The Dolomite Landscape of the Alta Badia (Northeastern Alps): A Remarkable Record of Geological and Geomorphological History

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Mauro Marchetti, Alessandro Ghinoi, and Mauro Soldati

Abstract

The Alta Badia (Eastern Dolomites) well synthetizes the remarkable geological and geomorphological features that enabled the Dolomites to be inscribed in the UNESCO World Heritage List. Spectacular dolomite mountain groups, built up during the Triassic in coral-reef and tidal-plain environments, stand out of mild slopes made up of clayey terrains deposited in deep inter-reef basins. The landscape is characterized by pale-coloured dolomite cliffs, towers and pinnacles rising above wide talus deposits and gentle grassy foothills witnessing a complex geomorphological long-term evolution. Pleistocene glaciers profoundly shaped the valleys and, at their retreat, periglacial and gravity-induced processes had a major role in slope modelling. Landslides have affected the valleys since the Lateglacial leaving a clear inprint on the landscape, as well as Man in recent times.

Keywords

Alpine landscape • Structural landforms • Glacial landforms • Landslides • Dolomites

10.1 Introduction

The Italian Dolomites are universally known for their scenic beauty and scientific interest. They are the quintessence of the 'dolomite landscape' worldwide and make up a unique geomorphological environment on Earth which was recognized by UNESCO as a World Heritage Site in 2009 (Gianolla et al. 2009; Soldati 2010).

Long-term complex geological events and Quaternary glacial advances have deeply influenced the modelling of the spectacular landscapes and landforms of this region. Majestic mountains separated by deep valleys are the remains of an ancient seabed and of reefs formed in a tropical sea due to the activity of algae, sponges and corals about 200 millions years ago. These structures were born due to long-term sedimentation associated to alternating sinking and rising of the seabed, which determined the development of very thick sequences of dolomites, finally lifted up to over 3000 m by tectonic forces.

Travellers and artists have visited the Dolomites since the eighteenth century, and described the landscape as the 'Pale Mountains' or 'Reign of Titans', which has been highly appreciated since then for its aesthetic value. The Dolomites are actually named after Déodat de Dolomieu (1750–1801), a French nobleman and scientist who discovered during his travel to Italy a 'strange calcareous stone' that did not react with acids. Thanks to the help of Nicolas de Saussure, a Swiss chemist, he realized that the rock consisted of a yet unknown mineral, which was then named 'dolomite' in honour of de Dolomieu himself.

The Alta Badia (Upper Badia Valley, Eastern Dolomites) represents an outstanding example of this dolomite landscape being characterized by high dolomite cliffs, pale-coloured rocky towers and pinnacles which rise from green gentle slopes made up of softer rocks, testifying to long-term and fascinating geomorphological evolution (Fig. 10.1).

M. Marchetti (✉)
Dipartimento di Educazione e Scienze Umane, Università di Modena e Reggio Emilia, Viale Allegri 9, 42100 Reggio Emilia, Italy
e-mail: mauro.marchetti@unimore.it

A. Ghinoi · M. Soldati
Dipartimento di Scienze Chimiche e Geologiche, Università di Modena e Reggio Emilia, Via Campi 103, 41125 Modena, Italy

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Fig. 10.1 Panoramic view of the Alta Badia from the Conturines group. In the background the Sella (*left*) and Gardenaccia (*right*) dolomite mountain groups are visible. In the foreground stands the Pralongià plateau at the bottom of which the villages of San Cassiano (*left*) and La Villa (*right*) are located (*photo* F. Planinschek, courtesy of Tourist Board Alta Badia)

A distinctive, spectacular geomorphological feature, common to many parts of the Dolomites, is the intersection of horizontal layers formed on the paleo-Thetys seabed and vertical fissures related to the endogenous forces which uplifted these mountains due to the collision between the Eurasian and African plates. Differential erosion has shaped the bedrock, producing a peculiar landscape, where high vertical dolomite cliffs that linked to gentle terrain underlain by clayey bedrock via ample cone and festoon-shaped debris deposits (Fig. 10.2). An added quality to the scenic value of the Dolomite cliffs is the famous phenomenon of intense colouring assumed by the rocky cliffs at sunrise and dusk (‘Enrosadira’ in the local Ladinian language, literally ‘becoming pink’).

The mountains of Alta Badia are included in two of the nine systems making up the UNESCO World Heritage Property (no. 5 Northern Dolomites, Sett Sass; no. 6 Puez-Odle). It should be emphasized that the inscription of the Dolomites on the World Heritage List is based on the recognition that the Dolomites show ‘superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance’ (Criterion vii) and ‘outstanding examples representing major stages of Earth’s history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic feature’ (Criterion viii) (Gianolla et al. 2009).

The Alta Badia is a privileged destination for winter and summer tourism. Beside the pristine areas of the mountain groups, which are part of the UNESCO property, a dense and interconnected network of ski-runs and rope ways has been developed thanks to the pioneering vision of Franz Kostner, who first opened the valley to the winter sports in 1930. He built the first sledge-track in Italy near the village of Corvara. During summer, visitors can take advantage of the numerous hiking paths and biking routes to reach any part of the valley and experience its unique landscapes.

10.2 Geographic Setting

Entirely within the Adige River basin, the Alta Badia lies in the Southeastern Alps, mainly within the Autonomous Province of Bolzano (South Tyrol) and only in a small sector in the Veneto Region (Fig. 10.3).

Fig. 10.2 The spectacular dolomite cliffs of the western side of the Conturines mountain group (*photo* C. Soldati)

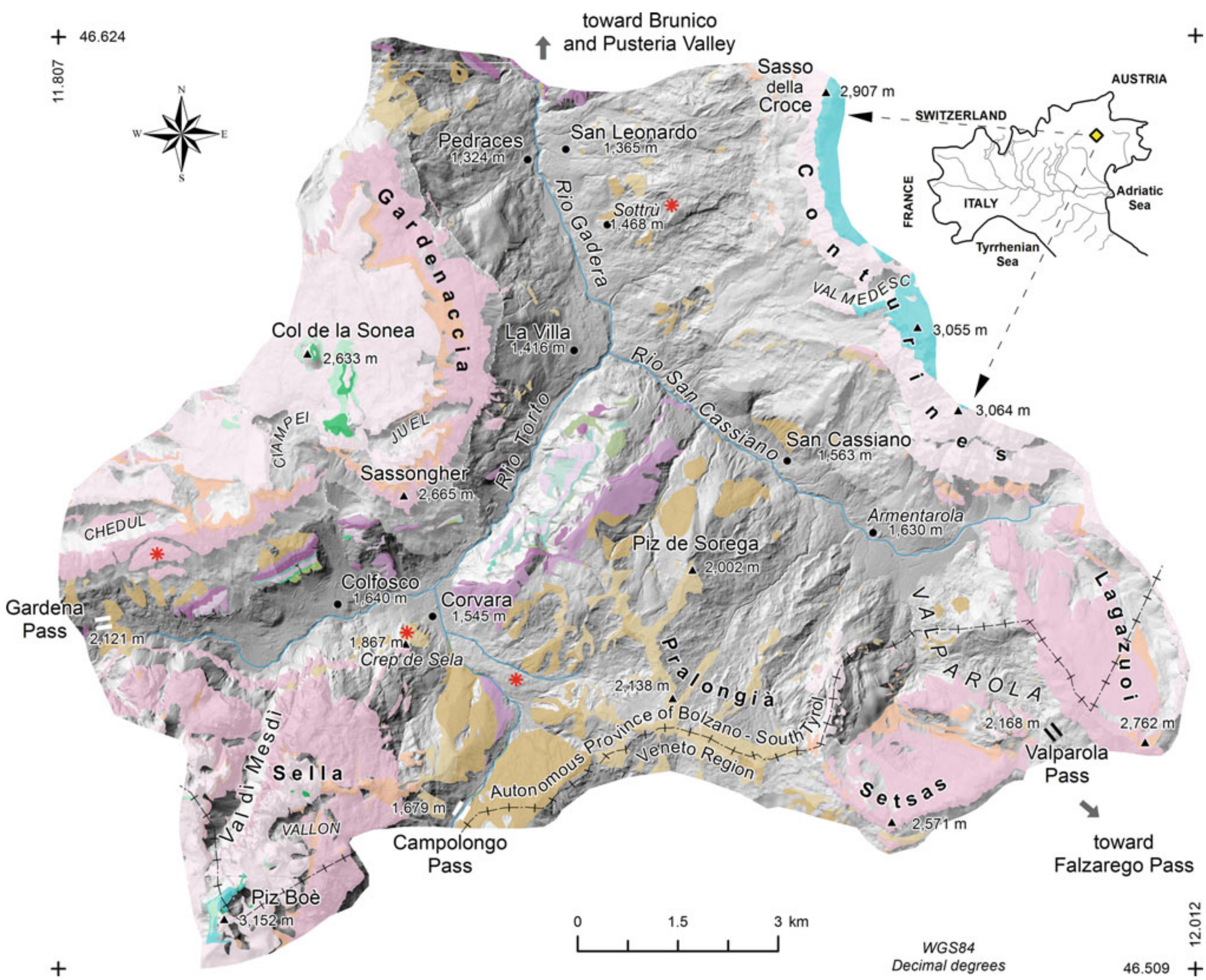

Fig. 10.3 Geographic and geological setting of the Alta Badia. Colours correspond to those used in the stratigraphic scheme of Fig. 10.4. *Red marks* refer to the landslides shown in Fig. 10.10. LiDAR data courtesy of Servizio cartografia provinciale e coordinamento geodati, Autonomous Province of Bolzano

The Badia Valley is part of the land of the Ladinians, a people that shares very old culture with roots back to almost 2000 years ago when the Rhaetians intermingled with the Roman conquerors. The latter had a strong influence on the Rhaetian language and, consequently, on the birth of the Ladinian language. After the collapse of the Roman Empire, the valley was subject to the ever growing political and cultural influence of the Germans that created a common sense of identity, even reinforced during and after the Napoleon's invasion. After the peace treaty of Vienna (1809), the Ladinian region was separated between the Napoleonic reigns of Bavaria (Gardena and Badia valleys) and Italy (Ampezzo, Fassa and Livinallongo valleys). After the Vienna Congress (1815), the Ladinian valleys and the whole South Tyrol became part of the Austrian-Hungarian Empire. At the end of the First World War (1918), the Badia Valley became part of the Italian Kingdom along with the whole South Tyrol.

Alta Badia can be reached through the Gardena Pass (2121 m a.s.l.) from the west, the Campolongo Pass (1679 m) from the southwest, the Valparola Pass (2168 m) from the southeast and from Brunico in the north, along the Rio Gadera. It is surrounded by spectacular dolomite mountain groups, such as Sella (reaching the highest elevation of the valley at Piz Boè, 3152 m), Puez (3025 m) and Conturines (3064 m). Along the three main water courses (Rio Torto, Rio San Cassiano and Rio Gadera), which trace a distinctive upside-down 'Y', the main villages are located, namely Colfosco (1640 m), Corvara (1560 m), San Cassiano (1540 m), La Villa (1420 m) and Pedraces (1325 m). These villages relied on a subsistence economy based on pasture, agriculture and handicraft until the 1950s, and only since then have undergone a continuous and well-governed urban expansion, thanks to the exploitation of the surrounding landscape especially for winter tourism.

Climate is typically alpine; it shows a mean annual precipitation of some 950 mm, with peaks in the summer months. The mean annual air temperature is around 5 °C with a mean monthly minimum in January (−4.9 °C) and a mean monthly maximum in July (15 °C).

10.3 Geological History

The Dolomites are a key area worldwide for the study of the Triassic history. In fact, the geological record from the Triassic is outstanding for the high sedimentation rates, remarkable variety of depositional environments and rich fossiliferous heritage. Subsidence and uplift events controlled the development of a series of carbonate platforms, surrounded by deep water basins, which from time to time were filled by volcanic, volcaniclastic and terrigenous sediments (Gianolla et al. 2009).

The geological record of the Alta Badia mainly includes the Triassic, though older rocks outcropping in the area testify to geological processes occurring back in the Upper Permian when the sea occupied this region for the first time after the Hercynian orogeny (Figs. 10.3 and 10.4; Bosellini et al. 2003; Brandner et al. 2007).

The Triassic sequence started with the growth of the first calcareous platforms in the area (Contrin Formation, Upper Anisian) around which basin sediments were deposited. The volcanic activity which occurred during the Upper Ladinian, when the Dolomites were part of the major volcanic district of Europe, produced pillow lavas and tuffs belonging to the so-called Fernazza Group, whose outcrops can be observed between Colfosco and La Villa. Contemporaneous with the volcanic activity, a highly subsiding area developed, creating a deep basin where thick sediment sequences made up of silty-arenaceous and claystone alternations deposited (Wengen Formation, Upper Ladinian); these mainly derived from the erosion of volcanic edifices located to the west. In the Alta Badia, these terrains crop out in the middle and lower parts of the slopes. From the end of the Ladinian to the Lower Carnian subsidence almost stopped, volcanic activity ended and a tropical shallow-sea environment allowed the growth of fringing reefs. The carbonate platforms representing this depositional environment refer to the so-called Sciliar Group (including Dolomia Cassiana, Lower Carnian) which makes up the basal portion of the Sella and Gardenaccia mountain groups and entirely composes the Setsas and Lagazuoi mounts. The surrounding basins were simultaneously filled by mainly fine sediments, giving origin to alternation of marls, marly limestones and calcareous marls (San Cassiano Formation, Upper Ladinian–Lower Carnian). These form the medium parts of most slopes and the upper part of the Pralongià plateau.

During the Carnian, the sea level dropped and the evolution of the carbonate platforms stopped, allowing for the deposition of carbonate and terrigenous sediments of the so-called Raibl Group, characterized by a typical alternation of colourful marls and argillaceous schists (Pordoi, Heiligkreuz and Travenanzes formations, Carnian) which often morphologically mark the transition between the cliffs of the Dolomia Cassiana and Dolomia Principale. The latter was formed during the Upper Carnian and Norian in a tidal flat environment; thanks to the continuous subsidence it reached remarkable thickness, up to 500 m in Alta Badia as seen in the Sella, Gardenaccia and Conturines mountain groups. At the end of the Triassic there was a remarkable change of the geological environment due to the deepening of the sea, and deposition of limestones took place during the Jurassic. The

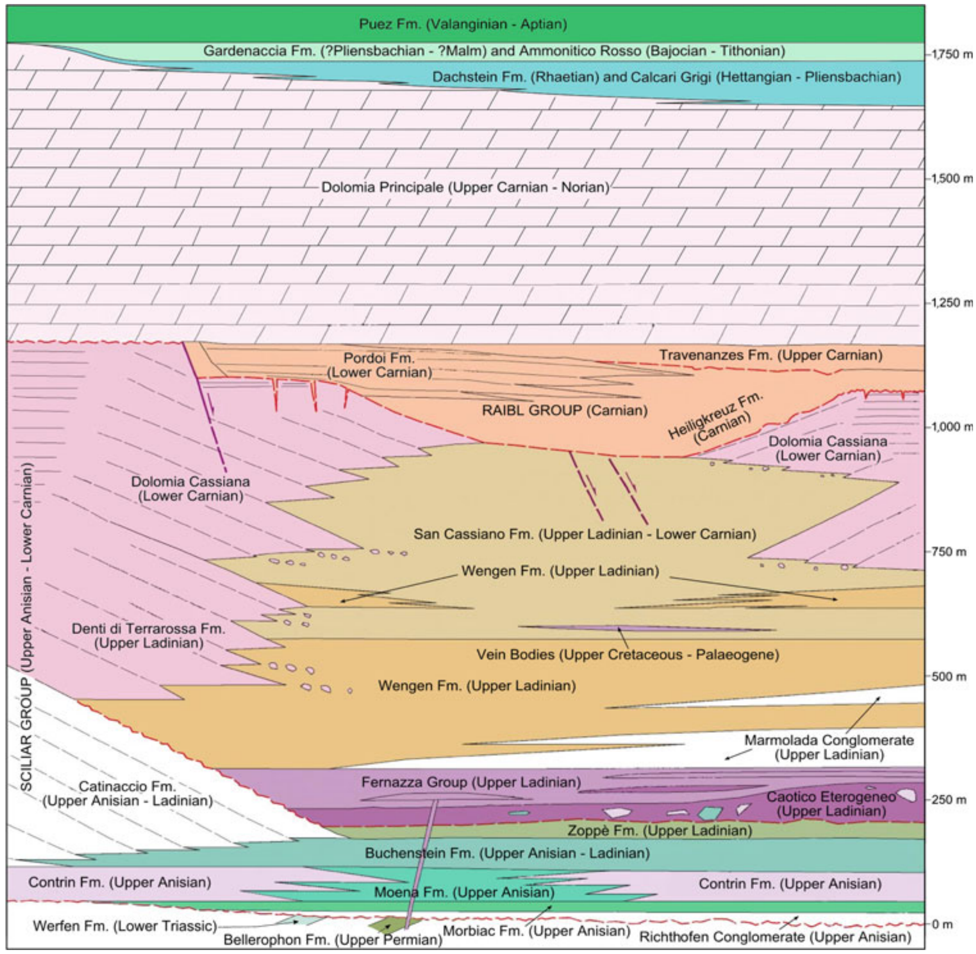

Fig. 10.4 Stratigraphic scheme of the geological sequence characterizing the Alta Badia and surrounding areas (Triassic—Lower Cretaceous). The dolomite formations are *rose*-coloured. The formations depicted in *white* are not outcropping in the Alta Badia

larger outcrops of this upper part of the sequence occur on the top of the Conturines mountain group (Dachstein Limestone and Calcari Grigi, Rhaetian-Pliensbachian), whilst more restricted outcrops can be found in the Sella and Gardenaccia mountain groups (Gardenaccia Formation, Ammonitico Rosso, Pliensbachian-Tithonian), together with the terrigenous sediments of the Lower Cretaceous (Puez Formation, Valanginian-Aptian) which close the depositional sequence of the area, preluding the onset of the Alpine orogeny.

From the tectonic viewpoint, the Dolomite region derived from the Tertiary shortening of a Mesozoic passive continental margin of the Tethys Ocean (Doglioni 1987; Doglioni and Carminati 2008). The Triassic and Jurassic periods were characterized by extensive tectonics that produced a horst-graben morphology with strong control on sedimentation. The Mesoalpine compressive phase (Eocene-Oligocene) was responsible for the origin of W- and SSW-verging thrusts which determined the overlapping of Upper Triassic to Cretaceous rocks on Cretaceous marls witnessed by isolated summits known as *Gipfelfaltungen* (summit overthrusts). Spectacular evidence of this tectonic process is the peaks of Piz Boè on the Sella group, and Col de Puez and Col de la Sonea on the Gardenaccia plateau. However, only 20 million years ago (early Miocene) the Dolomite region started emerging from the sea, during the Neoalpine compressive phase that caused a S-verging thrusting and folding of the region. During this phase a doubling of the stratigraphic sequence took place, giving origin to impressive dolomite massifs and cliffs such as those making the south-facing slopes of the Conturines group (Fig. 10.2). Since the emersion from the sea, the continuous and still ongoing uplift has raised the former coral reefs up to more than 3000 m.

10.4 Landscape and Landforms

Since the Upper Miocene, when the Dolomites emerged from the sea, terrestrial processes started shaping the uplifting rock masses which were at the same time subject to compressive tectonic forces responsible for their intense folding, thrusting and cracking. Meteoric water, weathering, gravity-induced processes and, during the Quaternary, repeated glaciations contributed to model the outstanding landscape that we can observe today. Valleys formed in weak rocks or along the major tectonic lines. In contrast, imposing mountain groups bounded by vertical cliffs correspond to the former coral reefs and massive calcareous platforms. This landscape was formed through different processes and following different rhythms, in connection with differential erosion, tectonics and climate changes. The resulting intense contrast between the light-coloured dolomite cliffs and the dark basin sediments enhances both the aesthetic appeal and scientific relevance of the Alta Badia landscape.

10.4.1 Structural Landforms

Tectonics repeatedly deformed and dismembered the original geological sequence and provided remarkable structural landforms.

Tectonic elements such as thrusts, faults and folds control the direction of valleys—as is the case of the northern Alta Badia N-S-oriented valley stretch, the San Cassiano valley and the Val di Mesdì—and have favoured the formation of saddles such as at Gardena Pass and Valparola Pass. Where tectonic elements are closely spaced, the cracking of the dolomite rocks favoured increased erosion giving rise to spectacular vertical features such as towers, pinnacles, spires and jagged crest lines which contrast with the sub-horizontal dolomite plateaus mentioned above. Inclined structural slopes can also be found, such as at Setsas mountain, where the north-facing slope shows a mild inclination with an angle equal to the slope and the south-facing slope being sub-vertical. These crossing lines provide the Alta Badia mountains with infinite shapes that are the true secret of the appeal of this region (Fig. 10.5).

Where ductile rocks are intercalated with the brittle ones, differential erosion has produced typical belts named *cengie* (ledges) that represent evident breaks in the vertical profile of dolomite cliffs and distinctive traits of mountain massifs such as the Sella group (Fig. 10.6). From a morphological viewpoint, the *cengia* is a lower inclined surface developed where the pelitic rocks of the Raibl Group are interposed between the vertical cliffs of Dolomia Cassiana and Dolomia Principale. The *cengia* is normally covered by scree deposits.

10.4.2 Glacial Landforms

During the Pleistocene, the Alta Badia was repeatedly occupied by glaciers that left a clear imprint in the area. The glacial heritage is related to the Alpine Last Glacial Maximum (LGM, 27,000–18,000 years BP; Monegato et al. 2007; Ravazzi et al. 2014) and to the subsequent Lateglacial phases. During the major glacial advances, including the LGM, ice masses reached the valley from the north, moving upstream from the Pusteria Valley. This is proved by allochtonous metamorphic and granitic clasts found within glacial deposits in the Alta Badia. Small metamorphic clasts recently found at the Gardena Pass (Fig. 10.7) lead to hypothesize also a secondary ice contribution from the west, that is from the Adige basin, through the Gardena Valley (Panizza et al. 2011).

Fig. 10.5 A close up of the Gardenaccia mountain group from the Pralongià plateau. In the *centre* the Sassongher tower which dominates the village of Corvara

Fig. 10.6 The typical 'cengia' (ledge) on the Sella group located between Dolomia Principale (*above*) and Dolomia Cassiana (*below*) in correspondence to the softer Pordoi Formation

Glaciers during the LGM were covering the whole Alta Badia up to some 2300 m a.s.l., with a maximum thickness of 900–1000 m. Therefore, only the highest peaks were jutting out of this sea of ice, though local high-altitude glaciers occurred at the top of the mountain groups (Fig. 10.8a).

The ice masses coming from the Pusteria Valley are likely to have overflowed the Valparola Pass in the eastern sector of the Alta Badia and the Campolongo Pass to the south. It should be emphasized that the whole Pralongià plateau was covered by ice during the LGM. Scattered dolomite erratic blocks can be found on its top, witnessing glacial transport since no dolomite rocks crop out there. Among LGM landforms, worth of notice are two parallel moraine ridges located at an altitude between 2000 and 2200 m on the right hand-side of the valley at the base of the dolomite cliffs overhanging the village of San Leonardo.

During the Lateglacial (18,000–11,600 years BP), once disappeared the LGM ice cap, the ice flow started its northward movement in the form of valley glaciers whose source areas were in correspondence of the Lagazuoi, Setsas and Sella groups. During this period, the Pralongià plateau was progressively left free of ice as witnessed by the dating of a charcoal sample found near Piz de Sorega, at an altitude of 1937 m. This sample was dated back to 16,610 BP (Panizza et al. 2011).

During the Lateglacial, the valley glaciers were responsible for the deposition of frontal and lateral moraines of limited height which can still be identified, especially in the southeastern sector of the Alta Badia, e.g. in the San Cassiano valley, though they were also here largely erased by subsequent erosional processes and landslides (Fig. 10.8b). Nevertheless, remnants of Lateglacial lateral moraines can be found at Pedraces and upstream La Villa, whilst quite well preserved frontal moraines can be observed in the San Cassiano valley, at Armentarola, as well as in Valparola and in the Setsas and Lagazuoi groups. These landforms testify

Fig. 10.7 The Gardena Pass seen from the Pralongià plateau. On the *left* the northern cliffs of the Sella group and on the *right* the southern cliffs of the Gardenaccia group. During the LGM, glaciers were flowing over the pass from the Gardena valley toward the Alta Badia

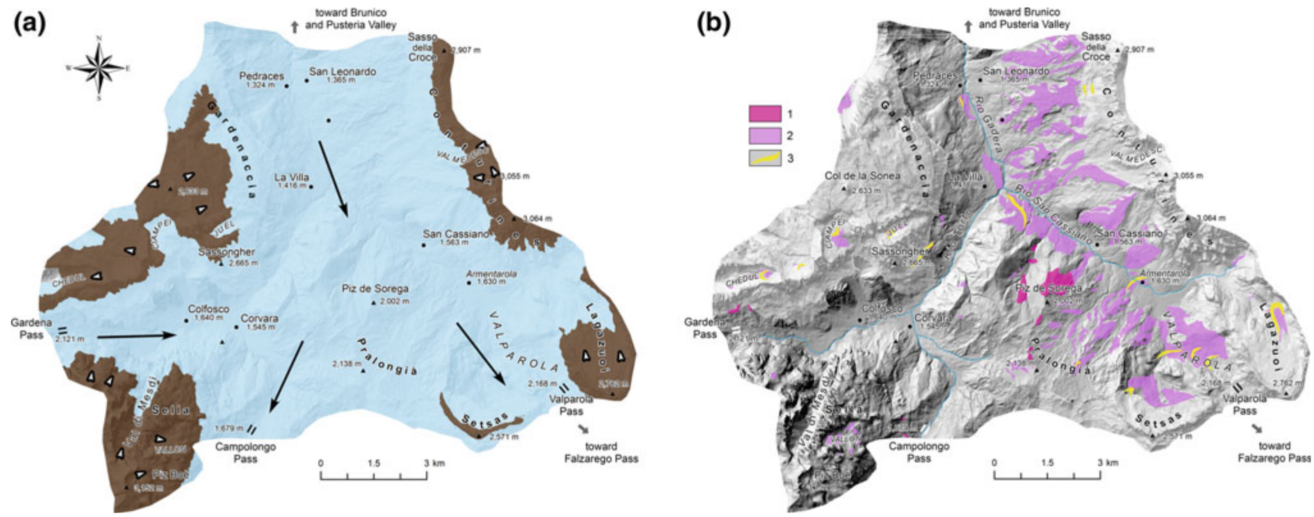

Fig. 10.8 Glacial features in the Alta Badia. **a** Ice cover during the Lastglacial Maximum; **b** moraines and glacial deposits in the area: *1* LGM deposits; *2* Lateglacial deposits; *3* Moraine ridges. LiDAR data courtesy of Servizio cartografia provinciale e coordinamento geodati, Autonomous Province of Bolzano

Fig. 10.9 The Marmolada glacier seen from Lagazuoi. In the foreground Col di Lana whose concave shape is related to a blasting occurred during the First World War. The *dark crests* consist of volcanic rocks, whilst Mt. Marmolada is made up of limestones

to glacial advances which are likely to have occurred during a general period of glacier withdrawal within the Oldest Dryas (namely, the Gschnitz and the Clavadel/Sanders stadials, *ca.* between 17,000 and 16,000 years BP), as per comparison with other Alpine valleys (cf. Ivy-Ochs et al. 2008). Moraines ascribable to younger Lateglacial stadials were not found in the Alta Badia, therefore it is possible that, after the Bølling-Allerød warmer phase, ice accumulation in the area in the Younger Dryas (12,900–11,600 years BP) was not sufficient to build new glacier tongues.

Glacial erosional landforms, in particular glacial cirques, are well preserved within the main mountain groups of the Alta Badia. They were shaped both during the LGM, when the highest parts of the main groups were emerging from the ice cap, and later on, during the Lateglacial, when they corresponded to source areas of valley or local glaciers. Spectacular examples can be found on the main mountain groups, such as on the western and southeastern margins of Gardenaccia (Chedul, Ciampei, Juel cirques), at Conturines (e.g. Val Medesc cirque), on the north facing side of Lagazuoi (e.g. Lagazuoi cirque), and on Sella (e.g. Vallon cirque).

Nowadays no glaciers are present in the Alta Badia. Nevertheless, from many parts of the area the largest glacier of the Eastern Italian Alps can be admired, that is the Marmolada Glacier (Fig. 10.9), which is located ca 12.5 km south of Corvara.

10.4.3 Periglacial Landforms

During the Lateglacial, periglacial processes became increasingly important and led to the origin of evident landforms, especially in the upper parts of the valley, at the base of the dolomite cliffs and on the top of the mountain groups.

Frost shattering processes caused detachment of debris from the dolomite cliffs, which contributed to the building-up of remarkable scree slopes and talus cones (Fig. 10.5). The size and distribution of the latter vary, depending principally on the jointing of the rock masses and secondarily on slope aspect.

At the base of the dolomite cliffs protalus ramparts can be found, mainly within the glacial cirques described above. Protalus ramparts in the Alta Badia are generally inactive, except for that of Piz Boè (2900 m). This demonstrates that at present snow and ice tend to have a lower persistence on the ground than in the past.

Two rock glaciers can be found in Alta Badia. An active one is located northwest of Piz Boè at an elevation of 2900–3000 m, showing high slope angles of frontal and lateral flanks. In turn, an inactive tongue-like shape rock glacier can be observed in the vicinity of the Valparola Pass at an elevation of 2100–2250 m; it consists of large dolomite blocks which are likely to have been detached from the southwestern side of Lagazuoi and accumulated on an ancient glacier or ice field.

10.4.4 Landslides

Landslides of different type and size characterize the landscape of the Alta Badia and make up the most common and widespread Quaternary deposits in the area. Slope instability processes, developed soon after the retreat of glaciers from the valleys, are responsible also for erosion, remobilization and burying of glacial landforms and deposits (Soldati et al. 2004; Borgatti et al. 2006; Borgatti and Soldati 2010). The first phase of marked slope instability occurred in the Preboreal and Boreal (about 11,500–8500 years BP) which was characterized by large-scale translational rock slides affecting the dolomite rock masses (e.g. Passo Gardena landslide; Fig. 10.10a) and earth slides and flows affecting the underlying pelitic formations (e.g. Corvara landslide; Fig. 10.10 b). The latter are likely to have been favoured by high groundwater levels due to an increase in precipitation and/or permafrost melting. A second cluster of landslide events has been recognized during the Sub-Boreal (about 5800–2000 years BP), when mainly rotational slides and/or flows occurred. Many of the events dated can be considered as

Fig. 10.10 Landslides in the Alta Badia: **a** Passo Gardena landslide, a rock slide which affected the dolomite cliffs of the northernmost part of the Gardenaccia mountain group in the early post-glacial; **b** Corvara landslide, an active earth slide/earth flow which reaches the homonymous village determining damages to the winding road leading to Campolongo Pass; **c** Sottrù landslide, a sudden reactivation of a historical earth slide/earth flow occurred in December 2012 on the right flank of Rio Gadera at the foot of the Conturines group (*photo* January 2012); **d** Crep de Sela landslide, a rock/debris slide evolving into a muddy debris flow detached in April 2014 from the lower slopes of the Sella group in the vicinity of Corvara (*photo* June 2014)

reactivations of older movements as a consequence of increased precipitation as in other Alpine regions.

Beside the indirect effect of glacier retreat on slope stability during the Lateglacial and early Holocene, the occurrence of landslides has always been strictly linked to lithological, stratigraphic and tectonic conditions. In particular, landslides have been favoured by (i) the presence of brittle rocks, such as the dolomites, which have been affected by rock slides and rock falls, especially along the highly jointed cliffs of the main mountain groups, and (ii) the widespread outcropping of formations with a ductile behaviour, such as the San Cassiano and Wengen formations, which has favoured the development of a series of earth slides and flows on the middle and lower parts of the slopes. Often, different types of movement combine, giving origin to landslides with a complex style. This is the case of the major landslides which have affected the Alta Badia since the Lateglacial.

The oldest dated landslide in the Alta Badia is the *Passo Gardena landslide* (11,500–8500 years BP), an impressive mass movement extending over an area of about 1.4 km^2 which detached from the southern slope of the Gardenaccia mountain group near the homonymous pass (Fig. 10.10a). This is a complex landslide consisting of a rock slide affecting the dolomite rock cliff which induced a earth slide—earth flow affecting the underlying clayey rocks of the Wengen and San Cassiano formations.

Following the retreat of the ice cap which covered the entire Pralongià plateau, earth slides and flows developed on the slopes of the plateau, giving origin to multiple landslide bodies that often joined together into some of the largest landslide deposits of the valley. The most spectacular is the *Corvara landslide*, a complex landform characterized by movement from multiple source areas, where rotational earth slides have detached, joining valleyward and giving origin to an imposing accumulation which reaches the upper part of the Corvara village (Fig. 10.10b). The landslide has been active since 10,000 years BP showing an intermittent activity throughout the Holocene, with periods of increased instability related to climate changes, such as between ca 5000 and 2500 years BP (Corsini et al. 2001). The landslide is still active today, with major sliding surfaces at depth from 48 to about 10 m. The rate of movement varies in different sectors of the landslide (from centimetres to a few metres per year), with the track area being the fastest (Corsini et al. 2005; Panizza et al. 2011).

Recent reactivations of older landslides have left impressive scars within the grassy and woody slopes, visible from very long distances. This is the case of the *Sottrù landslide* that occurred in December 2012, after almost 200 years of dormancy (Fig. 10.10c) (Ghinoi et al. 2014). A huge earth slide—earth flow destroyed a few houses and almost dammed the Rio Gadera, assuming a shape strikingly similar to that of its first documented activation of 1821.

The *Crep de Sela landslide* is the most recent slope instability event occurred in the Alta Badia. It dates back to April 2014 when a rock/debris slide evolving into an earth flow was reactivated at the outer limit of the Corvara village, creating a deep cut in the slope and a two-branch mass movement which almost affected newly built houses and a base camp of the Italian Army (Fig. 10.10d).

10.5 The First World War and Related Heritage

During the First World War (1915–1918 in Italy), a part of the alpine front line between the Italian and the Austrian-Hungarian armies crossed the Alta Badia in the vicinity of the Setsas and Lagazuoi mountain groups. The fights not only caused great human losses on both sides but also changed the morphology of some mountain crests and slopes due to massive bomb attacks. One of the most impressive examples is the crest line of Col di Lana (ca 2.5 km south of the Setsas), whose shape was strongly modified after the explosion of an Italian bomb that removed ca 10,000 tons of rock creating shell craters and huge troughs that are still visible on the summit (Angetter and Hubmann 2015; Fig. 10.9). Another huge blasting was carried out by the Austrians targeting an Italian outpost on the 'Cengia Martini' ledge on the Lagazuoi, close to the Falzarego Pass, removing ca 200,000 m^3 of dolomite rocks. Both armies dug tunnels within the Lagazuoi, which have been recently opened to the public, representing an open-air museum of the First World War (Fig. 10.11).

Though outside the Alta Badia, it is worth mentioning the 'Ice city' of the Marmolada glacier as a valuable heritage of

Fig. 10.11 Entrance to a First World War tunnel on the top of the Laguzuoi mountain group, at an elevation of ca 2600 m

the First World War. It was a 12 km-long network of tunnels and caves dug by hand into the glacier ice (up to 50 m-thick) by the soldiers of the Austrian-Hungarian army to protect themselves from the Italian bombing attacks. The ice retreat of 3.4 km^2 in the last 100 years has brought to light interesting remains of that life beneath the ice, including bodies of soldiers.

10.6 Conclusions

Besides its outstanding aesthetic value which has been appreciated since a long time ago, the Alta Badia is a site of exceptional scientific and educational value. The dolomite plateaus and cliffs—defined by the Swiss architect Le Corbusier 'the most impressive buildings in the world'—as well as the slopes beneath them, are a remarkable record of geological and geomorphological history, making them an open-air laboratory for Earth scientists and destination not to be missed by visitors interested in natural and environmental sciences. Research activity carried out within this 'laboratory' dates back to 1841 when Wissmann and Münster described in detail the famous fossil fauna of the San Cassiano Formation, named after the village of the Alta Badia, soon followed by the first geological map of the valley performed by Fuchs (1844). Since then, the valley has attracted natural scientists, at first, and later on specialized geologists and geomorphologists, who provided extensive literature on the area.

The dense network of rope ways and hiking paths developed in recent years favours the reachability of a series of geoheritage sites and observation points, even at the highest elevations, which enables visitors to take full advantage of different landscape components. It should be emphasized that an exemplary range of diverse landforms—resulting from the complex geological structure of these mountains and from climatic changes through time—provides the background of high geomorphodiversity both at a global and regional scale (Panizza 2009).

The conservation and protection of geological and natural heritage of the Alta Badia is guaranteed not only by UNESCO rules, but also by the long-standing existence of two Natural Parks in the area, Puez-Odle and Fanes-Senes-Braies established by the Autonomous Province of Bolzano, respectively in 1978 and 1980. Furthermore, it should be noted that the inhabitants of the Badia Valley have always been deeply tied to their land which has enabled harmonious development of villages and tourist infrastructures, and profoundly respectful of natural assets, even in recent times when tourist activities have largely become the main source of income.

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