Geomorphic Hazards in Austria

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Abstract

Endogenic and exogenic geomorphic processes of different types and spatiotemporal dynamics can be observed within the territory of Austria. If these processes affect assets such as exposed buildings or infrastructure lines, they turn into hazards. In particular in the mountainous parts and in the Alpine foreland geomorphic hazards of different magnitude and frequency have repeatedly led to economic losses and fatalities. Together, the mountains and the Alpine foreland account for approximately 70% of the Austrian territory. Consequently, geomorphic hazards are an important issue in Austria. In the following, a brief overview of the major types of these hazards and their characteristics is given, including river and torrential flooding, gravitational mass movements, snow avalanches, hazards associated with glaciers and permafrost, as well as seismic hazards. Furthermore, information on the temporal and spatial occurrence of major event types and associated losses is provided.

Keywords

Flooding • Gravitational mass movements • Snow avalanches • Soil erosion • Glacier hazards • Permafrost hazards • Seismic hazards

6.1 Introduction

Mountain areas are typically characterized by steep slopes, which can result in highly dynamic geomorphic processes such as landslides and other gravitational mass movements, sometimes also triggering further hazards in combination with cascading processes, leading to multi-hazard threats (Kappes et al. 2012). At the same time, significant proportions of mountain regions are used for human settlements with associated economic and transport infrastructure, which may be at risk from geomorphic processes. The latter is particularly true for Austria, dominated by high mountains on one hand, and relatively densely populated on another one.

Following Varnes (1984) and Fell et al. (2008), a natural hazard in the geomorphic context is rooted in either endogenous or exogenous processes, where the first generally result in an increase and the latter in a decrease in relief, both endangering any exposed element at risk. A geomorphic hazard, therefore, represents the potential interaction between the landscape processes and their impact on the human environment (Keiler and Fuchs 2016).

With respect to geomorphic processes, the description of hazard should include the locality, volume (or area), classification, and velocity (or pressure). Hence, information is required on its probability of occurrence within a given period of time for a specific location, referred to as frequency, and on magnitude, which refers to scientifically based measures of the strength of physical processes. If measures of magnitude concern impacts of an event on the anthroposphere (such as elements at risk exposed to natural hazards), intensity is used instead (Giles 2013). Assessments

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are repeatedly based on intensity estimates that incorporate human variables as indices of destruction, since direct measurements of process magnitude are often not available with respect to those geomorphic hazards which occur in mountain regions (van Westen et al. 2006).

In Austria, hazards of flooding, gravitational mass movements, snow avalanches and soil erosion can be found, as well as hazards associated with glaciers and permafrost and finally those connected with seismic activity (Embleton-Hamann 2007). In the following, a brief overview of the characteristics of these hazards is given, reflecting on some recent insights into the distribution and the influence of environmental change with a focus on the Austrian Alps and the Alpine foreland. Afterwards, a brief overview illustrates the consequences of these geomorphic hazards in relation to the human environment.

6.2 Characteristics of Hazards and Their Distribution in Austria

The spatial distribution of geomorphic processes inducing damage for hydrological hazards, landslides, rockfall and snow avalanches is shown in Fig. 6.1. Landslides are prominent along the Alpine margins within the Flysch zone composed from sandstones and shale/mudstones. Rockfall and snow avalanches are typical geomorphologic processes in the mountainous parts of Austria, while hydrological hazards (river flooding and torrential flooding) are relatively evenly distributed, with an increasing density in the mountainous areas.

6.2.1 River Flooding

A flood is a relatively high flow which overtaxes the natural channel provided for the runoff (Chow 1956) and is usually described in terms of its magnitude and frequency. The importance of a flood relative to smaller flows in shaping channel and valley morphology is dependent on the magnitude and duration of the hydraulic forces generated during the high discharge in comparison with the erosional resistance of the channel boundaries (Wohl 2004). Floods are related to or triggered by heavy or prolonged rainfall and rapid snowmelt, ice jams or ice break-up, damming of river valleys by landslides or avalanches, and the failure of natural or man-made dams (Arnell 2002). In hazard management in the European Alps two types of river flooding are distinguished: static and dynamic. Static flooding occurs in areas with relatively flat topography (Fig. 6.2). Water levels rise slowly and flow velocity is very low, if the water is moving at all. The damage caused by static flooding is regularly due either to the influence of the water on existing structures or on agricultural production. In dynamic floods, the water movement is much more rapid and affects the elements at risk due to erosion or direct impact of sediment load (Parker

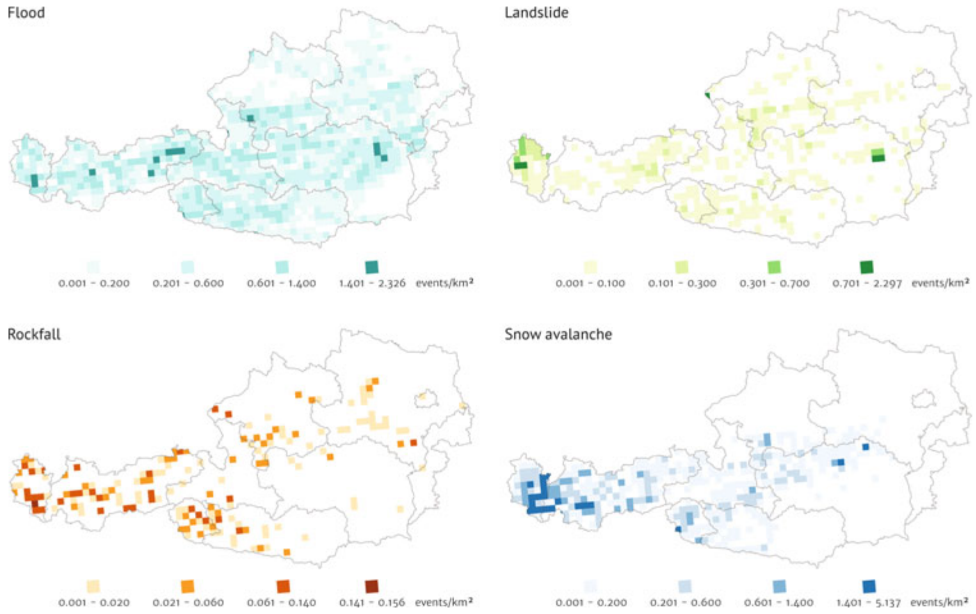

Fig. 6.1 Spatial distribution of geomorphological hazards causing damage between 1850 and 2014 in Austria, upper left: hydrological hazards, upper right: landslides, lower left: rockfall, lower right: snow avalanches. The grid cell size is 8000 × 8000 m. This material was originally published in 'Challenges for natural hazard and risk management in mountain regions of Europe' by M. Keiler and S. Fuchs, and has been reproduced by permission of Oxford University Press [https://oxfordre.com/naturalhazardscience]

Fig. 6.2 Static inundation along the Danube, Austria: flood event of August 2002. *Picture credits* Austrian Armed Forces, with permission

2000). According to the United Nations (2002), floods are among the most common, most costly and most deadly hazards world-wide. Barredo (2009) estimated an average annual loss of approximately 3.4 billion € due to major flood events over the period 1970–2006 in Europe. Flood events in Austria are observed as a result of prolonged heavy rainfall, sometimes in combination with (seasonally unusual) snowmelt in high-mountain regions, and can be recorded along all rivers of the country. As a result, the exposure of elements at risk is significantly high. According to Fuchs et al. (2015), almost 220,000 buildings are exposed to river flooding, which equates to 9% of the entire building stock in the country. The majority of these buildings are commercial buildings located in the floodplains along larger rivers.

6.2.2 Torrential Flooding

Mountain torrents repeatedly lead to debris flows and hyperconcentrated flows due to the considerable amount of sediment being transported either from the catchment downstream or eroded from the stream bed (Wohl 2004, see Fig. 6.3). Sediment load ranges from clay-sized particles to boulders measuring several metres in diameter. The destructive nature of mountain torrents is a result of the high density, combined with flow velocity and discharge (Fuchs et al. 2008). A general classification can be made depending on the relative concentration of water, fine and coarse sediment, as first suggested by Phillips and Davies (1991).

As defined by the Austrian Standards Organization in document No. 24800 (Austrian Standards 2009), debris flows are highly concentrated mixtures of water, fine and coarse sediment, and frequently woody debris (Mazzorana and Fuchs 2010). The coarse sediment is usually concentrated in the upper layers and at the front of the flow. The sediment concentration reaches values up to the plastic limit, but is often between 40 and 70% by volume. The specific bulk density of the mixture amounts to 1.7–2.4 kg/m^3. The flow is characterized as unsteady and non-uniform, and debris flows typically occur as surges (e.g. Pierson 1986). The flow behaviour is generally termed 'non-Newtonian', indicating that standard hydraulic models are not capable of describing the flow satisfactorily. The event volumes of debris flows vary considerably between several thousand to some hundred thousand cubic metres. Debris flows can be roughly classified due to the relative concentration of fine and coarse sediment by the prefix 'viscous/muddy' or 'granular/stony' to describe the main flow behaviour (e.g. Takahashi 1991).

The term hyperconcentrated flow was originally used for streamflow with sediment concentrations between 20 and 60% by volume (Neall 2004), and rheologically the fluid appears to be slightly plastic but flows like water (Pierson and Costa 1987). Consequently, hyperconcentrated flows possess fluvial characteristics, yet are nonetheless capable of carrying very high sediment loads.

Alpine settlements are often located in the run-out area on torrential fans, and as such an estimated 112,000 buildings are exposed to torrential flooding, most of them belonging to the category of residential buildings, hotels and guest houses as well as agricultural buildings (Fuchs et al. 2015).

6.2.3 Gravitational Mass Movements

Gravitational mass movements are defined as the downward and outward movement of slope-forming material under the

Fig. 6.3 Dynamic flooding of Trisanna river in Kappl, Austria, after the flood events of August 2005. *Picture credits* Austrian Armed Forces, with permission

influence of gravity and not requiring other moving agents such as water, air or ice. The term landslide is often used synonymously for any mass movement phenomena. However, in a pure sense, the term landslide is understood as a generic term describing downward movements of slope-forming material as a result of shear failure occurring along a well-defined shear plane (Dikau 2004). Gravitational mass movements are common natural hazards in mountain regions (Crozier 1999). Landslides are often connected to triggers such as heavy rainfall, rapid snow melting, earth tremors, slope undercutting, etc. Their impact on society ranges from low (small and shallow landslides in remote regions and less used areas) to high (collapse or burial of buildings and infrastructure, loss of life and loss of agricultural land). Although large magnitude landslides have a low probability, these events tend to result in significant loss of human life throughout Europe's mountain regions (Kilburn and Pasuto 2003). Society contributes to the occurrence of landslides (e.g. through land-use change, road construction involving slope undercutting or loading) as well as exacerbating the impact of the events by the construction of properties on steep slopes. Several classifications of mass movements have been published (e.g. Varnes 1978; Hutchinson 1988; Cruden and Varnes 1996), and most of them are based on morphology, type of material involved, mechanism of movement and rate of motion (Fig. 6.4). Falls, topples and rotational as well as translational slides can be found throughout the country, apart from flows and—quite rarely—large rock slides (Bergstürze). Whereas the first types are relatively frequent, reflecting the geology of Austria, rock slides are rather non-contemporary phenomena (Embleton-Hamann 2007).

Deep-seated and shallow landslides are common in many regions of Austria, in particular in those areas situated in the Flysch unit (Vorarlberg, Lower Austria and Styria) and areas of the Central Alps comprised of metamorphic rock types (phyllites and mica schist) (Fig. 6.5). Both deep-seated and shallow landslides are discussed in more detail in Chapter "The Walgau: A Landscape Shaped by Landslides". Moreover, shallow, often translational landslides, may also be associated with Quaternary deposits and weathered nappes.

As reported by Abele (1974), the total number of processes of the Bergsturz type is higher in the Northern and Southern Limestone Alps than in the crystalline Central Alps, which may be a result of the different weathering behaviour (for details, see Chapter "Giant "Bergsturz" Landscapes in the Tyrol"). In terms of volume, the Bergstürze of Köfels, Fernpass and Dobratsch are among the ten largest within the European Alps (Embleton-Hamann 1997); the latter is discussed in Chapter "Dobratsch—Landslides and Karst in Austria's Southernmost Nature Park". The Bergsturz of Köfels is the largest to have occurred in the crystalline Alps. Generally, Late Pleistocene glacier retreat resulting in an unbalanced relief due to oversteepened slopes was assumed to be the dominant Bergsturz trigger. More recent studies, however, suggest a rather continuous temporal distribution of landslide activities, with (i) some peaks of activity in the early Holocene at about 10 500–9 400 cal BP (calibrated years before present, present = 1950) and (ii) in the federal state of Tyrol a significant increase of deep-seated rockslides in the Subboreal at about 4200–3000 cal BP (Prager et al. 2008). Accordingly, Heuberger (1966) dated the Köfels Bergsturz as an early Holocene

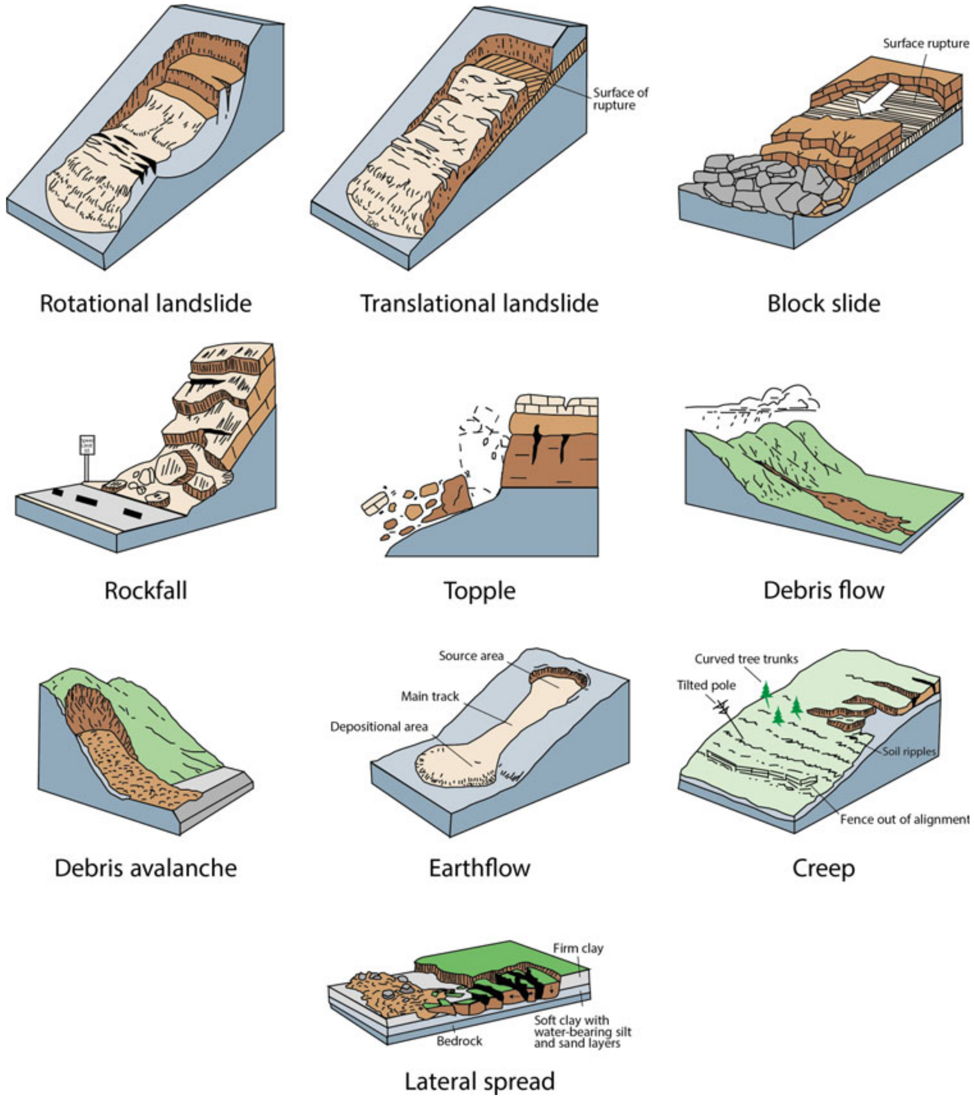

Fig. 6.4 Schematics illustrating the major types of landslide movement (Department of the Interior/USGS, with permission)

event at around 8710 ^{14}C years BP, whereas more recent dating suggests an age of 9527–9498 cal BP (Nicolussi et al. 2015). The new dating of the Köfels Bergsturz is close to the less well constrained age of the Flims landslide in the east of Switzerland. Flims is the largest Bergsturz in the Alps and is located 130 km west of Köfels. Thus, this near-synchronicity of these Bergstürze raises the question of a possible common trigger such as a strong earthquake (Nicolussi et al. 2015).

6.2.4 Snow Avalanches

Snow avalanches are a well-known hazard type related to snow. They are defined as the sudden release of snow masses and ice on slopes and may contain a certain proportion of rocks, soil and vegetation; the dislocation on the trajectory is thereby more than 50 m downhill (Wilhelm 1975). Due to the speed of the moving mass, snow avalanches can be distinguished from creeping and gliding movements of snow. A number of classifications of snow avalanches exist, developed in different countries and based on different classification principles (e.g. Kuroda 1967; de Quervain et al. 1981; Dzyuba and Laptev 1984). De Quervain et al. (1981) suggested a scheme to classify avalanches according to their release type, the shape of the trajectory and the type of movement, which is still used by the majority of scientists and practitioners in the field (Table 6.1). The snowpack evolution, from the beginning of solid precipitation accumulation until the snow cover melt, is crucial in relation to the release of snow avalanches. The conditions that lead to the release of avalanches and also a possible increase in avalanche hazard are often pervasive, but the prediction of individual avalanche events is extremely

Fig. 6.5 Landslide in Gasen/Haslau, Central Alps, c. 35 km northeast of Graz, in August 2005. *Picture credits* Arben Koçiu, Austrian Geological Survey, with permission

Table 6.1 Morphological avalanche classification system (de Quervain et al. 1973; Fuchs et al. 2019)

Zone	Criterion	Characteristic and denomination	
Origin	Manner of starting	From a point	From a line
		Loose snow avalanche	*Slab avalanche*
	Position of failure layer	Within the snowpack	On the ground
		Surface-layer avalanche	*Full-depth avalanche*
	Liquid water in snow	Absent	Present
		Dry-snow avalanche	*Wet-snow avalanche*
Transition	Form of path	Open slope	Gully or channel
		Unconfined avalanche	*Channelled avalanche*
	Form of movement	Snow dust cloud	Flowing along ground
		Powder snow avalanche	*Flowing snow avalanche*
Deposition	Surface roughness of deposit	Coarse	Fine
		Coarse deposit	*Fine deposit*
	Liquid water in deposit	Absent	Present
		Dry deposit	*Wet deposit*
	Contamination of deposit	No apparent contamination	Rock debris, soil, branches, trees
		Clean deposit	*Contaminated deposit*

difficult due to the high spatial variability and transient/dynamic nature of the snowpack (Schweizer et al. 2003). As a result, however, whole valleys may be endangered by snow avalanches during a winter season (Fig. 6.6). Different mechanisms of snow avalanche formation correspond to different volumes, repeatability and dynamic characteristics of the events (McClung and Schaerer 2006). In general, snow avalanches start from terrain that favours snow accumulation and is steeper than about 28°–60° (McClung and Schaerer 2006). On terrain inclined less than about 15°, snow avalanches start to decelerate and finally come to a stop.

Regarding the release type, snow avalanches are classified into two main groups: loose snow avalanches and slab

Fig. 6.6 Search and rescue team of the Austrian Armed Forces after the avalanche event of February 1999 in Galtür, Austria. *Picture credits* Austrian Armed Forces, with permission

avalanches. Loose snow avalanches are released from a more or less definable point in a relatively cohesionless surface layer of either dry or wet snow (Fuchs et al. 2015). The elements at risk are affected by the air pressure plume in front of the avalanche and/or by the high impact pressure of the snow in motion. Slab avalanches, in contrast, involve the release of a cohesive slab over an extended plane of weakness. Typically, natural slab avalanche activity is at the highest soon after snowstorms because of the additional load of the deposited snow (Schweizer et al. 2003). The existence of a weak layer below a cohesive slab layer is a prerequisite for the development of dry snow slab avalanches. This weak layer is either buried surface hoar or the result of metamorphism in the snowpack; during this metamorphism the properties of the snowpack change. Crystals formed by kinetic grain growth such as surface hoar or depth hoar (Fierz et al. 2009), together with changes in response to temperature and variability in water vapour gradients, can also be accompanied by formation of solid and icy layers on top of the snowpack. Such surfaces restrict the connection of new-fallen snow with the older snow below the solid layer and often form the horizon at which the snow masses start to move downhill. Slab thickness is usually less than 1 m, typically about 0.5 m, but can reach several metres in the case of large, disastrous avalanches (Bründl et al. 2010).

Exposure to snow avalanches is mainly a challenge in the western part of Austria and almost 10 000 buildings are at risk (Fuchs et al. 2015). Additionally, snow avalanches result in temporary road closures and in the interruption of train connections.

6.2.5 Soil Erosion

Water and wind can erode, transport and eventually redeposit soil. The initial impact of raindrops can break soil aggregates into primary particles by the translation of kinetic energy from the drops to the soil aggregates. Due to the influence of gravity, more soil particles are splashed downslope than upslope, and detached particles are splashed further downslope. The cumulative effect is a net downslope transfer of soil particles, known as splash erosion (Torri and Borselli 2011). When rainfall intensity exceeds soil infiltration capacity, runoff occurs. If flowing water concentrates in surface depressions, it incises into the soil and where the flowing water concentrates in shallow channels, rill erosion starts and may continue to the development of gullies (Fullen and Catt 2004). There is consensus among scholars that the distinction between these two forms of erosion is scale: while rills are incised into the topsoil (the A horizon), gullies are deeper and incise into the subsoil or parent material (the B or C horizons). As reported by Embleton-Hamann (2007), soil erosion has increased in Austria during the last decades as a result of intensification of agriculture and around 12% of the agricultural area in Austria has been classified as 'erodible land' (Strauss and Klaghofer 2006).

Focusing on geomorphology, the most prominent examples of soil erosion include the formation of large gullies and sunken roads ('Hohlwege') on loess soils of Lower Austria, which can be found especially in the wine-growing region of the Wagram, a distinct terrace landscape stretching east of the city of Krems along the Danube river (see Chapter

"Sunken Roads and Palaeosols in Loess Areas in Lower Austria: Landform Development and Cultural Importance" for details).

Less prominent, but still important, are shallow eroded areas, also known as 'Blaiken'. These usually have a size between 2 m^2 and 200 m^2 and a depth between a few decimetres and 2 m (Laatsch and Grottenthaler 1972; Schauer 1975) and are defined as phenomena where a loss of vegetation cover or topsoil has exposed the underlying, often unconsolidated material. Even if these erosion forms are relatively small in dimension, they nevertheless affect larger areas in the Austrian Alps and therefore lead to substantial material transfer. Moreover, a general destabilization of slopes results from 'Blaiken', leading to second-order processes such as an increase in snow gliding and a general increase in erosion activity, which in turn deepens and widens the initially limited dimensions of these shallow eroded areas (Wiegand and Geitner 2013).

Since the interactions between highland and lowland have a high relevance in mountainous areas and very often the highland is seen as the main cause of intensified hazardous conditions in the lowland, soil erosion is one of the main sources for sediment being further transported during flood events in mountain and foreland rivers. Therefore, it is crucial to avoid soil erosion, in particular on agricultural land. Practices such as mulch and direct seeding are promising, and the aim of these measures is to maintain a complete soil cover throughout the whole year. Soil management systems with reduced tillage intensity in combination with cover crops during winter are further effective solutions for reducing soil erosion brought about by water (Klik and Eitzinger 2010).

6.2.6 Glacier Hazards

Glaciers are accumulations of snow and ice on the surface of the Earth as a result of temperature and precipitation, covering high elevations in the Alps where the annual amount of snowfall (predominantly during the cold season) outweighs the annual amount of snow melt (predominantly during the warm season). Spatial and temporal variability of snow cover and snow depth are strongly related to regional and local precipitation patterns and temperature regimes, both parameters interacting with the terrain (Fuchs et al. 2015, 2019). Under these conditions, consecutive annual snow layers develop. The pressure of these layers forces snow at depth to change structure and density (recrystallization), first producing firn (density of 0.400–0.830 kg/m^3) and, when pores are sealed off to create air bubbles, ice (density of 0.830–0.917 kg/m^3, Stroeven 2004). When ice is thick enough to deform plastically under its own weight, glacier flow occurs, which is an effective erosive agent and has been responsible for shaping alpine valleys and producing distinct surface forms such as cirques, U-shaped valleys and moraines (Benn and Evans 2010).

From a geomorphic point of view, two major glacier hazards can be distinguished: (i) ice avalanches resulting from collapses and falls from glacier tongues and (ii) hazards related to glacier meltwater, such as a high sediment concentration of different grain size distribution in mountain torrents and glacial lake outburst floods (GLOFs). Ice avalanches are relatively scarce in the Austrian Alps but there are many records for the latter hazard type (Embleton-Hamann 2007). Hazards related to glacier meltwater are primarily determined by snowmelt and thus by spring temperature (Stewart 2009) and, during summer, also by ice melt of the glaciated areas. Glacifluvial processes are omnipresent in many catchments of the Austrian Alps and include erosion, transport and deposition, leading to the origin of new landforms or remodelling of existing ones. The type, rate and effectiveness of meltwater erosion are influenced by the nature of the basal substrate (sediment and bedrock), meltwater supply and pathway, and sediment supply (Brennand 2004). Recent studies have analysed the evolution of glacial lakes in the Austrian Alps since the Little Ice Age (Buckel et al. 2018). The latter study indicates that the formation of new glacial lakes is strongly related to glacier retreat and increasing temperatures, especially in the last 35 years, but also the local topography of the deglaciated area supports or counteracts the lake formation. Recently, GLOF hazards have received more attention since there may be increasing evidence of new proglacial lakes being formed as a result of glacier retreat, such as in the case of the Grindelwald Glacier in the Swiss Alps (Huggel et al. 2012) or in some of the high-mountain regions of Tyrol and Salzburg in Western Austria (Emmer et al. 2015). With respect to observed GLOFs, Aulitzky et al. (1994) and Embleton-Hamann (2007) reported two periods within historical time when relatively frequent lake outbursts were recorded, towards the end of the seventeenth century and during the nineteenth century, with a maximum in the 1860s. The outburst of some of these floods was related to supraglacial lakes and others related to marginal lakes dammed by glacier ice, such as the Rofener Ice Lake and the Gurgler Ice Lake in the Ötztaler Alps (see Chapter "The Upper Ötz Valley: High Mountain Landscape Diversity and Long Research Tradition" for details).

Major landforms giving the appearance of the Austrian Alps as a whole originate from the last (Würmian) glaciation, such as the glacial basins of the former outlet glaciers along the northern Alpine margin covered by lakes today and the associated large (terminal) moraines further northwards, as well as the associated fluvioglacial sandars (outwash plains), such as the 'Münchener Schotterebene' along parts of the northern Alpine margin (see Fig. 6.7). These

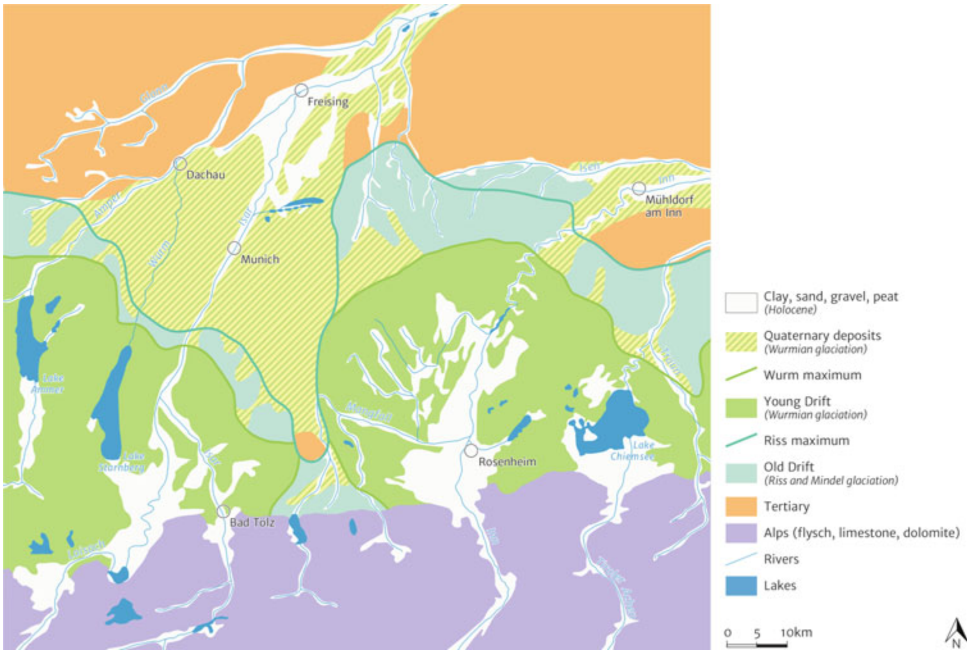

Fig. 6.7 Geological overview of the Munich region with Alpine margin, Young and Old Drift and the 'Münchener Schotterebene' (based on GK500 Bavaria)

landforms are valuable sources for palaeoenvironmental studies and may be a source for hazard types associated with sediment erosion and transport, such as dynamic flooding.

6.2.7 Permafrost

Permafrost is defined as ground (soil or rock) that remains below 0 °C for at least two years, and the term is defined purely in terms of temperature rather than the presence of frozen water (Harris 2004). As a result, apart from modelling its spatial distribution, permafrost is only detectable indirectly by assessing the distribution of distinct surface forms, such as rock glaciers, perennial snow patches and the occurrence of protalus ramparts. In the Austrian Alps, permafrost may occur at elevations higher than 2500 m asl, amounting to around 2% of the area of the territory or approximately 1600 km^2. According to a modelling exercise by Ebohon and Schrott (2008), most of the permafrost is located in the mountains of Tyrol (taking up 9.82% of the area of this province), followed by Salzburg (2.76%), Vorarlberg (1.90%) and Carinthia (1.65%). It has repeatedly been reported that mountain regions affected by permafrost could turn into hazardous areas due to warming associated with climate change (Harris et al. 2003, 2009; Haeberli 2013), resulting in melting of sub-surface ice and a subsequent destabilization of material. Hazard types may include any size of rockfall, such as those events observed during the summer of 2003 throughout the European Alps (Huggel et al. 2012), or changes in debris flow activity in mountain catchments (Sattler et al. 2011). Moreover, constructions in the Alps may suffer from melting permafrost, such as pillars of cable cars, snow rakes in avalanche starting zones and buildings. To give an example, the alpine hut 'Hochwildehaus', located at 2883 m asl in the Inner Ötz Valley east of the Gurgler Glacier, had to be closed in 2016 due to structural damage resulting from movements due to permafrost melt.

6.2.8 Seismic Hazards

Seismic activity in Austria is predominantly linked to alpine tectonics. Present-day tectonics of the Eastern Alps is characterized by strike-slip faulting regimes in a complex transition zone between the European, the Pannonian and the Adriatic stress provinces. Manifestations of vertical as well as horizontal stress decoupling within the orogen are due to a thermally and mechanically weakened crust. Differential vertical uplift derived from repeated precise levellings relative to the reference point in the Bohemian massif can be observed in western Austria including the Tauern Window, and subsidence, on the other hand, in the Vienna Basin and in the Styrian basin. This behaviour of vertical motions is related to the effects of isostatic response to active plate convergence and strain partitioning as well as to rebound occurring in response to Quaternary deglaciation and ice-induced erosion (Székely et al. 2002).

The list of major historical Austrian earthquakes includes 73 events for the period 1201–1978 (Drimmel 1980). According to the underlying statistics, a strong earthquake with a maximum intensity higher than 8.0° MSK (the Medvedev-Sponheuer-Karnik scale, also known as the MSK, is a macroseismic intensity scale used to evaluate the severity of ground shaking on the basis of observed effects in the fault area) occurs every 46.3 years, with a maximum intensity higher than 7.0° MSK every 8.5 years and a maximum intensity higher than 6.0° MSK (the limit of strong earthquakes) every 1.56 years. The identified seismotectonic fault lines include the Vienna Basin, the Mur-Mürz Valley fault contributing to the origin of the Vienna Basin, the Inn Valley (in particular at the intersection with the Wipptal disturbance) and the Lavant Valley fault zones (Aric et al. 1980; Grünthal et al. 1998). In parts of the Vienna Basin striking southwards to the Mur-Mürz tectonic disturbance, the so-called Thermenlinie is of considerable importance for seismic activity in the country, and around 50% of the seismic activity is registered in this area that is 250 km long and around 30 km wide (Embleton-Hamann 2007).

Even if strong earthquakes are rare in Austria, some major events have been reported starting in the thirteenth century. The so-called Neulengbacher earthquake of 15 September 1590 caused considerable damage and some lost lives in Vienna. Another earthquake with an intensity of 8.0° MSK occurred on 8 October 1927 in Schwadorf east of Vienna (the Vienna international airport 11/29 runway terminates there). On 7 October 1930 a 8.0° MSK earthquake resulted in heavy destruction in the village of Namlos (Tyrol), and on 3 October 1936 a 7.0°–8.0° MSK event was recorded at Obdacher Sattel (Styria). Finally, on 16 April 1972 a strong earthquake in Seebenstein (around 70 km south of Vienna) resulted in considerable losses in the city of Vienna. Further strong earthquakes have not been recorded so far in Austria (Grünthal et al. 1998). Nevertheless, some of the ground movements led to second-order consequences and can be interpreted in terms of multi-hazards (Kappes et al. 2012). Among them, the Puchberg earthquake of 1939 can be connected to the Losenheim rock avalanche, and the well-known Friuli earthquake of 1348 resulted in the Dobratsch Bergsturz (see Chapter "Dobratsch: Landslides and Karst in Austria's Southernmost Nature Park"). As a result of the 1976 Friuli earthquake, numerous smaller mass movements (mainly falls and topples) were reported to occur in Carinthia (Grünthal et al. 1998).

6.3 Consequences of Geomorphic Hazards

In the European Alps, an increase in the frequency and magnitude of geomorphic hazards and associated losses has repeatedly been claimed (i) as a result of increasing exposure of elements at risk (Fuchs et al. 2015, 2017), (ii) to be due to natural fluctuations in hazard occurrence (Schmocker-Fackel and Naef 2010) and (iii) due to the effects of climate change affecting triggers of these hazards (Huggel et al. 2012). In Fig. 6.8, the annual number of geomorphic hazardous events causing losses in Austria is shown for the period 1900–2014 with respect to snow avalanches, torrential flooding, landslides and river flooding, as well as the 10 years moving average of the total number per year. While between 1900 and 1959 an increase in the annual number of hazard events of around a factor of four can be concluded—presumably also due to an improved event observation—between 1960 and 1964 a decrease of around 50% is traceable, followed by an increase due to the excessive events in 1965 and 1966. Since then, the 10 years moving average steadily decreased again, which is in line with the increasing efforts invested in technical mitigation measures since the mid-1960s (Fuchs 2009; Holub and Fuchs 2009). Due to the high number of hazard events in 1999, 2002, 2005 and 2009, however, the curve is once more increasing to around 440 events per year. During the period of investigation, specific years with an above-average occurrence of individual hazard types can be traced, for example with snow avalanches in 1951, 1954, 1999 and 2009, torrential flooding in 1965, 1966, 2005 and 2013, and river flooding in 1904, 1959, 1966 and 2002. The trend reported in Fig. 6.8 is in clear contrast to the trends repeatedly presented for world-wide data and indicating an exponential increase in the number of events since the 1950s (Keiler 2013). Apart from hazard dynamics (the natural frequency and magnitude of events), decreasing dynamics in mountain hazard losses may result from (i) increased investments into technical mitigation (Holub and Fuchs 2009), (ii) an increased awareness of threats being consequently considered in land-use planning (Wöhrer-Alge 2013), both

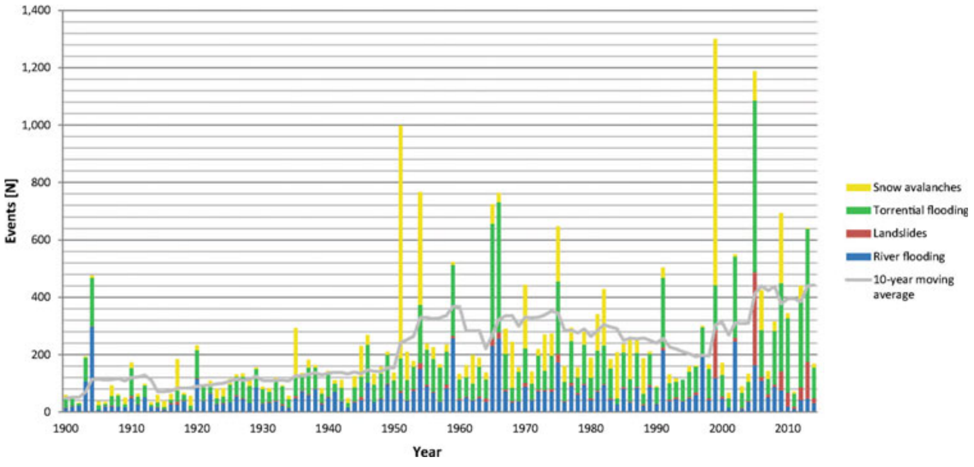

Fig. 6.8 Annual number of documented natural hazards causing losses in Austria (Fuchs et al. 2015, with permission)

leading to less exposure and (iii) decline in vulnerability (Jongman et al. 2015). Apart from the ongoing discussion of the effects of climate change influencing the hazard triggers (e.g. Auer et al. 2007; Keiler et al. 2010; Lung et al. 2013), the effects of dynamics in exposure have so far not been sufficiently studied in the context of a possible influence on dynamics of geomorphic hazards (Keiler and Fuchs 2016).

In general, the main challenge of risk reduction is rooted in the inherently connected dynamic systems driven by both geophysical and social forces, leading to the call for an integrative management approach based on multi-disciplinary concepts that take into account different theories, methods and conceptualizations (Fuchs and Keiler 2013).

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