UNIVERSITÀ DEGLI STUDI DI TORINO
DIPARTIMENTO DI SCIENZE DELLA TERRA

THE END-MORAINE SYSTEM OF THE PLEISTOCENE MOLETTA GLACIER (SUSA VALLEY, NW, ITALY)

CRETÌ E. [1*], GIANOTTI F. [1]
[1] EARTH SCIENCES DEPARTMENT, UNIVERSITY OF TORINO, TORINO, ITALY
(edoardo.creti@edu.unito.it, franco.gianotti@unito.it)

1. INTRODUCTION

The Dora Riparia River has a mountain 1050 km^2 wide basin (Susa Valley) characterized by a west-east oriented lower trunk valley. The high mean elevation of this catchment (1450 m with a maximum at 3619 m a.s.l. at Punta Roncia) and many plateaux up to 3000 m a.s.l. allowed the development of a 90 km long and 1 km thick glacier during the Pleistocene glaciations. The 150 km^2 wide Rivoli-Avigliana Morainic Amphitheatre surrounds the outlet of the valley. The Moletta (Fig. 1) catchment is a 5,8 km^2 wide tributary south-facing valley, with maximum elevation of 2963 m a.s.l. (M. Palon - Rocciamelone Group), on the left side of the lower Susa Valley north of Bussoleno (NW Italy). The Bussoleno village is located at 440 m asl on the T. Moletta alluvial fan which extends downvalley in the trunk valley floor. The surveys for the Susa Sheet of the Geological Map of Italy have shown how most of the north-facing righ tributary glaciers of the lower Susa Valley, and some of the south-facing (i.e. with unfavorable exposure) left tributary glaciers merged into the main glacier during the LGM (Fig. 3 in Cadoppi et al., 2002) and likely brought their fronts to the main valley floor when the Dora Riparia Glacier retreated during the Lateglacial. This behavior was not recognized for the Moletta tributary glacier, due to the lack of evidence attesting the glacier advance at low altitudes. A new geological survey (Cretì, 2019) was so carried out north of Bussoleno at the outlet of the Moletta Valley, with the aim of check in more detail the relationship between the tributary Moletta Glacier and the main Dora Riparia Glacier in the Last Glaciation.

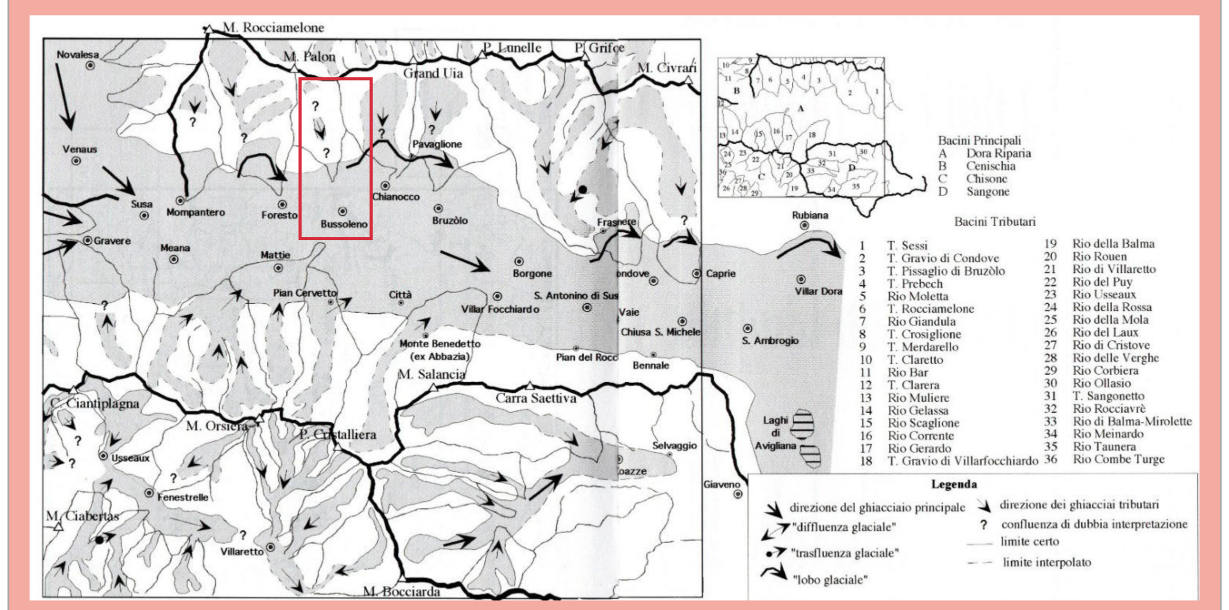

Fig. 1 – Rio Moletta basin (red box) north of the town of Bussoleno, Susa Valley.

2. GEOLOGICAL SETTING

2.1 Bedrock

The Alps are a double-vergence chain,divided into the following structural domains: Southern Alps, Australpine nappes, Penninic nappes and Helvetico zone.The study area (Fig. 2) is entirely included within the Dora Maira Massif which is part of the Penninic Domain. The latter is divided, from top to structural bottom, into various units (Gasco et al., 2011). The Piemontese Zone of calceschist with green stones, further divided into the Combin Unit and the Zermat-Saas Unit. The European continental crust units, on the other hand, are divided into: Upper Penninic nappes, formed by subducted continental crust units and including the Inner Crystalline Massifs (Dora Maira, Gran Paradiso and Monte Rosa); Intermediate Penninic nappes, consisting of the Gran San Bernardo Nappe and the Sub-Brianzonese Zone and finally the Lower Penninic nappes which constitutes the deepest units of the succession and emerges in the tectonic window of Ossola - Ticino. The Dora Maira Massif in turn is divided into three tectonometamorphic units: 1) the Lower Monometamorphic Unit (Pinerolese Complex), is the structurally lowest unit; 2) The Brossasco-Isasca Unit; 3) the Superior Unit. The Moletta Valley is located in the Penninic Domain at the tectonic contact between the Piemontese Zone and the Dora-Maira massif (the Superior Unit). It consists of oceanic crust made of serpentinite and prasinite (Piemontese Zone), oucropping in the upper sector of the valley and tectonically overlying (cargneule) on a continental crust made of paragneiss, micaschist and dolomite marble (Dora Maira Massif) outcropping in the lower sector (Cadoppi et al., 2002).

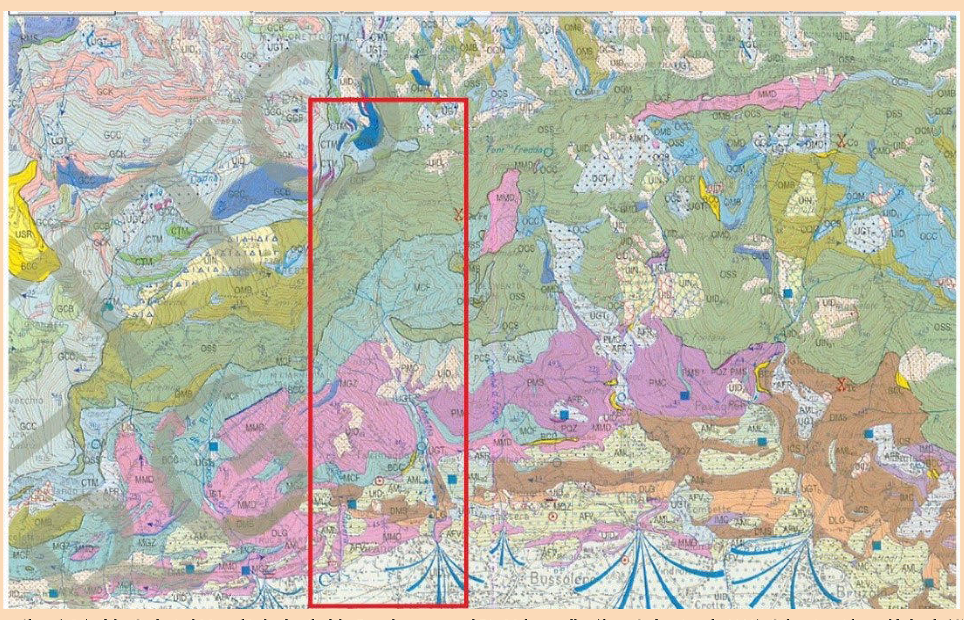

Fig. 2 – Susa Sheet (154) of the Geological Map of Italy, detail of the Bussoleno area and Rio Moletta valley (from Cadoppi et al., 2002). Calcescist with marble levels (CTM), serpentinite and serpentinoscist (OSS), dolomitic marble (PMC), calcescist (MCF), gray-blue marble (MGZ), meta-dolomite (MMD), "Pietra di Luserna" gneiss (DLG), Polymetamorphic Complex (DMS).

2.2 Quaternary coverage

The traces of Pleistocene glacialism are clearly recognizable in the widespread subglacial erosional forms and in the locally well preserved glacigenic deposits and forms, present on both sides of the valley. The Dora Riparia basin has been investigated since the second half of 19th Century (e.g., Sacco, 1887, 1921). During the last decades, the lower reach of the Susa Valley has been investigated for the geological survey of two geological sheets of the new Italian Geological Map at the scale 1:50.000, namely: Susa (Cadoppi et al., 2002) and Torino Ovest (Balestro et al., 2009). The stratigraphic subdivision was based on geomorphological and pedological data, without any chronological constrain. In detail, five units were distinguished in the amphitheatre (Balestro et al., 2009), two related to the Middle Pleistocene glacial expansions (S. Gillio synthem and Bennale synthem) and three related to the Late Pleistocene (Frassinere synthem, Magnoletto synthem and Crescentino subsynthem). Those related to the Late Pleistocene form a continuous set of internal moraine ridges in the amphitheatre characterized by little developed soils with 7.5-10YR hue index MUNSELL color. These units were traced along the lower reach of the valley (Cadoppi et al., 2002), where moraines and kame terraces are discontinuosly spread on both sides. More recently, the surface exposure dating method on erratic boulders from the lower reach of Susa Valley to the Rivoli-Avigliana terminal moraines has dated the LGM maximum glacier advance at 24.0±1.8 ka (Ivy-Ochs et al., 2018), in-phase to the Alpine LGM reconstructed in other sectors. In the Susa valley section, however, only the deposits and forms related to the phase of maximum expansion of the last glaciation (LGM, 29-19 ka BP) and its withdrawal phases (Lateglacial, 19-11.7 ka BP) are evident, with the exception of the traces of the penultimate glacial expansion preserved only in the sector close to the valley outlet. In the study area north of Bussoleno, the various sedimentary bodies present on the lower slope around the Moletta incision outlet have been interpreted by Cadoppi et al. (2002) as fluvioglacial deposits belonging to the Tributary Basins Unit (UGTb), while at a slightly higher altitude (between 600-800 m a.s.l.) all the glacigenic deposits would correspond to glacio-lacustrine sediments referable to the main glacier (in this case to the Cenischia basin; Magnoletto Unit). Thus no glacial till would have been referred to the tributary glacier at low altitude (below 1000 m a.s.l.) in this area.

3. METHODS

This work is essentially based on geological surveys aimed at mapping the Quaternary sediments and forms present in the area. The surveys were carried out in the period between the months of April and October of 2019. Previous works was examined and consulted, especially the 154-Susa Sheet of the Geological Map of Italy at the scale 1: 50000 (Cadoppi et al., 2002), An attribution to different genetic basins of origin (tributary and main) of the various glacigenic sedimentary bodies, was based on geomorphological analysis (plano-altimetric location and orientation of the depositional and erosional forms) and the petrographic composition of clasts (presence or absence of some marker lithologies). From the 154-Susa Sheet, , the only marker lithology identified for the Moletta basin is the dolomitic marble with a saccharoid aspect associated with tectonic breaches (PMC; Mesozoic cover of the Dora-Maira Unit). Considering the main basin (Susa Valley-Cenischia Valley), albitic-gneisses, micaschists and paragneisses that form intercalations within the calcescists (Puys-Venaus tectonometamorphic unit), the prasinitic and prasinite-gneisses, amphibolytic and chloritoscist schists and to the, massive and listed prasinites, actinolytic amphibolites and chloritoscists (lower Susa Valley – Lanzo Valley - Monte Orsiera tectonometamorphic unit) are the more useful marker lithologies. Topographic base was taken from the "BDTRE - Territorial Reference Data Bank of Bodies", with equidistance of 10 m between the contour lines, downloaded from the Geoportal of the Piedmont Region and reproduced at a scale of 1: 10000. DTM and Google Earth maps were also used.

Carta Geologica del settore di sbocco del Rio Moletta (Bussoleno, Valle di Susa) scala 1:5000

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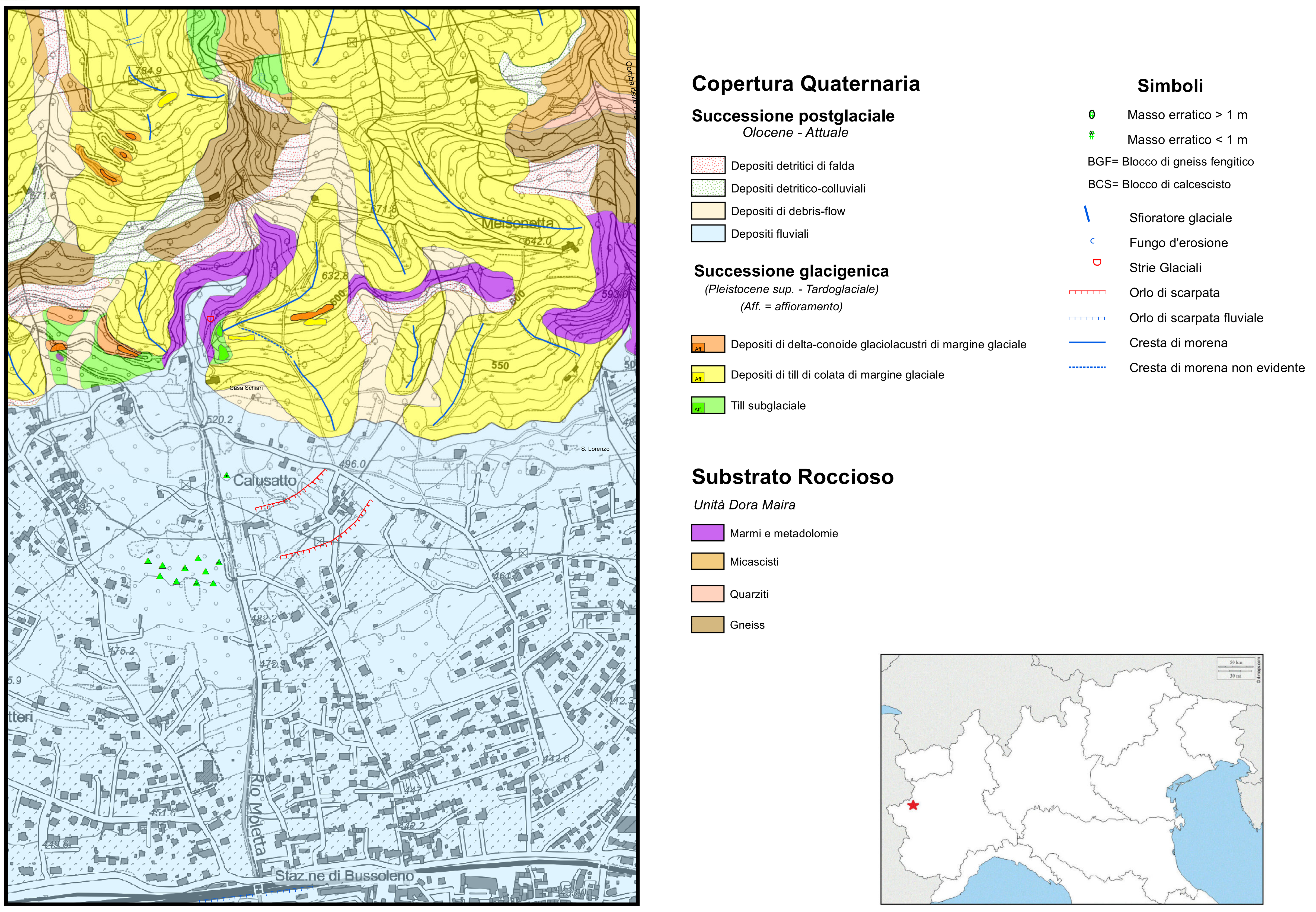

4. STRATIGRAPHY

The bedrock, with a diffuse subglacial abrasion shaping, is covered by Lateglacial (19-11.7 ka BP) glacigenic deposits (lodgement till, subglacial melt-out till, ice-marginal flow till, glacio-lacustrine and glacio-fluvial deposits) and by post-glacial gravitative deposits (talus debris and colluvial). Thick bodies of well stratified ice-marginal glacio-lacustrine gravelly sand, scattered on the trunk valley side, rest above the subglacial till and are referred mainly to the trunk glacier. Some geomorphological elements have been found on the valley side at the edges of the lower T. Moletta incision (a latero-frontal moraine ending at the valley side-valley floor border; N-S trending glacial-striae on roche moutonnée) and in the apex sector of the T. Moletta alluvial fan (a set of transversal scarps not due to river erosion; a cluster of 1-2 long serpentinite blocks; a big serpentinite erratic boulder). These elements are interpreted as the remnants of an end-moraine system largely buried under the alluvial fan deposits and referred to the Moletta Glacier.

4.1 Lodgement till and subglacial melt-out till

The subglacial till was found in a few outcrops, of which the main one is located in the southern sector of the area immediately north of Casa Schiari at an altitude of 560 m a.s.l. (Fig. 3). Silty sands and gravels, slightly over-consolidated, with a coarse massive stratification highlighted by the iso-orientation of the clasts. The strike and dip of the layers varies, , even if a 35-50° toward SE dipping stratification prevails (isoriented pebbles with a long-axis 130/45). The matrix is given by unselected sand, from coarse to very fine, silty, gray-yellow in color. Clasts are heterometric, with an average size of 8-15 cm up to 1 m. Pebbles and small cobbles prevail, while the blocks are rare. The clasts are subangular with rounded edges. The presence of faceted clasts but with not perfectly leveled facets and with surfaces not well smoothed, suggests limited transport over a short distance in subglacial position. The lithological composition of the clasts is varied: serpentinites, calcescists, impure marbles and metadolomie prevail. Quartzites are less than 10%. Gneiss and micaschists are absent. This petrographic composition is in agreement with a supply from the Rio Moletta basin. Layers with coarse matrix are weakly cemented . This deposit can be interpreted as subglacial till deposited by the Moletta Glacier. In particular the stratification and the low degree of over-consolidation specify the facies as a subglacial/submarginal melt-out till.

Fig. 3 – Subglacial melt-out till (outcrop located 10 m north of "Casa Schiari" at 560 m a.s.l.).

4.2 Glaciofluvial deposits and ice- marginal glaciolacustrine deposits

These deposits consist of well stratified alternated layers of fine gravel, sandy gravel, gravelly sand and silty sand: the first three lithofacies occur in 5-10 cm thick beds while the latter is more thinly bedded (< 2-3 cm) and laminated. They shows an inclined stratification dipping 10-25 ° towards NNE. The texture is mainly matrix-supported, but open-texture fine gravel is very frequent. Gravel sands are cemented. Clasts size is up to 7 cm, they are subangular and their composition is various. The matrix is characterized by the presence of abundant coarse sand and granules (2-4 mm) mixed with fine-silty sand. The abundant clasts of serpentinite suggest a main supply from the Moletta basin. These deposits are glaciotectonically deformed by faults and folds. The deposits can be interpreted as foreset of small fan-delta sedimented in ice-marginal lakes, mainly supplied by fluvioglacial streams (marginal, supra and proglacial). Numerous outcrops along the road to Falcimagna preserve a vertical exposure over time thanks to the weakly cementation of the deposits (Fig. 4). However, their morphological expression (kame terraces) is not preserved.

Fig. 4 – Glaciotectonically faulted ice-marginal glaciolacustrine deposits with a gently dipping planar-cross and plano-parallel bedding, cemented. (road to Falcimagna at 735 m a.s.l.)

4.3 Ice-marginal flow till

Some elongated reliefs with a moraine-like morphology have been found on the valley side laterally to the deep incision of the Rio Moletta; Most of them are N-S oriented (i.e. parallel to the Rio Moletta incision), while three of them are curved in plant. These deposits are visible in numerous small outcrops on the left side of the Rio Moletta. Here, slightly silty gravels and sands emerge, with poorly distinguished inclined stratification. They are predominantly clast-supported even though the matrix is locally abundant. The deposits are cemented. Clasts are heterometric, from angular to subrounded, with dimensions from centimetric to pluricentimetric up to small blocks (maximum size up to 1 m). These deposits have been interpreted as fluvioglacial sediment in the Susa Sheet (Cadoppi et al., 2002) and here re-interpreted as ice-marginal flow till forming moraines (Fig. 5), in which a supply from previous fan-delta deposits is important.

Fig. 5 – View of a lateral right moraine of the Moletta Glacier (NW of Casa Schiari at 600 m a.s.l.)

5. EVIDENCES OF THE TRIBUTARY MOLETTA GLACIER ADVANCE IN THE DORA RIPARIA VALLEY FLOOR

Some geomorphological elements have been found on the valley side at the edges of the lower T. Moletta incision (a latero-frontal moraine ending at the valley side-valley floor border; N-S trending glacial-striae on roche moutonnée) and in the apex sector of the T. Moletta alluvial fan (a set of transversal scarps not due to river erosion; a cluster of 1-2 long serpentinite blocks; a big serpentinite erratic boulder). These elements are interpreted as the remnants of an end-moraine system largely buried under the alluvial fan deposits and referred to the Moletta Glacier.

1) A **lateral moraine** turns toward south-east, and ends on the main valley floor north of Calusatto truncated by the Rio Moletta alluvial fan. This remarkable ice-marginal shape is clearly recognizable as the lowest and most internal left moraine of the Moletta Glacier.

2) The occurrence of **glacial striae** (Fig. 6) on a roche moutonnée of meta-dolomites north of Casa Schiari at 570 m asl. The N-S direction of the striae is indicates a genetic link with the Moletta Glacier and constitutes further evidence of the tributary glacier advance at a very low altitude.

3) The presence of **two scarps** on the alluvial fan with anomalous trending because they are oriented transversally to the slope of the dip of the fan. These forms are found on the continuation of the moraine and can be interpreted as the morphological evidence of one or two frontal moraines almost completely buried under the alluvial deposits.

4) The presence of a **concentration of outcropping boulders** in the upper sector of the Rio Moletta alluvial fan on the continuation of the scarps of Calusatto towards west at 490 m asl. The blocks are subangular and smoothed and are made of serpentinite and serpentinoscist and rare gneiss and calcschist up to 2 m in size, and form elongated ridges . Overall, a weakly arched accumulation with an E-W trending is recognizable. This element can be interpreted, in light and in accordance with the other evidences, as the coarse remain of a previous end-moraine totally demolished by the T. Moletta erosional activity.

Fig. 6 – N-S oriented glacial striae on a roche moutonnée of meta-dolomites (north of Casa Schiari at 570 m a.s.l.)

5) A little further upstream, the presence of a about 15 m^3 sized block of serpentinite on the alluvial fan surface is a fundamental element for our reconstruction. It constitutes a typical **erratic boulder** (Fig. 7) and so it is proof of the arrival of the glacial front at least up to this point.

Fig. 7 – Erratic boulder of serpentinite 2x3x2 m sized lying on the proximal sector of the Rio Moletta alluvial fan at 510 m a.s.l.

6. RESULTS

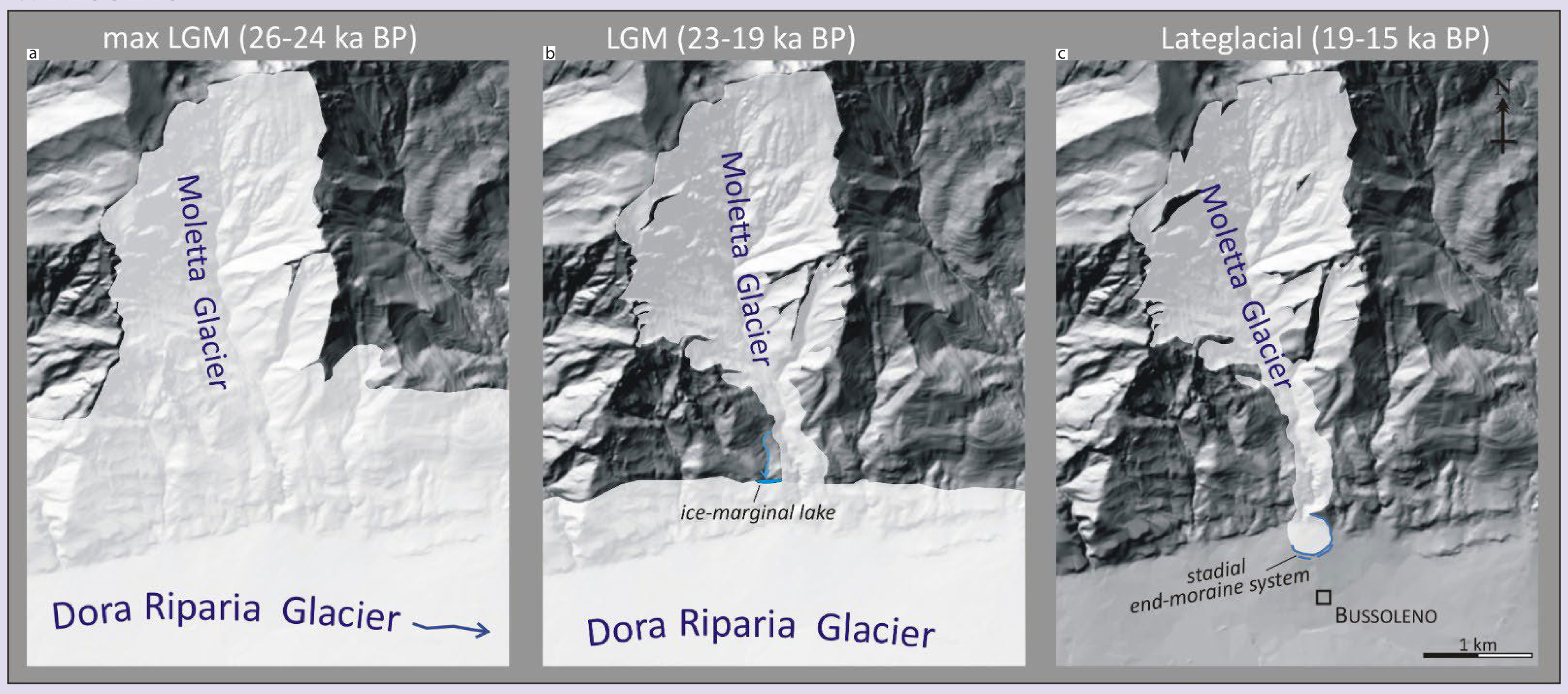

Fig. 8a – Moletta Glacier joined the Dora Riparia Glacier during the Last Glacial Maximum;

Fig. 8b - During a final stage of the LGM a series of ice-marginal lakes formed in ephemeral depression on the valley slope dammed by the two glaciers

Fig. 8c - Moletta Glacier reached the main valley floor in the Lateglacial

This study attests that the Moletta Glacier joined the Dora Riparia Glacier during the Last Glacial Maximum (Fig. 8a) and reached the main valley floor in the Lateglacial (Fig. 8c). During a final stage of the LGM a series of ice-marginal lakes formed in ephemeral depression on the valley slope dammed by the two glaciers, and quickly filled by fan-delta deposits, well visible in excellent outcrops, supplied by proglacial streams (Fig.8b).
A greater expansion of the tributary glacier is therefore recognized and reported on a new geological map compared to the previous extent reported in the Susa Sheet of the Geological Map of Italy (Cadoppi et al., 2002). The climato-stratigraphic context, in which the processes that led to the formation of the above elements took place, can be clearly identified in the context of the generalized glacial retreat that occurred in the Lateglacial (19-11.7 ka BP). In particular, the withdrawal of the Dora Riparia Glacier from the lower left side of the main valley left space for the advance of its tributary Moletta Glacier. The presence of more lateral moraines on the main slope on both sides of the tributary incision has been ascertained, but the recognition of a end-moraine apparatus in the locality of Calusatto, now completely buried by the fluvial deposits of the T. Moletta fan, allows to better reconstruct the glacier evolution.
With the complete withdrawal of the trunk glacier, the Moletta Glacier expanded on the fan sector at least up to an altitude of 482 m a.s.l. and 350 m away downstream of the valley mouth. This situation likely involved all the major tributary glaciers of the Val di Susa (Cadoppi et al., 2002) also on the left and therefore with unfavorable southern exposure of the basin. . Despite a generalized reduction in volume of all glaciers during Lateglacial, a protract advance of the tributary glacier fronts towards the main valley floor can be explained with the high steepness of these basins, their high accumulation/ablation area ratio and the short distances between glacial cirques and valley outlets. The present study has therefore identified new elements on the evolution of the area of confluence between the tributary Moletta Glacier and the Dora Riparia Glacier, which integrate the knowledge on the glacialism of the Susa Valley.

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