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ORIGINAL ARTICLE

Granite Landform Diversity and Dynamics Underpin Geoheritage Values of Seoraksan Mountains, Republic of Korea

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Abstract

Seoraksan Mountains in the Republic of Korea are presented as an area of outstanding geodiversity combining rock-controlled granite landforms, inherited cold-climate landforms and highly active contemporary geomorphological processes. Three generations of granites, ranging in age from Proterozoic to Cretaceous, are present and each of these supports distinctive morphology. Cretaceous granites are associated with most spectacular features such as domes and towers, fins, long rock slopes, and fluvial gorges. The latter host abundant waterfalls of different types, potholes, and bedrock channels. While no clear glacial landforms exist in Seoraksan, widespread blockfields, blockslopes, and blockstreams constitute the cold-climate legacy of potentially important palaeoclimatic significance. Slope steepness and extreme rainfall events are the decisive factors to explain frequent mass movements which leave visible erosional and depositional evidence on slopes and in valley floors. The geodiversity of Seoraksan makes the area highly suitable for outdoor geo-education and it is also argued that the area represents a highly diverse, non-glaciated mountainous geomorphological system that integrates source and sink areas and is of exceptional value and extraordinary scenic beauty.

Keywords Granite landforms · Geodiversity · Rock control · Viewpoint geosites · Seoraksan

Introduction

Within the general concept of geoheritage, the major interest is implicitly on inherited geological and geomorphological features which record various events from the history of the Earth (Reynard and Brilha 2018). Furthermore, these features are often fragile and at risk of irreversible transformation or even complete loss due to either natural processes or, perhaps more often, human activities. Thus, evaluation of geoheritage values typically goes hand in hand with conservation initiatives and proposals, aimed at designing best strategies to preserve valuable geological localities as they are (Prosser et al. 2013, 2018; Larwood et al. 2013; Gordon et al. 2018). This past-oriented and conservation-driven approach needs to be refined in dynamic mountainous environments, especially in the so-called "high mountains." In these settings, ongoing surface geomorphic processes considerably modify the physical landscape and as far as the scenery is concerned, rather little testifies to the distant geological past. In many specific cases in mid- to high latitudes, glacial landforms dominate the scenery but even these usually date back to the late Pleistocene. In such mountain environments, the contemporary geodiversity rather than the variety of inherited features is often considered decisive for the geoheritage value (Panizza 2009; Giardino et al. 2017; Coratza and Hobléa 2018). However, some mountain ranges, even if they were glaciated in the Pleistocene, retain their pre-Quaternary geomorphic features at both macro (e.g., remnants of elevated surfaces of low relief) and medium scale (e.g., tors and blockfields), formed under long-term controls of geological setting and climate change (Slaymaker and Embleton-Hamann 2009, 2018; Hall et al. 2013; Gunnell 2015). Thus, mountain geomorphological landscapes are inherently complex and this needs to be reflected in both geoheritage and geodiversity assessment (Thomas 2012; Gordon 2018).

In this paper, our focus is on one of the highest mountain ranges of the Korean Peninsula—Seoraksan Mountains, located in the north-eastern part of the Republic of Korea. Its biodiversity and esthetic values have long been known and appreciated, including the establishment of a National Park in 1970 and a UNESCO

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Fig. 1 The granite landscape of Seoraksan is typified by deeply incised valleys with bedrock channels and steep rock slopes dissected into a network of narrow ridges and ravines (photograph by P. Migoń)

Biosphere Reserve in 1982. However, while biological conservation is clearly a priority, geoheritage values are both under-researched and apparently less promoted, despite the outstanding scenery (Fig. 1). Consequently, there are two main reasons to present the Seoraksanstudy. First, rather little is known about the geodiversity of the Korean Peninsula in general. While the outstanding geoheritage of Jeju Island, in part inscribed as UNESCO World Heritage and also recognized as UNESCO Man and Biosphere Reserve and UNESCO Global Geopark, is well recognized internationally (Woo et al. 2013); limited information is available about the various mountain ranges within the Peninsula, with recognition and appreciation of geomorphology lagging behind an interest in the rock and palaeontological record (see Kim 2008). The northern part of the Peninsula is even less known, although scattered and dated publications leave no doubt that the mountainous environments there are spectacular (Lautensach 1945). Second, Seoraksan is a textbook example of granite mountainous scenery, with a combination of structural, fluvial, periglacial, and mass movement-related features that represent outstanding geodiversity and thus, is claimed to have significant geoheritage value. Consequently, the aims of this contribution include presentation of the extraordinary diversity of geomorphological features through the most representative examples, discussion of inheritance versus dynamics in the context of geoheritage, and outlining perspectives for popularization of geoheritage, with special focus on viewpoint geosites and management of a dynamic landscape.

Study Area

Location and Main Traits of Relief

Seoraksan is located in the middle of the Korean Peninsula, in the northern part of the Republic of Korea, overlooking the shores of the East Sea (Sea of Japan) (Fig. 2). It belongs to the coastal mountain range of Taebaek which runs along the eastern side of the Korean Peninsula in a NNW–SSE direction (Jo 2000). The highest peak, Daecheongbong, rises to 1708 m a.s.l. and several others exceed 1500 m a.s.l. No evident topographic boundaries of Seoraksan exist on either the northern or southern side. The mountainous terrain continues both towards the south and the north, although reaching slightly lower altitudes of 1000–1500 m a.s.l. In accordance with overall tilting of the Taebaek range to the west, Seoraksan shows some topographic asymmetry. Mt. Daecheongbong is located in the eastern part of the mountains and elevation drops sharply to the east, to the narrow coastal plain (2–3 km wide in the south, 5–10 km in the north), whereas to the west, it decreases gradually. West-facing drainage basins are therefore larger and more complex.

Seoraksan represents "classic" mountainous topography with narrow, often sharp-crested ridges separated by numerous deeply incised valleys (Fig. 3). The first-order topographic feature is a c. 30-km-long ridge of west-east extension which forms the morphological axis of the mountain area and includes all the highest peaks which exceed 1600 m a.s.l. It drops steeply to the south, to the WNW–ESE aligned valley system controlled by the strike of the Hangyeryeong Fault, beyond which a slightly lower (maximum elevation 1518 m a.s.l. at Garibong), southern part of Seoraksan extends. The backbone of the northern part of Seoraksan is a sinuous and, in sections, extremely rocky ridge running from Mt. Daecheongbong to the NNW, towards Hwangcheolbong (1381 m). Numerous secondary ridges and intervening short but steep valleys account for the considerable erosional dissection of the whole range. Gross geomorphic features of Seoraksan, as well as the predominance of bedrock channels in the range and uneven stream long profiles (see below), suggest that the area has experienced geologically recent

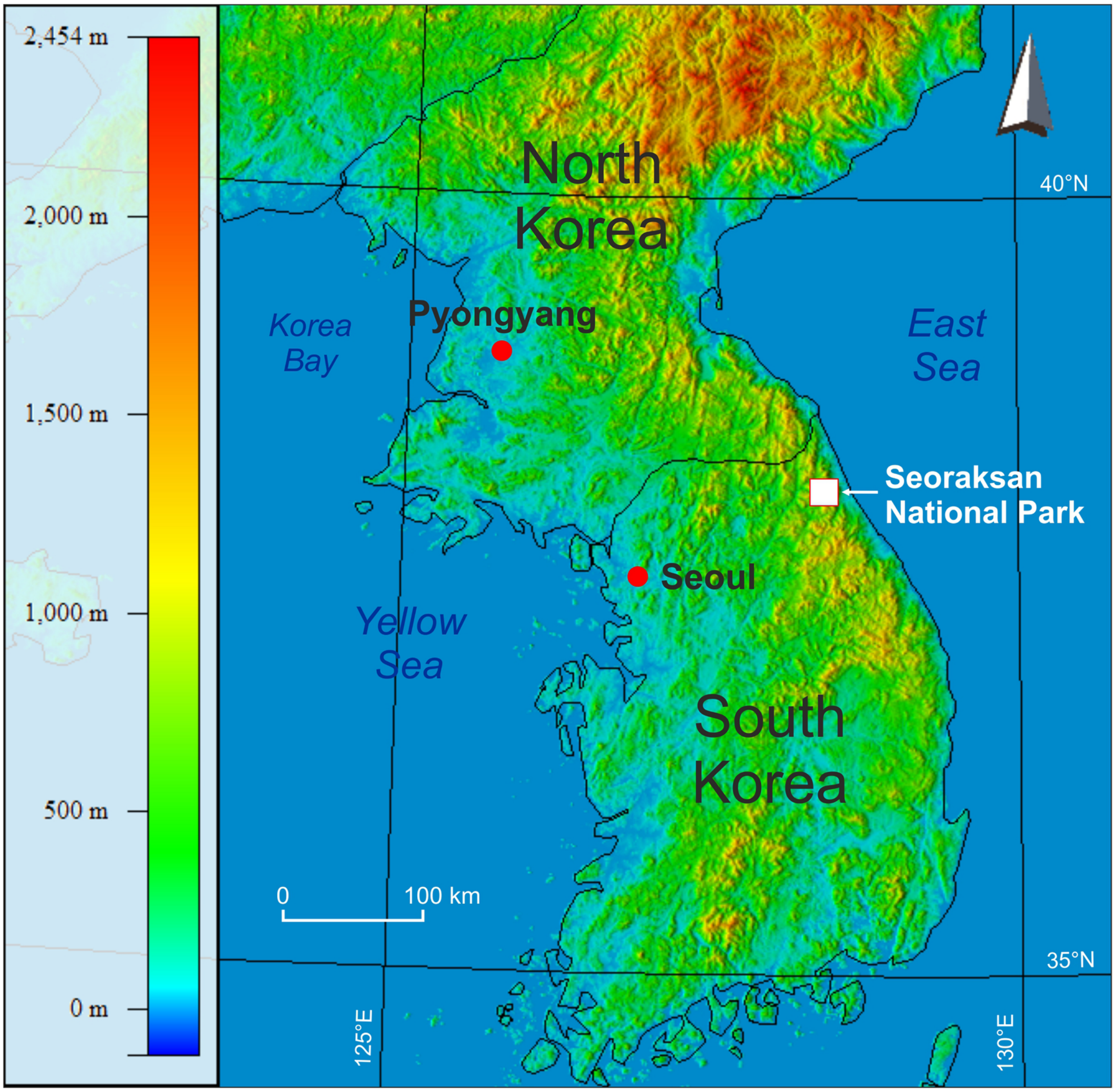

Fig. 2 Location of Seoraksan within the Korean Peninsula

uplift that accounts for its considerable elevation and terrain steepness. Unfortunately, no independent data are available to constrain this process.

Geology

Seoraksan is built of various igneous and metamorphic rocks which differ in age and record different stages of geotectonic evolution of the Korean Peninsula. Three main generations of rock complexes can be distinguished, of Proterozoic/early Paleozoic, Jurassic and Cretaceous age, respectively, with granites being an important component of each complex (Kee et al. 2010). Proterozoic rocks are represented by gneisses, subordinately by quartzites and amphibolites, intruded by a few lithological variants of granites. Due to subsequent deformation, the latter have acquired certain features of metamorphic rocks such as foliation and banding. The next generation of granites, collectively known as the Daebo Granites, is of Jurassic age. Zircon Pb-U ages for these granites range from 170 to 190 Ma (Kee et al. 2010). These are mainly biotite and two mica granites, equigranular, with medium to coarse texture, and locally weakly foliated. The youngest granites are of Cretaceous age and date from about 88 Ma. Again, several lithological variants are present, including coarser Seoraksan granites, with porphyritic texture and locally with large (a few cm long) potassium feldspar crystals, and finer Gwittaegicheong granites which form localized occurrences (stocks) within the more widespread Seoraksan granites. In the northern part of the National Park, where blockfields and blockslopes abound, quartz-feldspar porphyry is widespread. Stratigraphically, the Jurassic and Cretaceous granites are separated by clastic and volcanic rocks of the Baekdam Group which occur in the central-north part of Seoraksan (Kee et al. 2010).

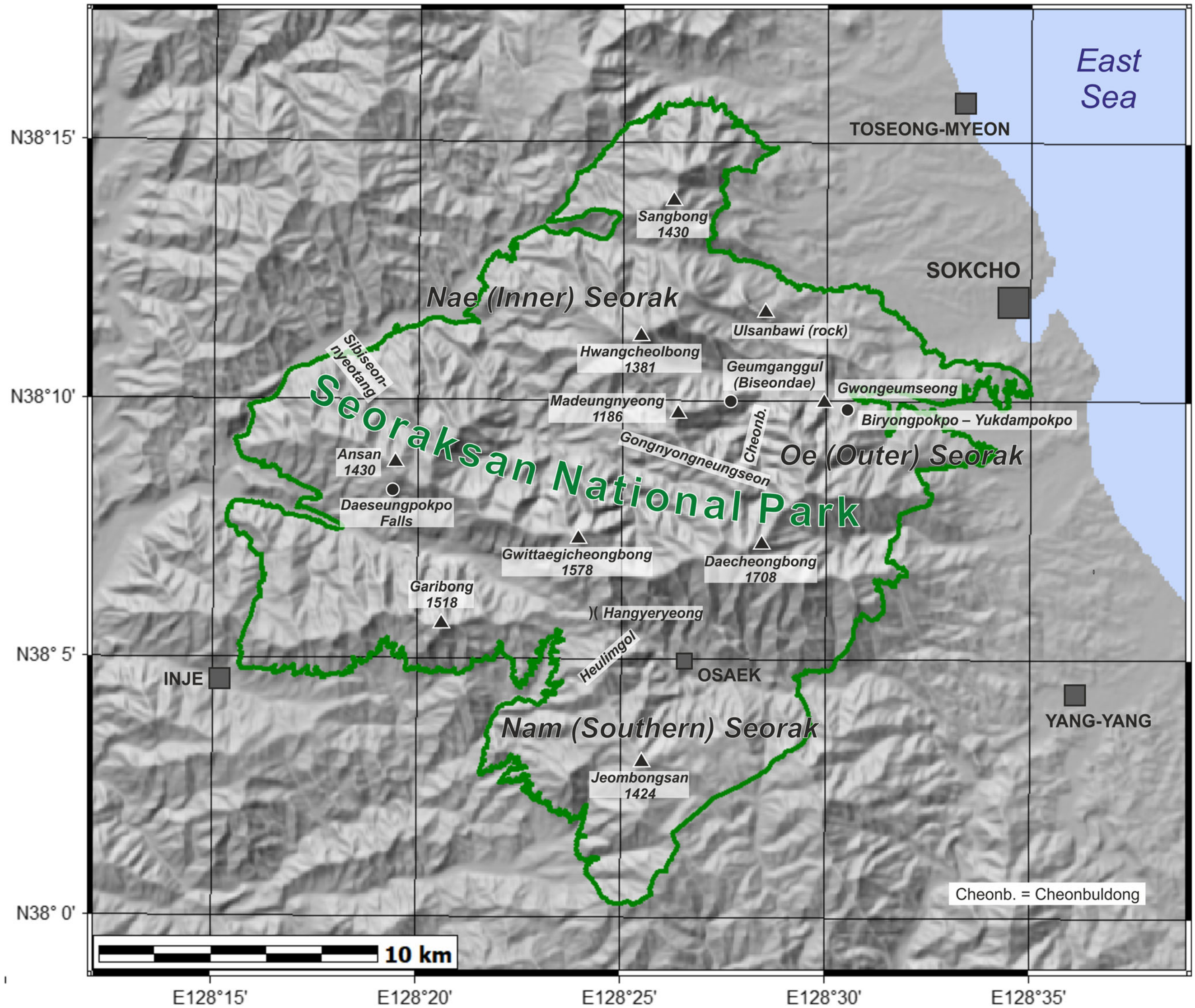

Fig. 3 Relief of Seoraksan and adjacent areas. White line shows the boundary of the National Park. Source: USGS (2004), Shuttle Radar Topography Mission, 3 Arc Second scene SRTM

Several major faults have been mapped around Seoraksan, trending NE–SW, NNE–SSW, and WNW–ESE and partly coincident with morphological boundaries of the mountain range. They are strike-slip faults and interpreted as multi-phase, active during the Mesozoic (Kee et al. 2010). However, their late Cenozoic reactivation is likely, considering the geomorphological characteristics of Seoraksan.

Granite Landforms and Key Geosite Localities

Structural Landforms

Structural (or rock-controlled) landforms are understood as those which owe their morphological characteristics to the properties of the bedrock itself, including its lithological features, discontinuities, orientation of strike and dip (if applicable), and juxtaposition of different rock types. While the role of exogenic processes to make the structure visible is obvious and each fluvial erosional landform in a rock-cut channel or a periglacial landform reflects bedrock control, the focus here is on relationships between rocks, granites in this particular case, and denudational landforms. Seoraksan is a most suitable location to examine such relationships due to the close occurrence of different variants of granite, good exposure, and wide vistas. Among the four localities considered below, Daecheongbong represents Proterozoic granites, whereas the remaining three are built of Cretaceous granite.

Daecheongbong

The summit part of Daecheongbong is not a classic geosite or geomorphosite. It is crowned by a mass of jointed bedrock outcrops and angular boulders which then give way to moderately steep but otherwise rather smooth, regolith-covered slopes, but the main value of the peak resides in an unobstructed panoramic view over the entire Seoraksan. Thus, it fits the category of viewpoint geosites (Migoń and Pijet-Migoń 2017). The view to the north is particularly noteworthy as it presents the contrast between smooth, largely forested slopes in the Proterozoic granites, and highly dissected erosional landscape in the Cretaceous Seoraksan granites, dominated by bare rock slopes and deep joint-guided ravines (Fig. 4a). The reasons for the different response of two rock complexes of similar composition to exogenic processes are attributed to the nature and density of discontinuities. Cretaceous granites are massive, with joint spacing from a few to > 10 m apart, and have tight fabric retarding granular disintegration and hence, regolith production. Following rock mass strength considerations (Selby 1980), very steep, weathering-limited slopes can be expected in such settings. The presence of narrow zones of dense fracturing (< 0.5 m apart) accounts for the origin of a network of ravines separating massive rock compartments. By contrast, Proterozoic granites have joint density in the order of 1–2 m and show evidence of foliation, which reduces rock mass strength, and easily yield to grain-by-grain breakdown. Therefore, not only the slopes are less inclined but regolith is produced more efficiently than mass wasting processes can evacuate it. Moderately steep slopes with occasional rock cliffs and tors typify the outcrop area of Proterozoic granites near water divides.

Ulsanbawi

Ulsanbawi is the most accessible among numerous granite monoliths in Seoraksan, reached by a marked trail from the main gateway to the Park in Oeseorak (meaning “the outer part of the Seoraksan Mountain”). The trail, equipped with ladders in the final part, allows visitors to get to the top of the mountain. Ulsanbawi is a steep-sided rock ridge built of the Seoraksan granite, c. 2 km long and 200 m wide, elongated NW–SE, and rising above moderately steep (c. 30°) regolith-covered slopes (Fig. 4b). Extension of the ridge follows regional discontinuities oblique to the main WNW–ESE trending faults, whereas perpendicular SW–NE joints divide the ridge into a number of individual compartments. However,

Fig. 4 Structural geomorphology of Seoraksan. **a** Contrast between smooth, regolith-covered, and largely forested slopes in Proterozoic granites (foreground and background right) and bare rock slopes in Cretaceous granites (background left) (view from Daecheongbong). **b** Granite monolith of Ulsanbawi, with overhangs and ledges testifying to rock slope failures. **c** Dome of Biseondae with curved surface-parallel fractures. **d** Rock fins separated by vertical joints along the Gongnyongneungseon ridge (all photographs by P. Migoń)

none of these joints has yet been hollowed out to form a ridge-cutting ravine. The rock slopes of Ulsanbawi are c. 150 m high. The massive primary structure of the monolith has allowed curved sheeting joints to develop and these, along with vertical discontinuities, govern the pattern of rock slope failures. Numerous scars and overhangs testify to the detachment of large volumes of rock, the complementary evidence being big boulders (as much as > 10 m long) scattered on slopes. In turn, degradation of the summit parts is controlled by the vertical joints and includes the development of clefts, separation of fins, and their eventual fall. Thus, Ulsanbawi is a very good example of both the geomorphic expression of a massive granite compartment amidst more jointed bedrock, the geomorphic role of joints, and the diverse patterns of rock slope degradation.

Biseondae

The triple dome of Biseondae is perhaps the best in Seoraksan, and certainly the most accessible type of a granite landform identified worldwide as the most characteristic for granites (Twidale 1982; Migoń 2006). It rises above the Cheonbuldong valley floor, with rock slopes reaching down to the bedrock channel (Fig. 4c). The total height of the dome is c. 250 m, with the western part being both the highest and most regularly shaped. The tripartite structure of Biseondae results from the presence of two zones of bedrock shattering, whereas the nearly perfect shape of the western dome is due to the paucity of vertical and horizontal joints. Instead, curved sheeting joints are prominent. Halfway up the rock slope, an artificially enlarged cavity of Geumganggul hosts a Buddhist shrine. The little observation deck at the entrance offers views over the Cheonbuldong Valley and towards Mt. Daecheongbong, complementing the view from the latter and showing the remarkable morphological contrast between two types of granites.

Gongnyongneungseon

This place name refers to the section of the ridge in the central part of Seoraksan which connects Mt. Daecheongbong in the south and Mt. Madeungnyeong in the north (Fig. 2). The ridge is accessible for hikers along a technically difficult trail which climbs or skirts consecutive granite peaks. While different shapes of granite residual peaks may be seen along the path, including domes, half-domes, conical peaks, and angular towers, the most characteristic are narrow fins (Fig. 4d). Fins, present mainly in the eastern part of the ridge, may be considered as equivalents of domes which have developed in places where vertical joints of one predominant direction are more closely spaced, whereas the perpendicular direction is under-represented. In such cases, there is little scope for curved unloading joints. Fins are characterized by high, nearly vertical walls 50–200 m high, facing two opposite directions, and a serrated crest line.

Fluvial Landforms

The fluvial morphology of Seoraksan is dominated by bedrock channels and high-energy, boulder-rich, braided channels. The former are particularly abundant in the headwater sections of valleys, although at many places, bedrock is concealed under recent debris flow deposits. Longitudinal stream profiles are very irregular, with multiple steps and more evident knickpoint zones. At the local scale, this fluvial assemblage certainly reflects the resistance of bedrock but it is also tempting to use it as an indicator of ongoing uplift of the area and incision in response. The most characteristic landforms testifying to ongoing incision are slot canyons and waterfalls. The latter are abundant and occur on streams of all sizes, in a variety of shapes, ranging from free falls for more than 50 m to steep chutes, and cascading staircases. Waterfalls are associated with potholes and other minor forms of bedrock erosion.

Sibiseonnyeotang

The name, which translates into "Twelve Fairy Bathing Springs," refers to the middle section of a valley in the westernmost part of Seoraksan, known for a string of potholes separated by chutes and waterfalls (Fig. 5a). The entire section, easily accessible via a hiking trail, is c. 300 m long, whereas the drop in elevation is c. 100 m. Potholes are of variable size and shape, from circular features a few meters across to elongated troughs more than 20 m long. Close to the downstream end of the reach, a double-step waterfall occurs, with a big pothole halfway down the drop. Above some potholes located in the thalweg, there are smaller landforms of this kind, probably activated during torrential flows generated by the summer monsoon rains and typhoons. The entire bedrock-cut reach has developed in an area where the resistant Cretaceous granite upstream contacts with apparently less resistant Jurassic granite downstream and, hence, waterfalls are lithology-controlled.

Cheonbuldong

The Cheonbuldong valley in the north-eastern part of Seoraksan is widely acclaimed as one of the highlights of the National Park for its impressive scenery, particularly in autumn. However, it also offers a spectacular collection of fluvial landforms which includes slot gorges, waterfalls, singular and strings of potholes, inclined rock slabs, and shallow rock-cut troughs. Among them, the slot canyon in the upper part of the valley deserves particular attention as the most accessible landform of this kind in Seoraksan. It is c. 100 m

Fig. 5 Bedrock fluvial landforms of Seoraksan. **a** Waterfalls and potholes in Sibiseonnyeotang. **b** Fracture-guided slot canyon in Cheonbuldong valley. **c** Daeseungpokpo Falls, the highest in Seoraksan. **d** Biryongpokpo Falls (all photographs by P. Migoń)

long and has a tight V-shaped cross-section (Fig. 5b). It is bounded by 60–80° inclined rock walls with densely spaced unloading joints. Two > 10-m-high waterfalls are present at either end of the slot. Controls on the occurrence of the canyon are structural. It follows a N–S zone of highly fractured rock.

Daeseungpokpo Falls

This is the highest waterfall in Seoraksan, with a single drop of 88 m (Fig. 5c), exposed for viewing from the observation platform in front of it, roughly at the height of the threshold. It is located within a minor tributary valley to the Jayangcheon trunk valley, the former beginning (upstream of the falls) only less than 2 km long upstream of the falls. Therefore, the amount of water is limited (which to some extent reduces the visual impact) and the threshold shows little evidence of dissection. However, Daeseungpokpo Falls is an excellent example of a knickpoint that separates a deeply incised, rejuvenated reach downstream, and a wide upstream section filled by thick boulder-dominated debris flow deposits. Both sections of the valley can be seen from a trail that connects the ranger station at Jangsudae in the main valley and Mt. Daeseungyeong in the main ridge.

Biryongpokpo Falls and Yukdampokpo Falls

These two easily accessible waterfalls close to the main tourist service area in Oeseorak offer contrasting examples of controls on waterfall origin. Biryongpokpo Falls is located further upstream and represents a single drop of 16 m into a large pool deepened by erosion. The origin of the falls is related to variable structural conditions along the stream length. The waterfall occurs at a spot where the stream leaves one heavily jointed and hence more erodible linear zone, makes a 90° turn and enters another jointed zone, parallel to the former. The fall is over the more massive threshold separating the two zones (Fig. 5d). Yukdampokpo Falls occur within a relatively straight reach, similarly over a more massive rock compartment. It consists of two parts: the upper one is a steep chute; the lower one is a free fall into a large erosional basin. Immediately upstream, two potholes separated by a series of rock slabs and a rock-cut trough indicate the presence of the same, less erodible zone across the valley.

Periglacial Landforms

During the Pleistocene, Seoraksan was not glaciated, or at least there is no unequivocal evidence for local glaciation. No evident cirques occur and none of the major valleys shows clear morphological features of glacial erosion (U-shaped cross-section, ice-molded hills). However, similar to some other Korean mountains (e.g., Rhee et al. 2017), a clear testament of cold-climate conditions is provided by extensive blockfields (products of in situ mechanical breakdown, with little subsequent movement) and blockslopes (some gravity-driven movement may have occurred) (Park 2000, 2003). Their occurrence is lithology-controlled. Practically, no blocky accumulations occur within coarse Seoraksan granites where the upper slopes are too steep to host blockfields anyway, whereas they are abundant in finer-grained and more jointed granite variants such as the Cretaceous Gwittaegicheong granite and in quartz-feldspar porphyry. Some metamorphic rocks support blocky accumulations too (e.g., along the main ridge west of Mt. Kkeutcheong), although these are almost entirely forested. Being located at rather low latitude and altitude, the blockfields of Seoraksan, although probably less scenic than other granite landforms, are equally valuable part of the regional geoheritage, possibly quite significant for palaeoclimatic research in East Asia.

Gwittaegicheongbong

The main ridge around Mt. Gwittaegicheongbong is extensively covered by blockfields which give way to blockslopes, especially on southwest-facing slopes (Fig. 6a). Individual blocks are up to 3 m long and the thickness of the cover is at least 2 m. Bedrock cliffs locally protrude through the blockfield. Many blocks stand in upright position and there are large, up to 1 m long, voids in between them. Nevertheless, blocks are generally stable which is consistent with fairly big weathering pits and pans developed on their upper surfaces. Some of these hollows are > 1 m long and 10–15 cm deep. Sections of bare blockslopes extend for up to 600 m and reach the bottoms of first-order valleys. Satellite images indicate minor relief within certain parts of blockslopes (stripes, furrows) but these cannot be seen from a trail that crosses the upper part of the blockfield.

Hwangcheolbong

North- and south-facing slopes of Hwangcheolbong in the northern part of Seoraksan host the most impressive and the most extensive blocky accumulations. Among the potential geomorphosites presented here, this is the only locality currently inaccessible, as the trail has been closed since 1991 for nature restoration. Nevertheless, the northeast-facing blockslope can be seen from a panoramic viewpoint on top of Ulsanbawi. Disregarding some forest patches within the blockslope, its entire exposed part occupies an area of 650 × 350 m (Fig. 6b). Bedrock cliffs, 2–3 m high, are present close to and across the ridge, accounting for its stepped profile. The blockslope itself is composed of angular fragments of variable size, up to 3 m long. Several topographic features suggest past cementation by ground ice and permafrost creep. These are closed elongated and linear hollows, lobate ramparts pointing downslope, and individual blocks in emerging position. Next to the main blockslope and east of it, block accumulations are confined to valleys and are distinctly elongated (= blockstreams), forming a branched pattern. These spatial relationships suggest the removal of fine material by throughflow and residual character of blocky accumulations which in turn points to a complex origin of blockfields in Seoraksan.

Sites Evidencing Contemporary Dynamics

Seoraksan is a very dynamic mountain environment. High rates of geomorphic processes result from the combined effects of high relative relief and abundant precipitation. The height difference between crest lines and valley floors is considerable, reaching the order of 1000 m or more over very short distances of 2–3 km, resulting in extremely steep slopes, where inclinations > 30° are the norm and sections > 50°, including nearly vertical rock slopes, are common. Annual precipitation is around 1200–1400 mm but a significant part of it comes as heavy summer rains with daily totals of the order of several hundred millimeters, and occasionally, Seoraksan is hit by a typhoon, with hourly intensities above 100 mm. In these circumstances, mass movements and torrential flows in channels are generated, capable of significant remodeling of the landscape.

The two most common mass movement processes are rock falls and debris flows, the latter transforming into hyperconcentrated flows within the channels and valley floors. These flows, given sudden generation by extreme rainfall, may be considered as flash floods in hydrological terms. Although both types are favored by geological conditions and rock properties, their triggers and geomorphic impact are different. Rock falls occur on very steep rock slopes which are subject to high tensile stresses, resulting in primary joint opening and the development of secondary unloading sheeting joints. Along these intersecting joint planes, large rock compartments are detached and move downslope. In this way, huge granite blocks fall, roll, or slide down, eventually reaching the footslopes or the valley floors. Debris flows, in turn, are distinctly weather-controlled phenomena and are initiated during typhoons on regolith-covered slopes. Movement typically starts with slow sliding of water-laden regolith over a

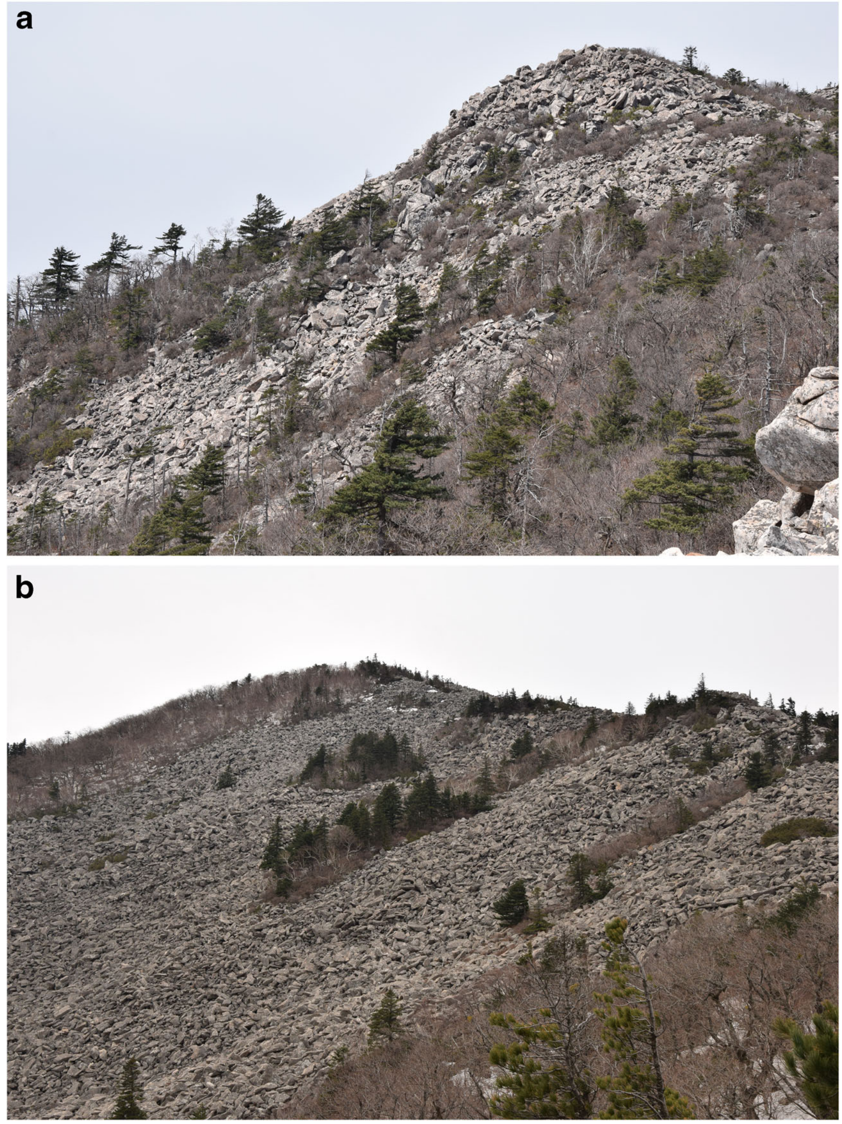

Fig. 6 Cold-climate heritage of Seoraksan. **a** Blockslopes below Mt. Gwittaegicheongbong. **b** Extensive blockfields and blockslopes at Mt. Hwangcheolbong. The irregular topography of the blockfields suggests modifications by permafrost creep (all photographs by P. Migoń)

steeply inclined sheeting plane and transforms into a flow after reaching a ravine or headwater valley. These debris-laden flows in Seoraksan may travel for many kilometers, completely transforming the pre-existing morphology of valley floors.

The visible evidence of mass movements and valley floor remodeling is ubiquitous in Seoraksan. The legacy of rock falls comprises scars and overhangs within rock slopes and chaotic blocky accumulations at the foot of rock slopes, including valley floors if there is direct slope-channel coupling. Debris slides leave exposed bedrock slabs within otherwise forested slopes, whereas subsequent flows produce big boulders scattered in the valley floors, lateral ridges (levees), and debris fans at the junction with a main valley. Exposed sequences of flow-related deposits may reach 10 m. Depending on the length of time that has elapsed since an event, these features are still bare or colonized by re-established vegetation. However, if trails or other infrastructure were affected, engineering work erases most geomorphic effects. Here, three representative localities in the southern part of the Park are characterized in more detail.

Osaek

Upstream from the hot spring resort of Osaek, the stream winds between granite towers and spurs built of massive Cretaceous Seorak granites. Vertical slopes connect the tops and rock benches with the valley floor and have been affected by frequent rockfalls. Their effects can be observed in the channel, in the form of numerous angular boulders, some up to 10 m, piled one upon another. Corresponding scars within rock slopes can be seen as well (Fig. 7a).

Hangyeryeong Pass

The trail from Hangyeryeong Pass to the main ridge climbs steeply through dense forest but from a few places upper sections of debris flow tracks may be seen (Fig. 7b). They provide a good illustration of the general mechanism, showing exposed, steeply dipping sheeting surfaces as the detachment area c. 25 m wide and a boulder-filled ravine below. Further up, the trail crosses the track of another debris flow, this time initiated within a low-angle, regolith-covered slope. Broken and transported tree logs can be still observed (Fig. 7c).

Heulimgol

The tributary valley of Heulimgol was completely re-shaped by a flood in 2009 and rehabilitated after 2012. The value of this locality, easily accessible due to its roadside setting, is thus not to see the effects of ongoing processes, as these have been erased, but the amount of work required to restore safety. The valley floor has been transformed into a box-shaped chute, with big blocks of local rocks used to stabilize the floor and the banks (Fig. 7d). However, a panel at the road bridge contains photographs indicating the scale of transformation due to debris flow and damage.

Dual Significance of Granite Landforms—Inherited Features and Ongoing Dynamics

Seoraksan provides an example of an area where inherited and contemporary geomorphological features combine into high-value geodiversity, additionally coupled with outstanding scenic attributes which directly bear on the area's popularity among tourists. It is not the only area for which such a combination was comprehensively documented and one might argue that each mountainous area is typified by a comparable association of values. However, in most examples, inheritance is linked with Pleistocene glacial legacy whose temporal context can be reasonably constrained by dating techniques. Examples include the Dolomites in Italy (Panizza 2009; Soldati 2010) and various other parts of the Alps (Bollati

Fig. 7 Evidence of contemporary geomorphological dynamics. **a** Huge boulders in the foreground are products of rock fall from precipitous valley sides directly into the channel (Osaek district of Seoraksan). **b** Scar left by regolith slide, transformed downslope into debris flow (above Hangyeryeong Pass). **c** Source zone of a debris flow (above Hangyeryeong Pass). **d** Channel rehabilitation after damage caused by a recent flood (Oeseorak district) (all photographs by P. Migoń)

et al. 2017; Giardino et al. 2017). In much fewer examples, both pre-Quaternary erosional history and Quaternary glacial inheritance are highlighted, such as in the Cairngorms, Scotland (Kirkbride and Gordon 2010; Hall et al. 2013). Non-glacial long-term evolution, much more problematic to date, is highlighted less frequently. Furthermore, contemporary dynamics is rarely addressed and its contribution to regional geoheritage, clearly focused on conservation, is either given a secondary role or, perhaps unintentionally, neglected.

Against this background, one can better evaluate the significance of Seoraksan's geomorphological heritage. Here, geomorphological inheritance is manifest not only in evidently "fossilized" features such as blockfields (although they probably should not be considered entirely relict—see Park 2000, 2003), but also in bedrock-controlled major denudational landforms such as domes, fins, and towers, which are products of long-term operation of exogenous processes, apparently in relation to ongoing, although poorly understood and constrained surface uplift. Likewise, minor erosional features such as waterfall steps and bedrock channels have their roots in the geomorphic history of the area. However, contemporary processes continue to shape these landforms, particularly through extreme geomorphic phenomena of rock and debris slides, debris flows, boulder falls, and floods. Separating inheritance from ongoing dynamics is neither feasible nor helpful in understanding and appreciating Seoraksan's geoheritage and the same is probably true for other non-glaciated mountain ranges which show considerable surface dynamics.

Seoraksan is an example of a predominantly granite geomorphological landscape and outstanding values of granite scenery in general have been emphasized many times. Leaving aside spectacular granite mountainous terrains glaciated in the past or at present, such as those of Yosemite (USA), Torres del Paine (Chile), Los Glaciares National Park (Argentina), or Serra da Estrela (Portugal), numerous non-glaciated granite mountains have long been appreciated for their physical landscape, even making their way into the UNESCO World Heritage List in recognition of their scenery, following the World Heritage criterion no. (vii). These include granite mountains of east China—Huangshan and Sanqingshan (Thomas 2010), prominent inselbergs massifs of the Namib Desert (Migoń 2010; Goudie and Viles 2015), or granite-gneiss domes in Rio de Janeiro (Fernandes et al. 2010). However, none of these examples highlights ongoing landforming processes as significant contributing agents. Other examples of granite landscapes of considerable value for geosciences such as those of south-west England (Dartmoor, Bodmin Moor – Campbell et al. 1998; Gunnell et al. 2013), Sardinia (Melis et al. 2017), Lower Austria (Huber 1999, Migoń et al. 2018), or the Mojave Desert, USA (Oberlander 1974), are more subdued and lack high-magnitude but short-duration geomorphic events which would considerably alter the scenery. Thus, in terms of current recognition and potential significance, Seoraksan can be considered as a benchmark terrain to demonstrate intertwining of inherited landforms and contemporary processes to shape granite scenery of outstanding scenic value which has never been shaped by glaciers.

Perspectives and Issues in Geoscience Outreach and Geo-education

Despite outstanding values, the geo-educational potential of Seoraksan is so far poorly exploited. Current outdoor interpretative facilities are almost entirely focused on biological values, ecosystem complexity, rare plant, and animal species. A few geomorphic localities, including several presented in this paper, have information panels focused on individual landforms such as waterfalls or peculiar boulders, but the stories told are local legends and tales rather than targeted attempts to enhance visitors' understanding. In other places (e.g., at Gwongeumseong and Gongyeongneungseon), large panels were erected but their information content is limited to naming peaks visible from these localities, nothing else. Another aspect is that many trails, accessible in the past, were closed due to long-term nature restoration projects and it is uncertain whether they will ever re-open. Among them, permanent closure of the Hwangcheolbong trail would be a particular loss since it shows the most impressive and varied examples of periglacial blockfields and blockslopes.

Commenting upon the deficit of interpretation of Seoraksan's geoheritage and geodiversity, it needs to be noted that erection of panels in the field is not necessarily the best option given technical difficulties in very steep terrain, paucity of suitable places, and negative impact on landscape esthetics. This applies to both exposed and valley-bottom settings. Mountain and ridge tops—viewpoint geosites sensu Migoń and Pijet-Migoń (2017)—are excellent locations to interpret the scenery, to highlight and explain rock control on landscape appearance, and to discuss spatial patterns of mass movements, since scars of depletion zones are often clearly visible and pathways of movement can be tracked down the valleys. Comprehensive interpretation, however, requires space and can hardly be reduced to a limited number of words, recommended in some theoretical considerations (Hughes and Ballantyne 2010; Macadam 2018). Large interpretation panels in open terrain would be very intrusive but also difficult to keep in good shape during harsh winter conditions. Likewise, too many panels cramped along a particular section of a valley are unlikely to make good impression. Therefore, downloadable mobile resources and information leaflets to be distributed at the beginning of trails and in National Park information centers would better suit the purpose and can be more tailored towards various categories of visitors with different levels of interest. Among various localities, the following are best suited to act as viewpoint geosites, developed towards interpretation of the whole scenery (Fig. 8): (1) the top of Ulsanbawi, (2) Gwongeumseong, (3) Geumganggul, (4) Gongnyeongneungseon, and (5) Daecheongbong (Fig. 4). However, at each of these sites, erection of large panels is not recommended for esthetic reasons, and at some, is not even physically possible (Geumganggul). Thematic geo-trails may focus on periglacial inheritance (Hangyeryeong to Gwittagicheongbong), fluvial bedrock erosion (Sibiseonnyeontang), and transformation of debris flows into “regular” river flow (Cheonbuldong valley to Oeseorak).

All initiatives towards popularization of geoheritage and geodiversity of Seoraksan may have one significant constraint, related to a theme argued to be significant for geoscientific value of the territory, i.e., contemporary geomorphic dynamics. Long sections of trails cross the terrain which is not only technically difficult but geomorphologically active, with impact on trail infrastructure. Processes affecting paths, boardwalks, and stairs include rock falls, slides, torrential/flash flood flows, and tree uprooting. In the last decade, several important trails had to be temporarily closed due to damage from geomorphic activity and some are closed for this reason at the moment. Critical sites are monitored, while in other spots, steep and potentially unstable rock walls have been artificially strengthened. However, the constant threat from surface processes may be also seen as an opportunity to increase knowledge about landscape dynamics, impact of natural events, their triggers, remedies, and countermeasures. In fact, in a few places, information panels recall specific events of this kind such as the collapse of an elevated boardwalk in Cheonbuldong Valley in 2007.

Conclusions

Seoraksan provides an excellent example of a mountainous terrain whose value and significance reside simultaneously

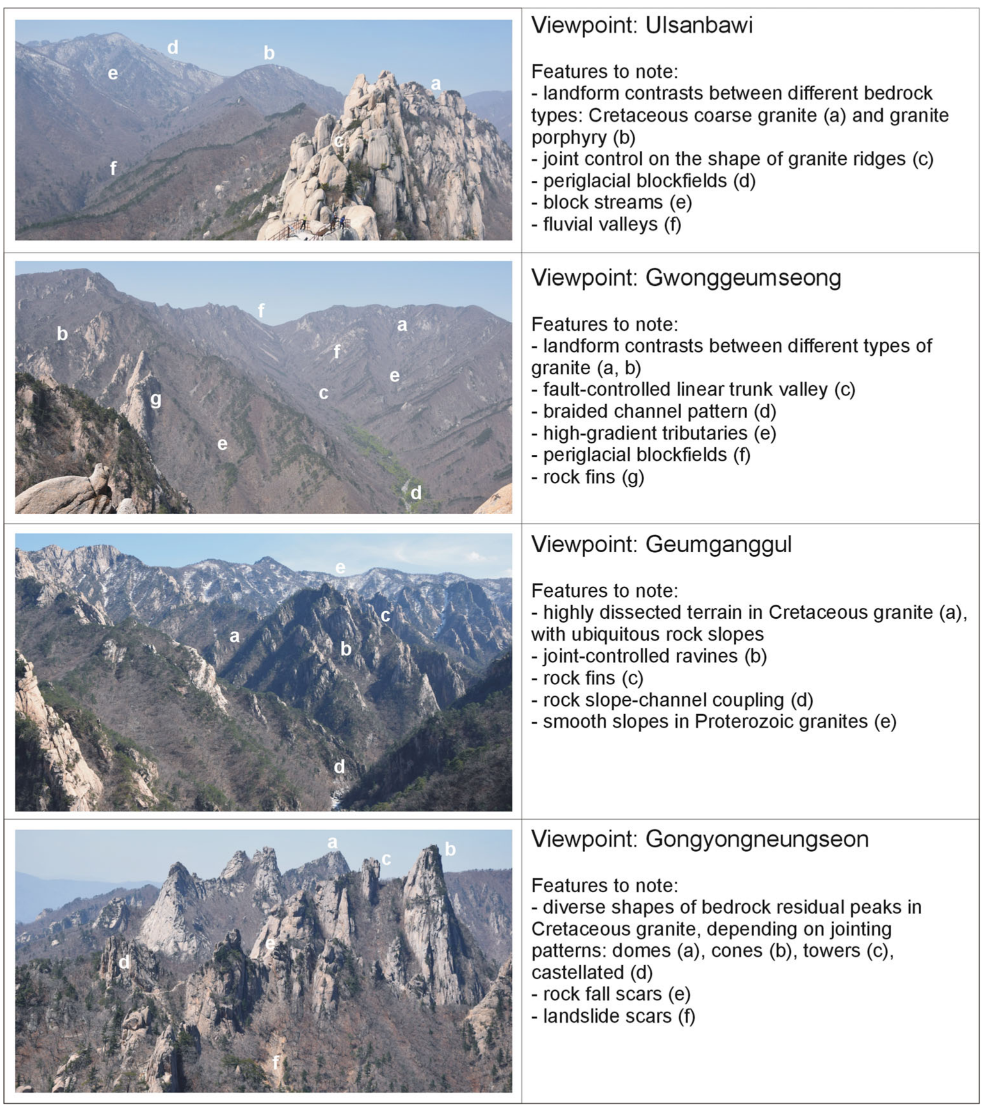

Fig. 8 Annotated panoramic views (parts of) from four viewpoint geosites in Seoraksan. The view from Daecheongbong is shown in Fig. 4a (all photographs by P. Migoń)

in both landform inheritance and contemporary geomorphological processes. The extraordinary geodiversity of the area, primarily geomorphological diversity, results from the combination of various regional and site-specific rock controls on landforms and processes, the presence of landforms formed over different timescales and subject to various pathways of remodeling under present-day conditions. Although never glaciated (at least, not re-shaped by glaciers to any evident extent), Seoraksan hosts numerous inherited landforms produced by cold-climate conditions as well as structural landforms whose assignment to certain narrowly-defined timespans does not seem possible. Therefore, referring to the conceptual issue of "significance" present at the interface of geosciences, and geomorphology in particular, and nature conservation and promotion (Migoń 2014), Seoraksan may indeed be considered as a highly significant representative of unglaciated, very dynamic granite mountain scenery, and possibly a "type geomorphic locality" for any comparative studies. Moreover, it is argued that strategies to develop geoeducation and more informed educational tourism should seriously consider this geological control—landform inheritance—contemporary geomorphological process triad which together explain the complexity of mountain landscapes, since Seoraksan is a most suitable place to explore these issues, also for general public.

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References

Bollati I, Pelfini M, Smiraglia C (2017) Landscapes of northern Lombardy: from the glacial scenery of Upper Valtellina to the Prealpine lacustrine environment of Lake Como. In: Soldati M, Marchetti M (eds) Landscapes and landforms of Italy, Springer, pp 89–99

Campbell S, Gerrard AJ, Green CP (1998) Granite landforms and weathering products. In: Campbell S, Hunt CO, Scourse JD, Keen DH (eds) Quaternary of South-West England. Chapman and Hall, London, pp 73–90

Coratza P, Hobléa F (2018) The specificities of geomorphological heritage. In: Reynard E, Brilha J (eds) Geoheritage. Assessment, protection, and management. Elsevier, Amsterdam, pp 87–106

Fernandes N, Tupinambá M, Mello CL, Peixoto MNO (2010) Rio de Janeiro: a metropolis between granite-gneiss massifs. In: Migoń P (ed) Geomorphological landscapes of the world. Springer, Berlin, pp 89–100

Giardino M, Mortara G, Chiarle M (2017) The glaciers of the Valle d'Aosta and Piemonte regions: records of present and past environmental and climate changes. In: Marchetti M (ed) Soldati M. Springer, Landscapes and landforms of Italy, pp 77–88

Gordon JE (2018) Mountain geodiversity: characteristics, values and climate change. In: Hoorn C, Perrigo A, Antonelli A (eds) Mountains, climate and biodiversity. Wiley, Chichester, pp 137–154

Gordon J, Crofts R, Díaz-Martínez E (2018) Geoheritage conservation and environmental policies: retrospect and prospect. In: Reynard E, Brilha J (eds) Geoheritage. Assessment, protection, and management. Elsevier, Amsterdam, pp 213–235

Goudie A, Viles H (2015) Landscapes and landforms of Namibia. Springer, Dordrecht

Gunnell Y (2015) Ancient landforms in dynamic landscapes: inheritance, transience and congruence in Earth-surface systems. Geomorphology 233:1–4

Gunnell Y, Jarman D, Braucher R, Calvet M, Delmas M, Leanni L, Bourlès D, Arnold M, Aumaître G, Keddaouche K (2013) The granite tors of Dartmoor, Southwest England: rapid and recent emergence revealed by Late Pleistocene cosmogenic apparent exposure ages. Quat Sci Rev 61:62–76

Hall AM, Gillespie MR, Thomas CW, Ebert K (2013) Scottish landform examples: the Cairngorms—a pre-glacial upland granite landscape. Scot Geogr J 129:2–14

Huber KH (1999) Zum Formenschatz der Granitverwitterung und –abtragung im nordwestlichen Waldviertel. In: Steininger FF (ed) Erdgeschichte des Waldviertels, 2nd edn. Waldviertler Heimatbund, Horn – Waidhofen/Thaya, pp 113–132

Hughes K, Ballantyne R (2010) Interpretation rocks! Designing signs for geotourism sites. In: Newsome D, Dowling RK (eds) Geotourism: the tourism of geology and landscape. Goodfellow, Oxford, pp 184–199

Jo W-R (2000) Geology and geomorphology. In: Kwon H-J, Huh WK (eds) Korea. The land and people. Kyohaksa, Seoul, pp 29–52

Kee W-S, Kim H, Kim BC, Choi S-J, Park S-I, Hwang SK (2010) Geological report of the Seoraksan sheet. Scale 1:50,000. Korea Institute of Geoscience and Mineral Resources

Kim YB (2008) Geoheritage of Korea. In: Leman MS, Reedman A, Pei CS (eds) Geoheritage of East and Southeast Asia. Lestari, Malaysia, pp 115–147

Kirkbride V, Gordon JE (2010) The geomorphological heritage of the Cairngorm Mountains. Scottish Natural Heritage Commissioned Report No 348 (ROAME No. F00AC104)

Larwood JG, Badman T, McKeever PJ (2013) The progress and future of geoconservation at a global level. Proc Geol Assoc 124:720–730

Lautensach H (1945) Korea. Eine Landeskunde auf Grund eigener Reise und der Literatur. K.F. Koehler-Verlag, Leipzig (reprinted as: Korea. A geography based on the author's travels and literature. Springer, Berlin 1988)

Macadam J (2018) Geoheritage: getting the message across. What message and to whom? In: Reynard E, Brilha J (eds) Geoheritage. Assessment, protection and management. Elsevier, Amsterdam, pp 267–288

Melis R, Di Gregorio F, Panizza V (2017) Granite landscapes of Sardinia: long-term evolution of scenic landforms. In: Soldati M, Marchetti M (eds) Landscapes and landforms of Italy, Springer, pp 351–363

Migoń P (2006) Granite landscapes of the world. Oxford University Press, Oxford

Migoń P (2010) Spitzkoppe: the world of granite landforms. In: Migoń P (ed) Geomorphological landscapes of the world. Springer, Berlin, pp 155–162

Migoń P (2014) The significance of landforms – the contribution of geomorphology to the world heritage programme of UNESCO. Earth Surf Proces Landf 39:836–843

Migoń P, Pijet-Migoń E (2017) Geo-interpretation at New Zealand's geothermal tourist sites – systematic explanation versus storytelling. Geoheritage 9:83–95

Migoń P, Różycka M, Michniewicz A (2018) Conservation and geotourism perspectives at granite geoheritage stes of Waldviertel, Austria. Geoheritage 10:11–21

Oberlander T (1974) Landscape inheritance and the pediment problem in the Mojave Desert of southern California. Am J Sci 274:849–875

Panizza M (2009) The geomorphodiversity of the Dolomites (Italy): a key to geoheritage assessment. Geoheritage 1:33–42

Park K (2000) Morphology and genesis of block fields on the Seoraksan National Park in Kangwon Province, Korea. J Korean Geogr Soc 35:653–663

Park K (2003) Block fields of Seoraksan National Park: age and origin. J Korean Geogr Soc 38:922–934

Prosser CD, Brown EJ, Larwood JG, Bridgland DR (2013) Geoconservation for science and society–an agenda for the future. Proc Geol Assoc 124:561–567

Prosser CD, Díaz-Martínez E, Larwood JG (2018) The conservation of geosites: principles and practice. In: Reynard E, Brilha J (eds) Geoheritage. Assessment, protection, and management. Elsevier, Amsterdam, pp 193–212

Reynard E, Brilha J (eds) (2018) Geoheritage. Assessment, protection, and management. Elsevier, Amsterdam

Rhee H-H, Seong YB, Jeon Y-G, Yu B-Y (2017) Bouldery slope landforms on Mt. Biseul, Korea, and implications for paleoclimate and slope evolution. Quat Geol 88:293–312

Selby MJ (1980) A rock-mass strength classification for geomorphic purposes: with tests from Antarctica and New Zealand. Z Geomorph NF 24:31–51

Slaymaker O, Embleton-Hamann C (2009) Mountains. In: Slaymaker O, Spencer T, Embleton-Hamann C (eds) Geomorphology and global environmental change. Cambridge University Press, Cambridge, pp 37–70

Slaymaker O, Embleton-Hamann C (2018) Advances in global mountain geomorphology. Geomorphology 30:230–264

Soldati M (2010) Dolomites: the spectacular landscape of the 'Pale Mountains'. In: Migoń P (ed) Geomorphological landscapes of the world. Springer, Berlin, pp 191–199

Thomas MF (2010) Sanqingshan: the incredible granite peaks of eastern China. In: Migoń P (ed) Geomorphological landscapes of the world. Springer, Berlin, pp 283–291

Thomas MF (2012) Geodiversity and landscape sensitivity: a geomorphological perspective. Scot Geogr J 128:195–210

Twidale CR (1982) Granite landforms. Elsevier, Amsterdam

Woo KS, Sohn YK, Yoon SH, Ahn US, Spate A (2013) Jeju Island Geopark – a volcanic wonder of Korea. Springer, Berlin – Heidelberg