17 Geomorphology and Landscapes of the Swiss National Park

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Abstract

The landscape of the Swiss National Park (SNP) is an area of unique beauty within the morphological systems of the Swiss Alps. This is due to bedrock lithology and its deformation history: the Austroalpine facies and structures are restricted to the southeasternmost corner of the country. The morphologically dominant and most visible rock type in the landscape is the Triassic "*Hauptdolomit*." It forms high cliffs, which supply extensive scree slopes. The Park is split into two areas: the larger heartland of the Engadine Dolomites and the glacially sculptured pass areas in the south and the much smaller mountain area of Macun to the north of the Engadine Line in the crystalline Austroalpine basement rocks. The high mountain areas of the Park display various types of periglacial features, including the famous and long-researched rock glaciers.

Keywords

Swiss National Park • Engadine dolomites • Engadine Line • Glaciation • Human impacts • Engadine

17.1 Introduction

The Swiss National Park (SNP) is a Wilderness Area of Category 1a according to the classification scheme of the International Union for Conservation of Nature (IUCN), implying strict preservation of all natural processes. The evolution of the landscape has therefore not been influenced by anthropogenic landscape design and protective geo-engineering structures for one hundred years, with the exception of the hydropower schemes in the Spöl Valley (*Val dal Spöl* in Romansh language). The SNP is situated in the southeastern corner of Switzerland, between the Engadine Valley (*Engiadina*) to the north and the Val Müstair to the southeast, extending into adjoining valleys to the south towards the border with Italy (Fig. 17.1). It has a surface area of 170.3 km^2, split into two parts with an area of 167 km^2 mainly along the Pass dal Fuorn and a 3.6 km^2 exclave at Macun (Fig. 17.1). The "entrance doors" to the Park are the village of Zernez in the Engadine Valley at 46°42′ N/10°06′ E and the Pass dal Fuorn when the Park is approached from Val Müstair (Fig. 17.1). The highest peak in the Park area is Piz Pisoc at 3,173 m a.s.l. The lowest point is in Val S-charl along the River Clemgia at 1,380 m a.s.l. The alpine topography in this area is unique for the Swiss sector of the Alps, due to the Eastern Alpine Facies bedrock with the Engadine Dolomites (*Engadiner Dolomiten* in German), a substantial sedimentary rock sequence of predominantly Lower Mesozoic age (in yellow and blue in Fig. 17.2), which is structurally surrounded by crystalline units.

This chapter gives a brief outline of the relationships between bedrock lithologies, structural deformations, and the current landscape in an alpine environment of exceptional beauty. Various publications have been produced for the Park's 100-year jubilee celebrations (e.g., Kupper 2012; Haller et al. 2013; Baur and Scheurer 2014). These publications are a rich source of information and also provide the background for this manuscript.

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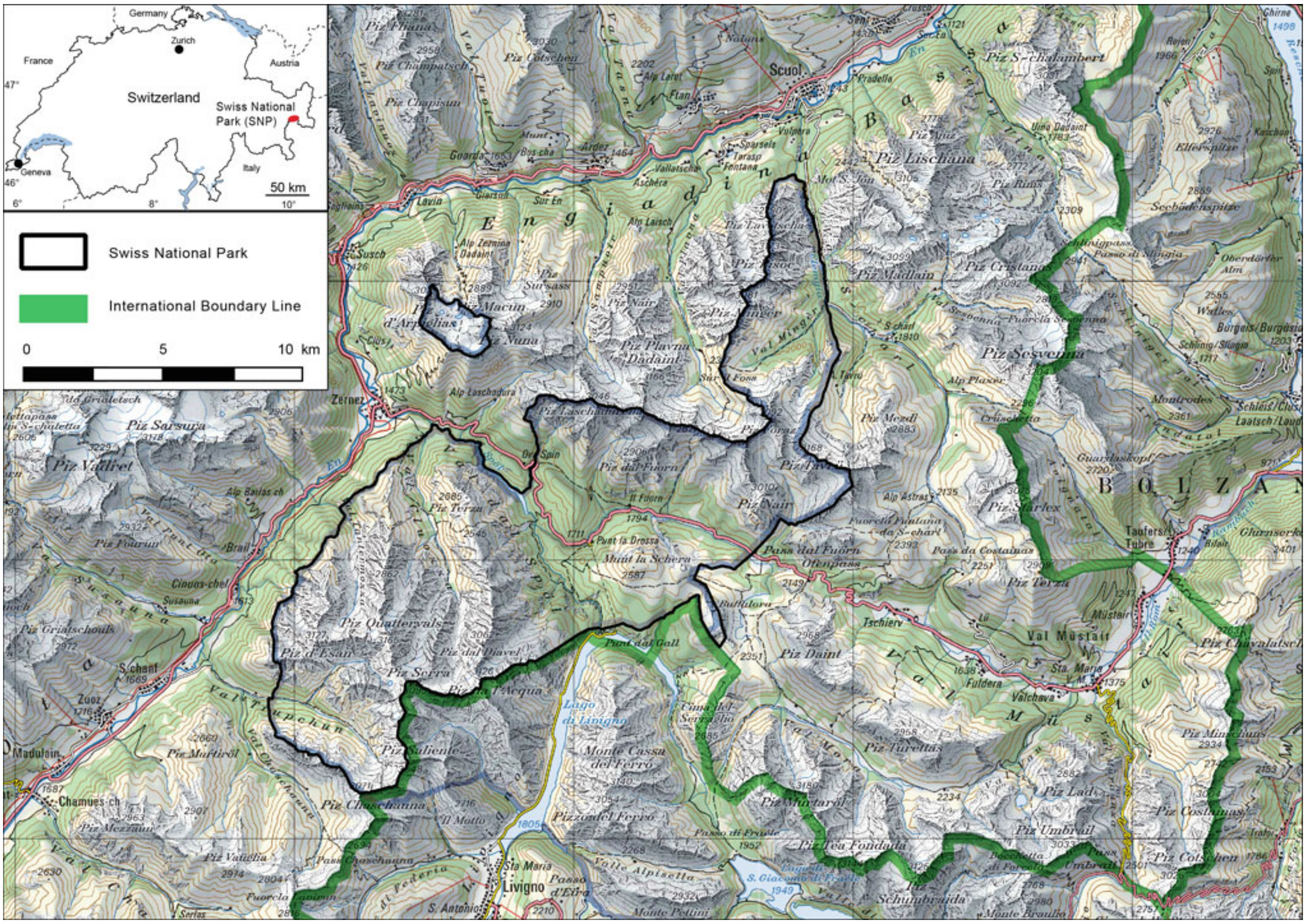

Fig. 17.1 Situation and topographic map of the Swiss National Park and the surrounding area (*Source* Swisstopo)

17.2 Geographical and Geological Setting

17.2.1 Geography

The SNP lies entirely in the Canton of Graubünden and, from a cultural point of view, in the realm of the Romansh language, the fourth official language in Switzerland. The official name of the Park is therefore "*Parc Naziunal Svizzer.*"

The boundaries of the SNP are essentially political as it is restricted to the higher parts of the mountains with less productive agricultural and forest areas (Fig. 17.1). These boundaries are the result of intense discussions between all parties involved, which finally led to the establishment of a protected area, which became effective under Federal law on August 1st, 1914. Some boundaries changed over the years: Val Tavrü (SW of Val S-charl) was given back to agricultural use in 1936 and, in contrast, the exclave of Macun was added to the Park in the year 2000, substantially supplementing the geomorphological diversity of the Park (Fig. 17.2).

The founding members of the Park are the Swiss Confederation, Pro Natura (the largest organization for nature conservation in Switzerland) and the Swiss Academy of Sciences. The Park is managed by the central park administration under supervision of the Federal National Park Commission; scientific activities are commissioned to the Research Commission of the Swiss National Park along with the Swiss Academy of Sciences. Today, the Swiss National Park is embedded within a set of neighbouring areas of varying protection status: the UNESCO Biosphere Val Müstair Parc Naziunal, the National Park Stilfserjoch (in Italy), the regional parks Adamello Brenta and Brenta (in Italy) and the Naturpark Kaunergrat (in Austria). In combination these parks form an almost uninterrupted protected area in the border zone of Switzerland, Austria, and Italy from the Central to the Southern Alps.

Five local communities contribute property to the SNP: Zernez (68.4%), S-chanf (13.5%), Scuol (13.4%), Val Müstair (4.7%), and Lavin (2.1%). Ownership of the parkland is both public and private and is compensated by a yearly interest paid by the Federal government. 50.9% of the surface area consists of primary soils devoid of vegetation

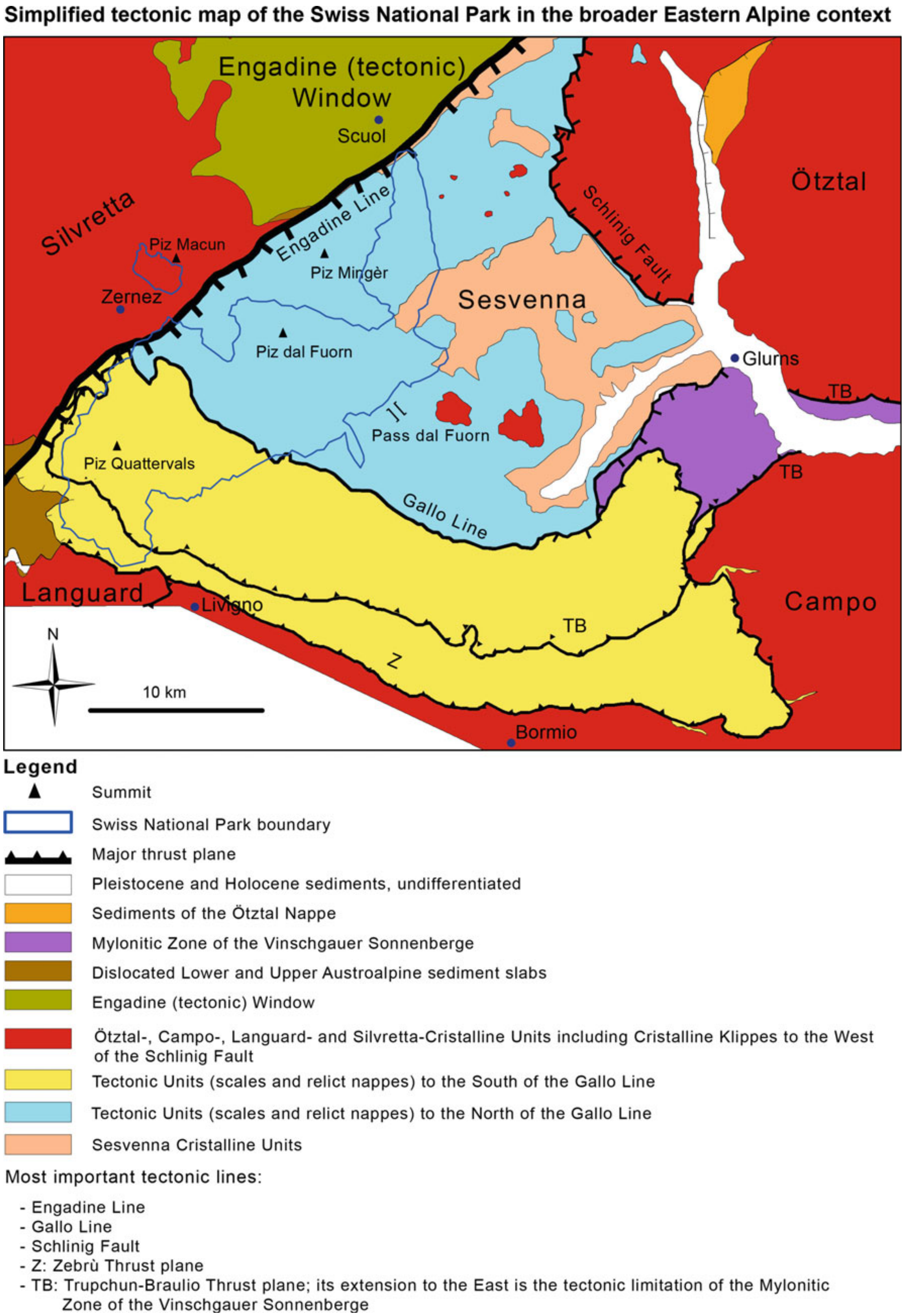

Fig. 17.2 Simplified tectonic map of the Swiss National Park in the broader Eastern Alpine context (modified after Zimmermann et al. 2014)

cover (*Rohböden* in German), 17.1% are grassland and alpine meadows, 31.4% are forested and 0.6% are rivers and lakes. Infrastructure accounts for 0.1% of the total area. The tree limit is between 2,200 and 2,300 m a.s.l. All surface waters naturally drain toward the Inn River (*En*, Fig. 17.1), which joins the Danube River on its course to the Black Sea.

The morphological heart of the Park is the broad valley of the Pass dal Fuorn, with the river Spöl in the lower and the river Il Fuorn in the upper sector. In the western part of the Park there are valleys draining directly to the Engadine Valley: Val Tantermozza and further to the west Val Trupchun. Entering the northernmost sector of the Park from the Lower Engadine Valley in Scuol the Val S-charl and its tributary Val Mingèr and Foraz can be followed. The park exclave of Macun is a unique plateau with about 40 small lakes and ponds.

The Park area has a very long tradition of economic activities, the most important of which are mining and forestry. The Engadine Valley was probably inhabited as early as 3,600 years BC. Around 1000 AD agricultural activity was widespread and around 1300 AD mining started to develop, with peaks of activity in the fourteenth and fifteenth centuries, and then again in the seventeenth century. Mining continued sporadically and was reconsidered as late as in the early twentieth century. The target ore in the Pass dal Fuorn area was iron. In the Val S-charl (at Piz Madlain) silver and lead have been mined for over 300 years. There is a museum worth visiting on the medieval mining industry in the village of S-charl. Local small scale mining produced anthropogenic morphology and small excavations, tunnels and local landfills are still visible. The most extensive mining operations with resulting landscape modifications were on Munt Buffalora just outside the borders of the Park. A comprehensive report on the history of the mining activities in the Engadine–Val Müstair area is given by Schläpfer (2013).

The evolution of the natural environment in the Park did not experience any major disruption until the 1950s. However, this quiet phase was interrupted in the late 1950s and early 1960s with the installation of the Lago di Livigno hydropower scheme (Fig. 17.1). This major impact has drastically changed the character of the river Spöl, from an alpine high-energy torrent with maximum yearly discharge of about 12 m^3s^{-1} until 1962 to the reduced, legally contracted remaining flow of 0.5 m^3s^{-1} resulting in a quiet and low-energy rivulet. Both the Lago di Livigno and the Punt dal Gall concrete dam are outside the Park, but the geo-ecological consequences are registered in the Park (Schlüchter 2014). The situation is different with the Ova Spin reservoir further down the Spöl Valley. Around 30% of the upper lake surface is in the Park as well as the left orographic border of the lake and half of the foundation of the dam wall. The hydropower scheme in the Spöl Valley causes a unique situation where waters from outside are brought into a natural park where they are fully managed for hydropower production. The Ova Spin reservoir is a central installation of the Engadine Hydropower Scheme (*Engadiner Kraftwerke*) as it is a reservoir for temporary water storage. From there, water is either pumped to the Lago di Livigno or sent to turbines further down the Inn Valley. This intermediate position makes the Lake of Ova Spin a sedimentation laboratory because the water remains on average only for around two days, thus causing an extremely high sedimentation rate of >60 cm/y. This sedimentation rate is among the highest known. Another aspect of interest is that some of the water brought to the Ova Spin reservoir is diverted further up valley from the Inn River, which is, to some degree at least, contaminated by the Upper Engadine wastewater treatment plant. The sediments in the Ova Spin lake therefore contain the wastewater signal from one of the most developed tourist resorts in the world: St. Moritz. The National Park is thus a sort of monitoring site of the human tourist ecology and its impacts on a largely unspoiled high alpine environment. A much more obvious human impact to the regular visitor of the Park is the road from Zernez across the Pass dal Fuorn to the Val Müstair (Fig. 17.1). This road divides the nature reserve in two parts, both acoustically and mechanically as seen in the number of accidents along the road, above all by motorbike traffic in summer and early fall. This is a significant problem, as this road is the only access to the north for the population of Val Müstair.

17.2.2 Geology

The geological setting for the area of the Park is best shown on a simple map (Fig. 17.2). One of the most important tectonic accidents of the Alps—the Engadine Line, a sinistral (left-lateral) wrench fault (Trümpy 1977)—cuts the area just to the northwest of the Park. To the northwest of the Engadine Line crystalline basement rocks are brought up against the sediments of the Engadine Dolomites by about 4 km, but in fact, the Engadine Line as a mechanical discontinuity cuts the rocks down to a depth of 10 km (Trümpy 1977). The exclave of Macun is situated in the crystalline rocks of the Silvretta to the northwest of the tectonic line. To the southeast the Engadine Dolomites are a tectonically complex set of faulted, folded, and pushed slabs of varying vertical and horizontal dimensions where they belong to the typical eastern alpine (Austroalpine) facies succession of mainly lower Mesozoic sediments. This sedimentary succession (Furrer 1993) spans roughly 210 million years of Earth history with the basal terrestrial sediments of the Münstertaler Verrucano (Permian), followed by thick shallow marine sandstones and dolomites (Triassic) with characteristic dinosaur tracks overlain by deeper marine marls, limestones, and radiolarian cherts (Jurassic to Lower

Cretaceous). The full sedimentary succession records the terrestrial environment of the old supercontinent Pangea during the Permian, its break-up phase with the shallow marine dolomites reflecting slightly changing sea levels (Triassic) and the full break-up and rifting of the northern from the southern continental margin with extensional faulting around 202 million years ago, with deeper marine sediments (Jurassic to Early Cretaceous) where the sedimentation ended (Furrer et al. 2013). The mountain building processes were initiated by compressive deformations involving folding and thrusting. The main lithologies, which not only control the deformation pattern of the Austroalpine sequence but also the morphology of today's landscape are: (i) the basal continental sediments (Permian); (ii) the main Triassic 1500 m thick unit of the "*Hauptdolomit*" (Main Dolomite); (iii) the Lower Middle Triassic Raibl-Group with evaporites; and (iv) the predominantly marly limestones and marls of the Jurassic and Cretaceous. The Main Dolomite dominates the attractive morphology of the mountains (Zimmermann et al. 2014).

17.3 High Diversity of Landforms

The landscape of the SNP is a scenery of contrasting landforms: the rolling lower hilly areas of the Spöl Valley and the upper reaches of the Fuorn Valley contrast sharply with the high rock walls of Piz Laschadurella, dal Fuorn and Nair to the north or with Piz Terza, Murter, da l'Acqua and Quattervals to the south. These peaks are the prominent mountains of the Engadine Dolomites in the heart of the SNP (Fig. 17.3). They all consist of Triassic Main Dolomite. Piz Laschadurella, Piz Fuorn, and Piz Nair are located to the north, Piz Terza, Piz da l'Acqua, and Piz Quattervals (Fig. 17.1) to the south of the Gallo Line, a major thrust with northerly/northwesterly compression onto deformable units of the Raibler-Beds (Fig. 17.2). The high peaks are tectonically speaking solitary scales or slabs, or more complex stacks of dislocated slabs. This means that the peak-and-wall morphology is preconditioned by tectonics. This is given also by the lithology of the high peaks: the Main Dolomite is a hard rock resistant to folding and mechanical thinning.

Fig. 17.3 A typical view of the Engadine Dolomites with Piz Quattervals and Piz d'Esan (photo H. Lozza)

Fig. 17.4 Northward thrust of the Piz Nair Slab marked by the highly deformed (brownish) Raibler-Beds in the rocky slopes to the east of Fuorcla da Val Botsch. The deformed and easily eroded Raibler-Beds are responsible for rounded morphologies in the Engadine Dolomites (photo C. Schlüchter)

However, it is sensitive to brittle faulting and a number of substantial faults are visible along the road between Zernez and the Pass dal Fuorn. The high peaks of the Engadine Dolomites are spread over a substantial area between the Engadine Valley and the Val Müstair. The northernmost peaks Piz Lavetscha and Piz Pisoc toward Val S-charl (Fig. 17.1) within the SNP are also prominent members of the Engadine Dolomites. They are a key example of the broken-up and thrusted sequence of scales consisting of the Main Dolomite. A morphological textbook example is the northward thrust of the Piz Nair slab toward the Piz Murters at the Fuorcla da Val Botsch (Fig. 17.4), which the hiking trail between Val dal Botsch (south) and Val Plavna/Val Mingèr (north) crosses and where the Raibler-Beds display the mechanical deformation resulting in the soft morphology of the Fuorcla.

The mountains of southeastern Switzerland, namely, the Engadine Dolomites, are characterized by simple geometry, in sharp contrast to the Central and Western Swiss Alps (see for example Pfiffner, this volume): they are of a uniform elevation of 3,100 m. This situation is called “*Ostalpine Gipfelflur*” or Eastern Alps Summit Level (Staub 1934; Trümpy et al. 1997) and is considered to be a remnant of an orogenetically older part of the Alpine landscape than the Penninic and Helvetic central and western sectors of the Alps. This also implies that the Engadine Dolomites are an erosional relict of a formerly much more comprehensive mountain range or of a vast plateau dissected by important faults along which early drainage evolved (possibly as early as the Late Cretaceous). The triangle of the Engadine Dolomites—consisting of sedimentary rocks of mainly Triassic age on continental units of Permian age, overlain with some Jurassic to Lower Cretaceous sediments and surrounded by Austroalpine crystalline basement rocks (Fig. 17.2)—tectonically forms a vast arch-like A-form, oriented SW–NE. The soft rounded morphology of the central Val dal Fuorn and further to the SE with the plain at Buffalora and the Val Müstair lies in the basal Permian sandstones and fanglomerates of the Münstertaler Verrucano, where the Triassic sequence has mainly been removed. This erosion has formed the wide-open Val dal Fuorn.

Landscape elements of exotic beauty can be found in the upper reaches of Val da Stabelchod and at Chaschabella

Fig. 17.5 Unique pillars in the National Park (photo H. Lozza)

(south of Munt la Schera; Fig. 17.1). They are individual, free standing pillars which are up to 10 meters high and several meters in diameter (Fig. 17.5). They consist of angular, secondary cemented polymictic rock fragments of sand, gravel and boulder size and they occur in the gypsum-bearing Raibler-Beds. They should be referred to as "secondary karst features" as they constitute refilled karst openings and tunnels by scree from slopes situated above washed into the system through flood events. The sediments of the pillars are a relict and breccia-type facies of what is called *Rauhwacke* (cornieule). The cement of these sediments is secondary calcite and is therefore more resistant to current erosion than the original Raibler-Beds (containing gypsum) where the karst channels originally formed. Specific karst landforms are of restricted importance within the Park and are not shown on maps.

A striking morphological element of the Engadine Dolomites are the extended, voluminous, and characteristic scree slopes below the high walls of the peaks. Such vast scree slopes do not form elsewhere in the Swiss Alps and there are no other dolomite sequences of comparable thickness forming high peaks in Switzerland. Physical weathering of the dolomite produces characteristic gravelly to bouldery scree sediments which form steep slope surfaces determined by the internal angle of friction (Fig. 17.6). These scree slopes can be potential hazard areas as the material is easily mobilized by running water and thus sensitive to locally concentrated rainfall during summer storms. Intense erosion and scree remobilization occurred in Val dal Botsch, in the Piz Nair area, and Val Cluozza (Fig. 17.1) in summer 2014, with substantial accumulations in the depositional fans below the transport channels. In Val dal Botsch aggradation locally exceeded 2 m in a single event (Fig. 17.7).

In the current climatic conditions, dolomitic rocks, especially when interbedded with gypsum or *Rauhwacke* in tectonically stacked and therefore highly deformed situations, produce spectacularly collapsing slopes caused by intense physical erosion. Typical examples are the uppermost part of Val Vallatscha at the easternmost limit of the Park and Piz Daint to the south of Pass dal Fuorn. In both cases, the lithology of the rocks involved are the Raibler-Beds and the geometry of the strata (dip slopes on Piz Daint) is crucial.

The position of the Engadine Valley is set by the Engadine Line, which cuts the mountains to a depth of over

Fig. 17.6 Extensive scree slopes, typical morphological element of the Engadine Dolomites. Physical weathering of dolomitic carbonates favors their formation (photo H. Lozza)

Fig. 17.7 Voluminous scree formations easily remobilized during heavy rainfall, producing considerable deposits further downvalley (Val da Botsch July 2014 flooding) (photo C. Schlüchter, 2015)

Fig. 17.8 The high Macun plateau, view to the north, with lakes and rock glaciers (photo H. Lozza)

10 km. The Silvretta crystalline unit to the north of this lineament is part of the Austroalpine basement rocks—a complex succession of granites, gneisses, amphibolites, and ultrabasic rocks penetrated to the east by the Engadine Window of Penninic rocks (Fig. 17.2). At Zernez, the Engadine Valley turns to the north (Fig. 17.1) and cuts a multistep open gorge into the crystalline basement rocks of the Silvretta nappe. The Engadine Line and the present valley merge again at Scuol. The morphogenetic penetration of the river Inn to the basement rocks, thus abandoning the Engadine Line, is a major morphological dilemma in the SNP area, which remains unsolved. It is not merely coincidence that postglacial displacement along the Engadine Line has been mapped only four kilometers to the east of Zernez in the Val Laschadura (Schlüchter et al. 2013). The evidence for postglacial movement is given by "parasitic structures" with dextral orientation. Such observations make a tectonically controlled course of the northward bend of the river Inn the most likely explanation.

The SNP Macun exclave is in the crystalline Austroalpine basement rocks and is therefore not part of the Engadine Dolomites; as a consequence, it displays a different morphology. Macun has a complex multi-cirque morphology containing a wide plateau in the center with about 40 shallow small lakes and ponds (the so-called Macun "*Seenplatte,*" Fig. 17.8) at an average elevation of about 2,625 m a.s.l. The surrounding mountain crests are pointed and sharp, with an unnamed peak to the south of Piz Macun being the highest point with 3,046 m a.s.l. The high Macun plateau is open to the north where surface waters drain directly to the Engadine Valley.

At the Last Glacial Maximum (LGM), the area of the SNP was almost completely covered by glacier ice. The main valley glacier descending the Engadine Valley from the Engadine Ice Dome was joined by a second ice lobe through the Valley of Livigno. At Piz Mezdi in the Macun mountains the Engadine Valley Glacier reached an elevation of 2,820 m a.s.l. Glacial striae at Il Jalet (directly south of the Pass dal Fuorn) at 2,300 m a.s.l. clearly indicate ice flow across the pass toward the Val Müstair. The cirques developed around the high peaks of the Engadine Dolomites show that local ice joined the main ice streams above 2,800 m a.s.l. (Florineth 1998). Glacial morphological terms have an interesting significance in the Romansh language: **Munt** la Schera (=Mountain la Schera), **Mot** Tavrü, or **Mont** in some dialects mean an "easy to climb" mountain top, which has been moulded by glacial erosion, producing a rounded topography. In contrast a **Piz** (d'Arpiglias) is a pointed peak: its morphology is exclusively controlled by frost weathering and it has not been overridden by a glacier. The exact position of the trimline as the morphological marker of maximum elevation of glacial erosion is difficult to determine in the Engadine Dolomites. Fortunately, in the Macun mountains made of crystalline rocks glacial erosional features are better preserved. The glacially scoured lower valleys and mountain slopes are a prominent contrast to the "unpolished" rock walls above around 2,800 m of the Engadine Dolomites. Constructive glacial landforms are rare in the area of the SNP, most likely due to active morphological shaping of the mountains during the retreat of the LGM glaciers. In a few high mountain cirques moraines from unknown Lateglacial or Early Postglacial local

Fig. 17.9 A periglacial specialty at Macun: the "salami boulders," which move slowly downslope, depending on the moisture content of the soil matrix (photo C. Schlüchter)

readvances are present. Despite the fact that they are rare, they document multiple local glacier advances. The most characteristic examples are in Val dal Botsch and Val da Stabelchod, west of Piz Nair, between 2,300 and 2,600 m a.s.l.

The high mountain areas above the forests and continuous grasslands of the SNP are world famous for periglacial landscape elements as pioneering work was carried out here on such features and processes (see Gärtner-Roer and Hoelzle, this volume).

After the discovery of rock glaciers in the Alps, André Chaix started a general survey of this landscape element in the SNP in 1917 (Chaix 1923). It was also here that displacement rates of rock glaciers were measured over decades (Eugster 1973) and the rock glacier in Val Sassa inspired Jäckli (1978) for a model-case in soil mechanics (for a review of the importance of the SNP for research on permafrost and rock glaciers in Switzerland, see also Gärtner-Roer and Hoelzle, this volume). Measurements on creep in rock glaciers over the past 30 years show a marked reduction in displacement rates, which is of interest in the context of climate warming. Rock glaciers have been mapped in most of the high valleys in the Park. Exceptionally well-developed successions of inactive and active examples are around the peaks of Macun (Fig. 17.8). The high Macun plateau displays unique periglacial features, the so-called "salami boulders." Boulders of several cubic meters in original size decompose into slab-shaped slices through differential soil creep as a function of mainly soil moisture and slope angle. A simple precondition for this peculiarity to occur is the gneiss lithology of the boulders (Fig. 17.9).

An example of well-developed and widespread periglacial features are the earth lobes (Fig. 17.10), for example on Munt la Schera, and the delicate slopes with terracettes on Margunet, east of Piz dal Fuorn (Fig. 17.1). The earth lobes on Munt la Schera are monitored continuously. Furrer (1954) did a first study on the processes involved. The solifluction landforms are favored by bedrock lithology (Engadine Dolomites), which produces large quantities of scree and by the inner-Alpine continental climate with strong annual temperature and humidity gradients. Recently, Keller (2013) produced a map of the periglacial facies associations in the SNP based on climate modeling and field surveys.

Fig. 17.10 Example of solifluction landforms to the north of Pass dal Fuorn (western slope of Munt de la Bescha, view north toward Chaschlot) (photo C. Schlüchter)

Snow avalanches and their geomorphic effects in gullies and in the corresponding run-out areas are the high-energy version of periglacial processes. Repeated avalanche activity has caused sustainable interaction between surface geology and vegetation. An example is still visible in Val da Barcli, just west of the SNP boundary, where a destructive avalanche moved downhill from the southern slopes of Macun in 1999.

Deep valleys constitute another striking landscape element in the SNP. Some of them are deeply cut gorges, mainly around the western park border: Spöl River below Lake Ova Spin or Lower Cluozza and Fuorn up to Punt la Drossa. The northeastern boundary of the SNP to the south of Scuol follows the river Clemgia which flows for several kilometers in a morphologically active gorge in the dolomite rocks. The upper reaches of the rivers are largely characterized by open, braided channel systems (Fig. 17.11) with substantial sediment input from lateral tributaries. These rivers are an important landscape element enjoyed by visitors, who recognize them as unspoiled wilderness (Fig. 17.12).

17.4 Conclusions

The SNP is characterized by landscapes of contrasting beauty: the high rock walls and the pointed peaks (Piz) of the Engadine Dolomites versus the rolling hills of the Fuorn Valley leading to the Pass, the deeply cut valleys and gorges of the lower parts versus the open and broad upper valley floors, the high mountain periglacial and bare rock areas versus the forest of the lower slopes and the Mots, Munts, and Monts, the mountains smoothly eroded by the glaciers of the last ice age. The Macun exclave is a landscape of its own in the crystalline rocks of the Silvretta, contrasting sharply with the sedimentary bedrock landscape in the heartland of the SNP. In addition, it represents a unique cirque plateau of lakes and ponds, with exceptional periglacial features. To explain the course of the Engadine Valley bending around the mountains of Macun and leaving the tectonically predetermined direction of the valley remains a challenging and open geomorphological question in the larger area of the SNP.

Fig. 17.11 Braided river (in low-energy mode) in the Swiss National Park, Upper Val dal Botsch (photo C. Schlüchter, 2016)

Fig. 17.12 The rivers in the National Park are an important element of unspoiled wilderness (photo H. Lozza)

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