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The porphyritic facies and the endoskarns of the Traversella monzodiorite: Implications for the evolution of the main intrusion (Ivrea, Italy)

by *J. Vander Auwera*[1]

Abstract

A porphyritic and explosive facies of the Traversella monzodiorite – the Arissa porphyrite – is described and considered as a late reintrusion of a magma similar to the main monzodiorite. The explosive character of the porphyrite was likely induced by the separation of a fluid phase which is not the metasomatic fluid responsible for the skarn formation. The main monzodiorite appears a better candidate for the fluid source.

The occurrence of the late Arissa porphyrite and the relative chronology of endoskarns and magmatic veins indicate that the Traversella pluton has crystallised from several distinct magma batches. This feature can explain the dispersed Isr-values obtained in the intrusion and which were formely considered as resulting from an assimilation process during the fractional crystallisation of one single liquid. On the other hand, a simple fractional crystallisation process is capable to account for the major as well as trace element evolution of the intrusion, especially of U and Th.

Bimetasomatic skarns developed at the expense of the monzodiorite are observed as dm-thick veins and massive skarns at the concact between monzodiorite and calcic lithologies. The first metasomatic reaction induces the formation of a pyroxene zone made up of clinopyroxene and plagioclase (andesine). In the most internal part of the skarn, a Ti-rich garnet (2% to 3.7% TiO_2) develops at the expense of the Ca-rich plagioclase (bytownite). A chemical mass balance calculation of the metasomatic process indicates that Ca and the alkalies were the elements affected most: Ca strongly increased whereas the alkalies were completely leached out. μ_{CaO} and μ_{K_2O} appear as the controlling metasomatic factors.

Keywords: Monzodiorite, porphyrite, explosive facies, skarn, metasomatism, Traversella, Italy.

1. Introduction

The Traversella monzodiorite is a small plutonic body whose magmatic activity is associated with the late evolution (Tertiary) of the Alps. Its emplacement (Oligocene) postdates the active subduction event of Cretaceous age which has induced the closure of the Ligure-Piemontese basin (Dal Piaz et al., 1972).

This intrusion, well-known for its association with an important skarn mineralization (magnetite-scheelite), was studied by several authors such as Müller (1912), Colomba (1913) and Kennedy (1931). More recently, van Marcke de Lummen and Vander Auwera (1990), have shown that the geochemical and isotopic evolution of the intrusion can be accounted for by an assimilation fractional crystallisation process (AFC).

In this paper, we will first focus on the occurrence of a peculiar porphyritic and explosive facies of the monzodiorite already mentioned by Kennedy (1931) and on its possible link with the main intrusion. Field data will then be used to suggest the existence of several discrete magmatic events during the emplacement of the Traversella monzodiorite and to discuss the AFC model proposed by van Marcke de Lummen and Vander Auwera (1990). In the last section of the paper, new data on the metasomatic transformations which have affected the diorite itself (endoskarns) will also be presented.

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2. Geological setting

The Traversella monzodiorite emplaced in the southern border of the Sesia-Lanzo zone (Italian Alps) as a tarditectonic intrusion (no evidence of deformation) of Oligocene age (30 ± 5 Ma: KRUMMENACHER and EVERNDEN, 1960; CHESSEX, 1962). It is contemporaneous with the Biella, Bregaglia and Adamello plutons located more eastwards and also with the andesitic volcanism (calc-alkaline, potassic to shoshonitic: VENTURELLI and THORPE, 1984).

All these intrusions (Adamello, Bregaglia, Traversella) display metasomatic rocks in their contact aureole, giving evidence for fluid circulation in their surroundings: metasomatic veins are present in the roof pendants of Bregaglia (BUCHER-NURMINEN, 1981); Ti-rich veins and skarns have been described in the country rocks of the Adamello batholith (GIERE et al., 1988; GIERE, 1990); mineralized skarns are abundant in the contact aureole of the Traversella intrusion (MÜLLER, 1912; KENNEDY, 1931; VANDER AUWERA and ANDRÉ, in press). The Traversella monzodiorite is the only one to be associated with an ore deposit (Fe-W-Cu).

The country rocks of the Traversella monzodiorite belong to the "eclogitic" micaschists formation of the Sesia-Lanzo zone. This formation essentially made up of gneisses and micaschists also comprises dolomitic marbles, calcic hornfelses and lenses of eclogites. The observed parageneses result from a Cretaceous high-pressure metamorphism (60-90 Ma: HUNZIKER, 1974; P = 7 to 15 kb and T = 500 °C to 600 °C: COMPAGNONI et al., 1977; DESMONS and O'NEIL, 1978; LOMBARDO and VENTURELLI, 1980; ROBERT et al., 1985) which is supposed to be linked with the ac-

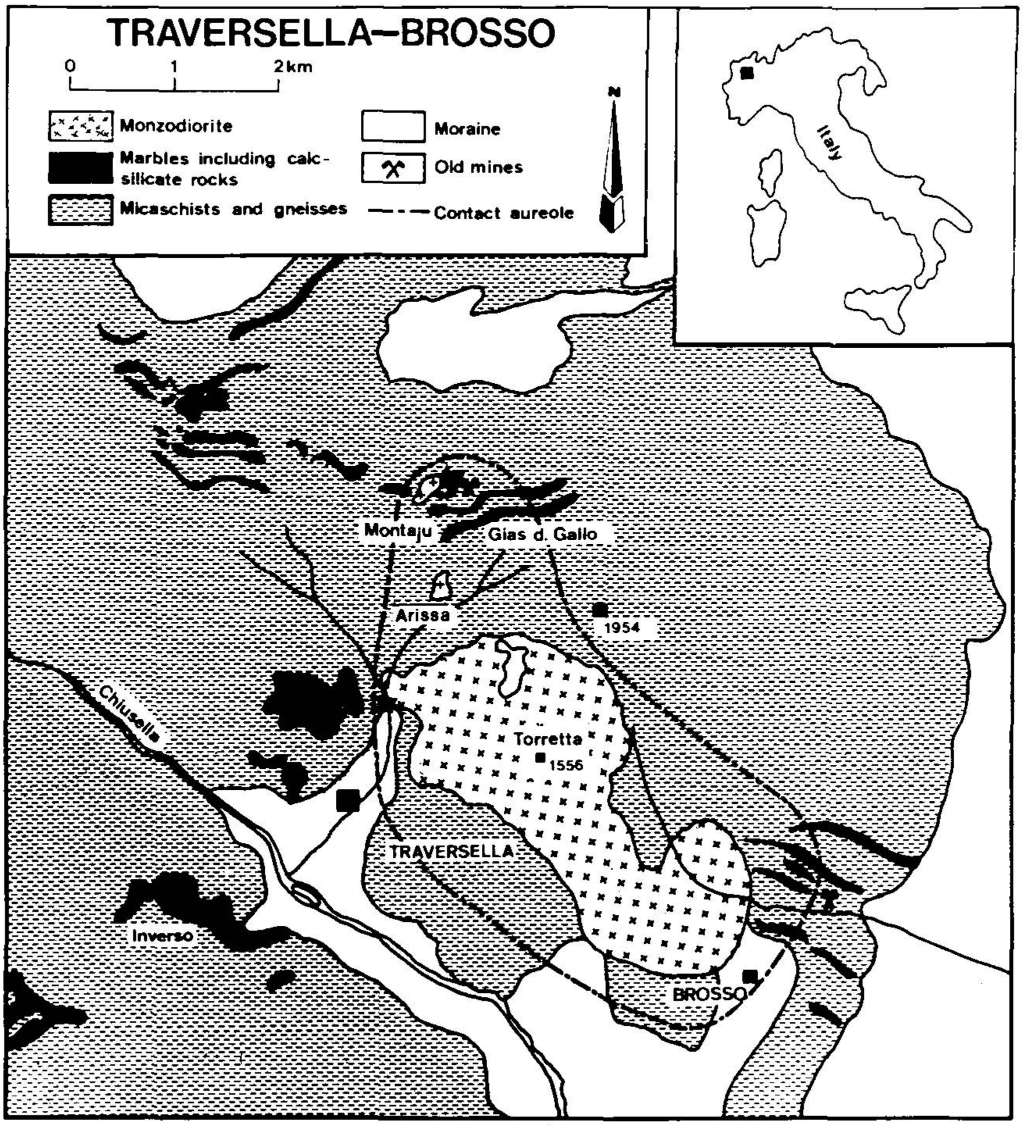

Fig. 1 Schematic geological map of the Traversella-Brosso area (after MÜLLER, 1912). Dashed-dotted line: contact metamorphism limit.

tive subduction of oceanic and continental crust (DAL PIAZ et al., 1972). In the northern part of the Sesia-Lanzo zone, these high pressure parageneses have been overprinted by a greenschist facies metamorphic event of Eocene age (40 Ma: HUNZIKER, 1974).

The pluton (Fig. 1), extensively described by COLOMBA (1913), KENNEDY (1931) and VAN MARCKE de LUMMEN and VANDER AUWERA (1990), is a small stock of 8 km^2 in extension, composed of a medium-grained diorite to quartz diorite and monzonite. The main minerals are amphibole, biotite, plagioclase, augite with variable amounts of quartz and K-feldspar, as well as magnetite, ilmenite, apatite and sphene as accessory phases. The granitic facies are scarce and only one pegmatite has been observed. Abundant aplites crosscut the monzodiorite and seem to have been generated by a back-veining process (VAN MARCKE DE LUMMEN and VANDER AUWERA, 1990). A simple fractional crystallisation process is capable to explain the major element trends as well as the evolution of most trace elements. Nevertheless, the enrichment in U and Th, as well as the increase of $\delta^{18}O$ in the late stages of differentiation and the high I_{Sr} are better explained by a fractional crystallisation process coupled with an assimilation process (AFC), (VAN MARCKE DE LUMMEN and VANDER AUWERA, 1990).

3. Evolution of the Traversella pluton

3.1. THE ARISSA PORPHYRITE

A subvolcanic porphyritic diorite occurs at Arissa, midway between the main monzodiorite body and the small outcrops of similar rocks at Montaju and Gias del Gallo (Fig. 1) (these later ones are supposed to be cupolas of the main mass underlying the country rocks between the northern margin of the main intrusion and Gias del Gallo as evidenced by the larger width of the metamorphic aureole in this area [KENNEDY, 1931]). The most characteristic feature of this porphyritic diorite is that it forms the cement of brecciated blocks of micaschists. These angular blocks, of decimetric to metric size, are tilted relative to each other. The porphyritic diorite is made up of phenocrysts of zoned plagioclase (sometimes with recurrent zoning), biotite, quartz and locally amphibole in a mesostasis of dominant plagioclase with some biotite. In variation diagrams, it plots on the trend defined by the main intrusion and its REE pattern is strictly parallel to that of the common monzodiorite (VAN MARCKE DE LUMMEN and VANDER AUWERA, 1990). These geochemical features point to a comagmatic origin of the monzodiorite and the "porphyrite". As first proposed by KENNEDY (1931), this porphyrite could correspond to a chilled facies of the intrusion. It is probably the case for the porphyritic facies found at the direct contact of the intrusion, for example at Gias del Gallo (VANDER AUWERA, 1988). Nevertheless, the peculiar Arissa porphyrite does not seem to follow this rule as no brecciated facies has been observed in the main intrusion or at its contact. Consequently, the Arissa porphyrite could correspond to a later reintrusion of the same magma.

An estimation of the emplacement pressure of the Arissa porphyrite can be made if it is assumed that the micaschists fracturing has been induced by the separation of a fluid phase. BURNHAM and OHMOTO (1980) have shown that this process releases large amounts of mechanical energy ($P\Delta V_R$) which may produce extensive fracturing. Using the model calculated by these authors for a granodioritic magma with an initial H_2O content of 2.7% (conditions which according to the experimental data of MAALOE and WYLLIE [1975], are in agreement with those of the Traversella pluton), the fracture intensity observed in the micaschist blocks embedded in the Arissa porphyrite points to an emplacement pressure around 1 kb. This corresponds to a lower pressure than that of the main intrusion for which an estimation of 2 kb has been made based on the contact metamorphic parageneses: the occurrence of andalousite in the hornfelses suggests a pressure lower than 3.5 kb (HOLDAWAY, 1971), whereas the appearance of corundum along with andalousite (CHATTERJEE and JOHANNES, 1974) points to a pressure around 2 kb.

In this model, the fluid phase separated from the porphyrite could be responsible for the skarn development. Field evidence however clearly show that the skarn formation is penecontemporaneous with the main monzodiorite and then earlier than the Arissa porphyrite. Garnet-

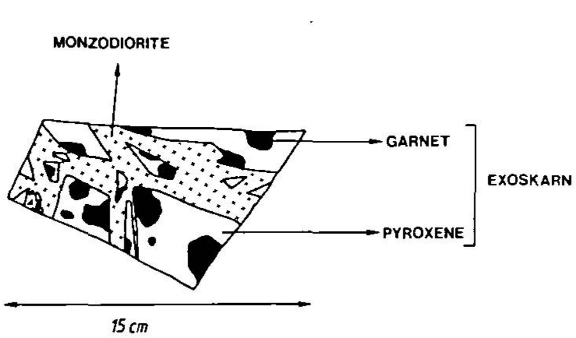

Fig. 2 Garnet-pyroxenite brecciated by monzodioritic veins (sample 86TR300, location: Montaju).

pyroxenites developed during skarn formation at the expense of calcic hornfelses are locally cut or even brecciated by monzodioritic veins (Fig. 2). Moreover, the monzodiorite itself is locally transformed into skarns (see 4.2.). It is likely that the Arissa porphyrite was of a too small size to generate the necessary amount of fluids for skarn formation but it is a good indication that the main monzodioritic intrusion could contain a definite amount of dissolved volatiles to generate a fluid phase responsible for the skarn formation.

3.2. EVOLUTION OF THE MAIN INTRUSION

The late intrusion of the Arissa porphyrite suggests that the Traversella pluton could be formed by several successive intrusions. This hypothesis is also supported by field observations made on the skarns developed on monzodiorite (endoskarns: see 4.2.). Fig. 3 shows a skarn developed at the expense of a monzodioritic vein (Z1, Z1' and Z2 zones of endoskarns: see section 4.2. and Tab. 1) surrounded by an exoskarn (garnet-pyroxenite formed at the expense of calcic hornfels). This sample is likely to correspond to a monzodioritic vein crosscutting a calcic hornfels and both rocks were later transformed into skarn. The late character of the metasomatism relative to the emplacement of the vein is demonstrated by the perpendicular orientation of the metasomatic cpx relative to the contact plane observed between the monzodiorite and the calcic hornfels (Z1' zone on Fig. 3); the parallelism between the metasomatic zoning and the contact plane and finally, by the increasing proportion of metasomatic cpx from the core of the monzodioritic vein to the contact with the exoskarn (skarn developed on calcic hornfels). These observations thus point to a magmatic event of monzodioritic composition earlier than the skarn formation. On the other hand, as already mentioned (Fig. 2), skarns are also crosscutted by monzodioritic veins: garnet-pyroxenites are locally brecciated by magmatic veins or can have their garnet replaced by an assemblage of quartz, feldspar and magnetite at the contact with the monzodioritic vein (Fig. 4). This is clear evidence for an intrusive event later than the skarn formation. These two types of observations on the endoskarns suggest that the skarn formation is penecontemporaneous with the main monzodiorite but also that this intrusion could have been emplaced in successive stages.

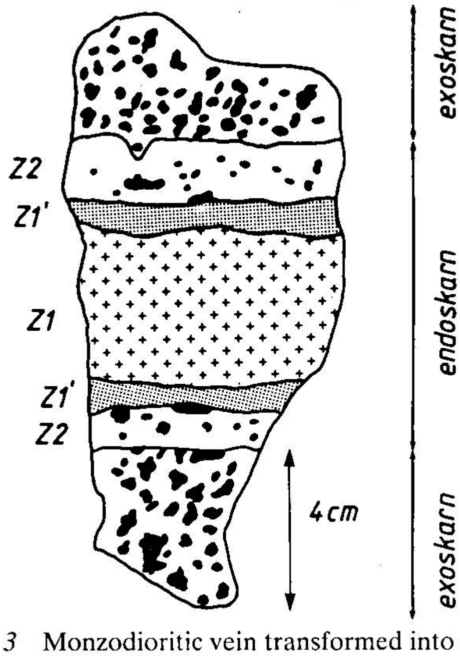

Fig. 3 Monzodioritic vein transformed into endoskarn (the untransformed monzodiorite is no more observable on the sample): Z1 zone is composed of plagioclase, clinopyroxene and relicts of hornblende and biotite; Z1' zone consists of a Ca-richer plagioclase (bytownite) and an increased proportion of cpx relative to Z1 zone, cpx having a perpendicular orientation relative to the metasomatic zoning; Z2 zone is formed of garnet, cpx and some plagioclase. The exoskarn surrounding the endoskarn is a garnet-pyroxenite of skarn on calcic hornfels (see Tab. 1 and text for description of the endoskarns), (sample no 85TR123, location: Montaju).

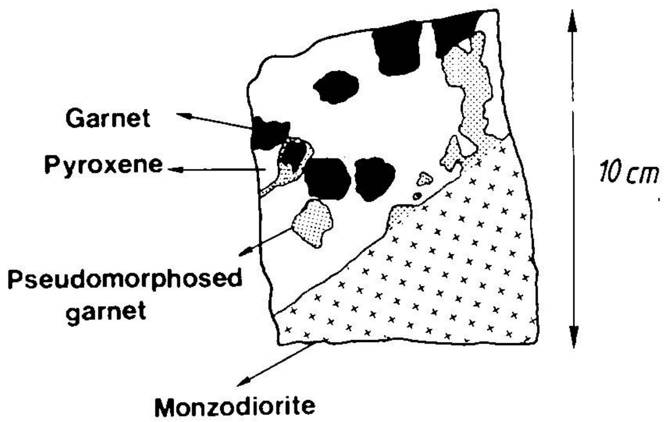

Fig. 4 Contact of a monzodioritic vein with a garnet-pyroxenite (skarn on calcic hornfels); the garnet is partially or completely transformed into an assemblage of quartz, feldspar and magnetite at the contact with the monzodioritic vein (sample no 84TR34, location: Montaju).

The hypothesis of several distinct magma batches to generate the Traversella monzodiorite suggests another possible interpretation for the pluton evolution. The dispersed initial strontium isotope ratios related by VAN MARCKE DE LUMMEN and VANDER AUWERA (1990) to an AFC process during the fractional crystallization of a single liquid, can actually reflect several magma batches with various degrees of crustal contamination. The lack of correlation between I_{Sr} and

K, Rb, SiO_2, MgO (Fig. 5), features which should be observed in an AFC process (TAYLOR and SHEPPARD, 1986), also corroborates the hypothesis of several magma batches. According to VAN MARCKE DE LUMMEN and VANDER AUWERA (1990), the AFC model was supported by the U, Th contents, which in a U vs. Th diagram do not define a linear trend but plot along a curve. Considering that U and Th could behave as incompatible elements during the differentiation of the intrusion, these authors suggested that the stronger enrichment in Th relative to that of U was due to an AFC process. Nevertheless, the non-linear distribution of these elements can also be explained if the elements have lost their incompatible character during differentiation (TREUIL and JORON, 1975). This seems to be the case here because of the liquidus crystallization of zircon in the late stage of evolution (VAN MARCKE DE LUMMEN and VANDER AUWERA, 1990). In a bilog diagram (Fig. 6), the points actually define a linear trend with a slope different from 45° which is representative of a simple fractional crystallization process (TREUIL and JORON, 1975) and precludes an incompatible behaviour of the elements. In the later model the high U and Th contents of the intrusion reflect an intrinsic characteristic of the magma, as also observed in the contemporaneous calc-alkaline volcanic rocks (VENTURELLI and THORPE, 1984). On the other hand, the linear trends observed in major element variation diagrams and bilog trace element diagrams for the representative points of the intrusion suggest that the different magma batches belong to the same series.

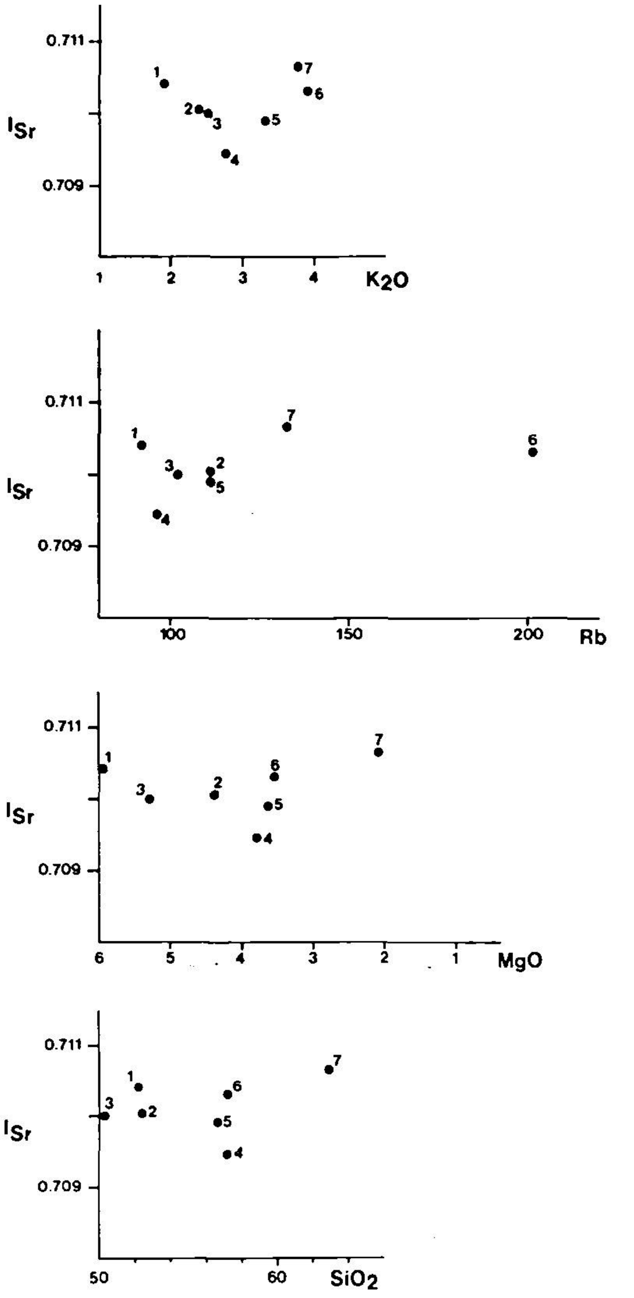

Fig. 5 I_{Sr} versus K_2O(%), Rb (ppm), MgO (%), SiO_2 (%) (data from VAN MARCKE DE LUMMEN and VANDER AUWERA, 1990).

4. Related skarns

4.1. THE INTRUSION AS SOURCE OF METASOMATIC FLUID

Massive skarns (infiltration skarns) developed at the expense of the various lithologies occurring in the contact aureole of the intrusion (micaschists, gneisses, dolomitic marbles, calcic hornfelses) (KENNEDY, 1931; MÜLLER, 1912; VANDER AUWERA, 1988). As observed in many skarn deposits, they occur mainly in the contact aureole thus pointing to a direct control of their formation by the intrusion. Moreover, the similar

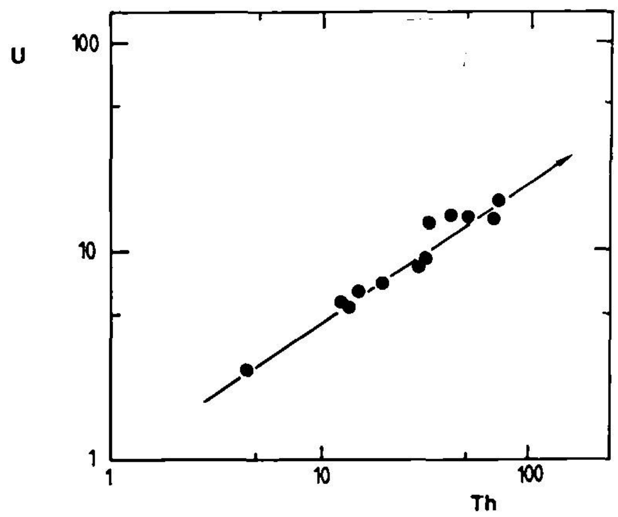

Fig. 6 Bilog diagram U : Th (ppm) (data from VAN MARCKE DE LUMMEN and VANDER AUWERA, 1990);

isotopic composition of the metasomatic fluid ($\delta^{18}O$, I_{Sr}) to that of the pluton suggests that this fluid has been equilibrated with the monzodiorite (VANDER AUWERA and ANDRÉ, in press). It could be either a metamorphic and/or a meteoric fluid driven in convection cells by the heat of the intrusion and finally equilibrated with the monzodiorite, or a magmatic fluid exsolved from the crystallising intrusion, the later hypothesis being the simpler one.

The high salinities (30% to 58% wt% NaCl) of the primary metasomatic fluid deduced from fluid inclusions data and the occurrence of scapolite in skarns on gneisses (VANDER AUWERA, 1988) are in agreement with the salinities observed in other skarn deposits (KWAK, 1986) and with the hypothesis of a metasomatic fluid derived from the intrusion. Direct measurements of salinities of magmatic fluid present in the glassy inclusions of the Mont Cenis granite indeed give 55-77 wt% NaCl for the early fluids (FREZZOTTI, 1989) whereas in the Monte Pulchiana intrusion (FREZZOTTI et al., 1988), the salinities of the primary fluid range from 30 up to 55 wt% NaCl.

4.2. SKARNS FORMED AT THE EXPENSE OF THE MONZODIORITE

The skarns developed on the monzodiorite (endoskarns) occur either as dm-thick veins (Fig. 3) crosscutting the calcic hornfelses or as massive skarns at the contact between the intrusive and the surrounding calcic lithologies. They are considered bimetasomatic skarns as they result from chemical reactions between two rock types of contrasting compositions, initially in chemical disequilibrium. The reaction between the two lithologies is made possible by the fluid circulation at the contact.

The untransformed rock (Z0) which is no more observable on the sample of Fig. 3 is the common monzodiorite made up of plagioclase (andesine), biotite, hornblende, ± K-feldspar ± cpx, and apatite, zircon and sphene as accessory phases. The first transformation (Z1') linked to the metasomatic process is the disappearance of K-feldspar and the reaction of hornblende and biotite to give a metasomatic clinopyroxene (Di_{25}-Hed_{75} to Di_{50}-Hed_{50}) which is richer in Ca and Fe than the cpx of magmatic origin occurring as relicts in the core of hornblende. In Z1 zone, the relicts of hornblende and biotite have completely disappeared and the plagioclase is Ca-richer (bytownite). The last zone of the skarn is defined by the crystallization of a Ti-rich garnet (And_{65}-Gro_{35} to And_{80}-Gro_{20} with 2% to 3.7% of TiO_2) at the expense of plagioclase. These observations are summarized in Tab. 1.

Tab. 1 Mineral association of the metasomatic column developed at the expense of the monzodiorite.

Z0	Z1	Z1'	Z2
Plagioclase (andesine)	Plagioclase (andesine)	Plagioclase (bytownite)	garnet
biotite			
hornblende	cpx	cpx	cpx
± K-feldspar			
± quartz	± quartz		
apatite sphene zircon	apatite sphene zircon	apatite sphene zircon	apatite sphene zircon

A chemical mass balance of the metasomatic transformation can be calculated with the Gresens equation (GRESENS, 1967) which relates the composition and volume variation during metasomatism:

$$100\,(f_v \cdot g_B/g_A \cdot c_nB - c_nA) = x_n$$

where f_v is the volume factor ($f_v \cdot V_A = V_B$ with V_A and V_B for the volume of rocks A and B); g_A and g_B, the specific gravities of A and B; c_nA and c_nB, the weight fraction of component n in A and B; x_n, the variation of component n during transformation of A into B. According to the strong composition variability of the monzodiorite (see Tab. 2), the chemical mass balance has been estimated on samples collected on the same outcrop. During the transformation of the monzodiorite (Z0) into the pyroxene zone (Z1), the TiO_2 : Al_2O_3 ratio remains constant (see Tab. 2). This implies that these elements were either mobilized in the same way or perfectly inert. As they occur in different minerals (Al: plagioclase; Ti: sphene), it is more likely that these elements were not affected by the skarn formation, i.e. $x_{TiO_2} = x_{Al_2O_3} = O$ in the above equation. With these constraints, two independant estimations of f_v can be made: at constant TiO_2, f_v equals 1.09 whereas at constant Al_2O_3, f_v equals 1.08. These concordant values suggest that the development of the first zone was made at relatively constant volume and permit to calculate the gain or loss of the other elements.

In the second zone of the skarn, there is a slight decrease of the TiO_2/Al_2O_3 ratio (see Tab. 2) suggesting that one or both of these elements were mobilized. As among the available data (i.e. major elements), no other element ratio remains constant from the protolith through this last zone

Tab. 2 Chemical mass balance of the metasomatic transformation of the monzodiorite calculated with the Gresens equation (GRESENS, 1967) (g = specific gravity of the different zones).

	DIORITE Z0	VARIATION RANGE OF THE INTRUSION		PYROXENE ZONE (Z1)	GARNET ZONE(Z2)
		Min	Max		
SiO2	57.92	52.22	66.54	51.18	41.24
TiO2	0.83	0.57	1.13	0.82	0.70
Al2O3	17.97	15.50	18.45	17.74	19.66
Fe2O3	6.47	4.13	10.46	8.21	7.91
MgO	3.67	2.05	4.39	4.76	3.62
CaO	5.73	3.79	9.47	12.88	22.23
Na2O	1.54	0.46	3.59	1.65	0.00
K2O	3.96	1.62	4.27	0.89	0.00
g	3.20			2.97	2.94
Ti/Al	0.0462			0.0462	0.0356
Ti/Fe	0.1283			0.0999	0.0885
Ti/Mg	0.2262			0.1723	0.1934
Al/Fe	2.7774			2.1608	2.4855
Al/Mg	4.8965			3.7269	5.4309
Fe/Mg	1.7629			1.7248	2.1851
Percentages of gain or loss relative to the monzodiorite					
SiO2		-1	+33	-12	-35
TiO2		-21	+33	0	-23
Al2O3		-	-	0	-10
Fe2O3		-31	+78	+27	+12
MgO		-43	+17	+30	-9
CaO		-24	+82	+125	+257
Na2O		-68	+152	+7	-100
K2O		-60	+25	-77	-100

(see Tab. 2), the inert behaviour of one element cannot be proved. The evaluation of the chemical mass balance of the last zone has then been based on the assumption that its formation occurs at constant volume (LINDGREN, 1912). Results are presented in Fig. 7 and Tab. 2. The most affected elements are CaO and alkalies: K and Na are completely leached out in Z2 zone, whereas CaO is strongly increased.

As temperature and pressure can generally be considered as constant during the same metasomatic process, the gradients in chemical potentials of perfectly mobile components appear to be the controlling parameters of the observed transformations. Consequently, they are used as axis of phase diagrams (KORZHINSKII, 1959; BURT, 1972), drawn using Schreinemaker's geometric rules (ZEN, 1966) and quantified on the basis of thermodynamic calculations (HELGESON et al., 1978). Fig. 8 shows that the successive zones (Z0-Z1-Z2) observed in the skarns on monzodiorites can be obtained by an increase of μ_{CaO}. In this diagram, the normal monzodiorite is on the univariant curve: K-feldspar = an + qtz where plagioclase, K-feldspar, biotite and quartz are stable simultaneously. The transformation of biotite into clinopyroxene implies an increase of μ_{CaO} with μ_{K2O} constant or increasing. The crystallization of garnet is also due to an increase in μ_{CaO} with constant or decreasing μ_{K_2O}.

5. Conclusions

The Arissa porphyrite has similar geochemical features than the main intrusion and could correspond to a reintrusion of the same magma at lower pressure ($\approx$ 1 kb) than that of the main monzodiorite body ($\approx$ 2 kb). The separation of a fluid phase is assumed to be responsible for its explosive character. Nevertheless, this fluid phase is not the source of the metasomatic fluid

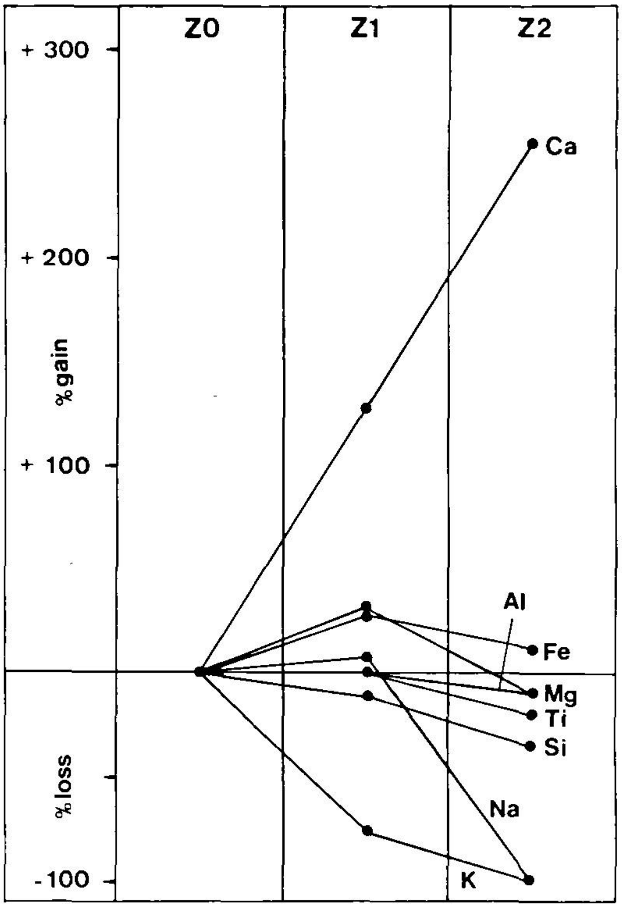

Fig. 7 Evaluation of mass transfer during the metasomatic transformation of the monzodiorite and calculated with the Gresens equation (GRESENS, 1967). Variations of the oxides are expressed as percentages of gain or loss relative to the untransformed monzodiorite (see Tab. 2 and text for detail of calculations).

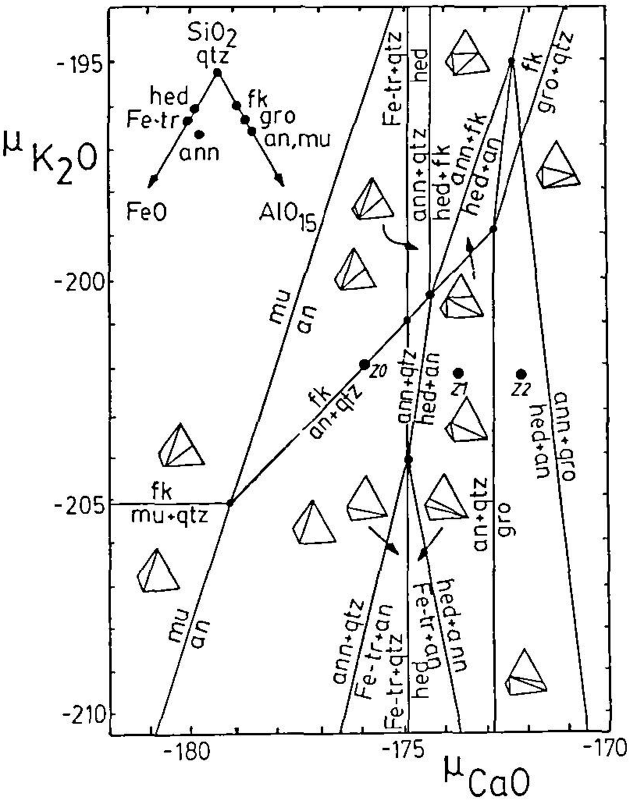

Fig. 8 (after VAN MARCKE DE LUMMEN and VERKAEREN, 1986). $\mu_{CaO}-\mu_{K2O}$ (kcal/mole) diagram in the system K_2O-CaO-FeO-Al_2O_3-SiO_2-H_2O (Na_2O is considered as an accessory component) with the minerals: quartz (qtz), anorthite (an), K-feldspar (Ksp), muscovite (mu), annite (ann), Fe-tremolite (Fe-Tr), hedenbergite (hed) and grossular (gro). $P_S = P_F = 2$ kb, T = 600 °C, $X_{H2O} = 1.0$. ZO, Z1, Z2 refer to the different zones observed in endoskarns (see Tab. 1).

as field evidence strongly suggest that the skarn formation is penecontemporaneous with the main monzodiorite. This one thus appears a better candidate for the fluid source.

The occurrence of the Arissa porphyrite as well as field observations on the endoskarns suggest that the Traversella pluton was generated by several magma batches. This mechanism can take into account the dispersed I_{Sr} values obtained in the intrusion, in a better way than the AFC process formely proposed by VAN MARCKE DE LUMMEN and VANDER AUWERA (1990). The high I_{Sr} values (0.70947 to 0.71064) however point to variable amounts of a crustal component in the distinct magma batches, whereas the linear trends obtained for major and trace elements suggest that the various magmas belong to the same series.

The monzodiorite itself is locally affected by bimetasomatic transformations. Mass transfer evaluation show that during these transformations Ca was strongly increased whereas the alkalies (Na, K) were completely leached out. μ_{CaO} and μ_{K2O} appear to be the controlling factors of the observed reactions.

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