THE HERCYNIAN POST-TECTONIC PLUTONIC AND HYPABYSSAL ROCKS OF THE MONTNEGRE MASSIF, CATALONIAN COASTAL RANGES (NE SPAIN)

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INTRODUCTION

The Montnegre Massif is part of the Catalonian Coastal Ranges, extending 60 km NE from Barcelona and outcropping over an area of about 550 sq.km. (Fig. 1). Both the Catalonian Coastal Ranges and the Pyrenean Axial Zone form the main Hercynian outcrops in the NE of the Iberian Peninsula, whose principal features were described by JULIVERT et al. (1980) in Newsletter 2 of IGCP Project No. 5, and Guide to Field Trips in the Eastern Pyrenees and Catalonian Coastal Ranges (1981, IGCP Project No. 5).

The Catalonian Coastal Ranges are considered to be a fragment of the southern branch of the Hercynian orogenic belt. Together with the Pyrenean Axial Zone and the Montagne Noire, these ranges are thought to be an eastward prolongation of the West Asturian/Leonese

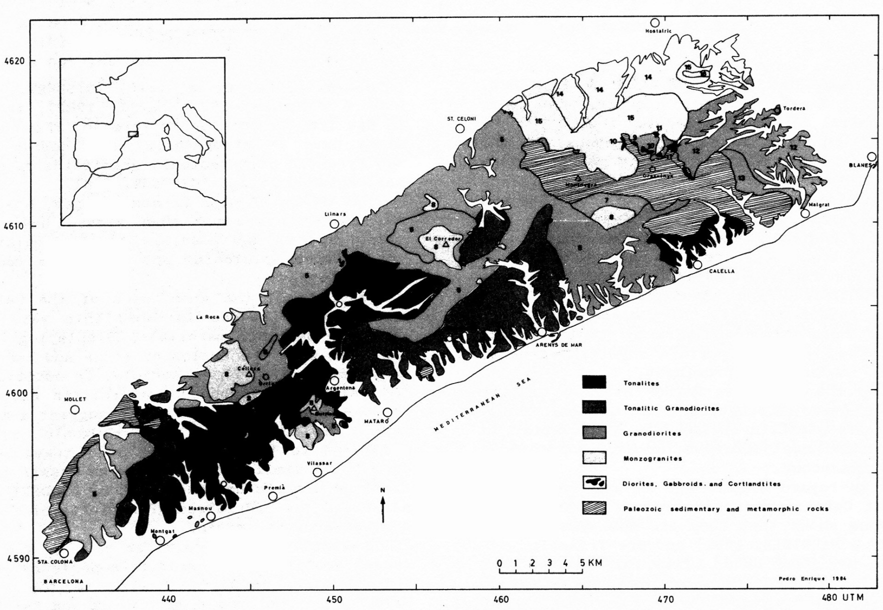

Fig. 1: Geological map of Montnegre Massif: plutonic rocks. Numbers are explained in the text and figures.

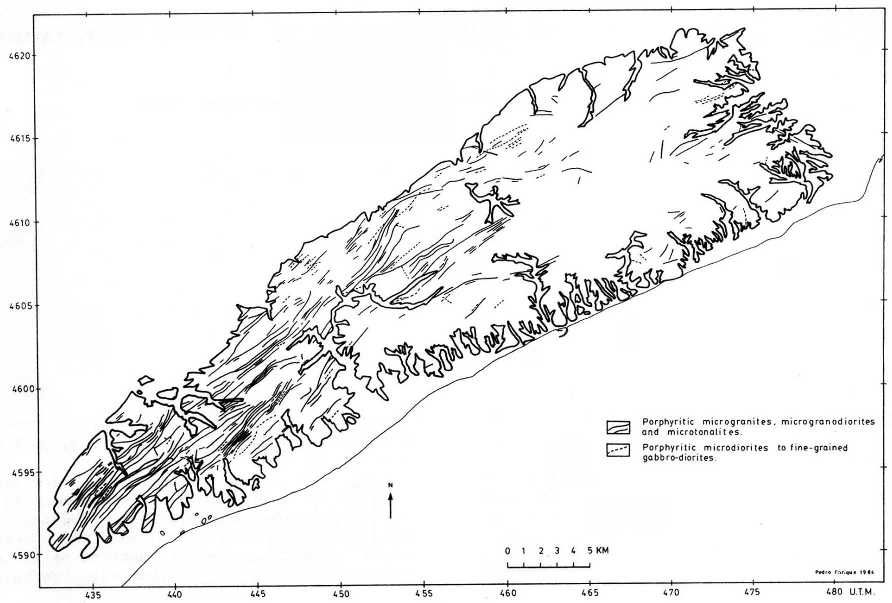

Fig. 2: Geological map of Montnegre Massif: main dykes of hypabyssal rocks.

Zone (JULIVERT, 1979; JULIVERT & MARTINEZ, 1983). It should be noted, however, that there are several differences between them.

Most of the Paleozoic outcrops of the Catalonian Coastal Ranges are formed of a very important series of post-tectonic plutonic intrusions, mainly of granodiorite, tonalite and monzogranite compositions, although some diorites, gabbroids, and ultramafic rocks also exist in lesser amounts.

An important porphyritic microgranite, microgranodiorite and microdiorite dyke swarm exists associated with the plutonic rocks. In the northern part (Costa Brava) felsite masses and dykes, sometimes with a rhyolitic aspect, become increasingly prominent.

All the intrusive rocks studied display calc-alkaline affinities and the main rock-types are biotitic or hornblende-biotitic. In the southernmost outcrops, some orthopyroxenes sometimes occur.

With regard to the age of the intrusions in the Catalonian Coastal Ranges, geological evidence shows that they are post-Viséan (JULIVERT & MARTINEZ, 1981) and pre-Triassic.

On the other hand, it should be noted that in the Southern Pyrenees calc-alkaline volcanic rocks outcrop widely. They are composed of basaltic andesites, andesites, dacites, and rhyolites (often ignimbritic) (GISBERT, 1981; PUGA & FONTBOTE, 1979; MARTI, 1982), ranging in age from Stephanian to Permian. These rocks might have a petrogenetic relationship with the Pyrenean post-tectonic granitoids of similar emplacement age (GISBERT, 1981).

In the Catalonian Coastal Ranges, however, no sediments younger than Viséan have been preserved, so any possible genetic relationship between plutonism and volcanism remains speculative.

Almost all the granitoids of the Catalonian Coastal Ranges intruded into very low-grade metamorphic materials, displaying sharp contacts with the enclosing rocks and inducing a thermal metamorphism aureole. In addition to the existence of abundant miarolitic cavities in some granities, these facts suggest a high-level emplacement of the plutonic rocks. According to the above features, these rocks seem to be similar to the Iberian Massif calc-alkaline granitoids considered by CAPDEVILA et al. (1973) as hybridized granitioids of infra- or basi-crustal origin.

Likewise, they are similar both to the Pyrenean granitoids "en massifs supérieurs" (AUTRAN et al., 1970), and also to the late-Hercynian batholiths from Corsica and Sardinia (DI SIMPLICIO et al., 1974; BRALIA et al., 1981).

Finally, it may be noted that, in opposition to the Iberian Massif and the Pyrenees, autochthonous and para-autochthonous granites linked to regional metamorphism are very scarce, although small stocks such as the Osor syntectonic muscovite leucogranite are known (DURAN, 1981).

PETROGRAPHIC DATA

The plutonic rocks from the Montnegre Massif show a wide compositional range varying from leucogranites to hornblendites, although granodiorites are by far the most important types. From the petrographical and geochemical points of view, it seems possible to differentiate two groups, separated partly by a band of Paleozoic materials (Ordovician, Silurian, Devonian, and Lower Carboniferous). This band is roughly elongated in an E-W direction where the highest topographical point in the Massif (Montnegre, 757 m) is situated.

These Paleozoic materials are intruded by the granitoids, with the development of a prominent contact metamorphism aureole surrounding them. In this aureole are several hornfels varieties containing cordierite, chiastolite, diopside, garnet, idocrase, wollastonite, and other metamorphic materials.

The plutonic rocks south of the Paleozoic materials form a group of somewhat homogeneous plutons. Most of the contacts between them are sharp; others seem to be gradational, although this has not yet been proven due to the slight compositional variation among some types and their intense weathering.

The Southern Montnegre plutons are formed of the following petrographic types:

1. Hornblende-biotite gabbrodiorites (very small outcrops);
2. Heterogranular hornblende-biotite melatonalites (small outcrops);
3. Hornblende-biotite tonalites;
4. Biotite tonalitic granodiorites with accessory hornblende;

5,6,7 Biotite granodiorites;

8. Biotite leucogranites, and muscovite-biotite leucogranites (sometimes with accessory garnet).

The Northern Montnegre plutons are smaller in area and are composed of the following types:

9. Ultramafic rocks with cortlandtitic affinities: olivine hornblendites (very small outcrops);
10. Gabbroid rocks of bojitic composition (calcic plagioclases and amphiboles);
11. Pyroxene-hornblend-biotite diorites;
12. Porphyritic biotite granodiorites (with K-feldspar megacrysts);
13. Muscovite-bearing biotite granodiorites;

14,15,16. Pink biotite granites.

The petrographic nomenclature is based on STRECKEISEN (1976) (Fig. 3) and DE LA ROCHE et al. (1980) (Fig.4). Both classifications generally coincide, although some differences exist, mainly in the most basic types.

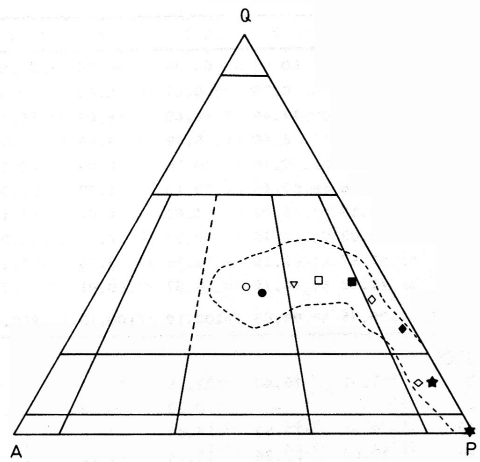

Fig. 3A: Average compositions of main mapped plutonic types plotted in QAP (STRECKEISEN, 1976) diagram. Symbols as in Fig. 6.

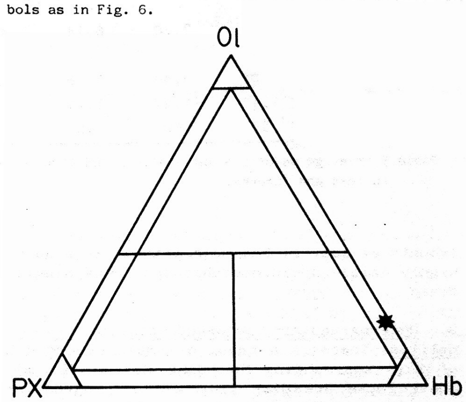

Fig. 3B: Plot in OL-PX-HB (STRECKEISEN, 1976) diagram of ultramafic type ("cortlandtite").

PLUTONIC ROCKS

Southern Montnegre

1. Hornblende-biotite gabbrodiorites. There is a small outcrop N or Dosrius, near the contact between granodiorites (5) and tonalites (3). The rock is medium-grained, dark, and rich in biotite and hornblende, with small

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	53.44	60.91	64.36	66.36	68.05	69.17	70.43	75.34	45.44	48.73	59.01
TiO_2	1.02	0.75	0.67	0.61	0.53	0.50	0.40	0.12	0.41	0.46	0.97
Al_2O_3	18.00	17.46	16.65	16.03	15.55	15.45	15.02	13.48	7.47	17.36	17.76
Fe_2O_3T	9.08	6.40	5.18	4.59	3.90	3.51	3.16	1.17	14.68	7.38	6.62
MnO	0.14	0.10	0.10	0.09	0.07	0.06	0.06	0.04	0.20	0.11	0.10
MgO	4.86	2.45	2.13	1.77	1.39	1.09	0.92	0.24	23.67	8.59	3.23
CaO	9.10	6.02	4.82	4.01	3.46	2.87	2.86	1.19	3.19	13.19	6.26
Na_2O	2.02	2.75	2.83	2.87	3.01	3.09	3.17	3.36	0.52	1.20	3.20
K_2O	1.67	2.29	2.78	3.04	3.27	3.99	3.79	4.74	0.38	1.02	2.66
L.I.	1.52	0.75	0.67	0.81	0.77	0.63	0.42	0.49	2.18	2.02	0.89
TOTAL	100.85	99.88	100.19	100.18	100.00	100.36	100.23	100.17	98.14	100.06	100.70
CIPW											
Q	7.91	18.40	22.75	26.01	27.95	27.74	29.58	34.63	-	-	11.72
C	-	-	0.22	0.72	0.76	0.83	0.50	0.65	0.40	-	-
Or	9.86	13.53	16.42	17.96	19.32	23.57	22.39	28.00	2.24	6.02	15.71
Ab	17.09	23.26	23.94	24.28	25.46	26.14	26.82	28.42	4.39	10.15	27.07
An	35.11	28.53	23.91	19.89	17.16	14.23	14.18	5.90	15.82	38.96	26.23
Di	8.12	1.07	-	-	-	-	-	-	-	21.17	3.86
Hy	14.33	8.83	7.50	6.14	4.74	3.62	3.17	0.86	45.44	16.04	9.05
Ol	-	-	-	-	-	-	-	-	20.88	1.33	-
Mt	4.94	4.05	3.48	3.18	2.79	2.62	2.37	0.95	5.97	3.46	4.28
Il	1.93	1.42	1.27	1.15	1.00	0.94	0.75	0.22	0.77	0.87	1.84
An%	67	55	50	45	40	35	35	17	78	79	49

Table I: Average major-element analysis and CIPW norms of rock-types of Montnegre Massif described in text. Numbers in text and figures.

amounts of quartz. The main mineral is a quite highly calcic hypidiomorphic and zoned plagioclase.

2. Heterogranular hornblende-biotite melatonalites. There is a group of small outcrops N of Teià surrounding Mt. Sant Mateu (490 m). These rocks are dark grey and heterogranular with large hornblende crystals (up to 2 cm long), biotite and plagioclase. The groundmass is granular and medium- to fine-grained containing the same minerals as the large minerals described above, in addition to quartz. The plagioclase is hypidiomorphic and strongly zoned, often revealing patchy zoning.

These rocks are in contact with the tonalites with which they seem to have co-existed in the magmatic state: they show smooth sinuous contacts; they are both reciprocally enclosed as enclaves; a narrow hybrid zone between them is sometimes present.

3. Hornblende-biotite tonalites ("Sant Mateu Tonalites"). These rocks cover a large area in the southern partof Montnegre in a continuous outcrop, elongated from SW to NE. They are light grey in colour and rather coarse-grained, and the existence of some large idiomorphic hornblende crystals (up to 2.5 cm long) gives a heterogranular appearance to the rock. Biotite also forms idiomorphic crystals with pseudo-hexagonal habit, often reaching 1 cm in length. Plagioclase tends to be idiomorphic, while K-feldspar (orthose and microcline), very often interstitial, forms poikilitic plates with very irregular borders, and includes small idiomorphic crystals of plagioclase and biotite.

Examination of thin sections shows that the rock consists chiefly of idiomorphic to hypidiomorphic plagioclase, strongly zoned, with oscillatory and patchy zoning. The anorthite content of the plagioclases is high, ranging from labradorite (in some crystal cores) to oligoclase, although Ca-rich andesine is the most frequent composition.

The plagioclase crystals are generally twinned on the Albite Law and more rarely on the Pericline and Carlsbad Law. Synneusis on several plagioclase crystals may sometimes be seen. The more calcic zones of the plagioclases are usually at least partly altered

	12	13	14-15-16	17	18	19	20	21	22	23	24
SiO_2	70.33	70.88	73.28	71.83	67.96	62.89	56.30	53.90	56.52	47.74	68.21
TiO_2	0.40	0.31	0.21	0.19	0.49	0.77	0.74	0.93	0.87	1.05	0.37
Al_2O_3	15.07	15.16	14.12	14.66	15.73	16.60	17.30	17.74	18.00	24.09	15.71
Fe_2O_3T	2.76	3.00	1.97	2.19	3.43	5.65	7.01	7.49	8.01	8.28	4.08
MnO	0.07	0.04	0.06	0.05	0.07	0.10	0.10	0.12	0.16	0.14	0.10
MgO	1.02	0.53	0.45	0.63	1.21	2.29	5.10	5.18	3.69	3.02	0.83
CaO	2.86	2.19	1.27	1.81	3.31	4.85	6.13	7.30	6.52	6.96	2.53
Na_2O	3.43	3.55	3.70	3.47	3.20	2.74	2.34	3.20	3.27	3.77	4.14
K_2O	3.52	3.56	4.23	3.99	3.31	2.92	1.64	1.63	2.38	3.27	3.18
L.I.	0.66	0.68	0.70	1.06	1.07	1.12	3.08	2.98	1.24	1.04	0.85
TOTAL	100.11	99.90	99.99	99.89	99.78	99.93	99.74	100.47	100.66	99.36	100.00
CIPW											
Q	29.21	30.72	31.96	31.26	27.30	20.88	13.63	5.18	8.00	-	24.64
C	0.65	1.48	1.14	1.34	0.86	0.11	0.53	-	-	1.69	0.85
Or	20.80	21.03	24.99	23.57	19.55	17.25	9.69	9.63	14.06	19.32	18.79
Ab	29.02	30.03	31.30	29.36	27.07	23.18	19.79	27.07	27.66	21.30	35.02
An	13.53	10.86	6.30	8.97	16.42	24.05	30.40	29.22	27.40	34.52	12.55
Ne	-	-	-	-	-	-	-	-	-	5.01	-
Di	-	-	-	-	-	-	-	5.60	3.99	-	-
Hy	3.26	2.20	1.60	2.24	4.07	8.09	17.18	14.62	11.62	-	3.51
Ol	-	-	-	-	-	-	-	-	-	8.63	-
Mt	2.07	2.27	1.57	1.70	2.47	3.75	4.00	4.37	5.01	5.10	3.06
Il	0.75	0.58	0.39	0.36	0.93	1.46	1.40	1.76	1.65	1.99	0.70
An%	32	27	17	23	38	51	61	52	50	62	26

into sericite; in addition, some clinozoisite may be formed.

K-feldspar (generally microperthitic) is present in minor amounts and often shows the cross-hatched twinning of microcline. On the other hand, there are occasionally some myrmequitic intergrowths between plagioclase and K-feldspar. Quartz is abundant as allotriomorphic polycrystalline aggregates, generally showing undulatory extinction. Biotite, also present in considerable amounts, displays an intense brown to yellow pleochroism, and contains many inclusions of idiomorphic prismatic apatites. It also contains idiomorphic zircons, small idiomorphic plagioclases, and ore minerals in lesser amounts. A hypidiomorphic, sometimes twinned hornblende is present in smaller amounts, showing a strong green pleochroism, and including some apatites and zircons. Many melanocratic inclusions with apparently homogeneous distribution in the overall outcrop are contained in the tonalites. They are generally microgranular enclaves (DIDIER? 1973) of quartzdioritic composition (see Tables 1 and 2, no. 22). Their size is variable, normally ranging between 20 and 30 cm. They are usually rounded and a progressive change in composition and grain-size towards the enclosing rock is displayed. The biger and seemingly less assimilated inclusions are quartzdioritic (STRECKEISEN, 1976) or gabbrodioritic (DE LA ROCHE et al., 1980) in composition (see Figs. 3 and 4), and show sharp contacts with the tonalites. These enclaves are fine-grained (about 1 mm) and often porphyritic, with some large hornblende and plagioclase crystals. They contain abundant small idiomorphic biotite and hornblende crystals, sometimes poikilitically enclosed in K-feldspar or quartz. These enclaves also contain hollow acicular or elongated apatite crystals which probably formed by chilling (WYLLIE et al., 1962; REID et al., 1983). On the other hand, metamorphically-derived (mainly pelitic) enclaves (Table 1, no. 23) are present in the tonalites, but in very subordinate proportions. They are very rich in biotite and plagioclase, showing a relict or mimetic foliation, and often have angular borders. They do not contain any hornblende but may have some aluminic metamorphic minerals such as corundum and deep green spinel (hercinite).

A complete changing sequence from pelitic

	2	3	4	5	8	9	10	11	12	14	15	22
Q	16.2	27.8	32.0	33.6	35.3	-	0.5	9.7	34.6	35.4	30.2	7.9
FK	1.3	5.5	6.2	13.0	29.8	-	0.3	2.0	18.4	24.2	30.2	3.3
Pl	44.0	49.6	46.1	41.5	30.5	-	51.1	62.1	38.4	34.4	32.9	50.3
M	-	-	-	-	0.05	-	-	-	-	-	-	-
B	26.3	13.9	13.1	11.1	4.0	-	-	13.0	7.2	4.4	6.2	17.9
Amph	10.2	1.6	1.0	-	-	74.3	47.7	3.8	-	-	-	14.5
Aug	-	-	-	-	-	0.6	0.0	1.8	-	-	-	-
Opx	-	-	-	-	-	-	-	5.4	-	-	-	-
Ol	-	-	-	-	-	16.9	-	-	-	-	-	-
Ap	0.65	0.19	0.34	0.17	0.03	-	-	0.68	0.24	0.19	0.22	0.43
Zr	0.05	0.03	0.10	0.04	0.01	-	-	0.39	0.11	0.06	0.17	0.16
O	0.60	0.09	0.16	0.01	0.00	4.0	0.4	1.12	0.03	0.14	0.13	0.16
Sp	-	-	-	-	-	2.4	-	-	-	-	-	-
Phl	-	-	-	-	-	1.8	-	-	-	-	-	-
Cl+Ep	0.8	0.8	0.8	0.6	0.3	-	-	-	0.9	-	-	2.0
Q	26.30	33.57	37.98	38.14	36.92	-	0.91	13.13	37.77	37.67	32.35	12.89
A	2.04	6.67	7.37	14.75	31.13	-	0.60	2.64	20.15	25.76	32.40	5.45
P	71.66	59.75	54.64	47.10	31.94	-	98.48	84.23	42.06	36.57	35.25	81.66
Ol	-	-	-	-	-	18.41	-	-	-	-	-	-
Amph	-	-	-	-	-	80.90	-	-	-	-	-	-
Px	-	-	-	-	-	0.67	-	-	-	-	-	-

Table II: Modal compositions of main rock-types of Montnegre Massif. Numbers as in text and figures.

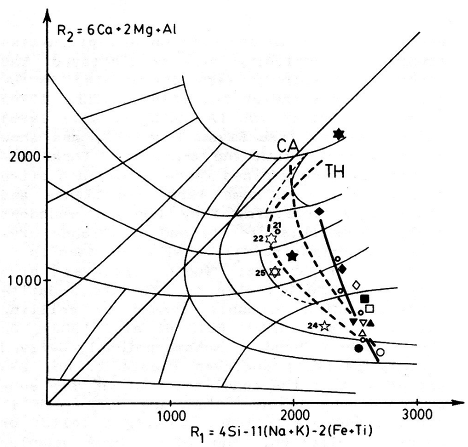

Fig. 4: Average compositions of main plutonic and hypabyssal types and enclaves plotted in R_1R_2 (DE LA ROCHE, 1980) diagram. Symbols of plutonic rocks as in Fig. 6. Small circles: hypabyssal rocks; open stars: enclaves.

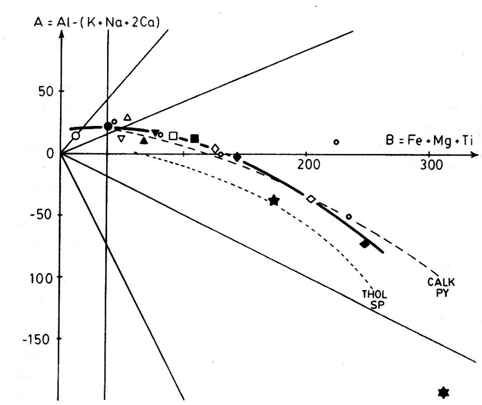

Fig. 5: Average compositions of main plutonic and hypabyssal rocks plotted in A-B (DEBON & LE FORT, 1983) diagram. CALK: calc-alkaline trend from French and Spanish Pyrenees; THOL: tholeiitic (plutonic) trend from Sparta Complex (Oregon) (DEBON & LE FORT, 1983).

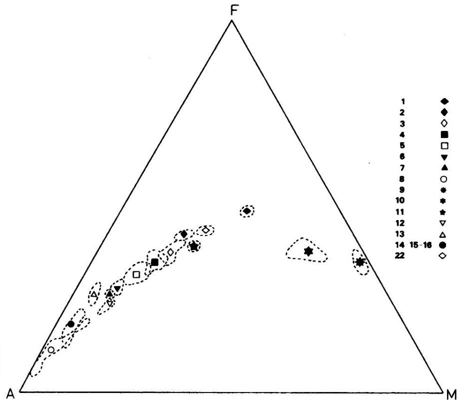

Fig. 6: Average compositions of main mapped plutonic rocks plotted in AFM diagram. Numbers as in the text and Fig. 1. F = total Fe as FeO; A = $Na_2O + K_2O$; M = MgO.

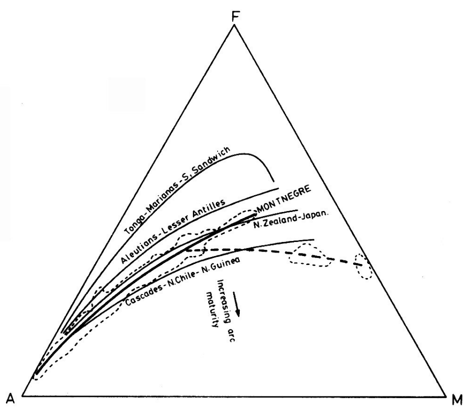

Fig. 7: AFM diagram for volcanic suites from modern magmatic areas showing differences due to art maturity (BROWN, 1982) compared with Montnegre plutonic trends. Solid line: main plutonic types; broken line: small outcrops of diorite-bojite-cortlandtite types.

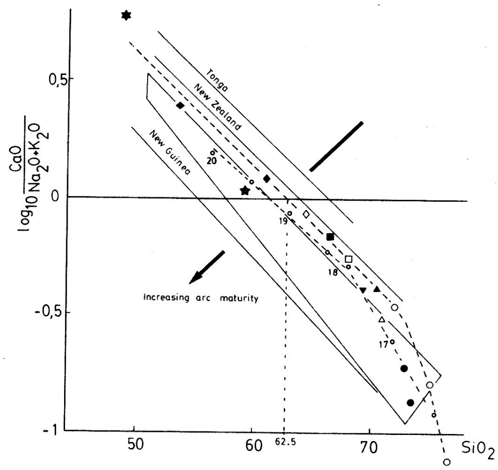

Fig. 8: Calc-alkali ratio-silica trends for volcanic suites from modern magmatic arcs showing change from calcic to calc-alkaline suites with increasing maturity (BROWN, 1982). Symbols represent main average compositions of plutonic and hypabyssal rocks of Montnegre Massif. Oblique dashed lines: trends for plutonic and hypabyssal rocks mentioned. Symbols and numbers as in Fig. 6 and text.

hornfelses to migmatitic rocks (formed by induced anatexis) and surmicaceous enclaves may be found, the latter representing the restites in the most evolved states (BIDIER, 1973).

4. Biotite tonalitic granodiorites with accessory hornblende ("Llavaneres Tonalitic Granodiorites"). These rocks outcrop quite extensively on the coastal slope of the Massif, between the towns of Matarò and Arenys de Mar. They have similar features to the tonalites described above, but differ in that they are richer in K-feldspar and have little and less apparent hornblende. They are rather coarse-grained and contain abundant quartz-dioritic microgranular dark enclaves, bearing biotite and hornblende.

A noteworthy feature is the common occurrence of allanite as an accessory mineral sometimes reaching 1 cm in length and 2 mm in width. Contacts of the rocks with the hornblende-biotite tonalites are not clear and may be gradational.

5. Medium-grained biotite granodiorites ("Orrius Granodiorites"). These granodiorites represent themost abundant granitic rocks in the Montnegre Massif, distributed in several

isolated outcrops. They seem to intrude into the tonalitic granodiorites and tonalites, firstly due to their sharp contacts, and secondly to the existence of some granodiorite dykes thrown out into the latter two rock types.

Paleozoic materials (mainly Cambro-Ordovician) are sharply intruded by these granodiorites. Big stoped and rotated hornfels blocks may sometimes be found near the contacts, but in most cases only minor piecemeal stoping may be observed. These granodiorites are finer-grained (3-4 mm) than the rock-types described above, and their dark microgranular enclaves (Fig. 4, no. 25) are usually scarce and small (5-15 cm). Some metamorphic enclaves also exist, and one of them, almost exclusively composed of sillimanite, has been found.

These have a lower colour index than tonalitic rocks and do not contain hornblende, although it can occur rarely as an accessory. K-feldspar is relatively abundant in allotriomorphic and poikilitic plates including biotite and plagioclase. Biotite displays a prismatic habit.

In thin section they show dominant plagioclase and quartz, the former being hypidiomorphic-idiomorphic and strongly zoned. Allotriomorphic K-feldspar and hypidiomorphic biotite are also quite frequent. Idiomorphic apatites and zircons are usually included in biotite.

Two different granodiorites outcropping in smaller areas have also been mapped. They are lower in colour-index and richer in K-feldspar than the normal biotite granodiorite. Some of their features are as follows:

6. Fine-grained heterogranular biotite granodiorites. These rocks are mainly characterized by their fine grain-size and by two different habits of biotite (prismatic and flaky). They also present some plagioclase and biotite larger than normal.

7. Biotite granodiorites with flaky biotite. These rocks are granular, medium-grained, and do not contain prismatic biotite.

8. Biotite leucogranites, and muscovite-bearing biotite leucogranites (sometimes with accessory garnet). ("Céllecs-Burriac-Corredor Leucogranites"). In contrast to grey granodiorites and tonalites, a group of whitish rocks is present in relatively small outcrops (2-3 km maximum diameter). These outcrops stand out against the average topographic surface because of their resistance to erosion.

These rocks have monzogranitic composition and bear some biotite, although in most samples this mineral is less than 5%; they are therefore considered as leucogranites.

They show important variations in grain-size and biotite content, and this mineral may be totally absent in some places. Likewise, they may give way to aplites or pegmatites, often over very short distances.

Near the orders or at higher-level positions, the plutons may change towards a finer-grained facies, usually with little muscovite, and occasionally some garnet. The medium- to coarse-grained biotitic types may include a few dark microgranular or metamorphic enclaves (the latter very micaceous and sometimes with garnet). However, these enclaves are extraordinarily scarce and small (generally less than 5 cm). Very rarely some biotite granodiorite enclaves may also be found.

Leucogranites normally show very sharp and flat contacts, which may cut the banding and schlieren of tonalites obliquely. Nevertheless, neither magmatic stoping (as may be seen further to the north in the Costa Brava; ENRIQUE, 1981) nor tonalite xenoliths have ever been observed.

On the other hand, leucogranites seem to be later than granodiorites, since these are crossed by some leucogranitic dykes and, in addition, they may contain granodiorite enclaves, as mentioned previously, although the granodiorite-leucogranite contacts do not seem to be sharp. Furthermore, leucogranites have often been seen situated on top of the granodiorites (more precisely, between granodiorites and tonalites). So leucogranites might represent the apical part in some granodiorite intrusions (VILADEVALL, 1975; ENRIQUE, 1979, 1981).

Under the microscope the leucogranites show an allotriomorphic microstructure. Orthose and microcline are abundant and conspicuously perthitic. Plagioclase and generally twinned oligoclase may be zoned, although the zoning is less strong than in tonalites and granodiorites. Biotite is very scarce and displays a tabular or flaky allotriomorphic habit.

Northern Montnegre

The Northern Montnegre plutonic group is predominantly of monzogranitic composition. This kind of rock presents very important variations in grain-size but little change in composition.

Granodiorites are also widespread and in addition some diorite, gabbroid, and ultramafic stocks are present. All plutonic rocks intrude into Paleozoic rocks (mainly Silurian, Devonian, and Lower Carboniferous, in this area) producing intense contact aureole metamorphism.

9. Ultramafic rocks. A group of very small outcrops of ultramafic rocks exists at the contact with the Silurian-Devonian rocks in Northern Montnegre, near Orsavinyà. They are very coarse-grained (1-3 cm) and show cort-

landtitic affinities (ENRIQUE, 1983,in press). Amphibole and olivine account for almost the whole rock, but it also contains phlogopite, deep green spinel, and ore minerals in minor amounts. Clinopyroxene is present as an accessory; orthopyroxene has not been observed. Large allotriomorphic amphibole crystals showing brown to colourless pleochroism include poikilitically many allotriomorphic olivine grains. Following STRECKEISEN's (1976) classification, these rocks are olivine hornblendites.

10. Rocks of gabbroid composition. There are several small stocks of basic rocks closely related to the ultramafic rocks just described. They have a simple composition and are formed almost exclusively of a zoned, highly calcic plagioclase (bytownite; see Table 1). They may contain some augite, and generally have no biotite. They are therefore considered as bojites (HATCH et al., 1972; HUGHES, 1982). These rocks display an ample mineralogical variation from leucocratic (more plagioclasic types) to hornblenditic types. Although intense weathering does not allow good observation, the above-mentioned compositional variations may possibly be attributed to gravitational crystal differentiation.

11. Pyroxene-hornblende-biotite diorites ("Can Camps Diorites"). These rocks appear in quite small outcrops. A heterogeneous mixed zone, formed of quartzdiorites to granodiorites, separates the diorites from the neighbouring bojites and hornblendites (ENRIQUE, 1983, in press). The diorites are fine-grained (1-2 mm) and dark grey in colour. They are composed of several minerals: zoned plagioclase, biotite, hornblende, orthopyroxene, augite, and quartz; K-feldspar is very scarce (see Table 2).

12. Porphyritic biotite granodiorites ("Tordera Granodiorites"). A biotite granodiorite bearing rather abundant megacrysts of K-feldspars (up to 2 or 3 cm) outcrops in the most easterly part of the Montnegre Massif round Tordera and Palafolls Castlè. Biotite has normally tabular or flaky habit, and is less abundant in these rocks than in the main South Montnegre granodiorites.

Quartz is present as allotriomorphic forms and plagioclases form rather intense zoned and hypidiomorphic grains. These rocks contain few dark microgranular enclaves.

13. Muscovite-bearing biotite granodiorites ("Roca Miralles Granodiorites"). South of the porphyritic granodiorites described above and bordering the pelitic to quartzitic Carboniferous materials, a belt of coarse-grained granodiorites outcrops. These rocks have hypidiomorphic K-feldspar, and are relatively rich in biotite. A little muscovite is also present. It is noteworthy that these granodiorites are crossed by many narrow aplite and pegmatite dykes.

14,15,16. Pink leucocratic biotite monzogranites ("Montnegre Granites"). The most northerly part of the Montnegre Massif is formed of a large outcrop of granite-composition rocks with biotite as mafic mineral. Although they are very different in grain-size from place to place, their chemical composition is very uniform. They generally have pinkish tonalites and contain abundant dark microgranular enclaves in many zones. These enclaves are fine-grained and quite rich in flaky biotite, their composition being granodioritic (Table 1, no. 24, and in figures). These enclaves may be very large, sometimes reaching a length of 1 m. They often show a narrow (1-5 cm wide) hybrid zone with medium composition between the enclave and the enclosing granite.

According to the predominant microstructure, three facies granite facies have been mapped: coarse-grained (14), fine-grained (15) and porphyritic (16).

In thin section the microstructure ranges from granular to porphyritic (transition to microgranite). Granular textures are generally allotriomorphic to hypidiomorphic. Mineralogically they are rich in K-feldspar (normally little perthitic orthose). Some plagioclases show intense zoning, although they are often weakly zoned.

HYPABYSSAL ROCKS

An important dyke swarm of hypabyssal rocks crosses the tonalites, granodiorites and leucogranites, mainly in Southern Montnegre. These rocks are mainly of granitic and granodioritic composition. Rocks of tonalitic, dioritic and gabbrodioritic compositions also exist in very subordinate amounts. Neither dolerites nor lamprophyres have been found, although the latter are very prominent in the Costa Brava granites, some km to the north.

The main mapped hypabyssal rock-types are as follows (see Fig. 2):

17. Biotite porphyritic microgranites;
18. Biotite porphyritic microgranodiorites;
19. Hornblende-biotite porphyritic microtonalites;
20. Hornblende-biotite porphyritic microdiorites;
21. Fine-grained hornblendic (sometimes augite-bearing) gabbrodiorites.

Porphyritic microgranites and microgranodiorites are the most important dykes, not only in number but also in width and length. These dykes may reach several km (often 4 or

5), and their width usually attains 20 or 30 m. Their most frequent orientation is NE to ENE, but some may display a NW strike.

In this section the granite, granodiorite and tonalite porphyries show typical porphyritic microstructure. Phenocrysts are normally bipyramidal ß-quartz with magmatic corrosion, strongly zoned plagioclase, idiomorphic biotites, and sometimes K-feldspar and hornblende. The groundmass is microgranular, very fine-grained at the contacts (often black), and somewhat more coarse-grained towards the central part of the dykes.

In Northern Montnegre, and specifically in the pink Montnegre Granites, dykes are very scarce and are generally of more leucogranitic composition.

GEOCHEMICAL DATA

All the major elements were analysed with an atomic absorption spectrophotometer, from fluoboric solution (after FRENCH & ADAMS, 1973). The following international standards were used: NIM-G, GA, G-2, AGV-1, DRN, NIM-N, NIM-P, BR, and NIM-D.

Modal compositions of the main rock-types are shown in Table 2 and Figs. 9 and 10.

CIPW norm compositions were obtained after calculations from HUTCHINSON (1974). They have been modified for Fe, using directly $Fe_2O_3^T$ corrected by the Oxidation Index (Ox) after LE MAITRE (1976) (Table 1).

Samples plotted in DE LA ROCHE et al. (1980), DEBON et al. (1982), and AFM diagrams (see Figs. 4-5 and 6-7) show a typical calc-alkaline trend.

PEACOCK's (1931) or alkali-lime index is about 62.5 (see Fig. 8); following this classification, these rocks therefore belong to a calcic series.

In the diagram log calc-alkali ratios against silica (BROWN, 1982) (Fig. 8) the Montnegre rocks are plotted above the normal andesite range. This fact, stressed also in the AFM diagram, might, according to BROWN (1982) reveal the lower maturity of these rocks as opposed to that of the andesites mentioned above. Following the same author, this might represent magmatic activity coming from a small evolved magmatic arc overlying a thin continental crust.

The high alkali-lime index (over 60) and the distinctive pattern on the AFM diagram are coherent with compressional plutonic rock suites which are believed to be directly related to the subduction process (PETRO et al., 1979).

CONCLUSIONS

The plutonic rocks of the Montnegre Massif belong to a composite batholith in which several different intrusions may be recognized.

The rock compositions of the plutons range from acidic leucogranites to ultramafic cortlandtites. However, the more widespread types are granodioritic and tonalitic.

Many contacts between different plutons are clearly sharp and at least some leucogranite plutons post-date the tonalites and granodiorites.

A prominent dyke swarm cuts all the plutonic rocks, mainly in the southern zone. The dyke-rock composition ranges from intermediate porphyritic microdiorites to porphyritic microleucogranites and felsites, although the most abundant types are of granitic composition.

All the igneous rocks show a typical calc-alkaline trend and have a calcic character according to PEACOCK's (1931) classification.

The Montnegre plutonic series shows a similar trend to the recent calc-alkaline volcanic series of intermediate maturity.

The trend in the AFM diagram and the high alkali-lime index are consistent with compressional rock suites related to subduction processes.

The existence of andesitic to rhyolitic volcanism in the Pyrenees not far from the studied plutonic and hypabyssal rocks showing similar age and compositions, also suggests a possible subduction zone in this area during the Upper Carboniferous to Lower Permian.

The shallow emplacement of allochthonous plutons and the scarcity of migmatite zones and autochthonous granitoids also suggests a deep crustal or infracrustal origin.

If the previous conclusions are correct, RIDING's (1974) proposed model of the Hercynian Orogenic Belt to the east of the North Iberian microplate could be compatible with the preliminary results obtained in the Catalonian Coastal Ranges in the Montnegre area.

Nevertheless, the above considerations cannot be taken as definite, as they are at present drawn from a petrographical study and preliminary research into major geochemical elements. Further research is yet to be carried out on trace elements and isotopes to enable a fuller conclusion to be reached.

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