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**Autor:** Colombo, Annita / Siletto, Gian Bartolomeo / Tunesi, Annalisa

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# Pre-Variscan magmatism in the central Southern Alps: the Monte Fioraro magmatic complex

by *Annita Colombo*[1], *Gian Bartolomeo Siletto*[1], *Annalisa Tunesi*[1]


### Abstract

The Monte Fioraro magmatic complex is the largest acidic stock occurring in the Orobic Southalpine basement (Northern Italy), on the main ridge between Valtellina and Val Brembana. It is composed of granitic and granodioritic metagranitoids consisting of some apophyses and a main body with an undeformed core and a foliated rim. It was previously interpreted as Hercynian (pre-Permian) in age. Structural investigations point out that the rim and the apophyses of the Monte Fioraro magmatic complex are deformed at least starting from the $D_2$ phase of deformation recognized in the country rocks and associated with greenschist facies metamorphic conditions. Microstructural investigations on metagranitoids evidence a pre-$D_2$ association of qtz + pl + Kfs + bt + wm + grt; thermobarometric determinations led to T estimates around 550 °C (grt-bt; grt-wm) and P around 6–7 kb (pl-bt-grt-wm; $Si^{4+}$ content in wm). Therefore, the Monte Fioraro magmatic complex also suffered a metamorphic phase under amphibolite facies conditions before $D_2$ deformation and it must be pre-Variscan in age, probably Ordovician.

The metagranitoids are slightly peraluminous and subalkaline. They show high contents of Rb, Th, HFSE and Ce and low contents of Ba and Sr; REE are moderately fractionated ($La_N/Yb_N$: 5.4–10.2) with Eu/Eu* averaged ratio: 0.38. The overall chemical data are consistent with those of compared Ordovician orthogneisses.

The geochemistry evidences an emplacement in a post-collisional and tensional environment. The Monte Fioraro magmatic complex could therefore be related to a late magmatic phase emplaced in a mature-arc setting, involving a major contribution from a within-plate source.


*Keywords:* pre-Variscan, Ordovician magmatism, Southalpine basement, geochemistry, Northern Italy.

## Introduction

The granitoids occurring as stocks or lenses in the central sector of the Southalpine domain (Orobic Alps), except the Val Biandino pluton (Rb–Sr WR isochron on granites: 286 ± 20 Ma, THÖNI et al., 1992; DE CAPITANI et al., 1988), lack radiometric, isotopic and geochemical (p.p.) data. The granitoids are generally regarded as Hercynian in age (pre-Permian) by previous authors (D'AMICO, 1974 with references therein), but some of them could be older in age, possibly Ordovician. Actually, a pre-Variscan magmatic event is well documented in the western sector of the Southalpine basement (BORIANI et al., 1981) as well as in the eastern sector of the Austroalpine basement (PECCERILLO et al., 1979), but it is unknown in the Orobic Alps. On the other hand, the Ordovician magmatism is well known in Europe and data on the orthogneisses of the Massif Central, France, are particularly abundant (DOWNES and DUTHOU, 1988 and references therein).

The purpose of this work is to shed light on the Orobic granitic orthogneisses (Fig. 1), namely on the largest stock, the "Monte Fioraro granite" (BONSIGNORE et al., 1971), which occurs on the watershed between Valtellina and Val Brembana. Recent structural data (SILETTO, 1990; 1991) suggest a pre-Variscan intrusion age. This hypothesis is explored taking into account thermobarometric and geochemical data.

## Geological setting

The northern part of the Orobic Alps is a basement complex which consists of metapelites, metapsammites, quartzites, minor marbles and amphibolites. Metagranitoids occur as stocks or lenses interlayered within the basement: they

[1] Dipartimento di Scienze della Terra, Università di Milano, Via Botticelli 23, I-20133 Milano, Italy.

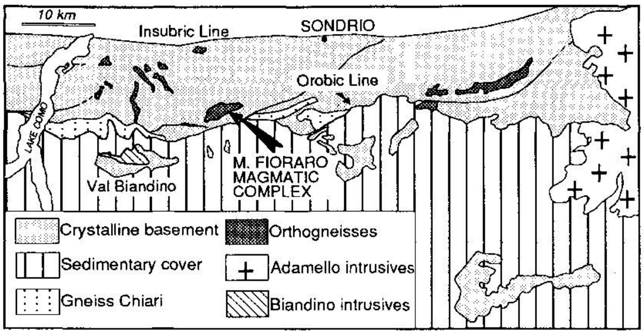


*Fig. 1* Geological sketch map of the Orobic Alps (Italian Alps) from Lake Como to Adamello massif.

range in composition from granites to granodiorites. Most leucocratic types (the so-called "Gneiss Chiari del Corno Stella") are often located near the contact between the basement and the Permo-Mesozoic sedimentary cover (Fig. 1). Intermediate and mafic rocks are less frequent and are mainly represented by Oligocene porphyritic dykes.

In the basement rocks, the main metamorphic imprint is considered pre-Alpine because the sedimentary cover is non-metamorphic. Two synmetamorphic phases of deformation are recognizable in the basement: $D_1$ developed under amphibolite facies conditions, whereas $D_2$ was associated to a widespread retrogradation to greenschist facies conditions (MILANO et al., 1988; SILETTO, 1991). Few radiometric age determinations (BOCCHIO et al., 1981; MOTTANA et al., 1985) were performed on basement metapelites and point to a Variscan age for the amphibolite facies metamorphic stage (368–312 Ma). After the Variscan ductile deformations ($D_1$ and $D_2$), during the Alpine convergence, the basement was thrusted upon the Permo-Mesozoic sedimentary cover along the E–W trending Orobic Line (Fig. 1).

Previous authors (BONSIGNORE et al., 1971; D'AMICO, 1974) described separately the almost undeformed core as "Monte Fioraro granite" and the foliated rim as "Monte Pedena orthogneisses". In this study we prefer to indicate the overall rocks of the stock as Monte Fioraro magmatic complex, also including some deformed apophyses occurring in the southernmost area.

A mafic dyke crosscuts the rims of the stock and the $D_2$ structures and is considered linked to the post-collisional Oligocene magmatism. Diorites s.l. occur as dykes or small bodies mostly near the rims of the magmatic complex. The mafic rocks also suffered a recrystallization under greenschist facies conditions. The relationships between mafic and acidic rocks have not been studied in detail.

Thermal effects due to the emplacement of the M. Fioraro magmatic complex are not identified in the metapelitic country rocks (Filladi di Ambria).

## Structural observations

The country rocks of the Monte Fioraro magmatic complex suffered two pre-Alpine synmetamorphic phases of deformation ($D_1$ and $D_2$), followed by two phases of deformation under very weak to non-metamorphic conditions ($D_3$ and $D_4$). The $D_1$ structures are represented by cm-scale rootless folds and relic foliation, underlined by white mica and biotite. At the granular scale, where the effects of $D_2$ are less pronounced, garnet is preserved in the quartz-rich domains of $S_1$ foliation.

In the country rocks, in the foliated rim and in the apophyses of the Monte Fioraro magmatic complex, the main foliation is related to $D_2$ and is axial planar to tight or isoclinal folds. $S_2$ foliation is synchronous with greenschist facies metamorphic retrogradation and white mica and chlorite are stable on $S_2$ planes. The third phase of deformation ($D_3$) developed a crenulation cleavage without mineral growth in the most phyllitic layers and metric open folds also in the apophyses. $D_4$ structures mainly consist of cataclastic bands associated to the Alpine Orobic thrust.

The lithological boundary between the Monte Fioraro apophyses and the host-rock metapelites (Fig. 2) is deformed at least since the onset of the $D_2$ deformational phase: some structures in the apophyses can possibly be interpreted as $D_1$ folds, but an intrusive origin cannot be totally disregarded.

## Petrography and petrology

Petrographic and microstructural investigations performed on samples from the Monte Fioraro magmatic complex indicate that the rocks suffered a pre-$D_2$ metamorphic stage developed under amphibolite facies conditions. Actually a mineralogical assemblage constituted by quartz, K- feldspar, plagioclase (17–23% An), biotite (Fe = 3.06–3.34; Ti = 0.1–0.25; $Al^{VI}$ = 0.7–1 p.f.u.), white mica ( Fe = 0.22–0.36; $Si^{4+}$ = 3.2–3.25 p.f.u. ), ± garnet (Alm ≈ 0.74, Grs = 0.14–0.16, Sps ≈ 0.03, Pyr ≈ 0.05 p.f.u.), apatite and zircon (small quantities), ± sphene, opaques can be observed (see Tab. 1 for the analytical data on minerals).

Where the $D_2$ deformation is less intense, garnet and biotite (pre-$D_2$) show moulded structures and rational boundaries.

The preferred dimensional orientation of biotite and white mica is parallel to $S_2$, but their

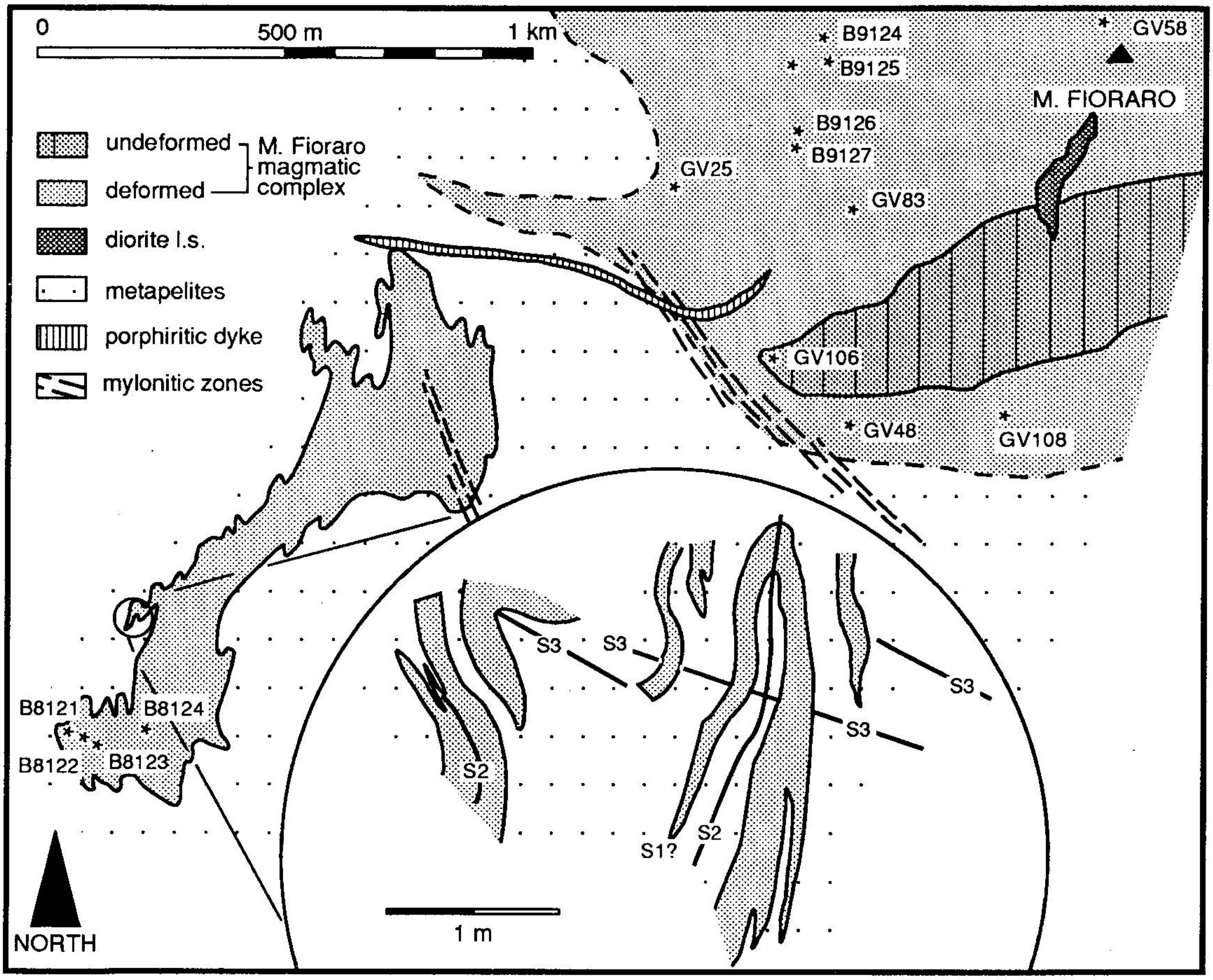


*Fig. 2* Geological sketch map of the Monte Fioraro magmatic complex and form surface map of a contact between metagranitoids and surrounding metapelites.

{001} planes are locally transversal and the rims are dissolved. The biotite is also stable in strain shadows of garnet porphyroclasts. $D_2$ retrogradation is marked by new growth of white mica ($Si^{4+}$ = 3.12–3.17; Pg = 0.84–0.107 p.f.u.) and chlorite along biotite and white $mica_1$ {001} planes, in biotite strain shadows, in the necks of the boudinaged biotites, in biotite and white $mica_1$ grains folded by $D_2$. During this phase the garnet is replaced by chlorite and white mica; chlorite also grows in the strain shadows of the replaced garnets.

Temperatures of the pre-$D_2$ assemblage in the metagranitoids were estimated considering the Fe–Mg exchange between garnet and biotite. PERCHUK and LAVRENT'EVA (1983) calibration (PL in Tab. 1) leads to temperatures ranging from 508–554 °C for a pressure of 5–7 kb, in good agreement with T°C (480–534 °C) obtained using HOLDAWAY and LEE (1977) calibration (HL in Tab. 1). Garnet-muscovite calibration according to GREEN and HELLMAN (1982) and plagioclase-muscovite pairs according to GREEN and USDANSKY (1986) lead to T estimates in the range 500–590 °C (SILETTO, 1991) for P = 7 kb.

The pressure for the pre-$D_2$ metamorphic stage was estimated using the geobarometer plagioclase-biotite-garnet-muscovite (GHENT and STOUT, 1981), yielding pressures in the range 6–8 kb (SILETTO, 1991), while the $Si^{4+}$ content (3.20–3.25 p.f.u.) in the muscovite (MASSONNE and SCHREYER, 1987) suggests a pressure in the range 5–6 kb for an assumed temperature of 550 °C.

These thermobarometric data suggest that the Monte Fioraro magmatic complex suffered the Variscan amphibolite facies metamorphic stage, followed by the greenschist retrogradation ($D_2$) previously described.

*Tab. 1* Selected microprobe mineral analyses and thermobarometry of the Monte Fioraro magmatic complex.

| | Biotite formula based on 22 O | | | Garnet formula based on 12 O | | | White Mica formula based on 22 O | | | | Plagioclase formula based on 8 O | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 34.30 | 35.34 | 36.08 | 37.69 | 37.80 | 37.11 | 49.79 | 48.10 | 49.16 | 48.10 | 63.66 | 60.04 | 65.00 |
| $TiO_2$ | 1.32 | 1.09 | 1.68 | 0.01 | 0.00 | 0.01 | 0.56 | 0.36 | 0.71 | 0.36 | 0.02 | 0.01 | 0.00 |
| $Al_2O_3$ | 18.05 | 19.16 | 18.68 | 20.45 | 20.89 | 20.95 | 32.71 | 34.45 | 33.38 | 34.45 | 22.10 | 22.81 | 23.08 |
| FeO | 25.52 | 24.81 | 24.15 | 34.53 | 34.38 | 33.83 | 3.02 | 2.03 | 3.29 | 2.03 | 0.82 | 1.45 | 0.00 |
| MnO | 0.07 | 0.07 | 0.13 | 1.16 | 1.12 | 1.26 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| MgO | 7.30 | 6.40 | 7.28 | 1.22 | 1.26 | 1.09 | 1.69 | 1.14 | 1.42 | 1.14 | 0.05 | 0.24 | 0.05 |
| CaO | 0.07 | 0.10 | 0.02 | 6.05 | 6.39 | 6.73 | 0.04 | 0.00 | 0.04 | 0.00 | 3.09 | 5.02 | 3.64 |
| $Na_2O$ | 0.05 | 0.08 | 0.00 | | | | 0.20 | 0.64 | 0.29 | 0.64 | 9.31 | 9.16 | 8.31 |
| $K_2O$ | 9.16 | 9.47 | 10.07 | | | | 8.42 | 9.04 | 7.71 | 9.04 | 0.08 | 0.12 | 0.08 |
| Total | 95.84 | 96.52 | 98.09 | 101.11 | 101.84 | 100.98 | 96.42 | 95.76 | 96.00 | 95.76 | 99.13 | 98.85 | 100.16 |
| Si | 5.36 | 5.45 | 5.46 | 3.01 | 3.00 | 2.97 | 6.48 | 6.32 | 6.42 | 6.32 | 2.84 | 2.72 | 2.84 |
| $Al^{IV}$ | 2.64 | 2.55 | 2.54 | 0.00 | 0.00 | 0.03 | 1.51 | 1.68 | 1.58 | 1.68 | | | |
| Al | | | | | | | | | | | 1.16 | 1.22 | 1.19 |
| $Al^{VI}$ | 0.69 | 0.93 | 0.80 | 1.93 | 1.95 | 1.95 | 3.51 | 3.66 | 3.55 | 3.66 | | | |
| Ti | 0.16 | 0.13 | 0.19 | 0.00 | 0.00 | 0.00 | 0.05 | 0.04 | 0.07 | 0.04 | 0.00 | 0.00 | 0.00 |
| Fe | 3.34 | 3.20 | 3.06 | | | | 0.33 | 0.22 | 0.36 | 0.22 | 0.03 | 0.06 | 0.00 |
| $Fe^{+3}$ | | | | 0.07 | 0.05 | 0.06 | | | | | | | |
| $Fe^{+2}$ | | | | 2.24 | 2.23 | 2.21 | | | | | | | |
| Mn | 0.01 | 0.01 | 0.02 | 0.08 | 0.08 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mg | 1.71 | 1.47 | 1.64 | 0.15 | 0.15 | 0.13 | 0.33 | 0.22 | 0.28 | 0.22 | 0.00 | 0.02 | 0.00 |
| Ca | 0.01 | 0.02 | 0.00 | 0.52 | 0.54 | 0.58 | 0.01 | 0.00 | 0.01 | 0.00 | 0.15 | 0.24 | 0.17 |
| Na | 0.02 | 0.02 | 0.00 | | | | 0.05 | 0.16 | 0.07 | 0.16 | 0.80 | 0.81 | 0.71 |
| K | 1.83 | 1.86 | 1.95 | | | | 1.40 | 1.52 | 1.28 | 1.52 | 0.01 | 0.01 | 0.01 |
| Alm | | | | 0.75 | 0.74 | 0.74 | | | | | | | |
| Sps | | | | 0.03 | 0.03 | 0.03 | | | | | | | |
| Pyr | | | | 0.05 | 0.05 | 0.04 | | | | | | | |
| Grs | | | | 0.14 | 0.16 | 0.16 | | | | | | | |
| Ab | | | | | | | | | | | 0.84 | 0.76 | 0.80 |
| An | | | | | | | | | | | 0.16 | 0.23 | 0.19 |
| Pg | | | | | | | 0.04 | 0.10 | 0.05 | 0.10 | | | |
| Mu | | | | | | | 0.96 | 0.90 | 0.94 | 0.90 | | | |

Thermobarometry of the Fioraro metagranitoids

| Sample n° | Bt X Mg | Grt X Mg | Grt X Mn | Grt X Ca | WM $Si^{4+}$ | HL T °C | PL T °C | MS P Kb | MS T ref °C |
|---|---|---|---|---|---|---|---|---|---|
| 9121–101 | 0.338 | 0.050 | 0.026 | 0.174 | | 508 | 531 | | |
| 9121–103 | 0.315 | 0.050 | 0.027 | 0.180 | | 534 | 554 | | |
| 9121–705 | 0.350 | 0.043 | 0.030 | 0.193 | | 480 | 508 | | |
| B 8123–117 | | | | | 3.21 | | | 6.5 | 550 |
| 9121–802 | | | | | 3.24 | | | 7.2 | 550 |
| 9121–505 | | | | | 3.16 | | | 5.0 | 550 |

X $Mg^{Bt}$ = Mg / Mg + Fe; X $Mg^{Grt}$ = Mg / (Mg + Fe + Mn + Ca); X $Mn^{Grt}$ = Mn / (Mg + Fe + Mn + Ca); X $Ca^{Grt}$ = Ca (Mg + Fe + Mn + Ca). HL = Holdaway and Lee (1977); PL = Perchuk and Lavrent'eva (1983); MS = Massonne and Schreyer (1987). N° anal. Bt/Grt = 21; n° anal. WM = 19.

Chemical analyses were carried out with an ARL SEMQ electron microprobe at the C.N.R. Centro di studio per la Geodinamica Alpina e Quaternaria, in Milano. In all the analyses, natural silicates were used as standards. The accelerating voltage was 15 kV and the sample current 15 nA. The structural formulae of minerals were calculated with the Fortran program MINSORT (Petrakakis and Dietrich, 1985).

*Tab. 2* Rock analyses of the Monte Fioraro magmatic complex.

| Sample | YB9121 | B 8121 | GV 42 | GV 43 | B 9124 | GV 83 | GV 19 | B 9127 | B 8122 | GV 4 | GV83B | GV 6 | B 9126 | GV 58 | B 8123 | XB9121 | GV 48 | GV 25 | GV 106 | GV 108 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 62.66 | 63.70 | 64.36 | 65.24 | 68.45 | 68.48 | 69.65 | 69.87 | 71.10 | 71.40 | 71.48 | 71.60 | 71.83 | 71.91 | 71.99 | 72.02 | 72.27 | 73.33 | 73.53 | 74.89 |
| $TiO_2$ | 0.69 | 0.66 | 0.23 | 0.85 | 0.40 | 0.43 | 0.48 | 0.31 | 0.31 | 0.32 | 0.29 | 0.25 | 0.28 | 0.43 | 0.35 | 0.28 | 0.24 | 0.24 | 0.27 | 0.25 |
| $Al_2O_3$ | 17.68 | 17.13 | 16.50 | 15.58 | 14.71 | 17.27 | 15.55 | 14.33 | 14.06 | 14.10 | 14.74 | 14.24 | 13.56 | 15.31 | 14.03 | 13.91 | 14.38 | 14.56 | 14.74 | 14.50 |
| $Fe_2O_3$ | 0.85 | 0.81 | 1.08 | 1.98 | 0.78 | 0.84 | 0.73 | 0.72 | 0.79 | 0.67 | 0.38 | 0.89 | 0.82 | 0.89 | 0.55 | 0.81 | 0.15 | 0.51 | 0.29 | 0.76 |
| FeO | 4.28 | 3.96 | 4.77 | 3.56 | 2.61 | 1.13 | 2.88 | 1.77 | 2.30 | 2.25 | 2.10 | 1.60 | 1.71 | 2.11 | 1.91 | 1.95 | 1.36 | 1.46 | 1.33 | 1.63 |
| MnO | 0.12 | 0.10 | 0.07 | 0.06 | 0.10 | 0.03 | 0.05 | 0.08 | 0.10 | 0.03 | 0.04 | 0.04 | 0.08 | 0.03 | 0.08 | 0.09 | 0.02 | 0.02 | 0.01 | 0.01 |
| MgO | 1.35 | 1.20 | 1.03 | 1.06 | 0.81 | 0.87 | 0.86 | 0.88 | 0.95 | 0.88 | 0.89 | 0.72 | 0.70 | 0.93 | 0.67 | 0.66 | 0.87 | 0.82 | 0.91 | 0.93 |
| CaO | 2.08 | 2.02 | 2.91 | 2.39 | 1.06 | 3.07 | 1.15 | 0.74 | 0.91 | 0.66 | 0.59 | 0.53 | 0.62 | 0.83 | 1.00 | 0.75 | 0.42 | 0.31 | 2.46 | 0.47 |
| $Na_2O$ | 5.75 | 5.82 | 3.04 | 2.52 | 4.70 | 4.33 | 2.53 | 4.33 | 5.59 | 2.88 | 2.56 | 2.97 | 4.16 | 3.78 | 5.94 | 5.83 | 2.90 | 2.96 | 4.78 | 5.80 |
| $K_2O$ | 2.32 | 2.26 | 4.05 | 4.27 | 5.04 | 2.70 | 5.07 | 5.34 | 2.02 | 5.35 | 5.55 | 5.54 | 5.15 | 2.86 | 1.63 | 1.95 | 5.92 | 5.30 | 1.01 | 0.74 |
| $P_2O_5$ | 0.18 | 0.17 | 0.07 | 0.25 | 0.20 | 0.20 | 0.13 | 0.17 | 0.15 | 0.09 | 0.12 | 0.10 | 0.12 | 0.10 | 0.14 | 0.19 | 0.11 | 0.13 | 0.16 | 0.12 |
| LOI | 1.47 | 2.16 | 2.35 | 1.27 | 1.42 | 0.98 | 1.30 | 1.28 | 1.30 | 0.93 | 0.90 | 0.91 | 1.08 | 1.33 | 1.26 | 1.14 | 0.78 | 1.23 | 0.71 | 0.88 |
| Total | 99.43 | 99.99 | 100.46 | 99.03 | 100.28 | 100.33 | 100.38 | 99.82 | 99.58 | 99.56 | 99.64 | 99.44 | 100.11 | 100.51 | 99.55 | 99.58 | 99.42 | 100.87 | 100.20 | 100.98 |
| Rb | 136 | 131 | 145 | 142 | 216 | 53 | 185 | 173 | 114 | 169 | 189 | 195 | 196 | 128 | 74 | 101 | 150 | 155 | 70 | 29 |
| Sr | 255 | 254 | 139 | 140 | 112 | 228 | 110 | 130 | 127 | 97 | 77 | 79 | 105 | 165 | 118 | 113 | 156 | 85 | 305 | 450 |
| Ba | 474 | 498 | 916 | 972 | 464 | 964 | 713 | 446 | 167 | 497 | 459 | 429 | 336 | 584 | 249 | 195 | 975 | 441 | 398 | 344 |
| Y | 29 | 41 | 44 | 38 | 45 | 38 | 45 | 44 | 29 | 50 | 56 | 49 | 44 | 48 | 38 | 41 | 34 | 41 | 35 | 47 |
| Nb | 43 | 40 | n.d. | 22 | 36 | 39 | 31 | 31 | 41 | 34 | 39 | 31 | 28 | 37 | 35 | 39 | 40 | 39 | 53 | 46 |
| Zr | 343 | 324 | 278 | 256 | 243 | 354 | 258 | 226 | 200 | 240 | 209 | 188 | 184 | 284 | 189 | 180 | 211 | 199 | 233 | 236 |
| Cr | 18 | 17 | n.d. | 24 | 9 | 7 | 11 | 6 | 6 | 5 | 4 | 10 | 3 | 8 | 7 | 6 | 4 | 4 | 5 | 4 |
| Ni | 10 | 10 | n.d. | 13 | 6 | 4 | 8 | 4 | 7 | 5 | 4 | 8 | 3 | 6 | 2 | 4 | 4 | 4 | 11 | 3 |
| V | 52 | 52 | n.d. | 70 | 28 | 21 | 39 | 15 | 14 | 15 | 10 | 37 | 12 | 25 | 20 | 16 | 11 | 10 | 24 | 10 |
| Th | 37 | 37 | n.d. | 12 | 29 | 13 | 16 | 33 | 44 | 25 | 11 | 17 | 28 | 14 | 38 | 34 | 11 | 11 | 10 | 11 |
| La | 88 | 86.76 | 51 | 50 | 58.68 | 61.42 | 60 | 51.48 | 50 | 52 | 49 | 40 | 40.76 | 60.00 | 41.78 | 39.98 | 15.57 | 42.28 | 15.11 | 32.38 |
| Ce | 209 | 155.49 | 94 | 91 | 110.54 | 114.23 | 110 | 99.00 | 106 | 102 | 98 | 77 | 76.93 | 114.54 | 85.54 | 83.94 | 33.31 | 80.42 | 34.07 | 66.72 |
| Nd | n.d. | 63.81 | n.d. | n.d. | 45.67 | 47.18 | n.d. | 40.04 | n.d. | n.d. | n.d. | n.d. | 33.18 | 45.06 | 32.91 | 32.00 | 12.99 | 33.43 | 15.89 | 26.82 |
| Sm | n.d. | 12.63 | n.d. | n.d. | 9.99 | 9.77 | n.d. | 8.92 | n.d. | n.d. | n.d. | n.d. | 7.82 | 9.61 | 7.46 | 7.41 | 3.81 | 7.66 | 4.50 | 6.24 |
| Eu | n.d. | 1.72 | n.d. | n.d. | 1.16 | 1.27 | n.d. | 0.92 | n.d. | n.d. | n.d. | n.d. | 0.61 | 1.12 | 0.74 | 0.59 | 0.66 | 0.65 | 0.79 | 0.98 |
| Gd | n.d. | 10.17 | n.d. | n.d. | 8.95 | 8.28 | n.d. | 7.90 | n.d. | n.d. | n.d. | n.d. | 7.04 | 8.07 | 6.28 | 6.57 | 4.32 | 6.71 | 5.06 | 6.37 |
| Dy | n.d. | 8.02 | n.d. | n.d. | 7.98 | 7.43 | n.d. | 7.71 | n.d. | n.d. | n.d. | n.d. | 7.47 | 8.31 | 6.45 | 7.21 | 5.69 | 7.17 | 6.03 | 7.64 |
| Er | n.d. | 4.10 | n.d. | n.d. | 5.59 | 3.52 | n.d. | 4.45 | n.d. | n.d. | n.d. | n.d. | 4.39 | 4.69 | 3.91 | 4.07 | 3.39 | 3.95 | 3.75 | 4.59 |
| Yb | n.d. | 3.27 | n.d. | n.d. | 3.87 | 2.89 | n.d. | 3.76 | n.d. | n.d. | n.d. | n.d. | 3.98 | 4.28 | 3.72 | 3.78 | 3.30 | 3.80 | 3.36 | 4.02 |
| Lu | n.d. | 0.56 | n.d. | n.d. | 0.66 | 0.48 | n.d. | 0.59 | n.d. | n.d. | n.d. | n.d. | 0.65 | 0.68 | 0.62 | 0.62 | 0.52 | 0.59 | 0.55 | 0.65 |
| Total REE | | 346.53 | | | 252.06 | 256.47 | | 224.77 | | | | | 182.83 | 256.36 | 189.41 | 186.13 | 83.56 | 186.66 | 89.11 | 156.42 |
| $La_N/Yb_N$ | | 17.93 | | | 10.25 | 14.37 | | 9.25 | | | | | 6.86 | 9.47 | 7.54 | 7.15 | 3.19 | 7.52 | 3.04 | 5.44 |
| $La_N/Sm_N$ | | 4.32 | | | 3.70 | 3.96 | | 3.63 | | | | | 3.28 | 3.93 | 3.52 | 3.40 | 2.57 | 3.47 | 2.11 | 3.27 |
| $Gd_N/Lu_N$ | | 2.26 | | | 1.69 | 2.15 | | 1.67 | | | | | 1.35 | 1.48 | 1.26 | 1.32 | 1.03 | 1.42 | 1.15 | 1.22 |
| Eu/Eu* | | 0.46 | | | 0.38 | 0.43 | | 0.34 | | | | | 0.25 | 0.39 | 0.33 | 0.26 | 0.50 | 0.28 | 0.51 | 0.48 |

All elements analysed by X-ray fluorescence spectrometry except for REE and Y determined by ICP. The precision was better than 15% for Lu, better than 10% for Y and Yb, better than 5% for all the other REE.
LOI: loss on ignition. Major oxides in wt%, trace elements and REE in ppm. n.d. = not determined.

## Geochemical data

The chemical data of the samples of the Monte Fioraro magmatic complex are represented in Tab. 2. In the following diagrams, the results are compared with those of Ordovician orthogneisses occurring in the Massiccio dei Laghi (466 ± 5 Ma, Rb–Sr WR isochron; BORIANI et al., 1981 and unpublished data) and in the eastern Austroalpine basement (PECCERILLO et al., 1979); unfortunately the latter analyses lack trace elements.

The composition of the Monte Fioraro rocks ranges from granitic to granodioritic with $SiO_2$ contents between 63 wt% and 73 wt% and $Al_2O_3$ contents around 13–14 wt%; the character is subalkaline.

Almost all the samples exhibit a peraluminous character as shown in the A-B diagram (Fig. 3) of DEBON and LE FORT (1988): this feature seems to be a peculiar characteristic of the most acidic of the compared Ordovician orthogneisses.

The trace elements spidergram (Fig. 4a), normalized to ORG composition (PEARCE et al., 1984), shows a well-defined negative Ba anomaly (5–20 x ORG), high contents of Rb (10–45 x ORG), Th (15–50 x ORG), Nb (3–4 x ORG), Ce (2–4 x ORG). Zr and Y are slightly lower than the normalizing value (0.6–1 x ORG) and Sm close to 1. Such a pattern is compatible with those of post-collisional granites. Two samples (GV 106–108) show higher Sr and lower K, Rb and LREE contents than the other ones, suggesting a different composition of the K-feldspar; the sample GV 48 has low LREE contents (Fig. 4b). The high Rb and Th contents indicate clearly strong crustal imprint in magma generation. With respect to the Massiccio dei Laghi two mica orthogneisses, the Monte Fioraro samples have slightly higher Rb and Th contents, much higher HFSE and lower Ba contents.

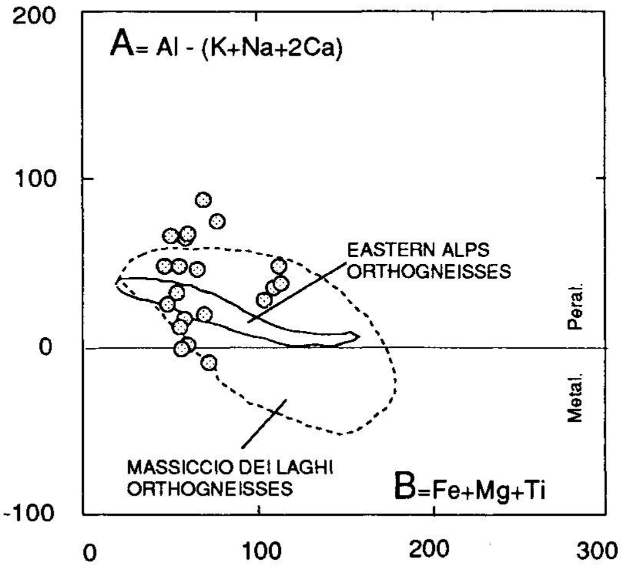


*Fig. 3* A vs B diagram, according to DEBON and LE FORT (1988) of the Monte Fioraro metagranitoids. A = Al (K + Na + 2 Ca); B = Fe + Mg + Ti. This diagram separates peraluminous rocks or minerals, with positive A value ("aluminous index"), from metaluminous ones.

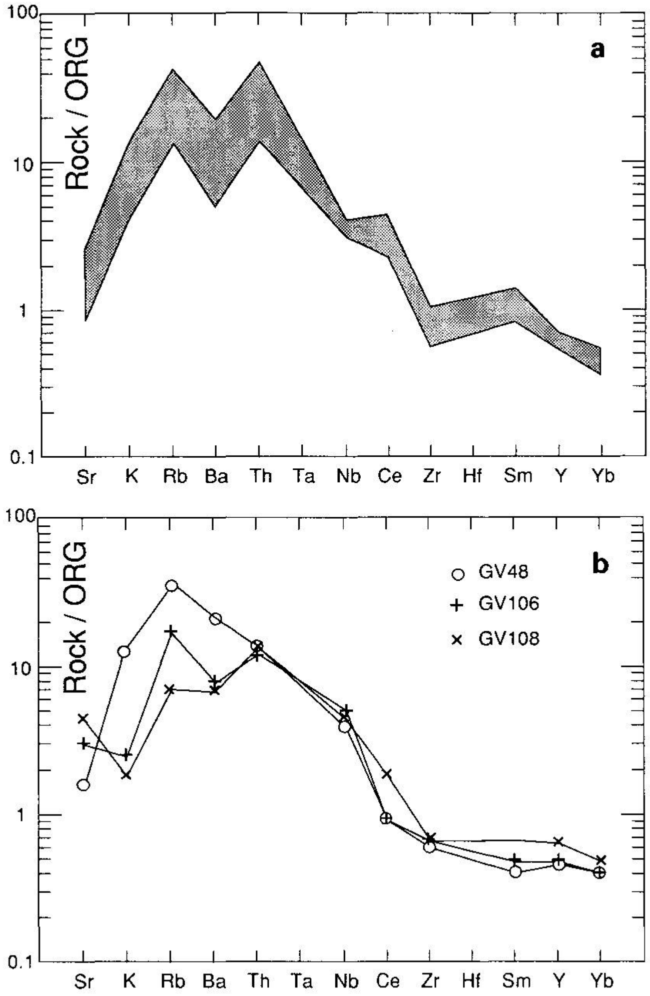


*Fig. 4* ORG-normalized patterns of the Monte Fioraro metagranitoids. The dotted field represents almost all the samples (Fig. 4a), except GV 106, 108, 48 (Fig. 4b).

The REE contents of 13 samples were analyzed in Nancy by ICP. The corresponding chondrite-normalized abundance patterns are shown in figure 5. The overall REE abundance is quite homogeneous (Tab. 2) with few exceptions: two samples (GV 106 and 48) show very low total REE (80–90). They can be interpreted as leucogranitic portions of the stock. Actually the REE contents decrease with respect to $SiO_2$ content: this condition was also observed in other granitic suites (TINDLE and PEARCE, 1981) with a silica content exceeding 65–68%. For example, the compared Ordovician orthogneisses, which have a wider compositional variation than the Monte

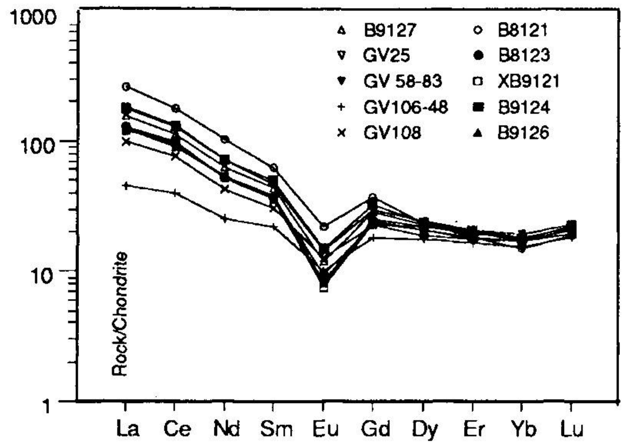


*Fig. 5* Chondrite-normalized REE patterns of the Monte Fioraro metagranitoids.

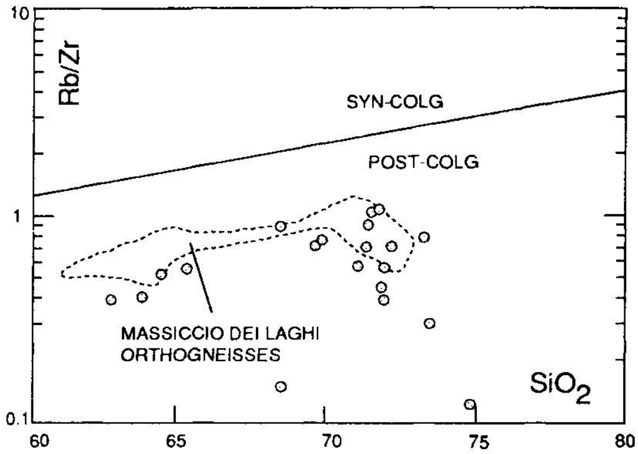


*Fig. 6* Rb/Zr ratio vs $SiO_2$ showing the classification of the Monte Fioraro metagranitoids as post-collisional granites in origin.

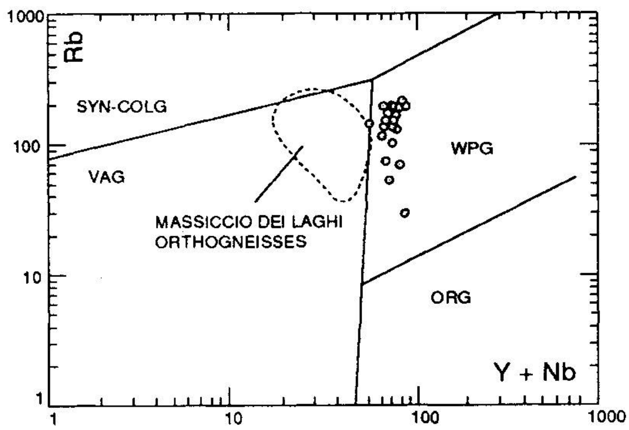


*Fig. 7* Rb vs Y+Nb diagram showing the classification of the Monte Fioraro metagranitoids as within-plate granites (WPG) in origin. On the contrary, the Massiccio dei Laghi orthogneisses plot in the Volcanic Arc Granite field (VAG).

Fioraro rocks, show an increase in REE contents up to 68–70% of $SiO_2$ and then a decrease in the more differentiated samples.

The REE patterns generally show moderate fractionation ($La_N/Yb_N$ between 5.4 and 10.2, with few exceptions, see Tab. 2). The LREE are more fractionated with respect to HREE (averaged ratios: $La_N/Sm_N$: 3.4; $Gd_N/Lu_N$: 1.5); actually, there is a distinct flattening within the HREE from Dy to Lu. This behavior could be mainly due to initial separation of minor phases such as zircon and apatite followed by the fractionation of major phases. The Monte Fioraro metagranitoids exhibit a well-defined negative Eu anomaly (Eu/Eu* averaged ratio: 0.38), probably due to initial plagioclase separation from the melt.

The REE abundance and pattern of the Monte Fioraro metagranitoids are similar to those of the Ordovician orthogneisses of the compared series, and also with those of the Massif Central, France (Downes and Duthou, 1988).

Therefore, the overall geochemical features of the samples of the Monte Fioraro magmatic complex appear to be compatible with those of the acidic Ordovician magmatic rocks.

## Discussion and conclusion

Mesostructural analyses suggest a pre-$D_2$ intrusion age for the Monte Fioraro magmatic complex, because the rim and the apophyses are deformed by the $D_2$ deformation recognized in the country rocks and associated to the late-Variscan greenschist facies retrogradation. Petrological and thermobarometric investigations point to the existence of an amphibolite facies metamorphic assemblage preserved as $D_1$ structural relics in the country rocks and as mineralogical relics in the metagranitoids. This metamorphic stage may be ascribed to the climax of the Variscan event. Consequently, the intrusion age of the Monte Fioraro magmatic complex is probably pre-Variscan. The comparison with Ordovician orthogneisses evidenced a good chemical affinity, supporting a possible Ordovician age for the Monte Fioraro magmatic complex intrusion.

Taking into account the relationships between trace element geochemistry and tectonic setting using the different empirical tectonic discrimination diagrams (Pearce et al., 1984) and the so-called immobile or relatively immobile elements (such as Zr, Y, Nb), we note that the samples of the Monte Fioraro magmatic complex have contrasting features. The trace element contents along with the Rb/Zr ratio (Fig. 6; Harris et al., 1986) point to an emplacement in a post-collisional environment, but the enrichment in HFS elements, such as Nb and Y, is more compatible with a within-plate environment (Fig. 7). This consideration is also strengthened by the quite homogeneous Y/Nb ratio, which is a typical feature of each A-type granitic suite (EBY, 1990), together with high $Na_2O + K_2O$ and low CaO contents. Also in the multicationic R1-R2 diagram (not reported here; DE LA ROCHE et al., 1980), the Monte Fioraro samples mostly plot between the late-magmatic and anorogenic fields proposed by BATCHELOR and BOWDEN (1985) for granitic suites. Moreover, according to the classificatory criteria of ROGERS and GREENBERG (1990), major, trace, RE element abundance, the relatively flat REE patterns, the strongly negative Eu anomaly and the low HREE contents are in agreement with the features of PO (Post-Orogenic) granites. All these parameters suggest an emplacement into tensional environments, at the final stage of an orogenic cycle.

On the contrary, the Ordovician orthogneisses of the Massiccio dei Laghi (and also of the Massif Central, France) show features more similar (Fig. 7) to those of volcanic arc granites (VAG) and appear to be connected to a compressive setting: the occurrence of eclogitic rocks in the country rocks may support this consideration (BORIANI et al., 1991).

We suggest a possible explanation for the different tectonic setting of probably coeval magmatic series in the Southalpine basement. The observed variation of geochemical features in the metagranitoids from the western area to the easternmost Orobic Alps, could be linked to a different distance from an hypothetical subduction zone proposed by BORIANI et al. (1991). The Monte Fioraro magmatic complex could have been emplaced in a mature-arc setting (BROWN et al., 1984), involving a major contribution from a within-plate source. Consequently, the intrusion age of the Monte Fioraro magmatic complex could be expected slightly younger than that of the westernmost Massiccio dei Laghi orthogneisses (466 ± 5 Ma, Rb–Sr WR isochron).

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