**Geological map of the middle Orco Valley, Western Italian Alps.**



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**Geological map of the middle Orco Valley, Western Italian Alps**

Ivano Gasco*, Marco Gattiglio

Dipartimento di Scienze della Terra, Università degli Studi di Torino, Via Valperga Caluso 35, I-10125 Torino, Italy

* Corresponding Author: Phone: +39 011 6705335; Fax: +39 011 6705339; E-mail: ivano.gasco@unito.it

**Abstract.** Detailed mapping of the middle Orco Valley in the western Italian Alps allowed for the reconstruction of the lithostratigraphy and the structural evolution of different tectonic units along a geological section from the Gran Paradiso Massif to the Gneiss MinutiComplex of the Sesia-Lanzo Zone. The studied nappes can be grouped into a Lower Tectonic Element which underwent eclogite facies metamorphism and an Upper Tectonic Element pervasively equilibrated under greenschist facies conditions and lacking evidences of high pressure metamorphism. The mapping of Quaternary deposits, geo-morphological features and brittle structural elements provided evidence for the occurrence of a deep-seated gravitational slope deformation on the left side of the middle Orco Valley.

## 1. Introduction

The middle Orco Valley is located in the Western Italian Alps *ca* 50 km north-west of Torino (Fig. 1a) where it exposes from bottom (west) to top (east) a geological section from the Gran Paradiso Massif (Compagnoni *et al.,* 1974) through the Piedmont Zone (for a review see Michard *et al.,* 1996; Dal Piaz, 1999) and up to the Sesia-Lanzo Zone (Compagnoni *et al.*, 1977). The Gran Paradiso Massif represents one of the three Internal Crystalline Massifs (the other two are the Dora-Maira and the Monte Rosa) originating from the Briançonnais terrain, or from the European distal margin, while the Sesia-Lanzo Zone is part of the Austroalpine Domain, representing the distal Adriatic margin (Avigad *et al.*, 1993) or is interpreted as an extensional allochthon within the Piemont-Ligurian ocean (Froitzheim *et al.*, 1996). These two continental units are separated by the Piedmont Zone representing the remnants of the Alpine Tethys (Dal Piaz, 1999).

The relative age of the tectonic coupling between oceanic lithosphere and continental crust units is still under debate: Lapen *et al.* (2007) proposed that the Monte Rosa-Gran Paradiso Massifs and the Zermatt-Saas Unit were coupled under eclogite facies conditions and were then exhumed together by a buoyancy-driven process. Instead Kassem and Ring (2004) proposed that the Gran Paradiso was early coupled to the Zermatt-Saas Unit during the subduction stage before reaching eclogite facies stage. On the contrary, Pleuger *et al*. (2005) suggested tectonic coupling between the Monte Rosa Massif and the Zermatt-Saas Unit before the greenschist facies metamorphic re-equilibration. A more complete description of the metamorphic ages and PT conditions reached by the studied units is reported in Gasco *et al.*, (2009).

The geological map covers an area of 35 $km^2$ located north of the village of Locana (Fig. 1b) across two adjacent valleys: the northern side of the middle Orco Valley and in the Ribordone Valley up to the watershed with the Soana Valley.

In this area, three different paleo-geographical units were investigated from bottom to top: the Gran Paradiso Massif , the Piedmont Zone and the Gneiss-Minuti Complex of the Sesia-Lanzo Zone and different deformation phases were identified. The aim of this study was to reconstruct the tectono-metamorphic evolution of these three geological units and to investigate their tectonic boundaries. In this work we present a geological map containing information on the bedrock lithostratigraphy, tectonic structures, fracture systems, Quaternary cover, and the neo-tectonic features.

The geological map accompanying this paper is the result of a Master's Degree thesis that was initially conducted in 2005. The map was then revised in 2007-2008 as part of a PhD thesis.

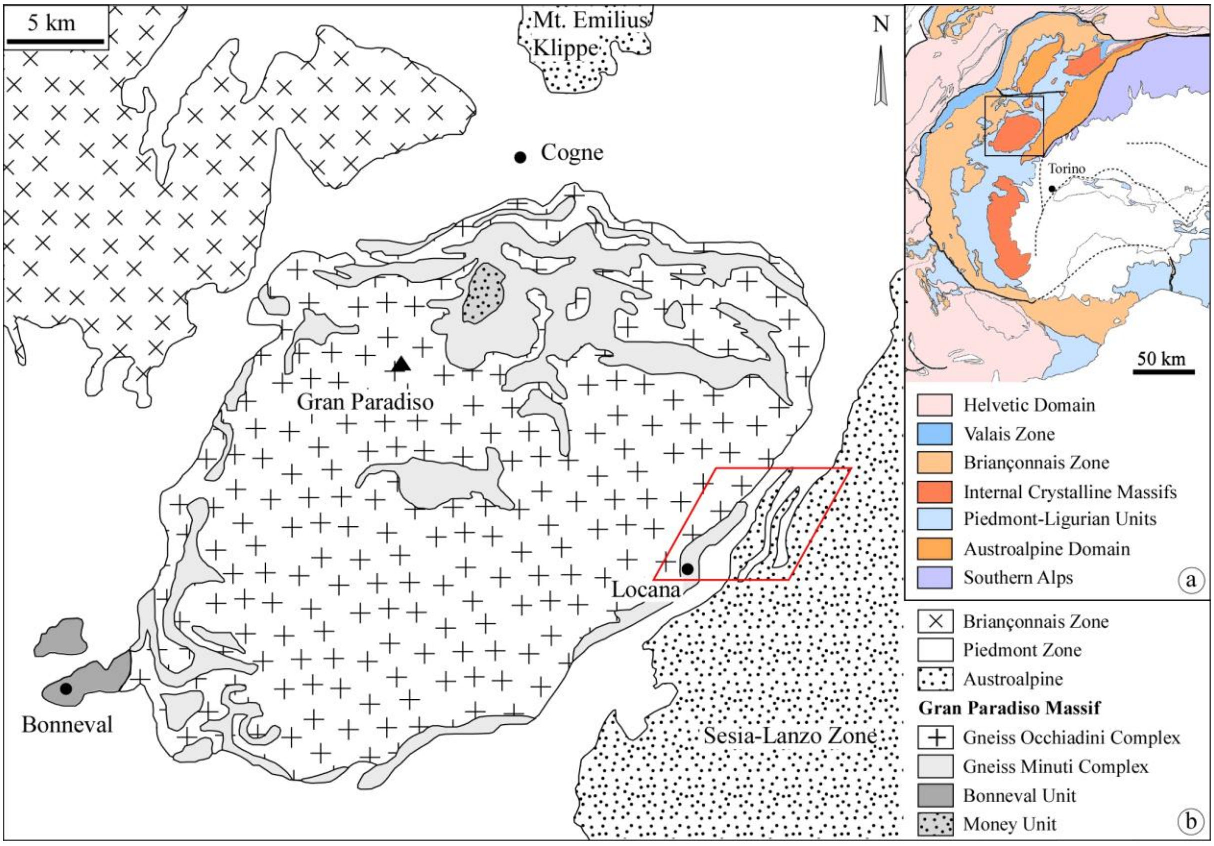



**Fig. 1.** a) Simplified tectonic map of the western Italian Alps (modified after Schmid *et al.*, 2004). b) Simplified geological map of the Gran Paradiso Massif (GP) and surrounding units (modified after Compagnoni and Lombardo, 1974). The location of the study area on the eastern margin of the GP is indicated with a red box.

## 2. Methodology

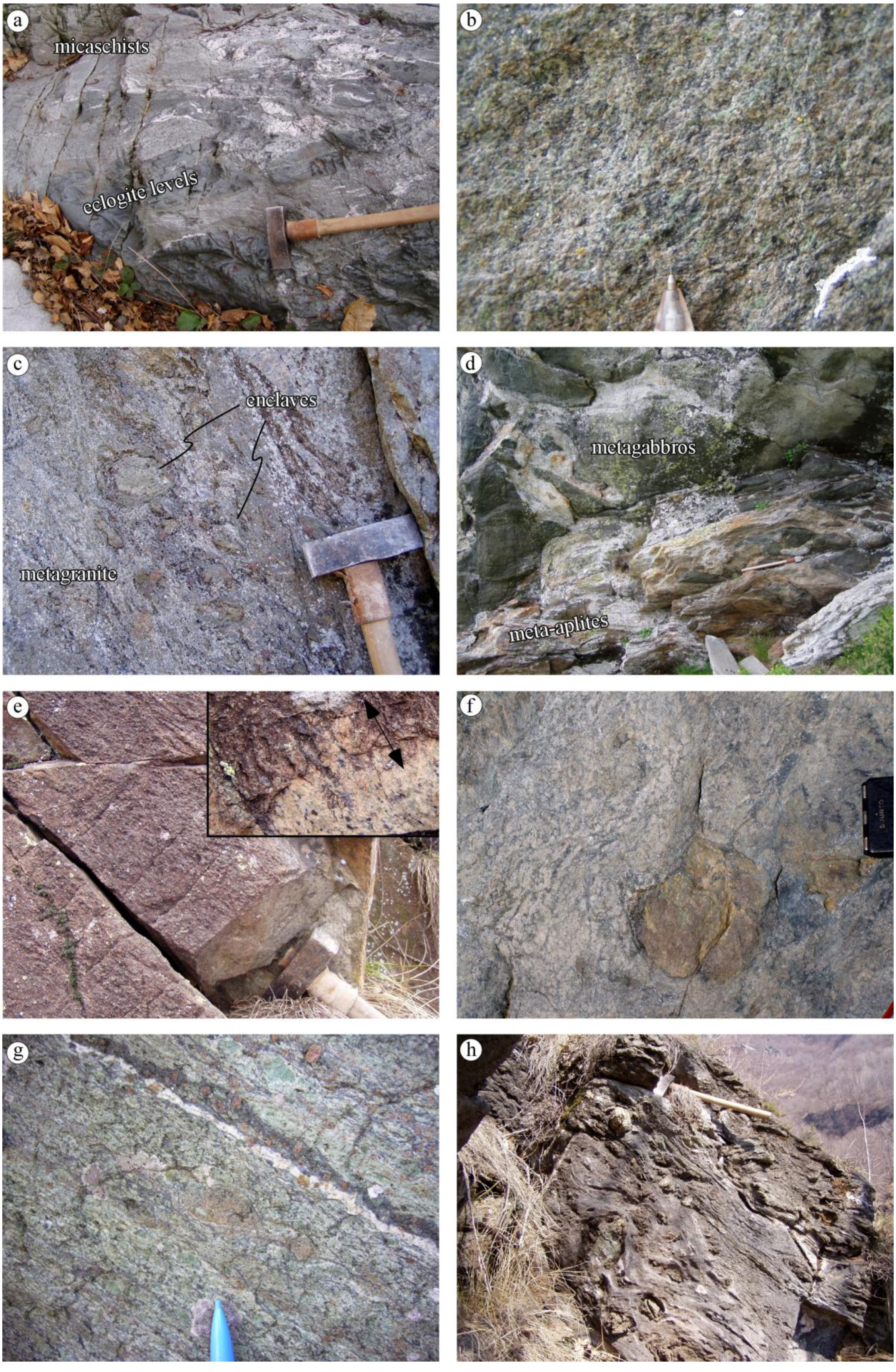
Geological mapping was performed at a 1:10,000 scale using the topographic maps (Carta Tecnica Regionale) released by the Regione Piemonte (authorization n. 4/2010). In the field, the regional foliation, i.e. the most pervasive metamorphic surface developed in rocks, was considered as the reference foliation for the reconstruction of the structural evolution and was named $S_1$. It is subparallel to the lithological layering and represents a composite foliation generated by the transposition of an older metamorphic surface which is locally still possible to recognize. Lithologies, structural data and geomorphological features were drawn and stored using ArcGIS 9 from which a TIFF image of the geological map was exported. This raster output was then imported into Canvas X to assemble the final geological map at the 1:10,000 scale as presented here. The cross sections were drawn orthogonal to the overall trend of the nappe contacts and of the regional foliation, and the alignment diagram of Nevin (1949) was used to determine the apparent dip of the regional foliation. The stereo diagrams are equal-area projections plotted in the lower hemisphere with the software Stereonett and represent the structural features related to the different deformation phases identified and to the sets of fractures/faults. Abbreviations are as follows: S for syn-metamorphic surface or axial surface of folds, L for stretching lineations and A for fold axes and intersection lineations, while subscript numbers are related to the different deformation phases identified. Minerals abbreviations were assigned according to Kretz (1983) with the update of Bucher and Frey (2002).

## 3. Lithostratigraphy

The tectonic units investigated, from west to east and from the lower to the upper structural level of the Alpine chain, are as follow: the Gran Paradiso Massif, the Piedmont Zone and the Sesia-Lanzo Gneiss Minuti Complex. In agreement with literature (for a review see Dal Piaz, 1999) the Piedmont Zone was separated into two units: the lower one which shows many similarities with the Zermatt-Saas Unit and the upper one which instead displays an affinity with the Combin Zone.

The Gran Paradiso Massif consists of orthogneisses, Grt-bearing micaschists and rare Mesozoic cover (quartzites and dolomitic marbles respectively outcropping N of Schiaroglio and along the Rio Furà at 930 and 1200 m) preserved near the tectonic contact with the overlying Lower Piedmont Zone. The orthogneisses are heterogeneously deformed owing to strain localisation during the Alpine orogeny and show different textures ranging from isotropic rocks with magmatic structures perfectly preserved, to augen-gneisses, to flaser-gneisses. Locally, thin layers of whiteschists which developed along Alpine high-pressure shear zones are present and are transitional to augen-gneisses. The Grt micaschists host metabasites bodies (Fig. 2a) consisting of up to 1 metre-size lenses or layers of fine-grained eclogites, and up to 100-150 m thick fine- to medium-grained metagabbros that locally preserve eclogite facies assemblages (Fig. 2b). Pre-Alpine intrusive contacts between the orthogneisses and metapelites are locally well preserved and comprise magmatic breccias consisting of fine-grained meta-granite with enclaves of metapelites (Fig. 2c) or metabasites (Fig. 2d). Clear magmatic contacts between metagabbros and metapelites have not been identified, but intrusive relationships between metagabbros and orthogneisses occur near Alpe Arzola in the Ribordone Valley, where medium-grained eclogitic metagabbros lenses are cut and enveloped by fine-grained aplitic-dykes (Fig. 2d). These outcrops suggest that metagabbros are older than orthogneisses, as already inferred by Biino and Pognante (1989) in the southern part of the Gran Paradiso Massif.

The Lower Piedmont Zone is a stack of nappes formed by ultrabasic and/or basic rocks with minor carbonatic-pelitic cover sequences. The ultrabasic bodies mainly consist of serpentinites that envelop 10 to 100 m thick lenses of metamorphosed spinel-lherzolites, showing a well preserved pre-Alpine mantle foliation (Fig. 2e). Small bodies of metagabbros rarely occur within the ultrabasic rocks. The basic bodies mainly consist of three rock-types: epidote-albite amphibolites with eclogite relics, metagabbros (light-coloured Act + Zo + Wm rocks, Fig. 2f) and well-preserved eclogites (Fig. 2g). The Mesozoic sedimentary sequences of the Lower Piedmont Zone are poorly preserved or developed, show a maximum thickness of 10 m and are very heterogeneous in composition consisting of marbles, silicate marbles, calcschists (Fig. 2h), micaschists and impure quartzites. These lithologies are transitional to each other and locally are inter-layered at the decimetre-scale and therefore they cannot be differentiated on the geological map.


a
micaschists
eclogite levels
b
c
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d
metagabbros
meta-aplites
e
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g
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**Fig. 2.** Main rock types of the Gran Paradiso Massif: a) folded eclogite lens within GP basement micaschists; b) well preserved eclogite facies assemblage (Grt + Omp) in the metagabbros; c) magmatic breccias consisting of metapelite enclaves in a medium-grained metagranite; d) meta-aplites enveloping and crosscutting metagabbros. These structures are interpreted as preserved magmatic relationships suggesting that granitoids have intruded the gabbros. Main rock types of the Lower Piedmont Zone: e) meta-peridotites showing a well preserved mantle foliation. The inbox shows the foliation defined by black magnetite aggregates on ex spinel and by green Cpx; f) light-coloured Mg-Al metagabbro with Fe-Ti eclogite enclaves; g) well preserved eclogite facies assemblage (Grt + Omp + Gln) in metabasite; h) carbonate rich calcschists with marbles and micaschists clasts. Outcrops coordinates are given in Table 1.

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| Fig. 2 | X | Y | Fig. 3 | X | Y | Fig. 4 | X | Y |
|---|---|---|---|---|---|---|---|---|
| a | 379150 | 5031478 | a | 381789 | 5029875 | a | 380284 | 5032170 |
| b | 380359 | 5033486 | b | 381834 | 5029859 | d | 380737 | 5030717 |
| c | 378514 | 5031583 | c | 385126 | 5032071 | f | 380814 | 5030572 |
| d | 380381 | 5033401 | d | 383175 | 5029782 | g | 380674 | 5030769 |
| e | 379836 | 5031142 | e | 382818 | 5032250 | | | |
| f | 381134 | 5030493 | f | 383999 | 5036457 | | | |
| g | 381031 | 5030716 | | | | | | |
| h | 380778 | 5030810 | | | | | | |

**Table 1.** Map coordinates (in meters) of the pictures of Fig. 2, 3 and 4 given in the UTM 32N European Datum 1950 system.

The Upper Piedmont Zone is mainly composed of calcschists (Cal + Qtz + Wm + Ab in different proportions) with up to 50 m thick bodies of greenstones, serpentinites/ophicalcites and gneissic rocks (Qtz + Ab + Wm + Chl).

The Gneiss Minuti Complex of the Sesia-Lanzo Zone represents an heterogeneous continental crust with subordinate Mesozoic cover (Gasco et al., 2009). It mainly consists of homogeneous intermediate to acidic orthogneisses (Fig. 3a) and their monzodioritic to granodioritic protoliths (Fig. 3b) associated with minor leuco-gneisses interpreted as meta-aplites. Layered gneisses made up of alternating Qtz-rich and phyllosilicate-rich levels possibly represent detrital layers because they are devoid of meta-aplites and other meta-magmatic rocks. If this interpretation is true, the Qtz-rich and Chl-rich levels are meta-arkoses and metapelites, respectively. Other minor rock-types are greenstones, metagabbros and micaschists. We interpret the latter ones as a pre-Alpine basement because of the presence of red biotite relics, which is typical of pre-Alpine amphibolite facies metapelites. The Mesozoic cover consists of rare quartzites and of carbonate rich calcschists with levels rich in gneiss clasts in a carbonatic-pelitic matrix which we interpret as meta-conglomerates (Fig. 3d; N of Chioso Bosco). The boundary between the Gneiss Minuti Complex and the Upper Piedmont Zone calcschists is locally well exposed (e.g. along the road from Ribordone to Talosio and N of Bardonetto) and is characterized by an alternation of the two rock types or by gradational transitions (Fig. 3e). Moreover, many lens shaped levels of gneisses are present within the calcschists (Fig. 3f) throughout the study area (see geological map) and are here interpreted as sedimentary products. These features can be indicative of a stratigraphic contact between the Sesia-Lanzo gneisses and the Piedmont Zone calcschists which therefore should have the same stratigraphic position of the carbonate rich Mesozoic cover described by Gasco et al. (2009). In that paper the authors considered the Piedmont calcschists and the Sesia-Lanzo Gneiss Minuti as separated tectonic units but the re-investigation of the contact and the presence of reciprocal intercalations is here interpreted as stratigraphic as already supported by Pognante *et al.*, (1987) in the same area. However, this stratigraphic interpretation is not the common one since most authors interpreted this contact as tectonic (e.g. Reddy *et al.* 1999).

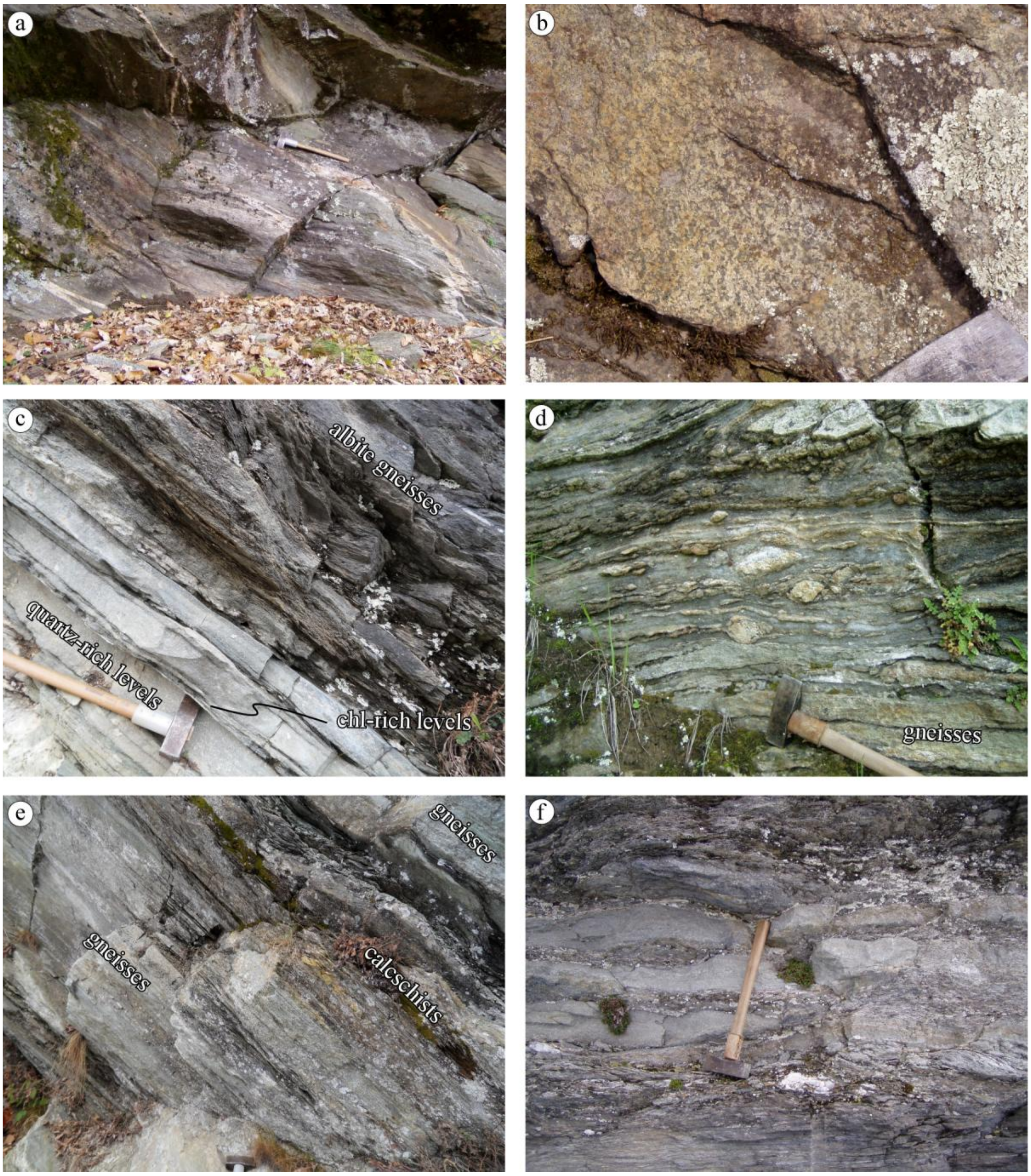


**Fig. 3.** Main rock types in the Upper Tectonic Element: a) gneisses with folded aplite dykes; b) medium-grained meta-monzodiorite/granodiorite with a well preserved magmatic texture; c) albite gneisses with acidic-basic alternations interpreted as detrital levels; d) meta-conglomeratic level with gneissic intercalations within the carbonate rich Mesozoic cover; e) transitional contact between gneisses of the Sesia-Lanzo and the calcschists of the Piedmont

Zone; f) Sesia-Lanzo gneiss levels within Piedmont Zone calcschists. Outcrops coordinates are given in Table 1.

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**4. Structural Data**

According to the lithostratigraphic setting described above we have grouped the studied units into two Tectonic Elements. The Lower one is composed of the Gran Paradiso Massif and the Lower Piedmont Zone which both preserve eclogite facies assemblages. The Upper one consists of the Upper Piedmont Zone and of the Sesia-Lanzo Gneiss Minuti Complex both of which do not show any eclogite facies relics and display well developed greenschist facies assemblages.

The structural evolution of the study area is only briefly described here, while the stereoplots with the structural elements of the different deformation phases and of the fracture/fault systems are reported on the geological map. The geologic cross sections reported in the map are drawn at the same scale as the outcrop map (i.e. 1:10,000 scale) without considering the Quaternary deposits. They show in detail the lithostratigraphy and the structural relationships between the different units. A detailed description of the structural evolution is reported in Gasco et al. (2009).

In the study area the regional composite foliation $S_1$ developed during the $D_1$ transpositional deformation event and mainly dips E to SE by 40-60°. Older pre-$_{D1}$ foliations are sometimes preserved in $D_1$ hinges. Otherwise, pre-D1 structural elements can rarely be distinguished from those of $D_1$.

In the Lower Tectonic Element $D_1$ folds are isoclinal to rootless and transpose an early pre-$S_1$ foliation rarely preserved in relict $D_1$ hinges. Fold axes ($A_1$) are parallel to the stretching lineations ($L_1$) and both show a NE-SW to E-W direction. Kinematic indicators mainly consist of σ-shaped porphyroclasts which are consistent with top to W sense of shear and are mostly developed in the orthogneisses. The $S_1$ regional foliation developed under greenschist facies conditions following pre-$S_1$ event/events developed under eclogite facies conditions (Gasco *et al.*, 2009).

In the Upper Tectonic Element, $D_1$ folds are isoclinal to rootless with E-W directed axes which are sub-parallel to the stretching lineation $L_1$. The main foliation S1 is marked by greenschist-facies minerals and pre-S1 relic foliations do not show any high-pressure minerals.

The $D_2$ event deforms the $D_1$ structures in all tectonic units, but its structural imprinting mostly affected the Gneiss Minuti of the Sesia-Lanzo Zone and the Upper Piedmont Zone. $D_2$ developed poly-harmonic and asymmetric folds that show close to isoclinal profiles, but an axial plane foliation rarely occurs. Axial planes dip 30-60° E to SE, while the fold axes are scattered on the average maximum circle of the foliation planes suggesting the presence of non-cylindrical structures. At the microscopic scale, $S_2$ developed under greenschist facies conditions and is defined by a spaced crenulation cleavage. $D_2$ also developed a mylonitic foliation along the contact between the Lower and the Upper Tectonic Elements showing top to E normal sense of shear. This tectonic contact separates rocks with different metamorphic evolutions, eclogite facies bearing in the footwall and greenschist facies in the hangingwall, and has been named Orco Shear Zone (Gasco *et al.*, 2009). This regional scale structure has the same position and significance of the Gressoney Shear Zone (Reddy *et al.*, 1999).

The $D_3$ deformation phase developed asymmetric folds with open to close profiles which indicate a top to SE asymmetry. Locally box folds were observed and axial planes dip mainly NW by a range of inclination from 30° to sub-vertical and fold axes are directed NE-SW with low inclination.

The $D_4$ folding stage is only detected at the macro-scale by analyzing variation in orientation of the $S_1$ foliations. Axial planes strike NW-SE at high dip angle, while fold axes plunge E to SE.

A NE-SW directed extensional crenulation cleavage (ECC as defined by Platt and Vissers, 1980) is well developed in calcschists and locally in serpentinites and gneisses at the meso-scale and mainly in the Upper Tectonic Element. ECC surfaces dip mainly to SE with high angle and show top to SE normal shear. Locally, at the contact between calcschists and gneisses, ECC steps gradually into frictional structures in the latter, suggesting development at the brittle-ductile transition regime.

It has not been possible to establish the relative age between the $D_4$ folding stage and the extensional crenulation cleavage, but since the latter developed at the brittle-ductile transition it should be younger than the folding event.

Brittle tectonics is mainly represented by fracture systems associated to minor faulting. The subscripts denote frequency and do not imply a relative age. The fracture systems are described according to their orientation and the rose diagrams are plotted both for strike and dip-direction. Four main joint systems have been identified and the most pervasive are represented on the geological map.

- The first system $K_1$ is the more frequent and shows a NW-SE strike direction (Fig. 4a) and is characterized by high angle (> 70°) conjugated surfaces.
- The second system $K_2$ strikes N-S and is characterized by medium to high angle joints (> 50°) mainly dipping towards W.
- The third system $K_3$ trends E-W with medium to high angle fractures (> 55°) dipping towards N.

- The fourth system $K_4$ strikes NE-SW with medium to high angle fractures (> 40°) mainly dipping toward NW.

Also the fault systems are described according to their orientation and their frequency and four different systems were identified:

- The first fault system $F_1$ strikes NE-SW and has been separated into an high angle fault system ($F_{1A}$ > 65°) which shows mainly strike slip movement and a medium angle fault system ($F_{1B}$ < 65°) with normal or reverse slip movement.
- The second system $F_2$ strikes N-S and is mainly characterized by sinistral strike-slip faults to normal faults.
- The $F_3$ system shows a NW-SE strike direction and is consists of dextral strike slip to oblique faults.
- The last system $F_4$ trends E-W with dextral and sinistral strike slip faults.

Few chronologic criteria were observed consisting of quartz veins associated to the $K_4$ system which are cut by the $K_3$ system, therefore suggesting that $K_4$ is older than $K_3$. At some outcrops it was possible to observe that the strike slip movement of the fault planes associated to $K_1$ and $K_2$ is reactivated into normal movement. On the contrary the E-W strike slip faults ($F_4$ system) reactivated an older normal slip movement.

## 5. Quaternary deposits and geomorphology

Quaternary deposits and the morpho-structural elements are briefly described to complete the geological investigation in the study area.

*Glacial tills* are widespread along the valley slopes while are generally absent on the valley bottom which is mainly characterized by late fluvial modelling. The best morphological evidences of glacial activity are preserved in the Ribordone Valley NW of Schiaroglio village where the two lateral moraines of a small glacial tongue are still preserved (Fig. 4b, see also the geological map). These moraines (up to 50 m high) are mainly composed of blocks with of various size (up to 6-7 m) with a clast supported fabric which is locally open work. The tills generally consist of clast supported sediments with heterogeneous blocks and locally rest over matrix supported deposits with rounded blocks.

*Debris deposits* are abundant at the base of the cliffs composed of ultramafic rocks in the Orco Valley (Fig. 4c). Worth of note because of its abundance is the presence of diffuse detrital cover east and south of the Monte Arzola in correspondence with ridges with scarce outcrops of basement rocks. All these sediments are characterized by open work clast supported texture and generally are less than 2 m in size.

*Landslide deposits* are scattered and, interestingly, all the major landslides are located on the left slope of the Orco Valley. They consist of clast supported deposits with boulders up to 15 m in size and are placed at the base of cliffs or steep slopes (> 45-50°) without evidence of significant transport which suggest a rock-fall emplacement mechanism due to slope collapse (Fig. 4c). Minor landslide deposits (when preserved) are due to the erosion of glacial tills and only the headscarps are represented on the geological map.

*Alluvial deposits* occur in two distinct positions: on the valleys bottom and locally along the lateral mountain streams in correspondence to slope decrease. The former deposits are clast supported sediments generally with less than 1 m size but locally with up to 2-3 meter blocks and show a medium to coarse grained matrix. The latter are mainly placed along the lateral streams and are composed of clast supported deposits locally showing a convex upward shape typical of debris flows. These deposits are not represented on the geological map owing to their small extent. However evidences of possible activation of debris flows are represented on the map by black arrows along the mountain streams.

Many *morpho-structural elements* are indicative of the presence of gravity controlled slope instability on the left side of the Orco Valley extending to the right side of the Ribordone Valley altogether covering an area of *ca* 5 $km^2$. The presence of this slope instability was already reported by Arpa Piemonte (2004) but was never directly investigated. These morpho-structural elements consist of trenches (Fig. 4d-e), bedrock with open fractures (Fig. 4f-g) and of unusual and widespread debris deposits in correspondence with ridges and in the absence of cliffs. The geometrical analysis of fracture systems direction suggests that this gravitational instability is mainly controlled by the pervasive fracturation in the bedrock due to the $K_1$, $K_2$ and $K_4$ joint systems. Generally, $K_1$ and $K_2$ are sub-parallel to the slope while $K_4$ is orthogonal.

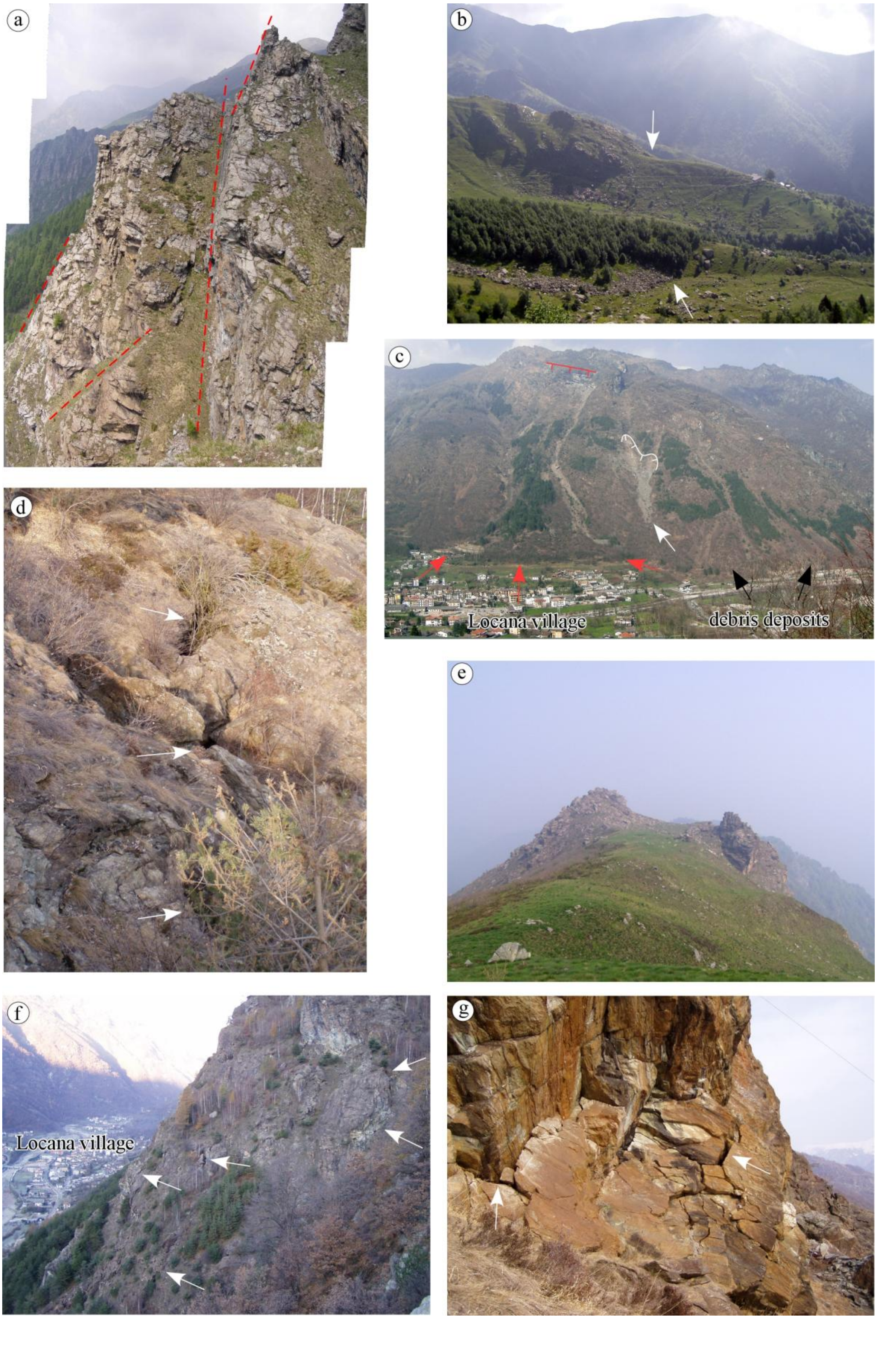
a
b
c
Locana village
debris deposits
d
e
f
Locana village
g

**Fig. 4.** Quaternary deposits and geomorphology: a) pervasive NW-SE $K_1$ fracture system in serpentinite on the high part of the left slope of the Orco Valley, b) lateral moraines (arrows) up to 50 m high in the Ribordone Valley. The lower arrow also shows the contact between a clast and a matrix supported glacial till; c) left slope of the Orco Valley showing a big landslide deposit on the left with a poorly visible headscarp and a recent landslide in the centre of the photo. To the right, thick debris deposits are present, d) 50-100 cm large trench partly covered by debris blocks, e) large depression/trench (> 100 m wide) on the watershed between the Orco Valley (to the right) and the Ribordone Valley (to the left), f-g) serpentinite bedrock with open fractures that are parallel to the slope. Outcrops coordinates are given in Table 1.

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## 6. Conclusions

Detailed field mapping in the Middle Orco Valley (NW Italy) has allowed to distinguish two main Tectonic Elements according to their different structural and metamorphic evolution. In general the Lower Tectonic Element (LTE) consists of units which preserve eclogite facies metamorphic assemblages, while the Upper Tectonic Element (UTE) shows no evidence of eclogitic minerals and displays well developed greenschist facies assemblages. These two Elements are separated by a ductile shear zone developed under greenschist facies conditions named Orco Shear Zone and known as Combin Fault (Ballèvre and Merle, 1993) or Gressoney Shear Zone (Reddy *et al*., 1999) in the Aosta Valley. Generelly, these shear zones are considered to be responsible for the exhumation of the eclogte facies units in their footwalls. This is in contrast with our observations that suggest that the Orco Shear Zone developed after $D_1$ which is already developed under greenschist facies. However, this fact does not exclude that these tectonic contacts are older than $D_1$ and that their old tectono-metamorphic history has been completely reworked and erased during the late exhumation stages (see Fig. 10 in Gasco *et al.*, 2009) finally suggesting that structural inheritance can play an important role during exhumation of deep subducted units.

The re-investigation of the contact between the Sesia-Lanzo gneisses and the Piedmont Zone calcschists suggests a possible stratigraphic relationship between the two nappes in the study area. However, this hypothesis needs to be confirmed in other sector of the western Alps before re-interpreting the relationships between these two units at a regional scale.

The mapping of morpho-structural elements and of pervasive fracturation of the bedrock on the left side of the Orco Valley (NE of Locana village) up to the watershed with the Ribordone Valley in combination with the slope of the cliffs (generally in excess of 40°), allowed the authors infer the presence of a deep-seated gravitational slope deformation with an extension of *ca* 5 $km^2$. This can be responsible for localized gravitational instability as already suggested by the widespread debris at the base of the slope.

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**Software**

The geological maps were drawn using ArcGIS 9 and were finally assembled with Deneba Canvas X for a better graphic output. The structural data were analyzed and plotted with

Stereonett. The cross sections presented in the geological map and the photographs were compiled with Deneba Canvas X.

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