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Hydrogeological implication of the Pliocene-Pleistocene torrential and debris flow succession around the Lanzo Ultramafic Massif (Western Alps)

Significato idrogeologico della successione torrentizia e di debris flow al margine del Massiccio Ultrabasico di Lanzo (Alpi Occidentali)

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ABSTRACT - A thick succession of deposits associated with torrential and debris flow processes preserved around the Lanzo Ultramafic Massif is described in this study. It represents the oldest Pliocene-Quaternary complex of continental sediments locally outcropping close to the inner margin of the Western Alps.

These sediments, observed into the deepest fluvial incisions, show prevalent gravel facies with clast supported texture and trough cross bedding. The decimetric clasts are derived locally because of the reworking of peridotite substratum. The matrix consists of a mixture of sand, silt and clay. Both the sedimentological features and the distribution into the watercourse incisions indicate torrential and debris flow genesis. In the sectors not incised by watercourses the succession is instead prevalently constituted by angular or poorly rounded clasts, derived from the local supply, with a scarce matrix and a stratification parallel to the slope. These features are a significant evidence that here the gravitative facies prevail. Silty sediments are observed locally, either without clasts or containing small peridotite fragments, with a bedding parallel to slope. These sediments are connected to colluvial processes and supplied by the reworking of mature soils developed at the expense of peridotite bedrock.

The definite stratigraphic position of the torrential and debris flow succession, located at the base of the different sedimentary Pliocene-Pleistocene units, and the strong weathering of sediments, indicated by their argillification and cementation by iron oxides, reflect an ancient age. This assessment is in agreement with the local interfingering with the Lower Complex of "villafranchian succession" (CARRARO Ed., 1996) that is related to the Middle Pliocene. The strong weathering of this succession produces the peculiar hydrogeological significance.

The hydrogeological conceptual model of the area is described. In the different areas some springs linked to permeability contrast and piezometric surface emergence are signalled. These springs are prevalently used for drinking water, irrigation or domestic purpose.

Some examples of springs around the Lanzo Ultramafic Massif are presented in a detailed geological map. The springs result from the difference in permeability between the ancient torrential and debris flow succession and the glacial, outwash and detrital cover. In these areas the ancient torrential and debris flow sediments have the hydrogeological role of a separation element between the shallow aquifer in the glacial, glaciofluvial and detrital deposits and the deep aquifer in the fracture network of the crystalline rocks.

KEY WORDS: debris flow, fluvial sediments, hydrogeology, Lanzo Massif, Pleistocene, Pliocene.

RIASSUNTO - Viene segnalata la presenza di una potente successione, connessa essenzialmente con fenomeni torrentizi e di *debris flow*, conservata ai margini del Massiccio Ultrabasico di Lanzo: costituisce il termine pliocenico-quaternario continentale più antico affiorante a ridosso del rilievo alpino occidentale, in corrispondenza delle incisioni fluviali più profonde.

Questi depositi sono caratterizzati da una facies prevalente ghiaiosa, con tessitura *clast supported* e un accenno di stratificazione incrociata concava: i ciottoli, di dimensioni decimetriche, sono di apporto locale derivando esclusivamente dallo smantellamento del substrato peridotitico; la matrice è costituita da percentuali di sabbia, silt e argilla estremamente variabili. L'insieme delle caratteristiche sedimentologiche e la distribuzione entro le incisioni modellate dal reticolato idrografico suggeriscono l'origine essenzialmente torrentizia. Nei settori privi di incisioni fluviali questi sedimenti contengono numerosi elementi angolosi, con una scarsa matrice e un accenno di stratificazione parallela al versante, indicativi di una genesi prevalentemente detritica. Ancora più localmente affiorano invece sedimenti essenzialmente siltoso-argillosi, di origine prevalentemente colluviale.

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La posizione stratigrafica, alla base delle diverse unità pliocenico-pleistoceniche affioranti, e l'alterazione molto spinta della successione descritta, caratterizzata da un elevato grado di argillificazione e cementazione da parte degli ossidi di ferro, è indicativa dell'età antica: l'interdigitazione, localmente osservabile, con i depositi "villafranchiani" del Complesso Inferiore (CARRARO Ed., 1996), suggerisce come la deposizione sia iniziata a partire dal Pliocene medio. La notevole alterazione è responsabile della permeabilità molto modesta di questi sedimenti, che determina particolari modalità nella circolazione idrica sotterranea.

È stato inoltre prodotto un modello geologico concettuale. Nelle diverse aree sono segnalate alcune sorgenti per contrasto di permeabilità e per emergenza della superficie piezometrica, utilizzate prevalentemente per usi idropotabili, agricoli o domestici.

Sono infine presentati alcuni esempi di sorgenti localizzate ai margini del Massiccio Ultrabasico di Lanzo, per i quali sono state realizzate carte geologiche di dettaglio. Le sorgenti esaminate sono connesse con differenze di permeabilità tra l'antica successione torrentizia e di *debris flow* e la copertura glaciale, fluvioglaciale e detritica: in queste aree gli antichi depositi torrentizi e di *debris flow* hanno il ruolo di elemento di separazione tra gli acquiferi superficiali, ospitati nei depositi glaciali, fluvioglaciali e detritici, e gli acquiferi profondi ospitati nel substrato cristallino.

PAROLE CHIAVE: colata di detrito, idrogeologia, Massiccio di Lanzo, Pleistocene, Pliocene, sedimenti fluviali.

1. - INTRODUCTION

During the surveying for the 1:50.000 "Torino Ovest" 155 Sheet of the CARG (Geological Map of Italy) project, the diffuse presence of a particular sedimentary complex on the slopes of the Lanzo Ultramafic Massif appeared. This succession is preserved in wide and very thick relicts. They were disregarded in the previous geological maps and exclusively described in the magnesite mineralization studies of the lower Susa Valley.

This succession consists of different facies and various age deposits and is extensively weathered. The strong argillification and cementation of these sediments produce their peculiar hydrogeological significance. Some springs localised around the Lanzo Ultramafic Massif are present at the top of these sediments and conditioned by their presence.

2. - GEOLOGY OF THE LANZO ULTRAMAFIC MASSIF

The Lanzo Ultramafic Massif (LUM) is localised in the internal part of the high-pressure, low-temperature metamorphic belt of the Western Alps between the lower Susa Valley and Viù Valley, 35 km North-West of Turin (fig. 1) (DAL PIAZ *et alii*, 1990). It represents one of the largest outcrops of peridotites in the world. This massif is well known because of the freshness of its rocks, in which ancient mantle and oceanic lithological associations are clearly observable (NICOLAS, 1974; BOUDIER, 1978; BODINIER *et alii,* 1986; PICCARDO *et alii,* 2007).

The LUM is interpreted as a slide of lithosferic subcontinental mantle, deeply transformed by asthenosferic melt impregnation and melt/rock interaction during the early rift evolution of the Jurassic Ligurian Tethys oceanic lithosphere (PICCARDO *et alii*, 2007).

The LUM is commonly divided into a southern body (55 km^2), a central body (90 km^2) and a northern body (5 km^2), which are separated by two broad mylonitic and serpentinized shear zones with a NW-SE direction (BOUDIER & NICOLAS, 1972; ELTER *et alii*, 2005; BALESTRO *et alii,* 2009b).

The core of the three bodies of the LUM is mainly composed of massive weakly serpentinised plagioclase peridotite with minor granular harzburgite and spinel peridotite. These rocks are frequently cut by gabbroic veins and dykes and sometimes by basalt. In the peripheral areas of the LUM the peridotite gradually becomes more serpentinised until it becomes massive serpentinite due to the Alpine high-pressure/low-temperature eclogitic metamorphic imprint (KIENAST & POGNANTE, 1988; LAGABRIELLE *et alii,* 1989; PELLETIER & MÜNTENER, 2006).

The peridotite preserves an ancient pervasive magmatic foliation and is cross-cut by three regularly spaced joint sets (0.5-1.5 m), isolating approximately equidimensional blocks with a typical cubic, prismatic or rhombohedral shape.

The LUM is bounded by high-pressure ophiolite and calcschist (Piemontese Zone *Auct.*) in the west and by continental units of the Sesia-Lanzo Zone in the north. In the east the LUM is covered by a thick Middle Pleistocene fluvial fan succession of the Stura di Lanzo River (Unità di Fiano). This latter deposit rests above a fluvio-lacustrine "villafranchian" succession Middle Pliocene to Lower Pleistocene in age (BALESTRO *et alii,* 2009a; FORNO *et alii*, 2009). Along the south-eastern edge of the LUM a succession of torrential and debris flow fans links the slopes of the peridotitic massif to the fluvial plain. Finally, in the south the LUM is bounded by the Rivoli-Avigliana Morainic Amphiteatre, situated at the mouth of the Susa Valley. The glacial and outwash deposits that form the amphitheatre were built during the various expansions of the Dora Riparia glacier. Two groups of moraines have been referred to the Middle Pleistocene glaciations, whereas the third group of moraines has been interpreted as the Late Pleistocene glacial expansion (PETRUCCI, 1970; CARRARO *et alii*, 2005; BALESTRO *et alii*, 2009b).

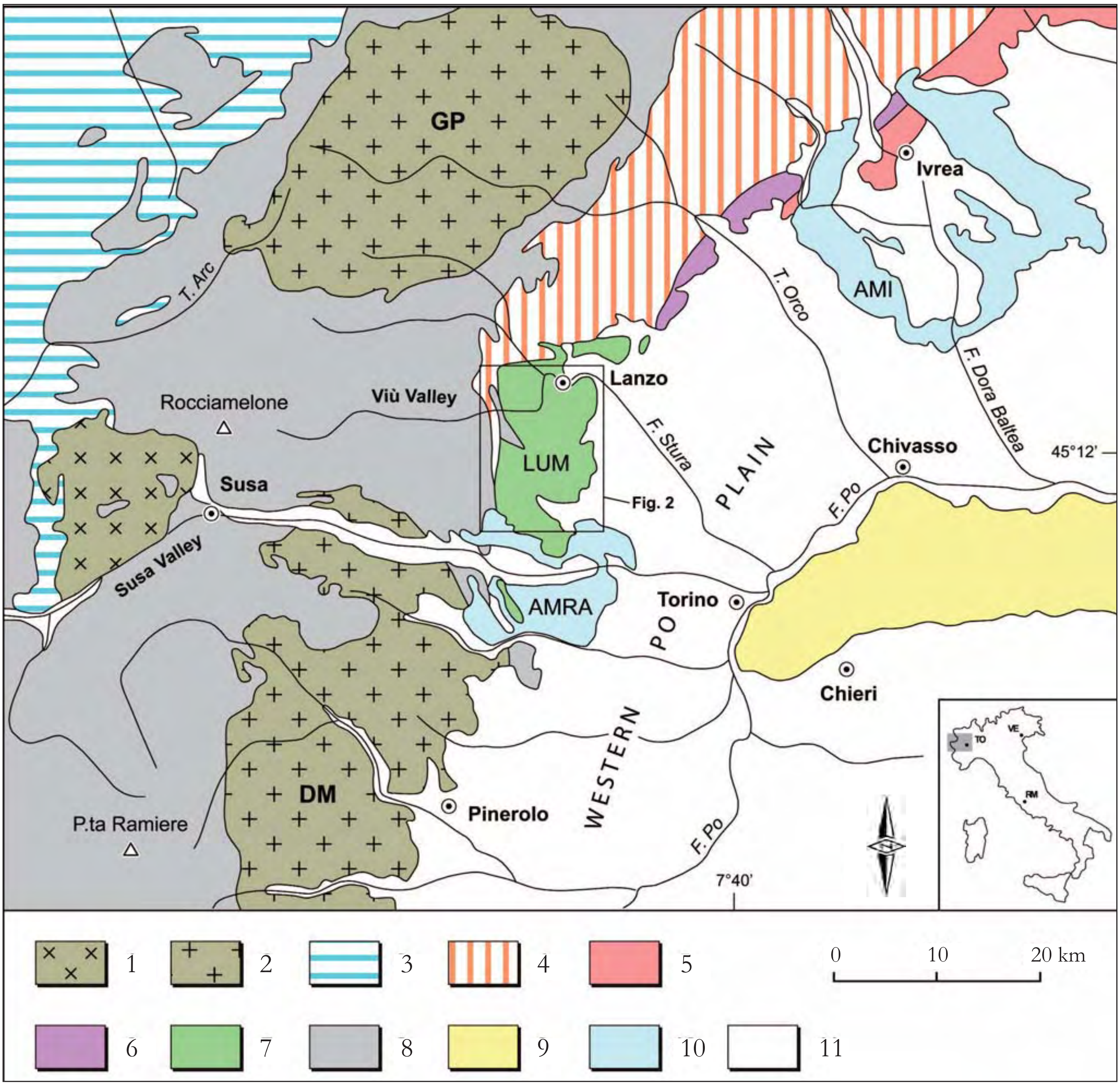

Fig. 1 - Structural sketch map of the Italian Western Alps (from Dal Piaz *et alii*, 1990, modified). 1: Ambin Massif (Pennidic Domain). 2: internal crystalline massifs of the Pennidic Domain (GP = Gran Paradiso; DM = Dora-Maira). 3: Grand St. Bernard Zone (Pennidic Domain). 4: Sesia-Lanzo Zone (Austroalpine Domain). 5: Ivrea-Verbano Zone (Southalpine Domain). 6: Canavese Zone. 7: Lanzo Ultramafic Massif (LUM). 8: ophiolite-bearing calcschist of the Piedmontese Zone. 9: Oligo-miocene succession of the Monferrato - Torino Hill (Piedmont-Ligurian Tertiary Basin). 10: Pleistocene glacial deposits (AMRA = Rivoli-Avigliana Morainic Amphitheatre; AMI = Ivrea Morainic Amphitheatre). 11: Quaternary fluvial and glaciofluvial deposits of the Western Po Plain.

- Schema strutturale delle Alpi Occidentali (modificato da Dal Piaz *et alii, 1990). 1: Massiccio d'Ambin (Dominio Pennidico). 2: massicci cristallini interni del Dominio Pennidico (GP = Gran Paradiso; DM = Dora-Maira). 3: Zona del Gran S. Bernardo (Dominio Pennidico). 4: Zona Sesia-Lanzo (Sistema Austroalpino). 5: Zona Ivrea-Verbano (Dominio Sudalpino). 6: Zona del Canavese. 7: Massiccio Ultrabasico di Lanzo (LUM). 8: calcescisti ofiolitici della Zona Piemontese. 9: successione oligo-miocenica del Monferrato - Collina di Torino. 10: depositi glaciali pleistocenici (AMRA = Anfiteatro Morenico di Rivoli-Avigliana; AMI = Anfiteatro Morenico di Ivrea). 11: depositi fluviali e fluvioglaciali quaternari della Pianura Padana occidentale.*

The rocks of the LUM are involved in intense and deep-seated chemical-physical weathering phenomena, particularly developed where peridotite crops out. This peridotite has high susceptibility to weathering due to the abundant presence of olivine, which constitutes about 60% of the whole rock volume. Weathering is caused by chemical processes such as hydration, hydrolysis, oxidation and leaching of femic minerals (olivine and pyroxene) occurring in the ultramafic rocks. Characteristics and degree of weathering are spatially heterogeneous relative to the local morphologic context of the LUM. On the watersheds and along steep slopes, erosive phenomena, related to the outflow of the meteoric waters, prevail and remove weathering products, exposing the bedrock. Locally, an eluvio-colluvial 1-2 m thick cover is present. This cover prevents gelifraction but allows weathering processes to develop along the fracture network sometimes at depths of about 8-12 m.

At the base of slopes, where erosion processes are less effective, weathering phenomena occur in depth and involve slope deposits (mainly mud-debris flow deposits and colluvial cover) and underlying bedrock at depths of tens of metres (e.g., Caselette and Val della Torre quarries). On the whole, weathered covers show a yellowish and reddish colouring with a mean colour index ranging between 7.5YR and 10R (Munsell Soil Colour Charts). Moreover weathering phenomena are responsible for widespread magnesite mineralisation (associated with minor dolomite, aragonite, opal and quartz), distributed in the peridotite bedrock and secondly in the torrential and debris flow deposits that mantle the base of slopes (NATALE, 1972; MIÈ & NATALE, 1978).

Weathering phenomena has been interpreted as a result of a long-term processes developed mainly during past sub-tropical climates before the Pleistocene glacial phases that were characterised by high temperature and abundant rainfall (NATALE, 1972; MIÈ & NATALE, 1978; FIORASO & SPAGNOLO, 2009).

3. - THE ANCIENT TORRENTIAL AND DEBRIS FLOW SUCCESSION

Around the Lanzo Ultramafic Massif (LUM), a torrential and debris flow succession is present (fig. 2). This succession is very particular with regard to its geologic and hydrogeological features. The main outcropping areas of these sediments are localised in the right lateral sector of the Lanzo alluvial fan (between Vallo and Givoletto, A4÷A12 in figure 2), in the lower Viù Valley (between Maddalene and Germagnano, A13 and A14 in figure 2) and in the lower Susa Valley (between Rubiana and Rivera, A1÷A3 in figure 2).

The strong deepening of the watercourses produced deep incisions (fig. 3), which allowed us to observe the deposits in great detail. Within the entire outcrop area, the complex lies on the substratum of the LUM (peridotite and serpentinized peridotite) or, locally, on the Piemontese Zone (ophiolite-bearing calcschists). It shows a definite stratigraphic position at the base of the different sedimentary Pliocene-Pleistocene units, and has strong weathering that is responsible for the peculiar hydrogeological significance. Because of these elements the complex can be referred to as the most ancient of the Pliocene-Quaternary continental succession outcropping along the inner margin of the western Alps.

In various areas the ancient torrential and debris flow succession is covered by different sedimentary bodies: the Lanzo alluvial Fan deposits (basal Middle Pleistocene Fiano Unit in FORNO *et alii*, 2009) (fig. 4); the Rivoli-Avigliana Amphiteatre glacial sediments (Middle-Late Pleistocene Magnoletto, Frassinere and Bennale Units in BALESTRO *et alii* (2009a); a peculiar facies of Lower Pleistocene to Holocene detrital sediments (block streams in FIORASO & SPAGNOLO, 2009); and more recent torrential and debris flow sediments (fig. 2).

The weathered torrential and debris flow succession is composed by numerous metres-thick overlapped lenticular bodies. The paucity of subsurface data does not allow us to evaluate the extension and the maximum thickness of this succession (estimated as 50-60 m). The lack of these sediments in the alluvial plain suggests that they are limited to the edge of the alpine chain.

Facies associations change from place to place. At the valleys' mouths, a coarse conglomerate prevails (fig. 5). It consists of decimetre-size angular to well-rounded elements and mixed with a variously abundant matrix. It shows alternating coarsening and fining-upward structures. The matrix is formed by a mixture of sand, silt and clay, with variable percentage within the same outcrop. Rare levels contain boulders over 1 m^3 in size.

These sediments have a clast supported texture and, only locally, a matrix-supported texture. They often show trough cross bedding (fig. 5). In some outcrops the imbricate structure of some elements

Fig. 2 - Geological map of the Lanzo Ultramafic Massif. a: "Gneiss minuti" (Sesia-Lanzo Zone). b: lherzolites, harzburgites and dunites (Lanzo Ultramafic Massif). c: serpentinites and serpentinized peridotites (Piemontese Zone and Lanzo Ultramafic Massif). d: metabasites (Piemontese Zone). e: calcschists (Piemontese Zone). f: weathered and cemented torrential, debris flow and detrital-colluvial deposits (Middle Pliocene to Lower Pleistocene?); number refers to the localities quoted in the text (A1 = Rubiana; A2 = Almese; A3 = Miosa; A4 = Givoletto; A5 = Rivasacco; A6 = Truc Miola; A7 = S. Biagio; A8 = Baratonia; A9 = Varisella; A10 = S. Maria della Neve; A11 = Rio l'Adrit; A12 = Vallo; A13 = Germagnano; A14 = Maddalene). g: Stura di Lanzo ancient fluvial deposits (Middle Pleistocene). h: glaciofluvial deposits (Middle to Upper Pleistocene). i: undifferentiated glacial deposits of the Rivoli-Avigliana Morainic Amphitheatre (Middle to Late Pleistocene). l: torrential and debris flow deposits (Late Pleistocene). m: recent fluvial deposits (Holocene). n: springs listed in table 2. See figure 1 for location of the area.

- Schema geologico del Massiccio Ultrabasico di Lanzo. a: "Gneiss minuti" (Zona Sesia-Lanzo). b: lherzoliti, harzburgiti e duniti (Massiccio Ultrabasico di Lanzo). c: serpentiniti e peridotiti serpentinizzate (Zona Piemontese e Massiccio Ultrabasico di Lanzo). d: metabasiti (Zona Piemontese). e: calcescisti (Zona Piemontese). f: depositi torrentizi, di debris flow e detritico-colluviali alterati e cementati (Pliocene medio - Pleistocene inferiore?); i numeri si riferiscono alle località citate nel testo (A1 = Rubiana; A2 = Almese; A3 = Miosa; A4 = Givoletto; A5 = Rivasacco; A6 = Truc Miola; A7 = S. Biagio; A8 = Baratonia; A9 = Varisella; A10 = S. Maria della Neve; A11 = Rio l'Adrit; A12 = Vallo; A13 = Germagnano; A14 = Maddalene). g: depositi fluviali antichi della Stura di Lanzo (Pleistocene medio). h: depositi fluvioglaciali (Pleistocene medio-superiore). i: depositi glaciali indifferenziati dell'Anfiteatro morenico di Rivoli-Avigliana (Pleistocene medio-superiore). l: depositi torrentizi e di debris flow (Pleistocene superiore). m: depositi fluviali recenti (Olocene). n: sorgenti elencate in tabella 2. Si veda la figura 1 per l'ubicazione dell'area.

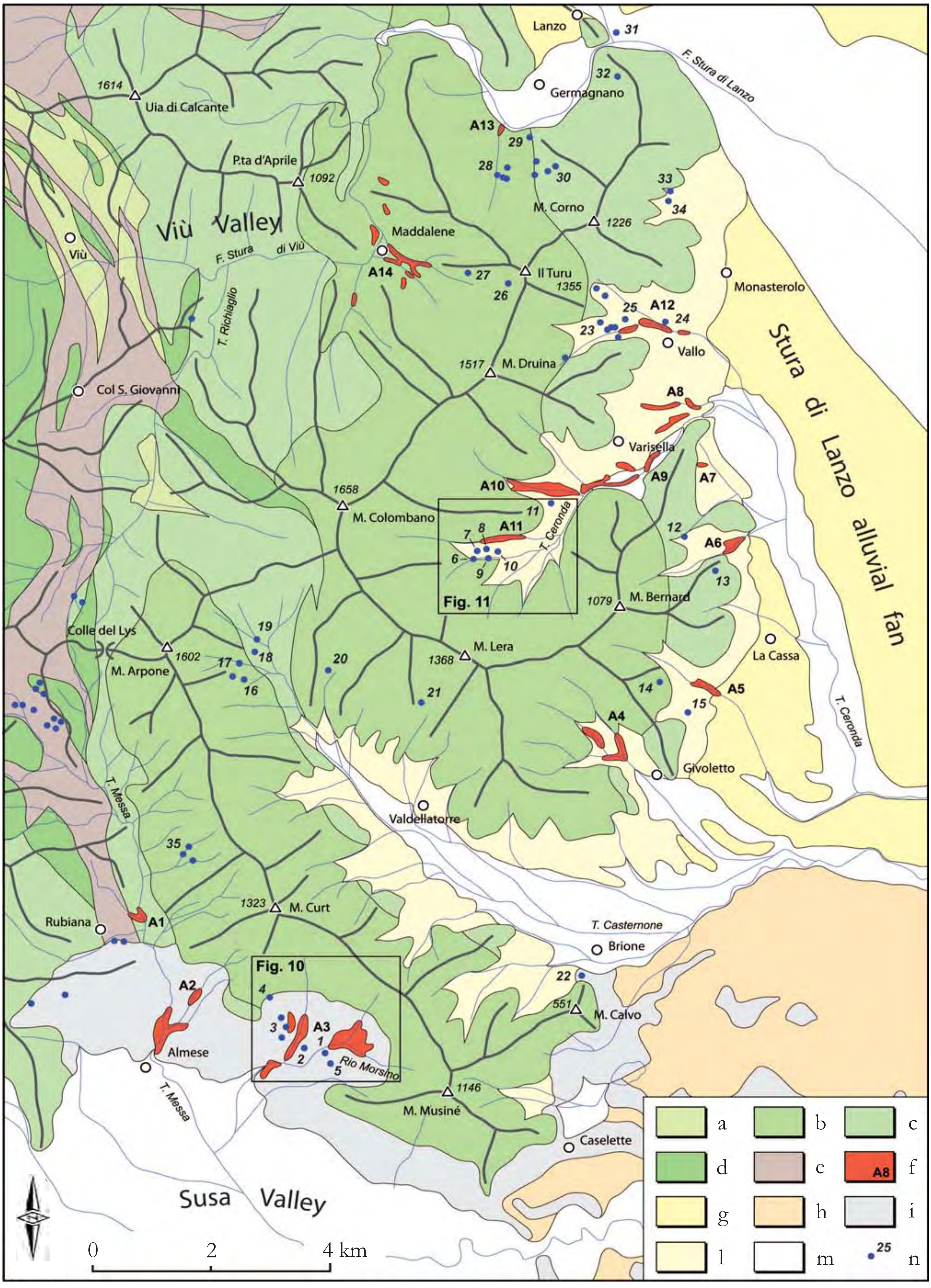
Lanzo
Germagnano
F. Stura di Lanzo
Uia di Calcante
1614
P.ta d'Aprile
1092
Viù Valley
Viù
F. Stura di Viù
T. Richiaglio
Maddalene
A14
A13
M. Corno
1226
Il Turu
1355
Monasterolo
A12
Vallo
M. Druina
1517
Col S. Giovanni
A8
Stura di Lanzo alluvial fan
Varisella
A10
A9
A7
M. Colombano
1658
A11
T. Ceronda
Fig. 11
A6
M. Bernard
1079
M. Lera
1368
Colle del Lys
M. Arpone
1602
La Cassa
A5
A4
Givoletto
T. Ceronda
T. Messa
Valdellatorre
M. Curt
1323
Rubiana
A1
T. Casternone
Brione
Fig. 10
A2
A3
Almese
Rio Morsino
M. Calvo
551
M. Musiné
1146
T. Messa
Caselette
Susa Valley
0 2 4 km
a b c d e f g h i l m n
A8
25

Fig. 3 - Wide outcrop of the torrential and debris flow succession (T. Ceronda incision, SW of Varisella).
- Esteso affioramento della successione torrentizia e di debris flow (incisione del T. Ceronda a SW di Varisella).

is evident. Sandy lenticular bodies with trough cross bedding, 10-40 cm thick, develop locally. Clasts are constituted by peridotite, serpentinized peridotite and serpentinite, with rare prasinite and meta-gabbrous, suggesting a local supply from the basins shaped in the LUM.

The sedimentologic features of these sediments and their distribution at the valleys' mouths suggest a prevalent torrential and debris flow genesis connected to a fan environment.

At the base of the slopes, in the sectors not incised by watercourses (Givoletto, La Cassa) these sediments are mainly constituted by angular clasts and show a poor bedding parallel to the slopes (fig. 6). The scarce matrix is composed of a sand, silt and clay mixture. In these sediments the detrital elements, supplied by physical crumbling of the slope, prevail. The clast petrographic composition indicates the local supply.

Locally, at least in the sheltered from erosion sectors (Rivera, Germagnano), silty sediments are observed, without clasts or containing small peridotite fragments, with a bedding parallel to the slope (fig. 7). These sediments are connected to colluvial processes and supplied by the reworked soils developed on peridotite.

The various facies constituting the ancient torrential and debris flow succession show an interfingering relationship. Moreover, they form wide torrential fans distributed at the base of the LUM slopes.

The succession is affected by a weathering that produces a strong argillification, responsible for continuous and thick clay patinas developed around the clasts and into the fractures. Clay aggregates, some centimetres in size, also diffusely develop.

Sometimes the weathering is so strong that peridotite clasts become entirely loose. Exclusively coarse and serpentinite elements are partially preserved. In the strongly weathered peridotite clasts in which there are the olivine crystals totally transformed to a clayey aggregate, the original rock structures are preserved. The strong weathering is related to the presence of peridotite substratum, highly sensitive to weathering in the hot-wet conditions prevailing before the Middle-Upper Pleistocene glaciations.

The weathering phenomena also produce a strong oxidation of Fe, responsible for the matrix's dark red colour (10R 4/4,6 - 2.5 YR 5/6), that appears throughout the whole thickness of the deposits (fig. 8). These sediments are also affected by the oxidation of Mn, which produces aggregates and continuous black patinas around the clasts.

These processes are responsible for the diffuse cementation of the sediments.

The strong cementation, providing resistance to erosion, allows for good preservation of these ancient sediments, even in sectors (e.g. Almese) subjected to further glacial exaration.

The described succession, which includes more different facies, also comprises overlapped bodies with decreasing grades of weathering, suggesting a sedimentation over a long period. The torrential and debris flow deposits are locally interfingered with the Lower Complex of the "villafranchian succession" (CARRARO Ed., 1996) (Unità di La Cassa in BALESTRO *et alii*, 2009a,b), that is dated to the Middle Pliocene (MARTINETTO, 1994; MARTINETTO *et alii*, 2006). This evidence indicates sedimentation during this period. The overlapping of Middle Pleistocene fluvial sediments (Fiano Unit in FORNO *et alii*, 2009) suggests that the sedimentation potentially continued during the Lower Pleistocene.

In the silty-clayey facies, fractures systems develop locally (Germagnano). These fractures, decimetric to metric in extension, show a discontinuous distribution. They are prevalently connected to contraction phenomena. Sometimes, fault systems with metric to some decametric length and different strike directions, connected to glaciotectonic deformation, are observed (Almese). In other places, local fault systems connected to gravitative collapses are observed (Vallo).

Fig. 4 - Irregular erosional surface between torrential and debris flow sediments, that are supplied from a local source, and the overlapped fluvial sediments connected with the Stura di Lanzo River (Fiano Unit).
- *Superficie di erosione, articolata nel dettaglio, che separa i depositi torrentizi e di debris flow, di alimentazione locale, e i depositi fluviali legati al bacino del T. Stura di Lanzo (Unità di Fiano).*

Fig. 5 - Trough cross bedded torrential sediments (T. Ceronda incision, SW of Varisella).
- Stratificazione incrociata concava dei depositi torrentizi affioranti lungo l'incisione del T. Ceronda, a SW di Varisella.

4. - HYDROGEOLOGICAL CONCEPTUAL MODEL

The hydrogeological conceptual model applied to the Lanzo Ultramafic Massif includes four hydrogeological units (tab. 1 and fig. 9).

Complex (**1**). This complex corresponds to glacial deposits that are essentially flow till (Almese), glaciofluvial and fluvial deposits (Almese, Germagnano), debris flow deposits (Varisella), block deposits with open-work texture (block streams) and gravitative deposits (diffusely distributed). These are porous sediments, with medium (flow till and debris flow deposits) to high (glaciofluvial deposits) and very high (block stream deposits) permeability. This complex constitutes a shallow aquifer.

Complex of the weathered torrential and debris flow succession (**2**). This complex consists of originally coarse deposits whose weathering produced an abundant fine matrix and chemical decomposition of clasts. The complex presents a permeability value from low to very low, comparable with the permeability of a very clayey silty sand. Such a complex represents an aquiclude forming the impermeable substratum of the overlying Complex 1.

Complex of the fractured crystalline rocks (**3**). The surface layer of the peridotite bedrock is often very fractured for some metres in depth (locally for about ten metres). This layer shows a medium permeability. It can host a shallow aquifer where it outcrops or is covered by Complex 1 deposits.
Otherwise it represents a confined aquifer where it is buried by Complex 2 deposits.

Complex of the poorly fractured crystalline rocks (**4**). This complex forms the main reliefs and the substratum of the Plio-Quaternary sedimentary succession. It consists of magmatic intrusive ultramafic rocks, such as lherzolite, harzburgite and dunite, and metamorphic rocks, principally serpentinite. The basement has a very low fissure permeability and it represents the basal acquiclude.

The shallow aquifer represented by Complex 1 feeds a set of springs conditioned by the morphology of its basal surface (top of the weathered

Tab. 1 - *Facies and features of the four hydrogeological complexes of the LUM.*
- Facies e caratteristiche dei quattro complessi idrogeologici del LUM.

Complex	Lithologic features	Hydraulic conductivity (m/s)	Primary or secondary porosity	Hydrostratigraphy	Estimated thickness (m)
1	glacial, glaciofluvial, fluvial, debris flow, block stream and gravitative deposits	from medium to high (10^{-1}÷10^{-4})	primary	aquifer	10-40
2	weathered torrential and debris flow deposits	from low to very low (10^{-6}÷10^{-8})	primary	aquiclude	20-60
3	fractured crystalline rocks	from medium to high (10^{-4}÷10^{-2})	secondary	aquifer	<10
4	poorly fractured crystalline rocks	low (10^{-5}÷10^{-6})	secondary	aquitard	>100

Fig. 6 - Sediments with angular clasts indicative of the prevalent detrital supply (Germagnano).
- *Sedimenti caratterizzati dalla presenza di clasti angolosi, indicativa di prevalenti apporti detritici (Germagnano).*

Fig. 7 - Lenticular silty body connected with colluvial supply (T. Ceronda incision, SW of Varisella).
- *Corpo lenticolare siltoso legato a locali apporti colluviali (incisione del T. Ceronda a SW di Varisella).*

torrential and debris flow succession) and the topographic surface (tab. 2). This surface shows an irregular morphology because it was dissected by watercourses.

Depending on the nature of the bedrock and sedimentary cover and their relationships, permeability of deposits, position of the water table and local topography, at least three types of springs developed in the study area: barrier springs (A in figure 9), contact springs (B and C in figure 9) and for piezometric surface emergence (D in figure 9).

The discharge trend of these springs is strongly influenced by the volumetric extension and permeability of the feeding aquifer.

Where the aquifer is wide, spring discharge is relatively high and it can be equal to some l/s (A and D in figure 9). In case of the spring located in position A, it is fed by direct infiltration waters in the aquifer and by snow melt and runoff coming from the highest sectors of the basin shaped in the substratum. This evidence ensures that the aquifer feeding the spring has a bigger and more continuous recharge over time. Some of these springs show a high variable discharge, especially where most of the aquifer is constituted by very high permeability sediments like block stream deposits. In this case, the discharge of the springs can vary from less than one to about 25 l/s in a period of a few hours, especially after particularly intense rain events.

Where the aquifer has a limited volumetric extension because it is dissected by watercourses (B and C in figure 9), spring discharge is low (mean discharge lower than 1 l/s), with a high variability index. These springs are often temporary; i.e., they undergo an interruption in connection with periods characterised by poor or null recharge to the aquifers.

Most of the described springs are used for drinking water (for example Fusalas, Rul, Lil and Falasca in Varisella commune; Listelli, Morsino Alto and Fontana Fredda in Almese commune), irrigation, or non drinking domestic use (tab. 2).

The supplying works typologies are represented above all by holding spoils, but also by burdened drainage.

Fig. 8 - Dark red colour (10 R 4/4) and strong cementation connected with weathering of the torrential succession (T. Ceronda incision, SW of Varisella).
- Colore rosso intenso (10 R 4/4) e sensibile cementazione della successione torrentizia, connessi con l'alterazione pedogenetica (incisione del T. Ceronda a SW di Varisella).

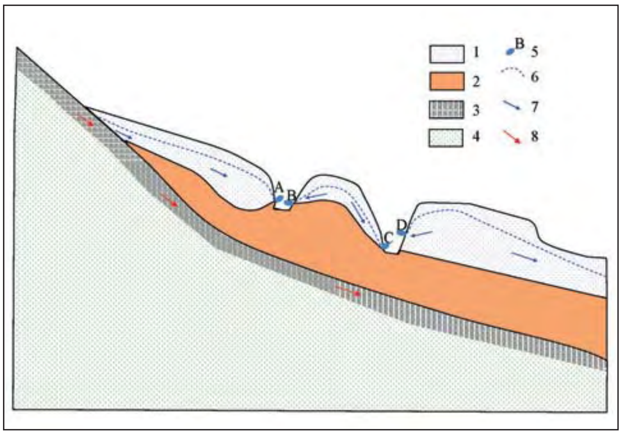

Fig. 9 - Conceptual hydrogeological scheme: 1: Complex of the glacial and glaciofluvial deposits; 2: Complex of the weathered torrent and debris flow deposits; 3: Complex of the fractured crystalline rocks; 4: Complex of the poorly fractured crystalline rocks; 5: springs with labels; 6: profile of the piezometric surface; 7: direction of flow into the shallow aquifer; 8: groundwater flow path into the fractured bedrock. A, B, C, D: springs.
- Schema concettuale dell'assetto idrogeologico e della circolazione idrica sotterranea. 1: Complesso dei depositi glaciali e fluvioglaciali; 2: Complesso dei depositi torrentizi e di debris flow alterati; 3: Complesso delle rocce cristalline fratturate; 4: Complesso delle rocce cristalline scarsamente fratturate; 5: sorgenti e relativa sigla; 6: profilo piezometrico della falda idrica; 7: linea di flusso nella falda idrica superficiale; 8: direzione di flusso della rete acquifera delle rocce cristalline fratturate. A, B, C, D: sorgenti.

The aquifer represented by Complex 3, developed in the first metres of the fractured crystalline bedrock, do not show significant springs. Part of Complex 3 can feed the block stream deposits aquifer; part of it is covered by the Complex of the weathered torrential and debris flow deposits creating a confined aquifer. In this last case, the Complex 2 of the weathered torrential and debris flow deposits has the hydrogeological role of a separation element between the shallow aquifer located in the glacial and outwash deposits and the deep aquifer in the fractured peridotite bedrock network.

5. - HYDROGEOLOGICAL FEATURES OF SOME SPRINGS RELATED TO WEATHERED TORRENTIAL AND DEBRIS FLOW SEDIMENTS

To explain the relationship between springs and the weathered torrential and debris flow deposits, two examples are considered: the Almese area (out-

Tab. 2 - *List of the springs of the LUM (from Provincia di Torino Archive and surveys of the authors). Numbers are referred to the springs mapped in figure 2. Commune and main catchment, discharge (l/s) and water use are indicated. Complex 1 is the main aquifer, formed by glacial, glaciofluvial, alluvial, debris flow, gravitative and block stream deposits. The asterisks (*) indicate springs mainly linked to block stream deposits. Complex 2 is the main aquiclude formed by weathered and cemented torrential and debris flow deposits. Discharge values are prevalently taken from Provincia di Torino Archive; some values are directly measured by the authors (+). In the Germagnano area the discharges of linked-to-block stream springs* range from 2-5 to 15-25 l/s (*Fioraso & Spagnolo*, 2009).*

- Elenco delle sorgenti del LUM (dall'Archivio della Provincia di Torino e dai rilevamenti degli autori). I numeri rimandano alle sorgenti rappresentate in figura 2. Sono indicati comune e bacino idrografico, portata e utilizzo dell'acqua. Il Complesso 1 è l'acquifero principale, costituito da depositi glaciali, fluvioglaciali, fluviali, di *debris flow*, gravitativi e di *block stream*. Gli asterischi (*) indicano le sorgenti strettamente legate ai depositi di *block stream*. Il Complesso 2 è l'acquiclude principale, costituito da depositi torrentizi e di *debris flow* alterati e cementati. I valori di portata provengono prevalentemente dall'Archivio della Provincia di Torino; sono contrassegnati (+) i valori direttamente misurati dagli autori. Nel territorio di Germagnano le portate delle sorgenti alimentate dai depositi di *block stream* variano da 2-5 a 15-25 l/s (Fioraso & Spagnolo, 2009).

commune / catchment	n°	spring name	discharge l/s	aquifer	aquifer substrate	use
Almese / Rio Morsino	1	Morsino Alto	2	Complex 1	Complex 2	drinking
	2	Fontanafredda 1	1	Complex 1	Complex 2	drinking
		Fontanafredda 2	1.05	Complex 1	Complex 2	drinking
	3	Listelli 1	0.04	Complex 1	Complex 2	drinking
		Listelli 2	0.07	Complex 1	Complex 2	drinking
		Listelli 3	0.06	Complex 1	Complex 2	drinking
		Listelli 4	0.04	Complex 1	Complex 2	drinking
		Listelli 5	0.07	Complex 1	Complex 2	drinking
	4	Bunino	0.08	Complex 1	peridotites	drinking
	5	Miosa	0.08	Complex 1	Complex 2	drinking
Varisella / T. Ceronda	6	Rul 1	1.11	Complex 1*	Complex 2	drinking
	7	Rul 2	1.04	Complex 1*	Complex 2	drinking
	8	Lil	0.08	Complex 1*	Complex 2	drinking
	9	Rio del Lupo	5^+	Complex 1*	Complex 2	untapped
	10	Fusalas 1	0.5 / 0.29^+	Complex 1	Complex 2	drinking
		Fusalas 2	0.5 / 0.22^+	Complex 1	Complex 2	drinking
	11	Falasca	5.4 / 4.8^+	Complex 1	Complex 2	drinking
	12	Valceronda	1.05	Complex 1	serpentinites	irrigation
La Cassa / T. Ceronda	13	Pra Maria	/	Complex 1	serpentinites	irrigation
Givoletto / Rio Risalto	14	La Douce	/	Complex 1	serpentinites	irrigation
	15	Mousset	/	Complex 1	serpentinites	irrigation
Val della Torre/T. Casternone	16	Fontanafredda 1	1	Complex 1	peridotites	drinking
		Fontanafredda 2	2	Complex 1	peridotites	drinking
	17	Arpone	2.05	Complex 1	peridotites	drinking
	18	Riva d'la Mena	4	Complex 1	serpentinites	drinking
	19	Codra	3	Complex 1	serpentinites	drinking
	20	Fontanabruna	2.05	Complex 1	peridotites	drinking
	21	Roch	2.05	Complex 1	peridotites	drinking
	22	Truc del Brione	0.05	Complex 1	peridotites	drinking
Vallo Torinese/Rio Tronta	23	Benna (8 springs)	total 8	Complex 1	Complex 2	drinking
	24	Galinverno	0.09	Complex 1	Complex 2	drinking
	25	Lupo	0.08	Complex 1	Complex 2	drinking
Germagnano/T. Stura di Lanzo	26	Lenciassa	1	Complex 1	peridotites	drinking
	27	Cugno	1.34	Complex 1	peridotites	drinking
	28	Gurba (4 springs)	total 4.5	Complex 1*	peridotites	drinking
	29	Stura	4.04	Complex 1*	peridotites	drinking
	30	Cerre, Griva, Vecchia, Fredda (4 springs)	total 13.45	Complex 1*	serpentinites	drinking
Lanzo Torinese/T. Stura di Lanzo	31	Via Cafasse	2	alluvial dep.		pisciculture
	32	Croassere	/	Complex 1	serpentinites	/
Cafasse/T. Stura di Lanzo	33	Rio Proglio	/	Complex 1	serpentinites	irrigation
	34	Montebasso	/	Complex 1	serpentinites	irrigation
Rubiana / T. Messa	35	Oliva (3 springs)	total 4.8	Complex 1	peridotites	drinking

crop A3 in figure 2 and geological map and cross-section in figure 10) and the Varisella area (outcrop A11 in figure 2 and geological map and cross-section in figure 11).

Listelli, Fontana Fredda and Morsino Alto springs (tab. 2) are located in the Almese commune (left side of the lower Susa Valley), between 460 and 470 m a.s.l., at the south-western side of the LUM (fig. 10). During the Last Glacial Maximum, this sector was covered by the Dora Riparia Glacier. Here the main aquifer (Complex 1) is represented by Late Pleistocene flow till and glaciofluvial deposits lying on the ancient torrential and debris-flow succession. Small bodies of subglacial deposits are covered by the other glacial deposits. Because of their very low permeability, subglacial deposits are referred to as hydrogeological Complex 2. The springs are placed along the deepest incisions modelled into glaciofluvial deposits, like Fontana Fredda spring hosted by an abandoned riverbed.

Fusalas spring is located in the Varisella commune at the eastern side of the LUM. It is picked up by two adjacent supplying works, between Rio dell'Adrit and Rio del Lupo, into a left tributary incision of the Rio del Lupo at 730 m a.s.l. (fig. 11).

This sector of the LUM was not involved in the Pleistocene glaciations because it is at a low elevation and is not connected with the main glacial valleys (Susa and Stura di Lanzo). Here, the weathered and cemented torrential succession (Complex 2) outcrops continuously along the Rio dell'Adrit incision. This unit is covered by debris flow sediments that are several metres thick, with low permeability because of their fine texture and strong weathering.

Extremely permeable block stream deposits rest on this unit in the high sector of the basin. Block stream deposits contain an aquifer with high transmissivity. They feed directly some springs localised at the distal edge of block streams, with intermittent discharges variable from dozens of l/s to less than 1 l/s, and strictly linked to rain water and snow supply (Rio del Lupo spring in tab. 2). In contrast, all of the caught springs linked to Varisella aqueduct, show rather constant and low (less than 1 l/s) discharges. They are distributed along the block stream lateral sides but they are localised into the debris flow deposits (Rul and Lil springs in tab. 2). These data are in agreement with the presence of an aquifer hosted by the debris flow deposits with low permeability and high water retention, recharged mainly by the high permeable aquifer in the block streams. The springs are probably located some metres above the contact between ancient torrential deposits and the debris flow cover. This location is due to the difference of permeability between these three kinds of deposits.

The low electrolitc conductibility values of the analysed spring waters of Varisella sector (Rul: 76 μS/cm; Fusalas: 99 μS/cm; Falasca: 95 μS/cm) indicate a low mineralisation of waters connected to the monotonous peridotite composition of the local bedrock and its detrital cover, without carbonatic and sulphatic lithotypes. This feature is also linked to their brief standing into the aquifer because of the short distance between the block streams edges and these springs (from some metres to some hundreds of metres).

The higher electrolitc conductibility of the analysed spring waters of the Almese sector (Listelli: 266 μS/cm; Fontana Fredda: 310 μS/cm; Morsino Alto: 256 μS/cm) is, instead, connected to the various lithological composition of the aquifer. It is represented by glacial deposits from Susa Valley and constituted by carbonate and silicate rock fragments.

6. - CONCLUSIONS

In this study we describe a wide-extensive and thick succession of torrential and debris flow deposits of Middle Pliocene-Lower Pleistocene age that had been disregarded in previous literature. These deposits lie on the peridotite bedrock of the Lanzo Ultramafic Massif.

The ancient succession is affected by weathering with strong argillification and iron oxidation. These secondary processes imparted comparable permeability values to different facies and produced an impermeable body that is very significant to the hydrogeological structure of the area.

The distribution of springs in the outcrop area of the torrential and debris flow succession was mapped in this study (fig. 2). Many springs are linked to the weathered deposits, interpreted as the main aquiclude (Complex 2) (tab. 1). This aquiclude bounds different shallow aquifers, hosted by the overlying permeable sediments (Complex 1). The latter consists of different facies if we compare the areas that were occupied by the Pleistocene glaciers (Almese) with the non-glaciated areas (Varisella). These facies (flow till, glaciofluvial, fluvial, debris flow, block stream and gravitative deposits) show variable permeability, from medium to very high (tab. 1). The presence of the low-permeability torrential and debris flow succession in the shallow subsurface causes water emergences where the topography is close to, or cuts across, the aquifer/aquiclude interface. The spring discharges are generally very low (1 l/s or less; tab. 2).

Only the springs fed directly by block stream deposits reach high discharges (25 l/s) but the discharge regime is highly variable in phase with the meteorological events.

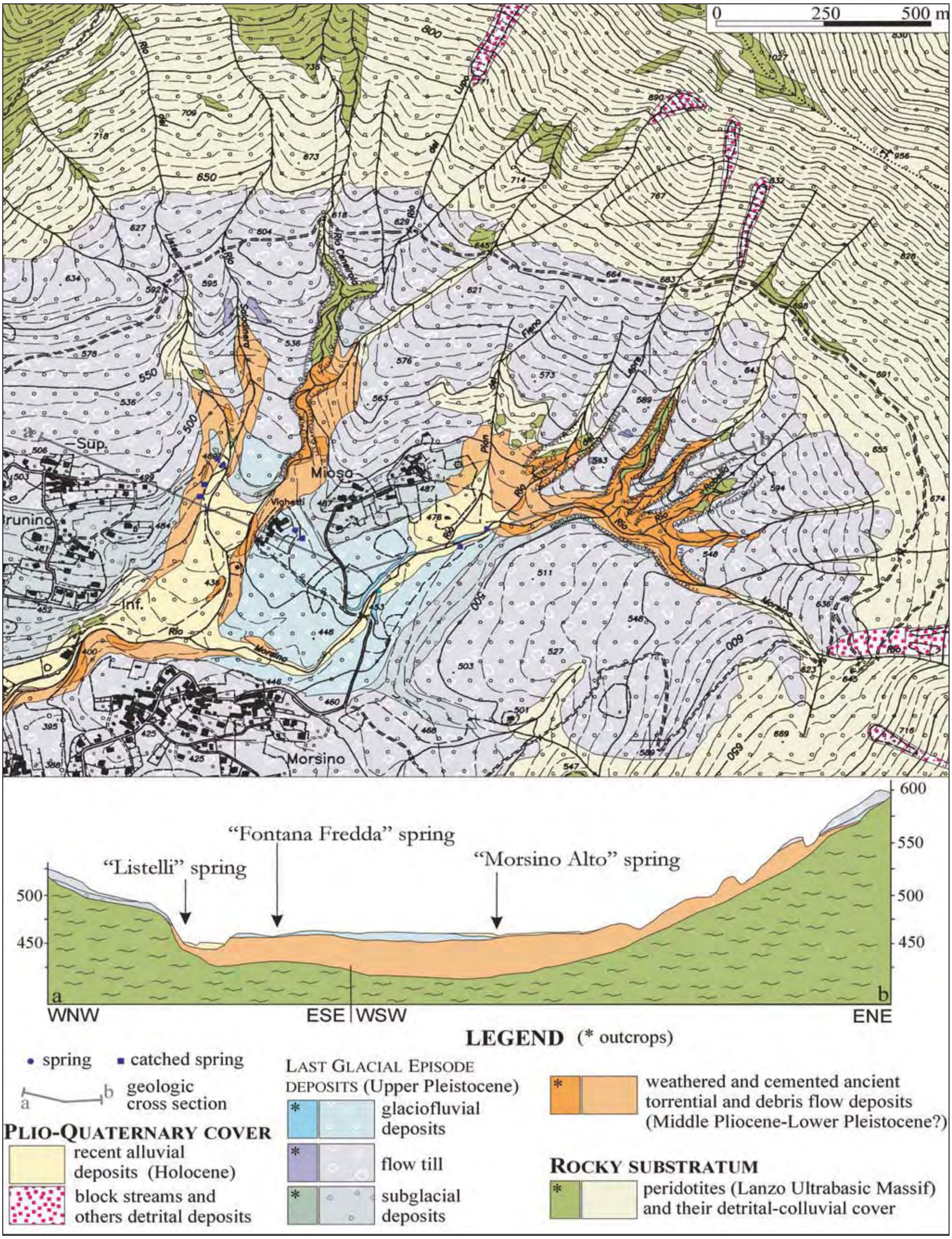

Fig. 10 - Geological map and cross section of the Almese, Morsino and Listelli springs (Almese, lower Susa Valley; see figure 2 for location of the area); vertical exaggeration in cross section is about 2,5.

- Carta geologica e profilo geologico dell'area delle sorgenti Almese, Morsino and Listelli (Almese, bassa Val di Susa; si veda figura 2 per l'ubicazione dell'area); l'esagerazione verticale nel profilo è di circa 2,5.

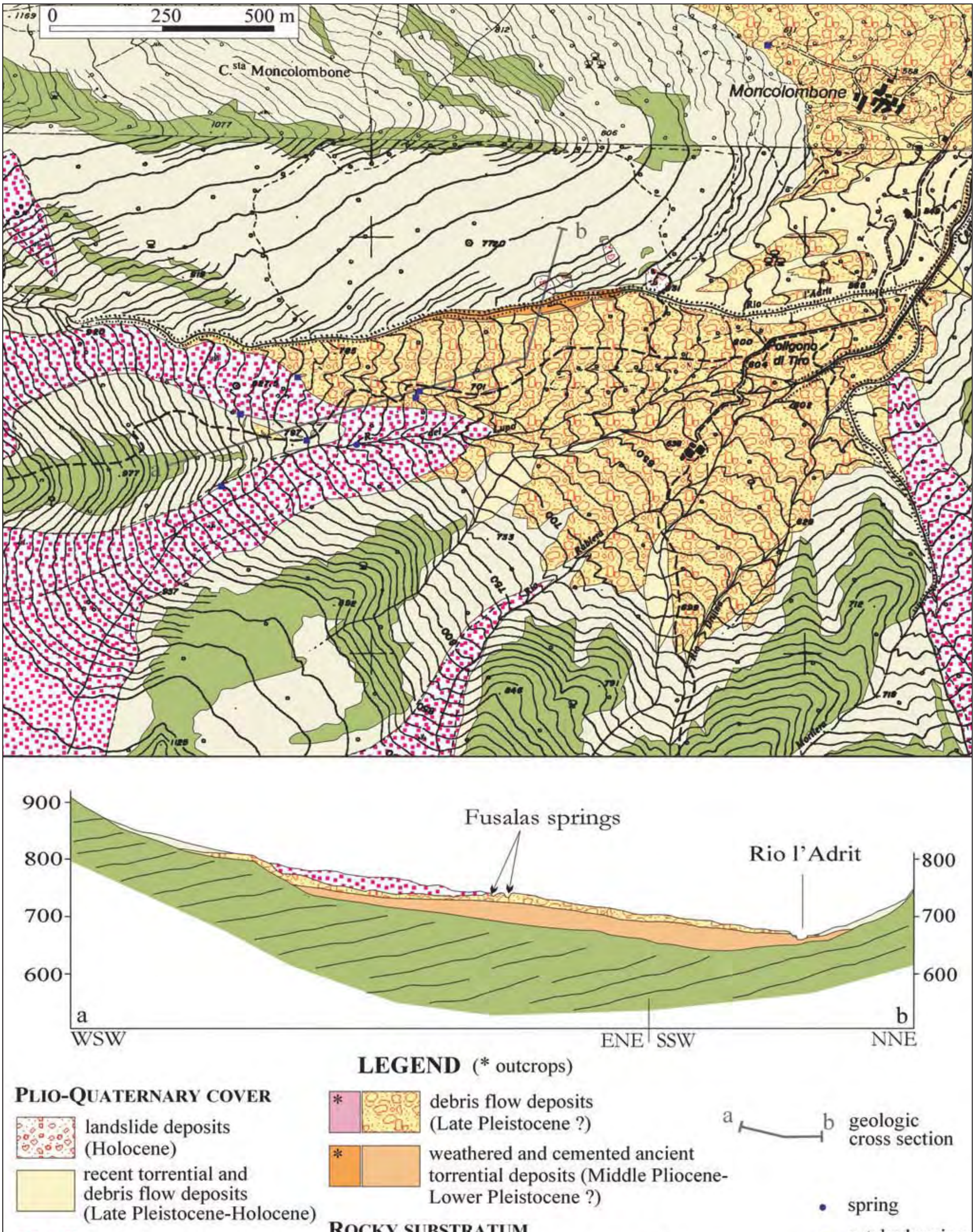

Fig. 11 - Geological map and cross section of the Fusalas springs (Varisella, Val Ceronda; see figure 2 for location of the area); vertical exaggeration in cross section is about 1,5.
- Carta geologica e profilo geologico dell'area delle emergenze Fusalas (Varisella, Val Ceronda; si veda figura 2 per l'ubicazione dell'area); l'esagerazione verticale nel profilo è di circa 1,5.

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