SESIA - VAL GRANDE GEOPARK

Annex 2

Copy of section B

“Geological Heritage”

With preface

B – Geological Heritage

Preface

Geologically the proposed Geopark is divided in two parts by the Insubric (Canavese) Line, a major tectonic structure that marks the border between the Southern Alps and the nappe piles of the Western Alps (Figure 3). In the territories northwest of the Canavese Line there are exposures of high- and ultra-high-pressure metamorphic rocks and fragments of ophiolites. Southeast of the Canavese Line, the Ivrea-Verbano Zone provides one of the most spectacular sections through rocks of lower crustal provenance. Together with the metamorphic and igneous rocks of the adjacent Serie dei Laghi, the rocks of this region record Palaeozoic accretion, metamorphic and magmatic processes, the effects of the Hercynian orogeny, post-orogenic magmatic underplating and associated lithospheric stretching and thinning, and effects associated with the position of the region in Alpine tectonism. In the lower Sesia valley is exposed a truly unique geologic association: a fossil supervolcano with its 25 km-deep magmatic plumbing system

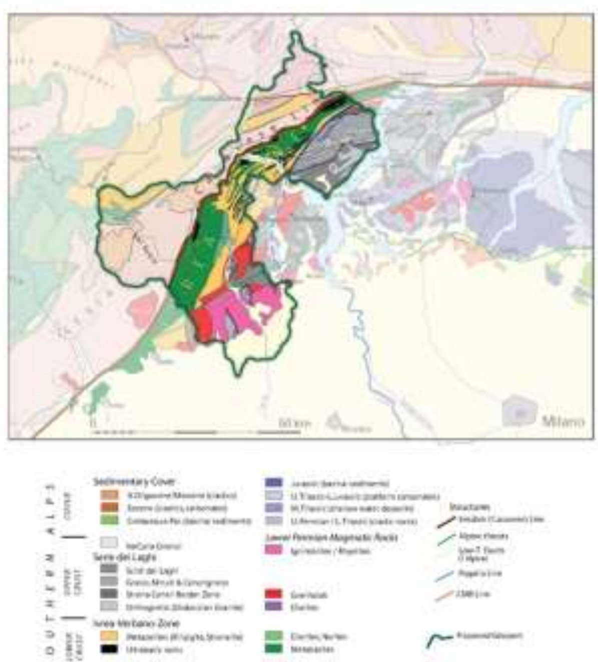

Figure 3. Regional setting of the proposed Sesia-Val Grande Geopark. The proposed park includes significant parts of the Ivrea-Verbano Zone and the Serie dei Laghi, and part of the Sesia Zone; modified after Brack et al, 2010

1. Location of the proposed Geopark

The proposed Sesia-Val Grande Geopark is located in northwest Italy where it sits astride the Canavese segment of the Insubric Line, a 1-km-thick mylonite belt that is a major tectonic boundary in the Alps (Figure 3). North and west of the Insubric Line, the Austro-Alpine domain consists of piles of nappes, which were assembled and affected by a metamorphic overprint reaching upper amphibolite facies during the Alpine orogeny. South and east of the Insubric Line, rocks of the South-Alpine Domain were not affected by this metamorphic event and preserve an older history despite experiencing substantial Alpine tectonic deformation. These rocks originally belonged to the northern margin of the Adriatic plate, and within them an exceptional record of metamorphic and igneous events are preserved within a virtually intact section through the pre-Alpine crust that is the focus of the proposed Geopark.

2. General geological description of the proposed Geopark: From the lower crust to the Permian Supervolcano

Geologic relations in the proposed Sesia-Val Grande Geopark are internationally renown and of world-class scientific significance. Accessible outcrops display the effects of dramatic geologic processes that shaped the continental crust through a wide range of crustal levels, from high-grade metamorphism, magmatism, anatexis and ductile deformation at depths as great as 25 to 30 km to the explosive eruption of a supervolcano at the surface of the earth 282 million years ago. For more than 40 years, this area has served scientists as an unprecedented crustal reference section in which geophysical observations and physical processes may be interpreted in the context of geology that is observable on the ground (Fountain, 1976, Kissling 2012, and references therein). As a Geopark, this area will be available to people of all backgrounds and ages to explore geologic processes that molded the evolving crust of a continent and produced the spectacular features that are preserved in accessible outcrops. For example, visitors may stand on fragments of the subcontinental mantle and trace clinopyroxene dikes that are the trails basaltic melts. They may visit the contact between an enormous gabbro intrusion in the deep crust to observe granitic segregations formed by partial melting of the adjacent crustal rocks. And they may visit the roots and the roof of a granitic pluton and marvel at the chaotic breccias produced by the explosive, caldera-forming super-eruption.

In addition to presenting to the public the world's most accessible reference section for the continental crust, the proposed Geopark will introduce the public to processes that operate on a global scale. Outstanding examples of plate-boundary deformation and tectonics are found within the proposed Geopark because it encompasses the Canavese Line, a 1-km-thick mylonite belt that forms the westernmost segment of the Insubric Line, the major tectonic boundary separating the Austro-Alpine Domain to the north from the South-Alpine Domain (African Plate) to the south. Stacked European and African nappes (slices of rocks) which formed the Alpine belt during the collision of Europe and Africa are beautifully exposed along the lower Ossola Valley, and northwest of the Canavese Line, the public may visit exposures of high-pressure and ultra-high-pressure metamorphic rocks, and fragments of ophiolites derived from the Tethys Ocean and obducted during the Alpine event. And because it extends from the Po Plain to the high Alps, the proposed Geopark will provide visitors with opportunities to also observe a record of climate change as recorded by Pleistocene geomorphology, recent glacial retreat, and patterns of human habitation dating to the Paleolithic.

The most distinguishing features of the proposed Geopark are outcrops within the South-Alpine Domain. Collectively these rocks form the Massiccio dei Laghi (Boriani et al., 1990a,b), which comprises two principal lithotectonic units, the Ivrea-Verbano Zone and the Serie dei Laghi, separated by the Cossato-Mergozzo-Brissago (CMB) and Pogallo lines. This terrane has been the object of intense and continuing scientific interest for decades because within it an association of accessible lower-, middle- and upper-crustal rocks constitutes an unprecedented model for interpreting the geophysics of the continental crust. Its scientific importance cannot be overstated, and the Massiccio dei Laghi has been the target of countless geologic fields by universities and professional societies. The number of scientific papers referencing the Ivrea-Verbano Zone alone has increased exponentially since 1970 and now exceeds 2,500. The following geologic description is focused on the Massiccio dei Laghi because collectively the relationships observable within it will provide geotourists with a unique exposure to processes that shaped the crust upon which they live.

The Massiccio dei Laghi: a window to depth

The Massiccio dei Laghi presents a spectacular cross section through the continental crust, from the lower crustal Ivrea–Verbano Zone to the middle– and upper-crustal Serie dei Laghi. This assembly of lower- and upper-crustal rocks can be observed over 50 km in a SW-NE direction, with an average width of about 25 km, and is considered worldwide as a model for a magmatically underplated and extended crustal section (Rutter et al., 1993; Schnetger, 1994; Quick et al., 1994; Henk et al., 1997). Many authors have interpreted this terrane as a coherent Lower Paleozoic continental section that was tilted to the present subvertical position during the Alpine orogeny, while others favor a model of trans-tensional emplacement of the Ivrea-Verbano Zone, in which this lower crustal unit may be seen as the exposed roots of an early Permian pull-apart basin (Boriani & Giobbi, 2004). These differing interpretations notwithstanding, the rock association exposed in the Massiccio dei Laghi represents an unprecedented opportunity for visitors to "walk through" the earth's continental crust, observing the mineralogy, textures and structures formed at different depths.

The Ivrea-Verbano Zone

Because of its accessibility and beautiful exposures of lower-crustal rocks, this area has been subjected to substantial structural, petrological, geochemical and petrophysical study by geoscientists from Italy, USA, Switzerland, Germany, Britain, Austria, France, Spain and Japan, and has been described in more than 2500 published papers during the past 40 years (Figure 4).

Figure 4. Total publications referring to the Ivrea-Verbano Zone.

The Ivrea-Verbano Zone mainly consists of a metamorphosed volcano-sedimentary sequence, referred to as the Kinzigite Formation, and gabbroic to dioritic intrusive rocks, referred to as the Mafic Complex (Figure 5). The metamorphic rocks are mainly metamorphosed shales and graywacke (the so-called kinzigites and stronalites), with minor quartzites, thin meta-carbonate horizons and interlayered metabasites (Sills and Tarney, 1984). Mantle peridotite lenses, tectonically interfingered with the metasedimentary rocks (Quick et al., 1995), occur in the northwestern part of the Ivrea-Verbano Zone, near the Canavese Line (e.g. Balmuccia in the Sesia valley and Finero in the Cannobina valley, among the proposed Geosites).

The metamorphic grade in the Ivrea-Verbano Zone increases towards the northwest, from upper amphibolite facies adjacent to the Serie dei Laghi, to granulite facies near the northwestern boundary of the Ivrea-Verbano Zone at the Canavese Line (Peyronel Pagliani and Boriani, 1967; R.Schmid, 1967; Zingg, 1983). The deep crustal rocks of the Ivrea-Verbano Zone were juxtaposed against the middle- to upper-crustal Serie dei Laghi by faulting along Cossato-Mergozzo-Brissago (CMB) Line (Boriani and Sacchi, 1973), which had effectively ceased before the beginning of the Permian igneous activity.

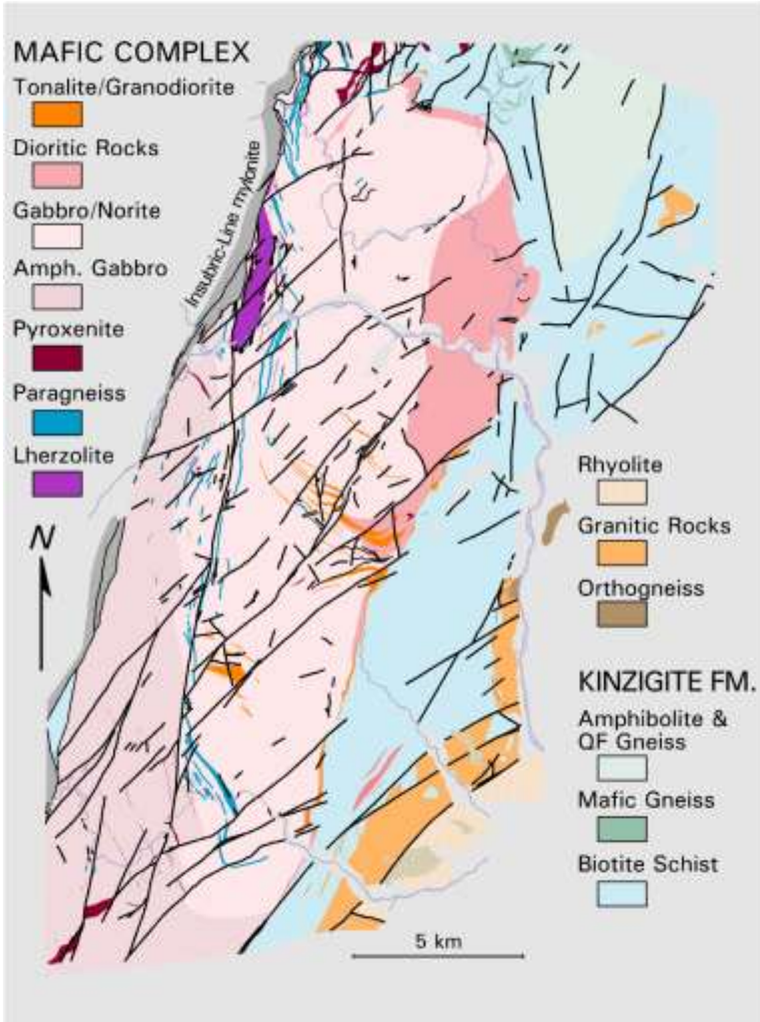

Figure 5. Geologic map showing the principal components of the the Ivrea-Verbano Zone in the vicinity of the Sesia Valley.

The Sesia Magmatc System

The Sesia Magmatic System, which cuts through this crustal section, constitutes a unique geologic reference section that not only allows scientists to interpret geophysical observations beneath active calderas in the context of geology observable on the ground, but also opens the door to people of all backgrounds and ages to explore geologic processes beneath a fossil supervolcano that is analogous to the famous active Yellowstone and Campi Flegrei calderas. It is a bimodal suite of basic and silicic volcanic and plutonic rocks that are part of a large Late Carboniferous to Early Permian igneous province that developed across Europe from Spain to Scandinavia in association with an extensive crustal rifting (Wilson et al 2004). At upper- to mid-crustal levels, the Sesia Magmatic system includes the Sesia Supervolcano and relics of a bimodal volcanic field of basaltic andesite and rhyolite, the voluminous Valle Mosso granite with volumetrically less significant basaltic to andesitic dikes and sills within it, and small intrusions of gabbro to granite along the projection of the CMB Line. At the deepest crustal levels, the Sesia Magmatic System is represented by the Mafic Complex of the Ivrea-Verbano Zone and by anatectic granitic rocks produced by partial melting of the Kinzigite Formation.

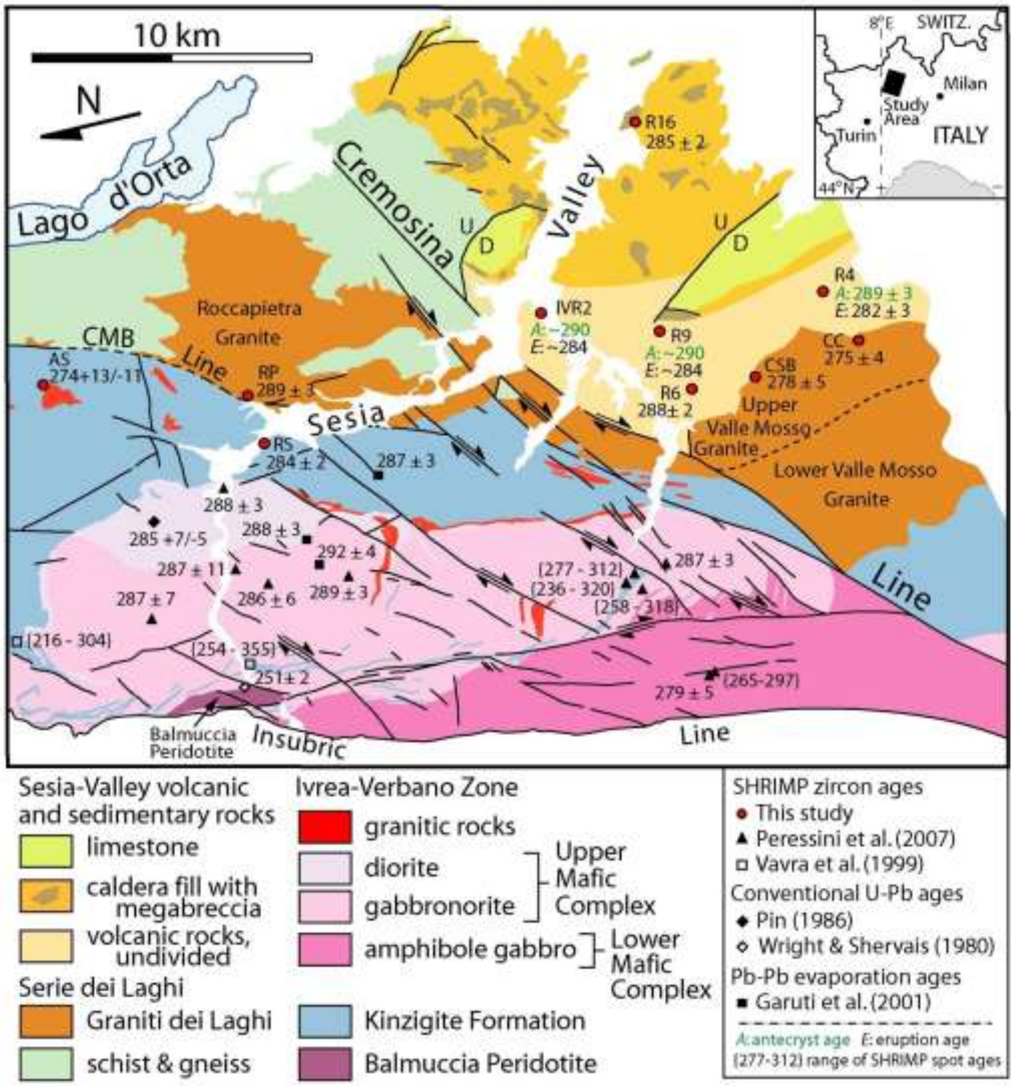

Figure 6. Geologic map showing the relationships of the principal units of the Sesia Magmatic System, including the Sesia Caldera, the Valle Mosso Granite, small granitic intrusions in the Kinzigite Formation, and the Mafic Complex (Quick et al., 2009)

The Sesia Supervolcano is one of the most significant and impressive components of the Sesia Magmatic System. Partially covered by younger sedimentary deposits of the Po plain, it is a huge rhyolitic caldera with a diameter exceeding 15 km. The estimated volume of ignimbrite erupted exceeded 300 km^3, making the caldera-forming event a "super eruption" (Quick et al., 2009). The Sesia Valley offers excellent exposures of volcanic megabreccia (proposed geosite n°24), a deposit characteristic of large calderas, in which blocks of pre-caldera volcanic and metamorphic country rocks are contained in the welded rhyolitic ignimbrite that fills the caldera. A portion of the caldera wall is preserved along which ignimbrite contains enormous landslide blocks of schist that have slid into the erupting caldera from the adjacent Serie di Laghi basement (proposed geosite n°26). Also preserved is the base of the caldera, which is intruded by coeval granitic rocks of the Valle Mosso Granite (Zezza, 1984). Ages on volcanic rocks indicate that volcanism lasted approximately 6 million years, beginning about 288 Ma and culminating in the caldera-forming eruption at about 282 Ma (Quick et al., 2009). Deposited on the caldera ignimbrite is the karstic Triassic marine carbonate of Monte Fenera, which hosts caverns utilized by Paleolithic inhabitants of the Sesia Valley.

The 6 km-thick Valle Mosso granite, which underlies and intrudes these volcanic rocks, consists of a fine-grained to granophyric "epizonal" facies with miarolitic cavities near the volcanic rocks and grades downward into a medium to coarse-grained "mesozonal facies". Major-element, trace-element and isotopic geochemistry and field relations indicate that it is a single, compositionally zoned pluton that was the source of the overlying silicic volcanic rocks. Inclusions of volcanic rock are contained within the granite near its roof, consistent with upward intrusion of the pluton into its volcanic pile. Mafic enclaves, produced by intrusions of the mafic component of the bimodal igneous suite are locally abundant at the deepest levels of the pluton.

The deepest rocks of the Sesia Magmatic System include the 8-km-thick Mafic Complex of the Ivrea-Verbano Zone (Figure 5 - 6; Rivalenti et al., 1975, 1981; Quick et al., 1992, 1994, 2003; Voshage et al., 1990; Sinigoi et al., 1994, 1996, 2010, 2011 and references therein), which intruded the deep crust around 288 Ma ago (Peressini et al., 2007). Textures and structures displayed in excellent outcrops indicate that synmagmatic deformation (proposed geosites **n°17** and **22**) accompanied the growth of this enormous intrusion, consistent with a gross arcuate fabric revealed by detailed mapping (Quick et al., 1992; 1994; 2003). The contact between the Mafic Complex and the Kinzigite Formation (proposed geosite **n°21**) is magmatic (Quick et al., 1994). During its growth, the Mafic Complex assimilated significant amounts of crustal material (Voshage et al., 1990; Sinigoi et al., 1995, 1996, 2011). Relicts of largely digested crustal layers, incorporated into the Mafic Complex and stretched during its growth (proposed geosite **n°18**), are clearly visible in the field. Also visible in the field is the intrusive contact of the Mafic Complex (proposed geosite **n°21**) along which heat released by the crystallizing Mafic Complex drove anatexis of the Kinzigite Formation, producing migmatites within 1 to 2 km from the intrusion (Snoke et al. 1999; Barboza and Bergantz 2000). Residual melt from the Mafic Complex and silicic melt generated by anatexis migrated to higher crustal levels where they crystallized small granitic sills and stocks (proposed geosite **n°23**) and the Valle Mosso Granite at higher crustal levels, and erupted to form the bi-modal volcanic complex at the top of the section.

The Serie dei Laghi

The Serie dei Laghi is composed of four main units (Boriani et al., 1990b), the Strona-Ceneri Zone, the Strona-Ceneri Border Zone, Orthogneisses, and the Scisti dei Laghi. Remnants of the Permian volcano–sedimentary cover of the Serie dei Laghi occur near Arosio in Switzerland (Reinhard, 1964), where they lie horizontally over the Strona–Ceneri rocks.

The Strona-Ceneri Zone is an amphibolite-facies metapsammitic sequence which comprises fine-grained massive gneisses (Gneiss Minuti) as well as medium to coarse-grained gneisses (Cenerigneisses). The Gneiss Minuti (Hornfelsgneise in the Swiss literature due to their granoblastic texture) are finely layered metasandstones with abundant calc-silicate lenses (beautifully exposed along the Cadorna road; proposed geosite **n°8**). Near the orthogneiss bodies they contain thin meta-aplites and metapegmatites. The Cenerigneisses (proposed geosite **n° 9**) are coarse-grained to conglomeratic gneisses containing a diversity of clasts, including calc-silicate nodules similar to those occurring in the Gneiss Minuti. These nodules are zoned (with Grt, Px, Hbl and Bt from core to rim; Boriani and Clerici Risari, 1970) and are interpreted as the metamorphic product of dolomite concretions, typical of many arenitic deposits (Figure 7).

Figure 7. Folded lens of calc-silicate in a Cenerigneiss

Petrography, geochemistry and field relations of the Strona-Ceneri metasediments support the interpretation of Gneiss Minuti and Cenerigneisses respectively as well sorted deposits from turbidity currents and as mass flow turbidites, deposited in an accretionary prism (Boriani et al., 1997; Caironi et al., 2004). Near the orthogneiss lenses, the Cenerigneisses acquire an augen texture due to the increasing presence of K-feldspar porphyroclasts; they could be the product of "melt infiltration and infiltration metasomatism" related to the Ordovician intrusions (Pinarelli et al., 2008).

The Strona-Ceneri Border Zone (Giobbi Origoni et al., 1997) forms a continuous horizon, one to several hundreds of meters thick, between the Strona-Ceneri Zone and the Scisti dei Laghi. It mainly consists of banded amphibolites, with lenses of ultramafites, metagabbros and garnet bearing amphibolites (retrogressed eclogites) and minor intercalations of paragneisses. The banded amphibolites (Giobbi Mancini et al., 2003) consist of cm-scale alternating dark (fine-grained amphibolites) and leucocratic layers (leptynites). They represent an example of LAG (Leptynite - Amphibolite Group), an association which is widespread throughout the Hercynian belt in Europe; it is formed by tuffites of alternate mafic and acidic composition deposited in a marine environment. Like the Cenerigneiss, the amphibolites grade into Bt - Hbl augengneiss towards the contacts with the Ordovician granitoids, suggesting the same infiltration mechanism (Pinarelli et al., 2008).

Banded and feldspar-bearing amphibolites are well exposed at Ponte Nivia (proposed geosite **n°7**) and along the Cadorna road (proposed geosite **n°6**).

The orthogneisses form large lens-shaped bodies accompanied by meta-pegmatite, meta-aplite and augen gneisses, mainly located within or close to the SCBZ. They range in composition from tonalite to granite (Pezzotta and Pinarelli, 1994) and show a calcalkaline affinity and mainly metaluminous character (Caironi, 1994; Boriani et al., 1995 with references). They were emplaced in the Ordovician around 450 – 460 Ma (Köppel and Grünenfelder, 1971; Boriani et al., 1982/83) and suffered the same Variscan regional metamorphism as their country rocks, recorded by mineral ages of 311 – 325 Ma (Boriani et al., 1995). The orthogneisses are well exposed along the Cadorna road at Ospedaletto and Mt Vadà.

The Scisti dei Laghi occur over a large area from Lago d'Orta to Lago Maggiore, near Verbania and, on the eastern shore of the lake, near Luino, were they are cut by the Val Colla-Cremosina fault. This unit corresponds to the Giumello gneise" in the Swiss literature (Reinhard, 1964). The Scisti dei Laghi consist of alternating micaschist and paragneisses, strongly foliated, with isoclinal folds. They contain typical quartz rods. A beautiful exposure of these micaschists is in the bed of the S.Bernardino river (proposed geosite **n°5**).

The CMB and Pogallo Lines

The contact between Ivrea-Verbano Zone and Serie dei Laghi occurs through an important subvertical tectonic lineament (Boriani et al., 1990a): the Cossato-Mergozzo- Brissago Line (CMB), characterised by the simultaneous occurrence of three distinctive features: high-T mylonites, basic-to acidic dykes and stocks (the «Appinite Suite») and migmatites. The line is dissected by later discontinuities, among which the most important is the Pogallo Line. The Pogallo Line is characterised by amphibolite to greenschist facies mylonites. The amphibolite facies mylonites related to the Pogallo Line may be observed in Val Pogallo (proposed geosite **n°12**).

A swarm of mainly mafic small stocks and dykes is intruded in a belt along the CMB Line. They are called Appinites after the Appin County in Scotland where similar rocks occur (although of different age). Between the Sesia and the Ossola valleys Appinites mostly form stocks of gabbrodioritic to granitic composition which, in some cases (Quarna, Alzo - Roccapietra), are strictly connected with the large granitic plutons occurring more to the south. Appinites also occur in the IV zone, although less abundant than in the Serie dei Laghi. In Val Cannobina (proposed geosites **n° 10** and **11**) the fine grained dykes show chilled margins (a grain size decrease) towards the contact with the country rocks, suggesting that the latter were cold enough to induce rapid cooling of the magma. The dykes are mostly concordant with the CMB mylonitic foliation, but some small dykes are subparallel to the Pogallo fault. The best estimates on the intrusion age of the Appinites are an U-Pb age of 285 ± 5 (Köppel and Grünenfelder, 1978-79) on a monazite from a dyke near Mergozzo and an U-Pb upper intercept of 275-285 Ma on discordant zircons (Mulch et al., 2002).

The Canavese Line

The Canavese Line is the westernmost stretch of the Insubric Line (Figure 3), a major alpine lineament that marks the boundary between the Central Alps, consisting of intricated refolded basement nappes (Milnes, 1974), and the Southern Alps with S-vergent thrusts (Laubscher, 1985). The Insubric Line accommodated a vertical uplift on the order of 10 to 20 km, since it juxtaposes the Alpine metamorphic rocks of the Central Alps with the pre-Alpine metamorphosed basement of the Southern Alps and its volcano - sedimentary cover (Niggli and Zwart, 1973; Frey et al., 1974).

In the area of the proposed Geopark, the Canavese Line consists of a 1 km thick greenschist facies mylonite belt. The mylonite sare derived (from S to N) from: a) Ivrea-Verbano rocks; b) Permo - Mesozoic cover rocks (Canavese Zone); and c) the Sesia Zone (Central Alps).

The progressive mylonitization of the Ivrea-Verbano rocks is well documented in Val Loana) the rocks are transformed into greenschist facies mylonites and phyllonites containing amphibolite-facies mineral relics (diopside and actinolite in the impure marble exposed at Lago del Marmo). The metasedimentary sequence of the Canavese Zone, including quartz-mica-rich clastic sediments (Permo-Triassic), dolomites (Triassic), and silicious limestones (lower Jurassic?), is dismembered and often imbricated with or folded into the Ivrea-Verbano-derived mylonites and thin ophiolitic lenses; members of this sequence may be observed in Val Loana. The phyllonites derived from the Sesia rocks (mostly orthogneisses) are exposed near the castle of Vogogna (proposed geosite **n°13**).

3. Listing and description of geological sites within the proposed Geopark, in terms of their international, national, regional or local value

The locations of the following geosites are shown in Figure 8

I= international value; N= national value; R= regional value

1. CHURCH OF ALBO (I): One of the main units of the Ivrea-Verbano Zone
2. CANDOGLIA (I): quarries of the pink marble of the Cathedral of Milano
3. PREMOSELLO (I): contact between continental mantle and lower continental crust
4. FINERO (I): one of the most studied mafic - ultramafic body of the world
5. BED OF THE SAN BERNARDINO RIVER (N): Scisti dei Laghi, an important Italian metamorphic unit
6. CADORNA ROAD: PIAN D’ARLA – OSPEDALETTO (I): the Leptynite – Amphibolite Group is very widespread in the European Hercynian belts
7. PONTE NIVIA (I): the Leptynite – Amphibolite Group is very widespread in the European Hercynian belts
8. CADORNA ROAD: P. FOLUNGO - MT. BAVARIONE (I): this is a complete section of the Strona-Ceneri Zone, a unit that has been investigated by many European scientists
9. PONTE CASLETTO (I): Cenerigneisses are a good example of metasediments with very complex evolution
10. SPOCCIA – ORASSO (I): the relations between the CMB line and the mafic Intrusion; the Appinite suite may be compared with similar rocks in Scotland.
11. ROAD PONTE SPOCCIA – SPOCCIA (I): the relations between the CMB line and the mafic Intrusion; the Appinite suite may be compared with similar rocks in Scotland.
12. POGALLO VALLEY (I): the Pogallo line
13. CASTLE OF VOGOGNA (I): mylonites of the Insubric (Canavese) line
14. PREMOSELLO – VOGOGNA (I): “fossil earthquakes
15. SCOPETTA - old bridge over the Sesia river (I): Mylonite of the Insubric Line.
16. BALMUCCIA (I): one of the best preserved mantle peridotites in the world.
17. VOCCA Near the village of Isola(I): High-temperature deformation of gabbro.

18. VOCCA near the bridge on the Gavala stream(I): Crustal rocks incorporated in the Mafic Complex.
19. ANICETI – VARALLO (I): The upper Mafic Complex where igneous structures are best preserved.
20. BOCCIOLARO (I): mingled diorite and mafic enclaves crops transition between main gabbro and Diorites.
21. CREVOLA-VARALLO (I): Mafic Complex – Kinzigite Formation contact.
22. VALSESSERA- LA FRERA (R): synmagmatic normal faults cross-cutting recrystallized and foliated gabbro.
23. Under the bridge of AGNONA (I): Mingling of mafic and acidic rocks boundary of lower and upper crust.
24. PRATO SESIA (I): Caldera Megabreccia.
25. PIANCONE(I): paragneiss layers, with norites, quartz-norites, charnockites and restitic paragneiss septa.
26. GARGALLO (I): caldera fill and caldera wall.
27. MONTE ROSA massif and its glaciers (N): granitic massif, glaciers and related landforms.
28. MONTE ROSA GOLD MINES (I): gold veins and ancient mining structures.
29. STOFFUL (R): talc-bearing serpentinites “pietra ollare”.
30. CIMALEGNA (N): high mountain geological-pedological track.
31. WOLD – FUN D’EKKU (R): glaciological track.
32. BOCCIOLETO (R): peculiar landform and genesis of the Giavine rock Tower.
33. UNIPIANO(R): Varallo: paleo-valleybottom during the last glaciation.

The following geosites under preparation at present or for future development

I= international interest; N= national interest; R= regional interest, Local interest

- BETTOLE (R): Limestone quarry and lime furnace, contact with Permian vulcanite.
- ARA “Giardino delle Grotte” (R): Magiaca river inside the limestone caves.
- MONTE FENERA (N): peculiar limestone “island” in the NW Alps, significant karst structures.
- MONTE FENERA CAVES (I): : complex karst system with relevant paleontological and archeological finds.
- PIEVE VERGONTE (R): Val Toppa gold mine
- ORNAVASSO (R): Quarries of the pink marble.
- VAL LOANA (near “Le cascine”) (L): Talc-bearing serpentinites “pietra ollare”.
- VAL LOANA (L): Limestones of the Canavese Zone.
- VAL LOANA (lago del Marmo) (R): Marble of the Ivrea-Verbano Zone.
- NIBBIO (N): Amphibolites of the Ivrea-Verbano Zone.
- PIAN D’ARLA (R): “Scisti dei Laghi” and view of Mt Zeda.
- CADORNA ROAD (M.Vadà) (N): Augengneiss.
- OSPEDALETTO (N) : Orthogneiss.
- MERGOZZO (I): White and green granites – granite ecomuseum.
- BALMUCCIA – VOCCA (beneath Cima Lavaggio) (I): Contact between mantle peridotite and Mafic Complex.

- DINELLI (along the Sesia river canyon): Pseudotachylite breccia.
- VOCCA-VALMAGGIA (R): abandoned nickel mines.
- GAMBERARO (N): Granitic dykes inside the kinzigite formation.
- ROCCAPIETRA (N): White Granites and CMB Line.
- VAL STRONA DI STRONA (R): Roof of the Mafic Complex.
- VALDUGGIA (R): Scisti dei Laghi is an important Italian metamorphic unit.
- MT. CAPIO (R): nickel ore mines inside the Mafic Complex.
- CAMPELLO MONTI (L): Nickel ore mines.
- VALLE MOSSO (N): lower contact of Valle Mosso granite intruded by mafic dykes.
- SAN BONOMIO (N): upper Valle Mosso granite whic intruded the volcanic rocks.
- RIMELLA (L): soapstone “pietra ollare” quarry.
- CAMPERTOGNO (R): fingering between alluvial deposits and debris fan.
- BOCCORIO (R): grey-green paragneiss with albite, two-mica end epidote.
- STOLEMBERG (N) : contact between the Monte Rosa micaschyst and eclogites-amphibolites.
- SCOPELLO (N): metamorphic rocks rich in glaucofane in Blueschist-eclogitic facies.
- RASSA (L): Alpe Massucco white marble quarry.
- MADONNA DELLA NEVE (L): Mignamitized Kinzigite Formation with petroglyphs.
- LOCARNO (L): Pink Marble quarry.
- PIODE – PIETRE GROSSE (L): huge blocks of landslide.
- VARALLO – CILIMO (R): Ophilcalcite quarry on a huge glacial boulder.
- VAL D’OTRO: one of the most beautiful hanging valley from last glaciation.
- VARALLO – CIVIASCO (R): marble and para-schyst in the kinzigite formation.
- PIODE-MOLLIA-RASSA (L): orthogenesis and metagranites with large feldspars crystal.
- ISOLELLO (R): contact between the second dioritic-kinzigtic zone and the Sesia Lanzo zone.
- RIVA VALDOBBIA (Val Vogna) (L): well preserved outcrops of the second dioritic-kinzigtic zone.
- VARALLO (Sacro Monte): paleo-valleybottom during the last glaciation.
- LAGO di SANT’AGOSTINO: spill way channel.
- ALAGNA: abandoned Mn mine.
- BALMUCCIA: geomorphological evidence of the Insubric Line.
- RIMELLA (I): one of the best outcrops of mylonites of the insubric line.
- PONTE DELLA GULA: canyon inside the diorite formation and well preserved diorite outcrops.

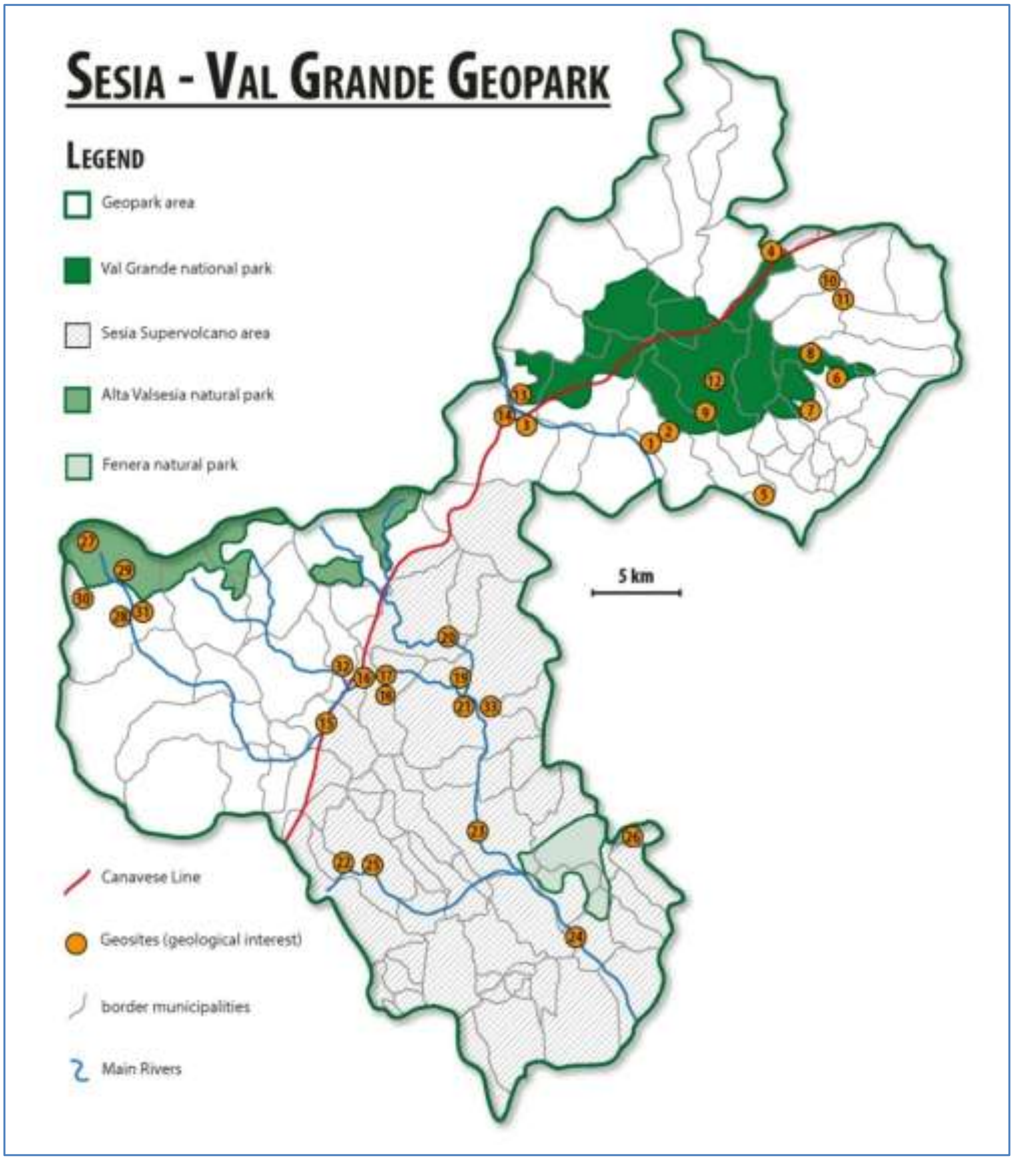

Fig. 8 Locations of the following geosites

4. Details on the interest of these sites

Val Grande

The proposed geosites are grouped according to the main geological themes. Here we give a brief description of the proposed geosites with more detailed descriptions provided in Annex 6: List and detailed description of existing and proposed geosites.

Ivrea-Verbano Zone. Although the Ivrea Verbano Zone is much better exposed in the Sesia area, some interesting outcrops may also be found in the Valgrande area. Typical kinzigites containing lenses and pods of pegmatite, due to incipient partial melting, may be easily observed in an outcrop near the church of Albo (geosite **n°1**). In the nearby village of Candoglia (geosite **n°2**), the famous pink marble used for the cathedral of Milan is exposed in thin intercalations within the kinzigites; the main quarry (Cava Madre) may be visited only asking permission to the

Fabbriceria del Duomo, owner of the quarry. The same marble may be also seen at Ornavasso. At Premosello, at the foot of the mountain slope in the western part of the village, an extraordinary outcrop (geosite **n°3**) shows the contact between lithospheric mantle rocks and the lower continental crust. The mantle is represented by a serpentinized peridotite, in the lower part of the outcrop; the lower crust is represented by a mafic granulite, in the upper part of the outcrop. The contact surface represents the Mohorovicic discontinuity, i.e. the crust / mantle transition. At the northern tip of the Ivrea-Verbano Zone, the famous Finero Complex (geosite **n° 4,** Figure 9) represents one of the mantle peridotite lenses tectonically interfingered with the metasediments. It consists of a peridotite slice enveloped into an intrusive magmatic sequence of mafic and ultramafic rocks. The main peridotite is well exposed in a quarry at Ponte Creves, whereas the mafic rocks crop out on the footpath from Ponte Creves to Provola.

Serie dei Laghi. Most of the territory of the existing Valgrande National Park is formed by these rocks. The metapelitic unit Scisti dei Laghi may be observed near Santino, in the bed of the S.Bernardino river (geosite **n° 5**). In this outcrop, the micaschists display original sedimentary features, such as alternate clay rich and arenaceous layers and typical quartz rods; multiple phases of plastic folding may also be observed. The different rock types forming the Strona-Ceneri Zone may be observed along a cross section following the Cadorna road, an old military road. The main horizon of the Strona-Ceneri Border Zone may be observed between Pian d'Arla and Ospedaletto. On an excellent outcrop (geosite **n° 6**) we can observe the banded amphibolites: this association of dark and light layers forms the typical "Leptynite - Amphibolite Group", widespread throughout the Hercynian belt in Europe. This association derives from the metamorphism of alternating mafic and acidic volcanic pyroclastic rocks deposited as tuffites in a marine environment. Similar amphibolites, grading into K-feldspar bearing varieties on approaching the orthogneisses, may be observed in another locality outside this itinerary (Ponte Nivia; geosite **n° 7**). Leaving the cars at Passo Folungo and walking on the road along the western slope of Mt Bavarione (geosite **n° 8**), we first meet the augengneisses, which are here strongly laminated (flaser gneiss). Then we find the Gneiss Minuti, with beautiful similar folds and calc-silicate nodules. In the last ten of meters before reaching the southern tip of the road the outcropping rock (here the Cenerigneiss) is mostly transformed by pre-glacial weathering processes in a coarse residual sand. The spectacular characters of the Cenerigneiss are better observed outside this area, at Ponte Casletto, in the bed of the Valgrande creek near Cicogna (geosite **n° 9**).

Rocks related to fault zones.

Cossato - Mergozzo - Brissago Line. Mylonites related to the CMB line are exposed on the Spoccia - Orasso footpath (Val Cannobina; geosite **n° 10**). The schistose rocks with subvertical attitude are intruded by nearly concordant mafic dykes (Appinite). A similar situation is observed on the road Ponte Spoccia - Spoccia (geosite **n° 11**), were the mafic dykes often show chilled margins, indicating rapid cooling of the magma against the much colder country rocks.

Pogallo Line. The mylonites related to the Pogallo Line (geosite **n° 12**) are very fine-grained dark rocks, in which are visible small white, more-or-less flattened lens-like crystals; the latter are minerals which behaved in a brittle way inside the plastic matrix during mylonitization. The mule track along the Pogallo valley also crosses the Gneiss Minuti, Cenerigneiss and orthogneiss before reaching the mylonites.

Canavese Line. Phyllonites related to this line are exposed near the Vogogna castle (geosite **n° 13**); they probably derive from orthogneisses of the Sesia Zone; the widespread occurrence of chlorite indicates temperatures around 450° during mylonitization.

A peculiar rock also related to a fault is the pseudotachilite, which can be observed at the foot of the slope at the municipal border between Premosello and Vogogna (geosite **n° 14**). Pseudotachylites are considered “fossil earthquakes”: they are found along seismogenetic faults and are the product of instantaneous quenching of a melt formed by heat generated by extreme friction along a fault. The appearance of the melt reduces friction to zero, producing the earthquake. The melt injected in fractures forms glass veins cementing the brecciated original rock (in this outcrop the rock is a mafic granulite belonging to the Ivrea-Verbano Zone).

Supervolcano plumbing system

Ten out of the twelve geosites proposed for this area are stops of the classical one-day excursion along the exposed plumbing system of the fossil supervolcano, a “journey from the centre of the earth,” which leads visitors to observe igneous and metamorphic rocks that were formed or recrystallized at depths as deep as 25 kilometres beneath the caldera at the time when the volcanic field was active. These rocks are tectonically bounded by the mylonites of the Insubric Line, which is well exposed at geosite **n°15**. From this point, visitors travel progressively upward through the crustal section to increasingly more shallow crustal levels, finally arriving at the megabreccia which constitutes the caldera fill of the Sesia Supervolcano. At geosite **n°16**, visitors stand on outcrops of the famous Balmuccia peridotite, one of the best-preserved outcrops of mantle rocks in the world, where a network of pyroxenite dikes record a complex story of multiple events of partial melting and generation of basaltic magma (of unknown age). Continuing up section, visitors enter the huge Mafic Complex, which intruded the deep crust at around 288 Ma. Gabbroic rocks of the Mafic Complex exposed at geosite **n°17** were penetratively deformed at very high temperature (hypersolidus) conditions, during the growth of the igneous body. Layers of crustal rocks were incorporated in the Mafic Complex and melted extensively, resulting in the strongly depleted granulites observable at geosite **n°18**. At higher crustal levels, gabbroic rocks at geosite **n°19** preserve igneous structures and underwent only minor high-T deformations because they were located in the roof of the growing Mafic Complex. At geosite **n°21** visitors can see the primary contact between the Mafic Complex and the country rocks, along which a spectacular migmatite was formed by melting of the country rocks in amphibolites facies, but under conditions of lower temperature with less complete removal of anatectic melt than at geosite **n°18**. Continuing up section, the excursion cross-cuts the upper-crustal section, reaching geosite **n°23**, where mingled granitic and gabbro-dioritic rocks (“appinites”) were intruded along the CMB Line. The classical excursion ends at geosite **n°24**, were visitors can see a spectacular outcrop of the megabreccia produced by the super-eruption of more than 300 km^3 of ignimbrite accompanying caldera collapse at about 282 Ma.

The visit of additional geosites requires a second day excursion. Compelling examples of synmagmatic deformation at the lowermost levels of the Mafic Complex can be seen in Val Sessera at geosite **n°25** and the caldera wall can be observed in proximity of Gargallo at geosite **n°26**. Possible geosites of outstanding quality in Val Sessera, Valle Mosso and Val Strona di Postua are not described here due to limitations on the length of the dossier, but are frequently visited by groups of students and researchers in geology.

Additional geosites

Seven geosites(**n°27** to **n°33**) in which the main scientific interest is the geomorphology, pedology and mining activity are located in the area of Alta Valsesia, and are described in detail in Annex 6

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