Journal of Maps

ISSN: (Print) 1744-5647 (Online) Journal homepage: https://www.tandfonline.com/loi/tjom20

Geomorphology of the Rio Cisles basin (Odle Group, Dolomites, Italy)

Paola Coratza, Alessandro Ghinoi, Mauro Marchetti & Mauro Soldati

To cite this article: Paola Coratza, Alessandro Ghinoi, Mauro Marchetti & Mauro Soldati (2019) Geomorphology of the Rio Cisles basin (Odle Group, Dolomites, Italy), Journal of Maps, 15:2, 546-554, DOI: 10.1080/17445647.2019.1633426

To link to this article: https://doi.org/10.1080/17445647.2019.1633426

JOURNAL OF MAPS
2019, VOL. 15, NO. 2, 546–554
https://doi.org/10.1080/17445647.2019.1633426

Science

OPEN ACCESS Check for updates

Geomorphology of the Rio Cisles basin (Odle Group, Dolomites, Italy)

Paola Coratza[a], Alessandro Ghinoi[a], Mauro Marchetti[b] and Mauro Soldati[a]

[a]Dipartimento di Scienze Chimiche e Geologiche, Università di Modena e Reggio Emilia, Modena, Italy; [b]Dipartimento di Educazione e Scienze Umane, Università di Modena e Reggio Emilia, Reggio Emilia, Italy

ABSTRACT
The results of geomorphological investigations carried out in the Rio Cisles basin in the Odle Group (Italian Alps) are presented. This is one of the most famous and spectacular mountain groups of the Dolomites, located in the north-western sector of the Gardena valley, an area of high tourism appeal. Field surveys and multitemporal aerial-photo interpretation led to the production of a geomorphological map at a 1:12,000 scale. This map outlines the features of an area of about 20 km^2, characterised by high relief energy, mainly due to the overlapping of large dolomite rocks masses on clayey rocks. The present morphology is the result of intense postglacial and paraglacial geomorphic activity, which has affected the area since the Upper Pleistocene. The geomorphological evolution of this area has been reconstructed and a new contribution is given to the comprehension of the geomorphology of the eastern Dolomites.

ARTICLE HISTORY
Received 29 January 2019
Revised 10 June 2019
Accepted 14 June 2019

KEYWORDS
High-mountain; mountain geomorphology; geomorphological mapping; Gardena valley; Dolomites; Italy

1. Introduction

The Rio Cisles basin (Odle Group) lies in the north-eastern sector of the Gardena valley, in the Autonomous Province of Bolzano (South Tyrol) (Figure 1). Its north-eastern part belongs to the Puez-Odle mountain group, which is one of the nine dolomite systems forming the Dolomites UNESCO World Heritage Site (Gianolla, Micheletti, & Panizza, 2009; Soldati, 2010). The latter was inscribed, as serial property, in the UNESCO list in 2009 for its exceptional scenic beauty and for the outstanding scientific importance of its geology and geomorphology. The study area is comprised within the protected area of the Puez-Odle Regional Nature Park, which was founded in 1978. The Park extends across about 10,722 hectares and is part of the Europe-wide 'Natura 2000' sites. The relative easy access to the area, characterised by a network of hiking trails, and its spectacular high-mountain landscape have enabled the valley to become a famous international tourist destination. The area of the Park encompasses remarkable geological and geomorphological features that enable a reconstruction of the long history of this sector of the Southern Alps, which dates back 200 million years. For this reason, the study area, like the Dolomites in general, is an outstanding open-air laboratory where processes and landscape evolution can be studied and disseminated to the non-specialised public (cf., Marchetti, Ghinoi, & Soldati, 2017).

General information on the geology of the study area is reported in a series of milestone papers (Bosellini, Gianolla, & Stefani, 2003; Castellarin, Vai, & Cantelli, 2006; Doglioni, 1987; Leonardi, 1967). Detailed geomorphological studies, though, have never been carried out, apart from those dealing with stratigraphic and palaeontological aspects in adjacent areas (Lukeneder, 2010; Lukeneder, Bechtel, & Gratzer, 2012). From the mapping point of view, the area is represented in the geological sheet no. 028 'La Marmolada' (1:50,000 scale) of the Geological Map of Italy (Brondi et al., 1977) and in the 'Geologische Karte der Westlichen Dolomiten – Carta Geologica delle Dolomiti Occidentali' (1:25,000 scale) of the Autonomous Province of Bolzano (Brandner, Keim, Gruber, & Gruber, 2007).

Thorough geomorphological investigations have been carried out in the adjacent areas of the Sasso Lungo Group (Coratza, Marchetti, & Soldati, 2005), the Alta Badia valley (Borgatti et al., 2007; Corsini, Marchetti, & Soldati, 2001; Ghinoi & Soldati, 2017) and, to the east, the Cortina d'Ampezzo valley (Panizza, Pasuto, Silvano, & Soldati, 1996; Pasuto, Siorpaes, & Soldati, 2005), but the geomorphology of this area has never been studied in detail. This research aims to investigate the geomorphological features of a significant and spectacular territory from the scientific and scenic standpoint. The Rio Cisles basin – Odle Group (Main Map) have been mapped and analysed

CONTACT Paola Coratza paola.coratza@unimore.it Dipartimento di Scienze Chimiche e Geologiche, Università di Modena e Reggio Emilia, Via Campi 103, Modena 41125, Italy

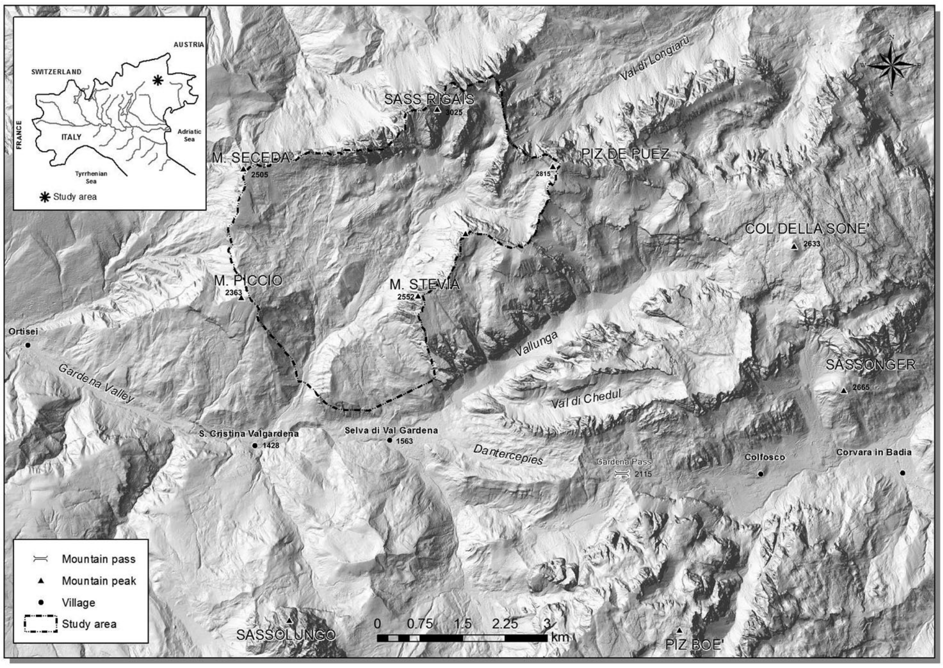


Figure 1. Geographic sketch map of the Rio Cisles basin and surrounding areas.

in order to provide detailed information on both active and inherited landforms and processes. The output is a 1:12,000 scale geomorphological map, enriched by a structural sketch map and a stratigraphic sketch of the Permian-Upper Triassic sequences. This study is the first step towards reconstructing the geomorphology of the Upper Gardena valley, which will enable to piece together the geomorphological evolution of a larger sector of the eastern Dolomites following the Last Glacial Maximum (LGM).

2. Geographic setting

The study area (ca. 20 km^2) is characterised around its perimeter by pale-white dolomite pinnacles and vertical cliffs, connected to the Rio Cisles valley by means of gently inclined south-east facing slopes, covered by woodlands and grassland pastures. The main mountain peaks surrounding the area are Mt. Seceda (2518 m) to the north-west, Mt. Piccio (2363 m) to the south-west, Mt. Stevia (2552 m) and Montischella (2644 m) to the east, Piz Duleda (2909 m) to the north-east and Forchetta Grande (2924 m) and Sass Rigais (3025 m) to the north.

The area is part of the Gardena basin, which, in turn, is part of the River Adige catchment. The two mainstream channels, which show a seasonal hydraulic regime, are Rio Cisles – originating from the nearby Firenze refuge (2037 m) – and Rio Mastlé – originating between the Fermeda and Piera Longia refuges (2200 m). At the southernmost limit of the study area, Rio Mastlé merges with Rio Cisles, which is a left tributary of the Torrent Gardena. The mainstream channels are mainly fed by meteoric water seeping through the fractures of the dolomite massifs at the northern and north-eastern boundary of the area. Their contact with the underlying marly and clayey formations gives rise to water springs. Seasonally, considerable water input may come from other reservoirs, such as talus cones, coarse-grain moraine deposits and rock glaciers, but also from hypodermic flux in high-pasture soils and, during intense precipitation, from debris flow channels.

The villages of Santa Cristina Val Gardena (1440 m) and Selva di Val Gardena (1550 m) are close to the south-western and south-eastern corners of the study area, respectively. Although they are small inhabited centres, they have acquired over time high tourist standards, for both winter and summer holidays. For this reason, man-made landforms are evident on all slopes, mainly related to the development of skiing facilities with a thick network of cableways and chair lifts, which reach almost the top of the monocline.

The study area is characterised by Temperate-cold or Boreal climate (Köppen, 1931). Accordingly, mean annual precipitation (1990–2016 period) is 881 mm. The rainiest months are June through August (scoring the highest number of rainy days), while the driest ones are the winter months, mostly characterised by snow precipitation. Mean annual temperature (1990–2016 period) is 4.8°C. The coldest month is usually January (mean −3.8°C); the warmest is July (mean 14.2°C).

3. Materials and methods

The geomorphological mapping of the Rio Cisles basin was carried out by means of field surveys at a 1:10,000 scale and aerial-photo interpretation. The latter consisted of a multi-scalar and a multi-temporal analysis of aerial photographs, using traditional stereoscopic techniques. In addition, a 5 m resolution Digital Terrain Model was used to obtain a 3D surface of the area. GoogleEarth™ high resolution satellite images were also consulted for detailed investigations.

Bedrock lithology and structural elements were derived from the geological map by Brandner et al. (2007), which was validated and implemented by means of field observations. All the information acquired was stored in an ArcGIS geodatabase.

Geomorphological mapping mainly followed the guidelines proposed by the Italian Geological Survey (Gruppo di Lavoro per la Cartografia Geomorfologica, 1994), recently updated by D'Orefice and Graciotti (2015) and with reference to recent Italian geomorphological maps (e.g. Bruschi, Coratza, Piacentini, & Soldati, 2012; Del Monte et al., 2016; Panizza et al., 2011). The guidelines envisage the representation of landforms and associated deposits using symbols of different colours, according to the geomorphological processes that led to their genesis, whereas their state of activity is marked by means of colour intensity.

Bedrock lithology was depicted by means of solid colours, grouping rock types according to their mechanical behaviour and, secondarily, to their age. In particular, not only has the lithological composition been taken into account, but also the response of each rock type to exogenous agents (see the stratigraphic sketch of the Permian-Upper Triassic sequences accompanying the geomorphological map). The first group (1a, 1b, 1c) includes all the dolomite rock types that show brittle geomechanical behaviour. Group 2 is characterised by extreme lithological variability and responds in a rather complex way to modelling agents. The third group is characterised by formations showing prevalently ductile geomechanical behaviour (3a, 3b). The fourth group includes igneous rock formations with essentially brittle behaviour. Finally, the fifth group includes the formations showing considerable lithological variability, but which should be distinguished from group 2, owing to chronostratigraphic reasons, since they are much older (5a, 5b, 5c).

4. The Geomorphological map

After introducing the geological and structural aspects of the area, the main geomorphological features characterising the area will be described according to their genetic origin and state of activity. In particular, the most common landforms are those related to gravitational processes, glacial deposition and periglacial activity; those related to running waters and fluvial reworking are also frequent.

4.1. Structural and geological setting

From a geological standpoint, the study area is characterised by massive rock cliffs made up of Upper Triassic dolomites and limestones underlain by basin deposits of volcanic, carbonaceous or calcareous origin, often deposited as Lower Triassic – Upper Permian turbidites (Brandner et al., 2007).

In detail, the bordering mountain ridges passing across Mt. Stevia, Monteschella, Forcella de la Rola, Forchetta Piccola and Sas Rigais peaks area formed by the well stratified shelf limestones of the Sciliar Group (Sella Sub-Group), with brittle mechanical behaviour. The ridge to the west, connecting Mt. Seceda and Mt. Piccio, shows parallel stripes of varicoloured alternations of limestones, marly limestones, marls, siltstones and sandstones of the Werfen Formation (Siusi, Andraz and Mazzin members), together with Anisian calcareous marls, marls and sandstones (Buchenstein, Contrin, Moena, Morbiac and Peres formations). Small outcrops of lamprophyres are scattered on top of this sequence, together with pillow and block lavas, volcano-clastic sandstones and siltstones, dikes and megabreccias from the Fernazza Group. More continuously, the Werfen-Fernazza sequence crops out along the eastern side of Rio Cisles, at the southern limit of the area, topped by the larger outcrop of the Wengen Formation, forming a south-east-verging monocline. The Wengen Formation, made up of pyroclastic sandstones and siltstones, covers most of the central part of the area. The presence of soft terrains has favoured the occurrence of landslides; their extension almost entirely hides the outcrops of the formation itself. A similar situation was observed in the adjacent Val Badia (cf. Corsini et al., 2001; Corsini, Pasuto, & Soldati, 1999; Corsini, Pasuto, Soldati, & Zannoni, 2005) and, further to the east, in the Cortina d'Ampezzo valley (cf. Panizza et al., 1996; Pasuto, Siorpaes, & Soldati, 1997). The only outcrop of the San Cassiano Formation (sequences of calcarenites, marls and silts showing overall ductile mechanical behaviour) can be found at the western foot of the dolomite peak of Monte Stevia.

The area underwent intense tectonic activity, attributable to diverse tectonic phases, whose effects are evident in the field and are significant for slope evolution. The whole stratigraphic sequence of the area was thrusted along a low-angle, west-verging fault cutting across the Bellerophon Formation, which corresponds to a mechanically weak layer made up of marl, clay, gypsum and marly dolomite. This thrust was hypothesised by Brandner et al. (2007), who observed the doubling of the stratigraphic sequence from the Bellerophon Formation to the Wengen Formation along a sinuous line that enters the study area at its south-western corner and runs parallel to the crest line stretching from Mt. Piccio to Mt. Seceda a few hundred metres west. The west-verging thrust might have released structures identifiable with right strike-slip faults, such as the certain fault east of the Mt. Seceda peak, and the uncertain one (of regional significance) which enters the area from Sass de Mesdì and exits at Forces de Sielles, with NW-SE direction. Several faults were identified as well as a thick network of joints affecting dolomite formations.

4.2. Structural landforms

The structural control on landforms is evident within the study area. The thrusting is responsible for the monocline structure of the central-western sector of the area, the strata having a mean dip direction towards east and inclination ranging from 25° to 40°. Consequently, the crest line from Mt. Piccio to Mt. Seceda is of structural origin, as well as the west-facing scarp below, although it was partly modified by gravitational processes. A second structural monocline is present at the southern limit of the area, east of Rio Cisles, on top of which the largest outcrop of the Wengen Formation is found. This structure is less inclined and far less fractured if compared with the one previously mentioned, which seems to be highly dismembered by NW-SE-direction fractures.

The regional strike-slip fault, which cuts across the north-eastern sector of the area, was assumed on the basis of a series of aligned tectonic and morphological features, such as the dissected dolomite massif at Sas de Mesdì forming the Forcela de Mesdì gorge. A second dissected smaller dolomite outcrop below, at Ciampis, and a dolomite outcrop with a clear mylonitic surface facing north-east, at Forcela de Sielles (Figure 2a).

Structural ridges can also be found in the Wengen Formation in the upper sector of the area, from Malga Piera Longia to the Fermeda refuges and also north of the Col de Raiser hotel. They both show a N-S direction given by the local attitude of the Wengen strata, which dip east like the whole monocline (Figure 2b).

4.3. Glacial and periglacial processes and landforms

Glaciers strongly shaped the area during the last LGM and evidence of ancient ice masses, such as cirques and till deposits, are widespread mainly in the central sector of the study area (Figure 3), as previously documented elsewhere in adjacent basins (Ghinoi & Soldati, 2017; Vandelli, Ghinoi, Marchetti, & Soldati, 2019). Among erosional landforms, the most significant ones are the cirques occurring in the dolomite outcrops of Sass Rigais (Figure 3c) and well preserved *roches moutonnées* on the round-shaped dolomite outcrop at Alpe di Cisles.

Moraine deposits composed by undifferentiated till are confined to the narrow valley of Rio Cisles, over its left slope and on more extended surfaces at Alpe di Cisles and I Ciampis. Scattered patches of moraine deposits can be found in at least three other sites, but of smaller extent. Since in the area the main outcropping rock type is dolomite, the moraine deposits can be recognised only by identifying chaotic deposits composed by dolomite clasts of different shapes and sizes, with just a small amount of fine matrix. In most cases, the moraine deposits are found quite far away from the surrounding mountain cliffs since transport by a glacier is the only possible means they could be deposited. In other cases, such as the narrow valley of Rio Cisles, the glacier origin is uncertain, since the left side is also characterised by debris cones and debris flows. Nevertheless, the bottom part of the left slope has a detrital cover, which is rather homogeneous in its stripe-like shape and remarkably different from the debris cones above. This characteristic and the fact that well recognisable moraine ridges are present a few hundred metres uphill, along the Rio Cisles course, points to a glacial origin also for the deposits at the bottom of the Rio Cisles left slope.

As mentioned before, at the height of some 2100 m uphill, along Rio Cisles, elongated moraine ridges can be observed bordering the alluvial deposits of more recent origin that form an elongated flat plain to the west. More precisely, it is a series of parallel lateral moraines that have been preserved from erosion by the underlying presence – possibly a few metres below the topographic surface – of the compact layers of the Sella Sub-Group dolomites and limestones. The outcrops of the latter usually have a rounded convex shape, which could be traced back to basal erosion by a glacier: this is the case for the NE-SW-elongated rocky outcrop at the north-western boundary of Alpe di Cisles.

Frontal moraine ridges can be found east of Fermeda hut (Figure 3d), south-east of Piera Longia hut and at the outlet of Val della Salieres, east of the peak of Sass Rigais. They all have small accumulation areas and likely testify to the presence of local Lateglacial ice masses, which found favourable conditions for their persistence despite their south-facing aspect.

A lateral-frontal moraine ridge stands north of Forces de Sielles. In shape, it mirrors the dolomite outcrop with the previously mentioned mylonitic surface (Figure 3a-b). The front of a glacier likely lied within these two morphologically convergent forms and its source area is entirely confined within Val de la Roa.

During the last stages of the Lateglacial, periglacial conditions characterised the area, with rock glaciers developing at the expense of dead ice bodies covered by extensive debris deposits, which were produced by frost shattering. This is the case of the four inactive rock glaciers hosted within Val de la Roa (Figure 4a), the rock glacier at Piera Longia and the festooned protalus rock glacier west of San Silvestro.

Periglacial conditions are also responsible for the production of large amounts of frost shattering debris, which has been shaped in the form of protalus

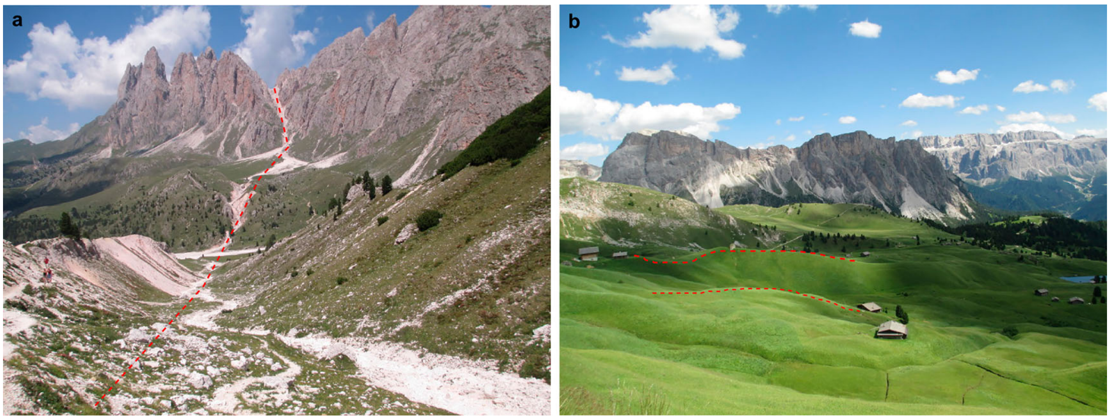


Figure 2. Structural landforms: (a) regional strike-slip fault cutting across the north-eastern sector of the area assumed on the basis of a series of aligned tectonic and morphological features; (b) structural ridges within the Wengen Formation in the upper sector of the area.

ramparts by the action of snow and gravity (Figure 4b), debris cones and scree slopes.

4.4. Gravity-induced processes and landforms

Debris cones and scree slopes, bordering the base of the dolomite cliffs (Figure 5a), were prevalently formed in periglacial conditions, when gravity processes played a major role in depositing frost shattered debris. Due to the recent increase in rainstorm frequency, most of the debris cones and scree slopes have been intensely modelled by debris flows, which have created large accumulation lobes. Nowadays, erosional processes seem to prevail over depositional processes, with intense deepening of the channels and far less accumulation; the latter is testified by the rapid growth of vegetation cover on most of debris flow cones (Figure 5b).

In the western sector of the study area, the marly and clayey components of the Wengen Formation, which show ductile mechanical behaviour, favour the activity of landslides owing to the availability of water guaranteed by precipitation, natural springs and snow

Figure 3. Glacial landforms: (a) panoramic view of the lateral-frontal moraine ridge at Forces de Sielles (dotted red line); (b) close-up view of the same moraine ridge (on the left) and the opposite mylonitised rocky outcrop (on the right); (c) a step-like sequence of glacial cirques east of Sass Rigais; (d) lateral and frontal moraine ridges east of Fermeda hut in the western sector of the study area.

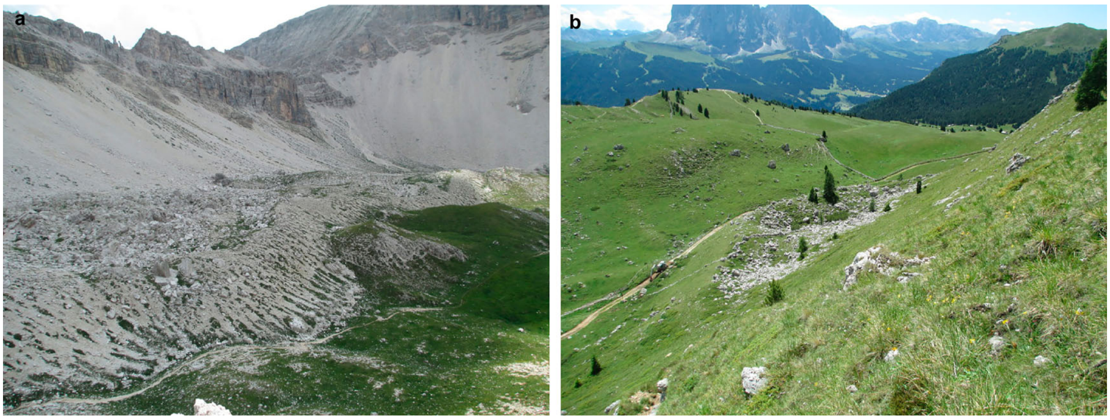


Figure 4. Periglacial landforms: (a) in the foreground, the lateral slope of the longest rock glacier of the area within Val de la Roa; (b) the inactive protalus rampart located north of Alpe di Cisles.

melt (Borgatti & Soldati, 2010; Soldati, Corsini, & Pasuto, 2004). The uppermost portions of this sector are mainly affected by widespread shallow landslides, typical of this Dolomite environment (cf. Panizza et al., 2011; Piacentini et al., 2012). On the other hand, the increasing amount of water permeating the soil at medium altitudes can trigger earth slides (Figure 5c) and earth flows, which tend to join at the valley bottom of Rio Mastlé. Currently, these slides and flows are active and affect cableways, ski pistes and meadows for pasture. In particular, the only hotel of the area, the Col de Raiser, lies on a Wengen outcrop which is almost totally surrounded by landslides threatening its stability.

Heading northward, there is a large rock fall deposit below the cliff of Grande Fermeda, which almost reaches the dolomite outcrop at Alpe di Cisles (Figure 5d). The vast area covered by the deposit may be explained by a large rock fall on a glaciated surface, probably the last remnant of a small glacier whose front moraine can still be seen just a few metres downhill of the rock fall deposit.

Figure 5. Gravity-induced landforms: (a) example of debris cones that border the dolomite cliffs of the area; (b) active debris flow channels affecting the debris cones on the left side of the upper Rio Cisles valley; (c) rock fall deposit below the cliff of Grande Fermeda; (d) partly active head scarp of the rotational earth slide affecting the clay-rich terrain of the Wengen Formation in the westernmost sector of the area.

Approaching the western border of the study area, the volcanic and volcano-clastic rocks of the Fernazza Group have been mainly affected by chemical weathering, which produced thin eluvium deposits where slope angles are low. To the east and south-east, where slope angles increase, the eluvium is subject to solifluction which gives rise to talus. However, the largest landslide of the area has affected the outcrops of the Fernazza Group. It is a rock slide (now inactive) that has its source area south-east of Mt. Piccio, whereas its main accumulation area is found below the path crossing Freines and Rio Cisles. Given its proximity to the west-verging thrust and to other faults with strike parallel to the landslide main axis, the tectonic fracturing of the rocky outcrops can be assumed as the main predisposing factor. The source area and the flanks are now active only as superficial debris slides and debris flows.

4.5. Fluvial and lacustrine processes and landforms

Accumulation landforms include alluvial fans, river terraces and alluvial deposits, whereas erosion landforms are represented mainly by scarp edges or terraces. At the altitude of some 2200 m along Rio Cisles (Figure 6a), an alluvial fan and a river terrace, both active, can be found. They are both composed of dolomite sub-angular-shaped clasts made available by the debris flows that border the left slope of the Rio Cisles source area and reworked by Rio Cisles itself. Another active alluvial fan, of smaller extent and composed of dolomite clasts, is located just a few metres down the valley; it was mainly built by the right tributary stream of Rio Cisles at their confluence. Just a few hundred metres upstream, an inactive alluvial fan can be found in a small depression within hummocky till. A thin strip of inactive alluvial deposit borders the left side of Rio Cisles, just before its outlet from the study area.

Ponds and small marshy areas, and related lacustrine deposits, dot the whole western sector of the study area, given the favourable conditions for their persistence where the topography becomes even and the underlying terrain is made of fine sediments from the Wengen Formation or eluvium deposits (Figure 6b).

5. Conclusions

The results of geomorphological surveys carried out in the Rio Cisles basin, accompanied by multi-temporal photo analysis, have been illustrated with special reference to the 1:12,000 scale geomorphological map. The latter, in A1 format, is accompanied by a stratigraphic sketch of the Permian-Upper Triassic sequences cropping out in the study area, and by a 1:55,000 scale structural sketch map. Detailed geomorphological investigations have enabled a reconstruction of the geomorphological evolution of the study area since the retreat of LGM glaciers (Marchetti, Soldati, & Vandelli, 2017). During LGM, in the central portion of the valley where Rio Cisles now flows, there were vast ice masses, which were fed by still visible cirques located in the northern sector of the area, between Sas de Mesdì and Forchetta Piccola. Smaller ice masses were also contained within Val de la Roa, in the north-eastern part and at the foot of the dolomite cliffs stretching from Forcella Piana to Sas de Mesdì. Following the retreat of ice masses, the ice present inside the moraine debris likely remained active for a long time, especially within Val de la Roa, which was more sheltered from solar radiation than the other parts of the study area. During the Holocene, the processes linked to gravity and the great availability of detrital material produced by frost shattering favoured the emplacement of numerous and vast debris cones and talus deposits, partially modified by debris flows. At present, the most active processes are earth slides and earth flows, which affect the mid-western sector, where rocks

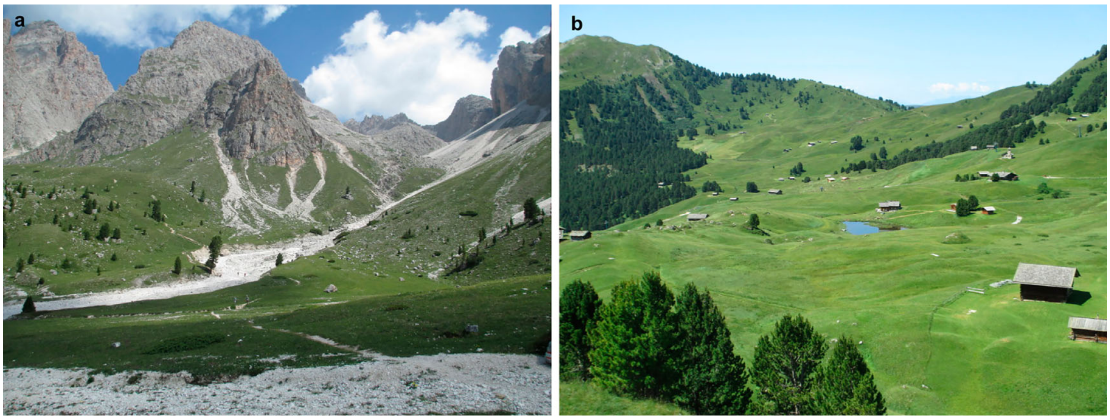


Figure 6. Fluvial and lacustrine landforms: (a) active alluvial fan and river terrace of Rio Cisles; (b) one of the many ponds and marshy areas characterising the upper western sector of the area.

from the Wengen Formation, showing ductile geomechanical behaviour, prevail.

The results of this research enrich the knowledge on the geomorphology of a key sector of the eastern Dolomites. In addition, the availability of a geomorphological map can also contribute to assess present and future geomorphological hazards, for a safer fruition by visitors of the Puez-Odle Regional Nature Park. The map can eventually be a basic document for the implementation of geotourist and geo-hiking maps and, more in general, for effective land management and territorial planning of the Park (cf. Faccini et al., 2018; Faccini, Roccati, & Firpo, 2012; Fuertes-Gutiérrez & Fernández-Martínez, 2012; Martinez-Graña, Goy Y Goy, & Cardeña, 2011; Serrano & Gonzalez Trueba, 2011).

Software

All cartographic design, including the layout, was carried out using the ESRI ArcMap 10.1. Data collected by field survey and air-photo interpretation have been geo-referenced, digitised and stored in a personal geodatabase. For each mapped landform a database containing attributes has been developed.

Acknowledgements

This paper outlines the results of investigations carried out within the framework of PRIN 2010–2011 MIUR Project on ‘Dynamics of morphoclimatic systems as a response of global changes and induced geomorphological risks’ (Co-ordinator: C. Baroni; Research Unit responsible: M. Soldati). The authors are thankful to Dr. Andrea Mary Lord and Prof. Giovanni Tosatti for reviewing the English text. They are also grateful to Dr. Serafino Angelini for his helpful suggestions on the design and graphical representation of the map.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Borgatti, L., Ravazzi, C., Donegana, M., Corsini, A., Marchetti, M., & Soldati, M. (2007). A lacustrine record of early Holocene watershed events and vegetation history, Corvara in Badia, Dolomites (Italy). *Journal of Quaternary Science*, *22*, 173–189. doi:10.1002/jqs.1039

Borgatti, L., & Soldati, M. (2010). Landslides as a geomorphological proxy for climate change: A record from the Dolomites (Northern Italy). *Geomorphology*, *120*, 56–64.

Bosellini, A., Gianolla, P., & Stefani, M. (2003). Geology of the Dolomites. *Episodes*, *26*(3), 181–185.

Brandner, R., Keim, L., Gruber, A., & Gruber, J. (2007). *Carta Geologica delle Dolomiti Occidentali – Tavola Est – Scala 1:25.000* [Geological Map of Western Dolomites – East Map – 1: 25,000 scale]. Bolzano: Ufficio Geologia e prove materiali, Provincia Autonoma di Bolzano – Alto Adige.

Brondi, A., Mittempergher, M., Panizza, M., Rossi, D., Sommavilla, E., & Vuillermin, F. (1977). Note esplicative della Carta Geologica d’Italia alla scala 1:50.000, F° 028 “La Marmolada” [Explanatory Notes of the Geological Map of Italy at 1: 50,000 scale, Sheet 028 “La Marmolada”]. Roma: Servizio Geologico d’Italia.

Bruschi, V., Coratza, P., Piacentini, D., & Soldati, M. (2012). Geomorphological features of the Rio della Rocca valley (northern Apennines, Italy). *Journal of Maps*, *8*, 445–452. doi:10.1080/17445647.2012.744705

Castellarin, A., Vai, G. B., & Cantelli, L. (2006). The alpine evolution of the Southern Alps around the Giudicarie faults: A Late Cretaceous to Early Eocene transfer zone. *Tectonophysics*, *414*, 203–223.

Coratza, P., Marchetti, M., & Soldati, M. (2005). Geomorfologia ed instabilità dei versanti del Gruppo del Sassolungo (Dolomiti occidentali). [Geomorphology and slope instability of the Sassolungo Group (Western Dolomites)]. *Geografia Fisica e Dinamica Quaternaria*, Suppl VII, 105–113.

Corsini, A., Marchetti, M., & Soldati, M. (2001). Holocene slope dynamics in the area of Corvara in Badia (Dolomites, Italy): chronology and paleoclimatic significance of some landslides. *Geografia Fisica e Dinamica Quaternaria*, *24*(2), 127–139.

Corsini, A., Pasuto, A., & Soldati, M. (1999). Geomorphological investigation and management of the Corvara Landslide (Dolomites, Italy). *Transactions Japanese Geomorphological Union*, *20*(3), 169–186.

Corsini, A., Pasuto, A., Soldati, M., & Zannoni, A. (2005). Field monitoring of the Corvara landslide (Dolomites, Italy) and its relevance for hazard assessment. *Geomorphology*, *66*, 149–165.

Del Monte, M., D’Orefice, M., Luberti, G. M., Marini, R., Pica, A., & Vergari, F. (2016). Geomorphological classification of urban landscapes: The case study of Rome (Italy). *Journal of Maps*, *12*, 178–189. doi:10.1080/17445647.2016.1187977

Doglioni, C. (1987). Tectonics of the Dolomites (Southern Alps, Northern Italy). *Journal of Structural Geology*, *9*, 181–193.

D’Orefice, M., & Graciotti, R. (2015). *Rilevamento geomorfologico e cartografia* [Geomorphological survey and mapping]. Palermo: Dario Flaccovio Editore.

Faccini, F., Gabellieri, N., Paliaga, G., Piana, P., Angelini, S., & Coratza, P. (2018). Geoheritage map of the Portofino natural park (Italy). *Journal of Maps*, *14*, 87–96. doi:10.1080/17445647.2018.1433561

Faccini, F., Roccati, A., & Firpo, M. (2012). Geo-hiking map of Mt. Penna and Mt. Aiona area (Aveto Natural Park, Italy). *Journal of Maps*, *8*, 293–303. doi:10.1080/17445647.2012.722404

Fuertes-Gutiérrez, I., & Fernández-Martínez, E. (2012). Mapping geosites for geoheritage management: A methodological proposal for the Regional Park of Picos de Europa (León, Spain). *Environmental Management*, *50*, 789–806. doi:10.1007/s00267-012-9915-5

Gianolla, P., Micheletti, C., & Panizza, M. (2009). *Nomination of the Dolomites for inscription on the World Natural Heritage List UNESCO*. Provincia di Belluno, Provincia Autonoma di Bolzano-Bozen, Provincia di Pordenone, Provincia Autonoma di Trento, Provincia di Udine. Retrieved from https://whc.unesco.org/uploads/nominations/1237rev.pdf

Ghinoi, A., & Soldati, M. (2017). Reappraisal of Lateglacial stadials in the Eastern Alps: The case study of Valparola (Eastern Dolomites, Italy). *Alpine and Mediterranean Quaternary*, *30*, 51–67.

Gruppo di Lavoro per la Cartografia Geomorfologica. (1994). Carta geomorfologica d'Italia – 1:50.000, guida al rilevamento. [Geomorphological Map of Italy – 1:50,000]. *Servizio Geologico Nazionale, Quaderni Serie III*, *4*, 1–42.

Köppen, W. (1931). *Grundriss der Klimakunde*. Berlin: Walter De Gruyter.

Leonardi, P. (1967). *Le Dolomiti. Geologia dei monti tra Isarco e Piave*. Rovereto: Ed. Manfredini.

Lukeneder, A. (2010). Lithostratigraphic definition and stratotype for the Puez Formation: Formalization of the Lower Cretaceous in the Dolomites (S. Tyrol, Italy). *Austrian Journal of Earth Sciences*, *103*, 138–158.

Lukeneder, A., Bechtel, A., & Gratzer, R. (2012). New geochemical data on fossil wood from the Albian of the Dolomites (Southern Alps, Italy). *Geologica Carpathica*, *63*, 399–405. doi:10.2478/v10096-012-0031-5

Marchetti, M., Ghinoi, A., & Soldati, M. (2017). The dolomite landscape of the Alta Badia (Northeastern Alps): A remarkable record of geological and geomorphological history. In M. Soldati & M. Marchetti (Eds.), *Landscapes and Landforms of Italy* (pp. 123–134). Cham: Springer International Publishing AG. doi:10.1007/978-3-319-26194-2_10

Marchetti, M., Soldati, M., & Vandelli, V. (2017). The great diversity of Italian landscapes and landforms: Their origin and human imprint. In M. Soldati & M. Marchetti (Eds.), *Landscapes and Landforms of Italy* (pp. 7–20). Cham: Springer International Publishing AG. doi:10.1007/978-3-319-26194-2_2

Martinez-Graña, A. M., Goy Y Goy, J. L., & Cardeña, C. Z. (2011). Natural heritage mapping of the Las Batuecas-Sierra De Francia and Quilamas Nature Parks (SW Salamanca, Spain). *Journal of Maps*, *7*, 600–613. doi:10.4113/jom.2011.1172

Panizza, M., Corsini, A., Ghinoi, A., Marchetti, M., Pasuto, A., & Soldati, M. (2011). Explanatory notes of the geomorphological map of the Alta Badia valley (Dolomites, Italy). *Geografia Fisica e Dinamica Quaternaria*, *34*, 105–126.

Panizza, M., Pasuto, A., Silvano, S., & Soldati, M. (1996). Temporal occurrence and activity of landslides in the area of Cortina d'Ampezzo (Dolomites, Italy). *Geomorphology*, *15*, 311–326.

Pasuto, A., Siorpaes, C., & Soldati, M. (1997). I fenomeni franosi nel quadro geologico e geomorfologico della conca di Cortina d'Ampezzo (Dolomiti, Italia). *Alpine and Mediterranean Quaternary*, *10*, 75–92.

Pasuto, A., Siorpaes, C., & Soldati, M. (2005). *Carta geomorfologica dell'area circostante Cortina d'Ampezzo (Dolomiti, Italia) [Geomorphological Map of the area surrounding Cortina d'Ampezzo (Dolomites, Italy)]*. Firenze: S.EL.CA.

Piacentini, D., Troiani, F., Soldati, M., Notarinicola, C., Savelli, D., Schneiderbauer, S., & Strada, C. (2012). Statistical analysis for assessing shallow-landslide susceptibility in South Tyrol (south-eastern Alps, Italy). *Geomorphology*, *151–152*, 196–206. doi:10.1016/j.geomorph.2012.02.003

Serrano, E., & Gonzalez Trueba, J. J. (2011). Environmental education and landscape leisure. Geotourist map and geomorphosites in the Picos de Europa National Park. *GeoJournal of Tourism and Geosites*, *8*, 295–308.

Soldati, M. (2010). Dolomites: The spectacular landscape of the "Pale Mountains". In P. Migon (Ed.), *Geomorphological landscapes of the world* (pp. 191–199). London: Springer Dordrecht Heidelberg.

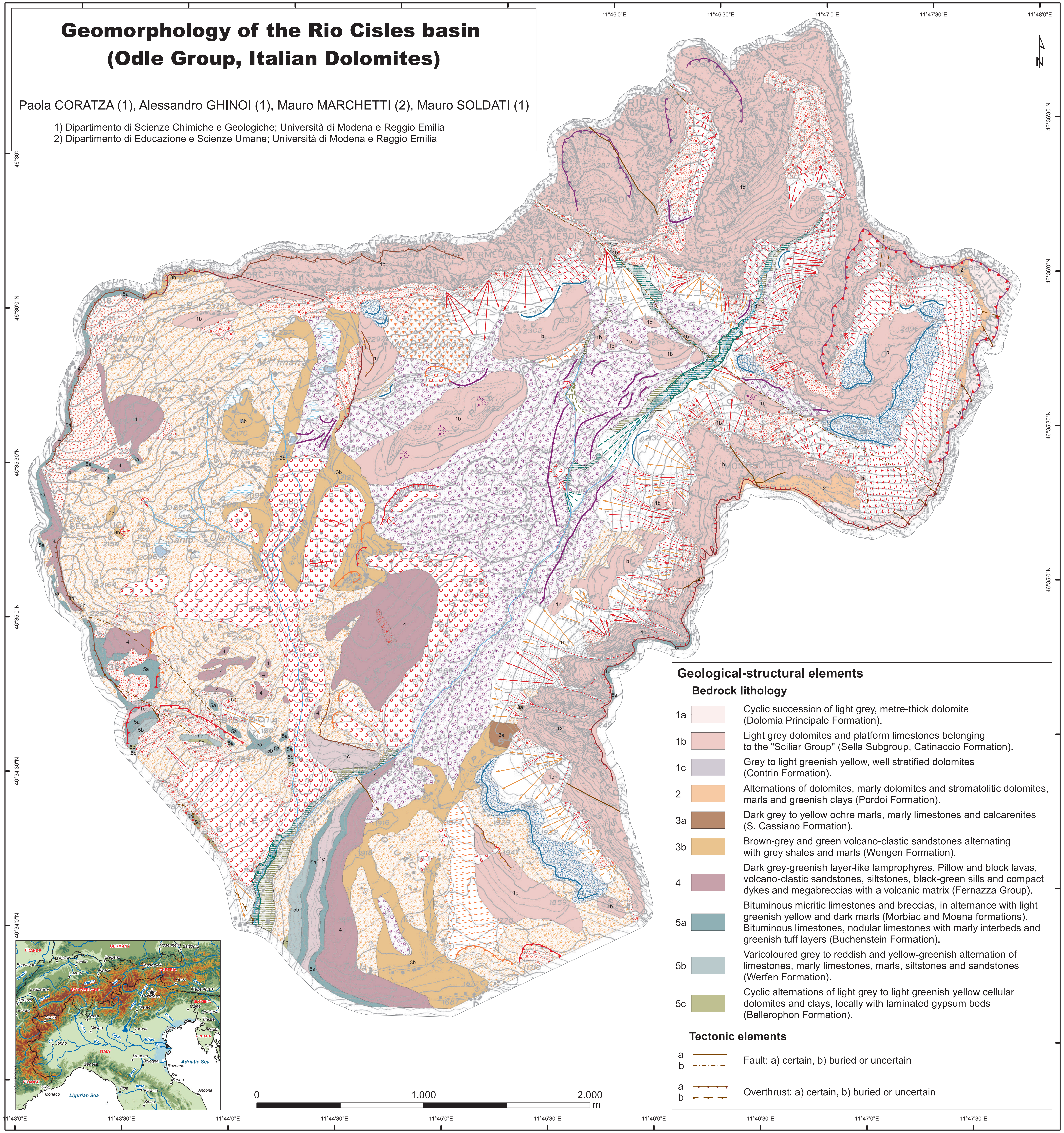
Soldati, M., Corsini, A., & Pasuto, A. (2004). Landslides and climate change in the Italian Dolomites since the Late glacial. *Catena*, *55*, 141–161.

Vandelli, V., Ghinoi, A., Marchetti, M., & Soldati, M. (2019). Discovery and dating of pre-LGM deposits in a high catchment of the Dolomites (Italy): New insights on climate-related geomorphological processes during the Late Pleistocene. *Geomorphology*, *332*, 22–32. doi:10.1016/j.geomorph.2019.02.004

Geomorphology of the Rio Cisles basin (Odle Group, Italian Dolomites)

Paola CORATZA (1), Alessandro GHINOI (1), Mauro MARCHETTI (2), Mauro SOLDATI (1)

1) Dipartimento di Scienze Chimiche e Geologiche; Università di Modena e Reggio Emilia
2) Dipartimento di Educazione e Scienze Umane; Università di Modena e Reggio Emilia



Geological-structural elements

Bedrock lithology

1a	Cyclic succession of light grey, metre-thick dolomite (Dolomia Principale Formation).
1b	Light grey dolomites and platform limestones belonging to the "Sciliar Group" (Sella Subgroup, Catinaccio Formation).
1c	Grey to light greenish yellow, well stratified dolomites (Contrin Formation).
2	Alternations of dolomites, marly dolomites and stromatolitic dolomites, marls and greenish clays (Pordoi Formation).
3a	Dark grey to yellow ochre marls, marly limestones and calcarenites (S. Cassiano Formation).
3b	Brown-grey and green volcano-clastic sandstones alternating with grey shales and marls (Wengen Formation).
4	Dark grey-greenish layer-like lamprophyres. Pillow and block lavas, volcano-clastic sandstones, siltstones, black-green sills and compact dykes and megabreccias with a volcanic matrix (Fernazza Group).
5a	Bituminous micritic limestones and breccias, in alternance with light greenish yellow and dark marls (Morbiac and Moena formations). Bituminous limestones, nodular limestones with marly interbeds and greenish tuff layers (Buchenstein Formation).
5b	Varicoloured grey to reddish and yellow-greenish alternation of limestones, marly limestones, marls, siltstones and sandstones (Werfen Formation).
5c	Cyclic alternations of light grey to light greenish yellow cellular dolomites and clays, locally with laminated gypsum beds (Bellerophon Formation).

Tectonic elements

a
b
Fault: a) certain, b) buried or uncertain

a
b
Overthrust: a) certain, b) buried or uncertain

LEGEND

Structural landforms

Active Inactive

Edge of structural scarp

Edge of structural scarp remodelled by degradation processes

Ridge

Gravity-induced slope landforms

Active Inactive **Erosion landforms**

Edge of scarp due to landslide

Degradation edge of scarp

Active Inactive **Accumulation landforms and deposits**

Landslide body due to rock fall

Landslide body due to earth flow and/or earth slide

Talus cone

Scree slope

Debris flow

Fan originated mostly by debris flows

Unmappable landslide

a b a b
Talus: a) less than 1 metre thick (on bedrock colour); b) more than 1 metre thick (white background)

Eluvium

Lacustrine landforms

Active Inactive **Accumulation landforms and deposits**

Lacustrine deposits

Fluvial landforms due to running water

Active Inactive **Erosion landforms**

Edge of alluvial erosion scarp or terrace

Active Inactive **Accumulation landforms and deposits**

Alluvial fan

Alluvial deposit

Glacial landforms

Active Inactive **Erosion landforms**

Edge of cirque

Edge of cirque remodelled by degradation processes

Roche moutonnée

Active Inactive **Accumulation landforms and deposits**

Moraine ridge

Glacial deposit

Periglacial landforms

Active Inactive **Erosion landforms**

Protalus rampart

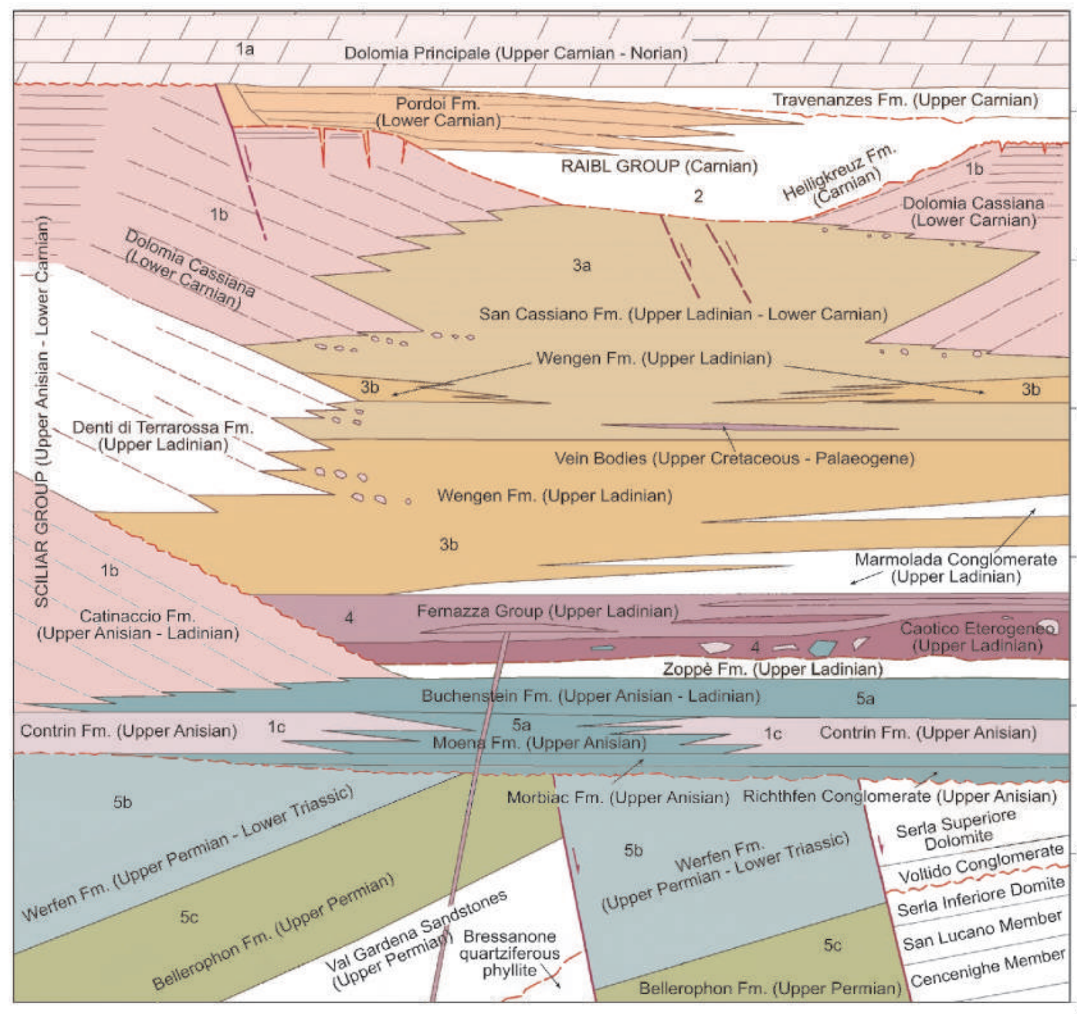
Rock glacier

Hydrography

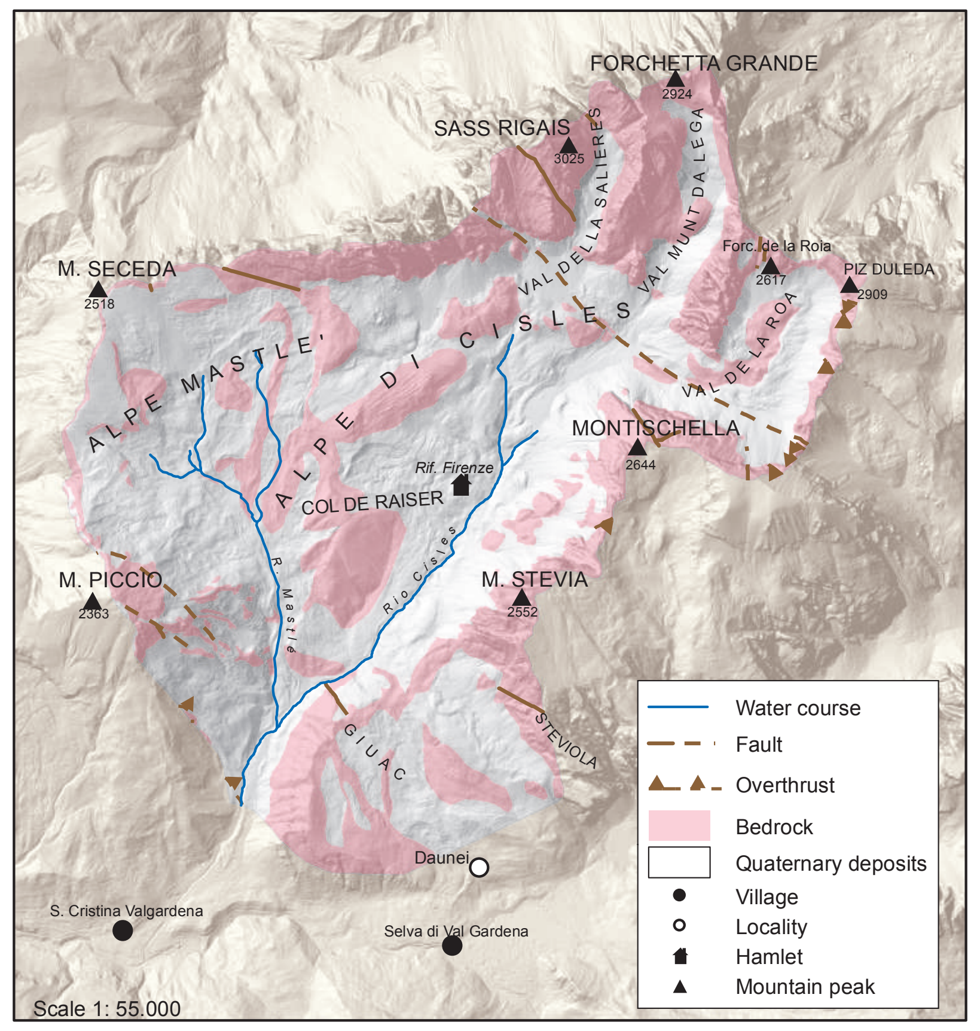
Ponds

Streams

Stratigraphic sketch of the Permian to Upper Triassic succession



Structural sketch map



Investigation carried out within the frameworks of PRIN 2010-2011 MIUR Project on the "Dynamics of morphoclimatic systems as a response of global changes and induced geomorphological risks"
(Co-ordinator: C. Baroni; Research Unit responsible: M. Soldati)

Geological data from "Geologische Karte der Westlichen Dolomiten - Carta Geologica delle Dolomiti Occidentali" (1:25,000 scale) of the Autonomous Province of Bolzano (Brandner, Keim, Gruber, & Gruber, 2007).
Stratigraphic sketch modified after Brandner, Keim, Gruber, & Gruber, 2007.

Coordinate system WGS 84 UTM 32 N