (San Miguel Arribas, 1966; Durán, 1985).

They form the largest dykes of the batholith. Characteristically, they have a strongly porphyritic texture with abundant bipyramidal corroded quartz phenocrysts (of 0.5 to 2 cm), highly zoned plagioclases (which display very prominent oscillatory zoning) and subhedral biotite. K-feldspar may be present as idiomorphic megacrysts (up to 7 cm in the Teià outcrops, S-Montnegre) and occasionally they may have a rapakivi-type plagioclase rim.

They rarely include xenolitic granitoids with a similar composition to the dyke-rocks but different from the enclosing rocks in which case they might represent cogenetic plutonic facies of the dykes.

Generally, these porphyries contain dark quartz dioritic or tonalitic microgranular enclaves with which they sometimes show relationships of hybridism (e.g. granodiorite porphyries of Martorelles quarry, S-Montnegre). They always display a textural variation from the contacts (chilled margins) up to the centre of the dyke . The finer-grained groundmass of the chilled margins is usually black, in contrast to the light grey coloured groundmass of the central facies of the dykes which is, however, is almost identical in composition (Enrique, 1984a).

Occasionally, in the widest dykes an aplitic grain-sized development of the groundmass which constitutes a transition to the plutonic rock-types (e.g. Teià, Alella, Dosrius, etc., outcrops, Enrique, 1985) may be observed.

In the Southern Montnegre these rocks sharply cut all the plutonic rocks, even the leucogranites (Almera, 1914).

Tonalite porphyries

These dykes are scarce and are only present in the zones of the batholith where tonalite plutonic intrusions exist. In the Montnegre massif they post-date the tonalites, the granodiorites and the leucogranites (e.g. Can Castellvell outcrops, El Corredor). They may be easily identified since they often contain large idiomorphic hornblende crystals in addition to highly zoned plagioclase, corroded quartz and biotite. The groundmass is sometimes micrographic.

In the zone of the southernmost plutons (Tarragona), these tonalite porphyries may contain orthopyroxene phenocrysts as well as hornblende, (Serra, 1985).

Dykes of diorite porphyries and diorites

These rocks form dykes of small dimensions (decimeters or meters in width and tens or hundreds of meters in length) and show a large diversity both in composition and texture.

The commonest types are black and have numerous euhedral highly zoned plagioclase phenocrysts (e.g. dykes of Teià, Cabrils, etc., S-Montnegre). They often contain a few phenocrysts of quartz which show intense magmatic corrosion and reaction rims. In their inner parts these dykes sometimes exhibit equigranular, fine- to medium-grained textures (diorites) mainly consisting of plagioclase and hornblende (e.g. Pineda, Tossa dykes, etc.).

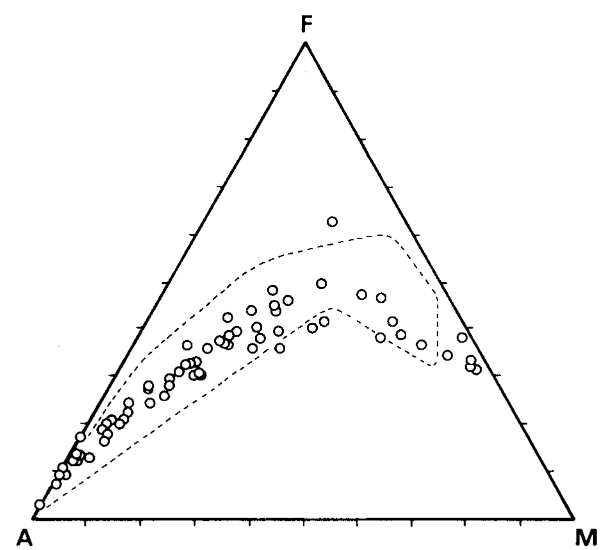


Figure 5.- AFM diagram of rocks from the Catalonian Coastal Batholith. The dashed line defines the field of some typical Andean plutonics (Trujillo, Lima and Arequipa segments) of the Coastal Batholith of Peru (Atherton et al, 1979).

Sometimes, these dykes contain elongated hornblende phenocrysts (e.g. Cabrils) which may be very abundant locally giving the rock a lamprophyric affinity (e.g. s'Agaró).

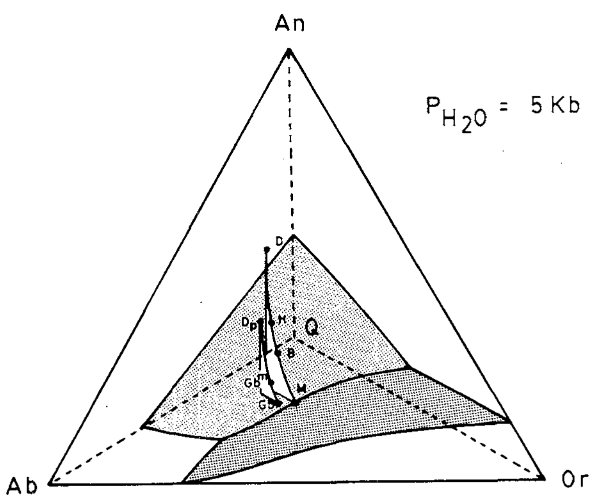


Figure 6.- An-Ab-Or-Qz (-H_2O) diagram showing the separate crystallization paths of two possible «superunits» of the Montnegre massif. D-H-B-M : quartzgabbros-tonalites-granodiorites- leucogranites from the southern Montnegre; Dp-Gbm-Gb: quartzdiorites-granodiorites-granites from the northern Montnegre.

Dykes of gabbro-diorites and quartz-diabases

These rocks are very scarce. They are black in colour and have a fine- to medium-grained uniform texture. They consist mainly of secondary amphibole and seritized plagioclase with, occasionally, clinopyroxene (e.g. Can Bosc del Corredor, Enrique, 1985).

GEOCHEMISTRY

Major element data

The plutonic and hypabyssal rocks of the Catalonian Coastal Batholith exhibit a broad range of chemical compositions which define a trend that correspond closely to those of typical calc-alkaline suites of active continental margins.This may be clearly observed when the compositions are plotted in the R_1R_2 (Fig.3) and AFM (Fig.5) diagrams.

It should be noted, however, that acidic and intermediate compositions account for the great majority of the present-day erosion level igneous outcrops, whereas those with basic and ultrabasic compositions are limited to very small areas.

Most of the Catalonian Coastal Batholith rocks are characterized by high calcium oxide/alkalis ratios in relation to SiO2 (alkali-lime index of Peacock, 1931, with values of approx. 60-62) which are almost exclusively found in rocks generated at compressional plate boundaries (Petro et al, 1979), and more specifically in those of subduction margins (Brown, 1979; 1982).

These high lime/alkali ratios are similar to those of several of the neighbouring Hercynian Pyrenean and Sardinian plutons, but differ notably from most of those of the Iberian Massif, French Central Massif and Southern Alps (Enrique, 1985).

Despite the close overall similarities between different plutonic intrusions from the Catalonian Coastal Batholith (almost identical trends in the AFM and R_1R_2 diagrams), which supports the hypothesis that they are derived from the same genetic processes, it is highly unlikely that all the rocks proceed from a common parent magma.

Rather, there seems to be, at least, two superunits the constituent plutonic units of which show consistent mineral, textural and chemical characteristics.

This may be noted in the Harker-type chemical diagrams (CaO vs. Na_2O, K_20 vs. Na_2O, etc). Furthermore, on an Ab-An-Or-Qz (normative) diagram each superunit defines its own smooth curve originating from different points in the plagioclase fields, which may be indicative of separate equilibrium fusion events in the source area for each superunit (Enrique, 1985) (Fig.6) as is normally observed in Cordilleran Batholiths (Presnall and Bateman, 1973; Atherton et al, 1979).

The dividing zone of these two above mentioned superunits in the Catalonian Coastal Batholith coincides very approximately with a paleozoic «septa» which separates the Northern Montnegre from Southern Montnegre granitoids (Enrique, 1985).

Trace element data

Most trace element characteristics of the plutonic and hypabyssal rocks of the Catalonian Coastal Batholith are very similar to the modern subduction-related igneous rocks (Table III).

The primordial mantle-normalized trace element patterns fit very well with those of the granitoids from Mesozoic and Cenozoic magmatic arcs (Brown et al., 1984), as may be seen in Fig.7 (where three Catalonian coastal batholith rocks of basic, intermediate and acidic compositions are compared with analogous rocks from Andean-type plutons of the Antarctic Peninsula, Tarney and Saunders, 1979).

Furthermore, in common with the Antarctic Peninsula plutons, there is an increase in Zr (and Nb) until the silica content reaches 60-65 % , after which there is a sharp decrease (Fig.8).

In contrast, in typical examples of simple fractional crystallization, Zr increases linearly with SiO_2 in the compositional range from basalt to ryodacite (e.g. the Deception Volcano) (Fig.8). Consequently, the decrease in Zr may imply either the existence of some minerals removing this element or of complex partial melting processes (Tarney and Saunders, 1979).

Samples from the Catalonian Coastal Batholith plot almost exclusively in the VAG field on the Rb vs. Y+Nb tectonic discriminant diagram (Pearce et al, 1984) (Fig.9). This field also includes the group of postectonic granitoids.

The fact that two very porphyritic high-level leucogranite samples proceeding from the Costa Brava massif plot in the WPG field might possibly point to an evolution towards an anorogenic granitic magmatism.

REE data are typical from calc-alkaline suites (Table IV) (cf. Atherton et al, 1979; Cocherie, 1985; etc.) and rocks proceeding from the same superunity display very similar patterns (Fig.10). For example, in southern Montnegre both quartz gabbros, tonalites, leucogranites, and granite porphyries have an almost identical behaviour, except for the more developed europium anomaly in the acidic samples. This suggests a common magmatic source for all these rocks although the relative LREE depletion in the leucogranites may indicate a complex crystallization (including the accessory minerals apatite and allanite) or even complex partial melting histories (Cocherie, 1985).

The patterns of the mafic and ultramafic rocks from the Montnegre massif display lower REE contents and, although, they show morphologies that are fairly similar to those of the other plutonics it may be difficult to explain the origin of the associated granitoids by simple fractional crystallization.

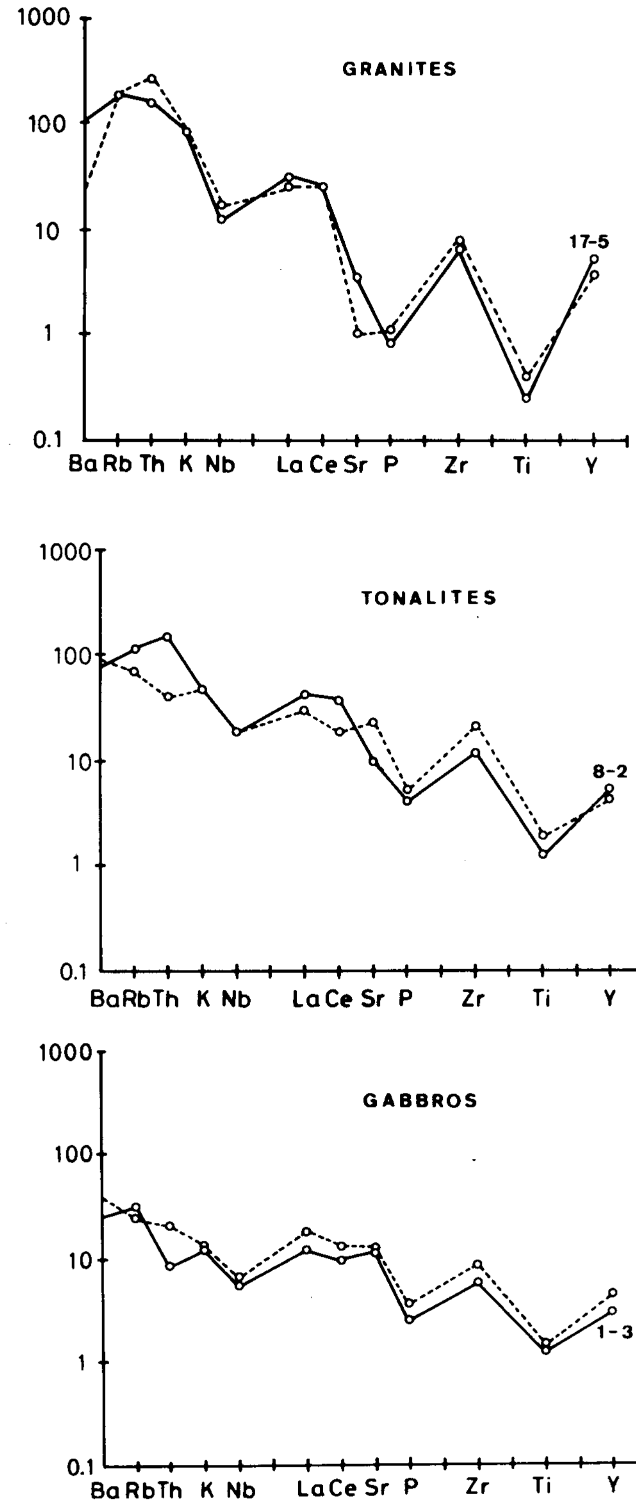


Figure 7.- Primordial Mantle-normalized trace element distribution for some Catalonian Coastal Batholith calc-alkaline plutonic rocks (solid lines), compared with some analogous rocks from the Mesozoic Andean plutons of the Antarctic Peninsula (dashed lines) (Tarney and Saunders, 1979).

In effect, both the ultramafic olivine hornblendites (regarded as ultramafic cumulates) and the leuco-hornblende gabbros (regarded as possible plagioclase cumulates) are richer in LREE than normal hornblende gabbros. Thus the remaining liquids should be depleted and not enriched as in the case of the granitoids.

Only the small europium anomaly present in the hornblende gabbros disappears in the leucogabbros probably by plagioclase accumulation in the emplacement stage.

This negative europium anomaly itself suggests an evolved condition of these gabbros, or, alternatively, an europium-depleted mantle source.

Northern Montnegre quartzdiorites and monzogranits have consistent similarities in their REE patterns (lending support to a common source and a common superunit) and differ slightly from southern Montnegre samples in being richer in LREE and having more pronounced negative europium anomalies (Fig.10).

Only two Rb-Sr whole rocks isochrons have been carried out to date (Enrique and Debon, 1987, in the Montnegre massif; Serra and Del Moro, in preparation, in the southern plutons).

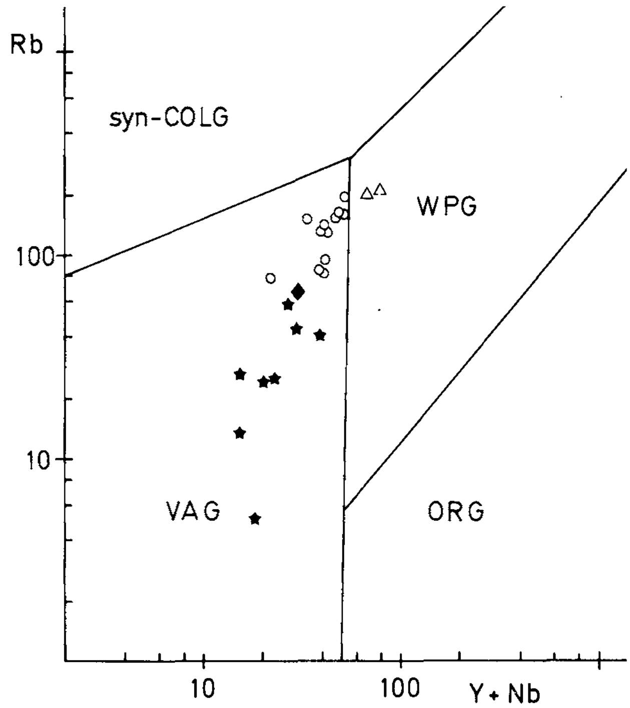


Figure 9.- Rb versus Y+Nb tectonic discriminant diagram (Pearce et al, 1984). The vast majority of samples of the Catalonian Coastal Batholith plot in the VAG field (Volcanic Arc Granites and Post-collision granites). Note the two porphyritic aplite samples plotting in the WPG (Within Plate Granites) (open triangles). Open circles: tonalites, granodiorites, granites and leucogranites; rhomb: granodiorite porphyry; stars: quartzdiorites, horblende gabbros and hornblendites.

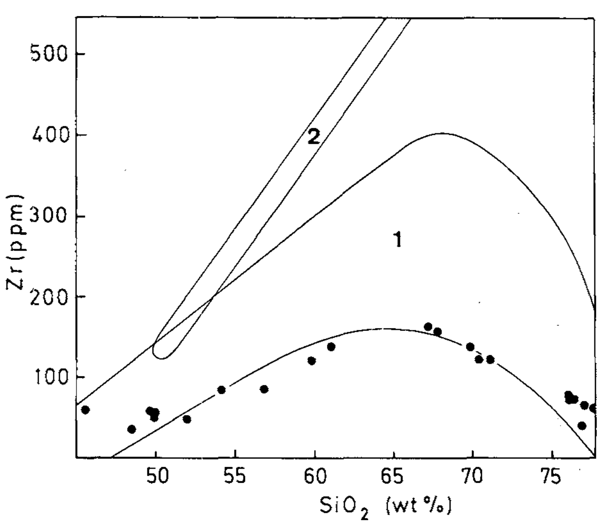
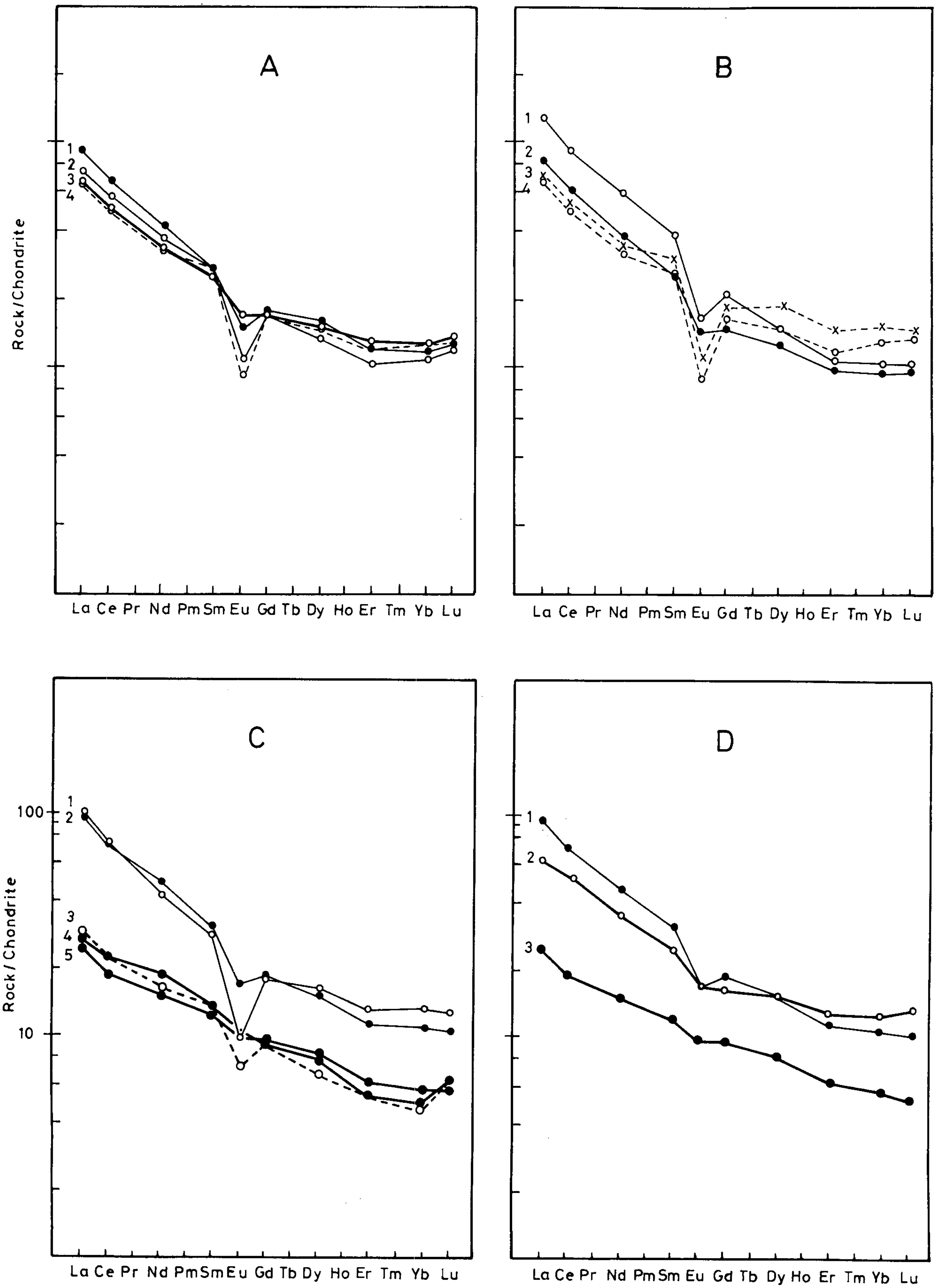


Figure 8.- Plot of Zr vs. SiO_2 for Catalonian Coastal Batholith plutonic rocks (circles). Their distribution fit very well with the Andean-type plutonic and volcanic rocks of the Antarctic Peninsula (field 1) and differ markedly from the volcanic Deception Island trend (with back-arc affinity) (field 2) (Tarney ad Saunders, 1979).

Sr_i is close to 0.710-0.711. Although these values seem to rule out the possibility of a purely mantle source the presence of associated gabbroic intrusions seems to preclude a purely crustal origin as suggested by Harris et al., 1986 for the nearby Pyrenean granitoids.

→

Figure 10.- REE abundances in samples of the Catalonian Coastal Batholith, normalized against chondrite values of Wakita et al, in: Henderson, 1984). A and B, Southern Montnegre. A: 1) melatonalite (8-4), 2) leucogranite (17-2), 3) quartz gabbro (4-1), 4) leucogranite (17-5). B: 1) granodiorite (13-2), 2) tonalite (8-1), 3) granite porphyry (24-1), 4) leucogranite (17-5). C: 1) leucogranite (18-3), 2) quartz diorite (1-6), 3) Olivinic hornblendite (1-1), 4) leuco-hornblende gabbro (1-4), 5) Hornblende gabbro (1-3). D. 1) quartz diorite (1-6), 2) quartz gabbro (4-1), 3) Hornblende gabbro (1-3). (Numbers of samples as in Table-V).


A
B
C
D
Rock/Chondrite
Rock / Chondrite
100
10
1
2
3
4
5
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu

CONCLUSIONS

The Catalonian Coastal Batholith plutonic and hypabyssal association forms a very complete calc-alkaline igneous suite which is considered to be post-tectonic since it was emplaced after the hercynian folding phases.

Most of the field and petrological features support a high-level emplacement.

The geochemical features are similar to those of calc-alkaline suites generated at convergent plate margins. The granitoids described here may be considered to be as of a post-collisional type (group-III of Harris et al., 1986) (or of a renewed «pre-collisional» type (?) (group-I), if these magmas had been generated in a marginal position in relation to the main collision zone (cf. Riding, 1974).

The granitoids may have been formed from the LIL-enriched mantle wedge above the subducted oceanic lithosphere as in the case of volcanic arc magmas. However, although it is very probable that they were isotopically modified by contamination with crustal materials, as in the case of the intrusive and extrusive Andean margins, such contamination might have been selective and therefore the major and trace element characteristics could have remained almost unaffected (Thorpe and Francis, 1979).

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