

## Some petrological and geochemical constraints on the genesis of the Baveno-Mottarone and Montorfano plutonic bodies

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**ABSTRACT.** — New data on zircon typology and trace element distribution for Baveno-Mottarone and Montorfano late-Hercynian plutonic intrusions are reported.

Trace element distribution suggests that granitoid rocks, characterized by an overall calc-alkaline affinity, were generated by crystal fractionation processes starting from hybrid melts («appinitic dykes»). These latter were probably produced by interaction of mantle derived melts with crustal material.

Zircon typology and trace elements suggest two main magmatic trends: 1) «appinitic dykes» + Mergozzo granite; 2) Mottarone granodiorite + Montorfano granite.

The interpretation of the more alkaline Baveno pink granite is at present controversial and different petrogenetic mechanisms may be envisaged.

**Key words:** Southern Alps, Hercynian belt, granitoids, zircon typology, HYGGE distribution.

### Geological and petrographic outlines

The Baveno-Mottarone and Montorfano plutons are multiple intrusions of late-Hercynian age, consisting of several granite facies distinguished on the basis of their composition and field relationships (SASSI, 1985; SESANA, 1985; BORIANI et al., 1988).

The samples analysed in this work belong to the following types:

— Montorfano granite (MN): white medium-grained biotite granite, rarely hornblende bearing; it represents the main facies of this pluton.

— So called «green granite of Mergozzo» (MR); it occurs in the northern part of the Montorfano body. The mineralogical composition (albite, chlorite, quartz, sericite, sphene and carbonates) may be interpreted as the result of low-T sub-solidus reactions (SASSI, 1985).

— Mottarone granodiorite (MT): a biotite-rich, medium-fine-grained granodiorite with sometimes heterogranular texture (plagioclase phenocrysts and K-feldspar megacrysts); it contains schistose xenoliths showing thermal metamorphic effects (presence of cordierite, spinel and corundum).

— Mottarone white granite (WBM): medium-grained biotite granite, forming the bulk of this pluton.

— Pink miarolitic granite of Baveno: medium-grained granite showing intense late-post-magmatic alteration due to the abundance of fluids in both pneumatolithic and hydrothermal stages. At the transition to the white granite WBM, the pink colour of

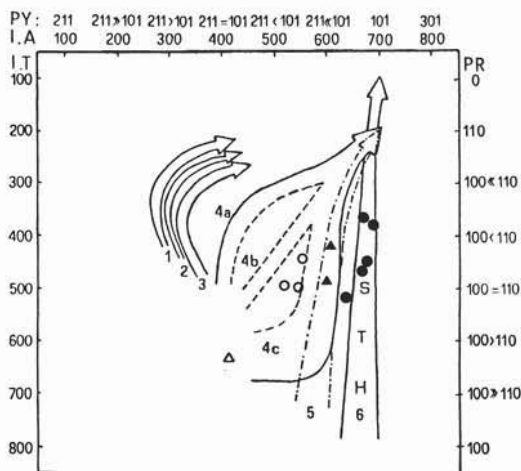


Fig. 1. — Typologic evolution diagram of zircon populations. Data after CAIRONI (1985b). Reported fields (after PUPIN, 1980, modified) represent:

1 to 3: aluminous and peraluminous granodiorites and granites; 4: calcalkaline field; a = tonalitic line; b = normal-K calcalkaline line; c = monzonitic line; 5: high-K calcalkaline field («shoshonitic line»); 6: alkaline granites; H = hypersolvus; T = transsolvus; S = subsolvus. Symbols as in Fig. 2.

the K-feldspar may disappear, although the rock is petrochemically identical to the typical pink facies. As a consequence, the contact between the two granite types cannot be mapped on mere field criteria.

Late Hercynian gabbro-dioritic dykes («appinites») occurring along the Strona-Ceneri/Ivrea-Verbano boundary (BORIANI et al., 1974) are also considered as possible parental magmas of granitic bodies.

### Zircon typology

The typologic study of zircon populations from the above mentioned granite facies indicates (CAIRONI, 1985a, b) that:

1) The Montorfano and Mottarone white granites (MN and WBM) represent different magmas; both show a calc-alkaline character, but they define separate trends on the typologic evolution diagram (Fig. 1);

2) The Mottarone granodiorite (MT) may be related either with the Mottarone white

granite (WBM) or, alternatively, with the Montorfano granite (MN);

3) The pink granite of Baveno shows peculiar features: its zircon populations have all the typical characters of crystals from aluminous alkaline granites. The zircon typology indicates a high alkali content already at high temperatures (about 850°C) and a high  $P_f$  of the magma: the fluid pressure extends the crystallization period of zircon towards low temperatures.

### Element composition

The major element chemistry (Table 1) suggests an overall calc-alkaline affinity (Fig. 2). On the basis of the QAP discrimination diagram (LAMEYRE & BOWDEN, 1982) MR may be referred to a low-K trend, whilst MT, MN, WBM and PB follow a medium-K trend (Fig. 3).

An overall sub-aluminous or slightly per-aluminous character is inferred from the A/NK and A/CNK ratios (Fig. 4). However, in spite of its intense late-post magmatic alteration, PB shows a primary aluminous alkaline character.

In the AFM diagram (Fig. 5) the samples show a well defined calc-alkaline trend; however MR is characterized by Fe-depleted compositions, suggestive of contamination or alteration processes.

REE patterns for the different plutonic bodies are reported in Fig. 6:

— MR is highly LREE-enriched (La-Sm  $400-35 \times \text{Ch}$ ) compared to HREE (Tb-Yb  $26-20 \times \text{Ch}$ ) and displays high overall REE fractionation ( $\text{La/Yb} > 30$ ) and small or no Eu anomalies;

— MN is characterized by LREE-enriched patterns (La-Sm  $195-40 \times \text{Ch}$ ; Tb-Yb  $28-18 \times \text{Ch}$ ); the La/Yb ratios range from 12 to 31 and the HREE patterns are significantly fractionated ( $\text{Tb}_N/\text{Yb}_N = 1.4-2.1$ ); significant Eu negative anomalies appear ( $\text{Eu}/\text{Eu}^* = .3-.7$ );

— WBM shows moderate LREE enrichment (La-Sm  $128-40 \times \text{Ch}$ ), slight HREE fractionation ( $\text{Tb}_N/\text{Yb}_N = 1.2$ ), very low La/Yb ratios (6-8), and large Eu negative

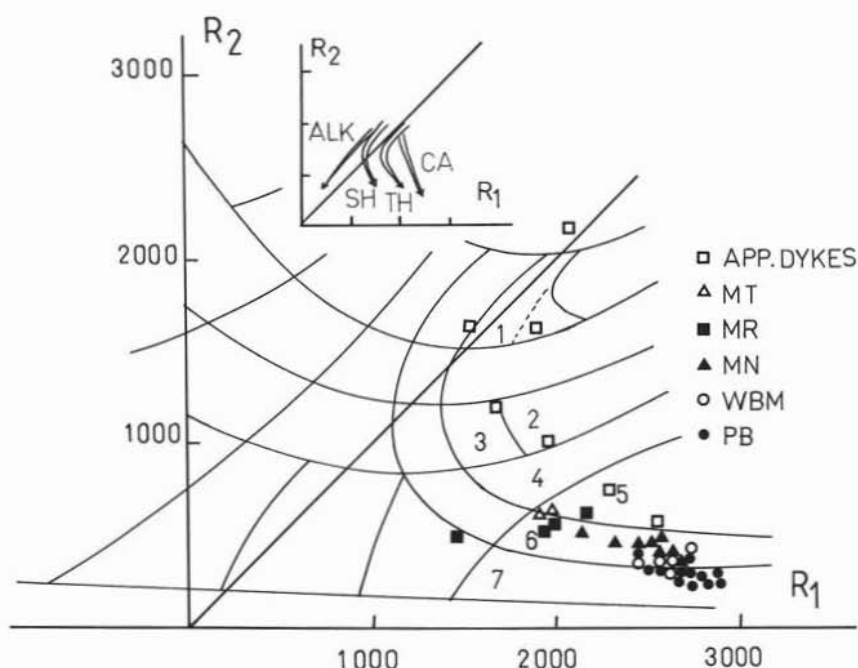


Fig. 2. — R1-R2 diagram (DE LA ROCHE et al., 1980) for appinitic dykes and plutonic bodies. Trends of alkaline (ALK), shoshonitic (SH), tholeiitic and calcalkaline (CA) rock series are reported for comparison. Fields: 1 = gabbro; 2 = diorite; 3 = monzodiorite; 4 = tonalite; 5 = granodiorite; 6 = granite; 7 = alkali granite.

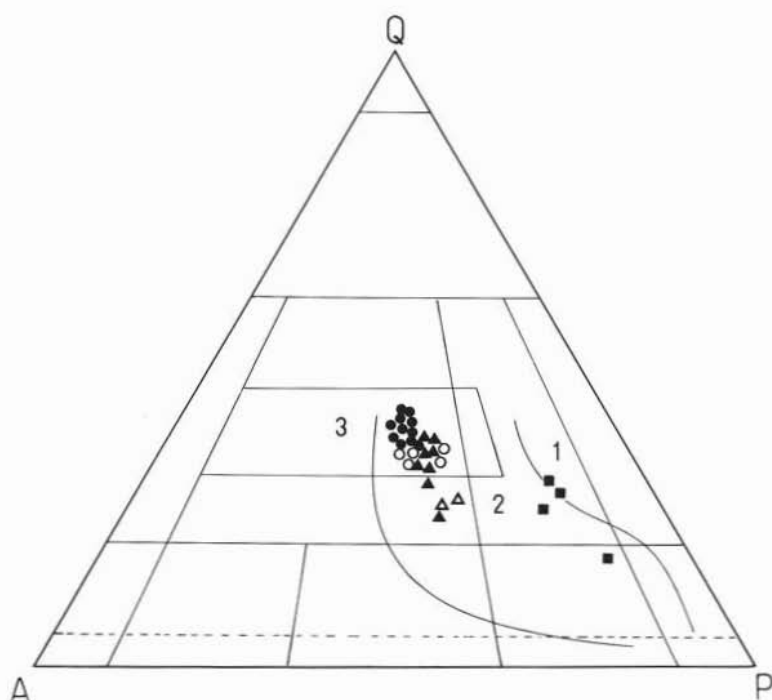


Fig. 3. — QAP diagram. Fields of low-K calcalkaline (1), medium-K calcalkaline (2) rocks and granitic rocks of crustal origin (3) are from LAMEYRE & BOWDEN (1982). Symbols as in Fig. 2.

anomalies ( $\text{Eu}/\text{Eu}^* = .2-.4$ );

— PB is characterized by large Ce and Eu negative anomalies and  $\text{Tb}_\text{N}/\text{Yb}_\text{N} < 1$ .

### Petrogenetic constraints

A systematic use of trace element distribution patterns in log-log diagrams

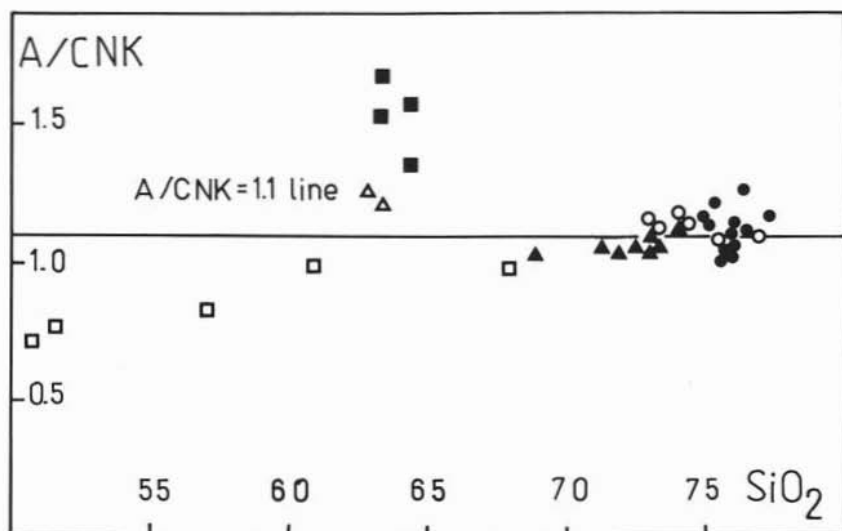


Fig. 4. — A/CNK vs.  $\text{SiO}_2$  diagram. Symbols as in Fig. 2.

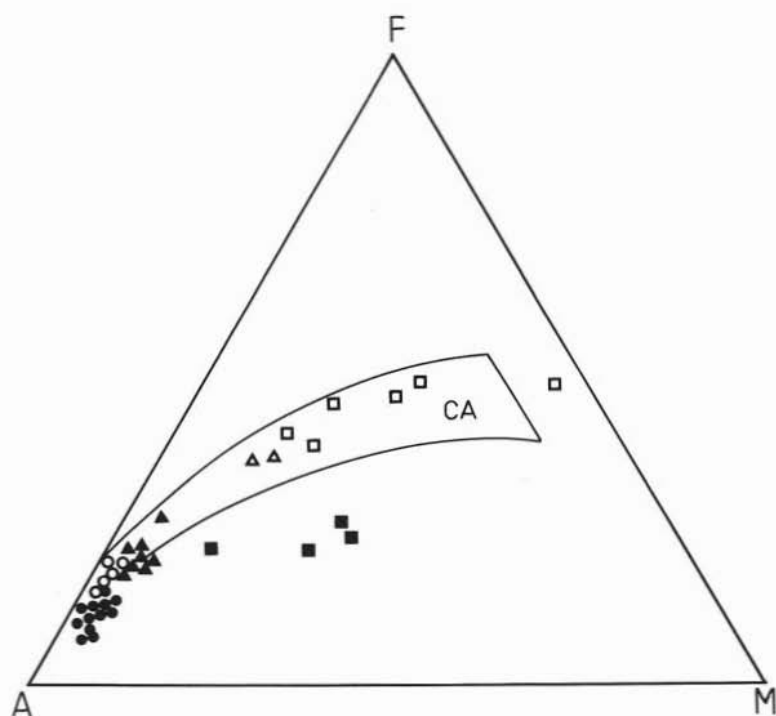


Fig. 5. — AFM diagram. CA is the field of calcalkaline rock series. Symbols as in Fig. 2.

TABLE 1

Major element average composition and trace element compositional range for studied plutonic bodies. Number of samples in brackets. Columns: 1 = Mottarone granodiorite (2); 2 = Mergozzo granite (4); 3 = Montorfano granite (10); 4 = Mottarone white granite (5); 5 = Baveno pink granite (21)

	1	2	3	4	5
SiO <sub>2</sub> %	64.02	64.60	72.59	74.04	75.98
TiO <sub>2</sub>	0.84	0.31	0.23	0.15	0.08
Al <sub>2</sub> O <sub>3</sub>	16.28	17.39	13.95	13.98	12.91
FeO	0.93	0.33	0.19	0.15	0.13
Fe <sub>2</sub> O <sub>3</sub>	4.29	2.66	1.91	1.57	1.05
MnO	0.06	0.01	0.04	0.03	0.02
MgO	1.87	3.88	0.32	0.19	0.16
CaO	1.96	0.43	1.35	0.87	0.48
Na <sub>2</sub> O	3.21	5.29	3.32	3.36	3.55
K <sub>2</sub> O	4.07	1.76	4.62	4.68	4.56
P <sub>2</sub> O <sub>5</sub>	0.28	0.13	0.08	0.06	0.04
L.O.I.	2.19	3.21	0.72	0.94	0.71
Total	100.00	100.00	99.32	100.02	99.67
Rb ppm	110 - 170	55 - 100	140 - 240	215 - 250	230 - 295
Sr	160 - 210	15 - 70	90 - 130	70 - 75	10 - 35
Th	26 - 29	33 - 36	27 - 37	31 - 37	28 - 39
Y	38 - 40	30 - 55	28 - 51	47 - 56	40 - 100
Zr	520 - 530	240 - 445	170 - 400	135 - 165	95 - 155
Nb	14 - 16	15 - 25	15 - 20	16 - 18	10 - 30
Ni	18 - 25	7 - 25	8 - 17	7 - 20	7 - 24
La	71 - 103	100 - 160	41 - 98	35 - 50	46 - 63
Ce	102 - 150	130 - 230	99 - 210	63 - 101	51 - 66
Nd	72 - 84	48 - 53	38 - 51	28 - 46	26 - 53
Sm	4 - 6	4 - 8	5 - 9	5 - 17	2 - 6
Eu	2.3 - 2.5	1.6 - 2.0	0.8 - 1.8	0.6 - 0.9	0.3 - 0.6
Tb	.9 - 1.1	0.9 - 1.6	1.1 - 1.6	0.9 - 1.9	0.8 - 1.7
Yb	3.6 - 4.7	3.0 - 5.0	3.2 - 3.8	3.1 - 6.1	4.0 - 6.2

(COCHERIE, 1986) demonstrates that simple petrogenetic models cannot account for the different bodies.

In logarithmic variation diagrams where a hydromagmatophile (HYG) element serves as an index of the degree of differentiation, straight regression lines indicate prevailing fractional crystallization processes according to the linear equation

$$\ln C_L = \ln C_O + (1-D) \ln C_L^*/C_O^*$$

where:  $C_L$  = trace element concentration in residual liquid;

$C_O$  = trace element concentration in parent melt;

$C_L^*$  = HYG element concentration in residual liquid;

$C_O^*$  = HYG element concentration in parent melt.

The bulk partition coefficient  $D$  for any element may thus be theoretically calculated from the slope ( $m$ ) of the least-squares fits ( $m = 1-D$ ).

A linear regression technique indicates that significant correlation and slope values are obtained if two main magmatic trends are assumed (Fig. 7):

1) Appinitic dykes-MR trend, where Rb, La, Zr, Th show incompatible behaviour;

2) MT-MN trend, where La and Zr behave as compatible elements.

The slopes of the variation lines showing correlation coefficients higher than 0.8 indicate  $D$  values for compatible elements in broad agreement with the petrographic evidence. The following  $D$  values have been calculated:  $D_{Ni} = 3.2$ ,  $D_{Sr} > 3$  for the Appinitic dykes-MR trend;  $D_{Ni} = 2.9$ ,  $D_{Eu} = 2.5-3.2$ ,  $D_{Sr} \approx 2.1$  for the MT-MN trend.

No simple relationships exist between the above identified magmatic trends and WBM, PB compositions. Given their small compositional range, it is difficult to evaluate whether they may be related to the same magmatic episode or not. In any case, zircon typology and REE data seem to fit the latter possibility better. Furthermore most trace elements, excluding Ni, suggest that WBM lie at the end of an hypothetical MT-MN-WBM liquid line of descent. Unfortunately, the interpretation based on trace element distribution has not at present a unique solution.

Although log-log diagrams are consistent with prevailing fractional crystallization processes, the latter can explain neither the poor correlation coefficients of variation lines presented by Eu and Sr, nor the compositional range of the obtained  $D$  values, nor the discrepancies between the fractionation degrees derived from major and trace element modelling.

Quantitative formulations using compatible

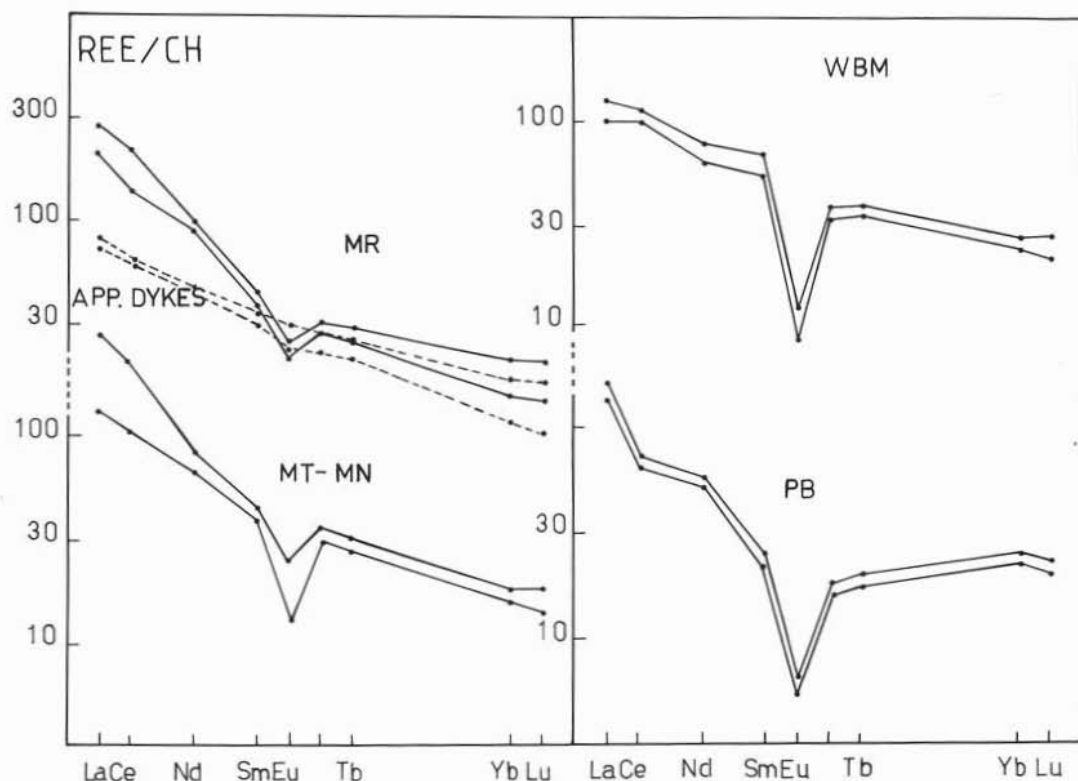


Fig. 6. — Range of REE content found in appinitic dykes and different plutonic bodies, normalized to chondrites.

elements vs. Rb and Th abundance (Fig. 8) clearly demonstrate that Eu and Sr behaviour in the Appinitic dykes and MR granite needs additional assimilation to be explained by fractional crystallization. Furthermore, a petrologic evolution of the different granites by crystal fractionation offers no satisfactory explanation about the presence of different parental magmas and their provenance.

The generation of different parental magmas by crustal assimilation plus fractional crystallization of a basic magma of mantle origin is consistent with the observed data and the theoretical modelling (Fig. 9). Further constraints are provided by recent Nd-Sr isotopic evidence (STILLE & BULETTI, 1987).

The hybrid parental melts evolved by additional fractional crystallization with or without further assimilation of lower and upper crustal components, thus generating the plutonic intrusions.

As a result of the contrasting trace element distribution WBM may be interpreted in two different ways: i) as independent differentiation trend; ii) as more evolved trend at the end of the MT-MN liquid line (according to Sr, Eu distribution). Both the interpretations are reported in Fig. 9.

The PB genesis is also controversial. Although geochemical considerations largely depend on late-post-magmatic alteration, some characteristics (zircon typology, major element chemistry, large Eu anomaly, HREE enrichment) suggest an alkaline geochemical affinity, and different petrogenetic processes may be envisaged. Possible mechanisms include high-temperature anhydrous melting of a quartz-feldspathic granulite source (related to uprising of magmas of mantle provenance?) as proposed for anorogenic A-granites by COLLINS et al. (1982), and fluid-melt fractionation at the top of the magma

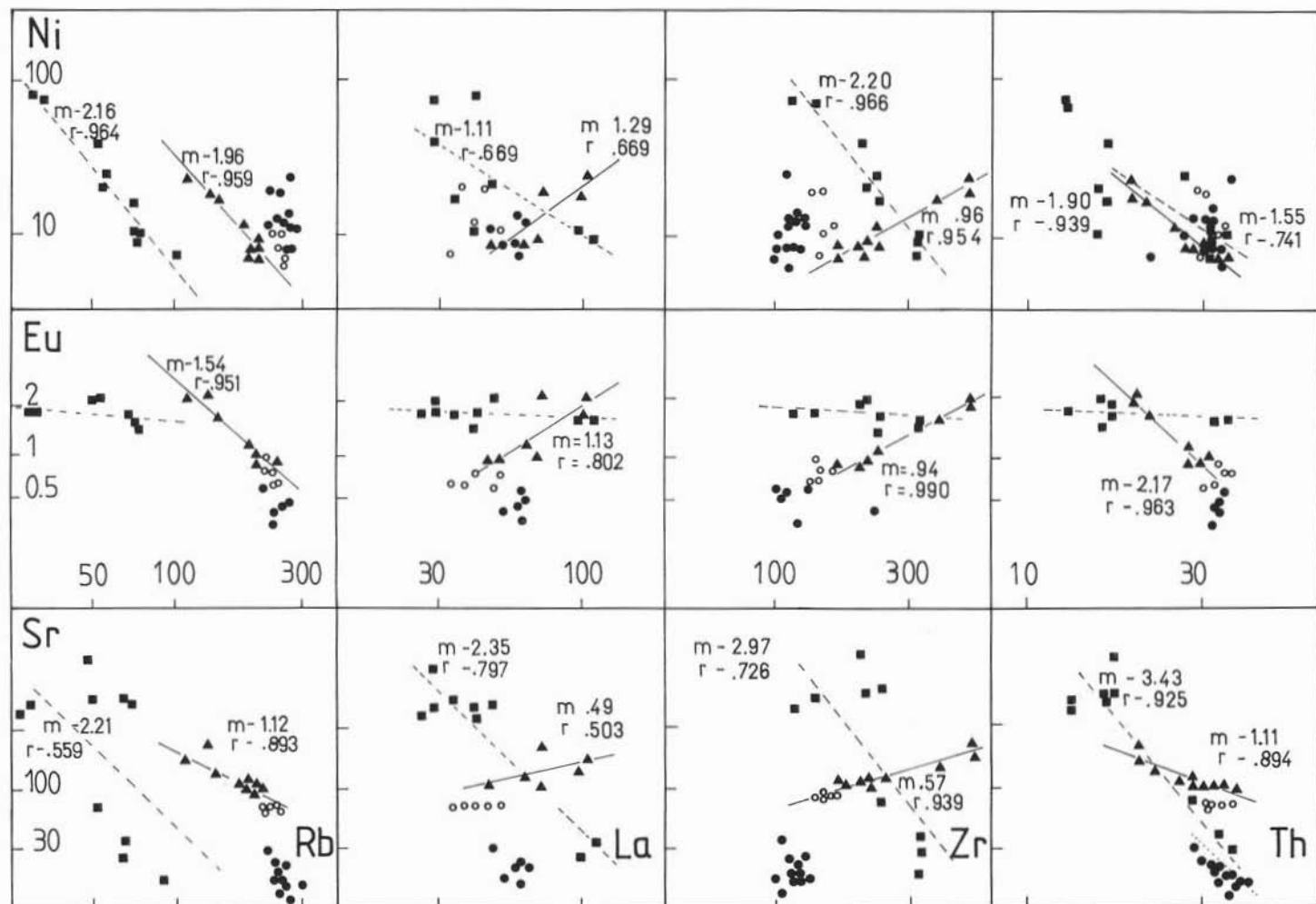


Fig. 7. — Log-log covariation diagrams. Symbols: solid squares = appinitic dykes and MR; solid triangles = MT and MN; circles = WBM; solid circles = PB.

chamber, perhaps induced by high Cl or F activity (HILDRETH, 1979; CHRISTIANSEN et al., 1984).

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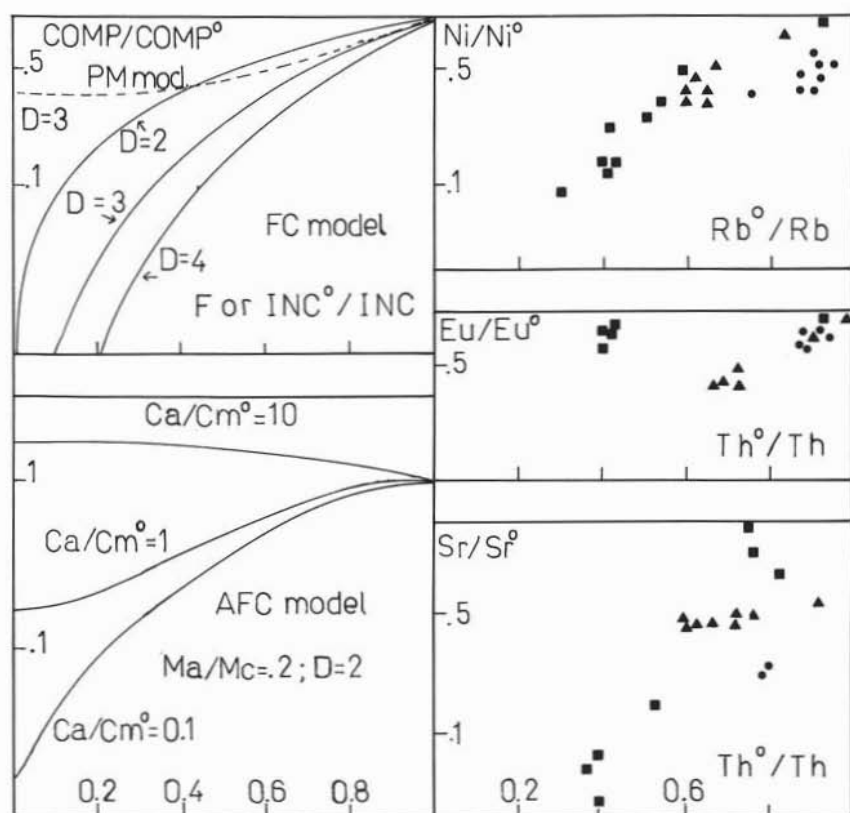


Fig. 8. — Behaviour of compatible elements (Eu, Sr, Ni) versus incompatible elements (Rb, Th). Reported quantitative formulations: PM = partial melting; FC = fractional crystallization; AFC = assimilation plus fractional crystallization (DE PAOLO, 1981). Symbols: squares = appinitic dykes + MR; triangles = MT + MN; circles = WBM + PB.



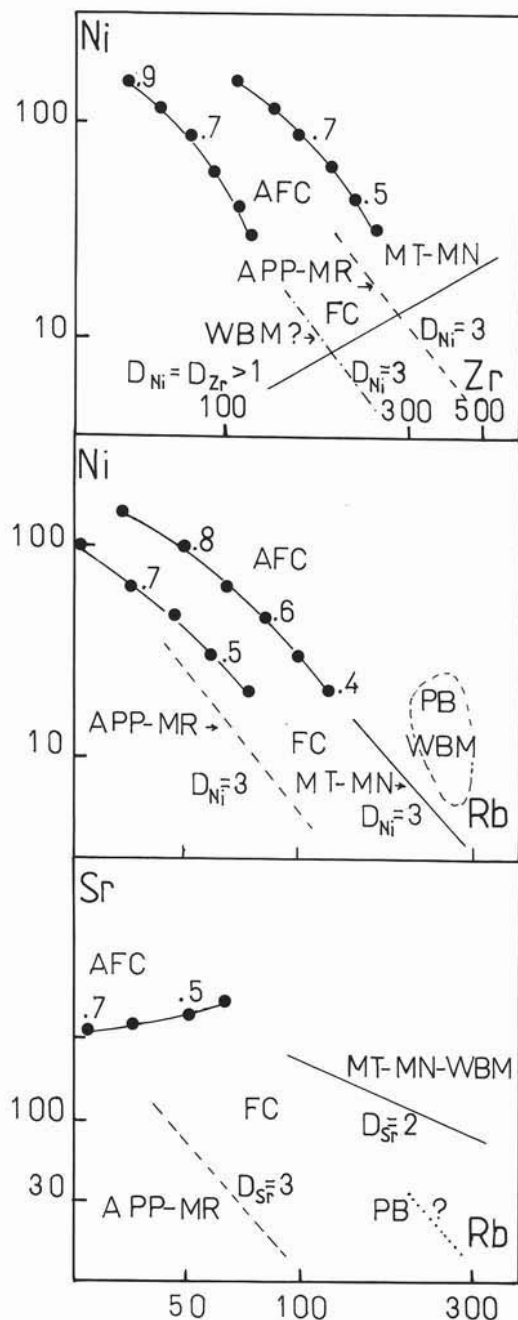


Fig. 9. — Theoretical AFC and FC petrogenetic models. AFC data:  $Mm/Mm^0 = F$ ;  $Ma/Mc = 0.4$ ;  $C_{Ni}^0 = 200$  ppm;  $C_{Ni}^a = 75$  ppm;  $D_{Ni} = 3$ ;  $C_{Zr}^0 = 40-100$  ppm;  $C_{Zr}^a = 165$  ppm;  $D_{Zr} = 0.1$ ;  $C_{Rb}^0 = 10-20$  ppm;  $C_{Rb}^a = 90$  ppm;  $D_{Rb} = 0.3$ .

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