Per. Mineral. (2007), 76, 2-3, 223-240
SPECIAL ISSUE: In honour of Ezio Callegari on his retirement

doi:10.2451/2007PM0026
http://go.to/permin

PERIODICO di MINERALOGIA
established in 1930

An International Journal of
MINERALOGY, CRYSTALLOGRAPHY, GEOCHEMISTRY, ORE DEPOSITS, PETROLOGY, VOLCANOLOGY
and applied topics on *Environment*, *Archaeometry* and *Cultural Heritage*

The Oligocene Biella pluton (western Alps, Italy): new insights on the magmatic vs. hydrothermal activity in the Valsessera roof zone

Piergiorgio Rossetti [*], Andrea Agangi, Daniele Castelli, Marta Padoan and Raffaella Ruffini [†]

Dipartimento di Scienze Mineralogiche e Petrologiche, Università degli Studi di Torino, Via Valperga Caluso, 35, 10125 Torino, Italy

Abstract. — The composite Biella pluton is part of an Oligocene volcano-plutonic complex whose origin is connected to the Alpine subduction-collision processes and that emplaced at shallow crustal levels within the eclogite-facies rocks of the Austroalpine Sesia-Lanzo Zone. In the roof zone of the pluton, small satellite igneous bodies are set within the Sesia-Lanzo country rocks, close to the main Biella pluton, and range in composition from quartz alkali feldspar syenite, quartz monzodiorite and monzogabbro, to quartz diorite and gabbronorite. Their geochemical features, including the REE patterns, are coherent with the calc-alkaline to shoshonitic affinity recognized in the whole volcano-plutonic complex. Field and petrographic data suggest that these bodies represent earlier crystallization/differentiation products of the Biella primary magma(s), which underwent contact metamorphic recrystallization during the multistage emplacement of the main pluton. Tourmaline-bearing hydrothermal breccias and different types of hydrothermal veins (including quartz-plagioclase-, quartz-tourmaline- and ankerite-quartz-sulphides-bearing veins) occur within both the intrusive rocks (satellite bodies + the main pluton) and their Sesia-Lanzo Zone country rocks. Both field relationships and vein assemblages suggest a close connection between the late-magmatic evolution of the Biella pluton and the multistage, boron-rich hydrothermal activity.

Riassunto. — Il plutone di Biella fa parte di un complesso vulcano-plutonico, legato all'evoluzione tardo-collisionale delle Alpi Occidentali, che si è messo in posto a livelli crostali relativamente superficiali all'interno delle rocce in facies eclogitica della Zona Sesia-Lanzo, appartenente al Dominio Austroalpino. Nelle rocce originariamente a tetto del plutone, sono presenti piccole intrusioni satelliti che presentano un ampio spettro composizionale, variabile da quarzo sieniti alcalifeldspatiche, quarzo monzodioriti e monzogabbri a quarzo dioriti e gabbronoriti. I loro caratteri chimici, inclusi i *pattern* delle Terre Rare, sono consistenti con l'affinità da calcalcalina a shoshonitica del complesso vulcano-plutonico. Le osservazioni di terreno e petrografiche suggeriscono che tali corpi rappresentano dei prodotti di cristallizzazione/differenziazione precoci a partire dai magmi primari del corpo intrusivo principale e che hanno subito una ricristallizzazione metamorfica di contatto connessa con la messa in posto dell'intrusione di Biella. All'interno delle rocce intrusive (sia dei corpi satelliti sia del plutone principale) e della Zona Sesia-Lanzo incassante sono presenti brecce idrotermali ricche di tormalina e diversi tipi di sistemi di vene idrotermali (tra cui

---

[*] Corresponding author, E-mail: piergiorgio.rossetti@unito.it

vene a quarzo e plagioclasio, a quarzo e tormalina, ad ankerite, quarzo e solfuri). Le relazioni di terreno e le paragenesi di vena e di alterazione suggeriscono uno stretto legame tra l'evoluzione tardo-magmatica del plutone di Biella e almeno gli stadi precoci dell'attività idrotermale multifasica, caratterizzati dalla circolazione di fluidi con elevato contenuto di boro.

KEY WORDS: *Calc-alkaline vs. shoshonite magmatism, hydrothermal activity, Sesia-Lanzo Zone, Periadriatic Igneous Province, western Alps*

INTRODUCTION

The igneous activity in the internal western Alps is part of the "Periadriatic Igneous Province", related to subduction-collision processes at convergent plate boundaries (e.g. Von Blanckenburg and Davies, 1995; Von Blanckenburg *et al.*, 1998; Rosenberg, 2004), which emplaced into the Austroalpine, Penninic and Southalpine domains, along the Periadriatic (Insubric) Lineament (e.g. Callegari *et al.*, 2004, with refs; see also the inset in Fig. 1). In the western Alps, this igneous province consists of Oligocene plutons (i.e. the so-called Biella or Cervo valley stock, the Traversella stock and the Miagliano stock) and coeval volcanic to volcaniclastic rocks and dykes of high-K calc-alkaline to shoshonitic affinity (e.g. Fiorentini Potenza, 1959; Carraro and Ferrara, 1968; Dal Piaz *et al.*, 1979; Venturelli *et al.*, 1984; Bigioggero *et al.*, 1994, Callegari *et al.*, 2004). Previous studies on the Biella and Traversella stocks have shown that their emplacement at relatively shallow depth was accompanied and followed by an intense circulation of fluid(s), testified by the occurrence of skarns (Traversella: e.g. Vander Auwera, 1990; Vander Auwera and Andre, 1991) and of different types of hydrothermal veins and breccia pipes (Biella: Senesi, 1999; Bernardelli *et al.*, 2000; Zanoni *et al.*, in press). A multistage hydrothermal evolution has been documented along the Cervo valley at the south-eastern margin of the Biella stock (Bernardelli *et al.*, 2000), where a tourmaline-rich hydrothermal system closely associated with the intrusive body developed within both the rocks of the Austroalpine Sesia-Lanzo Zone and its volcanic Tertiary covers.

In this paper, we give a first account of: i) the small satellite intrusive stocks recognized by Rossetti *et al.* (2002) within the Sesia-Lanzo metamorphics of Valsessera, at the eastern border of the Biella pluton, and ii) the hydrothermal activity affecting both the intrusives and the Sesia-Lanzo country rocks. These geological, petrographical and geochemical data give new insights on the earlier history of the Biella pluton and on the late-magmatic *vs.* hydrothermal evolution occurring within its roof zone.

GEOLOGICAL SETTING

The Oligocene late-orogenic magmatism in the Biella area includes plutons, volcanic to volcaniclastic sequences and minor dykes. The Biella pluton, located about 10 km NNW of Biella and deeply eroded by the Cervo and Sessera rivers, is a composite stock of shoshonitic affinity that emplaced at 30-31 Ma (Rb/Sr biotite age: Bigioggero *et al.*, 1994; U/Pb zircon age: Romer *et al.*, 1996) into the eclogite-facies rocks of the Austroalpine Sesia-Lanzo Zone, exposed to the north-west of the Insubric Lineament (Fig. 1). The Biella stock shows a broadly concentric structure, with a Granitoid (granitic to granodioritic) Complex at core, surrounded by inner and outer shell complexes of syenitic (the Syenite Complex) and monzonitic (the Monzonite Complex) compositions, respectively (Fiorentini Potenza, 1959; Bigioggero *et al.*, 1994). The Granitoid Complex consists of medium- to coarse-grained, porphyritic monzogranite to quartz-poor granodiorite, showing a decrease in the quartz content and finer-grained K-feldspar phenocrysts as the contact to the Syenite Complex is approached. The Syenite Complex consists of a medium-grained hypidiomorphic Cpx-bearing, biotite-hornblende syenite, locally including rounded enclaves of quartz monzonite rocks. The Monzonite Complex, which is the widest part of the exposed igneous stock, mainly consists of medium-grained, inequigranular two-pyroxene-biotite-hornblende quartz monzonite to melasyenite, with porphyritic monzodiorite varieties near the country rocks. Both the Monzonite and Syenite Complexes show a well-developed magmatic foliation marked by the preferred

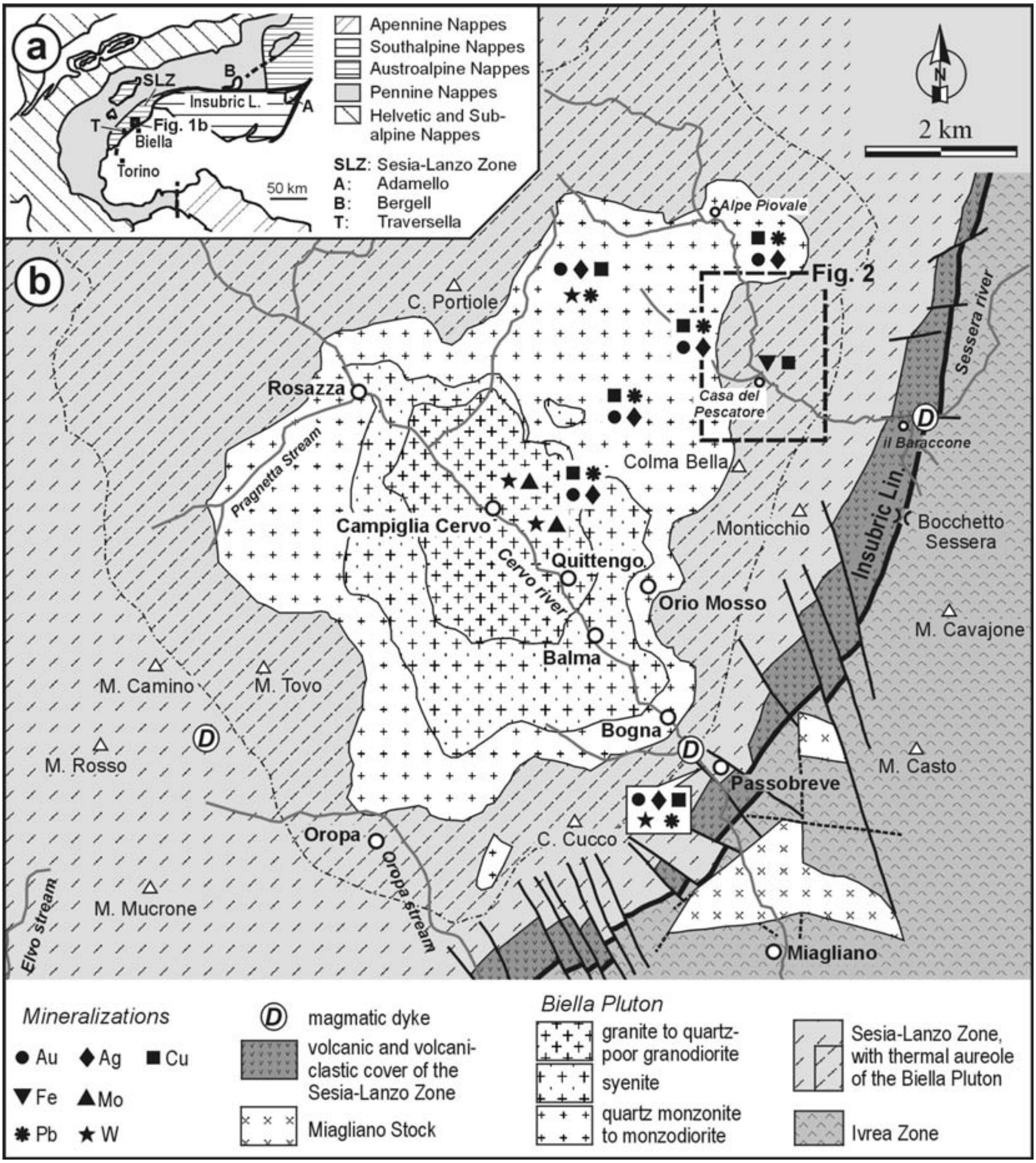


Fig. 1 - Geological sketch map of the Cervo and Sessera valleys (modified from Rossetti *et al.*, 2000 and Callegari *et al.*, 2004). Lithological subdivisions of the Biella pluton (based on Fiorentini Potenza, 1959) broadly correspond to the Granitoid, Syenite and Monzonite Complexes discussed in the text, respectively. The square locates the area of Fig. 2.

orientation of tabular K-feldspar. Intrusive relationships suggest that the Monzonite Complex crystallized first, followed by the emplacement of the syenitic and finally the granitic-granodioritic rocks (Fiorentini Potenza, 1959, Bigioggero *et al.*, 1994; Rossetti *et al.*, 2000; with refs.). According to Bigioggero *et al.* (1994), geochemical data and $^{87}Sr/^{86}Sr$ isotope ratios point to two distinct magma sources, one for the Monzonite Complex, and the other for the Syenite and Granitoid Complexes, which evolved by differentiation process. Petrologic and structural studies performed on the Biella igneous stock (Bigioggero *et al.*, 1994), the country rocks (Zanoni, 2007; Zanoni *et al.*, in press), and the hydrothermal vein system of the Cervo valley (Bernardelli *et al.*, 2000) suggest an intrusion at shallow crust levels.

The volcanic to volcaniclastic sequences occur as a narrow, steeply dipping belt, representing part of the non-metamorphic Tertiary cover of the Sesia-Lanzo Zone. To the southeast, the volcanic belt is truncated by the Insubric Lineament (Fig. 1). They consist of lava flows, pyroclastic and epiclastic deposits ranging in composition from basaltic andesite and andesite of high-K calc-alkaline affinity to trachyandesite and trachydacite of shoshonitic affinity (Medeot *et al.*, 1997; Medeot, 1998; Callegari *et al.*, 2004). The ages of the volcano-sedimentary sequences (29-33 Ma: Scheuring *et al.*, 1974; 31.5 Ma: Zingg *et al.*, 1976) are coeval to the Biella stock. Similar geochemical features between lavas and intrusive rocks and the same emplacement ages suggest that all these igneous rocks are comagmatic and belong to a single volcano-plutonic complex (Callegari *et al.*, 2004). This latter interpretation fits previous palaeomagnetic, geological and petrological data showing that the Oligocene igneous rocks and the Sesia-Lanzo country-rocks were submitted to a clockwise (towards southeast) tilting, along a NE-SW trending subhorizontal axis, during late Tertiary (Lanza, 1977, 1979). As a consequence, along both the Cervo and Sessera valleys shallow crustal sections, from deeper (to the NW) to shallower (to the SE) levels are exposed. Further evidence of the tilting are: the asymmetric distribution (in both size and contact-metamorphic mineral assemblages) of the aureole of the Biella stock (Fornasero, 1978; Zanoni, 2007; Zanoni *et al.*, in press), and the widespread occurrence of hydrothermal activity southeast of the same Biella stock, i.e. in portions of the Sesia-Lanzo rocks originally at roof of the intrusion (depth ≤ 2 km: Bernardelli *et al.*, 2000, with refs.).

Different types of hydrothermal mineralizations occur both within the Biella stock and at its roof (Fig. 1). Within the pluton they mainly consist of Mo-W ores as, for instance, the quartz + molybdenite ± scheelite stockworks and veinlets within the core Granitoid Complex, or the polymetallic Cu-Pb-Ag±Au±W±Mo mineralizations, which occur in different types of sulphide-bearing, quartz-rich veins along a broadly SW-NE trending belt that extends from the Granitoid Complex in the Cervo valley to the Monzonite Complex in Valsessera. In the country Sesia-Lanzo rocks at the original roof of the intrusion, Fe or Cu enrichments are found in Valsessera, within tourmaline- and ankerite-quartz-sulphides-bearing veins, respectively (Senesi, 1999; Rossetti *et al.*, 2002), while in the Cervo valley Cu-Pb±Ag±W±Au mineralizations occur, mostly associated with multistage tourmaline-bearing veins and breccia pipes, which affected the whole rock pile up to the volcanic cover. In the Cervo area, the most abundant ore minerals are sulphides (pyrite, chalcopyrite, arsenopyrite, tetrahedrite, galena, hessyte, tetradymite and Bi-sulphosalts) with minor scheelite and magnetite. Wallrock alteration differs in both intensity and mineral assemblages according to the vein type and the country lithology (Bernardelli *et al.*, 2000).

Finally, we remark that the Oligocene igneous activity in this area also includes: a variety of dykes of high-K calc-alkaline to shoshonitic affinity (Beccaluva *et al.*, 1983; Venturelli *et al.*, 1984) emplaced at about 32 Ma (Bigioggero *et al.*, 1983) into both the Sesia-Lanzo and the Ivrea Zones, and the smaller Miagliano stock (mainly quartz monzodioritic of calc-alkaline to high-K calc-alkaline composition) emplaced at 31-34 Ma (Carraro and Ferrara, 1968; Bigioggero *et al.*, 1994) into the Ivrea Zone, just to the southeast of the Insubric Lineament (Fig. 1).

The Valsessera roof zone

In the roof zone of Valsessera, the marginal facies of the Biella pluton intruded the eclogite-facies metapelite, orthogneiss, and minor metabasite of the Sesia-Lanzo Zone. The roof rocks record a polyphase Alpine ductile deformation pre-dating the intrusion (Zanoni *et al.*, in press, and refs. therein). A well-developed contact-metamorphic recrystallization is evident within the country Sesia-Lanzo rocks (Fornasero, 1978; Zanoni *et al.*, 2007) showing a thermal aureole much thicker than that observed in the Cervo valley. A complex history of brittle deformation and fluid circulation is further recorded, which - based on the analysis of veins/wallrock alteration assemblages and structural data- ranges from syn- to post-pluton emplacement (Rossetti *et al.*, 2002; Zanoni *et al.*, in press). Several stages of brittle deformation are in fact documented including sets of fractures, faults and brittle shear zones with different orientation and mineral filling assemblages, which affected both the Biella pluton and the country rocks (Zanoni *et al.*, in press).

A new geological map of the contact zone in Valsessera, based on 1:5.000 and 1:10.000 surveys, is shown in Fig. 2. In this area, the quartz monzonite of the outer shell often displays a well-developed magmatic foliation (Zanoni, 2007; Zanoni *et al.*, in press), and consists of K-feldspar phenocrysts + zoned plagioclase (from $An_{44}Ab_{52}Or_4$ in the core to $An_{11}Ab_{88}Or_1$ in the rim) + biotite ± clinopyroxene ± orthopyroxene + minor amounts of quartz, titanite and magnetite. Towards the contacts with the country rocks, the quartz monzonite becomes progressively finer-grained. The contact with the Sesia-Lanzo rocks is marked by a 10 m-wide igneous intrusive breccia composed of cm- to m-sized fragments of the country micaschist and gneiss, with a contact-metamorphic recrystallization, embedded in a fine-grained quartz monzonite matrix. Within the contact-metamorphosed Sesia-Lanzo country rocks, Rossetti *et al.* (2002) recognized several small satellite igneous bodies whose petrographic, geochemical and mineral chemical data will be discussed below. These bodies include: Hbl-Bt monzogabbro; gabbronorite to quartz diorite; Crd-bearing quartz monzodiorite; quartz alkali feldspar syenite, Pl-Qtz-Tr-Tur orbicular rocks (abbreviations after Bucher and Frey, 2002). To them, we should add a spessartite dyke cropping out a few hundred metres east of the mapped area shown in Fig. 2, close to the Insubric Lineament (Fig. 1).

A relatively large hydrothermal breccia crops out in the same area where the satellite bodies occur (Fig. 2); different types of hydrothermal veins crosscut both the intrusive rocks and the Sesia-Lanzo country rocks. Their field relationships and petrographic features will be also discussed.

PETROGRAPHY OF THE SATELLITE IGNEOUS BODIES

Hornblende-biotite monzogabbro

These rocks crop out on both sides of the Sessera river close to Casa del Pescatore and south of Poggio Pietra Bianca (Fig. 2), as small bodies intruded into the Sesia-Lanzo rocks, their outer contacts always being hidden below the Quaternary cover.

The monzogabbro shows a seriate porphyritic texture, with phenocrysts of plagioclase, clinopyroxene (usually replaced by Mg-hornblende) and biotite embedded in a granular groundmass composed of plagioclase, poikilitic K-feldspar, interstitial quartz, and accessory zircon, apatite and magnetite (included in Mg-hornblende). The plagioclase phenocrysts are labradorites with normal zoning, from An_{57} in the core to An_{48} in the rim.

Monzogabbro is affected by a pervasive alteration growth of fine-grained brown biotite overgrowing Mg-hornblende and replacing (together with ilmenite) the primary igneous biotite. This neoblastic biotite also pseudomorphically replaces, together with sericite and fine-grained epidote, the plagioclase phenocrysts, and locally forms small radial aggregates typically associated with quartz. Irregularly-shaped, mm-sized cordierite clots, partially transformed to fine-grained white mica and pinite, are often associated with tourmaline; they are likely to derive from contact-metamorphosed xenoliths. Late chlorite partially overgrows both primary and secondary biotite.

Gabbronorite to quartz diorite

These rocks crops out along the Sessera river close to Casa del Pescatore (Fig. 2) as a broadly tabular body, at least 50-60 m thick, dipping 45° to WNW. The body consists of darker to lighter irregular portions, ranging in composition from gabbronorite to Cpx-bearing biotite quartz diorite, respectively, with transitions from each other.

Gabbronorite shows a fine-grained porphyritic texture, with a magmatic assemblage composed of phenocrysts of plagioclase, orthopyroxene

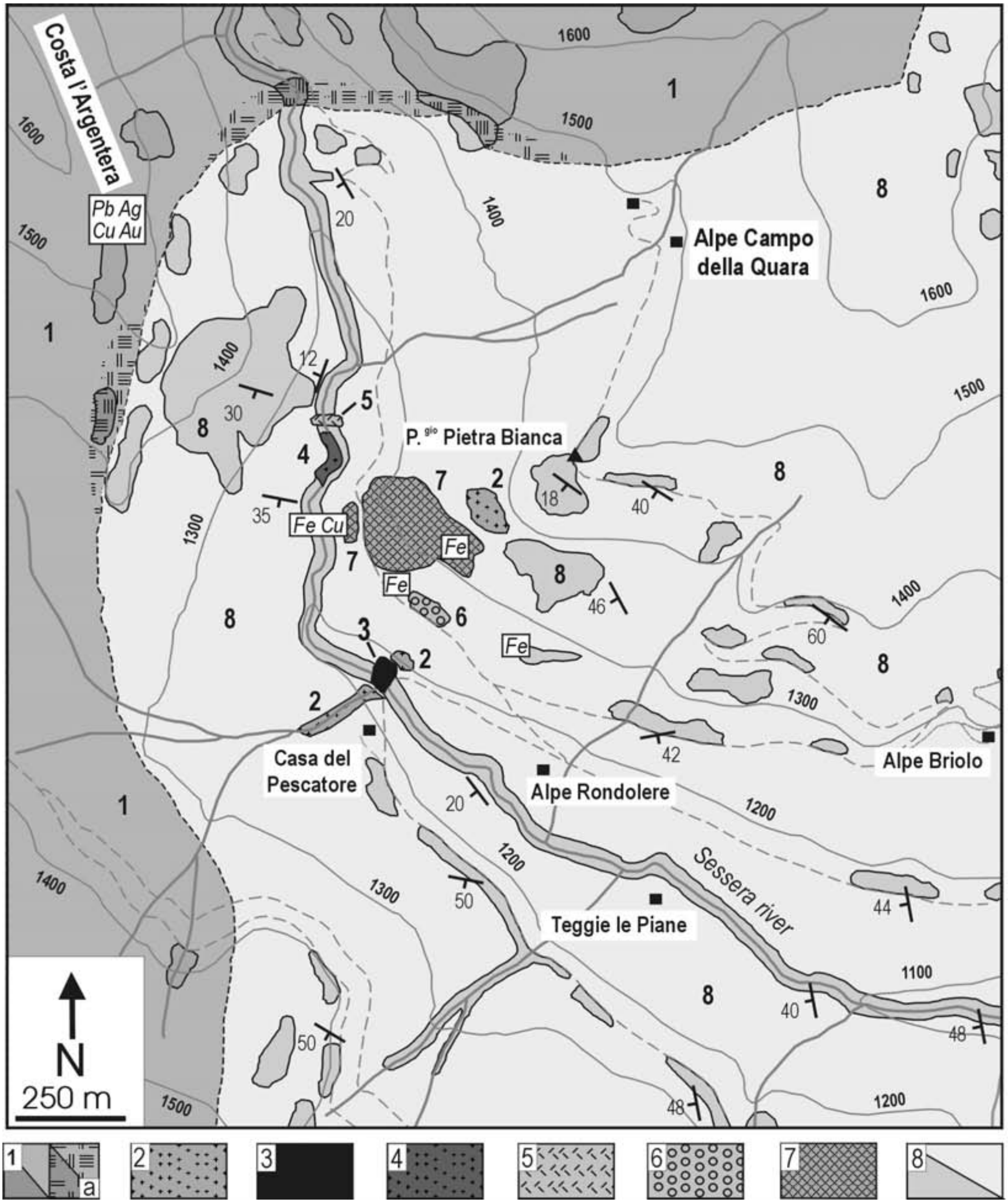


Fig. 2 – Geological map of the investigated Valsessera area, at roof of the Biella pluton (based on field works of Bassi, 1999; Senesi, 1999; Selvaggio, 2006). 1) quartz monzonite to monzonite of the Biella stock, with magmatic breccia (a) at the contact with the Sesia-Lanzo country rocks; 2) Hbl-Bt monzogabbro; 3) gabbronorite to quartz diorite; 4) Crd-bearing quartz monzodiorite; 5) quartz alkali feldspar syenite; 6) Pl-Qtz-Tr-Tur orbicular rocks; 7) hydrothermal breccia; 8) undifferentiated country rocks of the Sesia-Lanzo Zone. Attitude of regional S_2 foliation and occurrence of hydrothermal (*Fe*, *Fe-Cu*, *Pb-Ag-Cu-Au*) mineralizations are also shown. Note that both size and shape of the satellite igneous bodies merely correspond to the outcrops as their actual extension is unknown.

($En_{65}Fs_{35}$), augite (locally mantled by Mg-hornblende) and high-Ti biotite (TiO_2 avg. 6.0 wt%), embedded in a microgranular groundmass of plagioclase, biotite, ilmenite ± quartz, and accessory apatite and zircon. The plagioclase phenocrysts show a strong normal oscillatory zoning from An_{72} in the core to An_{26} in the outer rim. Plagioclase within the groundmass displays nearly the same range of compositions.

The transition from the gabbronorite to the quartz diorite portions is typically marked by the absence of orthopyroxene and a strong reduction in the amount of clinopyroxene. The quartz diorite consists of phenocrysts of plagioclase, biotite and minor clinopyroxene (mostly replaced by a late Ca-rich amphibole) in a groundmass of plagioclase, biotite, interstitial quartz, and accessory magnetite, titanite, apatite and zircon.

The magmatic assemblages of both gabbronorite and quartz diorite are affected by a pervasive alteration, characterized by the widespread growth of fine-grained brownish biotite after almost all the igneous minerals. This low-Ti biotite (TiO_2 avg. 3.5 wt%) overgrows the primary biotite (associated with ilmenite, Fig. 3a), Mg-hornblende and locally also plagioclase. Fine-grained sericite + epidote aggregates mainly replace plagioclase, cummingtonite and an actinolitic amphibole occur after orthopyroxene and clinopyroxene, respectively. A late alteration stage includes chlorite + granular titanite ± epidote overgrowing the biotite.

Cordierite-bearing quartz monzodiorite

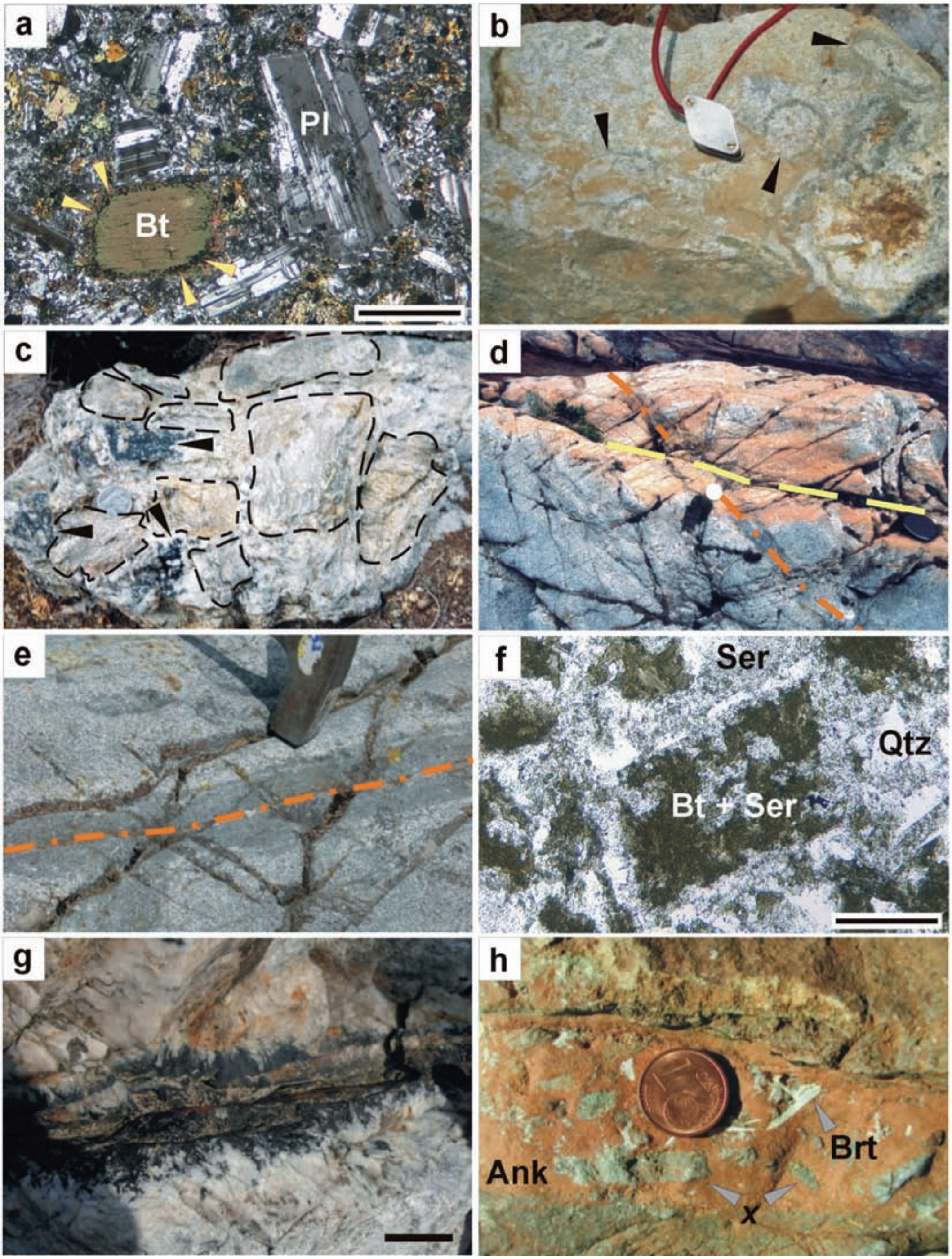
This rock-type crops out along the Sessera river, west of Poggio Pietra Bianca, as a decameter-sized body whose contacts against the country rocks are mostly covered by Quaternary deposits (Fig. 2). Only locally a clear intrusive contact with the host Sesia-Lanzo rocks is evident: monzodiorite dykelets from the main body are injected in the surrounding micaschists; and angular fragments of hornfelsed micaschist are spread in the outer margin of the quartz monzodiorite. The rock shows a microporphyritic texture, with phenocrysts of plagioclase, K-feldspar, minor biotite within a groundmass of plagioclase, K-feldspar, quartz and accessory apatite, zircon, titanite and magnetite. Plagioclase phenocrysts display a normal zoning, from An_{60-47} in the core to An_{46-29} in the rim. An additional ubiquitous phase is Fe-cordierite: its microstructural relationships with the other igneous minerals suggest it is part of the magmatic assemblage.

The magmatic assemblage is affected by strong pervasive alteration: K-feldspar is almost completely replaced by a very fine-grained aggregate of sericite ± brown biotite; the new, secondary biotite also replaces the primary plagioclase and, together with ilmenite, overgrows the igneous biotite. Cordierite is partially altered to sericite, often associated with tourmaline. Coarse-grained pyrite (with pyrrhotite inclusions) + quartz ± biotite ± tourmaline patches are likely an alteration product. Pyrite often overgrows igneous magnetite, though they locally show equilibrium relationships. Late quartz + prismatic epidote patches and variable amounts of chlorite (mostly overgrowing biotite) also occur.

Quartz alkali feldspar syenite

This rock-type crops out along the Sessera river within the Sesia-Lanzo rocks, as a planar, up to 10 metres thick body (most likely a dyke), steeply dipping north, some tens of metres to the north of the quartz monzodiorite (Fig. 2). It is a biotite quartz alkali feldspar syenite showing a fine-grained oligoporphyritic texture with microphenocrysts of K-feldspar and biotite dispersed into a microgranular groundmass of K-feldspar, quartz, magnetite ± albitic plagioclase with rare oligoclase cores, and accessory apatite, monazite and zircon. A slight igneous foliation is defined by the preferred orientation of the K-feldspar and biotite microphenocrysts. Some euhedral pseudomorphs consisting of fine-grained biotite + quartz + magnetite ± tourmaline suggest the additional occurrence of former igneous mafic (amphibole?) phenocrysts. Small granular aggregates of partly altered, coarse-grained cordierite have been interpreted as microxenoliths of hornfelsed micaschist.

The alkali feldspar syenite is affected by a strong pervasive alteration, which mainly consists of fine-grained aggregates of reddish biotite replacing the primary biotite and partly overgrowing (together with sericite + quartz ± tourmaline) the feldspar grains.


a
Pl
Bt
b
c
d
e
f
Ser
Qtz
Bt + Ser
g
h
Ank
Brt
x

Plagioclase–quartz–tremolite–tourmaline orbicular rocks

This rock-type crops out (south of Poggio Pietra Bianca: Fig. 2) only for some tens of metres along a road cut, its contacts with the country rocks being covered by Quaternary deposits. The orbicular rocks are characterized by the occurrence of abundant, whitish to light-green, sub-spherical orbicules (up to ~15 cm-in size) marked by a continuous, mm-thick dark-green rim (Fig. 3b). The orbicules are set in a light-coloured oligoporphyritic matrix showing a strong, pervasive alteration, with phenocrysts of sericitized plagioclase and few grains of an unidentified mafic component (now pseudomorphically replaced by aggregates of tremolitic amphibole) in a plagioclase, quartz ± K-feldspar groundmass, with accessory apatite and ilmenite. This groundmass is often transformed to a fine-grained assemblage of tremolite + plagioclase + tourmaline + quartz + titanite (replacing ilmenite) ± epidote. Coarser-grained anhedral titanite typically includes small grains of rutile at core. Some brown to greenish biotite occurs, mostly overgrowing tremolite and as thin veinlets.

An increase in grain size is generally observed in the orbicules. The dark green rims are composed of coarse-grained tremolite + tourmaline + plagioclase + euhedral titanite + quartz ± epidote and chlorite. Towards the orbicule cores, the same assemblage, depleted in tourmaline and tremolite, is observed. Irregularly-shaped poikiloblastic patches of Ca-rich scapolite include amphibole and apatite, and are often associated with pyrite and magnetite. At the very core, the orbicules are composed of coarse-grained, fresh zoned plagioclase (from An_{45} in the core to An_{30} in the rim), quartz, interstitial tourmaline, titanite and large euhedral apatite.

Spessartite dyke

The spessartite is exposed along the Sessera river, close to the Baraccone locality (Fig. 1), as a metre thick dyke, N-S trending and steeply dipping to the west. The dyke occurs at the contact between a thin slice of a matrix-supported breccia and mylonite *vs.* mylonitic gneiss related to the Insubric Lineament. This breccia pertains either to the Canavese Zone (as suggested by Schmid *et al.*, 1989) or to the sedimentary cover of the Sesia-Lanzo Zone.

The dyke is porphyritic and shows an igneous flow structure, with millimetre-sized phenocrysts of zoned amphibole (with a dark hastingsite core and a Mg-hastingsite rim) embedded in a groundmass of albitic plagioclase (An_{4-10}) and accessory magnetite with chromitic cores. The rock is affected by a slight pervasive alteration with green biotite intergrown with chlorite ± carbonate (often at rim of amphibole), fine grained epidote and pyrite.

GEOCHEMISTRY OF THE SATELLITE IGNEOUS BODIES

Preliminary major, trace and REE elements data on the intrusive rocks and the spessartite dyke are given in Table 1. Despite of the pervasive alteration discussed above, major element compositions (with the exception of the orbicular rock sample) are consistent with the igneous mineral mode classification, and are also in good agreement with

Fig. 3 - a) Pervasive alteration in gabbronorite: igneous phenocrystic biotite (Bt) is rimmed by fine-grained biotite and ilmenite (arrows); crossed polars, sample TV406, space bar is 0.5 mm. b) Pl–Qtz–Tr–Tur orbicular rock: sub-spherical orbicules, showing a dark green Tr-Tur-Pl-Ttn-bearing rim (arrows), are set in a pale-coloured, Pl-Qtz-bearing oligoporphyritic matrix. c) Hydrothermal breccia: in the boulder, 10 cm-sized clasts of Sesia-Lanzo Zone micaschists are embedded in a very fine-grained matrix composed of milled rock ("rock flour cement"). Voids are filled with Qtz-Tur hydrothermal matrix (arrows). d) Crosscutting relationships between Qtz-Pl and Ank-Qtz-sulphides veins in gabbronorite. The mm-thick Qtz-Plg veins (dotted-dashed orange line) are surrounded by cm-thick dark green (biotite- and sericite-rich) alteration halo, with sharp contact with the host rock. A cm-thick Ank-Qtz-sulphides vein (dashed yellow line), embedded in a dm-thick reddish (sericite + carbonate) alteration rim, crosscuts the Qtz-Pl veins. e) Detail of Qtz-Pl vein in gabbronorite: the mm-thick vein is surrounded by a dark green biotite- and sericite-rich alteration rim. f) Hydrothermal alteration after a Qtz-Pl vein in gabbronorite: the igneous plagioclase is pseudomorphically replaced by fine-grained greenish biotite and sericite (plain polarized light, sample TV405a, space bar is 0.15 mm). g) Qtz-Tur vein in hornfelsed micaschist: the cm-thick vein is surrounded by a bleached silicified alteration rim that also includes tourmaline, space bar is 3 cm. h) Ank-Qtz-sulphides vein: some barite laths and locally abundant microclasts of altered host rock (*x*) are embedded in a fine-grained ankerite-quartz orange matrix. The vein is surrounded by a reddish carbonate+sericite alteration.

Table 1
Major (wt%), trace and Rare Earth (ppm) element data of satellite igneous bodies from Valsessera

sample	TV585	TV588	TV604	TV606	TV437	TV603
SiO_2	53.80	56.50	56.30	61.00	58.50	50.20
TiO_2	0.91	0.84	0.90	0.43	0.95	0.73
Al^2O_3	16.65	16.65	16.65	16.10	17.85	16.15
Fe_2O_3T	7.94	8.98	7.21	6.03	2.29	6.69
MnO	0.13	0.07	0.08	0.06	0.05	0.09
MgO	4.05	3.53	3.94	1.02	3.85	9.18
CaO	6.76	5.28	2.17	0.51	7.11	4.96
Na_2O	2.76	2.71	2.15	1.83	4.74	5.36
K_2O	2.93	2.90	6.49	9.65	0.88	0.32
P_2O_5	0.45	0.45	0.46	0.23	0.46	0.18
LOI	0.86	1.20	1.19	0.73	1.38	5.03
Total	97.50	99.30	97.90	98.10	98.20	99.00
FeO	4.31	4.82	4.76	3.60	1.80	4.76

sample	TV585	TV588	TV604	TV606	TV437	TV603
La	48.2	50.8	5.1	68.7	11.1	19.7
Ce	95.9	96.5	10.5	126	43	37.7
Pr	10.9	11	1.4	13.4	6.9	4.2
Nd	42.8	42.1	6.5	48.3	33.2	16.6
Sm	8.6	7.8	1.9	8.3	8.4	3.3
Eu	2	1.7	0.8	1.3	1.8	1
Gd	7.5	7.1	2.1	7.9	7.3	3.3
Tb	1	0.9	0.4	1	1.1	0.5
Dy	5.1	4.1	2.3	4.7	5.7	2.6
Ho	0.9	0.8	0.5	1	1	0.5
Er	2.8	2.4	1.4	3.1	3	1.4
Tm	0.4	0.3	0.2	0.5	0.4	0.2
Yb	2.4	2.1	1.6	3	2.8	1.3
Lu	0.4	0.3	0.2	0.5	0.5	0.2
(Ce/Yb)N	10.2	11.7	1.7	10.7	3.9	7.4
(La/Sm)N	3.5	4.0	1.7	5.1	0.8	3.7
(Gd/Yb)N	2.5	2.7	1.0	2.1	2.1	2.0
Eu/Eu*	0.8	0.7	1.2	0.5	0.7	0.9
ΣREE	228.9	227.9	34.9	287.7	126.2	92.5

sample	TV585	TV588	TV604	TV606	TV437	TV603
V	217	202	203	38	174	166
Cr	20	20	20	<10	20	330
Co	34	26	46.2	23.6	26.5	37.6
Ni	8	10	70	<5	8	186
Cu	15	5	<5	<5	<5	72
Zn	74	86	59	52	57	62
Ga	19	20	20	19	20	19
Rb	124.5	190	252	292	76.5	8.4
Sr	570	523	223	191	608	338
Y	24.6	20.7	12.8	26.6	27.5	13
Zr	177.5	194.5	184.5	384	195.5	104.5
Nb	13	13	13	26	16	4
Mo	<2	2	2	6	4	<2
Ag	<1	<1	<1	<1	<1	<1
Sn	4	7	7	4	17	2
Cs	12	34.7	21.3	15.6	18.2	1.5
Ba	1670	901	2770	4260	370	119.5
Hf	5	6	5	12	6	3
Ta	1.4	1.5	1.8	2.3	1.7	0.8
W	145	151	231	145	161	91
Au	0.003	0.008	0.001	0.001	<0.001	0.005
Tl	0.7	1.3	1.1	1.3	0.5	<0.5
Pb	42	81	48	77	52	20
Th	32	37	33	104	36	6
U	7.4	9	6.5	26.9	8.7	2.2

TV585: Hornblende biotite monzogabbro
TV588: Cpx-bearing, biotite quartz diorite
TV604: Crd-bearing, biotite quartz monzodiorite
TV606: Biotite quartz alkali feldspar syenite
TV437: Pl-Qtz-Tr-Ttn-Tur orbicular rock
TV603: spessartite dyke

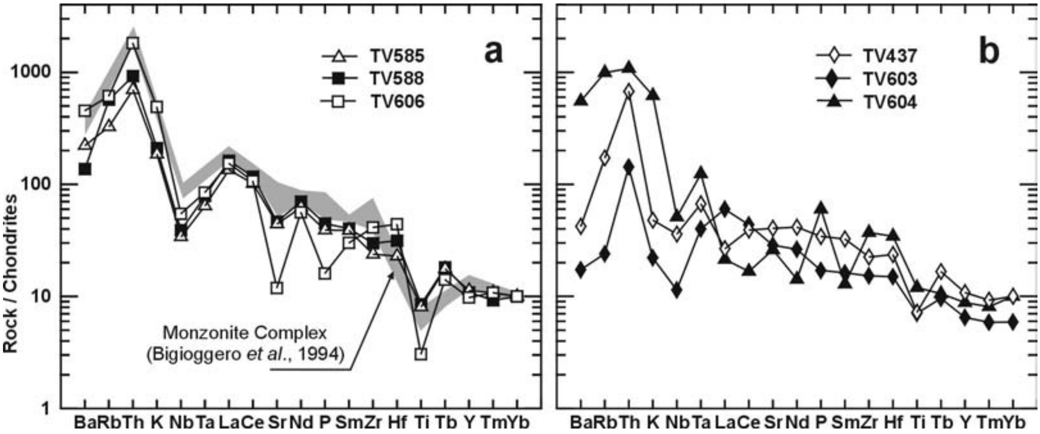


Fig. 4 – Chondrite-normalized (Thompson, 1982) spiderdiagrams for the satellite igneous bodies of Valsessera. For comparison in (a), compositions of monzonite rocks from the Biella pluton (data from Bigioggero *et al*., 1994: Pr, Pm, Ho and Tm values not available).

compositions of syenitic and monzonitic rocks from the main Biella pluton (e.g. Fiorentini Potenza, 1959; Bigioggero *et al*., 1994). Particularly, compositions of monzogabbro TV585 and quartz diorite TV588 (with $K_2O/Na_2O \sim 1.0$) indicate a high-K calc-alkaline affinity (cf. Peccerillo and Taylor, 1976); the Crd-bearing quartz monzodiorite TV604 and quartz alkali feldspar syenite TV606 are slightly peraluminous (normative corundum ~ 3.0 wt%) and display a shoshonitic affinity ($K_2O/Na_2O > 3.0$). Trace elements are enriched (from about 10 to 1000 times) relative to chondrite in all rock-types (Fig. 4). On the whole, they depict similar geochemical patterns, with negative spikes at Ti and Nb, and peaks at Rb and Th that, in the case of TV585 and TV588 rocks samples, almost overlap the pattern of monzonite from the Biella pluton (Fig. 4a).

The monzogabbro TV585, quartz diorite TV588, and quartz alkali feldspar syenite TV606 have total REE in the range 229-288 ppm and display very similar REE patterns (Fig. 5a), with a negative Eu anomaly from weak to moderate. These highly fractionated trends almost completely overlap the REE patterns of the intrusive Biella rocks analyzed by Bigioggero et *al.* (1994), but the negative Eu anomaly is slightly higher in the Valsessera samples. Their LREE patterns are comprised between those of the calc-alkaline and shoshonitic volcanics of Callegari *et al*. (2004) that also record a very similar HREE pattern, though the quartz alkali feldspar syenite TV606 is slightly enriched in HREE. Compared to these REE patterns, that of quartz monzodiorite TV604 is very flat and occurs at about 10 times chondrite (Fig. 5b), with a significant depletion in LREE and a positive Eu anomaly. Total REE in this sample is the lowest (35 ppm).

The spessartite dyke (sample TV603, Fig. 4b) is very low in K_2O, low in P_2O_5, Rb (Rb/Sr = 0.02), Nb, Th, U, and total REE, and high in Na_2O, Ni, and Cr (likely due to Cr-rich cores in magnetite); its composition plots between the low-K tholeiitic and calc-alkaline rock suites of Peccerillo and Taylor (1976). In the chondrite normalized spiderdiagram (Fig. 4b), the sample displays a pattern parallel to those of monzogabbro TV585 and quartz diorite TV588; its REE pattern (Fig. 6b) is similar to those of the monzogabbro, quartz diorite, and quartz alkali feldspar syenite, and of other low-K calc-alkaline Oligocene dykes from the western Alps (Venturelli *et al*., 1994).

As to the orbicular rocks, the composition of sample TV437 (Table 1) confirms the strong *subsolidus* modifications described above: major element data do not represent primary compositions and also the pristine trace elements distribution was at least partially modified (Fig. 4b). This sample is depleted in iron, K_2O, Ba, Rb, and LREE, and enriched in Na_2O, with respect to the other analyzed rocks and to those with the same silica range described in the Biella stock

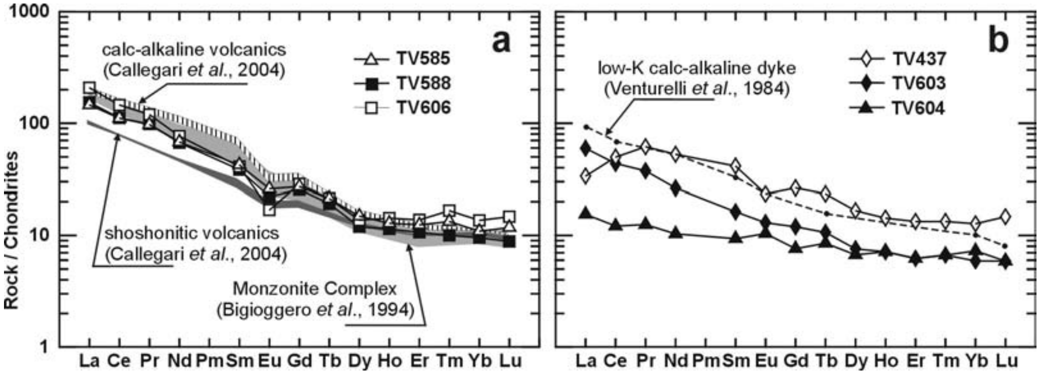


Fig. 5 - Chondrite-normalized REE patterns for the satellite igneous bodies of Valsessera. For comparison: (a) the monzonite rocks of the Biella pluton (Bigioggero *et al*., 1994: Pr, Pm, Ho and Tm values not available), and the calc-alkaline to shoshonitic volcanics of Callegari *et al*. (2004, Pr, Pm, Tb, Ho and Tm values not available); (b) a low-K-basaltic dyke within the Sesia-Lanzo micaschists (Venturelli *et al*., 1984, sample 118,: Pr, Pm, Dy, Ho, Er and Tm values not available). Data normalized according to chondrite abundances of Nakamura (1974).

by Bigioggero *et al*. (1994). However, it is worth noting that its HREE pattern (Fig. 5b) perfectly overlaps those of monzogabbro, quartz diorite, and quartz alkali feldspar syenite, with an equivalent negative Eu anomaly.

PETROGRAPHY OF THE HYDROTHERMAL BRECCIAS AND VEIN SYSTEMS

The multiphase hydrothermal activity in the area is testified by a hydrothermal breccia within the Sesia-Lanzo rocks, closely associated to the igneous bodies described above, and by different types of hydrothermal veins within both the igneous and metamorphic rocks, which are characterized by different mineral assemblages and a heterogeneous distribution.

Hydrothermal breccia

The hydrothermal breccia occurs as an hectometric body in the Pietra Bianca area (Fig. 2). It is a *clast-supported* breccia, composed of centimetre- to metre-sized, angular to slightly rounded clasts, randomly embedded in a finer-grained composite matrix (Fig. 3c). Its contacts with the Sesia-Lanzo country rocks are never exposed.

The clasts are composed of hornfelsed eclogitic micaschists, in which the former high-pressure metamorphic assemblage is mostly replaced by andalusite, fine-grained biotite, cordierite, oligoclase, K-feldspar and quartz. The original garnet is partly replaced by aggregates of reddish biotite + magnetite ± K-feldspar, while the original rutile is overgrown by ilmenite; tourmaline patches are common. This contact metamorphic assemblage is later irregularly affected by sericitization and/or chloritization processes.

The matrix is composed of materials from two different sources: i) an isotropic, very fine-grained hornfelsed matrix (showing the same metamorphic assemblage of the clasts with scanty garnet, white mica and rutile relics) likely derived from strongly milled micaschists; ii) cm-sized, patchy fillings of hydrothermal origin that are set between the clasts and/or the hornfelsed matrix. These patches consist of coarse-grained quartz + tourmaline ± magnetite ± pyrite aggregates, most of them being zoned, with a tourmaline-richer core and a quartz-richer rim. The core tourmaline often occurs as radial aggregates of cm-long, acicular crystals associated with quartz and very minor apatite, scheelite, monazite and locally barite and carbonate. Tourmaline shows an oscillatory zoning, with a shorl–dravite s.s. composition, and minor uvite and ferrischorl components. Magnetite may occur in quartz + magnetite domains either at core of the patches or along the contact with the breccia clasts and/or the hornfelsed matrix. These domains are characterized by up to 2 cm long,

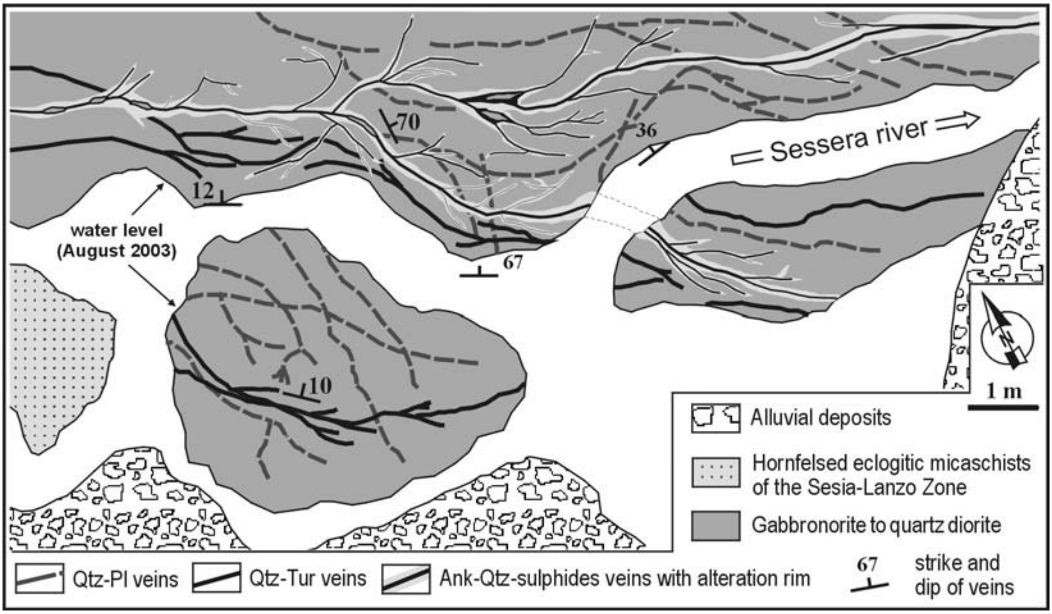


Fig. 6 – Crosscutting relationships between the Qtz-Pl, Qtz-Tur, and Ank-Qtz-sulphides vein systems within the gabbronorite to quartz diorite body at Casa del Pescatore, along the Sessera river. See Fig. 2 for the location, and text for discussion.

prismatic to needle-shaped magnetite crystals associated with interstitial, coarse-grained quartz. Quartz + magnetite may also occur as thin veinlets crosscutting the Sesia-Lanzo rock clasts. Pyrite ± pyrrhotite ± chalcopyrite, associated with chlorite, often overgrow magnetite. Preliminary analysis of hydrothermal quartz has shown that it contains hypersaline (liquid + halite + sulphates + vapour) fluid inclusions coexisting with vapour-rich (vapour + liquid) fluid inclusions.

The contact between the hydrothermal matrix and either the clasts and/or the hornfelsed matrix is sharp and reaction rims are absent or poorly developed, suggesting that they were broadly at equilibrium. Red contact-metamorphic biotite and andalusite are often well preserved at the contact. When present, hydrothermal alteration is mostly given by an increase in the amount of quartz + sericite in the host rock. However, tourmalinization is locally observed: the host schists are transformed to alternating monomineralic layers of quartz and tourmaline (the latter overgrowing phengite). Similarly, at the contact with the quartz-magnetite domains the schists are locally transformed to a metasomatic rock consisting of alternating quartz and magnetite layers. Fine-grained reddish biotite enrichments are observed in the clasts at the contact with quartz + magnetite veinlets.

Hydrothermal vein systems

Five main vein systems have been recognized, i.e. Qtz-Pl veins, Qtz-Tur veins, Ank-Qtz-sulphides veins, Chl-Qtz veins, and Qtz-sulphides veins (vein-type names based on the diagnostic phases). In this paper we will mostly focus on three of them (the quartz-plagioclase, the quartz-tourmaline and the ankerite-quartz-sulphides vein systems), which occur in both the satellite bodies and Sesia-Lanzo country rocks at roof of the Biella stock. For this reason the quartz-sulphides vein system, which only occurs within the outer rim of the Monzonite Complex at Costa l'Argentera and Alpe Piovale (and show similarities with the vein systems cropping out to the southwest within the pluton: Senesi, 1999; Rossetti *et al.*, 2002) will only briefly described. Also the chlorite-quartz vein system will not be discussed in detail, as it represents a minor product of late, low-temperature fluid circulation.

Based on unambiguous crosscutting relationships (Figs. 3d and 6), the following relative chronology among most of the vein systems has been established (from older to younger): 1) quartz-plagioclase veins, 2) quartz-tourmaline veins, 3) ankerite-quartz-sulphides veins, 4) chlorite-quartz veins. On the contrary, crosscutting relationships between the quartz-sulphides veins and the other vein systems have not been recognized.

Quartz-plagioclase veins. This earlier vein type has been identified in the gabbronorite, cordierite-bearing quartz monzodiorite and quartz alkali feldspar syenite bodies, as up to few mm-thick discontinuous veinlets with highly variable orientation. In the gabbronorite body these veins are composed of fine grained Ca-rich plagioclase (An_{46-31}) + quartz ± green biotite ± prismatic epidote (within, or at rim of plagioclase) and very minor pyrite and chalcopyrite. Preliminary analysis of the vein quartz revealed the occurrence of small hypersaline (liquid + halite + vapour) fluid inclusions. The plagioclase + quartz portion is sharply rimmed by a fine-grained green biotite + epidote ± tourmaline rim (Fig. 3e).

A strong composite alteration occurs at selvages of these veins, over a thickness of up to few centimetres. In gabbronorite, the following alteration sequence is observed, from the vein to the unaltered rock: i) an inner zone composed of very-fine grained, green to reddish, low-Ti (TiO_2 ~2.0 wt% on avg.) biotite + sericite completely replacing primary biotite and plagioclase (Fig. 3f). Pyrite ± magnetite ± chalcopyrite enrichments occur and primary magnetite is completely replaced; ii) an intermediate zone, where plagioclase is completely sericitized and primary biotite is overgrown by chlorite and titanite. Scanty pyrite occurs, overgrowing magnetite; iii) an outer alteration zone, where plagioclase and primary biotite are only partially overgrown by sericite and chlorite + titanite, respectively. In this portion, primary magnetite is generally preserved and pyrite is rare.

Quartz-tourmaline veins. It is the most common vein type, up to few centimetres thick, mostly trending SE to ESE and dipping 20-70° NE. The Qtz-Tur veins are often zoned and occur within all the satellite igneous bodies and also in the Sesia-Lanzo country rocks. The inner portion consists of fine-grained prismatic tourmaline (often with fine grained inclusions of rutile) + quartz ± carbonate ± barite ± epidote, whereas the outer portion is mainly composed of quartz + minor tourmaline (Fig. 3g). Magnetite is locally abundant, as a late phase often cementing tourmaline; pyrite ± chalcopyrite ± pyrrhotite enrichments occur, which post-date magnetite, even if opposite chronology is locally observed. Chlorite is often associated with magnetite and pyrite enrichments. Millimetre-thick, irregularly shaped monomineralic tourmaline veinlets locally occur.

The hydrothermal alteration is represented by strong silicification and sericitization, with growth of quartz + sericite ± pyrite ± magnetite ± chlorite ± apatite over the country rock assemblage; tourmalinization also occurs (see also Fig. 3g).

Ankerite-quartz-sulphides veins. These veins also occur within all the satellite igneous bodies and the Sesia-Lanzo country rocks. Particularly, they are abundant along the Sessera river, near Casa del Pescatore, as reddish veins up to 6-7 cm thick, which broadly show the same orientation of the quartz-plagioclase veins, trending ESE to SE and dipping 10-70° NE; however, based on crosscutting relationships, the ankerite-quartz-sulphides veins clearly post-date the quartz-tourmaline veins. They mostly consist of ankerite + quartz + pyrite + chalcopyrite ± barite ± calcite (Fig. 3h). An early deposition stage is represented by fine-grained, subhedral ankerite intergrown with euhedral barite, pyrite, chalcopyrite and interstitial quartz. A later stage consists of coarser grained euhedral ankerite and barite. Quartz also occurs as a final filling phase. Pyrite + chalcopyrite are locally abundant as centimetre-sized patches scattered throughout the veins.

The wallrock alteration is given by strong sericitization and carbonatation, with sericite + carbonate replacing all pre-existing phases.

Chlorite-quartz veins. Very thin chlorite + quartz ± epidote veinlets are common in the area, which locally crosscut the earlier Qtz-Pl-, Qtz-Tur-, and Ank-Qtz-sulphides veins, and do not develop any hydrothermal alteration in the country rocks. These are late, low-temperature veins (as it is commonly found along brittle structures in orogenic belts) and have not been studied in detail.

Quartz-sulphides veins. They only occur within the Monzonite Complex of the main intrusive body at Costa l'Argentera and Alpe Piovale, in the northwestern part of the area (Fig. 2), where an ancient mining activity for Ag and Pb is documented (cf. Di Gangi, 2001; Rossi *et al*., 2002). They crop out as up to few centimetres-thick, subvertical, SSE-NNW trending veins composed of quartz + sulphides ± white mica. Quartz occurs as intergrowths of fine- to coarse-grained euhedral to subhedral crystals; sulphides are generally abundant (up to 50 vol%) and are mostly pyrite + arsenopyrite, with highly variable amounts of chalcopyrite, galena, tetrahedrite, Bi-sulphosalts and minor sphalerite. White mica may frequently occur as fine-grained radial-shaped intergrowths. Veins are locally banded, with alternating sulphides- and quart-rich domains, locally showing a cataclastic structure. Wallrock alteration is a strong sericitization of the host monzonite.

As already mentioned, a relative chronology between the quartz-sulphides veins and the other vein types has not been established so far. As the mineral assemblage is suggestive of relatively high-temperature conditions, they could possibly pre-date the ankerite-quartz-sulphides veins.

DISCUSSION AND CONCLUSIONS

The satellite intrusive bodies and their relationships with the main Biella pluton

In the Sessera valley, small igneous bodies, ranging in composition from gabbronorite to quartz alkali feldspar syenite, are scattered within the contact-metamorphosed Sesia-Lanzo rocks at roof of the Biella pluton. Field relationships and petrographic characteristics show that they are coeval with the other Tertiary igneous rocks of the Biella area, and the available geochemical data evidence their high-K calc-alkaline to shoshonitic affinity. Therefore, these satellite bodies are undoubtedly part of the volcanic-plutonic Tertiary complex of Biella recently proposed by Callegari *et al*. (2004).

These bodies are affected, to a different extent, by *subsolidus* multistage alteration processes whose explanation is not straightforward. The pervasive alteration involves the mostly ubiquitous crystallization of new biotite + sericite ± tourmaline that, unlike the later hydrothermal alteration, are not spatially associated with the veins. In addition, the biotite related to pervasive alteration shows different compositions compared to magmatic and hydrothermal biotite: e.g. in the gabbronorite body, where all the three generations of biotite occur (see Figs. 3a and 3f), this type of biotite shows a TiO_2 content (avg. 3.5 wt%) which is intermediate between those of magmatic and hydrothermal biotite (avg. 6.0 and 2.0 wt%, respectively).

Two types of processes could explain such pervasive alteration at relatively high temperature in the roof zone of the Biella pluton: i) autometamorphism, induced in the satellite bodies by late-magmatic fluids accumulation at the apical portion of the magma chamber(s); ii) contact-metamorphic processes affecting early crystallization products that already recorded a magmatic evolution from gabbronorite to quartz alkali feldspar syenite. The first hypothesis would be in agreement with the occurrence of tourmaline in the alteration assemblage: late magmatic fluids can be, in fact, strongly enriched in boron (e.g. Dingwell *et al*., 1996; London *et al*., 1996; with refs.). Strong boron enrichments in magmatic-derived fluids connected with the Biella intrusion have been suggested by Bernardelli *et al.* (2000) to interpret the early hydrothermal vein systems at roof of the pluton in the southernmost Cervo valley and also occurred in Valsessera (see below). In this scenario, both texture and mineral assemblages of the Pl–Qtz–Tr–Tur orbicular rocks could be explained by the segregation of a hydrous, B-bearing fluid trapped in a crystallizing melt in the uppermost part of a magma chamber (e.g. Sinclair and Richardson, 1992).

On the contrary, the hypothesis of contact-metamorphic recrystallization induced by the emplacement of the main Biella pluton is supported by the location of satellite bodies within the contact aureole, the distribution of pervasive alteration, and features like the growth of biotite over the igneous plagioclase that, to our knowledge, is not generally observed as a product of simple autometamorphism processes. We consider the occurrence of the pervasive alteration in *all* the satellite bodies a strong indication of a contact-metamorphic overprint during the emplacement of the Monzonite Complex. This does not role out, however, the occurrence of autometamorphic transformations, which probably also occurred and may have affected, with variable intensity, at least part of the bodies.

The spessartite dyke, occurring well outside the contact aureole, was not affected by the strong alteration and/or recrystallization recognized in the other intrusive bodies. Its weak alteration could be related either to sub-solidus re-equilibrations, commonly recorded by igneous rocks, or to fluid circulation connected to the Insubric Lineament.

Relationships between magmatic and hydrothermal activity

A comprehensive analysis of the complex relationships between the igneous activity and the multistage hydrothermal evolution within the Biella stock and the country Sesia-Lanzo Zone is beyond the purpose of this paper. Focusing on the hydrothermal activity within the Sesia-Lanzo rocks and the satellite igneous bodies, several lines of evidence point to a close relationship between the magmatic activity and part of the hydrothermal system, as it will be discussed below.

The quartz-plagioclase veins. Both the vein assemblage (An-rich plagioclase + quartz) and type of alteration (strong biotite enrichments) stress their high-temperature character. Moreover, the hypersaline fluid inclusions in the vein quartz are typically found in magmatic-derived hydrothermal systems (e.g. Hedenquist, 1995).

The hydrothermal breccia body. As described above, both clasts and part of the matrix are affected by a strong thermal recrystallization, and the characters of the hornfelsed matrix suggest derivation from strongly milled Sesia-Lanzo rocks. We interpret this body as a magmatic-hydrothermal breccia pipe related to violent escape of late-magmatic fluids which caused brecciation at roof of the magma chamber, as often documented in shallow, magmatic-related hydrothermal systems (e.g. Warnaars e*t al*., 1985). In turns, the subsequent circulation of magmatic-derived hydrothermal fluids deposited the quartz + tourmaline ± magnetite fillings. This interpretation is further supported by the ubiquitous occurrence of hypersaline + vapour-rich fluid inclusions in quartz and tourmaline, which suggests exsolution of a boiling fluid.

The abundance of tourmaline in the hydrothermal system. Abundance of tourmaline-bearing veins in the Sesia-Lanzo rocks at roof of the pluton is a peculiar feature of the Biella body, also in the southernmost Cervo valley (Bernardelli *et al*., 2000). Our data show that tourmaline is also an important phase of the pervasive alteration assemblages observed in the earlier satellite bodies of Valsessera. On the contrary, tourmaline-bearing veins within the Biella pluton are rare. They locally occur only within the Monzonite Complex, while they are absent in the inner Syenite and Granitoid Complexes; moreover tourmaline-bearing pegmatites crop out within the Monzonite Complex (Rossetti *et al*., 2002). These data suggest that strong boron enrichments occurred during the late stages of monzonite crystallization; fluid overpressure in the monzonite probably caused the formation of the tourmaline-bearing breccia pipe at roof of the pluton. Based on the hydrothermal assemblages, the quartz-tourmaline-bearing veins are likely related to the same event, giving a relative chronology for the earlier quartz-plagioclase and the later ankerite-quartz-sulphides veins.

In a recent paper Zanoni *et al*. (in press), based on structural and petrographic studies, identified a number of brittle deformation structures containing mineral fillings, including the quartz-tourmaline veins, and suggested a post-pluton emplacement of the veins assisted by fluid circulation from cooling of the magma chamber. Our data confirm a post-pluton emplacement and suggest a close relationship between at least the early (quartz-plagioclase and quartz-tourmaline) vein systems and late-magmatic crystallization. The later ankerite-quartz-sulphides veins, which probably emplaced at lower temperature, may represent the product of either evolved magmatic fluids (± a meteoric component) or meteoric fluids, heated by the cooling magma bodies. Further investigations (particularly on fluid inclusions, isotopic compositions and pressure-temperature conditions) are needed in order to test and improve the proposed model, and to better constrain the overall late-magmatic to hydrothermal evolution of the Biella pluton.

ACKNOWLEDGEMENTS

D.C. and P.R. are indebted to Ezio Callegari for numberless and stimulating discussions on the petrogenesis of both igneous and metamorphic rocks: a twenty-five-years-long training that deeply influenced our research and teaching activity. Careful reviews by Maria Iole Spalla and an anonymous reviewer were much appreciated. This research was supported by Torino University grants to D.C. and P.R.

APPENDIX

Mineral compositions have been obtained using a SEM Cambridge Stereoscan 360 equipped with an EDS Energy 200 and Pentafet Detector (Oxford Intruments), and operating at 15 kV accelerating potential and 50 s counting time. Natural and synthetic mineral and oxide standards have been employed and raw data have been corrected using the INCA Suite v. 4.01.

Major and trace element data on selected rock-types (Table 1) have been obtained at ALS Chemex, Vancouver, using ICP-AES and ICP-MS techniques for major and trace elements, respectively. Gold has been determined by fire assay and ICP-AES; ferrous iron by HCl-HF acid digestion and titrimetric analysis. Detection limit for major elements is 0.01 wt% oxide, those for trace elements (collected according to the ME-MS81 Chemex protocol) are detailed at the ALS Chemex web page; the range for gold is 0.001-10 according to the Au-ICP21 Chemex protocol.

REFERENCES

BASSI S. (1999) - *Vene idrotermali a tormalina nell'aureola metamorfica del Plutone della Valle del Cervo (Val Sessera): petrografia ed analisi delle inclusioni fluide*. Unpubl. MSc Thesis, University of Turin, 232 pp.

BECCALUVA L., BIGIOGGERO B., CHIESA S., COLOMBO A., FANTI G., GATTO G.O., GREGNANIN A., MONSTRASIO A., PICCIRILLO E.M. and TUNESI A. (1983) - *Post collisional orogenic dyke magmatism in the Alps.* Mem. Soc. Geol. It., **26**, 341-359.

BERNARDELLI P., CASTELLI D. and ROSSETTI P. (2000) - *Tourmaline-rich ore-bearing hydrothermal system of lower Valle del Cervo (western Alps, Italy): field relationships and petrology.* Schweiz. Mineral. Petrogr. Mitt., **80**, 257-277.

BIGIOGGERO B., COLOMBO A. Del MORO A., SACCHI R. and VILLA I. (1983) - *Dati isotopici e radiometrici di filoni del Biellese.* Soc. Geol. It. – Soc. It. Min. Petrol., Convegno "Il magmatismo tardo-alpino nelle Alpi", Padova (Italy), Abstr.,1 p.

BIGIOGGERO B., COLOMBO A., DEL MORO A., GREGNANIN A., MACERA P. and TUNESI A. (1994) - *The Oligocene Valle del Cervo Pluton: an example of shoshonitic magmatism in the Western Italian Alps.* Mem. Soc. Geol. It., **46**, 409-421.

BUCHER K. and FREY M. (2002) - *Petrogenesis of metamorphic rocks*. 7th ed., Springer, Berlin, 2002, 341 pp.

CALLEGARI E., CIGOLINI C., MEDEOT O. and D'ANTONIO M. (2004) - *Petrogenesis of calc-alkaline and shoshonitic post-collisional Oligocene volcanics of the Cover Series of the Sesia-Lanzo Zone, Western Italian Alps.* Geodin. Acta, **17**, 1-29.

CARRARO F. and FERRARA G. (1968) - *Alpine "tonalite" at Miagliano, Biella (Zona dioritico-kinzigitica): a preliminary note.* Schweiz. Mineral. Petrogr. Mitt., **48**, 75-80.

DAL PIAZ G.V., VENTURELLI G. and SCOLARI, A. (1979) - *Calc-alkaline to ultrapotassic postcollisional volcanic activity in the Internal NorthWestern Alps*. Mem. Soc. Geol. It., **32**, 1-16.

DI GANGI G. (2001) - *L'attività mineraria e metallurgica nelle Alpi Occidentali Italiane nel Medioevo in Piemonte e Valle d'Aosta: fonti scritte e materiali.* BAR International Series, Oxford, **951**, 124-140.

DINGWELL D.B., PICHAVANT M. and HOLTZ H. (1996) - *Experimental studies of boron in granitic melts.* In: Grew E. and Anovitz L. (Eds.), Boron, Mineralogy, Petrology and Geochemistry in the Earth´s Crust. MSA Rev. Mineral., **33**, 331-385

FIORENTINI POTENZA M. (1959) - *Distribuzione delle principali facies petrografiche e della radioattività nel plutone "syenitico" di Biella (Valle del Cervo).* Rend. Soc. It. Mineral. Petrol., **15**, 89-131.

FORNASERO D. (1978) - *Studio geologico-petrografico dell'aureola termometamorfica del Plutone della Valle del Cervo (Biella).* Unpubl. M.Sc. Thesis, University of Turin, 186 pp.

HEDENQUIST J.W. (1995) - *The ascent of magmatic fluids: discharge versus mineralization.* In Thompson J.F.H. (Ed.), Magmas, Fluids, and Ore Deposits. MAC Short Course Series, **23**, 263-289.

LANZA R. (1977) - *Paleomagnetic Data from the Andesitic and Lamprophyric Dikes of the Sesia-Lanzo-Lanzo Zone (western Alps).* Schweiz. Mineral. Petrogr. Mitt., **57**, 281-290.

LANZA R. (1979) - *Paleomagnetic data on the andesitic cover of the Sesia-Lanzo-Lanzo Zone (western Alps).* Geol. Rundsch., **68**, 83-92.

LONDON D, MORGAN G.B. VI and WOLF M. (1996) - *Boron in granitic rocks and their contact aureoles.* In: Grew E. and Anovitz L. (Eds.), Boron, Mineralogy, Petrology and Geochemistry in the Earth´s Crust. MSA Rev. Mineral., **33**, 299-330.

MEDEOT O. (1998) - *Petrologia delle vulcaniti terziarie di copertura della Zona Sesia-Lanzo (Alpi Occidentali Interne).* Ph.D. Thesis, University of

Turin, 130 pp.

Medeot O., Callegari E. and Cigolini C. (1997) - *Petrochemical aspects of calc-alkalic and shoshonitic post-collisional Oligocene volcanics of the cover series of the Sesia-Lanzo Zone, Western Italian Alps.* Quad. Geod. Alp. Quatern., **4**, 77-78.

Nakamura N. (1974) - *Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites*. Geochim. Cosmochim. Acta, **38**, 757-775.

Peccerillo A. and Taylor S.R. (1976) - *Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu Area, Northern Turkey*. Contrib. Mineral. Petrol., **58**, 63-81.

Romer R.L., Schärer U. and Steck A. (1996) - *Alpine and pre-Alpine magmatism in the root-zone of the Western Central Alps*. Contrib. Mineral. Petrol., **123**, 138-158.

Rosenberg C.L. (2004) – *Shear zones and magma ascent: A model based on a review of the Tertiary magmatism in the Alps*. Tectonics, **23**, 1-21.

Rossetti P., Agangi A., Castelli D., Padoan M. and Ruffini R. (2002) - *Magmatic versus hydrothermal activity in the roof zone of the Valle del Cervo pluton (Italian western Alps)*. 81st Summer Meet. Soc. Geol. It., Torino (Italy), Abs. vol., 155-156.

Rossi M., Gattiglia A. and Rostan P. (2002) - *Miniere e metallurgia in Alta Val Sessera (Biella)*. In: Crestati G. (Ed.), Studi e ricerche sull'Alta Valsessera. Centri Studi Biellesi, Biella, **2**, 137-196.

Scheuring G B., Ahrendt H., Hunziker J.C. and Zingg A. (1974) - *Paleobotanical and geochronological evidence for the Alpine Age of the metamorphism in the Sesia-Lanzo-Zone*. Geol. Rundsch., **63**, 305-326.

Schmid S.M., Aebli H.R., Heller F. and Zingg A. (1989) - *The role of the Periadriatic line in the tectonic evolution of the Alps*. In: Coward M.P., Dietrich D. and Park R.G. (Eds.), Alpine tectonics. Geol. Soc. Spec. Publ., **45**, 153-171.

Selvaggio I. (2006) - *Mineralizzazioni a magnetite dell'Alta Valsessera: aspetti geologico-petrografici e archeometallurgici*. Unpubl. M. Sci. Thesis, University of Turin, 180 pp.

Senesi M. (1999) - *Studio geologico, petrografico e giacimentologico delle manifestazioni idrotermali associate al plutone della Valle del Cervo (Biella).* Unpubl. M. Sci. Thesis, University of Turin, 137 pp.

Sinclair W.D. and Richardson J.M. (1992) - *Quartz-tourmaline orbicules in the Seagull batholith, Yukon territory.* Can. Mineral., **30**, 937-954.

Thompson R.N. (1982) – *Magmatism of the British Tertiary volcanic Province.* Scot. J. Geol., 18, 49-107.

Vander Auwera J. (1990) - *The porphyritic facies and the endoskarns of the Traversella monzodiorite: Implications for the evolution of the main intrusion (Ivrea, Italy).* Schweiz. Mineral. Petrogr. Mitt., **70**, 237-245.

Vander Auwera J. and Andre L. (1991) - *Trace elements (REE) and isotopes (O, C, Sr) to characterize the metasomatic fluid sources: evidence from the skarn deposit (Fe, W, Cu) of Traversella (Ivrea, Italy)*. Contrib. Mineral. Petrol., **106**, 325-339.

Venturelli G., Thorpe R.S., Dal Piaz G.V., Del Moro A. and Potts P.J. (1984) - *Petrogenesis of calc-alkaline, shoshonitic and associated ultrapotassic Oligocene volcanic rocks from the NorthWestern Alps, Italy.* Contrib. Mineral. Petrol., **86**, 209-220.

Von Blanckenburg F. and Davies J.H. (1995) - *Slab breakoff: A model for syn-collisional magmatism and tectonics in the Alps.* Tectonics, **10**, 120-131.

Von Blanckenburg F., Kagami H., Deutsch A., Oberli F., Meier M., Wiedenbeck M., Barth S. and Fischer H. (1998) - *The origin of Alpine plutons along the Periadriatic Lineament*. Schweiz. Mineral. Petrogr. Mitt., **78**, 55-66.

Warnaars F.W., Holmgren C.D., and Barassi S.F. (1985) - *Porphyry Copper and tourmaline breccias at Los Bronces-Rio Blanco, Chile*. Econ. Geol., **80**, 1544-1565

Zanoni D. (2007) - *Messa in posto di plutoni tardo collisionali in unità continentali profonde esumate. L'esempio della Zona Sesia Lanzo (Alpi Occidentali Interne).* Unpubl. Ph.D. Thesis, University of Milan, 245 pp.

Zanoni D., Bado L., Spalla M.I., Zucali M. and Gosso G. (in press) - *Structural and petrographic map of the north-eastern margin of the Tetiary intrusive stock of Biella (western Alps, Italy)*. Boll. Soc. Geol. It., in press.

Zingg A., Hunziker J.C., Frey M. and Ahrendt H. (1976) - *Age and degree of metamorphism of the Canavese Zone and of the sedimentary cover of the Sesia-Lanzo Zone*. Schweiz. Mineral. Petrogr. Mitt., **56**, 361-375.