IT ISSN 0391 - 9838

Bollettino del Comitato Glaciologico Italiano - ser. 3

GEOGRAFIA FISICA e DINAMICA QUATERNARIA

An international Journal published under the auspices of the
Rivista internazionale pubblicata sotto gli auspici di

Associazione Italiana di Geografia Fisica e Geomorfologia
and (e) Consiglio Nazionale delle Ricerche (CNR)

recognized by the (*riconosciuta da*)

International Association of Geomorphologists (IAG)

volume 41 (2)
2018

COMITATO GLACIOLOGICO ITALIANO - TORINO
2018

GEOGRAFIA FISICA E DINAMICA QUATERNARIA

A journal published by the Comitato Glaciologico Italiano, under the auspices of the Associazione Italiana di Geografia Fisica e Geomorfologia and the Consiglio Nazionale delle Ricerche of Italy. Founded in 1978, it is the continuation of the «Bollettino del Comitato Glaciologico Italiano». It publishes original papers, short communications, news and book reviews of Physical Geography, Glaciology, Geomorphology and Quaternary Geology. The journal furthermore publishes the annual reports on italian glaciers, the official transactions of the Comitato Glaciologico Italiano and the Newsletters of the Intemational Association of Geomorphologists. Special issues, named «Geografia Fisica e Dinamica Quaternaria - Supplementi», collecting papers on specific themes, proceedings of meetings or symposia, regional studies, are also published, starting from 1988. The language of the journal is English, but papers can be written in other main scientific languages.

Rivista edita dal Comitato Glaciologico Italiano, sotto gli auspici dell'Associazione Italiana di Geografia Fisica e Geomorfologia e del Consiglio Nazionale delle Ricerche. Fondata nel 1978, è la continuazione del «Bollettino del Comitato Glaciologico Italiano». La rivista pubblica memorie e note originali, recensioni, corrispondenze e notiziari di Geografia Fisica, Glaciologia, Geomorfologia e Geologia del Quaternario, oltre agli Atti ufficiali del C.G.I., le Newsletters della I.A.G. e le relazioni delle campagne glaciologiche annuali. Dal 1988 vengono pubblicati anche volumi tematici, che raccolgono lavori su argomenti specifici, atti di congressi e simposi, monografie regionali sotto la denominazione «Geografia Fisica e Dinamica Quaternaria - Supplementi». La lingua usata dalla rivista è l'Inglese, ma gli articoli possono essere scritti anche nelle altre principali lingue scientifiche.

Indexed/Abstracted in: Bibliography & Index of Geology (GeoRef); GeoArchive (Geosystem); GEOBASE (Elsevier); *Geographical Abstract*: *Physical Geography* (Elsevier); GeoRef; Geotitles (Geosystem); Hydrotitles and Hydrology Infobase (Geosystem); Referativnyi Zhurnal.
Geografia Fisica e Dinamica Quaternaria has been included in the Thomson ISI database beginning with volume 30 (1) 2007 and now appears in the Web of Science, including the Science Citation Index Expanded (SCIE), as well as the ISI Alerting Services.

HOME PAGE: http://gfdq.glaciologia.it/ - CONTACT: gfdq@dst.unipi.it

Printed with the financial support from (pubblicazione realizzata con il contributo finanziario di):

– Comitato Glaciologico Italiano
– Associazione Italiana di Geografia Fisica e Geomorfologia
– Ministero dell'Istruzione, Università e Ricerca
– Consiglio Nazionale delle Ricerche
– Club Alpino Italiano

Geogr. Fis. Dinam. Quat.
41 (2018). 105-114, 6 figg.

DOI 10.4461/ GFDQ.2018.41.16

Irene Maria BOLLATI [1*], Riccardo CERRATO [2], Beatrice CROSA LENZ [1], Laura VEZZOLA [1], Elisa GIACCONE [3], Cristina VIANI [4], Thomas ZANONER [5], Roberto Sergio AZZONI [6], Anna MASSEROLI [1], Marco PELLEGRINI [1], Cristian SCAPOZZA [7], Andrea ZERBONI [1] & Mauro GUGLIELMIN [8]

GEOMORPHOLOGICAL MAP OF THE VAL VIOLA PASS (ITALY-SWITZERLAND)

Abstract: Bollati I.M., Cerrato R., Crosa Lenz B., Vezzola L., Giaccone E., Viani C., Zanoner T., Azzoni R.S., Masseroli A., Pellegrini M., Scapozza C., Zerboni A. & Guglielmin M., *Geomorphological map of the Val Viola Pass (Italy-Switzerland).* (IT ISSN 0391-9838, 2018).

The Val Viola Pass is a transboundary area between Italy (Val Viola Bormina) and Switzerland (Val da Camp), whose evolution has been triggered, since the Last Glacial Maximum (LGM), by intense reactivation of surface processes. Geomorphological mapping at a scale of 1:5000 provided an understanding of the deglaciation dynamics affecting this region. The geomorphological map (herein presented at scale 1:7000) extends for 5.35 km^2 between the elevations of 2305 and 3302 metres above sea level (m a.s.l.). The geomorphological map suggests that the area undergoes geomorphic processes typical of alpine environments of middle latitude, and had experienced a paraglacial-type re-equilibrium related to post-LGM land evolution, with predominant slope and periglacial processes. Moreover, current water action is evident at low elevations. Most of landforms are affected by major regional structures oriented NE-SW. On the Swiss side, specific investigations of the Paradisin rock glacier were performed by *Electrical Resistivity Tomography-ERT* to determine its internal structure. This was in order to understand its possible cryotic conditions, despite its relict appearance derived from its surface aspect.

Key Words: Geomorphological mapping, High mountain landscape, Deglaciation, Paradisin rock glacier, Electrical Resistivity Tomography, Val Viola Pass (Central Alps).

Riassunto: Bollati I.M., Cerrato R., Crosa Lenz B., Vezzola L., Giaccone E., Viani C., Zanoner T., Azzoni R.S., Masseroli A., Pellegrini M., Scapozza C., Zerboni A. & Guglielmin M., *Carta geomorfologica del Passo di Val Viola (Italia-Svizzera).* (IT ISSN 0391-9838, 2018).

Il Pas da Val Viola è un'area transfrontaliera compresa tra Italia (Val Viola Bormina) e Svizzera (Val da Camp), la cui evoluzione è stata condizionata, dopo l'Ultimo Massimo Glaciale (UMG), da un'intensa riattivazione dei processi superficiali. La cartografia geomorfologica, realizzata alla scala 1:5000, ha consentito di esemplificare le forme del rilevo dovute all'azione degli agenti morfogenetici attivi ma anche quelle relitte. La carta geomorfologica (qui riportata alla scala di 1:7000) copre un'area di 5.35 km^2, compresa tra le quote di 2305 e 3302 m (sul livello del mare). Da essa emerge che la regione è interessata dai processi tipici dell'ambiente Alpino delle medie latitudini e ha sperimentato un riequilibrio di tipo paraglaciale legato all'evoluzione post-UMG, caratterizzato principalmente da processi di versante e periglaciali. Inoltre, alle quote inferiori, l'azione delle acque risulta significativa. Gran parte delle forme del rilievo ha subito un controllo morfologico da parte delle strutture ad andamento regionale, orientate prevalentemente NE-SW. Sul versante svizzero dell'area di studio, specifiche analisi hanno interessato il rock glacier del Paradisin, che è stato studiato tramite tecniche di *Tomografia delle Resistività Elettriche (TRE)*, al fine di investigarne la struttura interna per comprendere le possibili condizioni criotiche nonostante il suo aspetto di rock glacier relitto, dedotto dall'aspetto superficiale.

Termini Chiave: Cartografia geomorfologica, Paesaggio di alta montagna, Deglaciazione, Rock glacier del Paradisin, Tomografia delle Resistività Elettriche, Pas da Val Viola (Alpi Centrali).

[1] *Dipartimento di Scienze della Terra "A. Desio", Università degli Studi di Milano - irene.bollati@unimi.it*

[2] *Dipartimento di Scienze della Terra, Università di Pisa*

[3] *Institute of Earth Surface Dynamics, University of Lausanne*

[4] *Università degli Studi di Torino, Dipartimento di Scienze della Terra*

[5] *Dipartimento di Geoscienze, Università di Padova*

[6] *Dipartimento di Scienze e Politiche Ambientali, Università degli Studi di Milano*

[7] *Scuola Universitaria Professionale della Svizzera Italiana (SUPSI), Istituto scienze della Terra*

[8] *Dipartimento di Scienze Teoriche e Applicate, Università degli Studi dell'Insubria*

* *Corresponding author:* Irene Bollati, *irene.bollati@unimi.it*

The geomorphological mapping was performed in the framework of the IV Stage for Young Geomorphologists "High Mountain Landscape and Climate Change" (Upper Val Viola, 29th July - 1st August 2016). It was financially supported by the Italian Association of Physical Geography and Geomorphology (AIGeo), the Swiss Geomorphological Society (SGmS), the Dipartimento di Scienze Teoriche e Applicate of Università degli Studi dell'Insubria, the Dipartimento di Scienze della Terra "A. Desio" of the Università degli Studi di Milano and by the Institute of Earth Sciences of the University of Applied Sciences and Arts of Southern Switzerland. The authors are grateful to Dr. Filippo Schenker and Dr. Chiara Celada for assistance during the field activities. The Federal office of topography swisstopo and Regione Lombardia also kindly provided geospatial data useful for further elaboration. The Geomorphological Map is available as Supplementary Material at http://gfdq.glaciologia.it/issues/

INTRODUCTION

The deglaciation following the Last Glacial Maximum (LGM) is one of the most important climate-driven processes that has occurred in the Alps, contributing to the modelling of landscapes of high mountain areas. It may be considered as a re-equilibrium period that deglaciated areas underwent after the retreat of Pleistocene glaciers. In the geomorphological literature, this specific phase is referred to as the paraglacial stage (*sensu* Church & Ryder, 1972). This phase, characterized by "non-glacial processes that are directly conditioned by glaciation," such as water and gravity-driven processes, showed changes over time with chronological constraints varying between different areas (Ballantyne, 2002a). Moreover, local geological and structural conditions play a meaningful role in driving these kinds of processes, also at a very local level (Cossart & *alii*, 2013). The rates of paraglacial-type processes depend on the time interval that has elapsed from the inception of deglaciation (Curry, 1999; Scapozza, 2016; Bollati & *alii*, 2017) and a new equilibrium is reached according to different models of progressive exhaustion (Ballantyne, 2002b).

Hence, during the latest Pleistocene and at the beginning of the Holocene, water-related, slope, periglacial processes and pedogenesis interplayed, shaping the landscape of the deglaciated valleys and mounts. Short periods of glacial advancement dating to the Holocene, further complicate the dynamic evolution of mountain surfaces (e.g., Ivy-Ochs & *alii*, 2009). The reconstruction of the time and steps of deglaciation and landforms evolution, undergoing different kind of processes, is therefore of the outmost importance in Alpine regions that are particularly sensitive to rapid climatic changes (Beniston, 2003). To address the reconstruction of surface processes and their temporal extent, geomorphological mapping is therefore mandatory, helping to identify the spatial organization, development and reciprocal interactions of relict glacial and periglacial landforms, as already demonstrated for the Alps (e.g., Baroni & Carton, 1986; 1996; Gruppo Nazionale di Geografia Fisica e Geomorfologia, 1986; De Graaff & *alii*, 1987; Federici & *alii*, 2003; Smith & *alii*, 2006; Lambiel & *alii*, 2016) and other mountain ranges (e.g., Azzoni & *alii*, 2017; Mariani & *alii*, 2018).

With regard to the Central Alps, many data are available, related to the recent behaviour of active glaciers (e.g., Salvatore & *alii*, 2015; Smiraglia & Diolaiuti, 2015; Carturan & *alii*, 2016), while other studies have focused on reconstructing, at local or regional level, the effects of post-LGM climate changes on the landscape (e.g., Hormes & *alii*, 2008; Ivy-Ochs & *alii*, 2009; Baroni & *alii*, 2014, 2017; Pelfini & *alii*, 2014; Colombo & *alii*, 2016; Scotti & *alii*, 2017).

The Upper Val Viola (Central Italian/Swiss Alps) is characterized by a mountain landscape, where glacial processes were very pervasive during the LGM, leaving erosional landforms and deposits of great interest from the perspective of reconstructing landscape evolution since the Pleistocene. Besides the glacial record, after the LGM a long-term transformation of the area led to the transition from glacial-dominated surface processes to a landscape where gravity, water-related, periglacial and possibly cryotic processes have increased in importance, involving the mobilization of the abundant debris at disposal and leading to a reworking or dismantling of the former deposits (paraglacial perspective). Burga (1987) examined in detail the stages of glaciation on both the Italian and the Swiss side of the study area. Hormes & *alii*, (2008) attempted to reconstruct the time of the Holocene slope processes along the lower Val Viola range and its lateral branch, Val Cantone-Dosdé. Cornelissen & Reitmaier (2016), analysing the distribution of Mesolithic settlements in the Swiss Alps, also suggested that in the vicinity of the Val Viola human exploitation started soon after the beginning of the Holocene. Finally, Scotti & *alii* (2017) collected Schmidt-hammer exposure-age dating to infer the time constrains of the deglaciation of the region.

However, a complete geomorphological mapping of the area is still lacking. To achieve new data on the glacial and post-glacial dynamics of the Upper Val Viola (between Italy and Switzerland), geomorphological mapping of the region was performed.

In addition, this analysis was supported by a geophysical investigation (i.e., *Electrical Resistivity Tomography-ERT*) of the Paradisin rock glacier, the main rock glacier within the area of study. The Paradisin rock glacier is in fact a relevant periglacial feature characterizing the Swiss side of the study area. At first glance, its morphology (mainly depressed in the frontal part) and the presence of vegetation coverage (partially covered by krummholz and shrubs) might justify the interpretation of this landform as inactive or even relict (*sensu* Barsch, 1996). However, not far from the examined area, Cannone & Gerdol (2003) demonstrated that active rock glaciers (velocities up to > 30 cm/year) can be quite extensively colonized by stress-tolerant herbs, thus the occurrence of vegetation on the Paradisin rock glacier is not enough to classify the landform as inactive or even relict (*sensu* Barsch, 1996), and so further analysis was considered necessary.

STUDY AREA

Geographic and climatic settings

The Val Viola is located at the border between Italy (Val Viola Bormina, Lombardy) and Switzerland (Val Viola Poschiavina, Graubünden Canton). The watershed between Italy and Switzerland crosses the Val Viola Pass and it corresponds roughly to the national border between two countries. The entire Val Viola Bormina is found in the Landscape Regional Plan of *Regione Lombardia* (https://www.cartografia.servizirl.it/viewer30/index.jsp, last access on December 4th 2018), mainly for the value of its landscape. Moreover, a portion of the valley is protected as a Site of Community Importance (SCI; IT2040012 - Val Viola Bormina - Ghiacciaio di Cima dei Piazzi) within the Rete Natura 2000, established after the Council Directive 92/43/EEC.

The area surveyed for geomorphological mapping extends for 5.35 km^2 and ranges between 2305 and the 3302 metres above sea level (m a.s.l.) of the Piz Paradisin peak.

The climate was continental Alpine, with cold winters and moderate summer temperatures. At the Federico Dosdè weather station (2000 m a.s.l., 2.57 km far from the eastern edge of the map), mean annual temperature (2010-2014) was 1.9 °C and mean annual precipitation is ~ 1020 mm (Soncini & *alii*, 2017), while at 2000 m a.s.l., average snow depth during the winter months is ~ 2.5 m (Guglielmin & Siletto, 2000).

Geological setting and recent geomorphological evolution

The Val Viola area is located within the Austroalpine Domain that characterizes south-eastern Switzerland and northern Italy and represents the remnants of the Adriatic passive margin formed during the Jurassic and stacked during the Late Cretaceous periods (Mohn & *alii*, 2011; Petri & *alii*, 2016). In particular, in the Val Viola area rocks of the Grosina and the Campo nappes outcrop (fig. 1a). The Grosina Nappe rocks outcrop in the southern part of the mapped area, while the Campo Nappe rocks characterize its northern part. These nappes were traditionally attributed to the Upper Austroalpine Domain; however, they have been recently distinguished as Middle Austroalpine (Mohn & *alii*, 2011). The Grosina Nappe consists of gneiss and metapelites and it is thrusted towards the North-West on the Campo Nappe. The micaschists and paragneiss in amphibolite facies of the Campo Nappe are sporadically intruded by Late or Post Varisican granitoids (285-259 Million years ago; Petri & *alii*, 2016).

The study area presents mainly evidence of Pleistocene glaciations and, in contrast to other Alpine regions, the effects of glacial retreat after the Little Ice Age (LIA) show less impact on the landscape in terms of paraglacial processes. According to Bini & *alii* (2009), during the LGM along the lateral slopes of the Upper Val Viola, the glaciers reached a maximum elevation of about 2800 m a.s.l. and only the rocky ridge departing from the Piz Paradisin towards the West was preserved by glacial modelling (Bini & *alii*, 2009; Supplementary Material, SM). Even if detailed data concerning the LGM and the onset of the deglaciation in the examined part of the Val Viola are not available, we might consider that the deglaciation of the European Alps started ~17.7 kiloannum (ka), in a relatively short time span, before the Gschnitz stadial glacier advance (17-16 ka) (Wirsig & *alii*, 2016). Only Burga (1987) studied the deglaciation time and glacial evolution in the examined area. The author referenced the moraines on the southwards slope of the Piz Paradisin to the Egesen I stadial (Younger Dryas), whereas the moraine ridges close to the Val Viola Hut have been interpretated as frontal moraines of the Egesen II stadial (Younger Dryas). Burga (1987) also reconstructed the LIA maximum glacier advance on the northern slope of the Corno di Dosdè, situated outside the eastern limit of the mapped area, at an elevation of 2400 m a.s.l., which represented the Holocene maximum advance of local glaciers. Hormes & *alii* (2008), analysing the direction of glacial striae and gouges, suggested for the LGM there was a glacial flow direction from the Upper Val Viola Bormina (NE) towards the Val Viola Poschiavina (SW). More data are available on recently existent glaciers. Nangeroni (1933) provided a detailed report of two glacial bodies located on the northern slopes of the Corno di Dosdé, one was a modest ice slab descending on the western side of the summit, whereas the other (defined as "Vedretta") was a small cirque glacier located on the eastern side of the peak. Diolaiuti & *alii* (2011) reconstructed the surface variation of local glaciers between 1954 and 2003. In this context, the Corno Dosdé Glacieret was considered by the authors to be extinguished as a glacier since the 1950s, as also indicated in the Italian Glaciers Inventory (Comitato Glaciologico Italiano & Consiglio Nazionale delle Ricerche, 1959; Smiraglia & Diolaiuti, 2015).

Finally, Guglielmin & Siletto (2000) mapped the distribution of permafrost in the whole Val Viola, suggesting that today permafrost is located above 2500 m a.s.l., while the relict permafrost can extend as far as 2000-2200 m a.s.l.

MATERIALS AND METHODS

Geomorphological mapping

The geomorphological map and the related cartographic and iconographic elaborations are included in the *SM*.

The geomorphological mapping was realized at a 1:5000 scale and the map is presented herein at a 1:7000 scale (see SM), covering an area of 5.35 km^2, between elevations of 2305 and 3302 m a.s.l. After the field survey, indispensable to provide detail of landform mapping (Smith & *alii*, 2006), analysis of available orthophotos and a Digital Elevation Model (DEM, here after) was performed. For the Italian side, data were retrieved from the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) Web Maps Services (WMS; http://geoportale.isprambiente.it/tematiche_pt/servizi-wms/, last access on December 4th 2018) and the Regione Lombardia shapefiles (http://www.geoportale.regione.lombardia.it/download-dati, last access on December 4th 2018). For the Swiss side, we collected data (shapefiles and/or WMS) from the swisstopo Geoportal (https://www.swisstopo.admin.ch/it/home.html, last access on December 4th 2018) and the Swiss geoportal (https://map.geo.admin.ch/, last access on December 4th 2018). Environmental Systems Research Institute (ESRI) DigitalGlobe & GeoEye (GIS User commonly; http://microsites.digitalglobe.com/arcgis/, last access December 4th 2018) represents another source of data covering both the Italian and Swiss sides of the border. Due to the transboundary features of the study area, an amalgamation between the data at disposal from the two countries (i.e., contour lines) was performed. As a result, a *Digital Elevation Model* (*DEM*; 10 m resolution) and a *hillshade map* (azimuth 45°) covering the whole area, were generated.

Lithologies were grouped according to their behaviour towards modelling processes (Panizza, 1972), a subdivision, in this specific context, that mainly corresponded to the pertinence of the structural domains (Mohn & *alii*, 2011; Petri & *alii*, 2016). Hence, the adopted lithology classification was as follows: i) gneiss (mainly Grosina Nappe), ii) granites and granodiorites (Upper Valtellina intrusive bodies within the Campo Nappe), and iii) paragneiss and micaschists (Campo Nappe). Hydrography features were depicted in light blue. Landforms were classified and coloured on the map according to the system proposed by the Italian Working Group for geomorphological mapping (Brancaccio & *alii*, 1994; Cosci & *alii*, 2007; D'Orefice & Graciotti, 2015; Campobasso & *alii*, 2018), with adaptations due to the scale of the map and to specific local features. The legend emphasizes the role of geomorphic processes. They were distinguished in structural-related (brown), slope (red), water-related (green), glacial (violet), periglacial (blue), and weathering-related (orange) processes. Of particular note were processes like earth- and debris-flow, sometimes debated as to their pertinence to water or gravity-related dynamics. As indicated in the most common classification of mass wasting processes (Varnes, 1978; Hungr & *alii*, 2014) and according to the adopted system, we considered earth- and debris-flows among gravity-related processes. Despite the fact that the activity of processes that generate landforms was currently intense for specific categories of features, including periglacial, slope, and water-related, and less intense for others, such as glacial, a distinction between active and inactive landforms was adopted in the legend of the map, using different intensities of colours (e.g., Baroni & Carton, 1986). Specifications for single cases are discussed within the *Results* section, where each category of processes and related landforms are described accordingly to the adopted classification.

Besides the main geomorphological map, a *Map of Geomorphological Processes* was made (see SM). The latter shows the spatial coverage of each category of processes: structural driven, slope, surface water, glacial and periglacial. A specific distinction was used between erosional and depositional glacial processes. This criterion was adopted since in the category of glacial erosion processes both the information of the exharated bedrock and the lithotype outcropping could be included. The map underlines the relative spatial distribution and the relations among geomorphic processes across the study area. Here, the lithologies are undistinguished.

Geophysical survey of a rock glacier

The Paradisin rock glacier was investigated to prospect its internal structure in order to understand the possible cryotic conditions despite its relict appearance (*sensu* Barsch, 1996) because of its surface aspect. In order to accomplish this task, *Electrical Resistivity Tomography (ERT)* was chosen to evaluate vertical and lateral variations mainly related to the different ice contents, typologies, and grain sizes.

Indeed, electrical resistivity is strongly increased when frozen material or high air content is present, whereas it decreases by some orders of magnitude if free water exists between sediments. ERT surveys were carried out with a

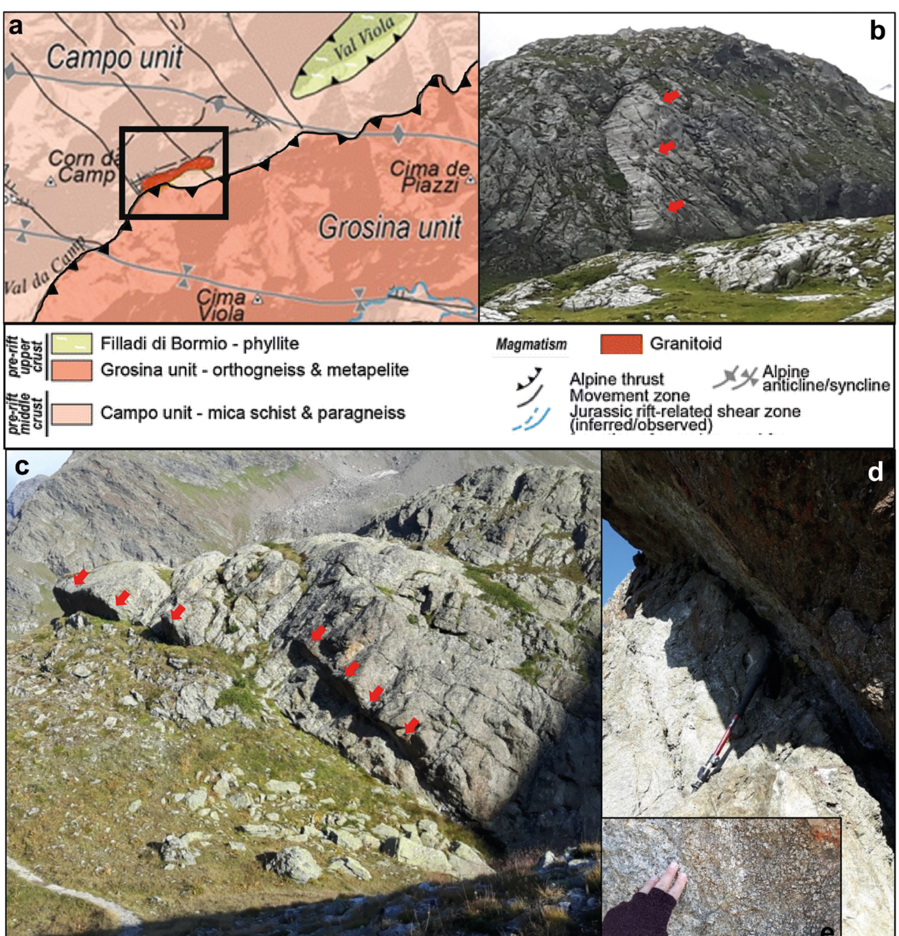

FIG. 1 - Structural landforms characterizing the southern portion of the study area. a) Location of the study area within the local structural map (after Petri & *alii*, 2016); b) fault plane (red arrows) with step like kinematic indicators is clearly visible from walking along the military road towards the Val Viola Pass; c) reverse scarp testifying a thrust plane (red arrows), corresponding to the overlapping of the Grosina Nappe on the Campo Nappe; d) detail of the plane and e) the cataclasite.

FIG. 2 - Selective erosion and weathering on granodiorites in the central part of the study area. a) selective erosion on quartz-rich veins intersecting granodiorites; b) honeycombs on granodiorites; c) combination of selective erosion and honeycombs.

16G electro-resistivity metre (Pasi Geophysics, Geophysical instruments, Torino, Italy), connected to 48 electrodes having constant separations of 5 m. A standard Wenner electrode configuration was adopted. Inversion of the data was achieved with the Res2Inv software (Geotomo Inc., Geophysical instruments, Torino, Italy).

RESULTS AND DISCUSSION

Structural and weathering landforms

A series of SW-NE oriented geological structures controlled the surface evolution of the region. A thrust, located in the southern part of the study area, and responsible for the structural overlapping of the Grosina Nappe on the Campo Nappe (Mohn & *alii*, 2011; Petri & *alii*, 2016; fig. 1, a), also drove land surface evolution (Ghiselli & *alii*, 2005). An evident reverse scarp on the hills bordering the southern part of the study area is the surface evidence of the thrust plane (fig. 1c, d). Along the thrust plane, a cataclasite is also present (fig. 1e). Moreover, on the eastern side of the Val Viola Pass a wide fault plane, characterized by the presence of steps and linear elements (fig. 1b), interpreted as kinematic indicators, is visible from the military road. Other hypothetic fractures follow the limit between the intrusive bodies and the metasedimentary rocks. The shape of hills, which reach an elevation between 2450 and 2500 m a.s.l., have resulted from the interplay between glacial processes and structural settings (fig. A in the SM). In fact, in the south-eastern part of the study area, characterized by a glacial exharated surface, a series of SW-NE elongated whaleback hills are present where the gneisses of the Grosina Nappe are thrusted on the Campo Nappe corresponding with the granodiorite intrusion. In correspondence of the edges of the granodiorite bodies, elongated depressions develop. Ponds and/or peat bogs occupy the depressions bordering the hills that are also characterized by a series of surficial parallel cuts SSW–NNE oriented. One of these cuts, the one towards the East, had evolved into a fluvial gorge.

The lithology of the exposed rocks has also driven surface erosion and weathering effects. In the central-southern part of the geomorphological map, where granite outcrops are extensive, glacial exharation and specific surface weathering is active on the substrate. In particular, outcrops are locally characterized by selective erosion, determined by their mineralogical composition, as shown by weathering-resistant quartz veins rising on rock surfaces (fig. 2a, c). Alveolar weathering generated other specific landforms (e.g., honeycombs; fig. 2b) that are sometimes associated with features resulting from selective erosion (fig. 2c). Its role in investigating surface evolution is important since it has been used in many morphoclimatic contexts as a proxy to estimate the duration and rate of weathering and, indirectly, of subaerial exposure of rock surfaces (e.g., Matsukura & Matsuoka, 1991).

Slope landforms and deposits

In the Val Viola Pass area (2467 m a.s.l.), consistent with the whaleback elongated hills, slope deposits, rock falls and topples are present (fig. 3a). Where the elevation as well as steepness of rock walls increase (fig. 3b), as in the north-western part of the Val Viola Pass, talus slope deposits, characterized by debris of different grain size, widely cover the foot of the rock walls. Currently, earth- and debris-flows affect the metasedimentary rocks of the Campo Nappe and the abundant Pleistocene glacial deposits spread in the area (fig. 3c). Solifluction and/or gelifluction lobes (fig. 4a and 6b) recur locally in the southern part of the region near the Val Viola Hut, or pervasively occupy wide portion of slopes, down the valley from the Val Viola Pass towards Italy and in the north-eastern portion of the map. At the time of the survey, we did not have any monitoring data to define their degree of activity. They were considered quiescent and for this reason they are put on the map in the active category.

Landforms and deposits due to running waters

Alluvial and colluvial deposits mainly characterize the central-eastern part of the Upper Val Viola, especially at lower elevations. Colluvium derives from the surface affected by sheet erosion acting on glacial and slope deposits, dissected by gullies. Moreover, V-shaped small valleys were also identified on central northern slopes. In these areas, westward of the Val Viola Hut, a trace of an inactive fluvial channel, with a SW-NE trend was also surveyed. Fluvial erosion scarps, both active and inactive and related to water incision, were located in correspondence of the confluence between Val Cantone, flowing N-S, and the main Val Viola, not far from the Val Viola Hut.

A gorge, superimposed on a SW-NE fracture on the most north-eastern whaleback granodiorite hill, is present, representing a deep cut associated with active water-related incision.

Glacial landforms and deposits

Widespread erosional and depositional features testify to the intensity of glacial passages during the Pleistocene over the whole study area. Whaleback hills are present in the southern part of the investigated area (fig. A in the SM). Generally, glacial exharation was guided by structural features as evidently emerged on the south-eastern side of the granite whaleback. In the same area, abundant subglacial deposits, possibly related to LGM or the late glacial advances of glaciers, are distributed in depressions surrounding the Val Viola Hut (2314 m a.s.l.). All around the hut, particularly on its western side, six moraine ridges were surveyed (fig. 4a), mainly oriented SW-NE, in between which there is an inter-moraine lake. These ridges were interpreted in the literature as frontal moraine due to the Val Cantone glacial flows (Burga, 1987). According to the

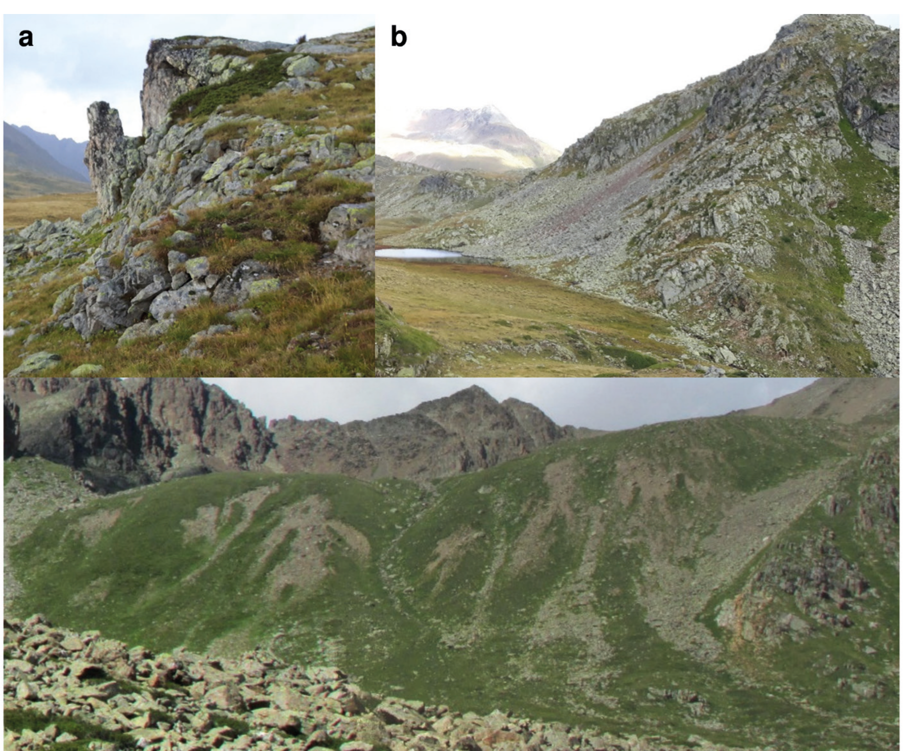

Fig. 3 - Slope landforms and deposits. a) Topples on the northern slope of the northern whaleback hill in the southern part of the area; b) slope deposits bordering the northern side of a granodiorite hill in the western part of the study area; c) earth-flows and surficial denudation affecting glacial deposits in the central-northern part.

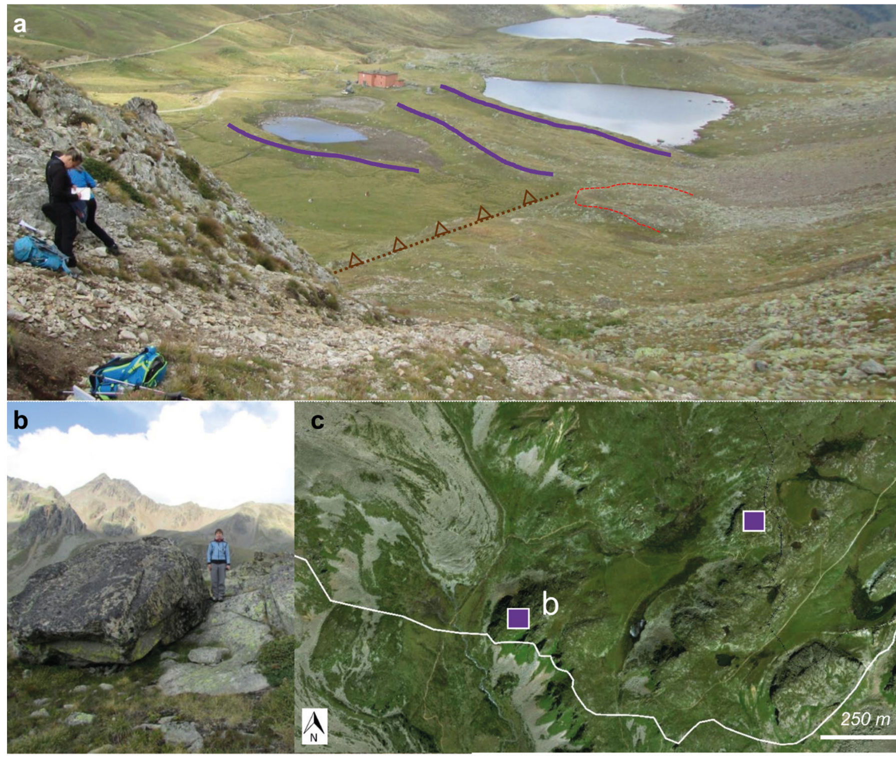

FIG. 4 - Glacial landforms and deposits. a) Rogen moraines (thick line) and inter-moraine lakes near the Viola Hut, a fault scarp oriented concordantly with the regional trends (dashed line with triangles) and a solifluction lobe (dashed line); b) example of erratic boulder on the most central-western hill; c) location of the erratic blocks on the top of the hills in the south-western part of the area.

occurrence of lodgment till deposit and the geometric orientation of the ridges, we propose to interpret the latter as rogen moraine related to the Val Cantone glacial flows.

Glacial striae and erosional grooves were surveyed on the top of the granitoid hills, in the central-southern portion of the study area (2400-2450 m a.s.l.), where Pleistocene shaping processes were very pervasive. At the top of the most elevated granodiorite hills, erratic boulders are also present (at about 2455 m a.s.l; fig. 4b, c). No alternative source for these boulders other than glacial transport could be proposed, since the hills were not connected to the surrounding slopes bordering the hydrographic basin.

Periglacial and snow-related landforms

In the area of study, periglacial features are widespread. The largest and most important feature is the Paradisin rock glacier (fig. 5c; SM), that occupies a surface of 0.26 km^2 with a length of about 900 m, at 2330-2500 m a.s.l. The rock glacier is characterized by an evident scarp, longitudinal furrows in the upper and central parts and many concentric furrows, with several deep conic depressions, in its frontal part (i.e., surficial through of rock glacier in the SM) (fig. B and C in the SM). The debris constituting the rock glacier has been interpreted as being of glacial origin.

The average concave (depressed) profile in its frontal part, reported on the map as a surficial trough of rock glacier, also appreciable in a longitudinal profile (fig. 5a), might indicate a general collapsed feature, which is traditionally classified as "relict" (*sensu* Barsch, 1996). Furthermore, the high degree of colonization by vegetation, mainly represented by krummholz and shrubs and the extensive lichenization of boulders, were considered indicators of the stability of the rock glacier. Therefore, if we considered these features, we might classify this landform as relict (*sensu* Barsch, 1996).

Concerning *ERT* results, they demonstrate the existence of a fourth-layered internal structure:

i) the upper layer, characterized by a thickness varying between 2-8 m, is resistive (in some spots exceeding 500 kΩ·m at < 8 m of depth) due to the very coarse nature of the upper part of the body or to the seasonal frozen state of the deposits;

ii) the second layer is not more than 5 m in thickness and less resistive than the uppermost layer (< 10 kΩ·m). It is interpretable as an unfrozen layer;

iii) the third layer with very high resistivity values (exceeding 20 kΩ·m) is located between ca. 10 and 32 m in depth and corresponds to the permafrost core of the rock glacier;

and iv) deeper than 32 m, unfrozen sediments (with values even lower than 0.25 kΩ·m) are present.

These high resistivity values are interpretable as a permafrost body that is overlaid by an unfrozen layer of debris. This fact underlines how the use of the rock glaciers as indicator or as tool for calibrating permafrost distribution models should be carried out with more caution.

A relict rock glacier (*sensu* Barsch, 1996), definitely smaller than the Paradisin rock glacier, is located within a bordering moraine related to the Egesen I stadial (Burga, 1987), SW of the Piz Cunfin (at about 2600 m, a.s.l.; fig. 6a). Another relict rock glacier is located in the north-western part of the area at an elevation of 2800 m a.s.l. A protalus rampart on a north-eastern slope (2520 m a.s.l.), immediately to the West of the Paradisin rock glacier, was also surveyed.

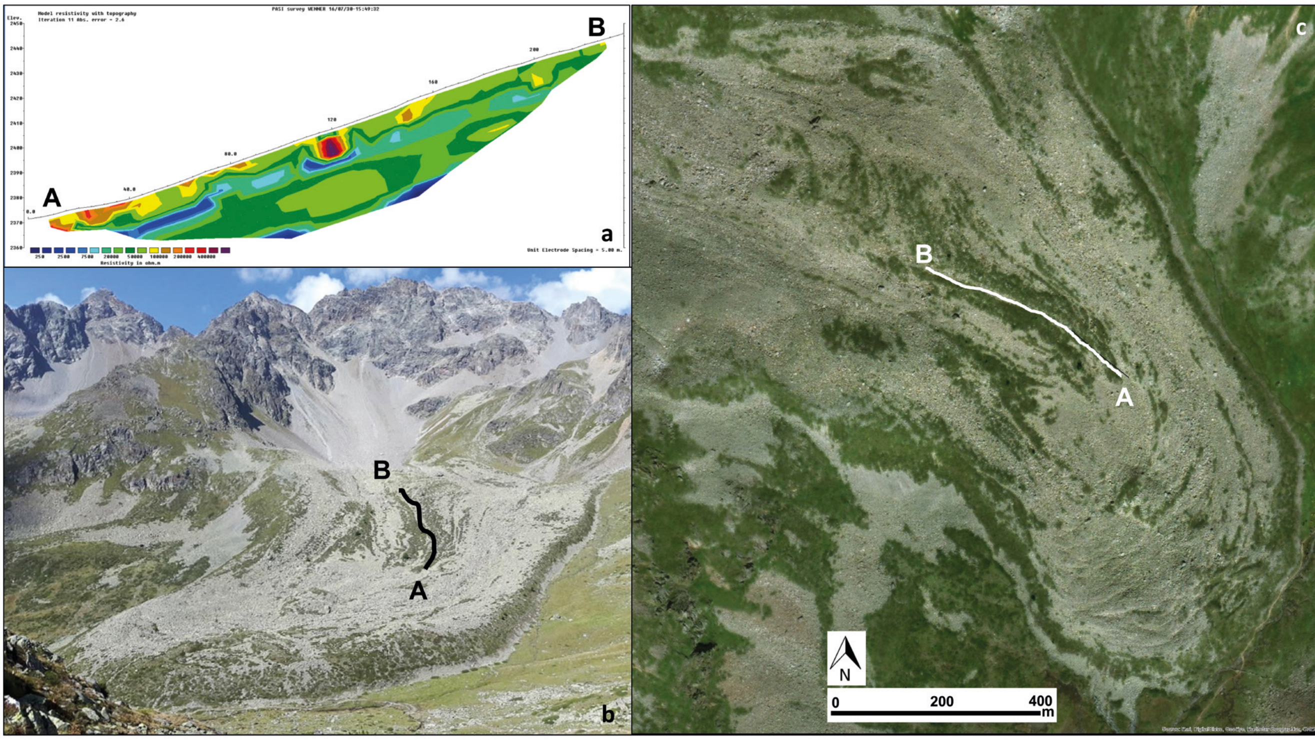

Fig. 5 - Paradisin rock glacier. a) ERT results where resistivity values lower than 10 kΩ·m (light blue and blue) are representative of unfrozen sediments; at depth greater than 10 m, higher values (green) represent frozen sediments, while in the upper part they can be due to the very coarse nature of the sediments or to the seasonally frozen state; b) panoramic view of the rock glacier with the trace of the ERT profile; c) aerial view of the Paradisin rock glacier with the trace of the ERT profile (Source ESRI, Digital Globe, GeoEye).

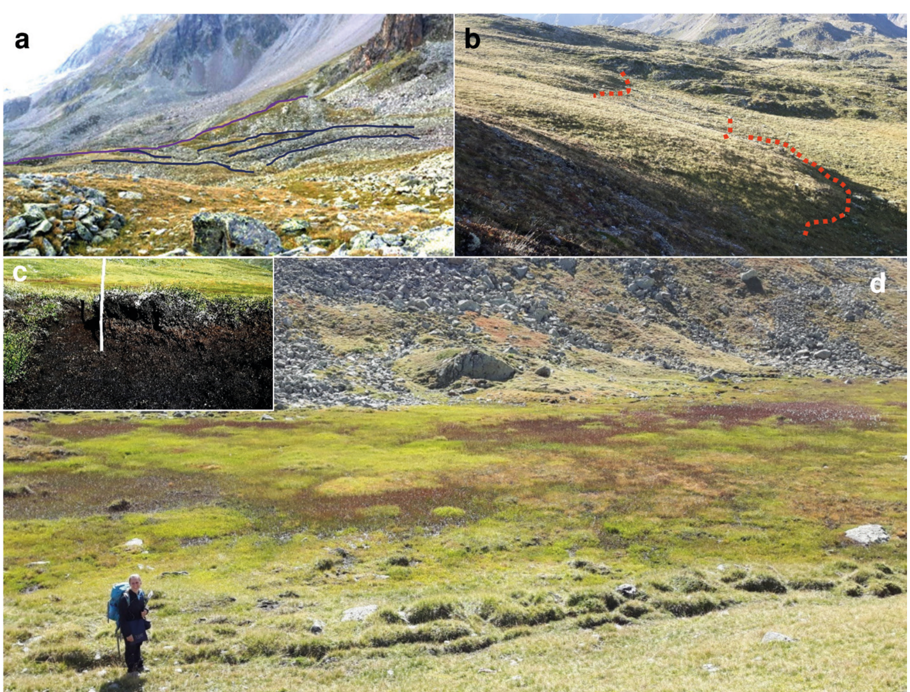

Fig. 6 - Periglacial landforms and deposits. a) The Egesen I moraine (violet) borders downvalley a rock glacier developed on glacial deposits located south-westerly to Piz Cunfin; b) solifluction lobes (red) developing on glacial deposits immediately E of the Val Viola Pass; c) peat bog and d) earth hummocks field within the Plan de la Genzana area, with a detail on the peat bog deposit (c).

Among the snow-related processes, snow avalanches affect the most elevated slopes and the related deposits are visible at the foot of the slopes seasonally.

In the investigated area, lakes are mainly located in structural or glacial overdeepenings, and their transition to peat bogs is common. Complex systems of lakes, wide peat bogs and earth hummocky fields (fig. 6c, d; fig. A in the SM) are mainly distributed along the borders and the fractured portions of the granodiorite intrusion, where wide depressed area, like the one of Plan de la Genzana (2402 m, a.s.l.; fig. 6d), are present.

CONCLUSIONS

The Val Viola Pass area was extensively modified by the glacial modelling related to the LGM and/or late glacial cold stages. After deglaciation, the action of paraglacial processes, driven by local geological and structural conditions, and of permafrost-related processes was recorded in representative landforms. Geomorphological mapping would indicate the absence of permafrost, at least at elevations lower than 2500 m a.s.l., as already indicated by Guglielmin & Siletto (2000). In fact, we interpreted the wide *Paradisin rock glacier* as a relict landform (*sensu* Barsch, 1996). Anyway, ERT analyses enhance the presence of permafrost, underlying the importance of a geophysical approach in the classification of some permafrost landforms, such as rock glaciers.

Our mapping suggests a pristine onset of surface processes, different from the glacial ones, soon after the end of the Last Glacial Maximum, therefore, highlighting the low resilience of high elevation mountain environments to rapid climate change and their high dynamicity. This is also confirmed for adjoining areas by other reports (e.g., Hormes & *alii*, 2008; Ivy-Ochs & *alii*, 2009; Pelfini & *alii*, 2014; Scotti & *alii*, 2017). Therefore, geomorphological mapping of high Alpine ranges offers a diachronic snapshot of the evolution of the ground surface in areas where distinct and synchronous geomorphological processes start shaping landforms, after the relative stability of Upper Pleistocene glacial conditions.

As already applied in other areas (e.g., Bollati & *alii*, 2013; Comitato Glaciologico Italiano, 2018), where landforms related to glacial and periglacial evolution are as evident as for the Val Viola Pass, geomorphological mapping could be the basis for illustrating thematic itineraries for the general public.

REFERENCES

Azzoni R. S., Zerboni A., Pelfini M., Garzonio C.A., Cioni R., Meraldi E., Smiraglia C. & Diolaiuti G.A. (2017) - *Geomorphology of Mount Ararat/Ağri Daği (Ağri Daği Milli Parki, Eastern Anatolia, Turkey).* Journal of Maps, 13 (2), 182-190. doi: 10.1080/17445647.2017.1279084.

Ballantyne C.K. (2002a) - *Paraglacial geomorphology.* Quaternary Science Reviews, 21 (18-19), 1935-2017. doi: 10.1016/S0277-3791(02)00005-7.

Ballantyne C.K. (2002b) - *A general model of paraglacial landscape response.* The Holocene, 12 (3), 371-376. doi: 10.1191/0959683602hl553fa.

Baroni C. & Carton A. (1986) - *Carta geomorfologia della Valle dell'Avio (Gruppo dell'Adamello) alla scala 1:15.000 con note illustrative.* Natura bresciana, Annali del Museo Civico di Scienze naturali, 23, 3-48.

Baroni C. & Carton a. (1996) - *Carta geomorfologia dell'alta V. di Genova (Gruppo dell'Adamello, Alpi Centrali) alla scala di 1:15.000 con note illustrative.* Geografia Fisica e Dinamica Quaternaria, 19 (1), 3-17.

Baroni C., Martino S., Salvatore M.C., Mugnozza G.S. & Schilirò L. (2014). - *Thermomechanical stress-strain numerical modelling of deglaciation since the Last Glacial Maximum in the Adamello Group (Rhaetian Alps, Italy).* Geomorphology, 226, 278-299. doi: 10.1016/j.geomorph.2014.08.013.

Baroni, C., Casale, S., Salvatore, M. C., Ivy-Ochs, S., Christl, M., Carturan, L., Seppi R. & Carton, A. (2017) - *Double response of glaciers in the Upper Peio Valley (Rhaetian Alps, Italy) to the Younger Dryas climatic deterioration.* Boreas, 46 (4), 783-798. doi: 10.1111/bor.12284

Barsch D. (1996) - *Rockglaciers: indicators for the present and former geoecology in high mountain environments.* Berlin, Springer Series in Physical Environment 16, Springer, 315 pp.

Beniston M. (2003) - *Climatic change in mountain regions: a review of possible impacts.* In: Diaz H.F., Grosjean M. & Graumlich L. (Eds.), Climate variability and change in high elevation regions: Past, present & future, 5-31. Springer, Dordrecht.

Bini A., Buoncristiani J.-F., Couterrand S., Ellwanger D., Felber M., Florineth D., Graf H.R., Keller O., Kelly M., Schlüchter C. & Schoeneich P. (2009) - *Die Schweiz während des letzteiszeitlichen Maximums (LGM).* Bundesamt für Landestopografie, swisstopo.

Bollati I., Smiraglia C. & Pelfini M. (2013) - *Assessment and selection of geomorphosites and trails in the Miage glacier area (Western Italian Alps).* Environmental Management, 51 (4), 951-967. doi: 10.1007/s00267-012-9995-2.

Bollati I., Pellegrini M., Reynard E. & Pelfini M. (2017) - *Water driven processes and landforms evolution rates in mountain geomorphosites: examples from Swiss Alps.* Catena, 158, 321-339. doi: 10.1016/j.catena.2017.07.013.

Brancaccio L., Castiglioni G.B., Chiarini E., Cortemiglia G., D'orefice M., Dramis F., Graciotti R., La Posta E., Lupia Palmieri E., Onorati G., Panizza M., Pannuzi L., Papasodaro F. & Pellegrini G.B. (1994) - *Carta geomorfologica d'Italia - 1:50.000. Guida al rilevamento. Quaderni del Servizio Geologico Nazionale*, Ser. III, 4, Istituto Poligrafico e Zecca dello Stato, 42 pp.

Burga C.A. (1987) - *Val Viola Bormina (Viola-System) - Gletscher undVegetationsgeschichte der Südrätischen Alpen seit der Späteiszeit.* Birkhausern: Memoires de la Societè Helvetique des Sciences Naturelles. Band/vol 101 DSNG 101. ISBN 3-7643-1923-2.

Campobasso C., Carton A., Chelli A., D'orefice M., Dramis F., Graciotti R., Guida D., Pambianchi G., Peduto F. & Pellegrini L. (2018) - *Carta Geomorfologica d'Italia alla scala 1:50.000. Aggiornamento ed integrazioni delle linee guida della Carta Geomorfologica d'Italia alla scala 1:50.000 (Fascicolo I).* Quaderni del Servizio Geologico Nazionale, Ser. III, 13, Istituto Poligrafico e Zecca dello Stato, 96 pp.

Cannone N. & Gerdol R. (2003) - *Vegetation as an ecological indicator of surface instability in rock glaciers.* Arctic, Antarctic, and Alpine Research, 35 (3), 384-390. doi: 10.1657/1523-0430(2003)035[0384:VAAEIO]2.0.CO;2.

Carturan L., Baroni C., Brunetti M., Carton A., Dalla Fontana G., Salvatore M.C., Zanoner T. & Zuecco G. (2016) - *Analysis of the mass balance time series of glaciers in the Italian Alps.* The Cryosphere, 10 (2), 695-712. doi: 10.5194/tc-10-695-2016.

Church M. & Ryder J.M. (1972) - *Paraglacial sedimentation: a consideration of fluvial processes conditioned by glaciation.* Geological Society of America Bulletin, 83(10), 3059-3072. doi: 10.1130/0016-7606(1972)83[3059:PSACOF]2.0.CO;2.

Colombo N., Paro L., Godone D. & Fratianni S. (2016) - *Geomorphology of the Hohsand basin (Western Italian Alps).* Journal of Maps, 12 (5), 975-978. doi: 10.1080/17445647.2015.1105762.

Comitato Glaciologico Italiano (CGI) & Consiglio Nazionale delle Ricerche (CNR) (1959) - *Catasto dei Ghiacciai Italiani, Anno Geofisico Internazionale 1957-1958. Ghiacciai della Lombardia e dell'Ortles-Cevedale*. Torino, Comitato Glaciologico Italiano, Torino, V. III, 172 pp.

Comitato Glaciologico Italiano (2018) - *Itinerari glaciologici sulle montagne italiane*. Collana Guide Geologiche Regionali della Società Geologica italiana. BE-MA Ed., Roma, 3 Vol., 600 pp.

Cornelissen M. & Reitmaier T. (2016) - *Filling the gap: Recent Mesolithic discoveries in the central and south-eastern Swiss Alps*. Quaternary International, 423, 9-22. doi: 10.1016/j.quaint.2015.10.121.

Cosci M., Masella G. & Pannuti V. (2007) - *Carta Geomorfologica d'Italia - 1:50'000. Guida alla rappresentazione cartografica*. Quaderni del Servizio Geologico Nazionale, Serie III, 10, Istituto Poligrafico e Zecca dello Stato, 42 pp.

Cossart E., Mercier D., Decaulne A. & Feuillet T. (2013) - *An overview of the consequences of paraglacial landsliding on deglaciated mountain slopes: typology, timing and contribution to cascading fluxes*. Quaternaire. Revue de l'Association française pour l'étude du Quaternaire, 24 (1), 13-24. doi: 10.4000/quaternaire.6444.

Curry A.M. (1999) - *Paraglacial modification of slope form*. Earth Surface Processes and Landforms, 24 (13), 1213-1228. doi: 10.1002/(SICI)1096-9837(199912)24:13<1213::AID-ESP32>3.0.CO;2-B.

De Graaff L.W.S., De Jong M.G.G., Rupke J. & Verhofstad, J. (1987) - *A geomorphological mapping system at scale 1: 10,000 for mountainous areas*. Zeitschrift für Geomorphologie, 31 (2), 229-242.

Diolaiuti G., Maragno D., D'Agata C., Smiraglia C. & Bocchiola D. (2011) - *Glacier retreat and climate change: documenting the last 50 years of Alpine Glacier history from area and geometry changes of Dosdè Piazzi glaciers (Lombardy Alps, Italy)*. Progress in Physical Geography 35 (2) 161-182. doi: 10.1177/0309133311399494.

D'Orefice M. & Graciotti R. (2015) - *Rilevamento geomorfologico e cartografia. Realizzazione-Lettura-interpretazione*. Palermo, Dario Flaccovio Editore, 360 pp.

Federici P.R., Pappalardo M. & Ribolini A. (2003) - *Carta geomorfologica del Parco Naturale delle Alpi Marittime e territori circostanti (Massiccio dell'Argentera) alla scala 1:25.000*. S.el.Ca, Firenze.

Ghiselli A., Bini A. & Zucali M. (2005) - *Structural analysis of "roches moutonnees" in western Orobic Alps (Lombardia)*. Supplementi Geografia Fisica e Dinamica Quaternaria, 7, 163-177.

Gruppo nazionale Geografia Fisica e Geomorfologia (1986) - *Ricerche geomorfologiche nell'Alta Val di Peio (Gruppo del Cevedale) - Geomorphological research in the upper Val di Pejo (Cevedale Group, Central Alps, Italy)*. Geografia Fisica e Dinamica Quaternaria, 9 (2), 137-191.

Guglielmin M. & Siletto G.B. (2000) - *Carta della criosfera*. Regione Lombardia, Territorio, Edilizia Residenziale, Firenze.

Hormes A., Ivy-Ochs S., Kubik P.W., Ferreli L. & Michetti A.M. (2008) - *^{10}Be exposure ages of a rock avalanche and a late glacial moraine in Alta Valtellina, Italian Alps*. Quaternary International, 190 (1), 136-145. doi: 10.1016/j.quaint.2007.06.036.

Hungr O., Leroueil S. & Picarelli L. (2014) - *The Varnes classification of landslide types, an update*. Landslides, 11 (2), 167-194. doi: 10.1007/s10346-013-0436-y.

Ivy-Ochs S., Kerschner H., Maisch M., Christl M., Kubik P.W. & Schlüchter C. (2009) - *Latest Pleistocene and Holocene glacier variations in the European Alps*. Quaternary Science Reviews, 28 (21-22), 2137-2149. doi: 10.1016/j.quascirev.2009.03.009.

Lambiel C., Maillard B., Kummert M. & Reynard E. (2016) - *Geomorphology of the Hérens valley (Swiss Alps)*. Journal of Maps, 12 (1), 160-172. doi: 10.1080/17445647.2014.999135.

Mariani G.S., Cremaschi M., Zerboni A., Zuccoli L. & Trombino L., (2018) - *Geomorphological map of the Mt. Cusna Ridge (Northern Apennines, Italy): evolution of a Holocene landscape*. Journal of Maps, 14, 392-401. doi: 10.1080/17445647.2018.1480976.

Matsukura Y. & Matsuoka N. (1991) - *Rates of tafoni weathering on uplifted shore platforms in Nojima-Zaki, Boso Peninsula, Japan*. Earth Surface Processes and Landforms, 16 (1), 51-56. doi: 10.1002/esp.3290160106.

Mohn G., Manatschal G., Masini E. & Müntener O. (2011) - *Rift-related inheritance in orogens: a case study from the Austroalpine nappes in Central Alps (SE-Switzerland and N-Italy)*. International Journal of Earth Sciences, 100 (5), 937-961. doi: 10.1007/s00531-010-0630-2.

Nangeroni G. (1933) - *Il glacialismo attuale nell'Alta Valtellina*. Bollettino del Comitato Glaciologico Italiano, Serie I, 13. 141-171.

Panizza m. (1972) - *Schema di legenda per carte geomorfologiche di dettaglio*. Bollettino della Società Geologica italiana, 91, 20-237.

Pelfini M., Leonelli G., Trombino L., Zerboni A., Bollati I., Merlini A., Smiraglia C. & Diolaiuti G. (2014) - *New data on glacier fluctuations during the climatic transition at~ 4,000 cal. year BP from a buried log in the Forni Glacier forefield (Italian Alps)*. Rendiconti Lincei, 25 (4), 427-437. doi: 10.1007/s12210-014-0346-5.

Petri B., Mohn G., Štípská P., Schulmann K. & Manatschal G. (2016) - *The Sondalo gabbro contact aureole (Campo unit, Eastern Alps): implications for mid-crustal mafic magma emplacement*. Contributions to Mineralogy and Petrology, 171 (5), 52. doi: 10.1007/s00410-016-1263-7.

Salvatore M.C., Zanoner T., Baroni C., Carton A., Banchieri F. A., Viani C., Giardino M. & Perotti L. (2015) - *The state of Italian glaciers: a snapshot of the 2006-2007 hydrological period*. Geografia Fisica e Dinamica Quaternaria, 38 (2), 175-198. doi: 10.4461/GFDQ.2015.38.16.

Scapozza C. (2016) - *Evidence of paraglacial and paraperiglacial crisis in Alpine sediment transfer since the last glaciation (Ticino, Switzerland)*. Quaternaire, 27 (2), 139-155. doi: 10.4000/quaternaire.7805.

Scotti R., Brardinoni F., Crosta G.B., Cola G. & Mair V. (2017) - *Time constrains for post-LGM landscape response to deglaciation in Val Viola, Central Italian Alps*. Quaternary Science Reviews, 177, 10-33. doi: 10.1016/j.quascirev.2017.10.011.

Smiraglia C. & Diolaiuti G. (2015) - *The New Italian Glacier inventory*. Bergamo, Ev-K2-CNR Ed., 440 pp.

Smith M.J., Rose J. & Booth S. (2006) - *Geomorphological mapping of glacial landforms from remotely sensed data: an evaluation of the principal data sources and an assessment of their quality*. Geomorphology, 76 (1-2), 148-165. doi: 10.1016/j.geomorph.2005.11.001.

Soncini A., Bocchiola D., Azzoni R.S. & Diolaiuti G. (2017) - *A methodology for monitoring and modeling of high altitude Alpine catchments*. Progress in Physical Geography, 41 (4) 393-420. doi: 10.1177/0309133317710832.

Varnes D.J. (1978) - *Slope movement types and processes*. In R.L. Schuster, R.J. Krizek (Eds.) Landslides, analysis and control, special report 176. Transportation research board, National Academy of Sciences, Washington, DC., pp. 11-33.

Wirsig C., Zasadni J., Christl M., Akçar N. & Ivy-Ochs S. (2016) - *Dating the onset of LGM ice surface lowering in the High Alps*. Quaternary Science Reviews, 143, 37-50. doi: 10.1016/j.quascirev.2016.05.001.

(Ms. received 20 July 2018; accepted 13 December 2018)