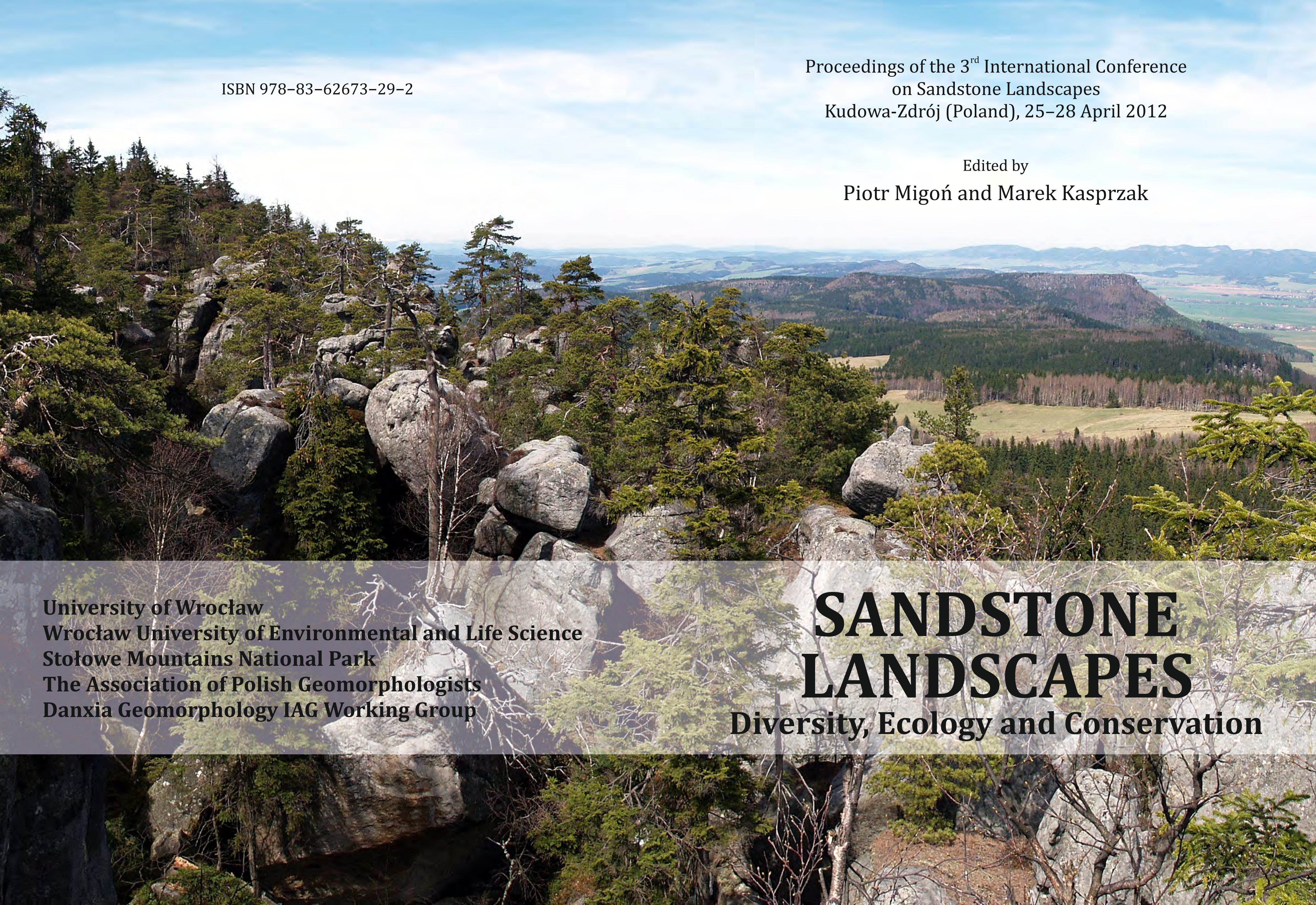

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on Sandstone Landscapes
Kudowa-Zdrój (Poland), 25–28 April 2012

Edited by
Piotr Migoń and Marek Kasprzak

University of Wrocław
Wrocław University of Environmental and Life Science
Stołowe Mountains National Park
The Association of Polish Geomorphologists
Danxia Geomorphology IAG Working Group

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Diversity, Ecology and Conservation

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Contents

Preface

Sandstone terrains, due to their distinctiveness and diversity, have long attracted attention from scientists from different disciplines. Increasingly, particularly close relationships between rocks, landscapes and humans in such terrains have been recognized, leading to the emergence of the general term 'Sandstone phenomenon'. This notion was first coined by Cílek and Kopecký (1998) and simply defined as '(...) the sum of all abiotic and biotic constituents associated with specific type of sandstone relief' (p. 9). It has been also commented that the term particularly applies to '(...) cases of interactive feedbacks among the substrate, microclimate, vegetation and fauna' (*op. cit.*). Subsequently, however, the concept was broadened and refined, providing background for the comprehensive evaluation of sandstone terrains, including the human factor. Thus, Cílek et al. (2007) observed that '[sandstone areas] often attract settlement or act as refuges, and may include 'art galleries' of previous civilisations (...). Possibly nowhere among Earth's landscapes can we observe such a close relationship between "stone and life" as in sandstone areas' (op. cit. p. 34). Consequently, the sandstone phenomenon was redefined as a case where '(...) the substrate, climate, life and human activity all participate in creating a single system intertwined by a complex network of feedbacks and interrelationships at multiple levels' (Härtel et al., 2007, p. 9).

In this spirit, in September 2002 the first international conference specifically focused on sandstone landscapes was organized in Doubice, the Czech Republic, on the outskirts of the Bohemian Switzerland National Park – one of the finest sandstone terrains in Europe. One of the outcomes of that conference was a monumental monograph 'Sandstone Landscapes' published a few years later (Härtel et al., 2007). It now serves as a major reference work for all researchers involved in sandstone areas, particularly in Europe. Three years later, in 2005, the second international conference on sandstone landscapes was held in Luxembourg, resulting in a thematic issue of 'Ferrantia' (Ries & Krippel, 2005), that includes a collection of papers presented during the conference. A long break followed the Luxembourg meeting and it was only in April 2012 that the third sandstone conference took place in Kudowa Zdrój, Poland. As previously, the conference consisted of paper and poster sessions, with more than 40 presentations delivered, and two field excursions to the most valuable localities in the sandstone tableland of Góry Stołowe Mts. It was attended by more than 60 participants from 8 countries (Austria, China, Czech Republic, France, Germany, Great Britain, Luxembourg, Poland). The conference received scientific patronage from the Polish Association of Geomorphologists and the Danxia Geomorphology Working Group of the International Association of Geomorphologists and the organizers enjoyed logistical support kindly provided by the staff of the Góry Stołowe National Park. Thematically, a wide spectrum of issues was covered, from geology of sandstone bodies through geomorphology and the origin of landforms at different scales (tors, weathering features, caves, speleothems), engineering geology and rock fall hazard assessment, soils derived from sandstone substrate, topoclimatic conditions in dissected sandstone terrains, vegetation patterns, peculiarities of sandstone flora, human use and misuse of sandstone resources, to management of tourist flows in protected areas and links between nature and philosophy.

This book provides a record of the Sandstone Landscapes III conference and includes all the presentations delivered at the meeting. However, their form varies. Most participants responded to the call for short papers, summarizing the key aspects of the work. However, in a few cases papers were not submitted and the editors decided to include non-refereed abstracts sent to the organizers prior to the conference instead. We believe that even in this form they will become a valuable reference source for future work in sandstone terrains.

Regarding the structure of the book, the editors decided not to subdivide it into individual parts by subject. We do not do so for two reasons. First, some papers are interdisciplinary in scope and hence, difficult to classify in this way. Second, we adhere to the spirit of the definition of Sandstone Phenomenon that aims to bridge between disciplines rather than to enhance dividing lines. Therefore, presentations are arranged alphabetically by authors.

Piotr Migoń and Marek Kasprzak (Editors)

Cílek, V., Kopecký, J., 1998. Introduction: Sandstone Phenomenon. [in:] V. Cílek, J. Kopecký (eds), Pískovcový fenomén: klíma, život a reliéf. Knihovna České speleologické společnosti, vol. 32, Praha – Broumov, 9–10.

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Wildfire in the Bohemian Switzerland NP (Czech Republic): Frequency, Distribution and Impact on Forest Vegetation

Abstract: The importance of wildfire for the existence of certain types of forest ecosystems is well known from the Mediterranean, North America, Scandinavia or Siberia. The general perception of Central Europe region is that this phenomenon does not occur naturally there and its ecological impact on forest vegetation dynamics has been neglected. However, observations in the areas with regular wildfire occurrence and the current palaeoecological knowledge suggest that the ecological role of wildfire on forest dynamics should be acknowledged also in Central Europe. Bohemian Switzerland National Park (BSNP) is situated in the northern border region of the Czech Republic neighboring on the Saxon Switzerland NP of Germany. Its landscape is composed mainly of sandstone rocks and covered by forest. Prevailing forest types are coniferous relic pinewoods (*Pinus sylvestris*) and man-made spruce stands (*Picea abies*), less often acidophilous beech forests (*Fagus sylvatica*). Compared to the rest of the Czech Republic, the occurrence of forest fires is markedly more frequent in this area. The aim of this study is to reveal the occurrence and the frequency and of forest fires in this unique region for the period 1975–2008 and to identify factors influencing their distribution in the landscape. Another aim is to describe the fire impact on forest vegetation on broader temporal scale (168 years). The historic wildfire occurrence was revealed by the archival record of the forestry administrations. There were detected 72 forest fires in the period 1975–2008 that affected 96 forest units in total. The linkage between wildfire occurrence and particular landscape structures was found out by spatial analysis using GIS software. We tested three groups of environmental factors: 1) relief, 2) vegetation composition, and 3) human activity. Distribution of forest fires in BSNP depends mainly on relief form and on species composition of the tree layer. Human activity has marginal effect on wildfire distribution. The wildfire impact on forest vegetation was revealed by phytosociological sampling of various post-fire succession phases. The oldest detected burnt-out area was 168 years old. We found a significant difference in species composition between particular successional stages. The impact of previous fire was still noticeable even in stages older than 100 years.

Introduction

The importance of wildfire for the existence of certain types of forest ecosystems is well known from the Mediterranean, North America, Scandinavia or Siberia (e.g. Zackrisson et Ostlund 1991, Engelmark 1993). The general perception of Central Europe region is that this phenomenon does not occur naturally there and its ecological impact on forest vegetation dynamics has been neglected (Clark et Merkt 1989, Ellenberg 1996). However, observations in the areas with regular wildfire occurrence and the current palaeoecological knowledge (Kuneš et al. 2005) suggest that ecological role of wildfire on the forest dynamics should be acknowledged also in Central Europe.

In Eurasian Boreal zone wildfire is often associated with Scotch Pine (*Pinus sylvestris*) forests. Scotch Pine stands often occur in drier habitats and produce resinous, easily flammable litter. Simultaneously it has several physiological and morphological adaptations to fire, e.g. thick bark, deep root system, quick regeneration on open places and on the mineral soil. Regular fires can maintain the pine stands also in places where other tree species would prevail regarding to local conditions (Engelmark 1987, Agee 1998, Angelstam 1998, Gromtsev 2002).

The Central European area where wildfire is frequent are the sandstone landscapes of the Bohemian Cretaceous Basin (Jankovská 2006). The local vegetation is formed mainly by coniferous forests and some of them resemble the boreocontinental pinewoods (Sádlo et al. 2011). Part of the sandstone area is the Bohemian Switzerland National Park (BSNP), the area of our study.

Aim

The aim of our study is: a) to map the occurrence and frequency of forest fires in BSNP in the period 1974–2008; b) to find out factors influencing wildfire distribution in the landscape; c) to evaluate the fire impact on forest vegetation over 168 years.

Materials and methods

Data. The study is based on archival forest fire records for the period 1974–2008 taken from the NP administration and from two local forestry administrations, LS Děčín and LS Rumburk. Each record included the date of the burn, ID code of the affected forestry management unit (FMU), the size of the burnt area, the cause of the fire, the material damage and other remarks. The FMU ID code enabled us to localize the fire event on the map using archival and current forestry maps with an accuracy of FMU. The FMU varies from 0.015 to 25.7 ha with the mean value of 1.7 ha and median value of 0.75 ha. The map of all detected FMU affected by fires in the period 1974–2008 was created using the ArcGIS 9.3 software (ESRI 2007).

Digitalized FMU were coded into two categories: (a) 'Burned FMU' and (b) 'Other FMU'. Burned units means FMU affected by fire in the period of 1974–2008 (96 polygons in total) and the others are those which do not intersect the 50 m buffer around burned units (3277 polygons in total). 'Burned FMU' were digitalized from the scanned forestry maps of the age relevant to the wildfire date. 'Other FMU' polygons came from the vector FMU map from 2001. From the total number of 3277 'Other FMU' a sample of 1000 was chosen by stratified random sampling so that the size distribution of the sample (in square units) corresponded to the size distribution of 96 'Burned FMU'. This sampling was necessary to avoid distortion of the results by the factor values correlation with the FMU size.

The set of 76 phytosociological relevés of forest vegetation was taken in the BSNP area. It encompasses various post-fire successional stages (1–168 years old) with control relevés in the neighboring unburned stand. All vascular plant and bryophyte species and their abundances using the New Braun-Blanquet scale (Westhoff and van der Maarel 1978) were recorded in each relevé of 100 m^2.

Data analyses. The influence of various environmental factors on wildfire distribution was tested in spatial analysis. We used three groups of factors: (a) relief, (b) vegetation, and (c) anthropogenic factors. For each factor the continuous layer covering the whole study area was created using the GIS software.

The **relief** factors were developed from the digital elevation model (DEM) taken by laser scanning LiDAR (TU Dresden, IPF 2005) and included: (1) height over the valley, (2) heatload index (McCune and Keon 2002), (3) rock height, (4) rockiness. The factors 1–3 were used as maximum value for each FMU polygon. The 'Rockiness' factor means rock outcrop abundance in the FMU.

The **vegetation** factors were developed from the current and archival forestry management plans (FMP). The factors are: (1) the abundance of particular tree species in FMUs measured in wood supply units (m^3/ha) and (2) the stand age in decades.

The **anthropogenic** factors were represented by the FMU distance from the nearest village and the nearest road (all asphalt roads inside and outside the BSNP area and marked tourist pathways). The distance was measured from the nearest edge of the FMU polygon.

For data analysis we used the ENFA method (Hirzel et al. 2002) based on the presence of data only. It compares the values of environmental factors at localities with wildfire to the factor variability in the whole study area. The comparison defines Marginality, i.e. the difference between the global mean and the mean for localities with fire presence, and Specialization, i.e. quotient of the standard deviation of the factor values of the whole study area and of the fire presence localities. Higher absolute values of marginality indicate more different conditions at the fire presence localities in comparison with the global mean, higher absolute values of the specialization indicate more restricted species occurrence under specific conditions.

The phytosociological relevés were analyzed by the RDA multivariate analysis using the Canoco software (Ter Braak and Šmilauer 1998). The age of the burned area including the code for the control relevés was used as a category variable. The potential solar radiation as a factor describing the environment quality was used as a co-variable.

Results

In the period of 1974–2008 71 fires that affected 96 FMU in total were detected in the BSNP area using the available archival records. Some of the FMU were affected by wildfire repeatedly in this period. The frequencies of the wildfire causes were: (a) unknown or unstated – 83%, (b) open fire –10% (tourists or forestry workers), (c) cigarette – 4%, (d) lightning – 3%. The size of the burned area was 0.75 ha (mean), 0.01 ha (modus), and 17.92 ha (max).

The results of the ENFA analysis show that the factors with the highest marginality and specialization values are relief factors (Rockiness, Heatload index, Height over the valley, Height of the rock), followed by vegetation factors (Abundance of the Scotch Pine, Age of the stand). The anthropogenic factors have the lowest marginality values. This indicates that the most important factors influencing wildfire distribution in the BSNP landscape are the shape of relief and vegetation composition. The anthropogenic factors comparing to the natural ones have negligible importance. The wildfire is more frequent on rocky places elevated over the valleys (the rock tops), on southern or south-western slopes, and in the older stands with higher abundance of the Scotch pine (*Pinus sylvestris*).

The analysis of vegetation samples shows the trajectory of the natural post-fire succession. The earliest post-fire successional stages (1–8 years old) are characterized by total change in species composition compared to the control relevés. We found high diversity of herbs (e.g. *Asteraceae* family, *Epilobium sp*.), grasses (*Agrostis sp*., *Calamagrostis epigejos*), ferns (*Dryopteris sp*., *Pteridium aquilinum*) and pioneer bryophyte species (*Marchandsia polymorpha, Ceratodon purpureus, Pohlia nutans, Funaria hygrometrica, Polytrichum sp*.), as well as strong regeneration of many trees, specially the pioneer species (*Pinus sylvestris, Betula pendula, Populus tremula, Salix caprea*).

The later phase (10–22 years old) is characterized by fast growth of seedlings of the pioneer tree species up to the shrub layer and by several plant and bryophyte species like *Calluna vulgaris, Molinia sp., Campylopus introflexus* and by increasing abundance of lichens.

Towards the latest phases (46–168 years old) the *Betula pendula* trees become mature and senescent. In the latest phases, the *Pinus sylvestris* become dominant with *Picea abies* in lower canopy. The difference in the herb and bryophyte layer composition between burned and control plots decreases with the age of the burned area but some differences still remain apparent in the oldest successional stages (93–168 years). The old post-fire plots are typical of higher abundance of

Pteridium aquilinum, Molinia sp., Rubus sp., Pohlia nutans, Campylopus introflexus and lichens. In the tree layer higher abundance of both *Betula pendula* and *Pinus sylvestris* and lower abundance of *Picea abies* is evident.

Conclusions

The results are consistent with the results from the regions where wildfire is considered as a natural environmental factor influencing the development of forest ecosystems. The higher effect of natural factors on wildfire distribution (in comparison with anthropogenic ones) indicates that wildfire would occur in the Bohemian Switzerland sandstone landscape also without the human impact. The Scotch Pine stands growing on elevated rock tops are the forests most influenced by the lightning caused wildfire. Considering fire adaptations of the Scotch Pine and the vegetation survey results we can conclude that the natural pine forests occurrence in the BSNP sandstone landscape is at least partly conditioned by regular wildfire regime.

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Origin of regular cavities in European sandstones: field evidence for dissolution of carbonate and silica cement

Abstract: The origin of cavities tens of centimetres to metres in diameter in sandstones, sometimes referred to as *tafoni*, has been attributed to salt weathering. A revision of such forms across central Europe showed that most cavities with circular, elliptical and subtriangular cross sections were initiated by the dissolution of carbonate and silica cement and that salt weathering is only a secondary, superimposed process. This is evidenced by spatial relation of the cavities with carbonate/silica concretions and by the preservation of tensional joints limited to inner cavity walls.

Introduction

The term *tafoni* was originally used for irregular cavities formed beneath a protective rock crust in granitic rocks on the island of Corsica (e.g., Bourcart 1930). Later, this term was adopted for products of cavernous weathering of sandstone tens of centimetres to metres in diameter which broadened towards the rock interior (Vítek 1979, 1981), and the origin of *tafoni* both in granites and sandstones was understood as related to salt crystallization (cf. Bradley et al. 1978). In a wider sense, the term *tafoni* is now used for products of cavernous weathering of all sizes.
Many regular cavities developed in the European quartzose sandstones, however, show no relation to salt weathering. Seifert (1936) reported their rapid formation on freshly exposed walls in Saxony by evacuation of loose sand from the cavity interiors. In the Góry Stołowe, Poland, Dumanowski (1961) noted that the interiors of spherical cavities were free of mineral cement and explained this fact by the previous presence of entrapped gas bubbles, a mechanism which can hardly cope with the multi-phase fluid flux history within the basin. Later, such cavities tended to be explained by case hardening/core softening processes and, despite the absence of a rock crust, their descriptions melded with those of true *tafoni* (cf. Vítek 1986).

Characteristic features of regular cavities

Regular cavities were studied in various sandstone areas of central and western Europe, notably in the Kokořín area (Fig. 1A–B) and the Klokočské skály Cliffs (Fig. 1C–E) in the Bohemian Cretaceous Basin (Upper Cretaceous, Czech

Republic), in the Chřiby Mts. (Paleocene, Czech Republic), in Petite Suisse (Fig. 1G–H, Lower Jurassic, Luxembourg), in the Góry Stołowe (Fig. 1I–J, Upper Cretaceous, Poland) and in strongly silicified Oligocene sands in the Fontainebleau Forest, France.

The cavities are circular or elliptical in cross section, tens of centimetres to a few metres in diameter. Tubular caves 10 m in length or more, with straight horizontal axes, are also developed. The inside walls of the regular cavities are more or less smooth, with occasionally preserved series of vertical ribs and grooves. No strengthening of the walls by any kind of cement was ever observed. Long axes of the cavities are typically parallel to one another at outcrop scale and sometimes even at area scale.

Subtriangular outlines of some of the cavities result from secondary flattening of their bottoms and enhanced sand removal from their apical parts. The interiors of such cavities commonly bear salt efflorescences and cm-sized honeycomb pits.

Association with carbonate concretions

The spatial association of cavities with carbonate concretions is best visible in outcrops of the Luxembourg Sandstone in the Petite Suisse area. Lenticular to ellipsoidal concretions of calcite-cemented sandstone (Van den Bril and Swennen 2009) are regularly exposed in lower levels of relief, e.g. in the valleys of the Halerbaach, Ernz Noire and Aesbaach rivers. They parallel the regular cavities in their shape and size. At some sites, cavities and carbonate concretions co-occur, with a full range of transitional stages of concretion detachment from the rock massif displayed within a single outcrop (Predigstuhl and Sept Gorges near Berdorf, Teufelsschlucht near Bollendorf). Dense vertical jointing restricted to the calcite-cemented portions is ubiquitous, and the dominant strikes of the joints correspond with the elongations of grooves in cavity interiors.

Regular cavities in the Jizera Formation sandstones in the Kokořín area concentrate into several stratigraphic levels falling within highstand systems tracts and corresponding to levels of maximum carbonate content further basinward. Where these levels lie low above the present valley bottoms, ellipsoidal concretions of calcite-cemented sandstone are preserved. Different stages of carbonate dissolution and concretion detachment can be observed at sites where cores of vertically jointed calcified sandstone are still preserved in cavity interiors (Kokořín village, Močidla Gorge). Series of vertical ribs and grooves on the inside walls of large elongated caves near Ješovice (Fig. 1F) follow tiny fractures limited to the nearest periphery of the caves, suggesting the former presence of rock with a higher elastic modulus in their cores (Adamovič and Mikuláš 2011).

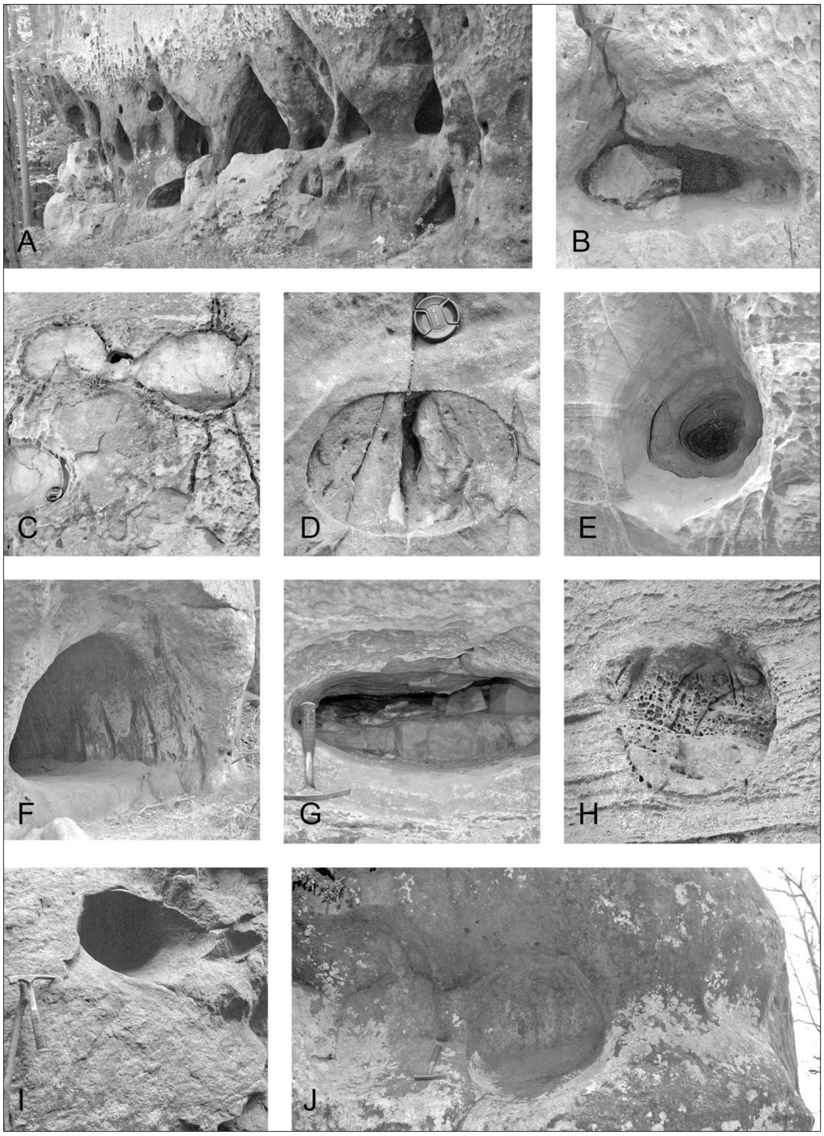

Fig. 1. Examples of regular cavities in sandstone districts in Europe and their concretionary precursors. **A, B** – Kokořín area, Czech Republic: A, a level with cavities 10 m above the base of the upper Jizera Formation (U. Turonian, U. Cretaceous) near Obrok; B, a cavity with a jointed calcite-cemented core from the same stratigraphic level near Kokořín. **C–E –** Klokočské skály Cliffs near Turnov, Czech Republic (U. Turonian): C–D, carbonate concretions 30–40 cm in diameter, now decalcified but accentuated by shallow grooves along rims; E, an elongated cavity 40 cm in diameter after a pre-existing concretion. **F** – Kokořín area, Czech Republic (U. Turonian): a cavity 1.4 m in diameter showing vertical grooves on its walls near Ješovice. **G–H** – Berdorf area, Luxembourg (Hettangian, Lower Jurassic): G, an elliptical cavity with a jointed calcite-cemented core at Perekop; H, circular carbonate concretion 70 cm in diameter with vertical jointing and rim accentuated by minute honeycomb pits at Heroldt. **I–J** – Góry Stołowe, Poland (U. Turonian to Coniacian, U. Cretaceous): I – elliptical cavities (largest 56 by 44 cm) on a crevasse wall at Diabelska Kuchnia, Szczeliniec Wielki; their counterpart is preserved on opposite crevasse wall; J – a spherical cavity 80 cm in diameter with preserved vertical grooves on its walls at Małpolud, Szczeliniec Wielki.

Caves in the Teplice Formation sandstones in the Klokočské skály Cliffs, tens of metres in length, were formed by coalescing of cavities 1–3 m in diameter. They follow the same stratigraphic level (Mertlík and Adamovič 2005). Their concretionary precursors can be assumed from the circular concretion rims visible in outcrops (Fig. 1C–D), although no traces of carbonate can be found now. Circular contours of concretion rims can be also occasionally found on vertical cliff faces in the Góry Stołowe Mountains where spherical cavities 0.2–1 m in diameter are a common phenomenon. Some of the cavities bear vertical grooves on their inner walls (Fig. 1J).

Spherical cavities and rock basins after detached carbonate concretions are a common phenomenon also in the Ciężkowice Sandstone (Paleocene to Lower Eocene) in the Polish and Slovak Carpathians. Giant concretions of calcified sandstone (1–3 m in diameter) are preserved embedded in these sandstones at several sites (Adamovič et al. 2010).

Association with siliceous concretions

In the Oligocene sands in the Fontainebleau Forest, France, high cavernosity was observed at sites rich in cryptocrystalline/amorphous silica. This is particularly notable in the La Dame Jouanne area near Larchant where a system of ellipsoidal cavities 0.2–2.5 m in diameter and up to 7 m long shows the same elongation (E–W) as the strongly silica-cemented portions of the rock.

Origin of vertical grooves/ribs on cavity walls

Systems of vertical grooves and ribs on the inner walls of the cavities were observed in most areas. Their association with joints is particularly clear where such joints demonstrably pass from the cavity wall into a carbonate concretion preserved in the cavity core (Petite Suisse area, Kokořín area – Kokořín) but is equally visible in some cavities where the concretion has been completely removed (Kokořín area – Ješovice). The joints have a tensional character and pass only to the nearest periphery of the calcite-cemented core. The rock farther from the concretions is usually deformed by a different system of joints of a much lower density. Such 'selective' type of brittle deformation has been previously reported from carbonate concretions in sandstone (e.g., Bessinger et al. 2003, Quesada et al. 2009). Calcified sandstone is characterized by a higher elastic modulus than the quartzose sandstone around, and is therefore more susceptible to the effects of regional tectonic stress. A dense network of tensional joints is formed within the carbonate concretion and its nearest periphery, parallel to the maximum principal stress vector. After a complete dissolution of the carbonate cement and removal of the loose sand, grooves on the cavity walls are often the only indication of the presence of a concretionary precursor.

Conclusions

The variety of stages of the development of regular cavities preserved in outcrop permit to conclude on the following scenario: (1) early diagenetic stage: origin of carbonate concretions at levels of elevated carbonate production, (2) late diagenetic stage: origin of tensional joints in the concretions and their periphery, parallel to maximum principal tectonic stress, (3) partial or complete dissolution of carbonate cement by flowing ground water, (4) upon exposure, removal of loose sand or gravitational detachment of a partly degraded concretion, cavity formation, and (5) modification of some cavities to a subtriangular shape by salt/frost weathering.

Based on the observations in a variety of geographical areas and sandstone lithologies, it can be assumed that many of the regular cavities so far considered true *tafoni* were in fact formed by the removal of carbonate or silica concretions. Elongation of such cavities can be thus used as an indicator of fluid flow in the early stages of diagenesis. The system of vertical grooves/ribs on cavity walls not only serves as evidence for a concretionary precursor but can be also used in paleostress analysis.

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Idols carved and sculpted in sandstone in western Europe

Abstract: Idols can be of the statue (statue menhir) or petroglyph kind. In many places in Spain and France they have been made using local sandstone. They vary in age, from the Copper Age up to the Roman Period. Dating is possible by means of characteristic attributes of the idols (weapon, clothes), which can be ascribed to particular historic periods. Similarities between different regions suggest widespread exchange of ideas at the time of idol carving.

Introduction

Idols can be of the statue (statue menhir) or petroglyph kind. In the same area one can find both. The first statues were engraved menhirs, the latest ones were sculpted. Most petroglyphs of the idol kind, as discussed in this study, are simple and have the same arms as the statue menhirs. In this contribution, idols varying in age from the Copper Age up to the Roman Period from Spain (Cantabria and Burgos) and France (Haut Languedoc, Massif de Fontainebleau and northern Vosges) are presented.

Spain

On the southern bank of the Ebro lake, in Monte Hijedo (south of Cantabria and west of Burgos), one can find wealdenesian sandstone with cliffs creating a beautiful landscape. Among the prehistoric and painting heritage we will focus on the idols. These are tall figures engraved on vertical parts of the sandstone cliffs. This type of engraving is unique. One can find single form idols in Ruanales (Redular) and Santa Gadea de Alfoz (Portillo Viejo). In Sorna twin idols occur. The best site is in Las Rozas with a frieze of 22 idols situated on both sides of a small cliff. They can be easily dated because some of them have a dagger (type Sejos), so these then are from the Copper Age. Apart from having these weapons these idols are very simple and are made to be seen from afar (Fig. 1, 2).

The last idol studied in the area can be found on a horizontal part of a big rock and is very similar to an idol engraved in granite in Galicia. This last type of idol with bands can be correlated with the menhirs of Sejos (Cantabria and Tabuyo del Monte (Leon).

Fig. 1. Partial view of Las Rozas, Cantabria, Spain.

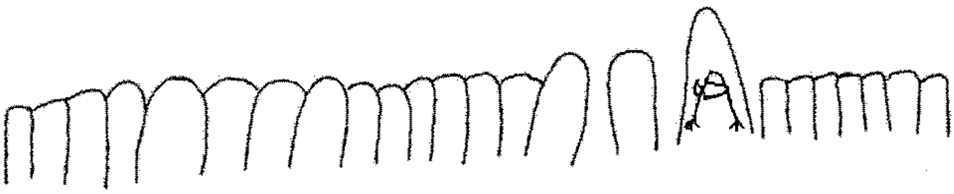

Fig. 2. Sketch to show the location of an idol at Las Rozas, Cantabria, Spain.

France

Massif Central. In the south of the Massif Central one can find a lot of statue menhirs carved or sculpted in sandstone, granite and schist. Sandstone monuments are more numerous (56%). These statue menhirs were the first monumental sculptures in Europe (Fig. 3). Male, female and transformed statue menhirs occur in the area. They represent a seated person with weapons for the male statues and with a collar for the female statues. They can be dated by the collars worn by the females shown on statues and by the weapons borne by the male statues. The period concerned is the Chalcolitic. Some statue menhirs were subsequently transformed, generally from male into female representations. Archeologists recognize four periods. During the last period there was a kind of competition between the use of granite and sandstone. During this time very tall statues were made (more than 4 meters high) in granite and forming beautiful sculptures in sandstone.

Prehistoric man displaced many rocks as far as 10 kilometers away from the site of origin. Nowadays statues are found lying face down and without any archaeological context. Most are made of Permian sandstone (red sandstone and white sandstone) and a few in Triassic sandstone at the borders of the area.

Most sandstone statues are kept in museums or private collections, while a copy is erected near the discovery place. The position is different for the granite statue menhirs, where some are protected but others are left in the open and thus, have become difficult to read.

These monuments are not unique. One can find statue menhirs from Ukraine up to Spain and Portugal. The rock used is local.

Massif de Fontainebleau. The local sandstone dates from the Tertiary era, Oligocene, Stampian stage and crops out south of Paris. Here one can find rock chaos, including many cavities. In the Massif de Fontainebleau, situated in a rock shelter of the Forêt des Trois Pignons, one can recognize a petroglyph with a face looking very much like the face of the most impressive female statue menhir of the Rouerge. In this shelter you can also see various petroglyphs (Fig. 4). The oldest idols date from the Mesolithic Period.

Northern Vosges. The dominant rock in the Northern Vosges is Triassic (Buntsandstein) sandstone. There are four sites with carved rocks from the Roman Period. These do not depict idols but gods. In Lemberg Pompösen Bronn one can find Gallo-Roman gods and a hunting scene, in Bildelmuehle a goddess, and in Dreibilderfels a Gallic god and goddess. The Triassic sandstone provides a beautiful colour to these sculptures. Further examples occur in Germany and Luxembourg.

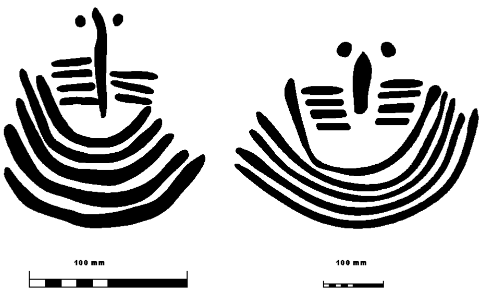

Fig. 4. Petroglyphs at Forêt des Trois Pignons (left) and Saint Sernin sur Rance Aveyron (right).

Fig. 3. Statue-menhir Albespy 1, Mounès Prohencoux, Aveyron, Pyrenees.

Conclusions

Idols are numerous all over Europe. They were made during Chalcolithic. Some likenesses prove that there were many exchanges during these periods. It is difficult however to determine if they are idols, gods or ordinary persons. All these idols should be protected. Most sandstone statue menhirs are protected, but in Fontainebleau, Spain and Northern Vosges there is not any protective scheme.

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Holocene fire dynamics and forest composition in the Elbe Sandstone area

Abstract: Large areas of North Bohemia are underlain by sandstones shaped by water erosion, producing a highly variable relief of deep gorges and exposed rock plateaus. This strongly affects vegetation composition which reflects local conditions and produces a patchy mosaic of forest types. One question that has not been answered is the former extent and fire history of relict *Pinus sylvestris* forests, expected in extreme habitats. A combination of palaeoecological methods was used to reconstruct the fire history during the Holocene. Macroscopic charcoal (> 125 μm) records from four peat cores taken from topogenous mires situated at the bottom of gorges show a continuous presence of fires nearby. Furthermore, soil samples of the volume of 10–15 l were taken from thirteen trenches dug at sites with low erosion potential. Taxonomic identification of charcoal fragments from soil profiles provide spatially precise data about former species distribution. Our results show that the extent of *Pinus sylvestris* dominated forests is greater than suggested by previous palynological data. This may have been caused by exclusion of fire-intolerant species from vegetation.

Introduction and background

Large areas of Mesozoic block sandstones are found in North Bohemia. Water erosion gave these landscapes a very rugged topography in the form of deep gorges and exposed ridges. This results in very rapidly alternating habitat conditions over relatively short distances. The composition of forest vegetation also reacts to changing ecological conditions. According to the results of palynological analyses of sediments taken from several topogenous mires, since the Subboreal period the area was covered by fir-beech forests (Abrahám 2006), whereas spruce dominated at wet bottoms of gorges and pine prevailed on exposed rock edges. Today these growths are mostly replaced by spruce monocultures, which have been preferred by foresters since the 18th century. The role of pine trees in natural forests remains unknown. Pine tends to be marginalized because of its weaker competitive ability, especially compared to beech. Palynological reconstructions limit its occurrence in the Elbe Sandstones area to edges of rocks and summit plateaus with a shallow soil cover (Kuneš et. al. 2007).

Paleoecological records, however, also document a continuous chain of fire events. These are indicated by elevated amounts of charcoal in the soil. At present, fires are mostly tied to coniferous vegetation, and therefore, the occurrence of charcoal in peat sediments suggests an uninterrupted presence of conifers in the area. The place of origin of micro-charcoal is unknown because charcoal pieces can be transported to the place of sedimentation. We used the pedoanthracological method, which provides spatially very precise information (Carcaillet, Thinon 1996), making possible to document the distribution of woody species in the past.

Data and results

Four cores were taken from topogenous mires in the Elbe Sandstones area. From the cores, 1 cm^2 samples were extracted at 1 cm intervals. The samples were prepared for microscopic determination of the number of charcoal fragments by wet sieving on a 125 µm sieve and chemiluminescence of plant tissue using hydrogen peroxide. Based on the depth-age model of sedimentation (the dating procedure has not yet been completed), a curve showing the speed of deposition of charcoal at each locality was created, documenting fire events in the close vicinity. Furthermore, soil test pits were dug at thirteen selected localities encompassing typical habitats of a sandstone 'rock city'. From these pits, 10–15 l of soil were sampled according to visible stratigraphy. Charcoal pieces for microscopic determination were obtained from this material by flotation and wet sieving. Sampling sites were selected so as to eliminate transport of charcoal from elsewhere. For this reason, flat plots with a slope of less than 3° and located outside a valley bottom were chosen.

Changes in the content of charcoal particles in peat cores confirm the continuous occurrence of fire events in the neighbourhood of the localities under study. The longest record is preserved at the locality 'U Eustacha' (Fig. 1), where the base of the core is dated to 5490 ± 125 BP (Baroň, Vařilová 2006). A conspicuous de-

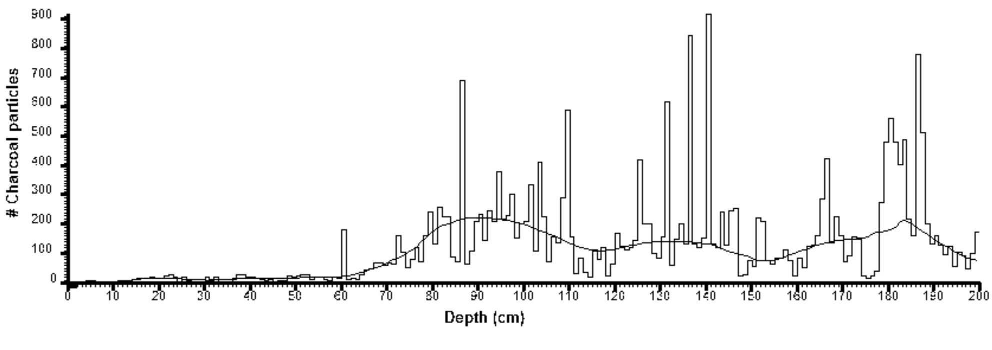

Fig. 1. Charcoal concentration in the peat profile "U Eustacha". The distinctive peaks above the curve (weighted average) indicate fire events. The bottom of the sedimentation basin is radiocarbon dated for 5490 ± 125 BP.

crease in the number of charcoal is apparent in the most recent layers of the sediment, which indicates a marked decrease of fire activity in the modern period. The species composition of the charcoal array obtained from soil samples confirmed the occurrence of all main woody species in the area: *Pinus sylvestris* (62%)*, Fagus sylvatica* (7 %)*, Quercus sp.* (8 %)*, Picea abies, Abies alba* and sporadic occurrences of species of early successional stages such as *Betula sp., Populus sp.* and *Acer sp.* The total taxonomic diversity reached twelve tree and shrub species (Fig. 2). The radiocarbon AMS dating of 27 samples revealed the dates covering the

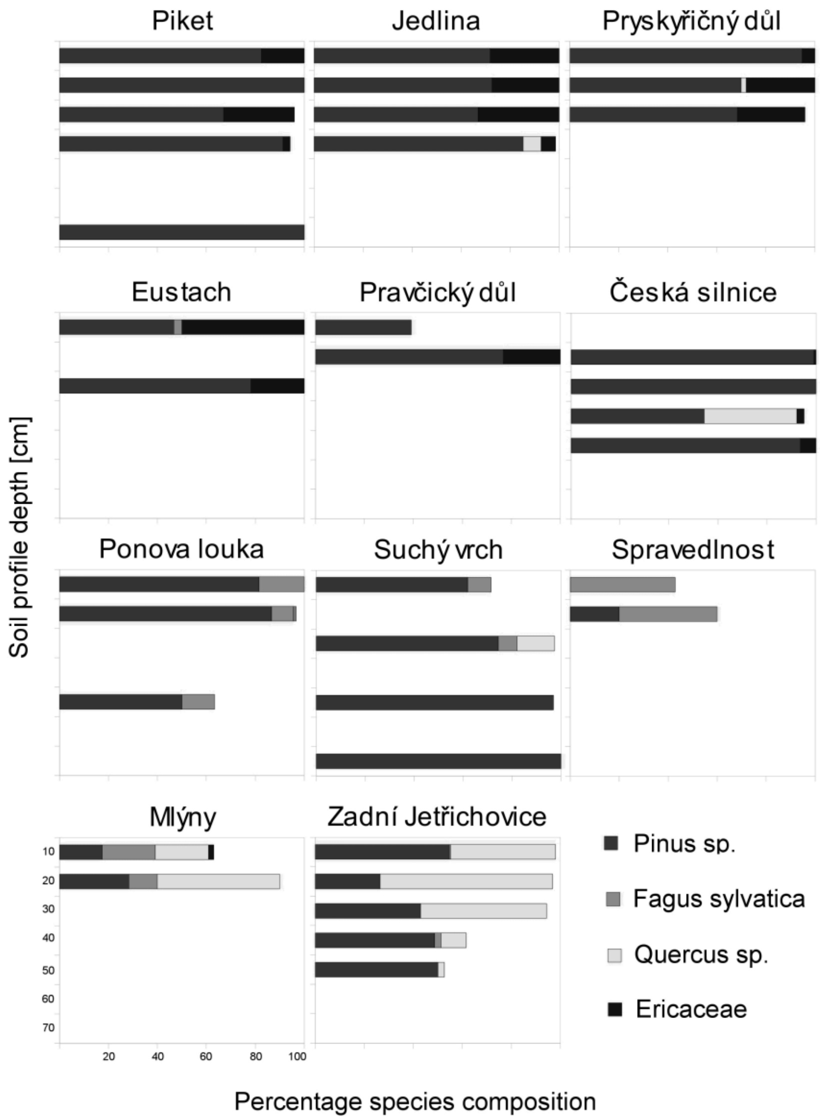

Fig. 2. Summary charcoal percentage diagram from the 11 soil profiles located in the sandstone area of the Czech-Saxon Switzerland. Only the main tree and shrub species are depicted.

entire Holocene period. There are several dates corresponding with the older and middle Holocene, but the major part falls within the Subatlantic period.

The species composition of charcoal assemblages is a surprisingly stable and does not show any important changes. The pine-dominated forest vegetation was a stable component of the sandstone landscape during the Holocene. The broadleaf species of *Fagus sylvatica* expanded in the area during the Subboreal, but it was limited to rich soils developed on basaltic bedrock. The distribution of charcoal fragments of *Pinus sylvestris* in relation to topography and soil conditions indicates the dominance of the species throughout the area of plateaus and sandstone ridges. Pine is not limited to exposed rock edges with shallow soil, but it is also abundant in the central parts of rocky plateaus in places with deep soil, where it is accompanied, to a smaller degree, by *Quercus sp.* The minor component of the charcoal spectra at such sites was *Picea abies*. The occurrence of this species was not restricted to the moist condition on the bottom of the gorges, but it grew on the rock plateaus too. The presence of charcoal particles in the soil and peat profiles confirmed fire occurrence in the pine-dominated forest since the Preboreal period.

Discussion

The presence of charcoal in peat sediments proves the occurrence of fires in the vicinity of all the localities under study. In the central part of the Bohemian Switzerland sandstone area, at the locality 'U Eustacha', there is a record of fire events from the end of the Atlantic period up to the present. According to the radiocarbon dating of the soil charcoal, forest fires have occurred in the area since the Preboreal period, with a marked increase in the Subatlantic. This begs the question of which types of forest vegetation were associated with fires and whether fires affected species composition. A higher frequency of fires in mixed oak forests from the Atlantic period would lead to the elimination of species susceptible to the effects of fire, such as members of the genera *Ulmus, Tilia* and *Fraxinus* (Tinner 2000). This process of gradual depauperization can be observed in the pollen record from several localities in sandstone areas of North Bohemia and is known as the 'Lužice catastrophe' (Ložek 1998). This is, however, attributed especially to natural acidification and impoverishment of the soil during the course of the Quaternary climatic cycle (Pokorný et Kuneš 2005). Therefore, fires were rather a consequence of changes in plant composition as the abundance of coniferous species increased.

Results of our analyses of charcoal contained in the soil show, however, that within the very rugged sandstone topography fires could have also influenced habitats in the middle of rock plateaus, where relatively rich and deep soils occur and where palynological reconstructions assume the presence of fir-beech forests in the Subboreal period. The species composition of soil charcoal assemblages from these habitats suggest a dominant position of *Pinus sylvestris* and the unusual stability of the pine-dominated forest vegetation. These places tend to dry out easily due to their slope orientation and sandy soil, thus creating ideal conditions for the occurrence of fires. The spread of *Fagus sylvatica* and later also *Abies alba* into these specific habitats was possibly blocked by the effects of fires occurring in this vegetation type during the whole Holocene.

Conclusions

Based on the content of charcoal in peat sediments, the occurrence of fires in the Elbe Sandstones is recorded since the end of the Atlantic period. The species composition of charcoal fragments contained in the soil shows a dominance of *Pinus sylvestris* during the whole Holocene, also at edaphically more favourable sites of rock plateaus.

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Eolian phenomena in sandstones and limestones of Egyptian Western Desert and their implications for Central European sandstone relief

Abstract: In the interior part of Sahara one can observe unusual and striking aeolian forms such as yardangs – aeolian formed ridges up several hundreds metres long, systems of wind formed lanes, aeolian tubes more than 2 m long, different types of depressions and large abrasion plateaus where relict hills witness wind erosion that has removed several hundred metres of sandstones, limestones and other sediments during Quaternary. These large scale forms are often accompanied by ventifacts. I observed Saharan ventifacts of unusual forms where strong winds are creating not only abraded surfaces but holes or cavities in the stone. Ventifacts developed on Central European river terraces are often of the same type as Saharan ventifacts, the wind velocity seem to have reached aprox. the same intensity, but can we now identify the large aeolian forms in the Central European sandstone landscapes that should probably accompany small scale wind features?

Introduction

In the last ten years I have participated in 14 excursions and expeditions in Sudan, Egypt and Middle East. Besides Quaternary and archaeological studies I have concentrated on the study of aeolian forms which are prevailing landforms in e.g. central parts of the Western Desert, but almost non-existing on large areas of the Sudanese Sahel or in the Syrian Desert. The paleoclimate and basically vegetational history of different and shifting climatic zones seem to be responsible for the intensity of wind erosion (Issar, Zohar 2004).

Large scale aeolian landforms such as aeolian valleys or systems of lanes and yardangs are in all cases accompanied by small scale forms such as ventifacts. From this – Saharan – point of view we can consider that ventifacts are in fact indicators of the existence of large aeolian landforms. If we accept this premise, we have to ask if this model can be verified in the Central European landscapes, where the large aeolian forms developed in solid rocks (not as loess or sand dunes) are not known but ventifacts are common. I do not have any definitive answer, but I would like to raise this question, because if aeolian forms are really developed even in the European temperate zone – then they could be identified mostly – if not exclusively – in sandstone landscapes and then maybe extended to other rocks.

Aeolian forms in the Egyptian Western Desert

The best examples are developed in the soft Upper Createaceous chalks and marls of the so-called White Desert, close to Farafra Oasis, in limestone plateaus between Bahariya, Dakhla and Siwa oases in the central part of the Western Desert or in silicied 'Nubian' sandstones of Gilf Kebir area (for review of geology see Said 1990). Possibly the most striking forms are large, 'polished' and abraded wind terraces covering tens of square kilometres accompanied by relict hills, sometimes in the form of spires and buttes. Some of these surfaces are covered by laminar, massive 2–5 mm thick layer of a calcite crust resembling cave flowstones that originated as former algal carpet developed on dew-watered surfaces. There occur too large abrasion plateaus where relict hills witness wind erosion that has removed several hundred metres of sandstones, limestones and other sediments during Quaternary (Thomas 1989).

The slopes of the relict hills and plateaus (mesas) may display a variety of unusual forms such as up to 60 m deep and 300 m wide eolian valleys (western slope of Gilf Kebir), systems of wind lanes 10–20 m wide and several meters high, common yardangs of all types, wind abris, rock perforations and other features. In the Farafra region of White Desert we can find horshoe shaped hillocks. They originate by strong wind action in one direction, where a wind „kettle“ finally developes. The circular movement of wind in the kettle creates the horseshoe-like depression and may divide the originally isometric hill into three individual rock formations – larger butte in the centre and two thin spires on both arms of the horseshoe.

Aeolian facettes and cones are very common. In some cases the circular movement of sand grains can lead to the formation of a tube some 10 cm in diameter and almost 2 m long. We have observed ventifacts in the shape of miniature yardangs half a metre long or even ventifacts with a central cavity that has developed as in a much larger horseshoe hill due to the circular movement of sand particles.

Eolian forms in solid rocks of Czech Republic

The only so far discovered aeolian forms on rock outcrops are facettes developed on Miocene quartzites of 'Salesius Hight' close to Osek and on hard Mesozoic sandstones of Dědek hill by Jestřebí, south of Česká Lípa in Northern Bohemia (see Adamovič et al. 2010, p. 176). However, ventifacts are extremely common on all Early Pleistocene river terraces, e.g. between Prague and Pilsen and elsewhere. The perfectly developed ventifacts are often formed by the most durable rocks such as Palaeogene silcretes, Ordovician quartzites, Cambrian quartz sandstones and conglomerates, vein quartz and other materials.

Have large aeolian forms ever existed in Central Europe ?

An intensive aeolian abrasion is recorded by the presence of ventifacts only during Early Pleistocene and to some degree in the Middle Pleistocene, but these younger ventifacts seem to be mostly inherited from older sediments. We know from observations of actual rates of formation of ventifacts or aeolian facettes developed on the e.g. World War II fortifications in the Western Desert, that a facette may develop within a few decades. The European ventifacts are composed of several facettes, so the formation had to take place during at least centuries but probably for a much longer period of time, because the stone had to be turned out several times.

Intensive and lasting eaolian abrasion would have to leave out at least some traces on the relief, but repeated ice age frost destruction may have blurred these aeolian traces. At this stage of knowledge we have to leave the question of large scale wind erosion open. Maybe it has never occurred, maybe the Early Pleistocene forms were destroyed by younger processes, but maybe we were not looking for these forms because we could not imagine that they have once existed.

Fig. 1 The characteristic surface of eolian abrasion plateau of Egyptian Western Desert (all photo taken by V. Cílek in Farafra region).

Fig. 2 The Saharan „rock mushrooms“ originate by the strong surface winds that carry quartz grains with high impact energy, while all Czech „rock mushroom“ originate either due to the sandstone lithology or weathering in humid condition of capillary water.

Fig 3 The plateau bedrock has a form of low yardang field, but the overlying strata of sandstones, marls and limesstones more than 200 m thick was taken away by Quaternary winds.

Fig. 4 Notice in the centre of the picture two parallel wind lanes that developed in this case by climbing winds while large wind valleys of Gilf Kebir are formed by falling winds.

Fig. 5 Horseshoe hill developed from a simple conical hill by the action of strong oriented winds. A shallow depression on the face of the hill caused circular wind movement and wind kettle started to develop. It cut large „U“ shaped depression into the hill and then it opened both arms of „U“ and created two slim towers and larger butte.

Fig 6 The polished surface of the sandy limestone is covered by hard laminar sinter that developed as biogenic deposit of periodic algae carpet watered by morning dew.

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Transboundary LiDAR-Based 3D Landscape Assessment in the Elbe/Labe Sandstone Mountains

Abstract: Simultaneous airborne imaging by digital optical and laser scanners collect spatial data needed for any sophisticated 3D landscape analysis and modelling. Airborne laser scanning is a direct method of remotely sensed spatial data acquisition. It provides densely collected digital 3D-surface point clouds at very high accuracy. There are many advantages over conventional data acquisition techniques. The capability to penetrate vegetation and thus measure ground points in wooded areas with high density is probably one of the most distinctive features. The strategic development and application of LiDAR sensing for supporting new approaches of transdisciplinary analysis, monitoring and management of the transboundary protected region of the Elbe Sandstone Mountains proves as an example for similar initiatives in other sandstone landscapes worldwide.

Introduction

The Elbe/Labe Sandstone Mountains in particular, and protected or unprotected sandstone areas and regions in general, are both highly vulnerable as well as extremely valuable in terms of conservation of natural and cultural heritage. In many cases protected regions in general extend over two or more national territories. After centuries of neglect many of these mostly remote regions are increasingly destabilised by the impact of economically driven planning and management strategies, especially in Central Europe (Lysenko et al. 2007).

Under the EU INTERREG project GENESE, airborne laser scanning (LiDAR) data and simultaneously acquired high resolution optical imagery of more than 800 km^2 of protected landscapes of the National Park Region Českó-Saske Švycarsko (Czech Republic, Germany) were collected along the Czech-German border and thus allow for a homogeneous 3D-documentation and analysis of transboundary sandstone landscapes, their specific patterns of land use and land cover, as well as their topography with special regard to large areas of dense forests.

Remote sensing for land use and land cover change detection and for landscape structural analysis, together with airborne laser altimetry for generating very high-resolution digital terrain models and vegetation cover models allow for the calculation and subsequent analysis and visualisation of the 3D-sandstone landscape models in general, of slope gradient and aspect models as well as erosion risk models in particular (Csaplovics, Wagenknecht 2006, Trommler, Csaplovics 2008).

Basic concepts of LiDAR data collection for 3D landscape assessment

Simultaneous airborne imaging by digital optical and laser scanners collect spatial data needed for any sophisticated 3D landscape analysis and modelling. Airborne laser scanning is a direct method of remotely sensed spatial data acquisition. It provides densely collected digital 3D-surface point clouds a very high accuracy. There are many advantages over conventional data acquisition techniques. The capability to penetrate vegetation and thus measure ground points in wooded areas with high density is probably one of the most distinctive features. Raw unfiltered laser data describe the surface with all their natural and artificial objects like trees, rocks and cliffs or buildings. For generating a digital terrain model (DTM) based on airborne laser scanning, data have to be separated into laser points representing the ground surface, and into laser points representing surfaces of vegetation layers (e.g. tree crowns) and artificial objects (e.g. buildings) by applying specific filter algorithms. Intensity-based laser systems ($\lambda \approx 1\mu m$) provide radiometric information on the scattering behaviour of the surfaces, which contribute to an increasing precision of surface detection. The accurate description of reflecting objects is additionally supported by methods of retrieving not only first pulse and last pulse data, but also the number and distribution of all reflections along the individual paths of beams (Wagner et al. 2008).

The implementation of formlines, breaklines and edges further increases the precision of digital terrain models. Research to develop algorithms for automatic extraction of these features has reached a pre-operational level. Analysing the spatial distribution and frequency of edges is also a measure for calculating structural parameters of the landscape such as patchiness or diversity (Maier et al. 2008).

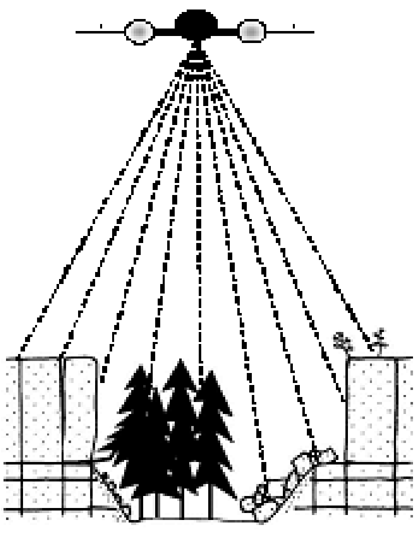

Fig. 1. Airborne laser scanner data collection over rugged terrain.

Implications of operational implementation

The capacity of airborne LiDAR data to unveil details of terrain surface structures more or less undisturbed by forest canopy stands for a paradigm change in the detailed spatial analysis of forest landscapes in general and of geomorphological details in rugged forested terrain in particular.

Apart from geological morphometric features, an investigation of patterns of anthropogenic impact, e.g. of archaeological sites under dense vegetation cover, especially in forested areas of the sandstone region, can hardly be inventoried in their spatial dimension. Often quasi-linear features such as lost ways and paths or walls and ditches, local features such as barrows and abandoned settlements can be detected for the first time by systematic analysis of ground surface digital terrain models derived from filtered LiDAR data.

Interaction between local climatic and human impact on land cover and land use of agricultural landscapes on the plateaus of the sandstone landscapes along the Elbe river increasingly provokes large-scale erosion of topsoil, especially after heavy rainfall which also affects conservation issues in that transboundary landscape of outstanding value in terms of natural heritage. Documentation and analysis of erosion risk models based on digital LiDAR ground surface models and remotely sensed land use information including pedological and agricultural data supports transboundary strategies that reinvent sustainable land use.

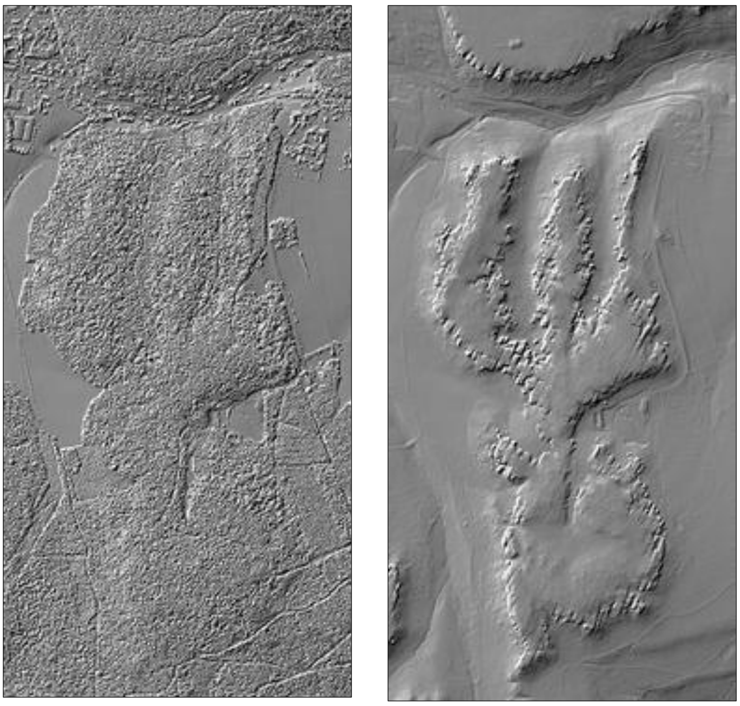

Fig. 2. Digital canopy surface model (left) and digital terrain model (right) of the forested landscape of the cliffs of the Nikolsdorfer Wände (Elbe Sandstone Mountains) (© EU-INTEREG-IIIA – GENESIS, IPF-TUD).

Conclusion

3D-landscape assessment by means of remote sensing in general and with special emphasis on LiDAR in particular contributes to the European perspective of issues and tasks of management of ecological networks in Central Europe and elsewhere (Muchoney 2008). Its strategic development and application for high-quality spatial data transfer, exchange and networking as well as interactive discussion and decision making in conservation of the sandstone landscapes along the Czech-German Elbe border region proves an essential contribution to new approaches of transdisciplinary analysis, monitoring and management of the transboundary protected region of the Elbe Sandstone Mountains and may become a model example for similar initiatives in other sandstone landscapes worldwide.

Acknowledgements. LiDAR data displayed in figure 2 stem from outputs of the project GeNeSiS (Geoinformation Networks for the Saxon-Bohemian Switzerland) under the European Community programme INTERREG, co-financed by the European Regional Development Fund and directed under the lead partnership of the Institute of Photogrammetry and Remote Sensing, TU Dresden, (E.Csaplovics). LiDAR imagery was prepared under the respective project activities at the Institute of Photogrammetry and Remote Sensing, Technische Universität Dresden, by Marco Trommler.

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Biological research and monitoring in the Elbe Sandstones (Saxon-Bohemian Switzerland)

Abstract: The intensity of biological research and monitoring in the Elbe Sandstones have increased significantly since 1990 when the Saxon Switzerland National Park was established, followed by the Bohemian Switzerland National Park in 2000. However, not only both national parks but also both protected landscape areas on the Saxon and Bohemian side are subject of many biological and forest projects and monitoring activities. Most of them focus on species distribution inventories and on studies dealing with particular habitat types: mainly forests (covering more than 90% of the area) as well as peat-bogs, gorges with climatic inversions and wetlands (including the Elbe river). Other projects aim at practical management issues, such as reconstruction of natural vegetation, invasion of alien species, bark-beetle monitoring, reintroduction of regionally extinct species, etc. Almost all monitoring and research activities are undertaken in collaboration with external academic institutions from both Saxony and Czechia. A significant part of projects is carried out in a transboundary framework.

Background

Initiatives to establish a national park in Saxon Switzerland have led since 1960 to numerous research projects. These activities were mainly born by the Tierkundemuseum Dresden and the NGO “Arbeitskreis Sächsische Schweiz”. Since 1990, the Elbe Sandstones have attracted an increasing attention of scientists and conservationists also on the Bohemian side. The main impulse was the 1990 declaration of the Saxon Switzerland National Park in Germany and start of preparation of the Bohemian Switzerland National Park in the Czech Republic (declared finally in 2000). These favourable circumstances enabled to start and initiate a whole spectrum of research and monitoring activities in nature conservation, social sciences, geology/geomorphology, as well as forestry and biology. The activities in two last-mentioned sciences are subject of the paper. The designation of both national parks and partially also the surrounding protected landscape areas as essential components of the Natura 2000 network support further research and monitoring activities.

The whole region of the Elbe Sandstones (Saxon-Bohemian Switzerland) includes both national parks and both protected landscape areas on the Saxon and Bohemian side and comprises an area of almost 800 km^2. Complex landscape structure (both horizontal and vertical) contributes to relatively high species diversity – despite the acid sandstones represent generally rather species-poor habitat – and increases the attractiveness for scientists and conservationists. The landscape includes not only sandstone habitats but also a part of Lusatian granite massif in the north and Tertiary volcanic hills in the south – partly as isolated elevations within the sandstone area and partly as an adjacent territory of the České středohoří (Böhmisches Mittelgbirge) Mts. (Riebe et al. 1999). A very specific role for diversity and research activities plays the deep Elbe Canyon between Děčín and Pirna.

Results

Since 1990s a wide range of academic and nature conservation institutions have been involved in the biological research and monitoring activities carried out in the Elbe Sandstones, such as Technical University Dresden, Charles University Prague and several regional universities (České Budějovice, Ústí nad Labem), institutes of the Czech Academy of Sciences, and also several regional museums in Saxony and Czechia. Furthermore, private companies and experts participate in research activities. Some limited research and monitoring activities are undertaken also directly by the staff of the protected areas.

During the last two decades several monographs showing results of the biological (but not only that) research have been published (Augst, Riebe 2003, Benda, Vysoký 2000, Härtel et al. 2007). A wide range of scientific papers have been published in various journals, nevertheless, a significant part of existing records is still not published and is available only in databases.

Within the research and monitoring activities two types of projects can be distinguished: (i) long-term research focusing mainly on inventory and mapping of flora, fauna and habitats of the region (these activities are usually financed from different sources in both countries, however, based on an agreed methodology), (ii) short-term projects (undertaken usually by external subjects and financed from transboundary EU programmes such as Interreg or Ziel 3).

An example of a long-term biological research is the mapping of vascular plants started in 1991 with the aim to publish a transboundary regional flora inventory (the floristic database comprises more than 300 000 records; see Fig. 1 for an example). Within the project, several studies have been undertaken aiming at mapping of critical taxa (e.g. Rubus, Pteridophyta) in collaboration with external specialists and institutes (Institute of Botany Průhonice, Czech Academy of Sciences, Arcto-Alpine Garden Chemnitz etc.). The most important data on plant distribution, including new species for the Czech Republic and Germany, have been acquired for cryptogams. In particular, bryophytes and ferns find in the Elbe Sandstones an important centre of diversity. Important records have been collected for algae and fungi as well. Lichens are monitored not only from the diversity point of view, but also as indicators of improving air quality.

There is a very detailed knowledge about the distribution of vertebrates in the Elbe Sandstones. Long-term ornithological research focuses not only on mapping the diversity of birds within the region but also on specific monitoring of populations of rare and threatened species, such as black stork, eagle-owl or Peregrine falcon. Through the bird ringing, the Elbe Sandstones region is involved in international ornithological activities. Recently, trail cameras documented presence of rare mammals such as lynx (Fig. 2) or otter. Migration of several species, such as wild boar and red deer, is monitored by telemetry technology.

In the last decade, an intensive research on various groups of insects and other invertebrates brought many new records not only for the Elbe Sandstones but also for broader regional or even Central European context and documented a rich insect diversity of the Elbe Sandstones. The most important findings have been recorded for Coleoptera, Lepidoptera, Odonata and Orthoptera.

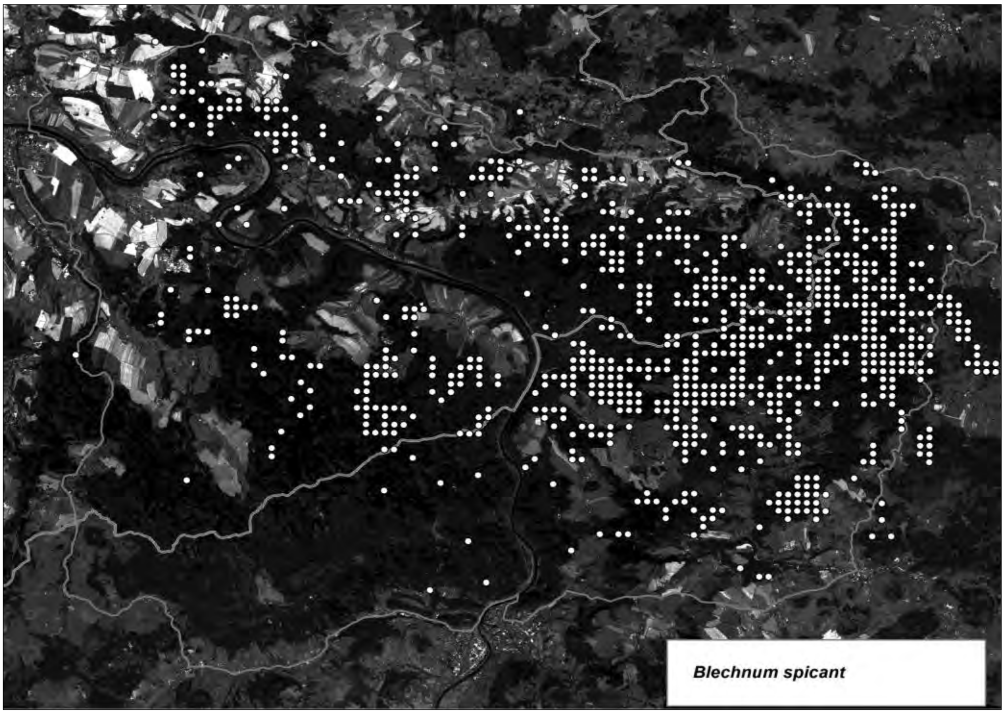

Fig. 1. Distribution of *Blechnum spicant* in the Elbe Sandstones. An example of the transboundary plant species distribution project.

Several research projects have focused on specific habitats. A special attention was paid to peat-bogs, where a complex inventory has been undertaken (hydrogeology, plant communities, vascular plants and bryophytes, insects) as well as for wetlands, including the extraordinary species-rich Elbe River valley (Fig. 3).

Fig. 2. Picture of Lynx taken by a trail camera in the Bohemian Switzerland National Park (2011).

Fig. 3. The almost unregulated Elbe River valley in the Elbe Sandstones hosts unique habitats and rich species diversity (Photo by Petr Bauer).

The forests represent the most important habitat type in the region, in particular in both national parks. Therefore, several projects have been running in the last two decades, such as mapping of the potential natural vegetation in the Saxon Switzerland national park (project by TU Dresden project), resp. mapping of the natural forest vegetation types in the Bohemian Switzerland national park (project by ÚHUL institute). Also further projects aimed at the reconstruction of natural forest vegetation in the Elbe Sandstones, basing on the forest history investigations (transboundary project by TU Dresden & Institute of Botany Průhonice), as well as on pollen analyses (project by Charles University Prague). Thanks to these projects, there is a basic understanding of the original vegetation and its changes during the Holocene. This forms an important base for reconstruction management in both Saxon and Bohemian Switzerland national parks.

Other monitoring and research activities in forests focus on practical management issues, such as invasive species projects (in particular *Pinus strobus*), monitoring of the bark-beetle population and of the plots attacked by the bark-beetle as well as monitoring of a large fire place (2006) in Jetřichovice (Bohemian Switzerland NP) left to natural succession.

A special attention has been paid to deep gorges. This habitat is studied within the project supported by the EEA/Norway grant (Complex monitoring of the natural environment of the Bohemian Switzerland NP). These studies focus interactions between biota and microclimate in the very specific environment of deep sandstone rock gorges and on particular species depending on the climatic inversion in gorges.

Recent projects, lead by the Technical University in Dresden, dealing with GIS data and in particular with digital terrain model of the Elbe Sandstones represent an extraordinary important tool for further biological and geomorphological research and monitoring.

Several projects concentrate on specific threatened species requiring recovery plans (e.g. local silver fir population) or reintroduction programmes – this was the case of successful comeback of two species: Peregrine falcon forming today in the Elbe Sandstones one of the most abundant populations in Central Europe and Atlantic salmon having in the Elbe River and its tributaries the only occurrence in the Czech Republic.

Conclusions

The biological research and monitoring in the Elbe Sandstones (Saxon-Bohemian Switzerland) encompass a large thematic spectrum from basic mapping of flora and fauna to scientific projects lead by academic institutes and universities focusing on population biology, ecological and taxonomic studies, palynology, GIS analyses etc. These activities cover not only both national parks but also the adjacent protected landscape areas and they represent an important base for decision making in practical conservation work. The transboundary scope of many research/monitoring projects is of extraordinary importance for joint management practices and joint conservation approach in Saxon and Bohemian Switzerland.

A more detailed overview of biological research/monitoring results in the Elbe Sandstones has been published e.g. by Riebe et al. (1999), Härtel et al. (2007) and Bauer et al. (2008).

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Central European sandstone regions as islands of montane and Atlantic floristic element

Abstract: The biogeographic importance of Central European sandstone regions does not consist in high species richness but in very specific species composition. This is obvious in two frameworks: (i) sandstone areas in a broader biogeographic context, (2) vegetation pattern and ecological conditions within a sandstone area. In deep, cold and wet gorges in sandstone rocks, two elements play the key role: montane/Alpine and Atlantic. Several Atlantic and Alpine (or Arctic-Alpine) species find in the Central European sandstone regions their isolated occurrence. Some Atlantic species find here the easternmost limit of distribution, while several montane or even Alpine species have in the deep rock gorges, particularly in the Elbe Sandstones, their lower vertical limit of distribution, at least within continental Europe.

Background

Central European sandstone landscapes forming the Bohemian Cretaceous Basin represent a good example of very specific eco-phenomenon ('sandstone phenomenon') with strong relation between relief and biota. Nutrient-poor substratum of quartzose sandstone (*Quadersandstein*) results in low alpha-diversity (species richness) of some taxonomic groups, such as vascular plants, while the steep gradients between very different types of environments enable high beta-diversity (diversity among habitats) of sandstone habitats. This contrast is reflected in several aspects of species composition in a sandstone rock ecosystem: (i) at the local level, various chorological elements interchange over a small area, (ii) at the landscape level, regions with sandstone rocks form pronounced ecological islands with typical consequences to species composition. There are quite many species significant from the biogeographic point of view, such as relics and species with isolated occurrence (exclave elements) (Härtel et al. 2007, Härtel, Marková 2005). These species can recruit from different biogeographic elements, however, in sandstone rock habitats it is the case mainly of Atlantic (oceanic) and montane/Alpine elements.

Results

The presence of montane or even Alpine, resp. Arcto-Alpine species in Central European sandstone areas is a consequence of climatic inversion in deep gorges. This is documented by several microclimatic measurements carried out in the area of Elbe Sandstones (Saxon-Bohemian Switzerland), recently carried by J. Wild and his team. Daily and seasonal dynamics of near-ground air temperature and soil moisture is monitored by more than 400 standalone stations every 30 minutes from 2010. Preliminary results show that not only temperature inversion but also maintaining of relatively warm climate during winter period contribute to specific stable humid and relatively cold climate of valley floors.

There are several montane species of vascular plants related to the gorges with climatic inversion: *Viola biflora*, an Arcto-Alpine element (ascending in Caucasus up to 3300 m a.s.l.), is probably one of the best examples. The species occurs in the Elbe Sandstones at its lowest Central European site (app. 130 m a.s.l.). The distribution of *Streptopus amplexifolius* within Europe is restricted to mountain ranges, while its distribution in Eastern Asia and Northern America covers also the boreal zone. Therefore, the occurrences of *Streptopus amplexifolius* in the deep

Fig. 1. Deep gorges in the Elbe Sandstones form a unique ecosystem with specific habitat conditions resulting in the inversion of vegetation belts and rich flora of cryptogams (Photo by Václav Sojka).

gorges of the Elbe Sandstone represent probably the lowest European or at least Central European localities. Among bryophytes, there is a whole range of species related to inversion gorges as the bryophytes evidently better respond to the very fine habitat pattern determined by differences in microclimate of the sandstone rock area than vascular plants. Some of them occur at the lowest Central European localities in the Elbe Sandstones. The best example is the liverwort *Hygrobiella laxifolia,* a montane-Arctic species growing typically in sub-Alpine to Alpine belt (1500 – 2500 m a.s.l.), however, in the Elbe Sandstones descending to the altitude of only 140–290 m a.s.l. (Müller 2003). These sites represent the lowest occurrence of this species within continental Europe. Other examples of montane-boreal, montane-Arctic or montane-Alpin-Arctic elements reaching in the Elbe Sandstones the Czech or Central European minimum of their vertical distribution include e.g. liverworts *Anastrophyllum michauxii, Geocalyx graveolens, Harpanthus scutatus, Lophozia grandiretis,* and mosses *Brachydontium trichodes, Dicranum fuscescens, Dicranum majus, Hylocomium umbratum* – newly discovered in 2011 by Němcová and Marková (Němcová 2011), *Pseudobryum cinclidioides, Rhabdoweisia crispata* and *Rhytidiadelphus subpinnatus*.

Similarly, the (sub)-Atlantic element is frequently represented within the flora of Central European sandstone regions. Several (sub)-Atlantic species reach in these sandstone regions their easternmost limit of distribution. Among cryptogams, two fern species *Hymenophyllum tunbrigense* and *Trichomanes speciosum* (gametophytes only) represent the most pronounced examples documenting the island phenomenon of the sandstone rock areas. *Hymenophyllum tunbridgense* was discovered in 1847 in Saxon Switzerland, however, 70 years later was reported as already extinct, probably also because of the excessive collection for herbaria. *Trichomanes speciosum* was reported for the first time in Central Europe in 1993 (Vogel et al. 1993) from Elbe Sandstones, in the next years almost from all sandstone regions in the Bohemian Cretaceous Basin, with the easternmost locality in Poland (Krukowski, Świerkosz 2004).

Further (sub)-Atlantic species are not specific to Central European sandstone landscapes only. However, they are often abundant in these regions compared with the surrounding landscapes. This species group include *Chrysosplenium oppositifolium, Corynephorus canescens, Galium saxatile, Hypericum humifusum, Juncus acutiflorus, J. filiformis, J. squarrosus, Lotus uliginosus, Potentilla anglica, Teesdalia nudicaulis,* among bryophytes e.g. *Plagiothecium undulatum* or *Schistostega pennata.*

Several (sub)-Atlantic species are extremely rare, e.g. *Luronium natans* or *Hypericum pulchrum* find in the Elbe Sandstones the only occurrence within the Czech Republic, among cryptogams e.g. the lichen *Cladonia subcervicornis*. Similarly, the liverwort *Kurzia sylvatica*, is known within the Czech Republic from sandstone regions only.

Fig. 2. Despite low altitudes, deep gorges of the Elbe Sandstones (Bohemian Switzerland National Park) include patches of natural waterlogged spruce forest covered with *Sphagnum* bog vegetation.

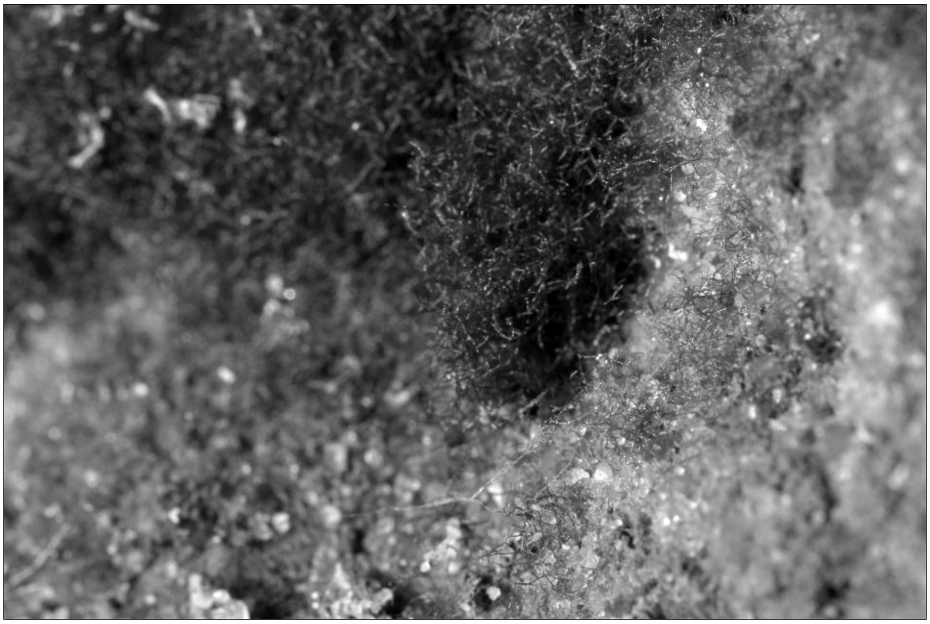

Fig. 3. *Trichomanes speciosum.* This characteristic Atlantic species is known within Central Europe only in the form of an independent gametophyte. Jánská rokle gorge in the Elbe Sandstones. (Photo by Václav Sojka).

Conclusions

Sandstone regions forming the Bohemian Cretaceous Basin represent a typically isolated refugium of montane and Atlantic species in the colline belt of Central Europe. The role of sandstone landscapes as ecological islands underpins their importance for biogeography and biodiversity conservation.

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New insights on biodiversity from old, climatically-buffered, infertile sandstone landscapes exemplified by Lesueur National Park, southwest Australia

Abstract

This paper tests hypotheses of OCBIL Theory (Hopper 2009), which aims for an integrated synthesis on the evolution, ecology, conservation and human use of biodiversity on the world's oldest, climatically-buffered, infertile landscapes (mainly sandstone and granite). The study site is Lesueur National Park, a 27,500 ha area of Mediterranean climate located near the west coast north of Perth in the Southwest Australian Floristic Region (Hopper and Gioia 2004). The national park has complex geology, with subdued uplands of Triassic and Jurassic sandstones capped by lateritic mesas, the highest being Mt Lesueur at a mere 313 m a.s.l. Lesueur National Park is a regional biodiversity hotspot of kwongan (sclerophyll shrublands) and woodlands, with 820 species of flowering plants, 15 mammals, 124 birds, 48 reptiles and 9 frog species. Among the plants, nine species are endemic to the park, 111 are regional endemics, and 81 taxa are at the limits of their geographical ranges (Burbidge et al. 1990).

OCBIL Theory predicts that biodiversity on the world's oldest, climatically-buffered, infertile landscapes will be characterised by (1) old persistent lineages, (2) rich in poorly dispersed local endemics displaying (3) accentuated speciation and (4) novel modes of conserving genetic diversity, with special adaptations to (5) nutrient poor environments and (6) saline soils, and (7) special vulnerability (e.g. to soil removal) and enhanced resilience (e.g. to fragmentation). Lesueur National Park is replete with examples illustrating these patterns.

Old lineages include species of Daspogonales and Ecdeiocoleaceae among plants, and the endemic honey possum (*Tarsipes rostratus*). Local endemics include the small proteaceous tree *Banksia tricuspis,* the mallee *Eucalyptus suberea* (Myrtaceae) and the shrubs *Hakea megalosperma* (Proteaceae), *Acacia forrestiana* (Mimosaceae), and *Asterolasia drummondii* (Rutaceae). Exceptional rates of turnover of plant species across the park's landscape occur, due to very limited seed dispersal capabilities in many lineages. For example, Mt Lesueur and Mt Michaud, less than a kilometre apart, have only 40% of their kwongan species in common.

Families in the park richest in species are Proteaceae (99 species), Myrtaceae (93), Fabaceae (57) and Orchidaceae (56), and the richest genera are *Acacia* (33), *Stylidium* (Stylidiaceae, 22), *Hakea* (21), *Melaeuca* (Myrtaceae, 20) and *Eucalyptus* (16). The flora of sandstone and lateritic outcrops, and of adjacent deep sands on old infertile upland landscapes is twice as rich in species as the flora on young more fertile landscapes such as along drainage lines with *Eucalyptus wandoo* woodland through the park. Accentuated speciation is affirmed in the old sandstone uplands.

Speciation through chromosomal divergence is evident in *Stylidium crossocephalum*. Much more work in this field is needed. Genetic diversity is conserved through adaptations to mobile pollinators such as birds and sexually-deceived male wasps, as well as through genomic coalescence mechanisms involving chromosome evolution.

Adaptations for nutrient mining in the phosphorus-limited soils of the park are diverse, ranging from cluster roots in Proteaceae and Cyperaceae, to sand-binding roots in Haemodoraceae. Complex interactions in food webs are evident, exemplified by moth larvae that feed on young inflorescences of *Banksia tricuspis* and, in turn, are food for small flocks of endangered black cockatoos. Fire is an occasional disturbance in the summer dry climate of the park, resulting in transitions through time in flowering and pollinator relationships. Early flowering post-fire opportunists such as kangaroo paws (*Anigozanthos* and *Macropidia* – Haemodraceae), and resprouting shrubs such as *Verticordia grandis* (Myrtaceae) benefit by receiving focussed attention of birds (honeyeaters) and honey possums in search of nectar. Extensive flowering of grass trees (*Xanthorrhoea* and *Kingia*) also occurs soon after fire, providing abundant nectar to insects and vertebrates. A rich halophytic flora occurs in the coastal salt lakes of the national park.

Undisturbed native vegetation in the OCBILs of Lesueur National Park has few invasive alien species. However, bulldozing and removal of the shallow topsoil reverses this situation, exposing the native vegetation not only to competition with invasive weeds, but also to the devastating root-rot disease *Phytophthora cinnamomi*. More than a quarter of the plant species in the park are susceptible to this soil-borne disease, which is transported across the landscape and is most infectious during warm wet conditions.

Land use of the region in which the national park is situated has undergone radical change since European colonization. Yued Noongar Aboriginal people lived as hunter-gatherers in the vicinity of Koomber Chiler (Mt Lesueur) for more than 45,000 years. They frequented the sandstone uplands in the winter-spring season of Djilba, harvesting edible root tubers of djooba (*Platysace juncea* Apicaceae) and warryn (*Dioscorea hastifolia,* Dioscoreaceae) from the more fertile alluvial soils, and the bulbs of born (*Haemodorum spicatum*, Haemodoraceae) from recently burnt sandplain. Detoxified seeds of the cycad *Macrozamia* (Zamiaceae) provided an edible and storable sarcotesta. Hunting and trading occurred until the first early-summer flowers of the parasitic tree *Nuytsia floribunda* (Loranthaceae) signalled the time to move to the coast.

Coastal exploration by the French Baudin expedition in June 1801 led to the sighting and naming of Mt Lesueur for the artist on board Charle-Alexandre Lesueur (1778–1846). British colonists traversed the park in 1839, but settlers avoided its uplands thereafter because of the presence of poison peas (*Gastrolobium* spp.) toxic to sheep, horses and cattle. This preserved the vegetation until it was threatened by a proposed open cut coal mine in the 1980s. After a controversial period, the national park was declared in 1991 because its rich endemic biodiversity was judged to be more valuable than the economic benefits of the proposed coal mine. Ongoing development of the national park has included placement of a new road and walk trails in the centre of the uplands, facilitating recreational access but posing considerable risk to spreading dieback disease. Ongoing scientific research, particularly by The University of Western Australia, continues to reveal fresh perspectives, accentuating the value of the sandstone upland OCBILs of Lesueur National Park.

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The system of environmental monitoring in the Stołowe Mountains

Abstract: This paper presents data (first phase of field and laboratory works) from soil monitoring system established in the Stołowe Mountains National Park. Based on 403 circular monitoring sites several soil parameters were analyzed, i.e.: thickness of forest litter, soil reaction, concentrations of available nutrients, total contents of heavy metals. Obtained data indicate high spatial variability of soil properties, soil types and concentrations of trace elements, typical for mountain soils.

1.1. Introduction and aim of study

Forest ecosystems are very fragile for any events that may cause rapid changes in ecological conditions. Storm winds and three throws, pest gradations, environmental pollution are major factors influencing the stability of tree stands. Especially airborne pollutants, by long range atmospheric transport, can seriously damage surface layers of soils (Szopka et al. 2011, 2013) and reduce their microbiological activity. To respond to the above-mentioned risks, both natural and anthropogenic, monitoring networks of forest ecosystems are set up. These monitoring systems have a few goals: to determine the current conditions of forest ecosystems, to track changes over time and to evaluate the effectiveness of management practice (Hamman, Desaules 2003, McKenzie et al. 2002, O'Neil 2005).

The main aim of the study was to provide up-to-date information about various ecological changes in the surface soil cover, with particular emphasis to concentrations of heavy metals in the Stołowe Mountains National Park (SMNP). Predicting the far-reaching environmental effects, potential ecological risk and spatial distribution of soil properties were further objectives.

Materials and methods

Between 2005 and 2007 Stołowe Mountains National Park has established a system of environmental monitoring to control the present ecosystems state and their transformation under both natural and anthropogenic influences, based on the concept of Miścicki and Nowacka (2007). The 403 circular monitoring plots have a diameter 8 m for soil and 25 m for forest stand observation, and monitoring sites (centroids) are arranged in a regular grid of 400x400 m (Fig.1).

Several environmental parameters was reported on each centroid: dominant and subdominant forest species, vegetation of forest floor, forest humus type and the thickness of forest litter, soil type, soil coverage with boulders and rocks, soil parent material, vegetation of forest floor, forest humus type and the thickness of forest litter (ectohumus). Soil sampling followed the procedure proposed by Karczewska et al. (2006). Forest litter was sampled using stainless steel cylinder (diameter 17 cm) in five replicates on each plot. Mineral soil was sampled in the layers 0–10 and 10–20 cm using stainless steel gouge corer in 5–10 replicates on each plot.

Several indicators of soil chemical status were analyzed, including particle size distribution, soil pH, exchangeable acidity, the contents of organic carbon, exchangeable base cations (Ca, Mg, K, Na), plant available forms of Mg, K and P, and the total content of trace elements (Pb, Zn, Cu).

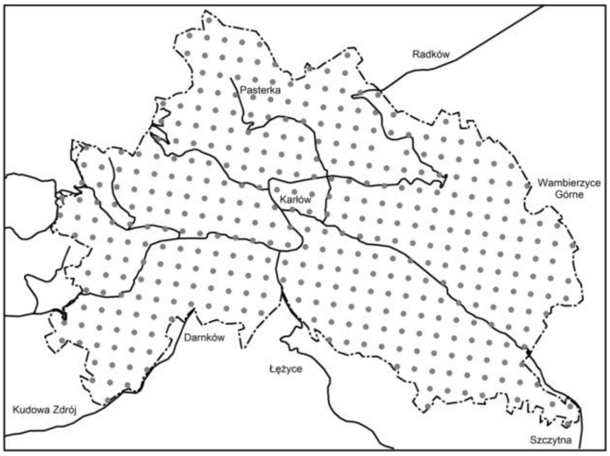

Fig. 1. Forest and soil monitoring sites in the Stołowe Mountains National Park.

Results and discussion

It was found that the distribution and abundance of the monitoring sites well represented the spatial variability of geology, soil cover and forest habitats. The soils of the Stołowe Mountains have, in general, an acidic reaction, at the average pH values of about 4.0–4.2. Negative correlation between altitude and soil pH, both in the mineral layers and ectohumus was found. Definitely it was stated that the lowest pH was in the soils under spruce stands as compared to soil under beech and sycamore forest. It was also shown that soils formed from the Cretaceous sandstones have pH slightly lower than soils formed from Permian sandstones, and significantly lower than soils derived from mudstones and granitoids. The sum of exchangeable base cations in the soils of the Stołowe Mountains is usually very low. The highest content of base cations have the soils developed of mudstone, including Eutric Cambisols, Luvisols, Gleysols and Stagnosols. The lowest amounts of base cations are present in Podzols developed from sandstones and in Dystric Cambisols derived from granites.

The content of organic matter is less connected with the type of the parent rock, but strongly depends on land use, vegetation type, climate and water conditions. The highest content was found in soils under spruce, larch and birch forests, significantly lower under beech and sycamore stands, while the lowest one – in the non-forest soils – typified meadows and pastures. Differences between these soils decrease with depth, but always the highest content of organic matter has been found under coniferous stands. Preliminary results lead to the conclusion that replacement of spruce with beech will result in a long-term reduction of organic matter in soil stock and in the associated release of carbon dioxide. The content of plant available macronutrients is probably the best indicator of soil fertility. Generally, the forest soils in the Stołowe Mountains have low (deficient) amounts of available magnesium, potassium and phosphorus. Elevated concentrations of nutrients, especially phosphorus, are usually relics from their former agricultural use and fertilization.

Concentration of heavy metals, especially of zinc, depends mainly on the type of parent rock and soil texture. The lowest amounts of metals were found in soils derived from sandstones, greater ones in soils from mudstones, and the largest ones characterize granite-derived soils. The difference between the content of zinc in soils derived from granite and sandstone is nearly fourfold. It is concluded that the generally low content of zinc in the soils of the Stołowe Mountains is similar to the natural background, and natural factors – such as bedrock and bioaccumulation – determine the spatial distribution of this element. The copper content in soils is affected mainly by parent rock. The average copper content in the mineral layers is low, about 5–7 mg/kg, and does not indicate anthropogenic pollution. However, significant dependence of copper accumulation and altitude was observed in the ectohumus layer of the forest soils. The highest concentrations of copper were found on the summit of the Skalniak ridge, in the western part of the Mt. Szczeliniec Wielki, and on the hills surrounding the village of Pasterka. These objects form a kind of an orographic barrier and are most exposed to polluted air masses coming from the west and south-west. It is expected that copper concentration will be reduced in the future in response to decreasing emissions of pollutants and regional improvement of air quality.

The lead content in mineral soil layers was only weakly correlated with the parent rock type and much more strongly with organic matter content and forest composition. The lead content is significantly higher under spruce stands (on various geological substrates) than under deciduous stands, especially at higher altitudes. These differences are most noticeable in the ectohumus layer (Fig. 2). As in the caseof copper, the highest concentrations of lead in ectohumus were found on the summit of Mt Skalniak, which is the most prominent orographic barrier for southerly air masses. As in the case of copper, significant decrease of lead content in soils is ex-

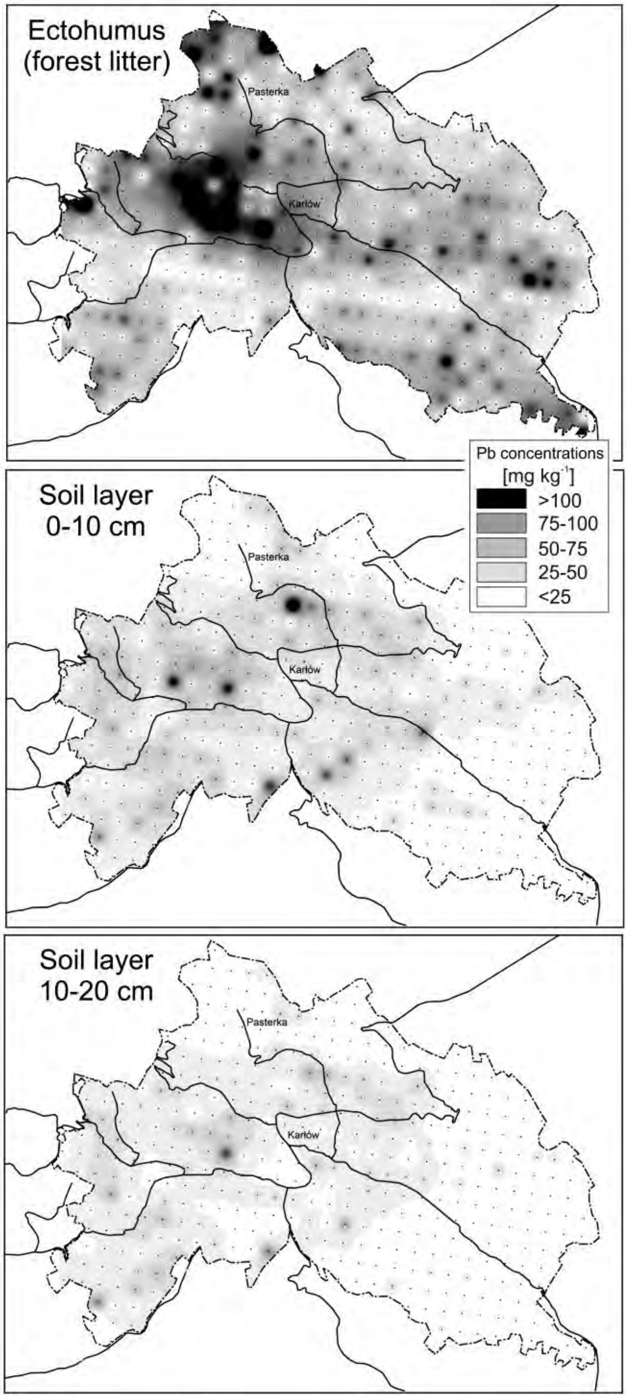

Fig. 2. Pb concentrations ($mg \cdot kg^{-1}$) in ectohumus and mineral layers (0–10, 10–20 cm) at investigated sites.

pected in the future. The impact of the main transit road on lead content in soils was much smaller than the impact of transboundary air pollution.

The first series of investigation was an inventory rather than the regular monitoring, and only repeated work, planned in 10-year intervals will have a character of a true monitoring study, and will show whether the explanation of phenomena occurring in the ecosystems of the Stołowe Mountains and the forecasts were correct. But already now, on the basis of the study and taking into account environmental considerations and economic plans, we can predict that both acidification, contamination with heavy metal, and the stock of soil organic matter will decrease in the soils of the Stołowe Mountains over the next decades.

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Micromorphological characteristics of Podzols developed from sandstone in the Stołowe Mountains (Poland)

Abstract: The concept of periglacial cover beds initiated an intensive debate on soil genesis, main soil forming processes, concept of polygenetic soils and criteria for soil classification. In this paper we show a method to identify soil layering and implications of this phenomenon. Micromorphology is a good technical tool to confirm an impact of cryoturbation and ice-segregation on slope processes on soil substrate, and sheds light on soil and landscape dynamics in the Pleistocene and Holocene.

Introduction and aim of study

Micromorphology of diagnostic horizons (albic, spodic) in Podzols has been documented in numerous papers (Arocena, Pawluk, 1991; Lundström et al., 2000; Rabenhorst, Hill, 1994; Schaefer et al., 2002; Schwartz, 1988). However, most publications concern primarily soil developed from loose sandy materials of various origins (aeolian, alluvial, glaciofluvial etc.). These findings do not always apply to soils formed from saprolites or cover-beds (Kleber, 1992; Mailänder, Veit, 2001) in the mountain environment. Especially in mountains, where bedrock plays a crucial role in soil formation, different slope deposits bearing features of frost action, solifliction, debris flow, landslides etc. can act as parent materials for soils. In these cases, verification of material origin based on micromorphology is very important.

The main objective of this paper is to characterize the micromorphological features of Podzols formed from sandstone saprolites or/and slope deposits in the Stołowe Mountains and to explain genesis of these soils, whether they formed from homogenous substratum or stratified slope materials. It is the first such work carried out in this area and on such soils in Poland.

Methods

Five soil profiles were located on slopes of Mt. Rogacz (so-called Skalne Grzyby area) in the Stołowe Mountains National Park. Pedons were described according to FAO Guidelines (2006), and soil reference groups were established using the FAO-WRB classification (IUSS, 2006). Particle size distribution of the 2 mm fraction, after removing organic matter, was conducted in water suspension with addition of heksametaphosphate-bicarbonate and sample dispersion. After that, hydrometer method and sand preparation on sieves were applied. For micromorphological analysis, undisturbed samples were collected with Kübiena boxes from selected mineral horizons and at various depths. The tins were air dried, impregnated with Araldite 2020 and sliced into thin sections. These were described under petrological microscope and terminology by Stoops (2003) was used.

Results and discussion

All describe pedons have soil morphology and properties associated with Podzols and suggest intensive eluviations and illuviation of soil constituents. Above the mineral substratum dark organic horizons (O) can be distinguished, beneath them light grayish (10YR 6/3, 2,5Y 8/1) albic horizons with single grain structure and texture of sand (with low addition of rock fragments, 5–30%). In almost all E horizons redoximorphic features were found, caused by poor drainage resulting from underlying dense spodic horizons. Subsurface B horizons are darker (10YR 2,5/2, 7,5YR 3/4), have strong platy structure, higher content of skeleton (up to 95%) and often sandy loam texture. Usually between E and B horizons abrupt or wavy and sharp boundary can be visible.

Microstructures of uppermost albic horizons were initial and consist of well sorted quartz grains, usually loose (Fig.1a), but sometimes bridged with finer material (silt), often with addition of organic matter. The c/f-related distribution was *coarse monic* to *single spaced porphyric/equal enaulic* (Stoops, 2003) and typical for the strongly leached E layers (DeConnick, Mc Keague, 1985). Plant remains were generally strongly fragmented and not recognizable. However, spherical charcoals and other larger charred plant remnants were found in nearly all thin sections, indicating frequent fire events during or before the formation of uppermost mineral soil layer. The volume of fine particles infilling spaces between larger quartz grains increases in the lower part of E horizons, at the transition to the illuvial Bh horizons.

In the subsurface illuvial horizon microstructures of soil matrix were very variable, depending mainly on the morphology of the soil. *Chitonic* and *enaulic* were most common c/f-related distributions in Bh horizons (Fig.1b), developed in loose or nearly loose sands on the plateau. The coarser grains have typical cracked organic coating of various thickness, or are bridged with fine earth particles and organic matter. The coatings are often reddish or brownish coloured due to saturation with free iron compounds, as documented by chemical analysis. However, relationships between fine and coarse distribution patterns are significantly different, in comparison with Podzols from central and eastern Europe developed from sand. In some thin sections, angular/subangular macro aggregates could be recognized, caused by large accumulation of organic matter very similar to Ah and AB horizons identified by Kowaliński (1969) in the Cambisols (acid brown earths) in the Karkonosze Mountains. Spodic subhorizons (Bhs, Bs) are cemented and whole spaces between quartz grains are filled with silt and clay material. Micromass is strongly saturated with iron or aluminium oxides and organometallic complexes (Fig.1c), which protect mineral grains against weathering (McKeague et al., 1983). In some deeper horizons (Bs) grains occur separately and have well preserved silt coatings (Fig.1d) on all surfaces, a phenomenon related to frost sorting processes (Van Vliet-Lanoë, 1998) and suggested to develop during long-term transport (non-laminated and with no convergent grains) (Drewnik, 2008).

Based on micromorphological investigations two separate layers can be distinguished in the examined Podzols: (1) relatively young upper layer, consisting of loose, fresh sandy material (product of sandstone weathering), transported and formed probably in late Holocene (charcoal presence) and (2) deeper, dense layer hosting spodic horizon with cryogenic pedofeatures (silt capping and platy structure) of Pleistocene age. This unusual microstructures and other features, combined with lithological discontinuity, support the opinion on the polygenetic origin of Podzols in Stołowe Mountains.

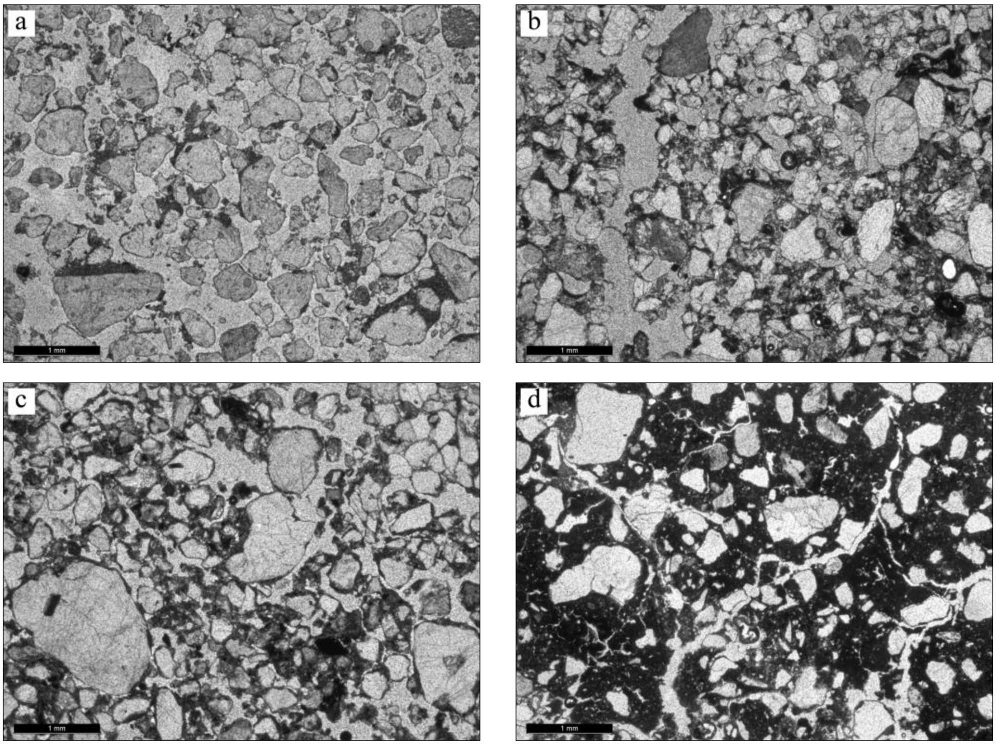

Fig. 1. Micromorphology of soils: (upper left) *single grain microstructure* in upper layer – SG2 profile, (upper right) initial bridges of organic matter and fine material between quartz grains in the transition zone between Es and Bhg horizon creating *chitonic/fine enaulic* microstructure, (lower left) well sorted mineral grains totally covered with silt material in Bs horizon, (lower right) highly compacted and impregnated micromass with iron oxides and organic matter (Bhs horizon).

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Impact of sandstone bedrock on the properties of cover deposits and soils in flysch catenas – examples from the Carpathians

Abstract: The study shows that important properties of cover materials being soil parent material in lower slope facets are visibly related to the properties of sandstones dominating in upper parts of slopes and differ from the properties of weathered bedrock underlying soil profiles. The influence was observed in soil texture, mineral composition of fine earth, lithology of coarse fractions and basic chemical characteristics.

Introduction

It is usually assumed that soil properties are closely related to the properties of rocks directly underlying a soil profile and consequently the rocks are termed 'parent material'. Any gradients of soil properties within a profile are thought to be results of vertical movement of water. This may not be true in many cases where slopes are mantled by layers of cover materials, which may have been transported even considerable distances downslope. Such mantles are presently often termed as 'cover-beds' (Kleber, 1992) and attract a growing interest of soil scientists, geologists and geomorphologists.

This study aims to evaluate the influence of sandstones dominating the bedrock in upper slope facets on the properties of cover materials mantling slopes in their lower sections, underlain by shale-dominated flysch layers.

Study area and methods

The study uses results obtained in two areas (fig. 1), located in different parts of the Carpathians but sharing a similar model of slope geology with sandstones dominating the summit and shoulder parts and shales building foot- and toeslopes. These areas are typified by significant lithologic contrasts and the occurrence of well-developed cover-beds (Kacprzak and Skiba, 2001; Kacprzak et al., 2010). The northern slope of Mt Góra Zamkowa (Wieliczka Foothills, western part of the Polish Carpathians) is built of sandstones and cherts of the Lhoty formation in its upper part, while the lower part is formed on clayey shales of the Variegated

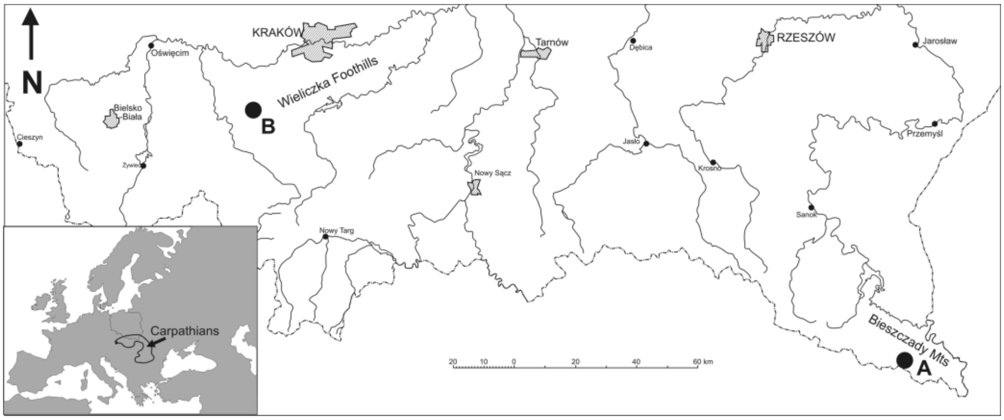

Fig. 1. Location of the investigated catenas. A – Mała Rawka, B – Góra Zamkowa.

Shales formation. On the northern slope of Mt Mała Rawka (Bieszczady Mts, eastern part of the Polish Carpathians), thick beds of the Cisna sandstones overlie fine-bedded and clayey flysch layers of the Lower Krosno beds and menilite shales.

The main soil characteristics analyzed in the study were particle size distribution, organic carbon content, soil pH and carbonate content. For selected soil horizons mineral composition was determined using the XRD method. Soil morphology and lithology of rock fragments were also taken into consideration.

Results

In the investigated areas, the depth of cover deposits and soils significantly increases downslope. Based on profile morphology, first of all colour, development of soil structure and observed consistence, it is possible to distinguish two main components of soil profiles along the slopes – surficial slope materials (cover-beds) and underlying autochtonous regolith which is a product of bedrock weathering.

The soils contain large amounts (often above 50%) of rock fragments, being the highest in the uppermost part of the catena and on steep sections of slopes. In the profiles located in foot- and toeslopes the lithology of coarse fractions differs within soil profiles – in the bottom profile sections it matches the bedrock, while in the top and middle sections sandstone or chert clasts dominate, matching the lithology of layers occurring upslope.

Soil texture in the upper parts of soil profiles is dominated by sand and silt fractions, despite the large fractional diversity of the flysch bedrock. On the other hand, vertical differences in particle size distribution within the investigated profiles were observed, proving the occurrence of lithologic discontinuities between the in situ regolith and cover materials, as well as within the cover materials themselves (Fig. 2). These discontinuities are observed in the lower slope sections, while in the shallower profiles in the upper, sandstone-dominated parts soil texture is more uniform within the profiles.

The mineral composition of top parts of profiles in the studied catenas is quite homogenous, being dominated by quartz. In the summit and shoulder parts the mineral composition of the soil profile and weathered bedrock is similar. In the footslope profiles, the mineral composition of the upper part of profiles corresponds with these of the profiles at summit and shoulders. At the same time, it is different from the composition the weathered bedrock (Fig. 3). The quantitative analysis of mineral composition proves the existence of discontinuities related to a various genesis of particular layers of slope materials, i.e. cover-beds.

The layers of cover materials occupied by the major part of the solum are remarkably richer in quartz, K-feldspar and plagioclases, while the bottom layers (usually 2C) are typified by a larger content of di-micas and smectites (Tab. 1). Some differences as e.g. the lack of biotite except the lowermost horizons could be explained by a more advanced weathering closer to the surface. However, normally an increase in clay minerals is interpreted as a result of more advanced pedogenesis, but in the investigated areas bedrock-derived regolith contains more clays than the solum formed in cover-beds whose characteristics are related to the properties of sandstones in the upper parts of slopes. Moreover, the changes in mineral composition are abrupt rather than gradual and follow the discontinuities distinguished on the basis on profile morphology.

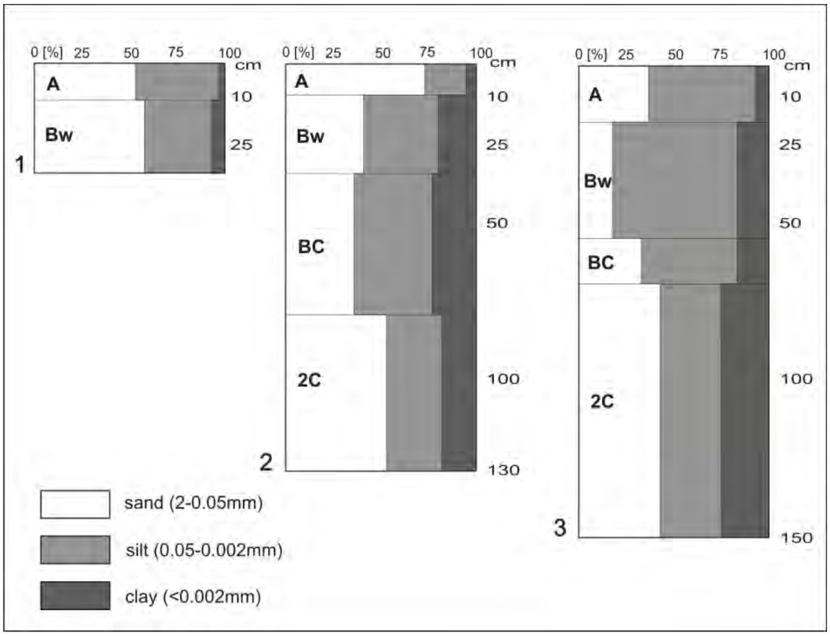

Fig. 2. Differences in soil texture in the catena of Mała Rawka. Profile 1 – summit, profile 2 – footslope, profile 3 – toeslope.

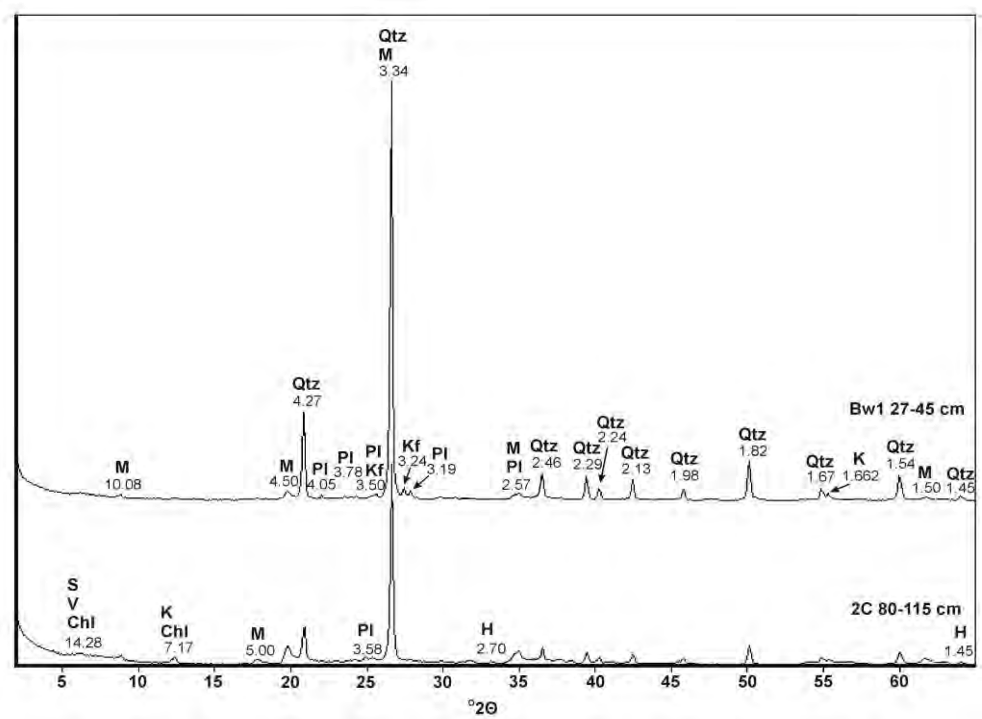

Fig. 3. Differences in the mineral composition of soil horizons formed in cover materials (Bw1) and shale bedrock (2C) – Góra Zamkowa footslope. Qtz – quartz, M – micas, Pl – plagioclases, Kf – K-feldspar, S – smectite, V – vermicullite, Chl – chlorite, K – kaolinite, H – hematite.

Tab. 1. Quantitative mineral composition of selected soil horizons.

Horizon	Depth (cm)	content (%) Quartz	K-feldspar	Plagioclases	Di-micas	Biotite	Chlorite	Kaolinite	Smectite	Hematite	Other
Góra Zamkowa – backslope											
Bw1	14–40	77,45	3,79	3,38	2,99	0,00	1,14	0,35	10,60	0,00	0,30
BC	67–90	64,90	2,14	1,77	7,25	1,45	2,35	1,74	18,00	0,00	0,40
Góra Zamkowa – footslope											
AB	5–27	66,87	6,62	3,92	4,52	0,00	1,81	1,88	14,38	0,00	0,00
Bw1	27–45	66,39	5,68	4,39	5,86	0,00	2,03	1,87	13,78	0,00	0,00
Bw2	45–66	59,85	5,63	4,03	8,54	0,00	1,50	2,55	16,70	0,00	1,20
2BC	66–80	43,64	2,52	1,73	14,14	0,00	3,79	4,57	28,94	0,57	0,10
2C	80–115	39,29	1,50	1,01	13,45	2,41	3,88	5,70	32,17	0,59	0,00

Taking into consideration the dominant content of quartz and the large content of silt in the earth fraction (often exceeding 50%), aeolian admixture cannot be ruled out. As in the investigated catenas the contribution of silt increases with diminishing distance to the valley floors, it would suggest short–distance transport from river beds in drier periods, under periglacial climatic conditions. The quartz-rich materials blown out of the river beds were products of mechanical weathering of sandstones occurring in the upper sections of valleys, so it is another, though indirect, impact of sandstone layers from upslope on the characteristics of cover-beds along the whole length of slope.

The differentiation of soil profiles into two parts is also visible in their chemical characteristics with pH being the parameter giving information in a way simple to measure. Soil pH in the profiles developed on sandstones is low (c. 4,0–4,5) and it remains so within the top sections (c. 50 cm) of profiles located down the slope, where there is a large difference between soil pH of the surficial section consisting of transported cover material and the bottom sections of profiles which owe their characteristics to the properties of bedrock underlying the profiles.

Organic matter in the studied profiles is concentrated in the topmost parts, in thin (c. 10 cm) A horizons, while the content of organic carbon as a rule does not exceed 1% in Bw horizons down to a depth of 50 cm. A large majority of roots is found in the parts of profiles developed in the more acidic cover materials which emphasizes the fact that it is the cover units that constitute the habitat for plants vegetating the slopes.

Conclusions

The presented data prove that cover deposits – transported and transformed by morphogenetic processes – constitute the parent material of soils occupying most of the investigated slopes.

The properties of these deposits, particularly texture and mineral composition, are to a large extent controlled by the properties of sandstones even though they only built the uppermost parts of the investigated catenas.

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Transboundary Education for Nature Conservation and Sustainable Development

Abstract

Within the project TREND (2009–2012) a series of activities in environmental education in Saxon-Bohemian Switzerland and the Lusatian Mountains was developed. The partners organize various bilingual programmes such as expert lectures and excursions providing valuable information about geology, flora, fauna and aspects of the cultural landscape, focusing on the unique transboundary sandstone region. The goal is to raise awareness of the sensitive landscape by children, youth and adults.

During expert lectures participants receive information about current results of researches or studies on the Saxon-Bohemian Switzerland. It is also a means of cross-border exchange between experts and people interested in nature enabling to discuss different versions, give suggestions and close new contacts. Topics discussed are e.g. archaeology and settlements, visitor management, habitats for flora and fauna, etc.

Expert excursions give the opportunity to visit special places of the regional history (fortresses in stone), first settlements (archaeological finds) and learn about landscape changes (protection of processes, monocultures, mixed or nature forests), as well as to discuss the national park philosophy.

The goal of educational programmes is to support children and youth in the understanding of geological processes, the national park philosophy and the necessity to protect our sandstone landscape. They learn e.g. by doing experiments, with the help of working sheets or special elements in the exhibition. The programmes are based on the curricula, but are taking place outside the school.

An additional module to develop awareness of the unique nature of the Saxon-Bohemian Switzerland sandstone landscape is a mobile exhibition. Topics are geology, flora, fauna and interaction with man, disposed on separate panels. The part on geology focuses on the development of the sandstone mountains by water, sand, pressure within a timespan of nearly 100 million years. Fossils are contemporary witnesses of the past. Rain, freeze and wind were and are the creative directors. In the topic fauna various habitats, endangered and successfully re-introduced species like peregrine falcon and salmon are presented. The Saxon-Bohemian Switzerland

also provides a rich diversity in flora due to the special landscape character and climate. The so-called 'cellar climate' in the relatively shady and wet, steep canyons of the national park region provides the necessary living conditions for many specialised species, amongst which several glacial period relicts are the most outstanding ones. The category interaction with man shows different cultural aspects, which can be found in landscape and architecture; the traditional 'Umgebindehaus' representing a good example for a mixed Slavic–German cultural development.

The project TREND is founded by European Union within the programme Ziel 3/ Cíl 3 with a total budget of 1.288.634,35 EUR. Lead partner is the Saxon Regional Conservation Foundation, National Park Information Centre Saxon Switzerland (GER). Project partners are Public Benefit Corporation Bohemian Switzerland (ČR), Association for Nature Conservation of the Upper Lusatian Mountains (GER) and Lusatian Mountains Association (ČR).

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Comparative morphology of sandstone tors in selected ridge-zones of the Beskid Mały Mts and the Chornohora Range (Outer Carpathians)

Abstract: The studies aim to indicate factors controlling morphology of tors in different climatic vertical zones of the Outer Carpathians. Lithology and morphology of 44 tors situated in ridge-zones of the Beskid Mały Mts and the Chornohora Range were studied. Though almost one-kilometer difference in altitude between the investigated areas, similarities of selective weathering features are distinct. It suggests that influence of geological factors is prevailing. Asymmetrically developed microforms at tors situated in the subalpine zone of the Chornohora Range are related to climatic factors.

Aims and methods

Spectacular sandstone tors are widespread in the Outer Carpathians but a question remains, as to what extent does the altitude affect their morphology? The aim of the study was to indicate the diversity of factors controlling morphology of tors located in selected ridge-zones of the Beskid Mały Mountains and the Chornohora Range (Fig. 1). For this purpose, a comparison between morphology of tors have been attempted. The 44 tors were examined in a detailed way, with the use of simple methods and tools, with particular focus on lithology and morphology.

Areas of interest

Location. The research was carried out in the E part of the Beskid Mały Mountains in the Western Outer Carpathians, along the main, monoclinal ridge of the range (Fig. 2). The research area was located at the altitude of 800–920 m a.s.l., in the lower montane forest zone, in the temperate climate zone. The second area of interest was located in the SE part of the Chornohora Range in the Eastern Outer Carpathians, within three monoclinal ridges heading NE from the ridge (Fig. 9). All examined tors are situated at the altitude of 1500–1850 m. a.s.l., mainly above the timberline in a severe climate of the alpine zone.

Fig. 1. Location of the Beskid Mały Mountains (A) and the Chornohora Range (B).

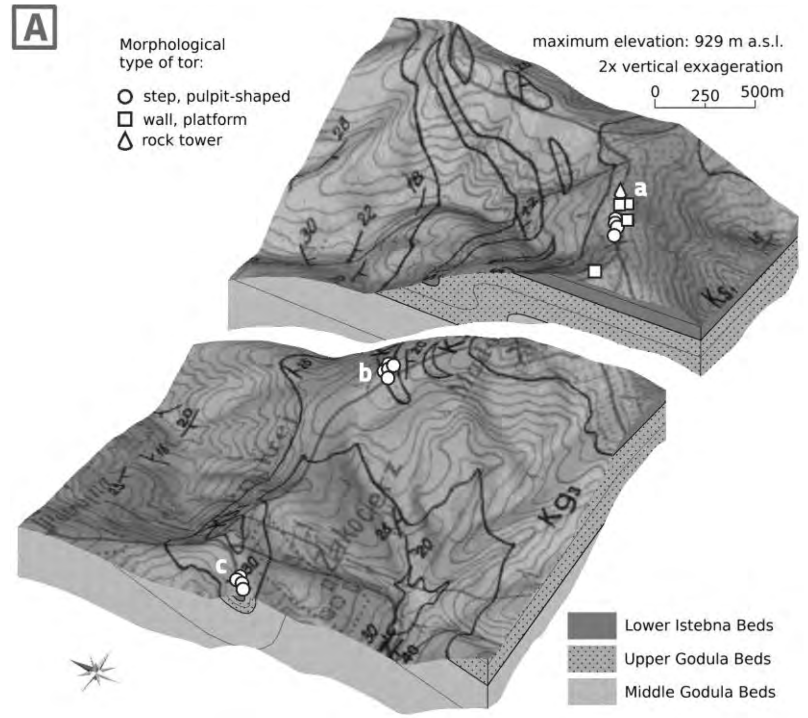

Fig. 2. Situation of the examined tors along the main ridge of Łamana Skała in the Beskid Mały Mts. Based upon Książkiewicz (1951). Types of tors according to the morphological classification by Alexandrowicz (1978). 3D visualizations prepared using Petrel software provided by Schlumberger.

Lithology. The examined tors are outcrops of medium- to thick-bedded sandstones and conglomerates. All dip toward SSW and SE at angles 20° to 35°. Distance between fissures ranges from 1.0 to 3.5 m. Sandstones are predominantly medium- to coarse-grained, quartz-rich, with feldspars and micas. Conglomerates of the Chornohora series are massive, fine to coarse-grained, with fragments of quartz, crystalline rocks and clastic rocks, including marls, cemented by various minerals (Sujkowski 1938, Liszkowski et al. 2003). Conglomerates of the lower Istebna beds are middle to coarse-grained with fragments of quartz, quartzite and gneiss, cemented by fine ferruginous minerals (Ksi ż kiewicz 1951).

Tors in the Beskid Mały Mts

In the Beskid Mały Mts three clusters of tors were investigated. They are located near the summits of Smrekownica, Łamana Skała and Beskid (Fig. 2). All of them belong to the the lower Istebna beds (Upper Cretaceous) of the Silesian Nappe (Ksi ż kiewicz 1951).

All clusters of tors are linear, mainly parallel to the ridge-axis (Fig. 2). The prevailing types of tors are pulpits and steps. Their height typically does not exceed 3 m (Fig. 6). Steps are the highest crags in the investigated area. They are elements of the main scarps of landslides exposed to the north (Fig. 3b). The other tors (e.g. tables and walls, located along the ridge-axis) are of monadnock type (Fig. 3a).

Tors in the Chornohora range

In the Chornohora Range three adjacent clusters of tors were investigated. They are located in ridge-zones of Kedrovaty, Stepanec and Vukhaty Kamin (Ear Stone) (Fig. 5). All of them are exposures of the Chornohora series (Upper Cretaceous) of the Hoverla Unit of the Chornohora Nappe.

The investigated clusters of tors are mostly irregular, rarely linear. Tors usually take shape of towers or pulpits. Their height typically does not exceed 4 m (Fig. 6). The highest tors are located at the ridge-axis, above wide valley heads. They are probably of monadnock type.

Microrelief of tors is lithologically controlled. Conglomerate outcrops have rounded and sub-rounded shapes, mainly as a result of granular disintegration. Sandstone outcrops are angular as a result of block disintegration. Directions of sandstone walls correspond to joints. Widened joints are rare in sandstone beds – they occur only in rock steps as a result of toppling. In conglomerates widened joints are more frequent. Vertical joints let water infiltrate easily inside the rock. Along them niches and rock shelters were created, especially in the basal parts of tors. Their

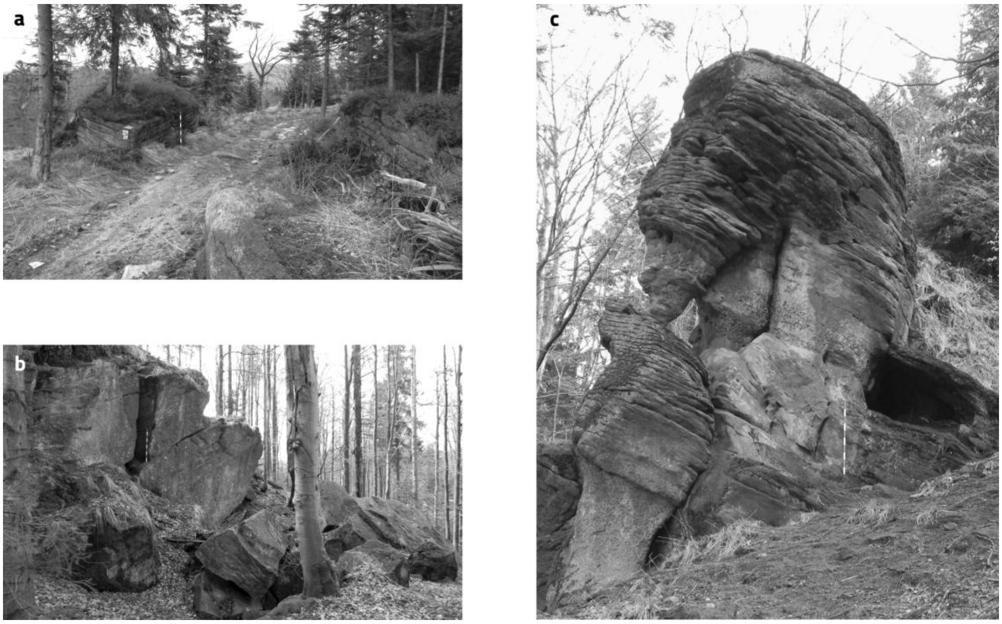

Fig. 3. Morphological types of tors in the Beskid Mały Mts. (a) Sandstone walls and tables at the ridge-axis; (b) Angular sandstone step with toppled boulders below – head scarp of a complex landslide; (c) Pulpit-shaped tor Zbójeckie Okno (Robber's Window), with a pillar and rock shelter into the conglomerate layer.

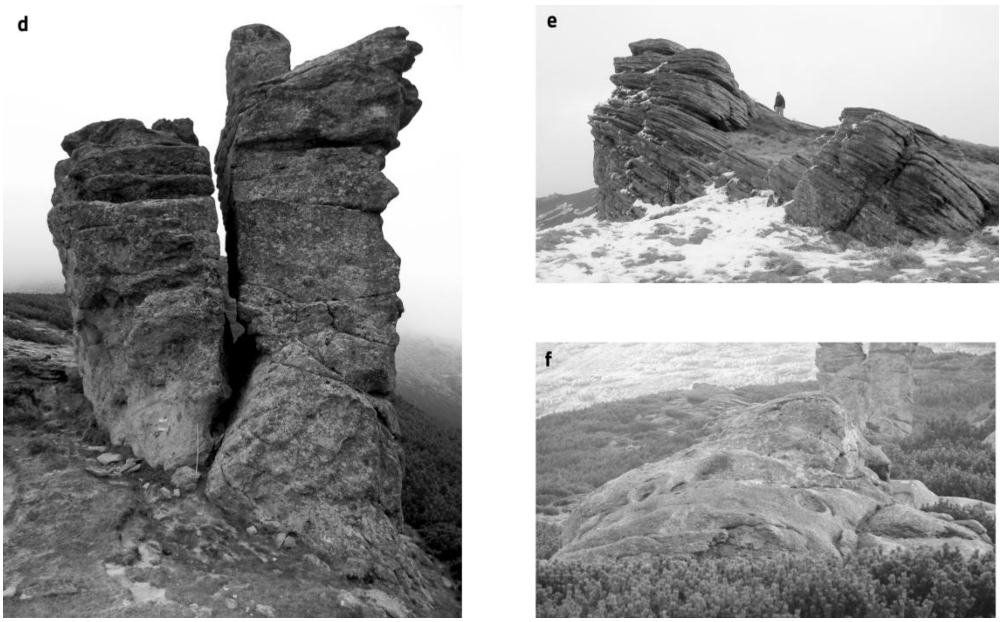

Fig. 4. Morphological types of tors in the Chornohora Range. (d) Rock tower called Vukhaty Kamin (Ear Stone) dissected by a widened joint; (e) Pulpit-shaped tors at the Stepanec Ridge; (f) Conglomerate tor called Zhaba (Frog), with many rock-basins (weathering pits).

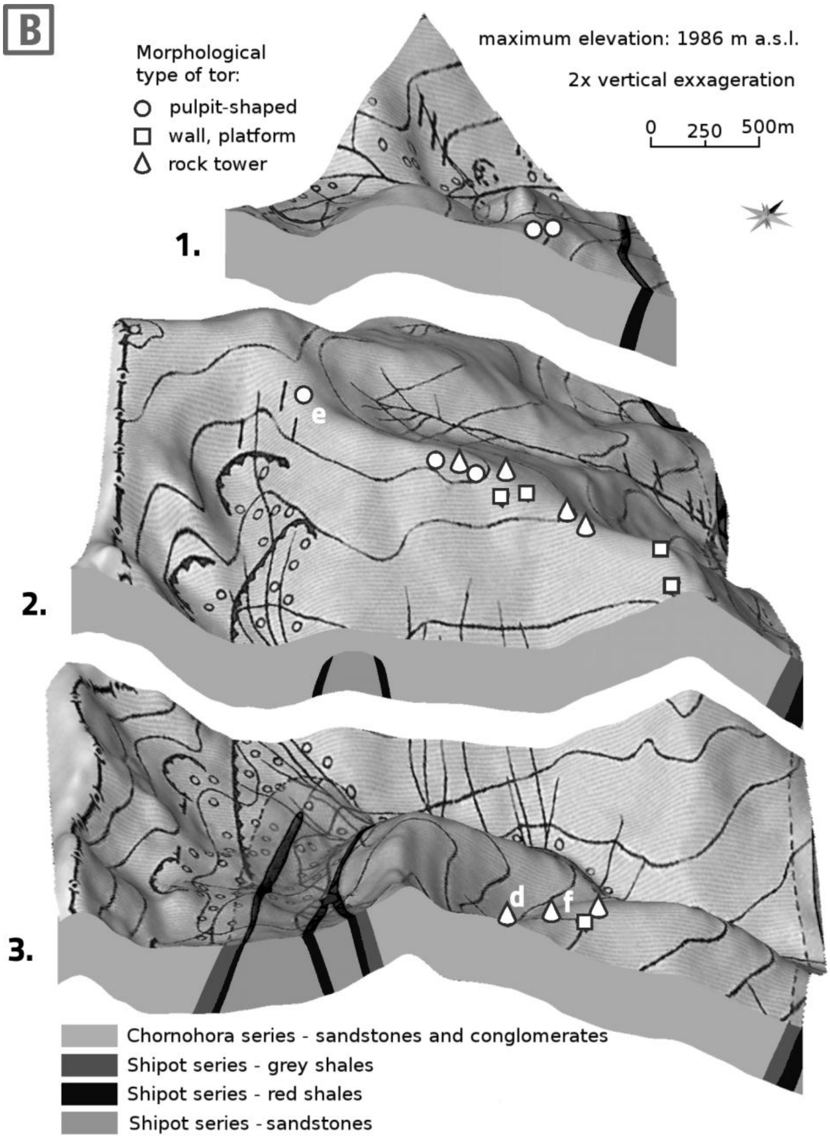

Fig. 5. Setting of the examined tors at the Vukhaty Kamin (1), Stepaniec (2) and Kedrovaty (3), the NE-side of the Chornohora Range. Based upon Z. Sujkowski (1938).

depth does not exceed 2.5 m. Rock pillar in the tor called Zbójeckie Okno is a remarkable feature of selective weathering in conglomerate (Fig. 3c).

Tors in the Chornohora Range show a large diversity of surface microforms. Widened joints in sandstone tors are very frequent, despite their setting relative to the ridge axis (Fig. 4d). Rock shelters occur at joint intersections, or under tilted fragments of massive beds. Flutes located along bedrock surfaces are distinctly deeper on the W and NW walls (Fig. 4e). Their evolution causes slab fragmentation of tor crests. Block disintegration is the result of lateral spreading or gelifuction. Conglomerate outcrops are modelled by granular disintegration, accelerated by cycles of crusting and spalling. Surface crusts are well-developed on the S and SW walls. Weathering pits occur on gently sloping top surfaces of tors (Fig. 4f). They are characteristic for thick-bedded sandstones with gravel-sized clasts. The biggest pit found (2.5 m in diameter) has originated from coalescence of a few smaller ones.

Comparison

Figure 6 shows selected results of comparative morphometric analysis of tors from the two study areas.

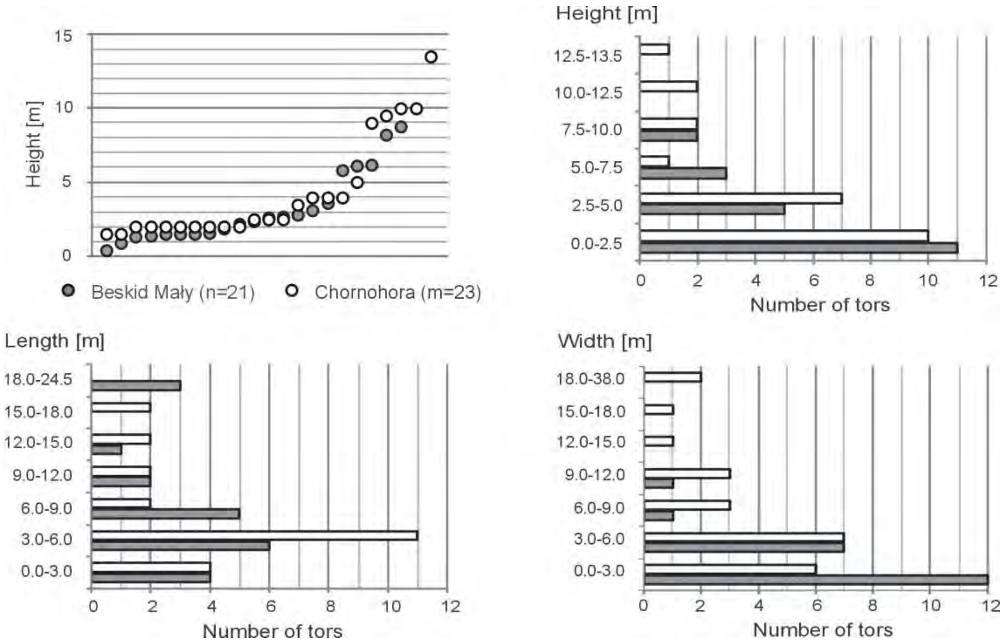

Fig. 6. Morphometric diversity of the examined tors.

Conclusions

Despite one-kilometer difference in altitude between the investigated areas, similarities of selective weathering features are distinct. Angularity of sandstone outcrops is the result of block disintegration. Rounded and sub-rounded shapes of conglomerate outcrops are mainly the result of granular disintegration, accelerated by cycles of crusting and spalling.

The examined tors in the Chornohora Range show a larger diversity of surface microforms. This could be controlled by geological factors: presence of large fragments of less resistant rock in the sandstones (spherical cavities on rock walls) or a different mineral composition of cement (flutes) (Table 1). It could be also related to climatic factors: higher exposure to the solar radiation, wind and precipitation (asymmetrically developed surface crusts and flutes).

Tab. 1. Diversity of weathering features

	Beskid Mały Mountains		Controlling factors	Chornohora Range		Controlling factors
	Sandstone	Conglomerate		Sandstone	Conglomerate	
Large scale features						
Widened joints	rare	frequent	gravity, erosion of joints	frequent	frequent	gravity
Pillars	absent	very rare	mineral composition of cement, erosion of joints	absent	very rare	mineral composition of cement, erosion of joints
Rock shelters	very rare	rare	gravity, capillary penetration, erosion of joints	very rare	very rare	gravity, erosion of joints
Blockfields	rare	absent	widened joints, gravity	rare	absent	gravity
Small scale features						
Surface crusts	inconspicuous	inconspicuous	exposure to solar radiation	conspicuous	conspicuous	exposure to solar radiation
Ledges	frequent	rare	bedding	frequent	very rare	bedding, exposure
Niches	absent	frequent	porosity	fairly frequent	frequent	porosity, lithoclasts of less resistant rock (?)
Weathering pits	absent	absent	lithology	fairly frequent	absent	lithology

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The Stołowe Mountains – studies in geomorphometry and new facts about landforms

Abstract: Studies on landforms of the Stołowe Mountains have a long tradition, but only recently it has become possible to provide a full, detailed characterization of morphology of the part of the massif included into the Stołowe Mountains National Park. The basis for geomorphometric analysis is provided a new data source – a digital elevation model derived from LiDAR (*Light Detection and Ranging*). Sub-metric precision of DEM from LiDAR exceeds that of all previous data sources, including topographic map at scale of 1:10 000 and older DEMs. Its horizontal resolution is about 0.6x0.6 m. Based on DEM, the surface of the Stołowe Mountains National Park was examined by primary and derivate parameters: altitude, slope, exposure, relief (relief energy) and others. Through visualization of DEM (shaded relief model) slopes were found where effects of mass movements are pronounced, in some cases interpreted as large landslides. Shaded relief model shows how slope shapes are adjusted to geological structure. The DEM fundamentally changes the view of the mesa of Mt Szczeliniec Wielki. Earlier mappings did not accurately capture the pattern of rock labyrinths. The analysis of the terrain also allows to specify drainage directions and to extract sub-basins on the mesa, including areas without surface outflow.

Introduction

Landforms of the Stołowe Mountains have been repeatedly described in many publications including monographs (e.g. Pulinowa 1989, 2008 and Migoń 2008). Although main landforms, their location and origin are well known and documented, the geomorphology of this area is not yet fully understood. This particularly applies to places which are difficult to explore, usually on steep slopes and landforms hidden under thick forest, which cannot be identified on aerial photographs. A new, more detailed look is possible with the use of DEM (Digital Elevation Model) developed from airborne laser scanning LiDAR (Light Detection and Ranging). An analysis of this digital data replaces completely a study of topographic map and its precision exceeds older existing elevation models, e.g. SRTM, ASTER GDEM or DTED. In this text, the sculpture will be analyzed in quantitative terms, using primary or derivate parameters (elevation, slope, aspect, relief energy, topographic grain, topographic wetness index). Examples of characteristic landforms will be presented, including the mesa of Mt Szczeliniec Wielki.

Data sources and methods

Precise DEM with horizontal resolution of 0.6 m used in geomorphometric analysis was built from data received from the Head Office of Stołowe Mts National Park (PNGS). Data cover the area of PNGS only. Complementary data from the rest of the Stołowe Mts area, including information on the part of the territory of the Czech Republic, were not available. The database includes information about the position in space of points of the test surface derived from an airborne laser scanning. During this optical remote sensing measurement, the area is swept by a laser beam at different angles. In effect, after the removal of errors, it becomes possible to separate from the resulting model of thematic layers, covering an area of the forest, undergrowth, the ground surface or other objects (Devereux, Amable 2009).

Data transformation and geomorphometric analysis was carried out using software: GlobalMapper, MicroDEM and SAGA GIS. The analysis was based on geomorphometrical parameters such as slope (incision), exposure, relief (sculpture energy) and topographic wetness index (TWI). Topographic grains (lineaments) were automatically determined. Understanding the first two parameters is not difficult, although for example in MicroDEM software up to 13 different algorithms to calculate the slope are implemented. Relief feature allows to highlight areas with the greatest energy of relief, and so height difference within the predefined distance from each raster cell (Guth 2009). In this work this distance was set at 250 m Topographical Wetness Index is a function of natural logarithm of ratio of local upslope contributing area and slope (Beven, Kirkby 1979) and it indicates the spatial distribution of surface soil moisture saturation, and is one of the basic elements of hydrological modeling of slopes and entire basins (Sørensen et al., 2006). TWI relies only on elevation and does not include insolation, the actual distribution of precipitation and soil sorption. Topographic Grains define the linear structure of the surface area (ridges, axes and morphological edges of valleys etc.). The algorithm is implemented in MicroDEM and allows to eliminate subjectivity in delimitation of relief lineaments. The final effect depends on determining the distance between the points to be calculated, surface, scale factor for the length of vectors and indicate the share of flat surfaces which are included in the final result (Guth 2003, 2009). The basin areas were created automatically for the mesa of Mt Szczeliniec Wielki, using procedure based on D8 flow formula.

Results and landform visualization

According to the received digital data (file .SHP with the border of PNGS), National Park covers an area of 6440 hectares (64.04 km^2), which almost does not differ from the surface reported in the official sources: 6 339.72 ha. Centroid of this field is determined by a point at N 50.4651488 ° and E 16.3523493 ° (near village

Łężyce Górne). The geomorphometrical analysis of sandstone landscapes in PNGS area can be characterized by the parameters listed below.

Elevation. In the area of PNGS the highest point is within the rock labyrinth of Mt Szczeliniec Wielki. The culmination is at 921.9 m a.s.l., which exceeds the value provided by geodetic measurements at 919.0 m a.s.l. (1:10 000 topographic map). The lowest point of PNGS has a height of 391.4 m a.s.l. and the average height of PNGS is 680.6 m. The distribution of classes in 100 m elevation intervals is shown in Fig. 1A. Within PNGS, areas with altitudes of 700–800 m a.s.l. dominate, occupying the entire central part of area (Table 1).

Topographic grains. Most lineaments coincide with rock walls and ridges visible in the physical landscape (Fig. 1B). This is particularly evident in the southern part of the area, such as along the escarpments of Lisi Grzbiet, Urwisko Batorowskie and other morphological edges. In the south lineaments delineate long, straight valley courses of Kudowski Potok, Potok Złotnowski and the upper reach of the Czerwona Woda valley. A relatively dense network of lineaments divides the central part of PNGS, where they are run across the slopes of curvature determined by structure. The northern part of the area contains fewer topographic grains, even along the escarpment of the Radkowskie Skały, which is morphologically obvious, but the course of escarpment itself is sinuous. In the north and north-east there runs also less straight, deeply indented valleys. Valleys are more extensive, amphitheatrical lowerings. The best example of this type of amphitheatrical recess is the upper part of the Pośna river valley. Lineaments are missing within tight sculptured area – among rocky fields (Skalne Grzyby, Białe Skały) and within peatbog terrain of Wielkie Torfowisko Batorowskie.

Aspect. The area is dominated by slopes directed to the south and north (Fig. 1C, Table 2). Small area of slope surfaces is exposed towards the west. Areas with the most uniform aspect are characteristic for the central part of PNGS. The greatest diversity of aspect relates to short, rough slopes in the west of the area and rocky surfaces in the north and north-east. In terms of exposure, particularly interesting parameter is present within amphitheater valleys in the Northern edge of the massif, for example, Lej Pośny and head valley of Cedron river floating towards Wambierzyce town.

Slopes. In the Stołowe Mountains area, due to structural control on relief, flat slope is identical with the upper surfaces of plateaus (Fig. 1D). Steep slopes determine structural edges. Excluding rock walls, the maximum slope of the surface within the PNGS reaches 88.0°. The calculated value of an average inclination is 13.1°, with standard deviation of 25.43%. The area is dominated by low slope values (Table 3). Slopes of 10° occupy more than 1/2 of the total area, the percentage of slopes steeper than 60° is minimal.

Relief energy. The analysis was performed for areas surrounding each raster cell, within a distance of 250 m. Parameter *relief* takes the highest values on the northern edge of the Stołowe Mountains, where high rock walls and well developed, amphitheatrical valley heads occur (Fig. 1E). The rock spurs of Krucze Skały west of Darnków village, slopes of Mt Rogowa Kopa sloping to the north-west of the Sawanna Afrykańska plateau and the slopes of the twin mesa of Mt Szczeliniec are also clearly characterized. Areas of low-relief energy dominate in total area.

Topographic Wetness Index. The visualization indicates potential conditions for concentration of moisture at the foot of long slopes and flattenings of the

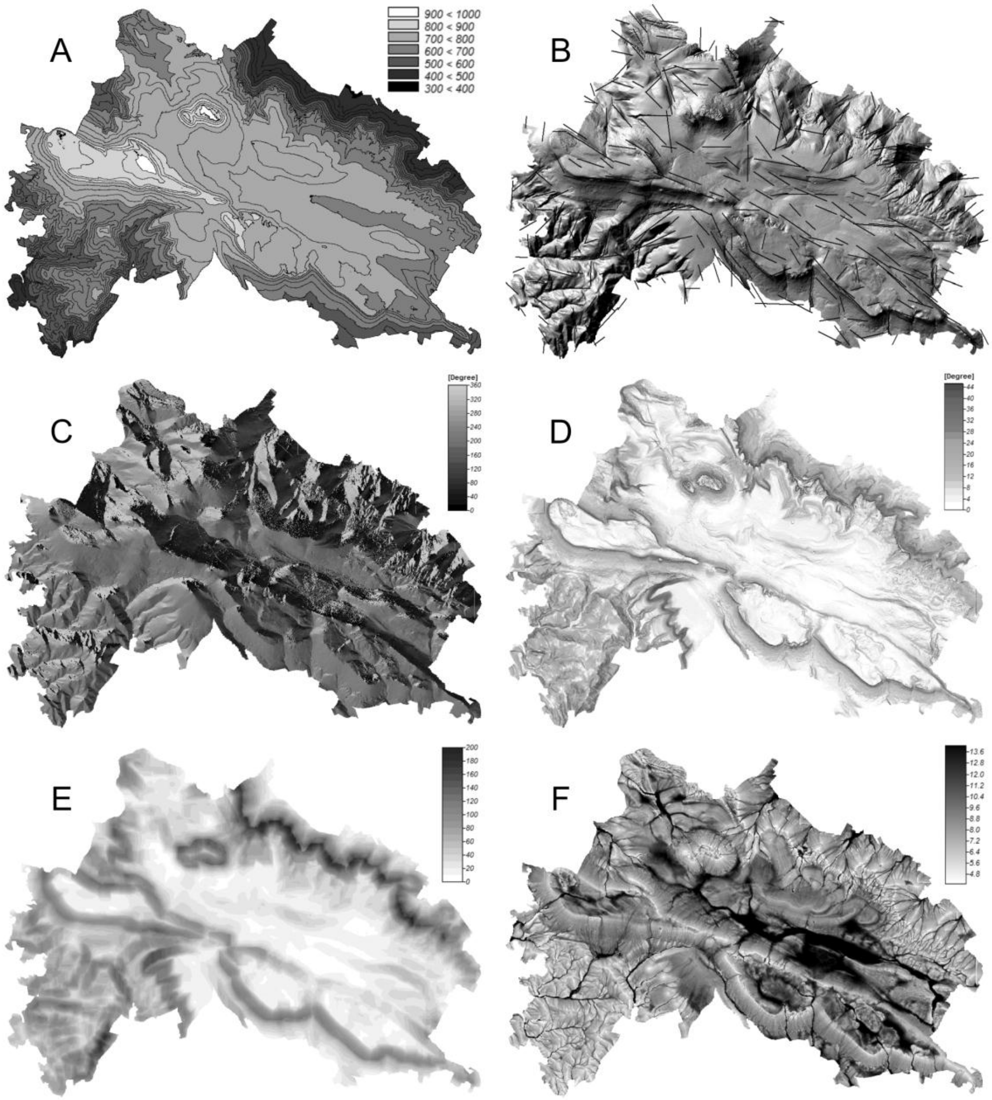


Fig. 1. Stołowe Mountains National Park examined by primary and derivate parameters:
A – altitude classes (contour lines 50 m), B – main relief lineaments in relation to hillshading, C – slope aspect, D – slope inclination, E – relief energy, F – topographic wetness index (non-dimensional scale).

Tab. 1. Altitude classes in the area of Stołowe Mountains National Park.

Altitude classes [m a.s.l.]	Area [km^2]	% of area
300–400	0.04	0.07
400–500	4.33	6.68
500–600	8.62	13.32
600–700	18.90	29.20
700–800	28.19	43.55
800–900	4.43	6.85
900–1000	0.21	0.33

Tab. 2. Slope aspect in the area of Stołowe Mountains National Park.

Aspect – azimuth [degrees]	Aspect	% of aspect	Main aspect	% of main aspect
0–45	N–NE	16.49	N	27.76
45–90	NE–E	13.78	E	23.13
90–135	E–SE	9.34	E	
135–180	SE–S	11.90	S	29.93
180–225	S–SW	18.03	S	
225–270	SW–W	10.90	W	19.19
270–315	W–NW	8.29	W	
315–360	NW–N	11.27	N	27.76

Tab. 3. Slope inclination in the area of Stołowe Mountains National Park.

Slope [degrees]	Area [km^2]	% of area	% of area
0–5	18.968	29.304	52.415
5–10	14.959	23.111	
10–15	9.889	15.278	25.671
15–20	6.727	10.393	
20–25	5.051	7.803	13.998
25–30	4.010	6.195	
30–35	2.759	4.263	6.297
35–40	1.317	2.034	
40–45	0.499	0.770	1.103
45–50	0.215	0.333	
50–55	0.119	0.184	0.301
55–60	0.076	0.117	
60–65	0.053	0.082	0.144
65–70	0.040	0.062	
70–75	0.025	0.038	0.058
75–80	0.013	0.020	
80–85	0.006	0.009	0.013
85–90	0.002	0.004	

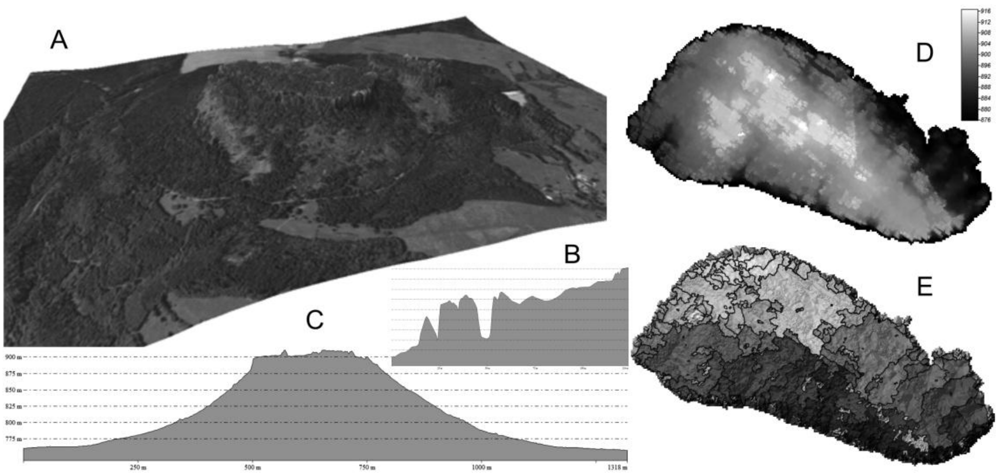
Stołowe Mountains (Fig. 1F). The most extensive area of this type coincides with the location of peatbogs of the Wielkie Torfowisko Batorowskie and other wetlands. Potentially dry areas emerge at convexities in slope profiles, especially around upper edges of morphological escarpments. In these cases the shape of the slope forces quick runoff down the slopes.

The case of Mt. Szczeliniec Wielki. Mt Szczeliniec Wielki, one of the most recognizable landforms within of the Stołowe Mountains, is a mesa elevated about 120 m above the surrounding area (Fig. 2). The area of mesa is 0.29 km^2. In the east, there is an area with reduced altitude in respect to the rest of the mesa. This part is probably the result of mass movements (sagging and landsliding). The shape and outline of the mesa was not correctly shown on the maps so far. Geodetic data in the past were not accurate because of difficult terrain. The DEM derived from LiDAR shows that the existing topographic maps present distorted and simplified situation. The rocky labyrinth of Mt Szczeliniec Wielki is drained radially in each direction and theoretically contains several catchments. In the model there appear to be somewhat isolated areas with no outflow, most likely indicative of mass removal by large-scale subterranean erosion.

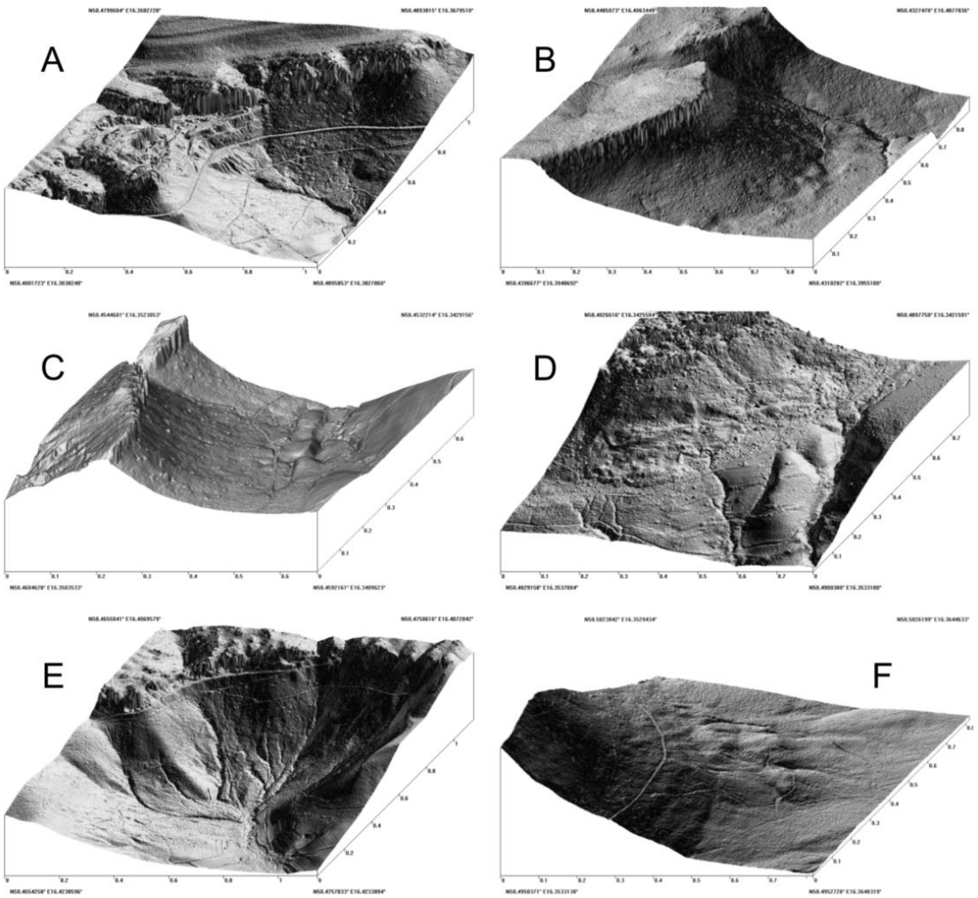
Landforms of the Stołowe Mountains in examples. Spatial visualisations of landforms which are characteristic or significant in the study of the Stołowe Mountains relief are presented in Fig. 3 with short descriptions.

Discussion and conclusions

In Poland, LiDAR data are still not common, mainly due to the cost of their acquisition. In the Lower Silesia region, as for 2011, LiDAR scanning was available



Ryc. 2. Examples of information provided by DEM for Mt. Szczeliniec Wielki and its mesa: A – 3D visualization, B – deep chasm of Piekiełko, C – transverse profile, D – elevations, E – topographic basins boundaries.



Ryc. 3. The landforms of the Stołowe Mountains in examples: **A** – Cliffed escarpment of the Radkowskie Skały above the Droga Stu Zakrętów road (Road of One Hundred Turns). In the area of Radkowskie Skały, individual rock formations are reproduced well enough to perform cartometric measurements. It is possible to distinguish single rocks groups and directions of further development of relief. Effects of rock fall and sediment deposition is indicated on the middle slopes. The varied shape of the surface above rock walls is structurally conditioned. **B** – Grodczy Dół valley in the southern escarpment of Urwisko Batorowskie – an incision of Bobrowa stream near the settlement of Szczytna-Ocieszów. This is another example of previously unknown forms on slopes. Below the cliffs, in the lower part of the slope, there are lobes indicative of gravitational movement of slope covers. **C** – The valley of Złotnowski Potok (Łężyce Górne), south of Lisia Przełęcz. The axis of the valley is marked by elevated levels imitating river terraces. Their smooth surfaces are due to human activities. Concave slope below the rock wall on the left side of the picture is littered with boulders and blocks creeping down the slope. Slopes on the right side of the valley are agriculturally used. **D** – The north-eastern slope of Mt Szczeliniec Wielki, the valley of Kozi Potok stream and headwaters of Pośna river. DEM reveals previously unknown details of hillslope relief. On the basis of this view one can infer surface instability and the presence of large-scale mass movements. The area is very difficult to cross due to lack of roads, steep slopes, uneven ground and dense undergrowth. **E** – Amphitheatre valley head in the headwaters of Cedron river near Wambierzyce Górne village. The form is typical for the northern escarpment of the Stołowe Mountains, where large sapping cirques occur. The convergent, concave slopes are incised by permanent and temporary rivers in a converging, radial arrangement. The model shows well the drainage network, difficult to detect and map on a steep, inaccessible, forested slopes. **F** – The slope below the Biała Skała spur, west of Droga Stu Zakrętów (the Road of One Hundred Turns). The visualization shows interesting convex forms below the forestry road, interpreted as effects of mass movements.

for the town of Wrocław (Wrocław Municipality) and the western Sudetes (Karkonosze National Park, Forest Promotional Complex of Western Sudetes). Similar database acquired by the Stolowe Mountains National Park are a valuable research material for almost all natural sciences and is the basis for geomorphometry and modeling of natural land-surface processes.

Sub-metric DEM derived from LiDAR data allows for direct measurements and provides statistics on the land surface organization of Stołowe Mts. Detailed information about regional morphology was obtained using primary parameters such as elevation, slope, exposure, and parameters derived from mathematical transformation of original parameters. This kind of information was impossible to obtain by analyzing topographic map, inaccurate for sandstone landscapes. Spatial terrain visualization could be useful to useful to detect landforms and signs of geomorphological processes in areas difficult to access (steep slopes, dense forest undergrowth).

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Tubes – remarkable conglomerate caves in Pfälzerwald (SW Germany)

Abstract: In western part of Palatinat formation of caves is supported by coalescence of tubes with similar direction of longer axis, also in the same geological layer. The formation can be found only in rock walls. Even other caves in Hauptkonglomerat, which do not contain tubes, have longer axis by 50 to 70 degrees in the west up to 100 degrees, which is also the direction of tubes in these layers. Statistic material is not sufficient to provide more detailed answers to questions posed by these phenomena.

Geological Situation

Tube structures (Fig. 1) are concentrated in an area 10 km wide and 35 km long along the western border of Pfälzerwald (Forest of Palatinat, south-western Germany). The area is situated between the city of Kaiserslautern in the north and the Bitch-region (France) in the south. Tubes occur in several stripes, so called corridors, with a width of a few hundred meters and a maximal length of 9 km. The tube-structures are mainly connected with the „Hauptkonglomerat" (Trias), between middle and upper Buntsandstein layers. The layers dip south-west by 4–6°. The locations are limited to some hills where walls of rock and steep slopes have formed. Outside the corridors along Pfälzerwald only isolated places with tubes have been found until now. Most of these tubes were found around the village of Oberwürzbach in Saarland (political section of SW Germany). In connection with tubes the caves of „Rothenborn" near the village of Neumühle (Newmill) were formed. They have been described several times, e.g. by Jakob in 1913. He considered the caves to be artificial. Gauda et al. (1982) examined the situation in the northern corridor and postulated natural formation of tubes and caves.

Region of investigation

Hauptkonglomerat along the western border of Pfälzerwald does not form connected walls of rock. One of a few exception is Hilsbachtal, south of city of Pirmasens, with some 100 m long walls of rock, actual the southern place where tubes are to be found. In all other places of tube occurrence, walls of rock are disconnected or isolated outcrops exist. Because of dipping layers the most containing corridor is

Fig. 1. Cave No 3 at Rothenborn.

situated between the villages of Hettenhausen and Krickenbach. In the west the localities are situated within the valleys, in the east on top of the mountains. Only in the southern corridor, caused by several faults in north-south direction, there is a multiple outcrop of Hauptkonglomerat. Only a few localities of tubes are not situated in Hauptkonglomerat but in Rehberg- or Karlstal-layer which are part of middle Buntsandstein. These are Bärenloch (Bear hole) near the city of Landstuhl in the north, the tube in Kostenfelsen near the city of Annweiler and the tube at Felsenkaserne near the village of Oberwürzbach.

Formation of tube structures

The location of localities shows some regularity. 86 out of 135 tubes found until now are situated in the northern corridor which has a width of 800 m and the length of 9 km (Fig. 2). The direction is 60°. Even all the other localities are placed on lines by nearly the same direction and, therefore, allow to postulate further corridors. The small number of tubes does not allow until now to make any statistics. Outside of the corridors no tubes were found even under equal topographical and geological conditions. In one corridor there were found only two tubes, but this is not verified. Nearby the upper cave in Bear-rock (Obere Bärenfelsenhöhle) is situated, with a length of 37 m and the 58° direction of longer axis, which is also the direction of the corridor.

Supposing that there exist other corridors, some more examinations of the landscape were done. On border of the southern corridor the 44 meter-long birch cave, as well as two other caves (23 and 18 m long) keep the direction of the corridors with longer axes striking 58–62°.

The places to find tubes are distributed over an area of 10 x 35 km^2 with some differences in formation of the tubes. In the rocks of „Bauwald“ and „Rothenborn“ the attain great diameters a few metres long, while in all other places tubes are small, usually with oval cross-cuts and length up to 1.5 m. In common they have cigar-like forms and other specifications of appearance: the direction of the longitudinal axis is 50–90° – with the exception of „Rothenborn“, clearly outside of fissure directions in the same place. The inclination of the axis is up to 10° to both sides.

The western locality is situated near the village of Oberwürzbach. By keeping the general direction of corridors, is the northern corridor of Kindsbach. By the way, the angle of the longitudinal axis of tubes increases versus south and west, around Oberwürzbach being about 100°.

Most tubes are without any filling, even if they are enclosed completely by the rock. Having enlarged cave no. 3 at Rothenborn in 1945, new tubes were cut without connection to the cave in those days. They did not show any trace of filling. Yet, some tubes contain a filling of less solid material which has another colour than the surrounding rock, and contains more iron-oxide. The grains of the filling are only connected by iron-oxide or iron-hydroxide, whereas the cement of the surrounding rock is a silicate.

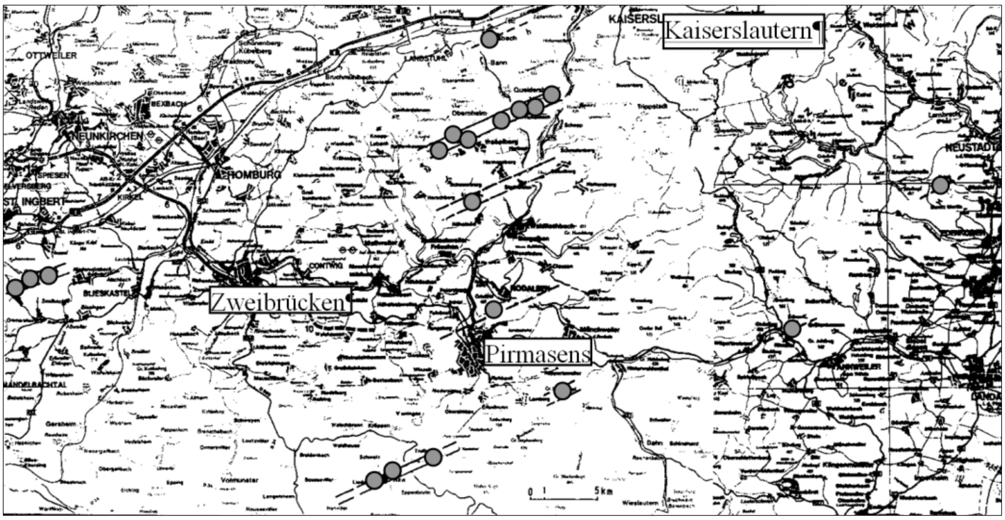

Fig. 2. Location of tubes and tube structures.

Formation of caves

Starting from the tube-structures several caves were formed. Some tubes are caves by their size, for example the „Bauwaldhöhle 1“ (cave in Bauwald) with the diameter of entrance of 0.7 m and the length of 8 m. Due to the alignment of the tubes are deposits for the forming of caves are favourable, even if not existing at each locality. At the north-eastern locality Am Hohen Stein there is a big number of tubes to see. They are situated too far from each other and therefore, they cannot create caves.

Tubes at the locality of „Rothenborn“ have other conditions. Due to the close neighbourhood of several long tubes with big diameters caves formed by weathering of rock between the tubes. This rock sometimes was only a few centimetres thick. So the 42 meters long cave 3 at Rothenborn was created. By ending and new beginning out of axis of the old cigar-like tube there were created specific profiles of cave which are signified by connected segments of a circle. These tubes are long up to 5 meters.

Other caves like cave 8 at Rothenborn or cave 2 in beech-tree-forest or in Bauwald-cave 1 seem to be one single tube which is forming the cave. There are some doubts about the influence of weathering by running or infiltrated water that may have enlarged the profile. The later enlargement of entrance section is evident at nearly all caves. In the fine-grained sandstone there are formed round forms which are connected without rupture to the tubes.

Another type of cave is formed of two tubes situated close together, sometimes pledged by half of diameter. This can be observed at „Dicke Berta“ or „Ramerfelsen 2“. Easy to see is weathering of the parts between the two tubes. Quietly influenced are these processes by the composition of rock, e.g. at the wall of

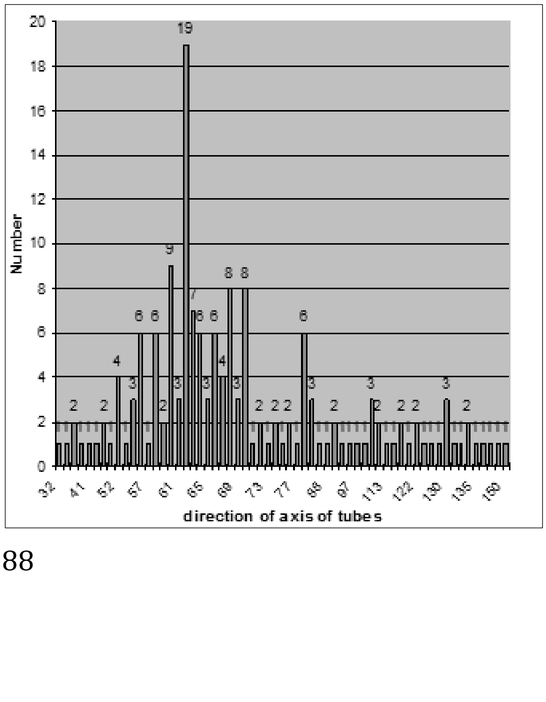

Fig. 3. Direction of the axis of tubes.

rock of Rotenborn, which is built by finely grained material. Southern localities are situated in coarse-grained to conglomerate-like layers. In coarse-grained layers the inside-walls of tubes are not as smooth as in finely-grain layers with less part of gravel.

Cave 1 and 5 at Rothenborn show on their ground several parallel running tubes, only partly conserved. The ceiling shows in the inner part only traces of tubes. In entrance region the ceiling is well curved over the cave.

Chemistry of rock

Examination of rock samples showed that the filling of the tubes contains 7% of iron. Iron is presented mainly in oxide and an analysis of grain size did not show any difference between tube wall and filling of the tube. Remarkable is less adhesion of the rock in the filling. We do not know until now, how the processes run to form the tubes. The origin of tubes with filling can be explained in running several steps by infiltration of sinking and mounting water with different chemical parameters. There is no explanation by this theory for tubes without any filling cut by artificial enlargement as the cave no. 3 at Rothenborn. These tubes must have been formed by another way or the filling must have been soloed completely and transported away.

Sponholz (1989) describes tubes in the republic of Niger/Africa. Her explanation of how those caves formed may not be transferred to tubes in West Palatinat, since tubes in Niger do not have a preferred longer axis.

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The pteridophytes of the Luxembourg Petite-Suisse sandstone area – Past, present and future

Abstract: The Luxembourg 'Petite Suisse' sandstone area is a real treasure trove for pteridophytes (ferns, horsetails and clubmosses). In fact, more than 90% of all pteridophytes known in Luxembourg occur, or have occurred in the 'Petite Suisse luxembourgeoise'. Some species have unfortunately disappeared, some rare taxa still exist in relict populations. Fortunately conservation measures are slowly put in place.

Introduction

The 'Petite Suisse luxembourgeoise' (Luxembourg's Little Switzerland) is an area of approximately 170 km^2, situated in the eastern part of Luxembourg between the river Sûre (German border) and the valley of the river Alzette. From a scientific point of view, the 'Petite Suisse' area is considered to equalise that part of Luxembourg Sandstone ('Grès de Luxembourg', a Lower Jurassic (Hettangian) sandstone, about 200 million years old) in which the sub-oceanic species *Ilex aquifolium* (Holly) is growing. It is one of Luxembourg's most outstanding landscapes.

Pteridophyte diversity

Considering the pteridophytes, that means ferns (Pteridopsida) and fern allies like horsetails (Equisetopsida) and clubmosses (Lycopodiopsida), the 'Petite Suisse' sandstone area is a real treasure trove (Reichling 2005). Numerous landform configurations with extended beech forests characterised as 'ancient' woods, conspicuous outcrops of Jurassic sandstone, scree-covered slopes, narrow and wet valleys, as well as large plateaus – with all the different associated biotopes and their special microclimatic conditions – contribute to an enormous diversity of ferns and fern allies. In fact, more than 90% of all pteridophytes known in Luxembourg occur, or have occurred in the 'Petite Suisse Luxembourgeoise'. The area is internationally known for its relict populations of Tunbridge Filmy-fern (*Hymenophyllum tunbrigense*, Fig. 1), first discovered in the heart of the sandstone area by the Belgian botanists Barthélemy Charles Dumortier and Pierre Michel in 1823 near the village of Berdorf (Massard 2001). This was the first discovery of this Atlantic species inside the continent, and the finding was directly published in 1824 by Alexandre Louis

Simon Lejeune in his *Revue de la flore des environs de Spa* (Lejeune 1824). So, the most remarkable fern of Luxembourg was also one of the earliest to be known.

Numerous botanists explored the region in the 19th century and lots of pteridophytes, including interesting species such as *Asplenium scolopendrium*, *Asplenium viride*, *Equisetum hyemale* (Fig. 2), *Huperzia selago*, *Lycopodium clavatum*, *Lycopodium inundata*, *Osmunda lunaria, Polystichum aculeatum* and *Polystichum lonchitis* were discovered in the sandstone area (Tinant 1836, Koltz 1874, 1879, Klein 1897). Other findings, such as the one of *Equisetum pratense* near Berdorf (Goffart 1934), were however contested later on.

The 20th century was marked by the works of André Lawalrée and Léopold Reichling. So Lawalrée (1951) mentioned for the first time in Luxembourg and in the sandstone area the hybrid *Polystichum* × *bicknellii* (= *Polystichum aculeatum* × *P. setiferum*), and in a complement published in 1952 (Lawalrée & Lawalrée 1952) the discoveries of *Polystichum setiferum*, *Dryopteris* × *Tavelii* and *Asplenium obovatum* var. *billotii* were reported. Concerning other taxa of the *Dryopteris affinis* group, it is worth noting the first discovery of *Dryopteris affinis* subsp. *affinis* (at that time known as 'Dryopteris paleacea auct.') in 1952 on Luxembourg Sandstone ('Grès de Luxembourg') – in the north of Luxembourg-City – by Léopold Reichling (Reichling 1953a,b). The early 1950s were particularly propitious for the findings of interesting ferns. Besides the above mentioned *Asplenium billotii*, new discoveries of *Asplenium viride* (Beck et al. 1951) are worth to be mentioned. Unfortunately, the *Asplenium* cf. *onopteris* discovered in 1952 near Berdorf (Reichling 1954) turned out later to be just an acute leaved form of *Asplenium adiantum-nigrum*.

Quite interesting is the *Trichomanes speciosum* (Killarney Fern) story. This second representative of the Filmy Fern Family (Hymenophyllaceae) was first found in the Luxembourg Petite Suisse sandstone area in 1993 (Rasbach et al. 1993). Again, it was the first discovery of such an Atlantic species inside the continent. The Killarney Fern occurs here as independent gametophytes with vegetative reproduction and dispersion by the way of gemmae (Fig. 3). In Luxembourg, the gametophytes of *Trichomanes speciosum* are largely present in the whole sandstone area as far as the valley of the river Alzette. The discoveries of the gametophytes on Devonian schist showed, however, that the species is quite widespread in the Luxembourg's Ardennes too. (Krippel 2001, 2009)

If the Killarney Fern can be found on different geological substrates, other species like *Hymenophyllum tunbrigense* are strictly restricted to the sandstone area and have a quite small distribution area. Other typical pteridophytes on sandstone are for example: the Rough Horsetail (*Equisetum hyemale*), the Lobed Maidenhair Spleenwort (*Asplenium trichomanes* subsp. *pachyrachis*, Fig. 4), the Soft Shield-Fern (*Polystichum setiferum*) as well as the hybrid *Polystichum* × *bicknellii* and the Lemon-scented Fern (*Oreopteris limbosperma*). In the sandstone area, some of the

Fig. 1. *Hymenophyllum tunbrigense* (Tunbridge Filmy-fern), still growing well in some gorges of the “Petite Suisse” sandstone area in Luxembourg. Photo Y. Krippel, 24.3.2006.

Fig. 2. *Equisetum hyemale* (Rough Horsetail) can develop extensive populations in the sandstone area. Photo Y. Krippel, 2004.

Fig. 3. *Trichomanes speciosum* (Killarney Fern) gametophytes on sandstone near Beaufort.
Photo Y. Krippel, 29.10.2006.

Fig. 4. *Asplenium trichomanes* subsp. *pachyrachis* (Lobed Maidenhair Spleenwort), a typical fern on calcareous rich sandstone outcrops. Photo Y. Krippel, 9.2001.

pteridophyte species (especially *Equisetum hyemale*, *E. telmateia* and *Asplenium scolopendrium*) can develop extensive populations. Other species have unfortunately disappeared over the last decades, for example: the Fir Clubmoss (*Huperzia selago*), the Lanceolate Spleenwort (*Asplenium billotii*) and the Green Spleenwort (*Asplenium viride*).

In fact, of the 50 pteridophytes (ferns, horsetails and clubmosses) currently present in the Grand-Duchy of Luxembourg (Krippel 2011, 2012), 40 taxa are represented in the Petite Suisse sandstone area; this represents a percentage of 80%. When the extinct species are considered as well, this percentage increases to 95%, which is quite an amazing percentage for this small area (170 km^2 compared to the 2586 km^2 for the whole country). The Petite Suisse sandstone area is a real biodiversity hotspot considering pteridophytes, as well as for bryophytes and lichens (Werner 1998, Reichling 2005, Krippel 2007), and it is therefore essential to avoid all further loss of cryptogams in the future.

Conservation measures

Considering nature conservation, the efforts of the responsible authorities are slowly going on. The Petite Suisse sandstone area is part of the European Natura 2000 Network (Règlement grand-ducal du 6 novembre 2009 portant désignation des zones spéciales de conservation) and two major Special Areas of Conservation according to the ‘Habitats Directive’ were designated for the region: LU0001011 – Vallée de l'Ernz noire / Beaufort / Berdorf (surface: 42 km^2) and LU0001015 – Vallée de l'Ernz blanche (surface: 20 km^2); the specific action and management plans are currently in elaboration. The designation of local nature reserves is in progress, and the first so-called “forest reserves” (RFI – Réserves forestières intégrales) have been declared. Rock climbing was restricted by a new set of local bylaws and the dense rambling net was reorganized in order to guide the tourists more effectively and to protect extremely fragile sites, i.e. associated to viewpoints on outcrops; measures that are about to show first positive results. A new bylaw (Règlement grand-ducal du 8 janvier 2010 concernant la protection intégrale et partielle de certaines espèces de la flore sauvage) enhances the protection of a certain number of pteridophytes, but special conservation measures were taken so far only for *Hymenophyllum tunbrigense* by withdrawing public access to the main site. However, the above mentioned efforts, together with the imminent creation of the Nature Park Mëllerdall – Petite Suisse luxembourgeoise (Arrêté grand-ducal du 27 octobre 2009 autorisant la constitution du Syndicat pour la création d'un Parc Naturel dans la région du Mullerthal, en abrégé «Syndicat Mullerthal») could well be the right step to conserve the beauty and integrity of this outstanding landscape and its exceptional pteridophyte-flora.

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Geological survey and eventual mining of shale gas – a new danger for the landscape of PLA Broumovsko and other sandstone regions of Europe?

Abstract

Shale gas extraction has developed in North America considerably over the past 10 years. It is now tried to promote this technology in Europe. New technologies – horizontal drilling and hydraulic fracturing allow the exploitation of fossil fuels which as yet have been beyond the scope of industrial interest. Their safety in relation to the environment is extensively discussed. Currently used methods bring considerably high risks to drinking water resources and potentially threaten aquatic ecosystems. Industrial activity is associated with significant increase in transportation by heavy trucks, is noisy and leads to emissions of pollutants. It may cause health problems in the affected regions.

This industry has also considerable influence on the landscape, which is inevitable. Thus the potential effects of mining would be much worse in protected areas. It is a paradox – the current applications of international companies for the shale gas exploration permits in the Czech Republic concern to a large extent protected areas. The proposed 778 km^2 Trutnov concession comprises the entire Protected Landscape Area Broumovsko (Fig. 1), the peripheral parts of the Krkonoše Mountains National Park, and is located next to the Góry Stolowe Nature Park.

Mining would change the rural landscape of the region, with famous sandstone rock nature reserves, to an industrial area, depriving it of the outstanding scenic beauty. At a typical shale gas production site, a 1–3 hectare space is needed, in addition to access roads for transporting materials to and from the well site. If not already present, both the site and access roads need to be built or improved to support heavy equipment. The result is that large anthropogenic terraces are created in hilly areas. More than 50 m high drilling rigs would be visible from everywhere and they remain illuminated at night. The drilling makes noise, and especially hydraulic fracturing is considerably noisy. This technology plays the key role in shale gas mining. Even after removing the giant drilling rig, other ugly-looking equipment stays on the surface, especially the various tanks, valves, piping installations, fences and also impoundments containing hazardous liquids (fracturing fluids, flow back,

Fig. 1. The cuesta of Broumovské stěny in the Protected Landscape Area Broumovsko.
Sandstone quarry in Božanov is seen in the mid-slope.

Fig. 2. Impact of shale gas mining on the physical landscape of the Roan Plateau, Colorado
(source: http://ecoflight.org/issues/detail/Colorado-Roan-Plateau/).

recycled produced water from the well). The spacing of the shale gas wells in the U.S. ranges from 1 well to 1.5 to 2.5 km^2. Sometimes the spacing goes up to 6 wells per 1 km^2. The look of the countryside is changed also by the new roads, pipelines and compressor stations (Fig. 2).

Will be the defense of public interests successful? Are we able to save good environment, nature conservation and recreational values of this region? Are the potential benefits of the shale gas extraction worth the risks and the negative side effects? Is this a potential threat for other sandstone regions?

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Relief development of a highly elevated monoclinal Babia Góra range built by Magura sandstone, Western Carpathian Mts

Abstract: The paper discusses the probable development of the relief of Mt. Babia Góra (1725), a monoclinal sandstone ridge dominating the area, from the Neogene until present. This development involves a gradual retreat of the slopes as a result of large-scale landsliding and valley deepening. The relief development is controlled primarily by the network of fractures along two dominant axes and progresses in the general direction from the valley bottoms towards the summit area. The study identified and relatively dated areas with various types of relief.

Introduction – study area

Babia Góra Mountain is the highest massif in the western flysch Carpathians (elevation: 1,725 m). It consists of a monoclinic ridge with an asymmetric cross section. The orientation of the ridge is generally west to east and its length is 10 km. Local differences in elevation exceed 1,100 m. The upper part of the ridge is formed of layers of resistant Magura sandstone tilted to the south. The northern slope is a cuesta with an average gradient of 40^{o} in the upper part and locally up to 70^{o}. The southern slope possesses characteristics of a penstructural slope with an average gradient of 25^{o}. Less resistant sub-Magura layers are found folded below the Magura sandstone. Valleys and deep passes are found atop outcrops of these sub-Magura layers. The valleys are deeper in the western part of the massif, where spring niches reach the main ridge. Valleys found in other parts of the massif tend to be less than 150 m deep and their spring niches can be found between 300 and 600 m below the main ridge axis.

Impact of landslides and previous views on landscape evolution

The greatest impact on slope relief is exerted by deep landslides, which include such geomorphic features as ridge and slope trenches, rock walls, rock niches, as well as large bulges of colluvial debris found on slopes. Landslide niches on the steep northern slope are deeper and rock walls are higher than on the southern slope. However, landslide niches on the southern slope occupy more surface area. The same is true of spring niches on the two slopes in the study area. As landslide niches grow, slopes recede. This is especially true of the northern slope. The geomorphological effect is a stepped hillslope topography. Other effects include the bending of the main ridge axis towards the south and its zigzag pattern.

A large number of flattened ridges have been identified across the Babia Góra area. The ridges are found at altitudes above valley floors that suggest a link with a traditionally accepted view in Polish geomorphology, which states that there exist four planation surfaces in the Carpathians. In the study area, the four planation surfaces are found at the following altitudes above valley floors: 500–1,100 m, 250–400 m, 120–200 m, 60–100 m. The four planation surfaces for the Carpathians are currently under review. The extent of landslide niches on the northern slope of Babia Góra and the extent of larger fragments of undisturbed northern slope were compared with research results obtained by S.W. Alexandrowicz (1978), who analyzed the stages of recession of the northern slope of Babia Góra since the Late Miocene. The deeper valleys and greater recession of the northern slope of Babia Góra, starting in the Neogene, may be explained in terms of a lower erosion base on the side of the Vistula River versus that on the side of the Danube River. The convergence of rivers flowing across the foothills north of Babia Góra also helps contribute to the formation of deeper valleys and more landslide activity. The recession of the northern slopes of Babia Góra has been estimated for about 5 km, while that of the southern slopes for 1 km at most. Valleys found at the base of the Babia Góra massif became deeper as pediments became fragmented following a period of negligible tectonic activity in the Carpathians. Figure 1 illustrates several debatable issues associated with relief evolution of Mt Babia Góra in the Neogene and the Quaternary.

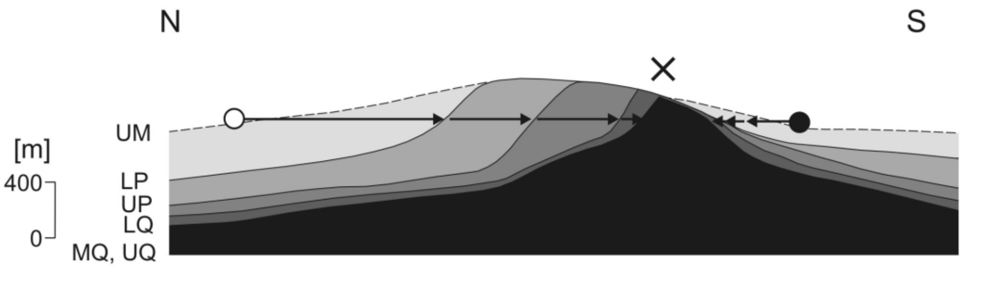

Fig. 1. Changes in the north-south cross section of the Babia Góra massif since the Upper Miocene. White circle – most likely location of the northern limit of the massif in the Upper Miocene, black circle – southern limit of Magura sandstone, x – current location of the crest of the massif. UM – Upper Miocene, LP – Lower Pliocene, UP – Upper Pliocene, LQ – Lower Quaternary, MQ and UQ – Middle and Upper Quaternary. The erosion base is located 200–300 m lower north of the massif relative to south of the massif, which results in deeper valleys and greater slope recession in this area. Relative terrain heights are marked and are not related to elevation above sea level. The massif's initially gentle dome has evolved into a monoclinic ridge.

Structural control

Current research of the author has identified a number of structural determinants of relief of Mt Babia Góra, which have been overlooked so far. Differences in slope steepness were traditionally explained in terms of resistant rock outcrops and dip angles. However, new research has shown that fractures in the massif determine relief change (Łajczak 2012). This conclusion is based on the analysis of valley axis directions, ridge axis directions (including main ridge axis), landslide niche slope directions, and spring niche slope directions. Fractures found across Mt Babia Góra are associated with faults, syncline axes and anticline axes. Two principal fracture directions have been identified: NW – SE (faults) and SW – NE (fold axes). One exception is the southern base of the main ridge beyond the Magura sandstone zone, where the direction of syncline axes and anticline axes changes more towards the north than it is the case at the northern base. The two main fracture directions in the Magura sandstone of Mt Babia Góra define the lines of movement of large rock masses, which in effect determine the pattern of river valleys and ridges including the main ridge. In the light of the general pattern of valley development, starting with landslide niches and proceeding to spring niches, higher areas of the massif feature landslide niche slopes that follow the main fracture directions in the Magura sandstone. At lower elevations, landslide niche slopes and spring niche slopes tend to follow the fracture directions in sub-Magura layers (Fig. 2). Younger landslide niches as well as spring niches follow a more recognizable trapezoidal pattern with walls following the previously mentioned bedrock fracture directions. Both landforms are surrounded by rock walls or steep slopes (up to 70^{o}) covered with weath-

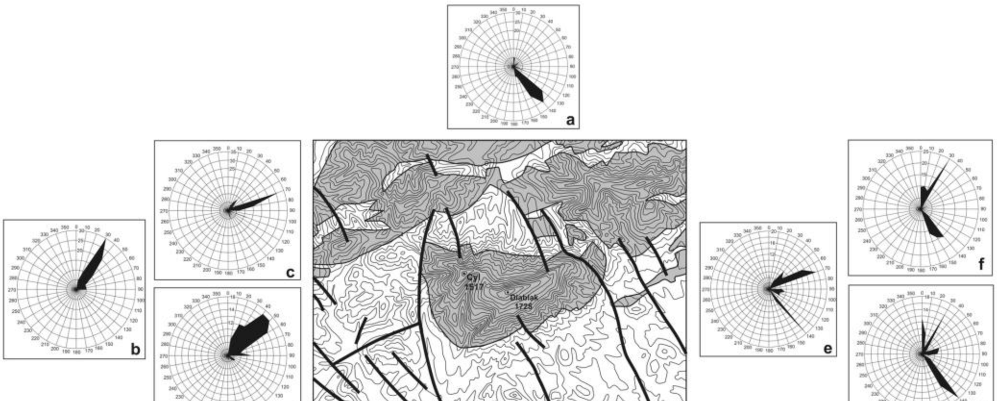

Fig. 2. Location of faults across Babia Góra Mountain and its immediate vicinity. Magura sandstone outcrops are marked in grey. Directions: a – faults, b – fold axes at higher elevations, c – orientation of Magura sandstone layers on the northern slope, d – orientation of Magura sandstone layers on the southern slope, e – orientation of sides of landslide niches in the upper part of the massif, f – orientation of sides of landslide niches in Magura sandstone in the lower part of the northern slope, g – orientation of sides of landslide niches in Magura sandstone in the lower part of the southern slope.

ering material as thick as one metre. Older landslide niches and more circular spring niches are surrounded by more gentle slopes. These slope fragments are covered with a thicker layer of weathering material. Increasingly younger landslide niches are found at higher elevations, which indicates the highest rate of slope recession across the highest parts of the Babia Góra massif. Locally young landslide niches are also found on the sides of spring niches and in their immediate vicinity. On this basis, it may be inferred that Babia Góra relief becomes younger starting with valley floors and leading up to the main ridge.

Patterns of relief evolution in space and time

Four unique areas of relief evolution have been identified across the Babia Góra massif (Fig. 3): A – northern slope and its base, where relief transformation has been greatest thanks to landslides and valley deepening, B – eastern part of the southern slope, with shallow and short valleys that have experienced the least amount of relief transformation, C – western part of the southern slope, fragmented by deeper valleys, D – western base of the massif with the largest number of known

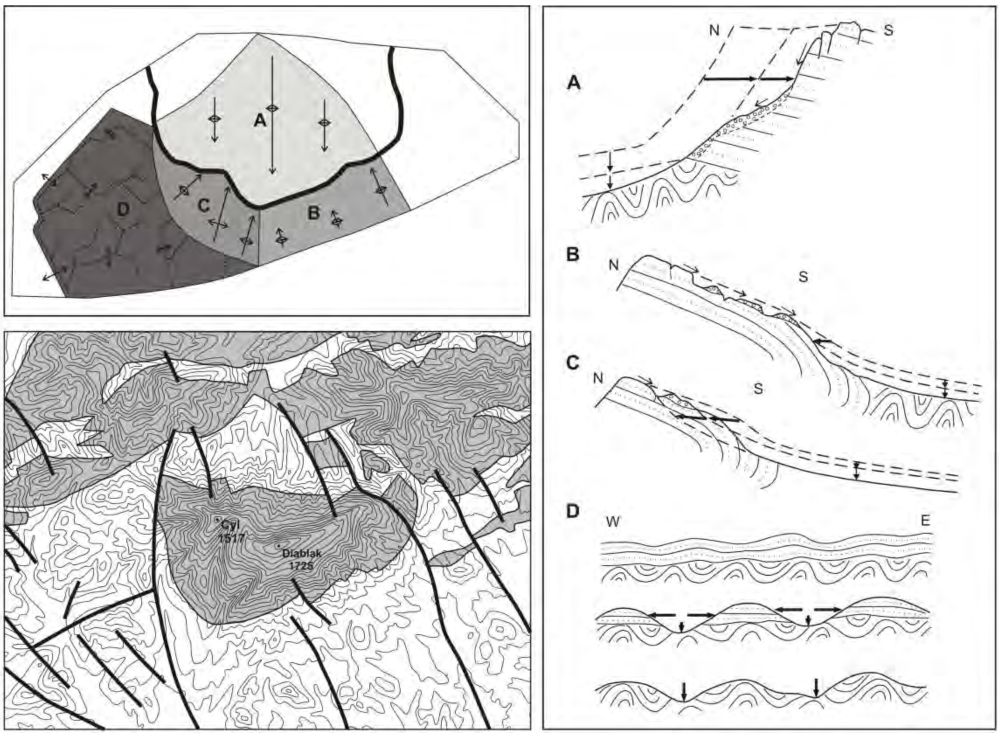

Fig. 3. Parts of Babia Góra massif differing in terms of the degree of slope relief evolution. Legend for A – D is found in the text. Shown are the extent of Magura sandstone and the location of faults. In the diagram in the upper left hand corner, the length of arrows corresponds to the length and width of valleys.

faults and a dense network of deep valleys. If it can be assumed that this area was covered with the Magura sandstone in its initial phase of relief development, then the complete removal of sandstone may suggest substantial relief evolution in the western part of the massif since the beginning of the Neogene. The formation of deep and long valleys in Area C may be associated with the development of valley networks in Area D.

Relief evolution across Babia Góra Mountain takes place via recession of slopes due to landslides and valley deepening. Five areas differing in age were identified across the massif (Fig. 4). The oldest area is the gentle upper part of the southern slope. The northern base and western base of the massif are younger, having experienced erosion of the Magura sandstone and featuring valleys formed exclusively atop hieroglyphic layers. Slopes at lower elevations and featuring spring niches possess even younger relief and landslides across most parts. This area consists of Magura sandstone alone. The upper part of the northern slope of the massif takes the form of a large rock niche and is even younger (Upper Pliocene). The youngest landforms (Quaternary) associated with deep landslides can be found in a narrow zone consisting of the highest part of the northern slope of the massif. Holocene relief evolution across Babia Góra Mountain has been negligible.

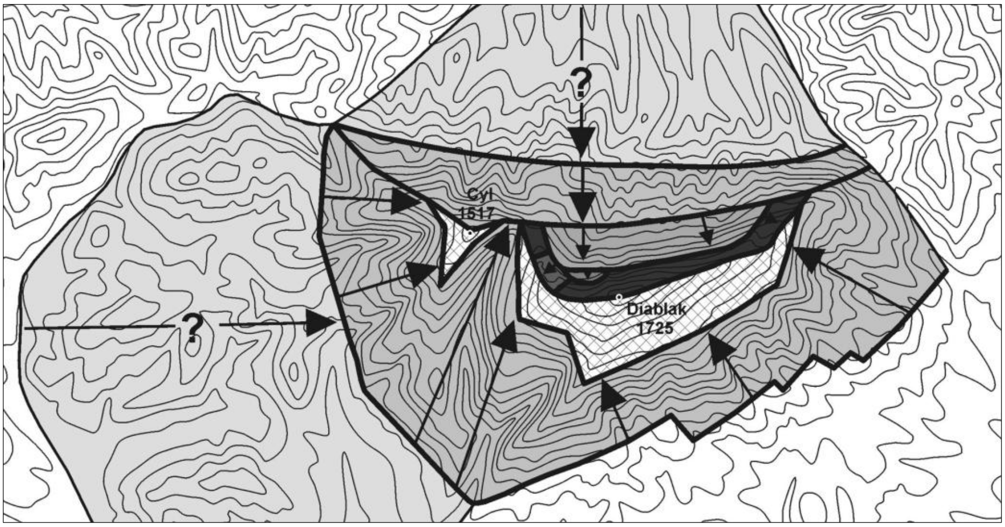

Fig. 4. Stages of slope recession and the relative age of relief elements in selected parts of Babia Góra massif (explanations in the text). Areas with the oldest relief are marked in white. Younger relief is marked using progressively darker colors.

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Monitoring of *Hygrobiella laxifolia* (Hook.) Spruce (Bryophyta) in the Bohemian Switzerland National Park

Abstract: Liverwort *Hygrobiella laxifolia* is a mountain-arctic species, which was found in 2003 as a new species for the Czech Republic in Bohemian Switzerland (Elbe Sandstone). It grows on boulders in periodically drying brooks and now is known from three localities. *Hygrobiella laxifolia* belongs to endangered species of bryophytes in the Czech Republic. The monitoring of this species started in 2008 at two localities in the Bohemian Switzerland National Park. Flood intensity plays the main role in the survival of *Hygrobiella laxifolia*. It blocks succession of bryophytes on the boulders, opens places for colonization of the species, but on the other hand may bury the populations under sand.

Background

Liverwort *Hygrobiella laxifolia* is a mountain-arctic species, which occurs in the Czech Republic only in the Elbe Sandstone (Fig. 1), where it was found in 2003 (Müller, 2003). It was known before from the Saxon Switzerland. This species

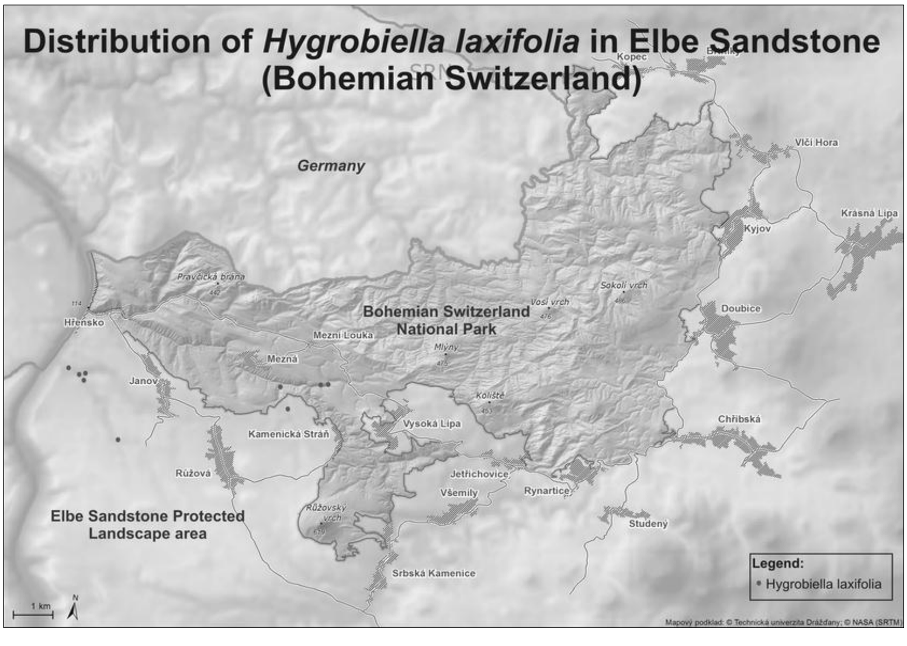

Fig. 1. Distribution of *Hygrobiella laxifolia* in the Elbe Sandstones.

occurrence is typical for the subalpine and alpine areas (1500–2500 m a.s.l.) in Central Europe, but in the Bohemian and Saxon Switzerland it grows at elevation of 140–290 m a.s.l. (Müller, 2004). Its localities represent the lowest occurrences of *Hygrobiella laxifolia* in Central Europe.

Hygrobiella laxifolia belongs to endangered species of bryophytes in the Czech Republic. It is short-lived shuttle species (Dierssen, 2001), which grows in the bottom of inversion gorges on sandstone boulders in beds of periodically drying brooks (Fig. 2, 3), where we find it in the association *Brachythecietum plumosi*, in the sub-association with *Dichodontium pellucidum* or in the sub-association *Racomitrietosum acicularis* (Müller, 2003).

Fig. 2. Periodically drying brook Suchá Kamenice (Elbe Sandstone Protected Landscape Area) – typical biotope of *Hygrobiella laxifolia*.

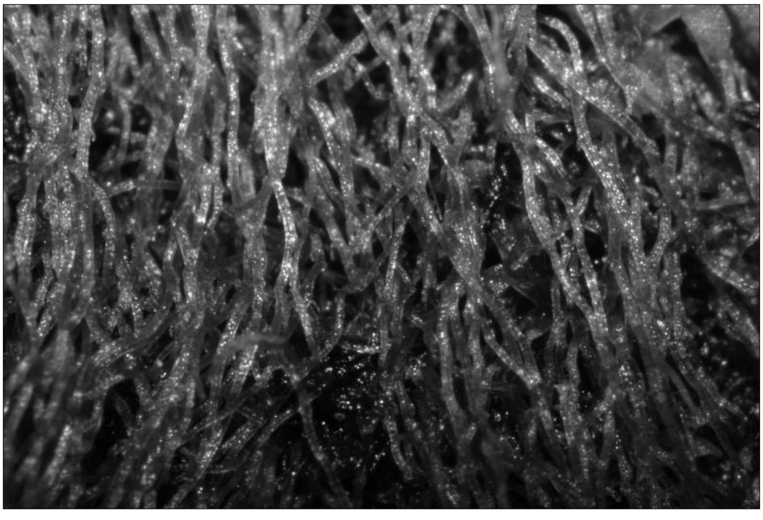

Fig. 3. Liverwort *Hygrobiella laxifolia* – detailed view (Photo by Václav Sojka).

Results

Hygrobiella laxifolia occurs in the Bohemian Switzerland in three gorges. It has been known since 2003 from the gorge called Soorgrund, which is situated near the village of Mezní Louka, and from the gorge of Suchá Kamenice brook, which is located near the village of Hřensko. In 2008 it was found in the gorge of Kachní potok brook, which is situated near the settlement of Kamenická Stráň.

Monitoring of this liverwort began in 2008, during the project of comprehensive monitoring of the state of natural environment of the Bohemian Switzerland National Park, which was subsidized from financial mechanisms EEA/Norway. *Hygrobiella laxifolia* was observed at three sites in Kachní potok brook and three permanent plots in Soorgrund gorge. Data on locality, habitat, population and microclimate (temperature, soil moisture) were collected (Fig. 4).

The aims of monitoring are: (a) to learn more about ecological requirements and population dynamics; (b) to find new localities; (c) to propose management measures based on new knowledge to intensify their nature protection.

Hygrobiella laxifolia grows in studied places on stones, boulders and rock outcrops, are situated in beds of periodically drying brooks. It is asociated with liverworts *Jungermannia sp., Marsupella emarginata, Pellia sp., Scapania undulata*, and mosses *Brachythecium rivulare, Dichodontium pellucidum, Heterocladium heteropterum, Hygrohypnum ochraceum, Rhizomnium punctatum*. The size of population of *Hygrobiella laxifolia* fluctuates between 88 dm^2 in 2009 to 11 dm^2 in 2011 in Soorgrund gorge and between 4 dm^2 in 2008 to 0 dm^2 in 2010 in the Kachní potok Gorge.

Conclusions

Hygrobiella laxifolia is mountain-arctic liverwort, which grows in deep inversions gorges on sandstone boulders in periodically drying brooks. It is very small, competitive weak species. Monitoring started in 2008 in two gorges, Kachní potok brook and Soorgrund gorge. Six monitoring plots were set up, where the data about the state of locality, habitat, population and microclimate were collected.

Floods and especially their intensity play the main role in the distribution of *Hygrobiella laxifolia*. Through the year brooks are usually dry, while water flow occurs only after thaw in early spring and after heavy rains in autumn. Floods block succession of bryophytes on boulders, open new places for colonization of *Hygrobiella laxifolia*, but on the other hand take off the populations and may cover them with sand. The dramatic changes in the size of populations of *Hygrobiella laxifolia* were caused by a big flood in August 2010. The size of monitoring populations in the Soorgrund gorge was reduced to 87%, but at other places in the brook the popu-

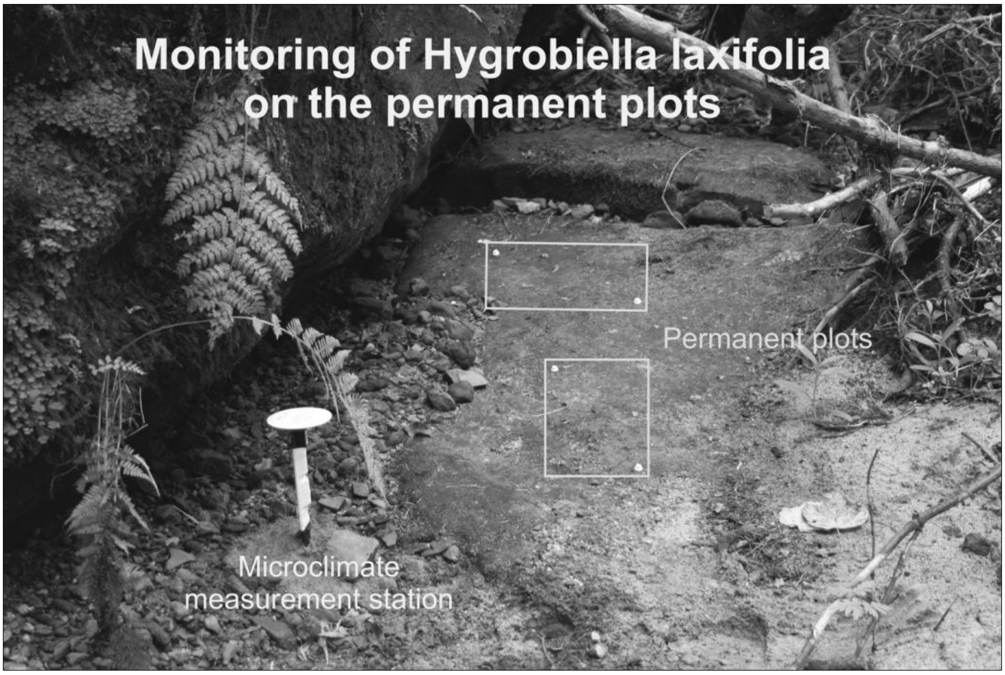

Fig. 4: The permanent plots of population no. 1 in the Soorgrund gorge, the situation in the year 2009.

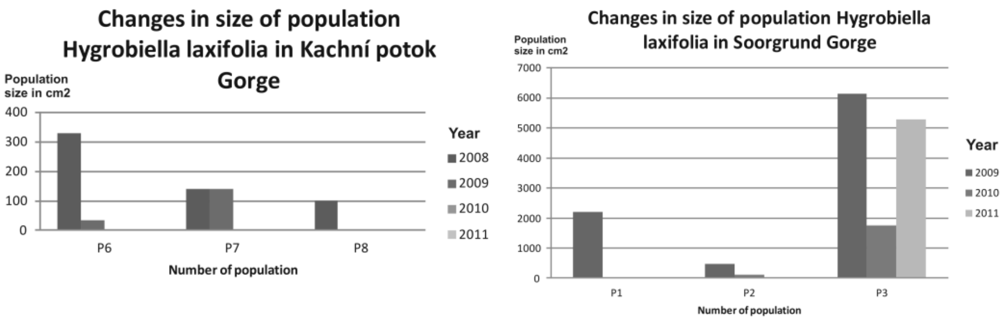

Fig. 5. Changes in size of monitoring populations in the years 2008–2011.

lation still exists. At Kachní potok brook the studied population was destroyed and new population was not found. Now we can study re-colonization and succession of bryophytes on boulders in these areas.

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Bryophytes in the Czech sandstone landscape areas

Abstract: Sandstone landscapes are very important areas for bryophytes. Due to specific abiotic conditions, these areas are relatively species-rich. The most species were found in the Elbe Sandstone, 334 species of bryophytes, and about 250 species were found in other areas (Adršpašsko-Teplické skály Cliffs, Bohemian Paradise, Polomené hory Hills). There are 5 main factors that influence the distribution of bryophytes in sandstone areas: substratum, relief, altitude, microclimate and oceanity/continentality of the area. Sandstone landscapes are important refugia of mountain and suboceanic species of bryophytes. Some of them reach their minimum of vertical distribution there, e.g. *Hygrobiella laxifolia*. The sandstone areas are important refugia of epixylic liverworts, which naturally occur in mountain spruce forests, e.g. *Anatrophyllum michauxii, Geocalyx graveolens, Kurzia sylvatica*. There are some bryophytes, which recently occur only in sandstone areas, e.g. *Campylopus fragilis* and *Kurzia sylvatica*, or were there rediscovered for the Czech Republic, e.g. *Harpanthus scutatus*.

Background

Sandstone landscapes are very important areas for bryophytes, with specific microclimate and mesoclimate conditions in sandstone rock cities, such as high dynamics and island character. Most sandstone regions in the Bohemian Cretaceous Basin have landscape structure with core zones formed by an acidic pseudokarst that are surrounded by forests, plateaus and locally present wetlands and calcareous sandstone outcrops. Other ecosystems (e.g. alluvia, volcanic hills, fields and settlements) are present mostly as patches or linear corridors. Bryophytes are able to migrate over long distances and to respond to fine-scale environmental variation. There are five main factors that influence the distribution of bryophytes in sandstone areas: substratum, relief, altitude, microclimate and oceanity/continentality of the area. At the first view the bryo-flora of sandstone areas is poor. There are relatively small groups of dominant and very abundant species, typically *Tetraphis pellucida*, and other abundant species, e.g. *Odontoschisma denudatum*. On the other hand there are relatively large groups of species strongly limited to sandstone landscapes, typically *Kurzia sylvatica* and species which grow on specific habitats (basalt rocks, calcareous sandstone rocks, bogs, wet meadows etc.). Bryophytes very sensitively react to relatively small changes in habitat conditions, especially changes in the chemistry of substrate and in microclimatic conditions. Therefore, bryo-flora of sandstone landscapes is relatively rich and the number of species included in Red List of bryophytes of the Czech Republic is relatively high, e.g. in the Elbe Sandstone 39% of bryophytes which are occurred in the Czech Republic grows and 26% bryophytes is listed in the Red List.

Results

The maximum information about bryo-flora of the Czech sandstone areas comes from the thesis by Dohnal (1950), Mrázová (1969), Salabová (1981), Bašková (1985), Černá (1987), Hubáčková (1988), and Paulů (1992). New data come from research projects (e.g. Gutzerová, 1994; Němcová-Pujmanová, 1995; Müller, 2005) and from the meetings of the Czech Bryological and Lichenological Society (e.g. Kučera et al., 2003; Kučera, 2006). Recently bryological research is run only in the Bohemian Switzerland.

In this paper we compare the bryo-flora of the Elbe Sandstones, Polomené hory Hills, Hradčanské stěny Cliffs, Bohemian Paradise and Adršpašsko-Teplické skály Cliffs. These areas differ in terms of geographical position and climatic conditions. Among them, the Elbe Sandstones are situated most to the west and hence, are most influenced by the Atlantic Ocean. Adršpašsko-Teplické skály Cliffs are the coldest and highest sandstone area of the Czech Republic. The driest and warmest area is the eastern part of the Polomené hory Hills.

Table 1. Altitudinal ranges of individual sandstone regions of the Czech Republic.

Region	minimum altitude	maximum altitude
Elbe Sandstones	110	726
Polomené hory Mts.	165	614
Ralsko-Bezděz Plateau	215	696
Bohemian Paradise	235	744
Broumovsko Region	355	919

Sandstone landscapes are important refugia of mountain, boreal and suboceanic species of bryophytes. Most of subarctic-subalpine-alpine species (5%) and boreo-mountain species (20%) occur in the Adršpašsko-Teplické skály Cliffs, at the second place are the Elbe Sandstones (3% of subarctic-subalpine-alpine species, 17% of boreo-mountain species). *Dicranodontium asperulum, Plagiomnium medium, Polytrichastrum alpinum* and *Tetrodontium repandum* are the subarctic-subalpine-alpine species which occur in both sandstone areas.

Boreo-mountain species are richly represented in other sandstone landscapes. There are 19% in the Bohemian Paradise and 15% in the Polomené hory Hills and Hradčanské stěny Cliffs. *Anastrophyllum minutum, Brachythecium starkei,* *Cephalozia lunulifolia, Dicranella cerviculata, Dicranodontium denudatum, Dichodontium pellucidum, Lophozia attenuata, Rhabdoweisia fugax, Sphagnum quinquefarium, S. russowii, Sanionia uncinata* and *Tritomaria exsectiformis* are the boreomountain species, which occur in the majority of sandstone landscapes.

Most suboceanic species of bryophytes (8%) occur in the Elbe Sandstones and many of these species (6%) were found in the Adršpašsko-Teplické skály Cliffs, Hradčanské stěny Cliffs and the Polomené hory Hills. *Leucobryum albidum, Mnium hornum, Pseudotaxiphyllum elegans, Rhizomnium punctatum* and *Thuidium tamariscinum* are the suboceanic species, which occur in the majority of sandstones areas.

Bryo-flora of sandstone landscapes is relatively rich. As many as 334 species of bryophytes (2 hornworts, 94 liverworts, 238 mosses) were found in the Elbe Sandstones and 87 (26%) of them are listed in the Red List, e.g. *Anastrophyllum michauxii, Dicranum majus, Fissidens arnoldii, Geocalyx graveolens, Harpanthus scutatus, Hygrobiella laxifolia, Lophozia grandiretis, Riccia cavernosa* and *Tetrodontium brownianum*. In the Polomené hory Hills 259 species occur (1 hornwort, 60 liverworts, 198 mosses) and 39 (15%) of them are included in the Red List, e.g. *Cephalozia catenulata, Geocalyx graveolens, Helodium blandowii, Microbryum curvicolle* and *Riccia cavernosa*. The same number of bryophytes (2 hornworts, 73 liverworts, 184 mosses) was found in the Adršpašsko-Teplické skály Cliffs and 34 (13%) of them are listed in the Red List, including *Anoectangium aestivum, Campylopus fragilis, Cephalozia catenulata* and *Dicranodontium asperulum*. 257 species (2 hornworts, 80 liverworts, 175 mosses) occur in the Bohemian Paradise and 39 (15%) of them are included in the Red List, e.g. *Bazzania tricrenata, Cephalozia*

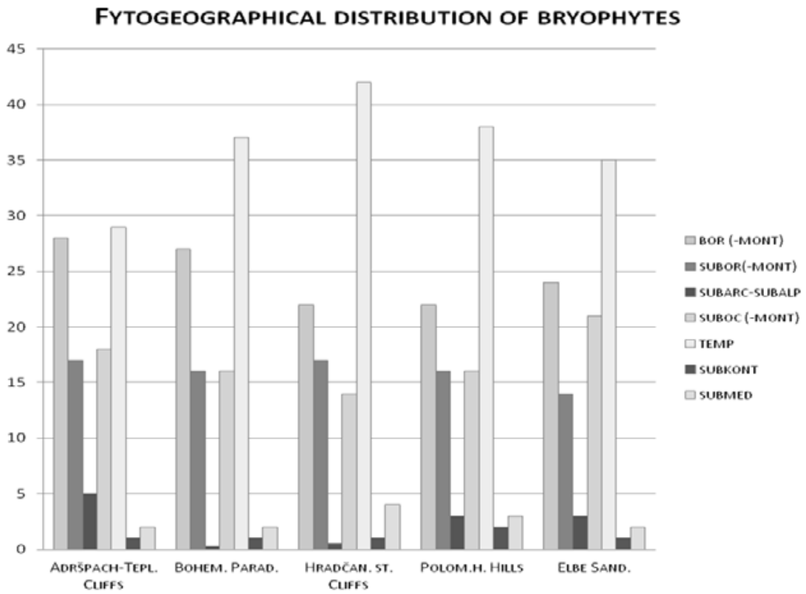

Fig. 1. Fytogeographical distribution of bryophytes in the Czech sandstone landscape areas.

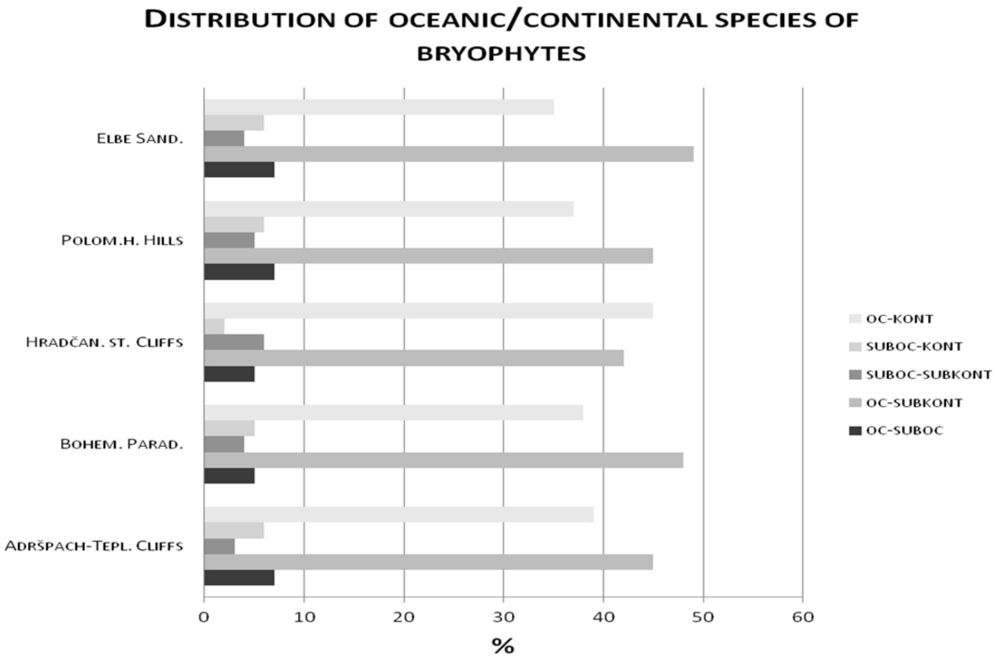

Fig. 2. Distribution of oceanic/continental species of bryophytes in the Czech sandstone landscapes areas.

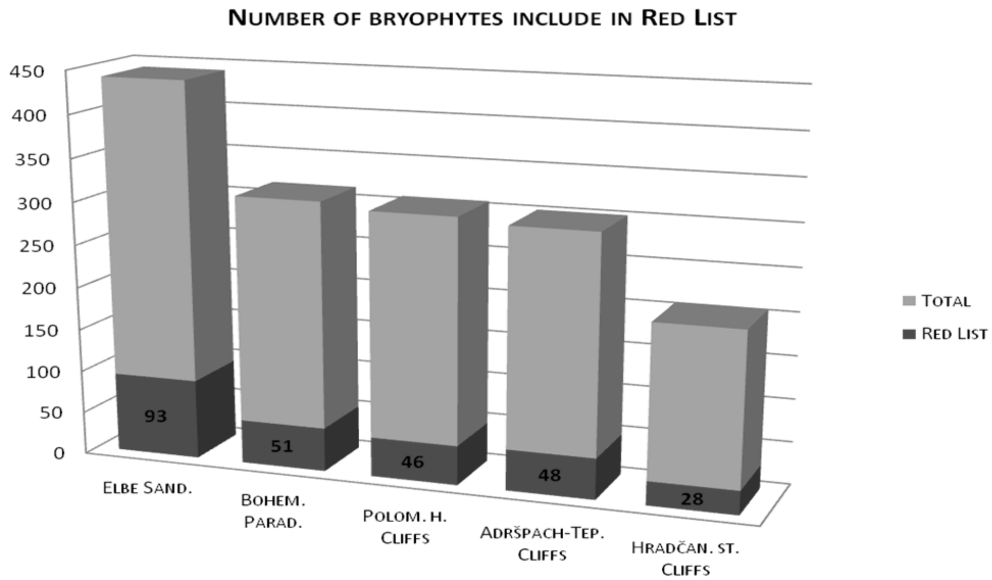

Fig. 3. Number of species occurring in the Czech sandstone landscape areas and listed on the Red List.

catenulata, Nowellia curvifolia and *Pedinophyllum interruptum*. Finally, 179 species (39 liverworts, 140 mosses) occur in the Hradčanské stěny Cliffs and 23 (12%) of them are listed in the Red List, e.g. *Campylopus fragilis, Campylophyllum calcareum, Eurhynchium striatulum, Hypnum sauteri* and *Riccardia incurvata*.

The liverwort *Kurzia sylvatica* and the moose *Campylopus fragilis* recently occur only in sandstone areas, where they grow on sandstone rocks (Duda, Váňa, 1986, 2005; Kučera, 2004).

Conclusion

The sandstone landscapes are important refugia of mountain and suboceanic species of bryophytes. Their higher occurrence is caused by climatic inversion in deep gorges and valleys. Some bryophytes reach here their minimum of vertical distribution, e.g. *Dicranum majus, Hygrobiella laxifolia* and *Hylocomiastrum umbratum*. The sandstone areas host a lot of epixylic bryophytes, which grow on sandstone rocks. Some of them have lost their natural habitat in mountain spruce forests, where they grew on decaying logs, e.g. *Anastrophyllum michauxii, Geocalyx graveolens* and *Kurzia sylvatica*. There are some bryophytes, which recently occur only in sandstone areas, e.g. *Campylopus fragilis* and *Kurzia sylvatica*, or were there rediscovered for the Czech Republic, e.g. *Harpanthus scutatus* in the Elbe Sandstone (Kučera et al., 2003).

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Sandstone boulders as a source of building stone material – a contribution to the cultural heritage of the Stołowe Mountains, Central Europe

Abstract: In the Stołowe Mountains numerous instances of sandstone boulder quarrying were mapped within talus slopes and on level surfaces where allochthonous residual blocks occur. The evidence of ancient quarrying includes split boulders, plucked boulder faces, ground hollows left after complete removal of a boulder, and heaps of small, unused stone which locally cover substantial areas. The majority of cut rock was utilised as a building or ornamental stone, but some was used to build dry walls. Talus slopes were chosen as sites of quarrying because of their proximity to villages, abundance of good quality rock material and relatively easy access on gentle slopes. Today, these sites should be considered as parts of the local cultural heritage.

Introduction

Cretaceous quartz and arkosic sandstones, soft enough to be easily dressed but sufficiently tough and durable to be appreciated as a building or ornamental stone, have long been favoured by stone masons working in the Sudetes. Hence, sandstone quarrying has been present in the region since the medieval times and many abandoned quarries in areas, where Cretaceous sandstone occur, are the legacy of this industry. While quarrying reached its peak intensity in the north-west part of the Sudetes, within the geological unit of North-Sudetic Trough, the Stołowe Mountains in the Central Sudetes were a place of widespread sandstone exploitation too. In this note, the phenomenon of quarrying sandstone boulders rather than solid rock outcrops is briefly described and evaluated.

Geomorphological background

Except for the south-eastern part close to the town of Polanica Zdrój, access to sandstone outcrops in the Stołowe Mountains posed some challenge. The layered structure of the mountains and high contrasts in rock mass strength between sandstone units and fine-grained sedimentary rocks in between (mudstone, marl, claystone) support the tableland landscape, whose characteristic elements are steep sandstone escarpments separating low relief terrain cut across weak, fine-grained rocks (Placek, 2011). Thus, sandstone outcrops occur high up the slopes, where they act as caprock and produce rock faces up to 40–50 m high. Below, talus slopes and then pediments extend towards the lower ground. Since settlements were founded on this lower ground, a more convenient source of building stone than distant escarpment rock faces was apparently sought, at least for very local purposes. Talus slopes, built of massive cubic sandstone blocks detached from the escarpment face by rock fall and subject to subsequent gravitational transport along the slope, were found to be such a source. Sandstone boulders of the talus are not uncommonly 4–5 m long, even in very distal sections of the slope, and cover large areas. Occasionally, big blocks can be found as far as 400–500 m away from the rock face, for instance below the spur of Biała Skała on the northern escarpment (Migoń, Kasprzak, 2012). Along with distance from the rock face, slope gradient diminishes and large sandstone boulders may even occur on gently inclined, 5–10° surfaces. These circumstances have made talus slopes below sandstone escarpments a ready source of building material in effectively unlimited supply.

Location of boulder quarrying sites

During detailed geomorphological field mapping of the Stołowe Mountains a number of localities below sandstone escarpments were identified, where loose sandstone boulders of the talus were widely worked and collected by local people to meet local demand for stone material. In all cases, these places were located in the vicinity of settlements, a few hundreds meters up the slope. Mapped locations include Ostra Góra, Borek (a hamlet belonging to the town of Radków), Kociołek and Góra Anny (Fig. 1). Quarrying activity was not limited to individual boulders. Quite to the contrary, stone exploitation must have proceeded at a considerable scale as shown by relict anthropic landforms and abandoned sandstone blocks. For example, above Borek there are more than one hundred individual sites of stone quarrying and dressing, gradually going higher and higher up the escarpment. They vary in style, from small ground hollows 2–3 m long, left after a single block was lifted and/or cut into smaller fragments, to fairly large heaps of leftover blocks, covering areas up to 15 x 15 m. The lowest location with the evidence of boulder quarrying is at 460 m a.s.l., while the most elevated traces of stone extraction can be found at 600 m a.s.l. Mid-slopes were apparently quarried most intensively as they combined the abundance of boulders with relatively easy access and moderate slope gradient.

Another source of building stone was boulders present on level surfaces near the villages of Karłów (locality Pustelnik; Fig. 2) and Łężyce (locality Sawanna Łężycka). Their provenance is uncertain and it is likely that they are ghost remnants of long degraded outliers in front of sandstone escarpments (Migoń, 2012, this volume). They do not occur in a similar abundance as talus blocks, are widely dispersed and heavily weathered. Therefore, despite the proximity to villages and easy transport, only some blocks were quarried. This is beneficial from the point of geoheritage conservation since otherwise these unique boulder clusters might have completely disappeared.

The testament of ancient boulder quarrying is revealed in a variety of forms: split boulders, plucked boulder faces, hollows left after complete removal of a boulder, and heaps of small, unused stone (Fig. 2). The use of stone was multiple. While

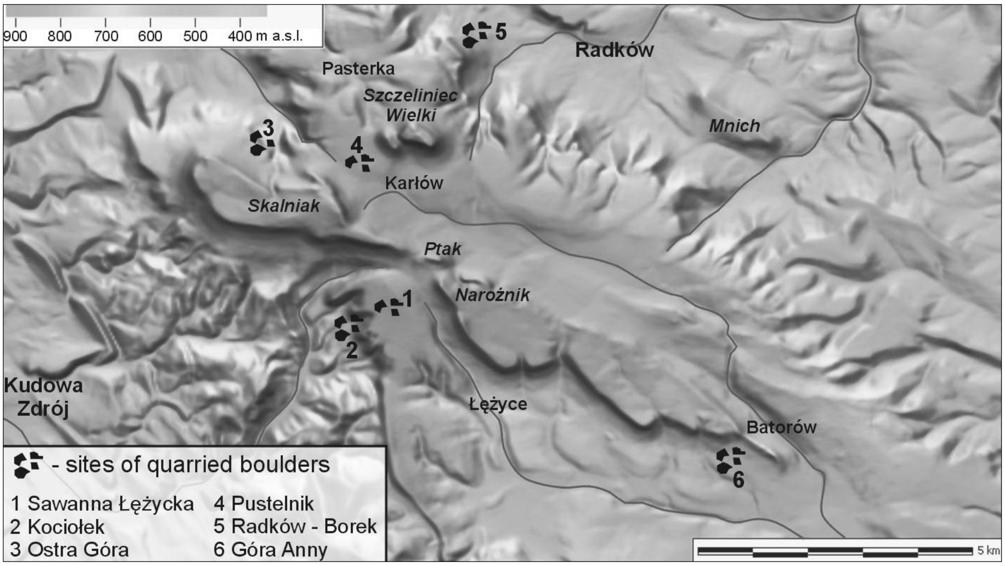

Fig. 1. Location of mapped sites in the Stołowe Mountains where boulder quarrying took place.

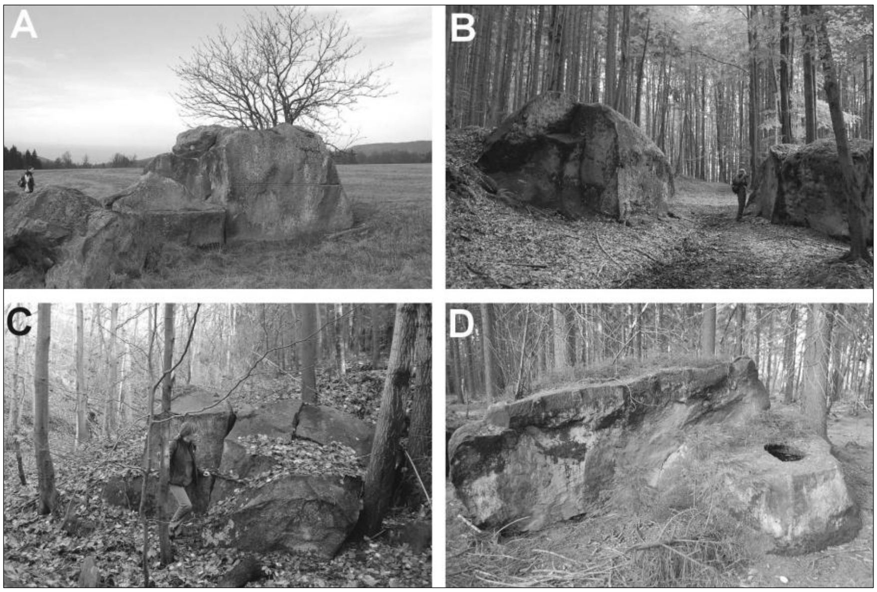

Fig. 2. Evidence of quarrying on residual sandstone boulders: A – Sawanna Łężycka, B – Radków-Borek, C – Kociołek, D – at the Karłów – Ostra Góra road.

the majority was utilised as building or ornamental stone, some was used to build dry walls in arable grounds which are common in some parts of the Stołowe Mountains, e.g near Batorów. It is difficult to say when boulder quarrying took place and in particular, whether it preceded the opening of large quarries at a few localities along the sandstone escarpments (e.g. Radków, Wambierzyce, Łężyce) or co-existed with industrial exploitation which lasted until World War II. Localities of Borek and Ostra Góra, where remnants of stone extraction are now within >100 years old beech communities, suggest that boulder quarrying as a whole is an ancient activity that occurred in the 19^{th} C or even before.

Evaluation

Past exploitation of sandstone boulders is of interest not only because it constitutes a part of the local heritage and the legacy of various interactions between humans and sandstone, covered under the umbrella term of 'sandstone phenomenon' (Härtel et al., 2007). It is a factor that needs to be considered while interpreting natural landforms. The sheer scale of boulder quarrying at some sites implies that boulders seen within talus slopes today, especially in the lower slopes, are only a fraction of those produced by natural processes. In some places to distinguish between a natural block slope and an anthropogenic stone heap is not immediately easy. Finally, although partial quarrying of boulders would be regarded today as vandalism and destruction of geoheritage, unexpected features have been revealed due to past activities. A huge sandstone boulder near Karłów – Ostra Góra road lost one of its corners, exposing a regular circular cavity (Fig. 2D). These are puzzling features and various hypotheses were advanced to explain their origin (Dumanowski, 1961). The presence of the cavity inside a sandstone block is an evident proof of sedimentary/diagenetic rather than weathering origin of such features.

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Longevity of residual sandstone boulders in the erosional relief of the Stołowe Mountains, Central Europe

Abstract: Among peculiar geomorphic elements of the Stołowe Mountains are two clusters of residual quartz sandstone boulders resting on nearly level surfaces underlain by fine-grained sedimentary rocks, mainly mudstones. A few tens of boulders 2–10 m long occur at each location, while some may have been completely quarried away in the past. Boulders are not rooted in bedrock which might suggest transport to their present-day location, but they do not continue towards sandstone-capped escarpments, located at least 400–500 m away and are separated from boulder-covered flats by linear troughs. Therefore, boulders are not considered as derived from caprock by rock fall and further moved by gravity-driven processes. Instead, a hypothesis is proposed that they are the only remnants of long eroded outliers in front of sandstone escarpments and settled down concurrently with surface lowering in weak mudstones. They owe their survival to high rock mass strength of poorly jointed sandstone, although their outer surfaces are considerably weathered. All these circumstances suggest that the boulders have protracted lifetimes, but these remain unconstrained at the moment.

Introduction

In the erosional relief of the Stołowe Mountains (SW Poland) outcrops of Cretaceous sandstone are associated mainly with escarpments, where they build the upper slope sections and support rock faces, occasionally as high as 40–50 m. Toppling, rock falls and rock slides from caprock are the mechanisms through which blocks are detached and displaced to the mid-slope, where they form a talus overlying softer rock that occurs below sandstone levels (Dumanowski, 1961). Subsequent gravitational movement accomplished by shallow slides and creep may dislocate the blocks even further, to the base of an escarpment. Thus, on a typical escarpment slope, the number of sandstone blocks decreases downhill and their size gets smaller.

Two notable exceptions occur in the Stołowe Mountains and these will be examined here. In both cases large sandstone blocks occur far away from the nearest outcrops, on local flats or terrain convexities, that renders an explanation by slow gravitational transport from escarpments improbable. Therefore, alternative mechanisms will be presented and discussed.

Location and characteristics

Figure 1 shows the location of two clusters of residual sandstone boulders which are of interest in this account. Their common features are the following: (1) sandstones belong to the upper sandstone level distinguished in the Stołowe Mountains, the quartz sandstone of Upper Turonian age (Jerzykiewicz, 1968; Wojewoda et al., 2011); (2) boulders are not rooted in bedrock but rest directly on mudstones and marls which underlie quartz sandstones (see Wojewoda et al., 2011) and supports the extensive intermediate plateau level of the Stołowe Mountains; (3) they occur far below the altitude at which quartz sandstones occur in situ, i.e. at least 60–80 m below it; (4) trough valleys separate the level surfaces with sandstone boulders from the footslopes of the escarpments; (5) boulder clusters are spatially isolated and do not continue towards nearest sandstone-capped escarpments.

One location is known as Sawanna Łężycka (Łężyce Savanna) and denotes a group of more than 30 boulders scattered across a nearly flat area of c. 0.25 km^2. The largest of them are 6–8 m long and stand up to 5 m high. They are a few tens of metres from each other, although some are fairly closely spaced (Fig. 2). Boulder surfaces are heavily weathered although they lack regular features in the form of weathering pits or flutes. A few bear signs of quarrying and stone dressing, hence it is likely that more boulders may have been present in the past. The nearest outcrops of the Upper Turonian quartz sandstone are more than 1 km to the east and north from the site.

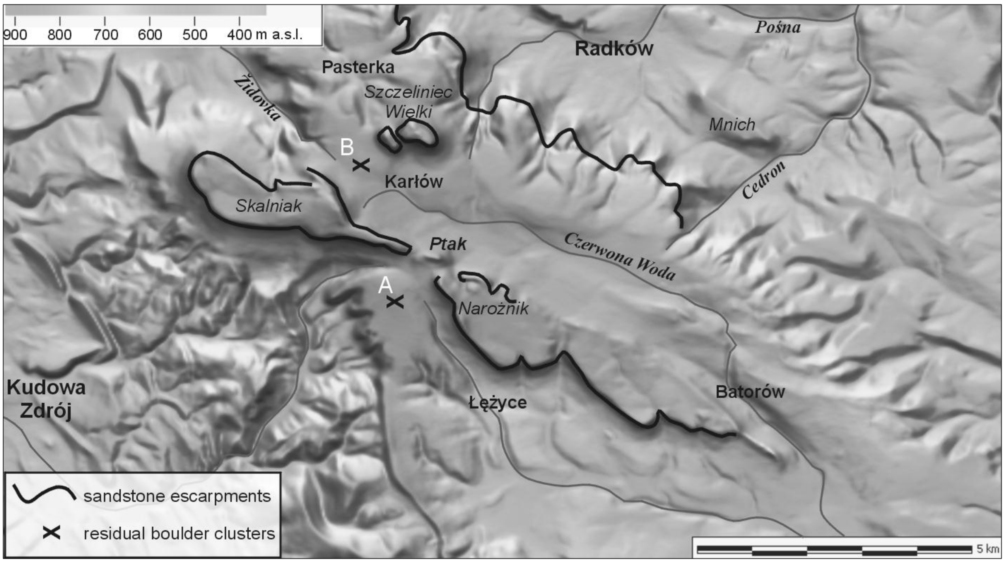

Fig. 1. Location of residual sandstone boulder clusters in the Stołowe Mountains: A – Sawanna Łężycka, B – Pustelnik. Skalniak, Narożnik and Szczeliniec Wielki form the upper plateau level, while boulder clusters rest on the intermediate plateau level.

The second location is north-west of Karłów, on a local flat surface known as Pustelnik (Migoń, 2010). As many as 20 large boulders rest scattered across the surface, in two separate clusters, although they nevertheless remain quite dispersed (Fig. 3). The largest blocks are 10 m long and 6.5 m high. As in Sawanna Łężycka, their current position is allochthonous, 400–500 m away from escarpments built of quartz sandstone and at least 60–80 m below the altitude level of its occurrence in situ. Geometry of bedding planes indicates considerable rotation of some blocks in both vertical and horizontal direction. Boulders at Pustelnik are heavily weathered too. Honeycombs, large weathering pans (up to 1 m across) on upper flat surfaces and tafoni may be found.

Fig. 2. Sandstone boulders at Sawanna Łężycka.

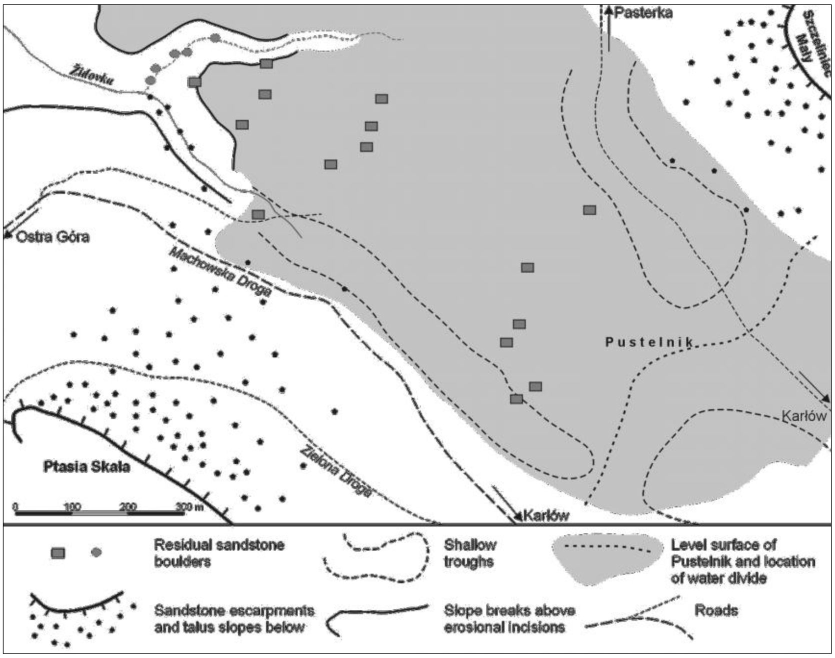

Fig. 3. Location of sandstone boulders at Pustelnik flat.

Boulders in V-shaped valleys below the plateau level

Both level surfaces which host sandstone boulder clusters diminish in extent due to stream incision in their marginal parts and associated headward erosion. The Sawanna Łężycka flat is undercut on its western side by a few steep-sided valleys, while the Pustelnik flat terminates on the northwestern side at two deep fluvial incisions (Fig. 1, 3). In both cases further boulders can be found within these valleys, although notably, on their floors rather than on slopes. West of Sawanna Łężycka, a boulder train nearly 600 m long fills the valley floor. Close to the headwater boulders are piled one upon another and become more scattered while going downstream. Their size is comparable to those at the level surface above the incision, especially in the upper reach. Boulders within the incision next to the Pustelnik flat are somewhat smaller than their plateau counterparts, 2–4 m long on average. Valleys at both locations are incised into mudstones and marls and hence, boulders are evidently allochthonous.

Origin

Allochthonous boulders in front of escarpments, made of rock identical with the one forming caprock, are usually explained in terms of gravity-driven transport from the rock face across mid-slope to the footslope. Transport mechanisms may be simple and involve only detachment and fall, or more complex, with several contributing mechanisms. However, in neither of the two cases presented here does a simple hypothesis of downslope transport from rock escarpments across the debris slope towards the piedmont surface seem valid. Its main weaknesses include the location of blocks on an almost level surface and the presence of topographic troughs at the foot of escarpments. To envisage mechanisms of transport of large rock blocks across flat terrain or even upslope remains a major challenge.

More likely would be a modified gravity-transport hypothesis, according to which rock faces are actively retreating, whereas blocks are the last vestiges of talus deposits. However, isolation of blocks in space is still inadequately explained, as is the absence of boulders towards the escarpments. Both these features are difficult to reconcile with continuous backwearing of the scarp which should have left more and more residual blocks as one approaches the higher ground.

Therefore, a preferred hypothesis (Migoń, 2010) assumes the existence of sandstone-capped outliers (mesas), already separated from the more extensive parts of the upper plateau (Fig. 4). In the first case (Sawanna Łężycka), the mesa was located in front of the present-day sandstone escarpment; in the second (Pustelnik), the mesa (or two, as there are two sub-clusters) occurred between the plateau of Mt Skalniak and the large twin mesa of Mt Szczeliniec Wielki. In both examples, residual boulders are interpreted as the last remnants of those terrain elevations, so they did not need to travel to their present-day locations. However, to be found in the contemporary position, individual boulders had to 'sink' by 50–60 m and outlive the underlying mudstones which would have been completely eroded. This is not improbable as quartz sandstones are massive and tough, characterized by high rock mass strength (Remisz, 2008), hence apparently able to withstand denudation of the underlying heterolithic complex (mudstones, calcareous sandstones, marls). Further support to this hypothesis is given by the presence of sandstone boulders in deep fluvial incisions into the intermediate plateau. Their occurrence in these geomorphic settings is evidently a by-product of backwearing of steep mudstone slopes and cannot be explained by fluvial transport. Concurrently with slope retreat, boulders become undercut and slide down the slope towards valley floors. Therefore, some are now located more than 200 m below the level of in situ occurrence of quartz sandstones.

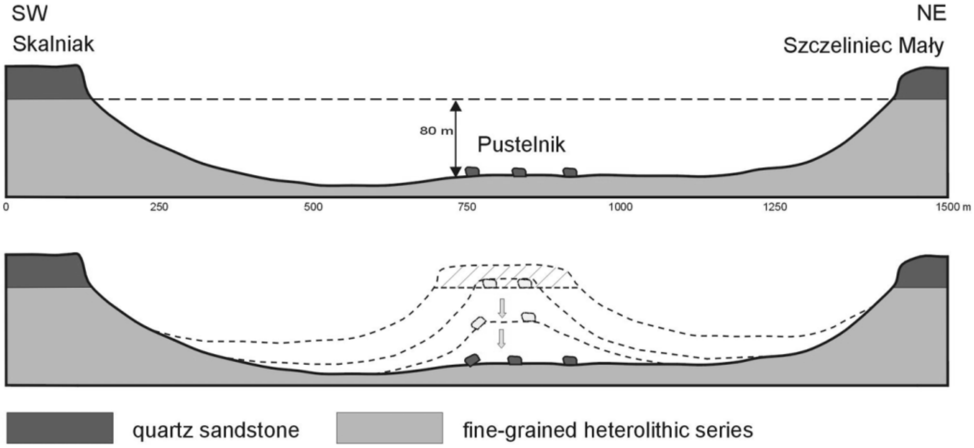

Fig. 4. Diagram to show the likely origin of sandstone boulders at Pustelnik flat: present-day situation (above) and geomorphic reconstruction (below).

At present, it is impossible to quantify the proposed longevity of residual sandstone boulders as no solid data about rates of surface lowering in soft sediments beneath sandstone exist, nor about rates of escarpment retreat in sandstone itself. An option to explore is to use cosmogenic isotopes to date surface erosion rates on residual sandstone blocks and the length of their exposure to cosmic radiation.

Conclusions

Clusters of allochthonous quartz sandstone boulders on the level surface of the intermediate plateau belong to the most mysterious geomorphic features of the Stołowe Mountains, yet they have been largely overlooked in the regional literature. Their occurrence within open ground contributes to their scenic value too. In this paper three hypotheses of the origin of boulder clusters have been forwarded. The simplest one involving detachment from escarpment caprock and gravity-driven transport downslope is dismissed as incompatible with local morphology. It is suggested that boulders are the last remnants of long eroded outliers of the upper plateau which ‘sank’ concurrently with surface lowering in weak mudstones and marls. They are features with protracted, albeit unconstrained lifetimes. Therefore, recognition of their exposure histories may shed a new light on the rates of evolution of sandstone escarpments

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Between sand and sandstone: microrelief on very weakly cemented sandstones

Abstract: Weakly cemented sandstones often show diverse microrelief features. These are of various origins, but animal action often plays an important part. Dwelling and nesting holes are initial caverns resembling honeycomb structures from well lithified sandstones, which may subsequently develop and enlarge through subsurface drainage. Rapid development allows to monitor the rates of evolution. Examples from around the Baltic region illustrate the contribution.

Extremely poorly litihfied/cemented sandstones (poor contact cement of Fe oxides and hydroxides, kaolinite, salt efflorescences of sea spray), passing continuously to consolidated sands, usually belong to the 'Morphofacies of Smooth Surfaces' (Adamovič et al., 2010). Besides the smooth surfaces, characteristic microrelief patterns may locally occur. These are of particular theoretical interest, especially because of their rapid development which enables a direct observation throughout their life. Our research focused on Jurassic sands and sandstones of the southern and western coasts of Bornholm Island (Denmark; Fig. 1A–G), Devonian sands and sandstones of Pskov region (Russia; Fig. 2), Cambrian sands and sandstones of the St. Petersburg region (Russia; Fig. 3A–E) and blocks of artificially hardened sand ('sand sculptures' stabilized by dispersed organic glue; Fig. 1H).

Poorly litihfied sandstones are attractive for trace-making activities of animals (dwelling and nesting), especially for insects (numerous hymenopterans) and birds (e.g., sand martin). The resulting tunnels are a few millimetres to a few centimetres (insects), or several centimetres to tens of centimetres (birds) in diameter. Ordered arrangement of the openings of the tunnels is based both on the physical properties of the substrate (limits of the collapse) and on the ethologically controlled standard distance from neighbours. Biogenic features of the microrelief further develop mechanically and/or chemically; the late stages may easily be misinterpreted. Importantly, the nesting/dwelling tunnels function as drainage routes during the wet season, and minute grooves may form below them.

The mechanism could be also responsible for relatively large (diameter of several decimetres) and long (up to several metres) cylindrical tunnels, known from numerous areas of weakly lithified sandstones. Drainage may be so strong that stream water may causes backward erosion in the distal part of the tunnel. At the same time, the rest may be protected (slightly hardened) from this kind of erosion. Cambrian sands/sandstones at the Tosna and Sablinka rivers (St. Petersburg region, Russia) enabled us to observe burrows of sand martins developing in this way.

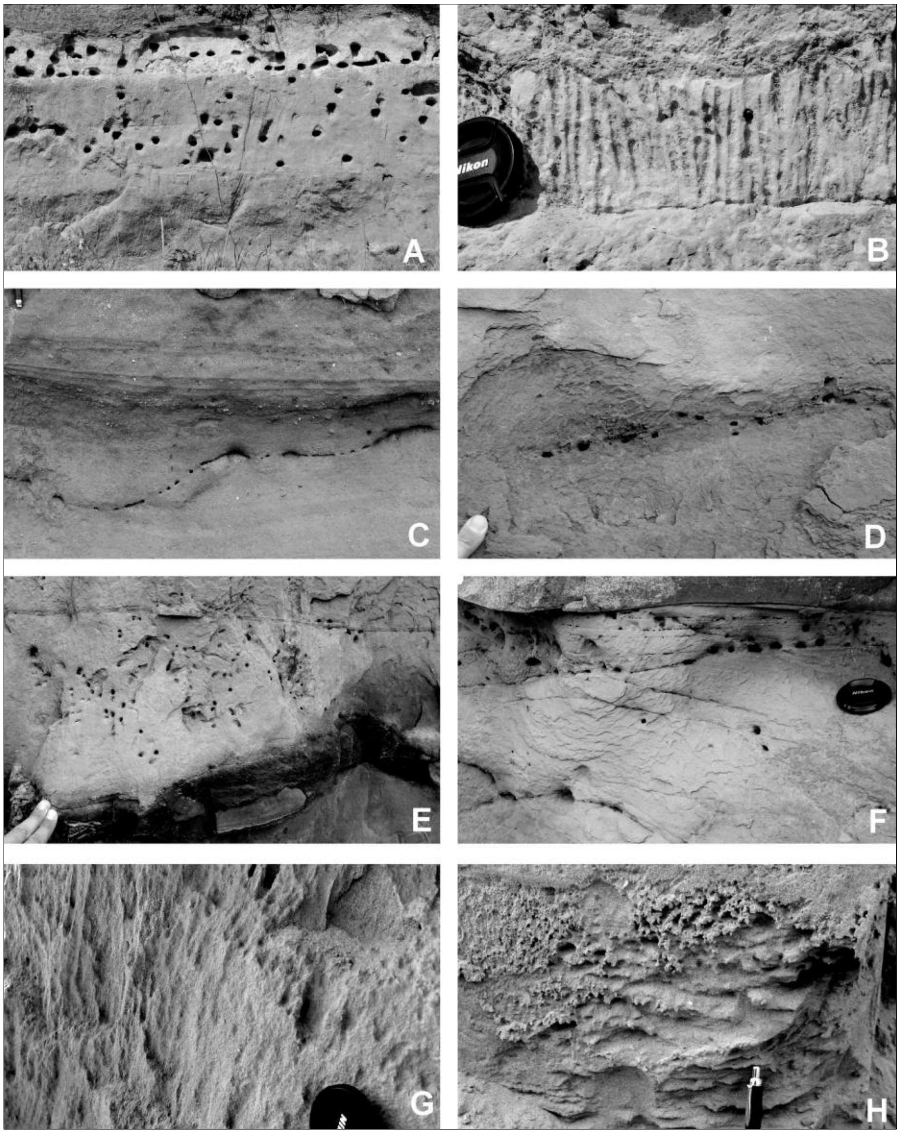

Fig. 1. Examples of microrelief features on poorly lithified sandstones. A – Holes of sand martin bird; B – small regular grikes; C – small honeycombs (partly based on insect holes) along a fissure; D – small honeycombs (partly based on insect holes) along a fine-grained bed; E – clusters of insect holes; F – insect holes and ‘inorganic’ honeycombs; G – minute conical grikes; H – initial forms of honeycombs, horizontal ledges and nodular surfaces. **A–B**: Jurassic sand/sandstone, Arnager, south Bornholm; **C–F**: Jurassic sand/sandstone, Hasle, west Bornholm; **G**: Pleistocene sand/sandstone, Limensgade, south Bornholm; **H**: sand sculpture four weeks after finishing, June 2006, St. Petersburg.

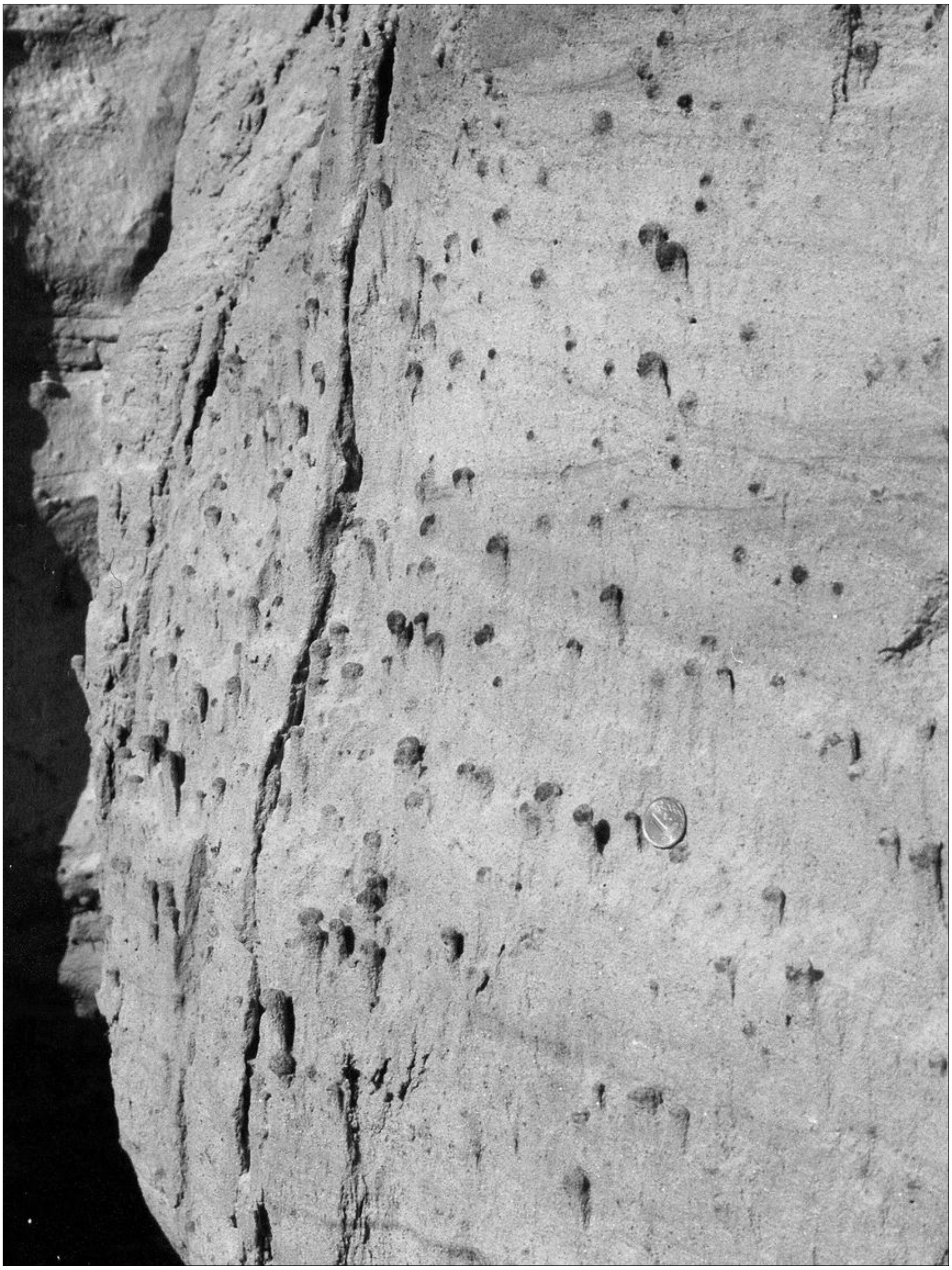

Fig. 2. Minute "hoodoos" formed on a subvertical sand/sandstone wall. Gauja Sandstone, Devonian at the Luga River near Luga, Russia. Coin diameter = 20 mm.

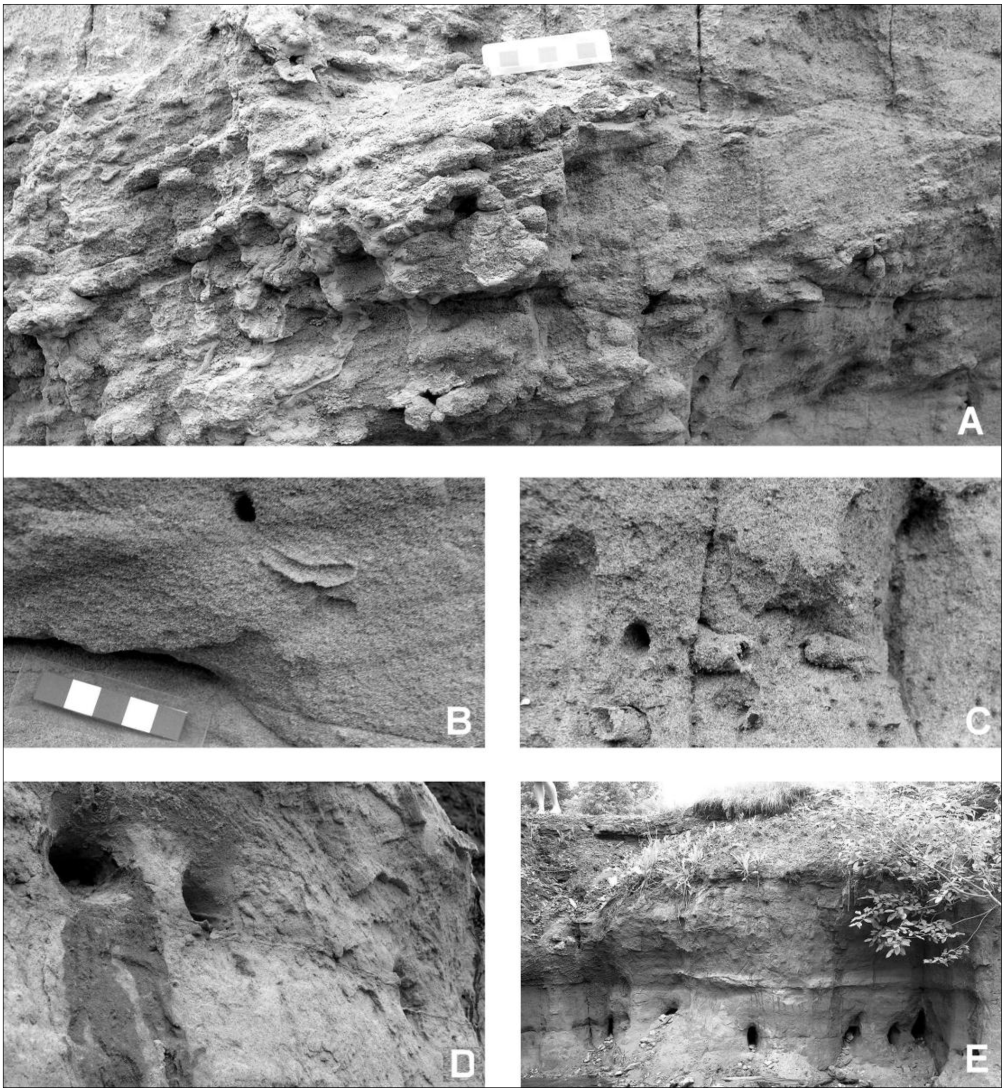

Fig. 3. Surfaces of Cambrian sands/sandstones at the Tosna and Sablinka rivers (St. Petersburg region, Russia) near the village of Ulyanovka. A – nodular surfaces; scale in centimetres; B – destructed hymenopteran burrow on a vertical sand/sandstone wall; its surface is partly impregnated by case hardening; scale in centimetres; C – destructed hymenopteran burrows on a vertical sand/sandstone wall; wall linings are composed of organic silk and sand grains; diameter of burrows is 6–9 mm; D – short cylindrical tunnels on a vertical wall, diameter of openings is approximately 20 cm; E – long cylindrical tunnels on a vertical wall; width of openings approx. 20 cm, length of tunnels c. 1 m.

Regular groove-like grikes represent another recurring feature on the surfaces of poorly litihfied sandstones. Water runoff was observed to form these structures, which often remain of unknown origin if present on older surfaces of well-lithified sandstones. More frequently, conical grikes develop, passing to minute rock/soil pyramids. Heterolithic poorly litihfied sandstones tend to form small-sized, non-durable horizontal ledges. Columnar jointing, analogous to that in loess accumulations, is sometimes present. Honeycombs are present in the form of shallow, flat holes covering subvertical surfaces. Deep holes can also be present as chains along bedding/joint planes or as clusters on biologically eroded sites.

Initial forms of honeycombs, horizontal ledges and bulbous/nodular surfaces were also observed on artificial substrates of sand sculptures. This confirms the possibility of short-time modelling of the honeycombing processes on experimental substrates.

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Distinct form of microrelief on steep slopes of the Rogowa Kopa, Stołowe Mts., SW Poland – in the light of geomorphological and pedological evidence

Abstract: In this study we mapped 82 pit-and-mound pairs within an area of 2.3 ha on the steep forested slope of the Mt Rogowa Kopa, the Stołowe Mts. After excavating three pit-mound forms within the upper, middle and lower section of the slope we were able to document inverted horizonation, as compared to the analysed adjacent control profiles. Within the mounds horizons of relict humus were detected, together with atypical course of soil pH and organic carbon content of the profiles. The pit-mound microrelief was interpreted as windthrow morphology and attributed to the process of tree uprooting.

Introduction

On the SW slopes of the Rogowa Kopa, the Stołowe Mts., there exists a very distinct form of surface microrelief. It consists of numerous pairs of mounds and pits, elliptical in shape, randomly distributed on a steep slope built of fine-grained sedimentary rocks, mainly mudstones and marls. Preliminary field data suggest it can be an effect of tree uprooting process (also called *tree throw*), which is thought to be very common in temperate unmanaged forests (e.g. Schaetzl et al., 1989a, b). In favourable conditions, an upheaved root system of a fallen tree, together with the attached soil material, called a root plate, forms a mound due to degradation of organic and mineral substance through erosional and mass wasting processes (e.g. particle fall, sheet wash, rain splash) and decomposition of a root system and tree trunk (Fig. 1). Many mounds and pits covering a land unit are called 'windthrow morphology', suggesting the probable cause of tree toppling – strong wind. However, such a morphology can also develop over a longer period of time due to secular processes.

The aim of this research is to investigate tree uprooting process in the light of geomorphological and pedological data. So far, both aspects of forested hillslope dynamics and soil evolution have not been studied in detail in the Sudetes. Additionally, methods of soil analysis are tested whether they are an appropriate tool indicating a relative age of pit-and-mound relief.

Study site and research methods

Mt Rogowa Kopa (790 m a.s.l.) is situated within the limits of the Stołowe Mountains National Park, which geographically belongs to the Middle Sudetes region. It is built of very fine sedimentary rocks (mudstones, marls, claystones, fine-grained sandstones) of the Upper Cretaceous age – Turonian (Rotnicka, 2007). The bedrock is mantled by 50–100 cm deep Cambisols (Kabała et al., 2002), and more precisely by Endoleptic and Haplic Cambisols. These soils are weakly developed and relatively young, supposedly of the Holocene age. There is no soliflution structures typical of older slope material of Pleistocene age. On the steep SW slope of Mt Rogowa Kopa a research polygon around 2.3 ha in size was set up (Fig. 2). It is covered by the fertile Sudetic beech forest (*Dentario enneophyllidis-Fagetum typicum*) consisting of 60% of beech (*Fagus sylvatica*), 40% of sycamore (*Acer pseudoplatanus*) and locally Norway spruce (*Picea abies*) and birch (*Betula*).

Research methods included detailed geomorphological mapping and measurement of individual tree throw mounds (width, length and height) and

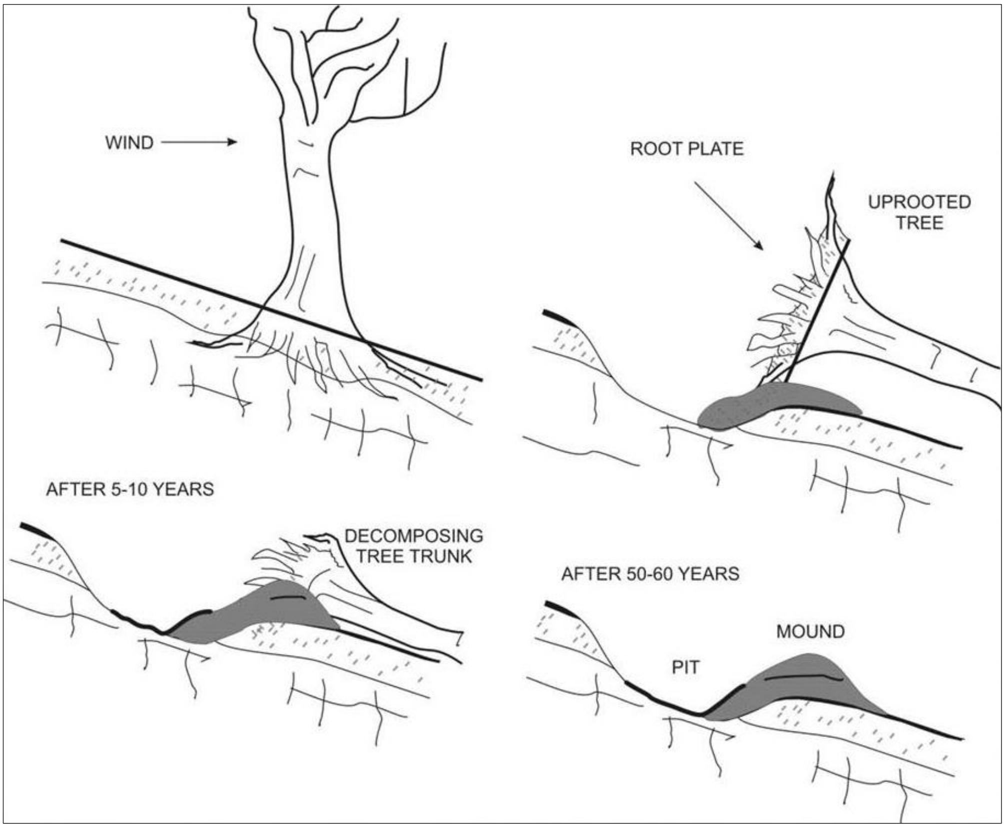

Figure 1. A sequence of pit and mound complex development due to tree uprooting caused by strong wind (Note: years after Šamonil et al., 2009).

pits (width, length and depth) to assess their approximate volumes. For this purpose an equation for a volume of half an ellipsoid was adopted from a work of Norman et al. (1995). Places with pit-and-mound pairs were mapped using a laser target marker (LTM) and geological compass. During field work, the most important features of mounds and pits were also noted, e.g. character of mound surface ('gravel armour', whether was rain washed or if it was covered by a leaf litter etc.), the degree of organic accumulation, retention and/or rock outcrops in pits.

Results of previous studies in different parts of the world suggest that tree uprooting can have a significant influence on soil evolution and changes in slope cover morphology (see review by Šamonil *et al.*, 2010), thus pedological field and laboratory methods were also applied. Along a longitudinal transect, three pit-and-mound pairs more than 100 cm deep were excavated, together with adjacent control profiles within present undisturbed part of the slope. First, morphology and basic

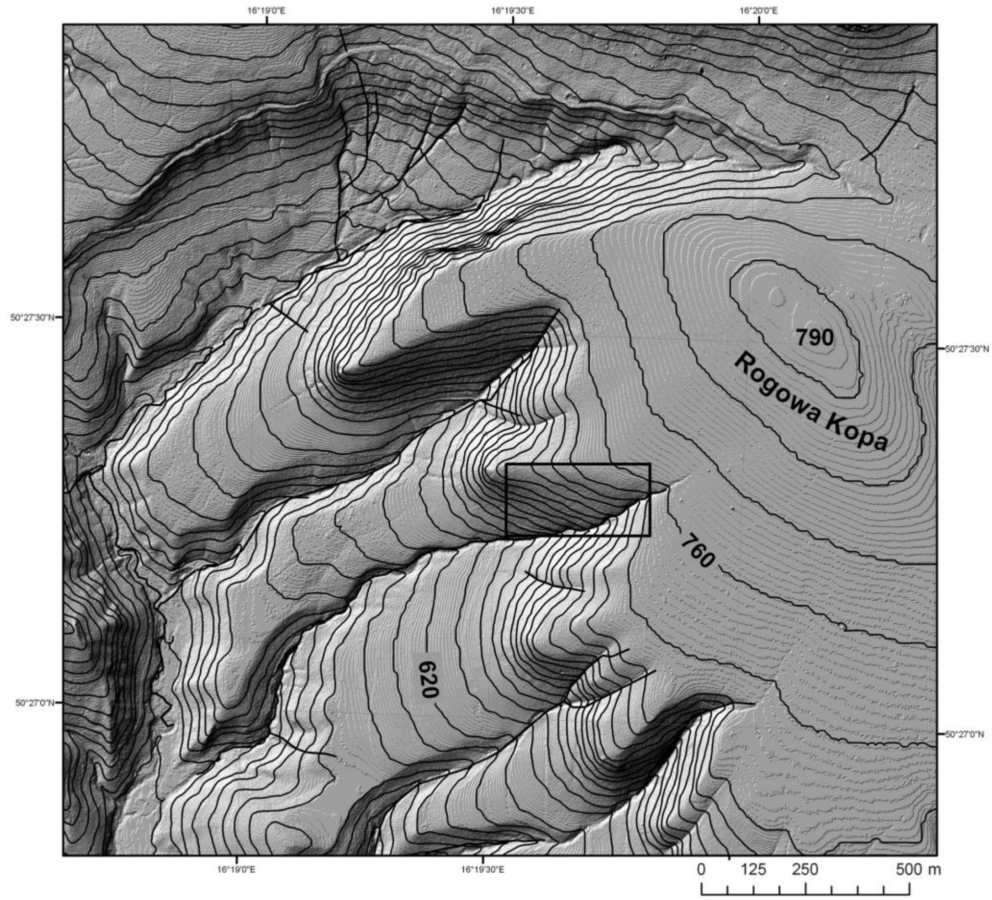

Fig. 2. Shaded relief elevation model of the Rogowa Kopa Massif. Black rectangle indicates the research polygon. Contour lines are 10 m intervals.

properties of soil profiles were described and samples were taken in two manners: larger ones from each distinguished horizon and smaller ones at regular intervals down the specific sections of profiles. Laboratory analyses comprised determination of soil colour in moist and dry state (Munsell system), particle size distribution (hydrometer method and wet sieving), organic carbon content (C_{org}, rapid dichromate oxidation technique), carbonates content (volumetric method), soil pH (potentiometric method in 1:1 H_2O and 1:2 0.01M $CaCl_2$) and bulk density.

Results

In total 82 pit-and-mound pairs were measured (around 40 per hectare). The calculated average mound volume was 1.7 m^3, slightly higher than the average pit volume (1.6 m^3). Mounds are clearly visible in slope topography, however all of them have been already lowered by erosional and mass wasting processes. All pits were filled to some extent with litter (20–30 cm). The pit-and-mound morphology covers 4.7% of the research polygon area. So far its age is not known but radiocarbon and dendrochronological dating is planned in the near future.

Soil profiles within mounds were much deeper than in control sites or pits, though contained less soil organic matter. In all mounds it was possible to detect alterations in the sequence of soil horizons that are interpreted as an effect of tree uprooting and subsequent long-term degradation of a root plate (Fig. 3). Both pH value distribution and soil colour in the mounds indicate partial soil profile inversion. This assumption is based on similarities in pH and colour between the mounds and adjacent control profiles (their lower horizons). Moreover, the soil pH and C_{org} vertical distribution under the mounds indicate that this part is a buried, undisturbed (now relict) soil (Fig. 3 and 4).

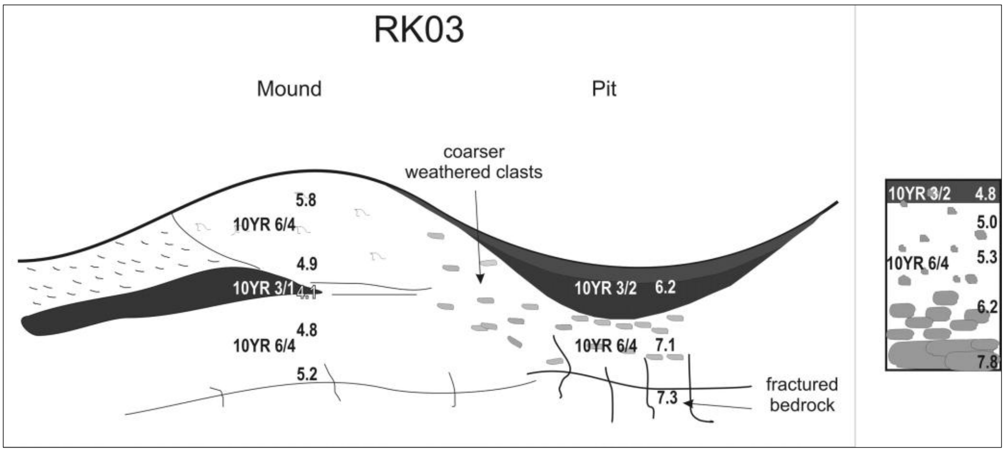

Fig. 3. Redistribution of pH values within the mound and pit complex (RK03) as compared to the control profile (on the right).

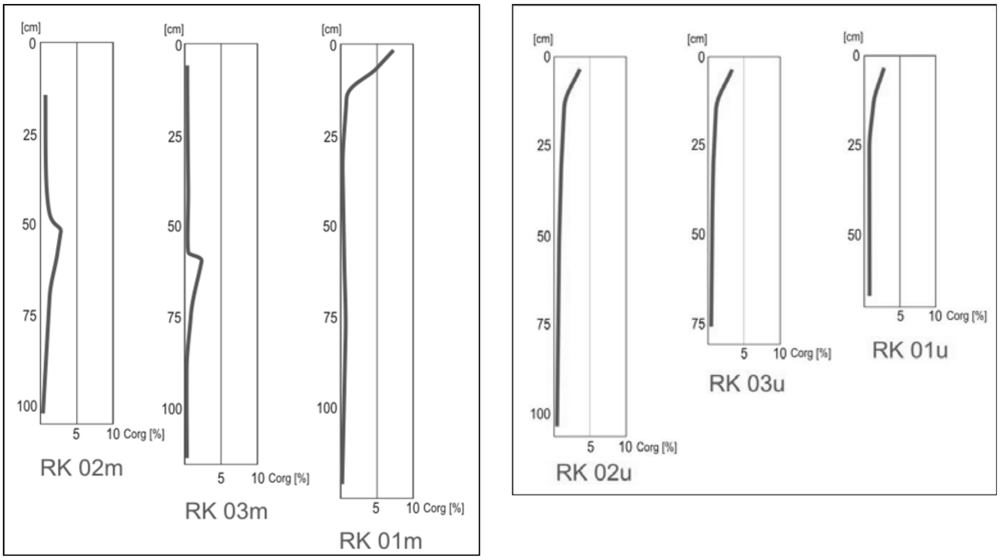

Fig. 4. Comparison of organic carbon content along vertical profiles within control sites (on the left) and through tree throw mounds (on the right).

Control profiles at undisturbed sites show similar curves of the organic carbon content with its higher concentration in the topsoil (Fig. 4), whereas two from three analysed profiles in the mounds, RK 02m and RK 03m, show higher concentration of C_{org} (up to 2%) in the middle parts and these sections are interpreted as buried A horizons. In the youngest form (in terms of its relative age), remnants of decomposed root system and tree trunk were still well visible, but the organic carbon content along the profile in the oldest form (RK 01m) did not reveal such differences. It rather resembles undisturbed profiles and shows the evidence of profile homogenization with time.

Discussion and conclusions

Extensive evidence published by different authors suggests that tree uprooting process has a very significant influence on various aspects of ecosystems (Schaetzl et al., 1989a, 1989b, 1990; Šamonil et al., 2010). The data already collected during field work on Mt Rogowa Kopa support this thesis, however further detailed studies are necessary. In this case the main question concerned is how did the process of tree uprooting contribute to soil development and hillslope dynamics?

Within the study site the most important feature is a relict form of windthrow morphology, which allowed to make an assumption that hillslopes of Mt Rogowa Kopa were significantly remodelled by tree uprooting process. Such hypothesis is supported by several properties of the analysed soil profiles in the mounds and pits, i.e. higher concentration of organic carbon within mounds indicating buried A horizons, tree trunk and root system remnants in mounds, higher pH values which are comparable to control profiles (their lower horizons). These properties, together with particle-size distribution, enable us to conclude that within the mounds former undisturbed soil material has undergone mixing or even partial inversion (in favourable conditions) due to, first, tree uprooting and, second, deterioration and decomposition of root plates. Schaetzl (1986) and Schaetzl and Follmer (1990) arrived at a similar conclusion. It is important to note that in the past pit-and-mound microtopography in other places was sometimes wrongly interpreted as an effect of contemporaneous congelifluction (Dylikowa, 1956) or frost processes of the Pleistocene or Holocene age (see references in Embleton-Hamann, 2004). In our case methods of soil analyses helped to narrow possible ways of interpretation.

In terms of changes in hillslope relief the most important one is a step-like slope profile which can affect for instance surface run-off with its concentration in pits and diffusion within mounds. Of similar importance is the uneven redistribution of soil material, both horizontally and vertically, on the hillslope surface. As a consequence of such disturbance, the course of pedogenesis was immediately altered and caused an increase in spatial heterogeneity of pedons.

Gathering all abovementioned results and their possible interpretation at least three general conclusions can be made:

1. In the long-term perspective (the Holocene) each part of the area could have been remodelled by tree uprooting, which in turn might have been a crucial factor of soil evolution in the investigated area.
2. Tree uprooting, as a component of bioturbation, is perhaps the main factor keeping the soils in a continual state of rejuvenation.
3. Methods of soil analysis can be a key tool to establish relative ages of pit-and-mound topography and to assess approximate stages of its development.

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A review on the research of China Danxia geomorphology in the past eighty years

Abstract: Danxia landform refers to erosional landscapes developed on red beds with scarp slopes. It is a special kind of red beds landform and has been studied for more than 80 years in China, where such landscapes are widely distributed throughout the country. By the end of 2011, more than 900 Danxia landform regions were recognized in China. They mainly developed on Meso-Cenozoic continental red beds. Due to the outstanding scenic and geoscientific value of Danxia landscapes, their research has generated increasing attention in China and has gradually formed an integrated academic system. In order to promote further research and global comparative study on Danxia-type morphology, Danxia Geomorphology Working Group of the International Association of Geomorphologists (IAG) was established in July, 2009. Besides, six representative Danxia sites in China were awarded the distinction of World Natural Heritage in 2010. This paper systematically introduces the definition of Danxia landform, its research history, essential characteristics, classification system, distribution, development mechanism, and future research on Danxia.

Introduction

The literal English translation of Danxia is 'red glow' or 'rosy cloud'. In China geoscience circles, Danxia refers to a kind of landform developed on continental red beds and is featured by steep cliffs. This term was first introduced by Chinese geologists in the 1920s (Feng and Zhu, 1928), originating from Mt. Danxiashan, Guangdong Province, China (Fig. 1). Danxia geology and geomorphology has been studied for more than 80 years in China, and the term is widely known and used both academically and in general society.

Based on the long-term study of Chinese earth scientists and the common views about typical Danxia landscape, Danxia landform is concisely defined as 'red beds landform that is featured by scarp slopes'(Peng, 2009). This definition can be further expanded as an erosional landscape formed from thick red beds that have been regionally uplifted, intensively faulted and deeply dissected by fluvial erosion, mass movement and weathering processes, producing a variety of cliffs and bounded peaks surrounded by deep canyons.

The definition above includes two essential elements: material and topography – i.e. coarse clastic rock and steep cliffs. It also contains two development conditions – geologic structure and exogenic forces.

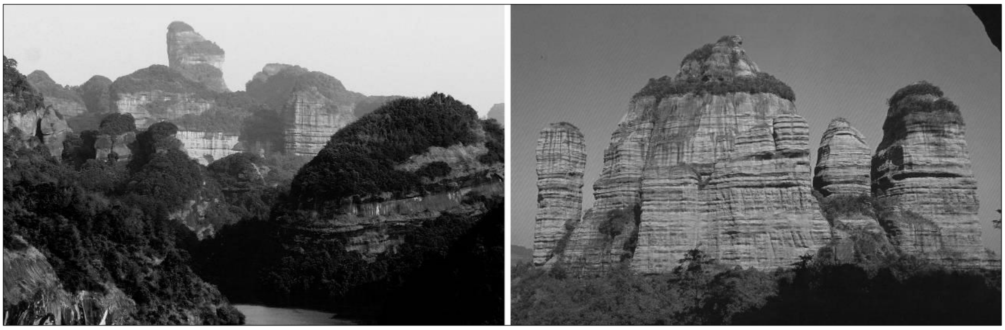

Fig.1. Classic Danxia landscape at Mt. Danxiashan (photographers: Hou Rongfeng, Xie Jinshu).

Red beds are the material foundation for the development of Danxia. The red beds responsible for the development of Danxia are mainly continental red clastic rock series, comprising primarily conglomerates and sandstones.

The geometrical feature of Danxia is steep cliffs. Steep cliffs at various scales and patterns are the basic elements that characterize the Danxia hilly blocks and canyon walls. Cliffs are considered to be the outstanding 'thumbprint' of Danxia landscapes.

The development of Danxia is controlled by geological structure. First, Danxia develops in regions where red beds were uplifted above the regional erosion datum. Second, geological structure controls the spatial pattern of the Danxia mountain blocks, and the attitude of strata determines the geometry of the hillslopes.

Exogenic processes are the direct sculptor of Danxia landscapes. After being uplifted, the red beds experience physical and chemical weathering, mass movement and fluvial erosion. Wind and biological weathering are other minor factors in the development of Danxia landscapes.

Essential characteristics of Danxia landform

Red scarp slopes are the most significant identification factor of Danxia landscape. Apart from a slightly larger dip near fault zones and basin margins, the majority of Danxia terrains results from *en bloc* uplift, with little tilting, so that the strata lie nearly horizontally. The basic slope shape can thus be summarized as 'flat top, steep slope, and gentle foothill' (Huang, 1982). These descriptors indicate the top surface controlled by nearly-horizontal rock layers; the scarp slope controlled by vertical joints; and the gentle colluvial slope controlled by the internal friction angle of the colluvial rocks, respectively (Fig. 2a).

The slopes of Danxia landscape that developed on the inclined terrain can be classified into three types: declining top, scarp body, and gentle foot (Fig. 2b). In some places affected by intensive tectonic activity, the dip angle of rock layers can

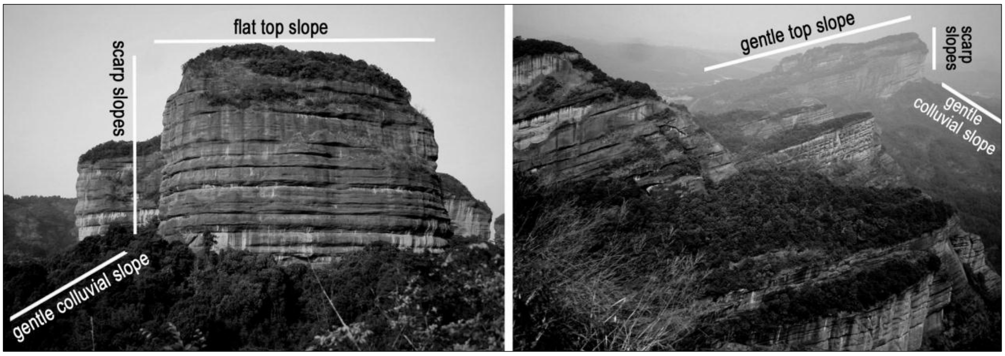

Fig.2. Basic slope shape of Danxia landform. (a) slope surfaces formed along horizontal; and (b) slope surfaces formed along gently inclined rock beds. (Photographer: Hou Rongfeng).

reach over 60°, and as a result, bedding planes may form scarp slopes (Huang, 1992).

Distribution of Danxia landscape in China

Danxia landscapes are widely distributed throughout China. More than 900 locations have been identified (Huang, 2011). They are found in tropical and subtropical humid zones, temperate humid and semi-humid zones, semiarid-arid zones and Qinghai-Tibet Plateau. Geographically, Danxia landscapes in China can be grouped into three regions of densest occurrence: southeast, southwest and northwest (Qi et al., 2005) (Fig. 3).

(1) Peak–hoodoo cluster Danxia in Southeast China. This type of Danxia landscape is found in the Chiang-nan Hilly Region of China, including Zhejiang, Fujian, Jiangxi, Guangdong, and Hunan Provinces. Danxia Peak-hoodoo is characteristically developed in association with water bodies in this region, and the scenery is very attractive.

(2) Plateau- mountain-valley Danxia in Southwest China. This type of Danxia landscape is found mainly in the transitional zone between the margin of the Sichuan Basin and its surrounding plateaus, as well as in the Yungui Plateau. Here, deeply-dissected, plateau-valley type Danxia and red beds-hill type Danxia has developed, with characteristically very irregular landforms. High red cliffs, associated with rapids and waterfalls, form a spectacular natural landscape.

(3) Danxia of arctic-alpine plateau and arid mountain type in northwest China. This type of Danxia landscape is found in Gansu Province and the surrounding provinces. There are numerous cold plateau-semiarid and arid Danxia landscapes at altitudes above 3,000 to 4,000 m. In the transitional region between the Qinghai-Tibet Plateau and the Loess Plateau, there is semi-arid hilly type Danxia landscape formation. Along the Hexi Corridor, from the piedmont of Qilianshan Mts to the piedmont of Tianshan Mts, a typical arid hilly type Danxia landscape occurs.

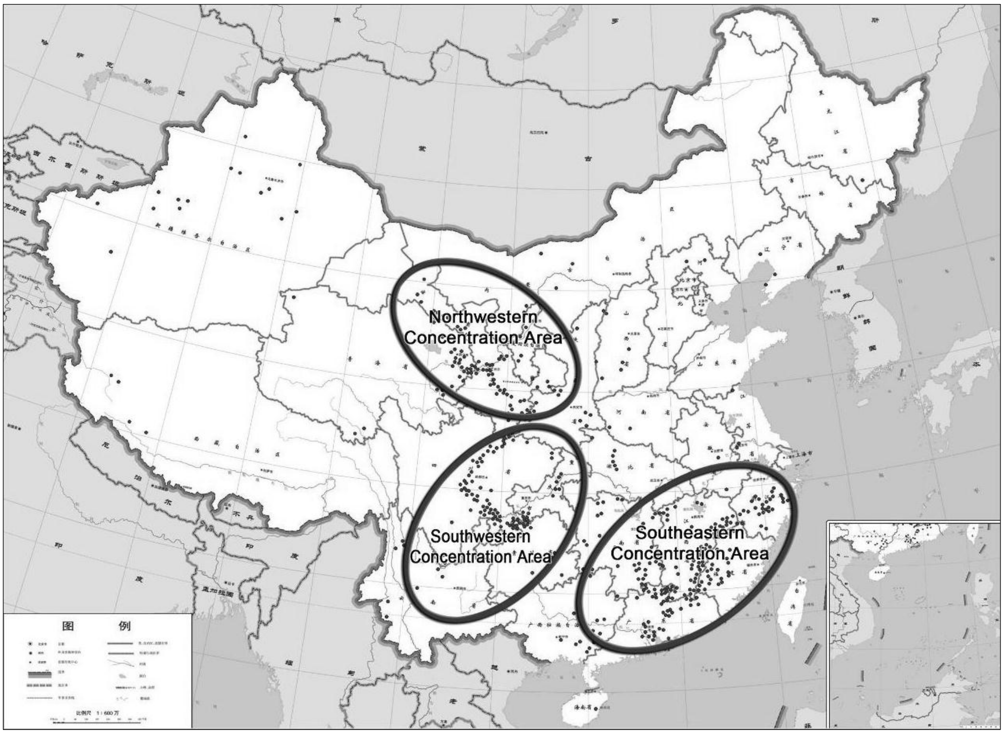

Fig.3. Distribution of Danxia landscape in China.

Development process of Danxia landform

The development process of Danxia landform is different from other types of landform. It is summarized in three main stages: young stage, mature stage, and old stage. The development process and characteristics of each stage of Danxia landform are shown in Table 1 and Fig.4.

Future work

The research on China Danxia has over 80 years of history. However, there is no specific international research on Danxia landform at present, but mature studies on red beds and sandstone landform. In addition, according to recent relevant research, a huge amount of red beds and Danxia-like landforms are widely distributed in every continent in the world except Antarctica, which favors academic communication and international cooperation among China Danxia, red beds and sandstone landform researchers throughout the world. After two successful meetings on China Danxia and the establishment of IAG Danxia Geomorphology Working Group, China Danxia research attracts increasing attention from international

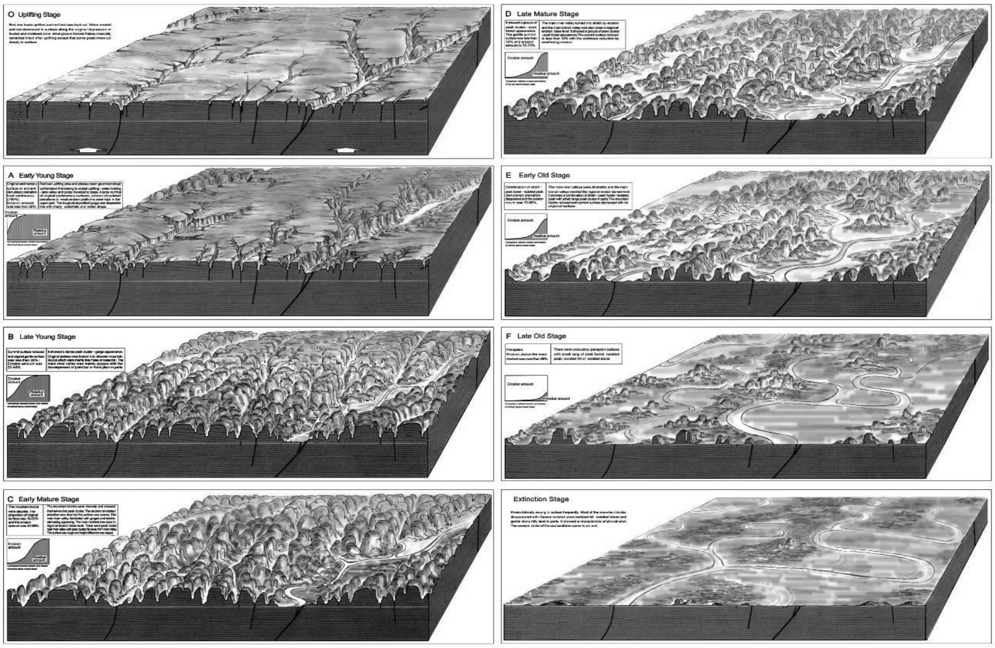

Fig.4. Development process of Danxia landform.

Tab. 2. Development stages of Danxia landform.

Stage	Evidence	Charateristics (long term stable after the tectonic uplift)
Early young	Keeps the original top area or denudation-planation surface(>50%); erosion amount <15%.	Red beds uplifted; combination of plateau geomorphology and canyon geomorphology. They belong to the steps of uplifting-incising-developing. On the top, large areas with original sedimentary tops, ancient planation surfaces or weak erosion platforms. Canyons with many waterfalls.
Late young	The top reduced, the original mild top area: 20-30%; erosion amount: 15–30%.	External shape is concentrated peak cluster-canyon, the original plateau dissected into mountain blocks with the shape of mesas or ridges. Main river valleys are gorges, some parts have floodplains. In the tributaries, there are still numerous lane valleys.
Early mature	The block scatters, original mild top area: 10–20%, erosion amount: 30–50%.	Scattered mountain bodies with the shape of peak clusters. Ancient planation surfaces are clear but the top is very small. Main river valleys near the erosion basis. Peak forest near the river valleys, in the area far away from valleys, there are peak clusters and the ground surface is rugged with the greatest height difference.
Late mature	Groups of peak clusters – peak forests, original top area: 10%, erosion amount 50–70%.	Main valleys reach the erosion basis. Lateral erosion is the main erosive agent, forming broad valleys,.but in some areas, there still may be some narrow valleys. Main branch valleys are also near the planation surfaces, the whole body is peak forest – peak cluster shape. The top areas occupy no more than 10%, and are lowered due to the long-term weathering and erosion.
Early old	Wide valley – peak forests – isolated peaks, original top disappears, erosion amount 70–85%.	All main valleys are broad valleys, and main branch valleys reach the regional erosion basis. The mountain body is scattered, and the whole area is the combination of broad valleys – peak forests – isolated peaks. In some parts, there are still small areas of peak clusters. The original top surface disappears.
Late old	Peneplain, above the riverbed, erosion amount >85%.	Main and branch valleys develop through lateral erosion. In red beds, there are undulant peneplain surfaces. In some places, small-scale peak forest, isolated peaks, hills and stones remain. The percentage of positive area is no larger than 15%.

colleagues. In order to promote the development of this new branch subject of geomor phology, more emphasis should be put on the global comparative study on Danxia-type morphology. Moreover, process-oriented research in selected Danxia-type landscapes, particularly focused on the processes involved in its shaping and structural geological conditions necessary to its development, should be deepened.

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Study on the weathering pattern and development process of Danxia bedding caves — cases on bedding caves of Jinshiyan Member of Danxia Formation at Mt. Danxiashan

Abstract: Bedding caves, characterized by rapid weathering of soft intercalated rock layers, are a type of negative landform widely distributed in Danxia landform area. Based on field investigation, three typical bedding caves were selected as study cases. This study involved field survey of development conditions and weathering features, followed by collection of rock samples and interlayer water for further laboratory tests. Soft interlaid rocks between layers generally belong to silty mudstone with high content of clay minerals and argillaceous cement. Due to strong absorbability, high porosity and low compressive strength, these soft rocks are vulnerable to weathering and easily broken into smaller pieces. The overlying and underlying rock layers are more resistant sandstones or sandy conglomerates, with large size particles, cemented mainly by calcium and iron oxides, low porosity and higher compressive strength. The weathering pattern and development process of Danxia bedding caves is described as to occur in the following stages: exposure of soft interlaid rock layers – formation of microcracks – expansion of microcracks and exfoliation of rock fragments – continuous weathering and recession of soft interlaid rock layers – formation of initial caves – enlargement of caves – destabilization and collapse of overlying rock.

Introduction

Danxia bedding caves are a type of negative landforms widely distributed in Danxia landform area. Featured by rapid weathering of soft interlaid rock layers, which are mainly composed by soft rock of red beds, Danxia bedding caves are of great significance to the development process of Danxia landform. However, in the previous studies on Danxia landform, researchers focused on resistant sandy conglomerate and the spectacular Danxia escarpments (Zhu et al., 2009; 2010; Peng, 2011), while the weathering pattern of soft interlaid rock layers and their effect on the slope evolution of Danxia landform were neglected. During recent research, we tried to study the relationship between differential weathering of red bed rocks and the development of Danxia bedding caves. This paper brings further data to elucidate this problem.

Setting

The study area, Mt. Danxiashan (24°57′55″N, 113°42′12″E), is located in the northeastern part of Shaoguan City, Guangdong Province, P.R. China, with a total area of 290 km^2. Based on field investigation at Mt. Danxiashan, three typical Danxia bedding caves (Hunyuan Cave, Longquan Cave and Wanxiu Cave) were selected as study cases (Fig. 1). The stratum of these three caves belongs to Jinshiyan Member (K_2d^2) of Danxia Formation. During the process of field study, we observed and measured lithology, joint system, climate and vegetation of these three bedding caves. Detail information about environmental setting of these three caves is presented in Table 1.

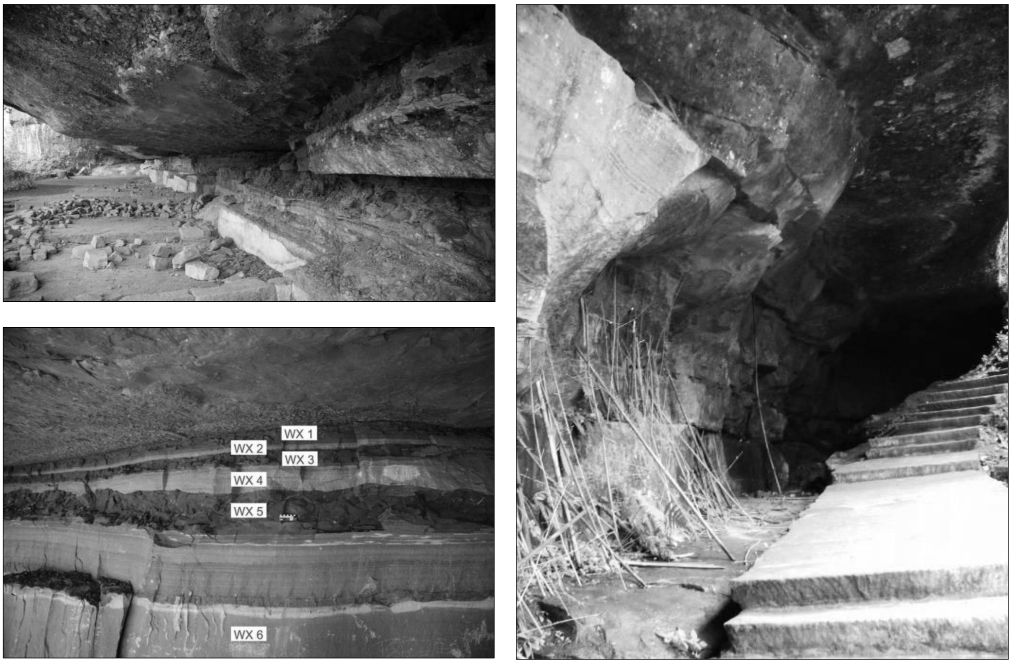

Fig. 1. Danxia bedding caves: Hunyuan cave (upper left); Alternation of soft and hard interlaid rock layers in Wanxiu Cave (lower left); (c) entrance to Longquan Cave (right).

Laboratory tests

Rock samples with different lithologies were collected from these three bedding caves. The rock types and ID number of samples are as follows.

- Hunyuan Cave: conglomerate (HY0), silty mudstone (HY1), micro-bedded siltstone (HY2), fine-grained sandstone (HY3);
- Longquan Cave: water-bearing siltstone (JS1), micro-bedded silty and fine-grained sandstone (JS2), fine-grained sandstone (JS3);

- Wanxiu Cave: silty mudstone (WX1), micro-bedded fine-grained sandstone (WX2), silty mudstone (WX3), micro-bedded fine-grained sandstone (WX4), pelitic siltstone (WX5), fine-grained sandstone (WX6).

Rock samples extracted from each rock type of the three caves were selected to make thin sections. Petrographic microscope examination of the thin sections focused on identification of main minerals, matrix, cementation, granularity, and cement types. Further tests included determination of oxide composition (Table 2, Fig. 2), analysis of physical properties (Table 3) and assessment of point load rock strength (Table 4).

Table 1. Comparison of environmental setting about Hunyuan Cave, Longquan Cave and Wanxiu Cave.

	Hunyuan Cave	Longquan Cave	Wanxiu Cave
Stratum	K_2d^2	K_2d^2	K_2d^2
Orientation	318°NW	330°NW	310°NW
Attitude	330°/5°	290°/8°	220°/7°
Feature of soft interlaid rock layers	Interlaid silty mudstone with crack filling structure	Interlaid siltstone with high water content	Alternation of soft and hard interlaid layers
Section features	Micro-vertical joints in soft rocks	Interlayer joints	Micro-vertical joints in both soft and hard rocks
Lithology of cave ceiling	Conglomerate, sandy conglomerate	Sandy conglomerate, conglomerate	Sandstone, sandy conglomerate, conglomerate
Cave shape	Flat	Frontal	Flat
Joint features	Nearly horizontal and vertical joints	Vertical and large joints	Nearly horizontal and bedding joints
Water content	Medium water content, no interlayer water	Abundant interlayer water	Medium water content, no interlayer water
Vegetation	Lichen grow only on hard rock surfaces and some plants grow in joints	Many plants grow on the underlying water-rich rock layer	No vegetation cover on rock surface
Climatic factors	With almost the same orientation, there are few differences in regional climate, but microclimate may vary from each other, and rainwater has a great effect on rock layers of Longquan Cave.		

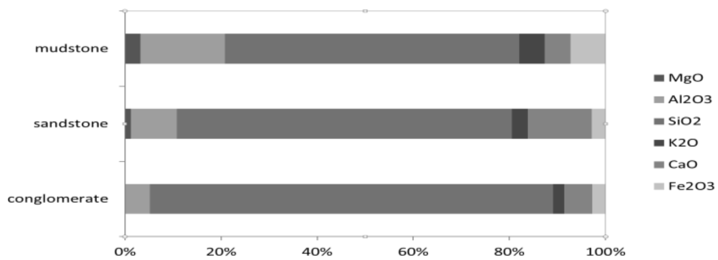

Fig. 2. Comparison of oxide content in different rocks.

Table 2. Percentage data of main oxides of rock samples.

Sample	Na_20	M_gO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3	WO_3
HY0	—	—	5.13	83.98	2.30	5.81	—	2.78	—
HY1	—	2.57	17.42	61.42	5.08	6.61	0.64	6.25	—
HY2	—	1.69	12.46	58.99	3.74	16.18	0.61	4.12	2.2
HY3	—	0.68	6.15	61.62	2.57	27.71	—	1.27	—
JS1	—	1.50	11.72	74.72	3.43	4.52	0.39	3.72	—
JS2	—	1.68	11.83	73.76	3.49	5.01	0.55	3.68	—
JS3	0.49	0.47	8.15	78.94	3.93	5.83	—	2.19	—
WX1	—	2.58	18.33	64.40	5.76	1.05	0.82	7.06	—
WX2	—	1.06	9.40	72.24	3.04	10.81	0.45	3.00	—
WX3	—	2.40	18.14	62.13	5.90	2.37	0.83	8.22	—
WX4	—	1.18	8.60	56.79	2.69	27.99	—	2.75	—
WX5	—	4.88	15.98	55.61	4.27	11.47	0.68	7.12	—
WX6	—	1.00	8.41	77.75	3.34	7.46	—	2.03	—

Table 3. Test data of physical properties of rock samples.

Sample number	Particle density (g/cm^3)	Dry density of rock block (g/cm^3)	Moisture content (%)	Water absorption (%)	Saturated percent sorption (%)	Coefficient of water saturation (j)	Porosity (%)
HY0	2.66	2.56	0.68	1.30	1.47	0.88	3.34
HY1	—	2.63	2.56	—	—	—	7.25
HY2	2.69	2.51	1.28	2.45	2.69	0.91	6.20
HY3	2.65	2.56	0.63	1.21	1.36	0.88	3.19
JS1	2.52	2.06	10.00	6.70	8.91	0.75	13.81
JS2	2.65	2.44	1.43	3.06	3.27	0.94	7.30
JS3	2.63	2.45	1.48	2.61	2.76	0.95	6.51
WX1	—	2.61	2.81	—	—	—	7.27
WX2	2.67	2.51	1.40	1.46	1.99	0.73	3.71
WX3	—	2.65	2.73	—	—	—	7.13
WX4	2.67	2.55	1.14	1.92	2.03	0.94	5.06
WX5	—	2.62	2.52	—	—	—	6.43
WX6	2.56	2.26	1.23	4.46	5.74	0.78	10.10

Table 4. Data of point load strength of rock samples.

Sample number	Mean value of point load strength in vertical direction (MPa)	Correction value of point load strength in vertical direction (MPa)	Mean value of point load strength in horizontal direction (MPa)	Correction value of point load strength in horizontal direction (MPa)	Anisotropic index of point load strength
HY1	1.27	1.25	0.67	0.63	1.98
HY2	1.36	1.40	0.68	0.68	2.06
HY3	1.88	1.91	1.81	1.89	1.01
JS1	—	—	—	—	—
JS2	1.38	1.59	0.66	0.71	2.24
JS3	1.57	1.62	0.96	1.07	1.51
WX1	1.20	1.12	0.62	0.56	2.00
WX3	1.53	1.50	0.64	0.65	2.31
WX5	1.78	1.83	1.03	1.09	1.68
WX2	1.75	1.74	1.37	1.33	1.31
WX4	2.42	2.55	1.36	1.84	1.40
WX6	1.75	1.75	1.55	1.65	1.06

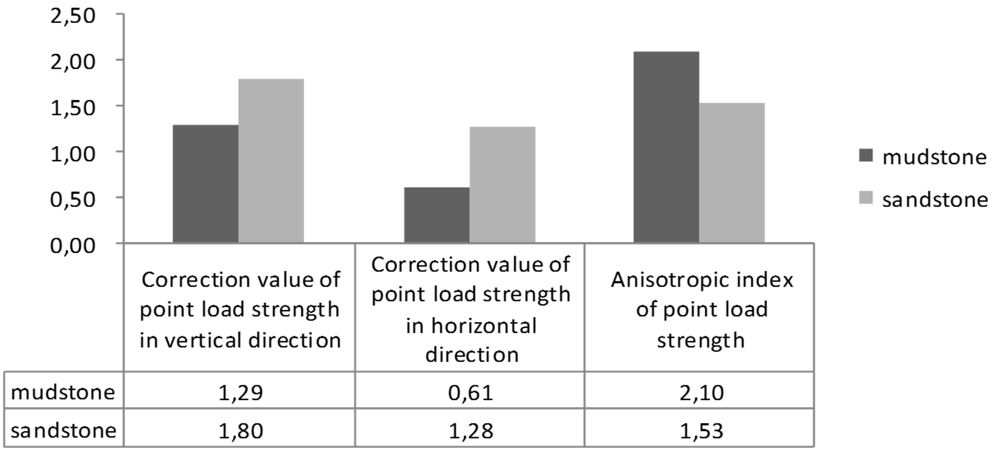

Fig.3. Statistical results of point load strength of rock samples classified by particle size.

Conclusions

(1) Great difference in lithology of cave profile is the fundamental reason for differential weathering and formation of Danxia bedding caves. The soft interlaid rock layers of Danxia bedding caves are commonly made up of silty mudstone, which contains a large amount of clay minerals and argillaceous cement. With high

porosity and water absorption, and low rock strength, these weak layers are vulnerable to weathering. By contrast, the weathering rates of overlying and underlying rock layers are much lower, since they are mainly composed of more resistant sandstone or sandy conglomerate, which are cemented by calcite and iron oxides. With less pore space and low water absorption, these rock layers have a relatively higher strength.

(2) Swelling and shrinking features of clay minerals, dissolution of calcite cement and hydration of iron oxides are important reasons for rapid weathering and recession of soft interlaid rock layers.

(3) The development process of Danxia bedding caves can be summarized as follows: exposure of soft interlaid rock layers – formation of micro-cracks – expansion of micro-cracks and exfoliation of rock fragments – continuous weathering and recession of soft interlaid rock layers – formation of initial caves – enlargement of caves – destabilization and collapse of overlying rock rocks – cliff retreat. This whole process is an integral part of the development mechanism of Danxia landform.

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'Šatlava' Archaeological Museum in Česká Lípa, northern Bohemia – Speleoarchaeology and speleoanthropology exhibition

Abstract

Šatlava as a historical building. The solid stone building of the so-called 'town magistrate's jailhouse' is a construction that was built onto the inner side of the medieval town walls and its origin is dated most likely to the middle of the 16th century. The historical ground floor of the building houses exhibitions dedicated to cave archaeology and medieval history of Česká Lípa. The other parts of the building are home to the archaeology offices of the Regional museum and gallery in Česká Lípa (Vlastivědné muzeum a galerie – VMG).

Speleoarchaeology in the sandstone landscape of northern and north-eastern Bohemia. In the sandstone areas of northern and north-eastern Bohemia, the field of speleoarchaeology started taking root significantly in the first half of the 1990s, when the joint efforts of archaeological and natural sciences institutions resulted in the discovery of dozens of new sites in caves or in rock shelters. These sites featured conditions unique for the preservation of varying materials allowing for the palaeoecological reconstruction of the landscape. The discovery of small mollusc shells, animal bones, teeth and horns, pollen, remains of carbonised wood, seeds and fruits among archaeological finds presents us with a unique opportunity to see the living conditions of man in the distant past. The archaeology office of the VMG has been participating in the long-term cave and rock shelter research, as well as in the processing of related research data. The vaulted cellar area of the oldest part of the 'Šatlava' building gives one the impression of underground cavities, and is being used to make the public aware of the contemporary scientific discipline of speleoarchaeology and speleoanthropology (a more general science of man and caves), as well as of the most interesting finds discovered in rock cavities from prehistoric times until today. These, for example, include a unique scaphoid-like vessel, most probably cult related, found in region of Dubá and dated to the Neolithic Period a rare preserved amphora-like pot from the turn of the Bronze and Iron and found under a rockface at Kokořín region; a gold Celtic coin from Kristova jeskyně (Christ's Cave) at Český ráj (Bohemain Paradise); and finds from medieval tar workshops around Bezděz Hill and Castle. Also featured are finds from the romantic

landscape of the Národní park České Švýcarsko (Bohemian Switzerland National Park), which was not as wild and unspoiled in medieval times as one would think. Also the Early Modern period has left a significant mark in the rock cavities, such as relics of historical events, mainly in the form of valuable rock inscriptions. Also several rock sites from the close of the World War II have been archeologically recorded, particularly in Český ráj, as has the hiking history been recorded in the use of the sandstone rock shelters and caves.

Little-known cave regions with archaeological finds. A smaller part of the exhibition is dedicated to other interesting cave sites in the Czech Republic that feature archaeological finds. Among the most significant is the karst Cave Jeskyně Na Špičáku near Jeseník, which features an extraordinary assemblage of 4000 rock inscriptions, paintings and engravings from the Late Middle Ages to the period of the World War II, including an extraordinary Renaissance scene with figures kneeling under a cross. These features were recorded in their entirety in 2003–2010 by the archaeology office of the VMG in Česká Lípa as part of a research project carried out by the Administration of Caves of the Czech Republic. Also presented are less known and interesting sites with cave finds from the High Middle Ages and the Early Modern period, i.e. the Nedobytná jeskyně (Unconquerable Cave) in the Ještěd karst region near Liberec and the talus and fracture cave Ledové sluje (Ice Cavern) in the Podyjí National Park in south Moravia.

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Remarks about the diversity of mountain Norway spruce forest in the Sudetes, with particular reference to the Szczeliniec Massif (Stołowe Mts, Poland)

Abstract: Between 2011 and 2012 from all sites in the Sudetes on which *Calamagrostio villosae-Piceetum* has been reported so far, 56 relevés were collected according to Braun-Blanquet approach. Collected material enabled us to compare the floristic compositions of the Norway spruce forests from the Karkonosze Mts, the Śnieżnik Massif, the Orlickie Mts, the Izerskie Mts, Wielka Sowa Mt. and the highest part of the Stołowe Mts. The results of analyses revealed that the area of *Calamagrostio villosae-Piceeteum* is limited to the highest part of the Sudetes and the association is well developed only in the Karkonosze Mts and the Śnieżnik Massif, with exception of single locality in the Izerskie Mts (the Płonka stream valley). The diagnostic species of this association are *Homogyne alpina*, *Plagiothecium undulatum*, *Sorbus aucuparia* var. *glabrata*, *Rumex alpestris, Athyrium distentifolium, Polygonum bistorta, Gentiana asclepiadea* and the differentiating species are *Trientalis europaea, Polytrichum commune, Deschampsia caespitosa* and *Nardus stricta*. The rest of earlier described localities of high-mountain Norway spruce forest (including the Szczeliniec Massif in the Stołowe Mts) probably belong to two separate associations: to the acidophilous *Vaccinio vitis-ideae-Abietetum*, with occurrence of *Abies alba*, *Betula pubescens* agg. and *Vaccinium vitis-idaea* and to the mesotrophic *Luzulo luzuloidis-Abietetum* with higher abundance of *Fagus sylvatica*, *Melandrium rubrum, Senecio ovatus* and *Rubus idaeus*. It suggests that the phytocoenoses which have been classified so far in Poland as *Abieti-Piceetum* (*montanum*) Szaf., Pawł. & Kulcz. 1923 em. J. Mat. 1978 should be divided into two separate associations.

Introduction

The systematic position of the Norway spruce forest occurring in the highest parts of the Sudetes seemed to be sufficiently clear and did not require further discussion. According to the recent, comprehensive synthesis about differentiation of Polish forests (Matuszkiewicz 2001) all the preserved stands of Norway spruce forests occurring above the 1000 m a.s.l. in the Sudetes belong to ass. *Calamagrostio villosae-Piceetum* (R. Tx. 1937) Hartm. ex Schluter 1966 and their area covers approximately 120 square km in the Karkonosze Mts, the Izerskie Mts, the Śnieżnik Massif, the Bialskie Mts and the small patches in the Sowie Mts and the Orlickie Mts as well (Matuszkiewicz 2001). However, many authors include here forests which occur close to the top of Szczeliniec Wielki and Szczeliniec Mały (the

Stołowe Mts). The first attempts to determine their syntaxonomical position were presented in the papers of Szmajda (1979), W. Matuszkiewicz & J. M. Matuszkiewicz (1996) and Pender (1996). All above mentioned authors agreed, that this forests present the impoverished form of *Calamagrostio villosae-Piceetum*, which occurs here below the typical borders of mountain zone, due to specific climatic and ecological conditions. This claim was also upheld by Świerkosz (2004, 2007).

In 2011, using the standardized transect methods (Mróz 2012), we collected phytosociological relevés from all sites in the Sudetes on which the *Calamagrostio villosae-Piceetum* has been reported so far. It enabled us to compare the floristic composition of the Norway spruce forests from the Karkonosze Mts, the Śnieżnik Massif, the Izerskie Mts, the Orlickie Mts, Wielka Sowa Mt. and the highest part of the Stołowe Mts.

Methods

In 2011–2012, 56 relevés of *Calamagrostio villosae-Piceetum* were collected according to Braun-Blanquet approach (Mueller-Dombois & Ellenberg 2003) and stored in a TURBOVEG database (Hennekens & Schaminée 2001). The area of the relevés was adapted to these proposed by Chytrý & Otypková (2003). All relevés were classified using the TWINSPAN method (Roleček et al. 2009) embedded within the JUICE program (Tichý 2002). A Total Inertia method was used as a measure of cluster heterogeneity (Tichý et al. 2007). Diagnostic species for particular vegetation units were determined using the phi coefficient as a measure of fidelity (Chytrý et al. 2002) in a synoptic table. The phi coefficient was used for clusters of equalized size (Tichý & Chytrý 2006). Only species with both a significant concentration in particular vegetation units (using the Fisher's exact test and the significance level $P < 0.5$) and phi coefficient ≥ 0.30 were considered to be diagnostic species.

Ordination analyses were performed using the Canoco 4.5/CanoDraw 4.1 software (ter Braak & Šmilauer 2002) for all data set. The structure of data set was tested with detrended correspondence analysis (DCA). Gradient length of the first DCA axis (2.026 SD units) indicated an application of linear ordination techniques. Principal component analysis (PCA) was used to recognize difference between the collected samples. Default options and logarithmic transformation of species cover data was used in PCA. Names of the plants are in accordance with the work of Mirek et al. (2002), and the bryophytes names follow Ochyra et al. (1992)

Results

TWINSPAN classification. According to TWINSPAN analysis three groups of relevés are distinguished. Synoptic table with modified fidelity phi coefficient and percentage frequency (Table 1) shows the main floristic differences between them. All fidelity values used in the paper are multiplied by 100.

Tab. 3. Synoptic table of three groups of relevés of Norway Spruce forest in the Sudetes with modified fidelity phi coefficient and percentage frequency in a superscript - Fisher's exact test > 3 (shortened table); Explanations: 1 – oligotrophic Norway spruce forest communities of “Stołowe Mts group” (800–900 m a.s.l.), 2 – mesotrophic communities of the mountain zone (900–1100 m a.s.l.), 3 – the Karkonosze Mts and the Śnieżnik Massif above 1100 m a.s.l., (with two relevés from the Płonka stream valley in the Izerskie Mts).

Group No.	1	2	3
No. of relevés	11	20	25
Betula pubescens agg.	86.7 ^{82}	–·	–·
Vaccinium vitis-idaea	62.6 ^{91}	–^{25}	–^{24}
Abies alba	39.0 ^{27}	–·	–^{4}
Melandrium rubrum	–·	37.9 ^{20}	–·
Rubus idaeus	–^{27}	33.8 ^{50}	–^{8}
Fagus sylvatica	–·	32.6 ^{30}	–^{12}
Senecio ovatus	–·	31.3 ^{20}	–^{4}
Homogyne alpina	–^{9}	–^{15}	77.3 ^{92}
Plagiothecium undulatum	–·	–^{45}	69.3 ^{96}
Polygonum bistorta	–·	–·	58.7 ^{44}
Rumex arifolius	–·	–·	52.3 ^{36}
Deschampsia caespitosa	–·	–·	49.0 ^{32}
Nardus stricta	–·	–·	45.5 ^{28}
Oxalis acetosella	–^{9}	–^{65}	44.2 ^{84}
Trientalis europaea	–·	–^{85}	43.3 ^{88}
Sorbus aucuparia v. glabrata	–·	–·	41.8 ^{24}
Athyrium distentifolium	–·	–^{15}	39.6 ^{40}
Dryopteris dilatata	–^{36}	–^{40}	39.4 ^{80}
Carex echinata	–·	–·	37.9 ^{20}
Polytrichum commune	–·	–^{10}	36.7 ^{32}
Gentiana asclepiadea	–^{9}	–·	33.6 ^{28}
Luzula luzuloides	–^{9}	–·	33.6 ^{28}
Picea abies	–^{100}	–^{100}	–^{100}
Deschampsia flexuosa	–^{100}	–^{100}	–^{100}
Vaccinium myrtillus	–^{100}	–^{100}	–^{100}
Polytrichastrum formosum	–^{100}	–^{100}	–^{100}
Dryopteris carthusiana	–^{100}	–^{85}	–^{92}
Sorbus aucuparia	–^{100}	29.2 ^{100}	–^{56}
Calamagrostis villosa	–^{64}	–^{96}	–^{96}
Pleurozium schreberi	–^{45}	–	–^{36}
Betula pendula	–^{27}	–^{30}	–^{4}
Galium saxatile	–·	–^{45}	–^{32}
Streptopus amplexifolius	–^{9}	–^{10}	–^{20}
Maianthemum bifolium	–^{9}	–^{25}	–^{20}

The stands investigated in the Stołowe Mts are characterized by a high participation of *Betula pubescens* agg., *Vaccinium vitis-idaea*, *Abies alba* and *Pleurozium schreberi*. Besides the relevés made in the Szczeliniec Massif, the single relevés from lower altitudes in the Karkonosze and the Izerskie Mts were included in this group as well.

The second part of vegetation plots, with higher share of *Fagus sylvatica, Melandrium rubrum, Rubus idaeus* and *Senecio ovatus* contains relevés collected between 925 and 1050 m a.s.l., in the Orlickie Mts, the Sowie Mts (Wielka Sowa Mt.) and the Izerskie Mts (Stóg Izerski Mt.). This group is clearly of a transitional character between mountain and high-mountain forests.

A distinctive feature of the third group is participation of *Sorbus aucuparia* var. *glabrata*, *Rumex alpestris, Athyrium distentifolium, Polygonum bistorta, Gentiana asclepiadea, Nardus stricta* and a high abundance of *Plagiothecium undulatum* and others species. This community occurs mainly above 1100 m a.s.l. in the Karkonosze Mts and the Śnieżnik Massif. Only two relevés from the Płonka stream valley (the Izerskie Mts) also belong to this group.

Ordination. Ordination diagram shows three separate groups of relevés, as it was presented in Table 1. PCA analysis revealed that the Norway spruce forest from the Stołowe Mts are separated not only from the phytocoenoses of the highest part of the Sudetes, but also from the second group of relevés (Fig. 1).

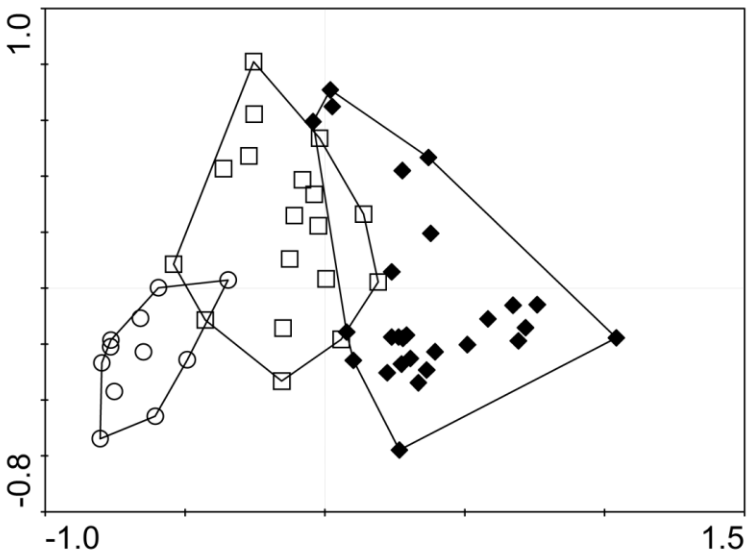

Fig. 1. PCA of relevés of Norway spruce forest in the Stołowe Mts, against the remaining part of the Sudetes. Explanation: circles – oligotrophic Norway spruce forest communities of “Stołowe Mts group” (800–900 m a.s.l.); squares – mesotrophic communities of mountain zone (900–1100 m a.s.l.); diamonds – the Karkonosze Mts and the Śnieżnik Massif above 1100 m a.s.l., (with two relevés from the Płonka stream valley in the Izerskie Mts).

1.2. Discussion

In opposite to the dominant opinion in the past, the Norway spruce forest in the highest part of the the Stołowe Mts probably belongs to an oligotrophic association *Vaccinio vitis-ideae-Abietetum* Oberdordfer 1957, which is common in the Czech Republic and Slovakia, and known in Poland only from the Beskid Mały (Klama & Salachna 2011). Preliminary analysis carried out by Świerkosz & Reczyńska (2012) suggested close relationship between this community and the rest of mountain forests occurred in the Sudetes below 1100 m a.s.l. However application of more advanced method analysis showed a significant difference between these communities. Abundance of *Fagus sylvatica*, *Senecio ovatus*, *Rubus idaeus* and *Melandrium rubrum* in the second group of analyzed relevés is typical of other association which has not been known from Poland yet – *Luzulo luzuloidis-Abietetum* Oberdorfer 1957. It suggest that the phytocoenoses classified so far in Poland as *Abieti-Piceetum montanum* Szaf., Pawł. & Kulcz. 1923 em. J. Mat. 1978 should be divided into two separate associations.

A distinctive feature of the Beskid Mały high-mountain forest belonging to ass. *Calamagrostio villosae-Piceetum* occurrence of *Homogyne alpina*, *Plagiothecium undulatum*, *Sorbus aucuparia* var. *glabrata*, *Rumex alpestris, Athyrium distentifolium, Polygonum bistorta, Gentiana asclepiadea* and the high abudance of *Trientalis europaea, Polytrichum commune, Deschampsia caespitosa* and *Nardus stricta*. The area of *Calamagrostio villosae-Piceeteum* is restricted to the highest part of the Sudetes and is well developed only in the Karkonosze Mts and the Śnieżnik Massif.

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The interplay between Taoist philosophy, Danxia Landscape and human beings – 'Tao follows nature'

Abstract: Longhushan Global Geopark not only boasts the typical Danxia landform but is also known as the birthplace of Taoism. Taoism is the only indigenous Chinese religion that has 25 million followers worldwide and in the Longhushan Geopark it dates back more than 1900 years. It has great influence on Chinese traditional culture such as life style and thinking methods. Zhang Daoling, the founder of Taoism, preached the philosophy of Taoism by interpreting nature and landforms. The important reason of choosing Longhushan was the presence of unique landforms and well preserved ecosystem. 'Tao follows nature' is the important motto of the religious doctrine. Tao is translated as 'way' or 'rule', advising people to respect nature, to follow the law of nature and to take it as a foundation for all activities. Longhushan is an example of the harmonious interplay of philosophy, nature and humanity.

Introduction

Longhushan Geopark is located in the north-eastern part of Jiangxi Province, in the southeast of China (Fig. 1). Not only it boasts typical Danxia landform (also being proposed as red beds landform or sandstone landform), but is also known as the birthplace of Taoism. Taoism is the only indigenous Chinese religion that has 25 million followers worldwide.

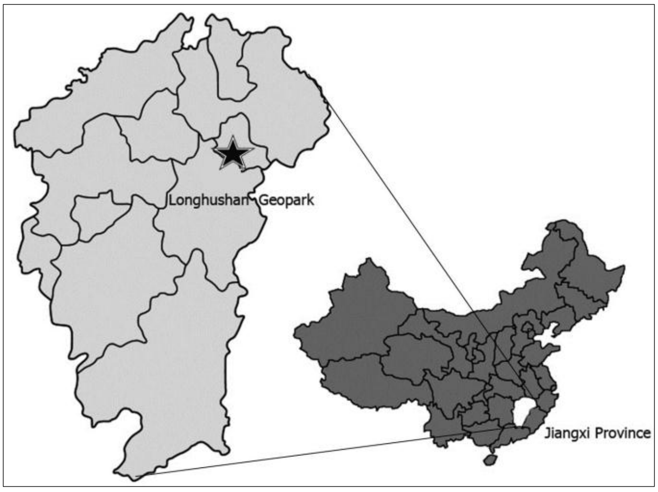

Fig. 1. Location of Longhushan Geopark.

Danxia Landform and its aesthetic beauty

Danxia landform, literally meaning ‘red glow’ or ‘rosy cloud’, is the name given in China to landscapes developed on continental, commonly red-coloured, sedimentary beds. It is characterized by steep cliffs with caves as a secondary feature (Fig. 2, 3). This type of landform has developed through long-term erosion.

Longhushan is renowned for the archetypal Danxia landscape, with the most complete series of Danxia landform, which developed in a Cretaceous rift-related red bed basin (Li et al., 2009). A Jurassic volcanic basin and a Cretaceous clastic sedimentary basin were superimposed to form the particular Xinjiang Basin (Application document, 2007). There are a variety of individual landform types such as peak clusters with steep cliffs, hoodoos, mesas, ‘stone castles’, rock walls, stone girders, and caves, making the geological park a rolling natural gallery. Danxia peaks are not high in relief. The elevations vary from 48 m a.s.l. to 401.1 m a.s.l. In traditional Chinese culture, the red colour symbolizes good fortune and joy. It corresponds with fire. Red is found everywhere during Chinese New Year and other holidays and family gatherings.

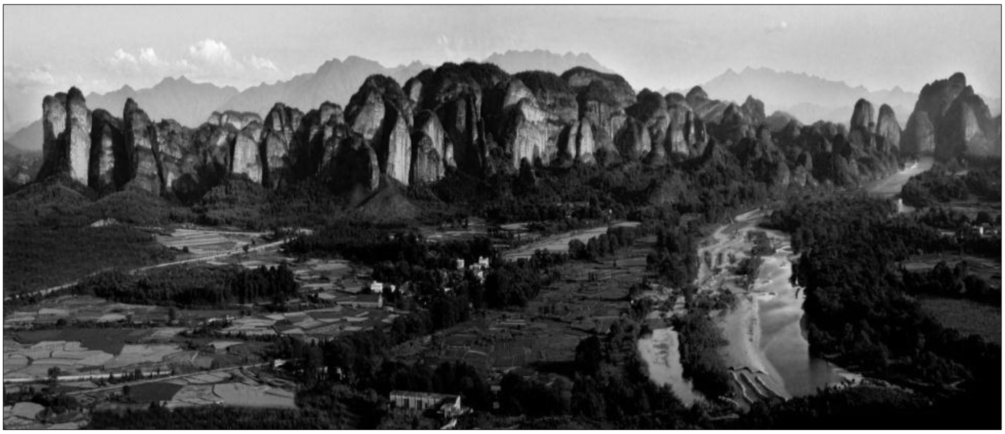

Fig. 2. Danxia landform in Longhushan – the peak cluster variant (Photographer Xia Chenglin).

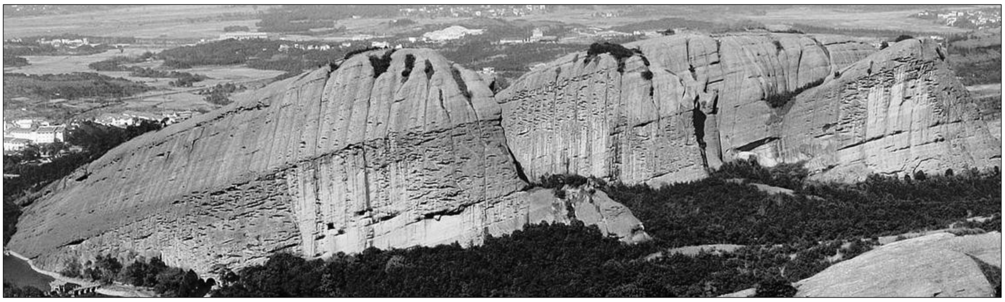

Fig. 3. An example of Danxia cuesta in Longhushan (Photographer Xia Chenglin).

The red-coloured Danxia mountains were worshiped by Chinese ancestors. The cultural development was nourished from the Chinese ancestors' recognition and utilization of the landform and natural phenomena, which in return, helped to protect it.

'Tao follows nature' – harmonious interplay of Danxia Landscape and humanity

Dating back more than 1900 years, Master Zhang Daoling (Fig. 4), the founder of Taoism, preached the philosophy of Taoism by personal cultivation and interpretation of nature and landforms using philosophical perspectives. 'Tao follows nature' is an important motto of Taoism (Le, 2004). 'Tao' is translated as 'way' or 'rule'. Following Nature is the basic idea, expressed in saying 'Man follows the way of earth, earth follows the way of heaven, heaven follows the way of the Tao, and the Tao follows the way of spontaneity'.

During the period when Taoism was most popular, there were 18 Taoist palaces, 81 temples and 36 Taoist schools in Longhushan. The best preserved architecture is the Shangqing Palace (Fig. 4), which was initially built in East Han Dynasty (25–220 AD). There are historical temples dotted around Longhushan and remain under conservation as national historical monuments.

The philosophy of following Nature is also applied in Taoist temple construction (Teather and Chow, 2000). Most Taoist temples are built along a mountain side. Many of them are wooden-framed, which is believed to be beneficial to health. Longhushan is located in a subtropical moist monsoon climate zone, with a large amount of annual precipitation reaching 1887 mm.

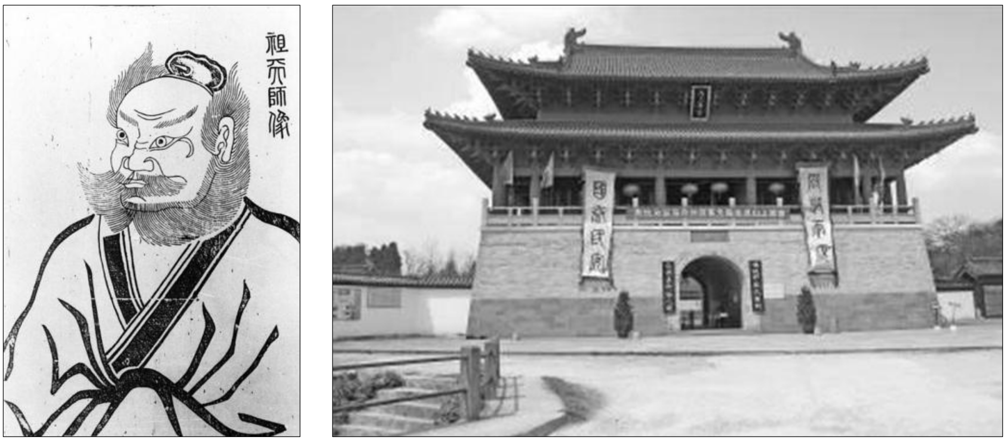

Fig. 4. Taoism in Longhushan. Founder of Taoism: Master Zhang Taoling, the founder of Taoism (left) (Application document, 2007); Shangqing Palace – the best preserved Taoist temple in Longhushan Geopark (right) (Photo Ren Fang).

Water resources are abundant in the Geopark. There are many water bodies such as the Luxi River, Longmen Lake and Qingshui Lake, and lush vegetation. It is not severely hot in summer and not too cold in winter. Seasonal difference is clear. Water is one among important factors for the formation of Danxia landforms. Taoism urges people to learn from water because water benefits all creatures but never competes with them. Water can change its shape with the changing of its vessel. Therefore, people who want to maintain harmony with the world should follow the virtue of water. Through personal cultivation, common people can shape good virtue and obtain immortality.

Taoism takes Nature as the fundamental theme of its faith, practices the major doctrines of 'Tao follows nature', 'Immortal Taoist cherishes lives', 'be kind, merciful and harmonious', 'relief world and benefit myriads' and is endeavored to create a fairy land in the real world, inspired by its fascinating imagination of a virtual fairyland (Wang et al., 2006). This faith to some extent educated people to protect and suitably utilize natural resources, providing us with the most profound ancient ecological wisdom (Zhang, 1999).

The unique Taoism culture derives from the interplay among philosophy, nature and human beings. Taoism has had a profound influence on classical Chinese society and still functions today. The harmonious interaction between human beings and nature makes Longhushan a unique and attractive place.

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Study of geological controlling factors in the formation of Danxia Landform in Longhushan Geopark, southeast China

Abstract: Danxia landform is the name given in China to landscapes developed on continental, commonly red-coloured, sedimentary beds characterized by steep cliffs. In this study, remotely sensed images are used to analyze basin geometry and lineament orientation in the area of Longhushan. Major relief features are related to NNE-trending main faults and ENE paleo-suture zone. At the smaller scale, the distribution of fractures and the orientation of bedding planes influence hydraulic conductivity, rock mass permeability and groundwater circulation pathways. The distribution of large caves along the western bank of the Luxi River is tightly related to facture orientation and the dip of bedding. Caves have preferentially developed on the down-dip side of bedding due to greater discharge of groundwater.

Introduction

Danxia landform (literally meaning 'red glow' or 'rosy cloud') is the name given in China to landscapes developed through long-term erosion on continental, commonly red-coloured, sedimentary beds, and characterized by steep cliffs. Six localities of Danxia landform became a UNESCO World Natural Heritage in 2010. Danxia landforms have recently drawn international attention. However, the study on the origin of Danxia is still insufficient. Some researchers noticed the karst-like features, including tower peaks and caves, which, hence, have been also called 'pseudo-karst' (Kempe et al., 1997; Wray, 1997). In this study it is aimed to assess the role of tectonic controlling factors in the development of Danxia landform in Longhushan Global Geopark , one of natural World Heritage sites.

Study area

Longhushan, featuring archetypal Danxia landform, is situated in northwest of Jiangxi Province of southeast China, covering 259 km² (Fig. 1). It is located in the Xinjiang Basin north of the Wuyi Mountains. Danxia landscapes in the area include Danxia peaks, peak clusters, caves, and V-shaped canyons. The elevations of Danxia peaks vary from 48 to 401.1 m a.s.l. The general relief is high in the southeast and low in the northwest and evolved from continental red beds belonging to the Hekou and Tangbian Formation of the Upper Cretaceous age (Fig. 2, 3). Sediments were distributed along piedmont pluvial and alluvial fans. The Hekou Formation is mainly composed of thick layered breccia, conglomerate, and sandstone interbedded with siltstone. The Tangbian formation primarily consists of sandstone and siltstone (Table 1). The Xinjiang Basin is a Late Cretaceous, rift-related red bed basin in the 3000 km wide NE-trending South China Fold Belt (Ren et al., 2002; Li and Li, 2007). It is located on the Beihai-Shaoxing Paleo-suture zone where the Yangtze and Cathaysia plates collided in the Neoproterozoic (Application Document..., 2007). A pair of X-shaped faults in ENE, NNE and NW directions controls the geometry of the Xinjiang Basin. Climate belongs to the subtropical moist monsoon continental type, with annual precipitation of 1,878 mm and annual evaporation of 1648.4 mm.

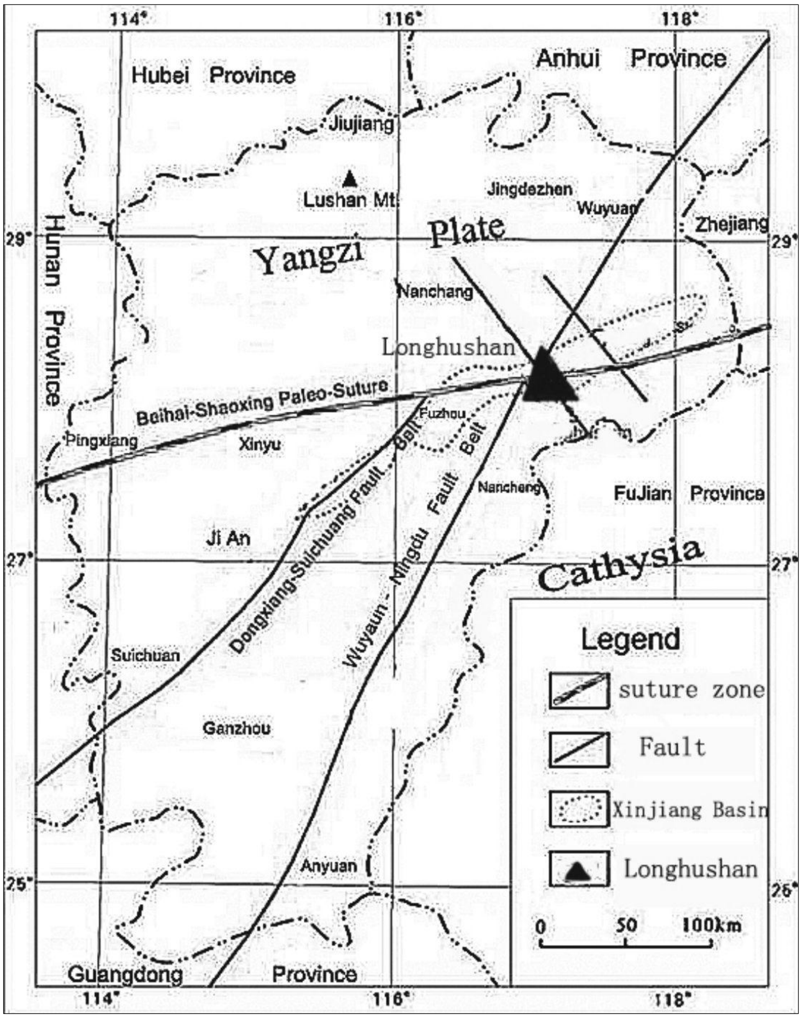

Fig. 1. Location of Longhushan Geopark and the Xinjiang Basin in SE China.

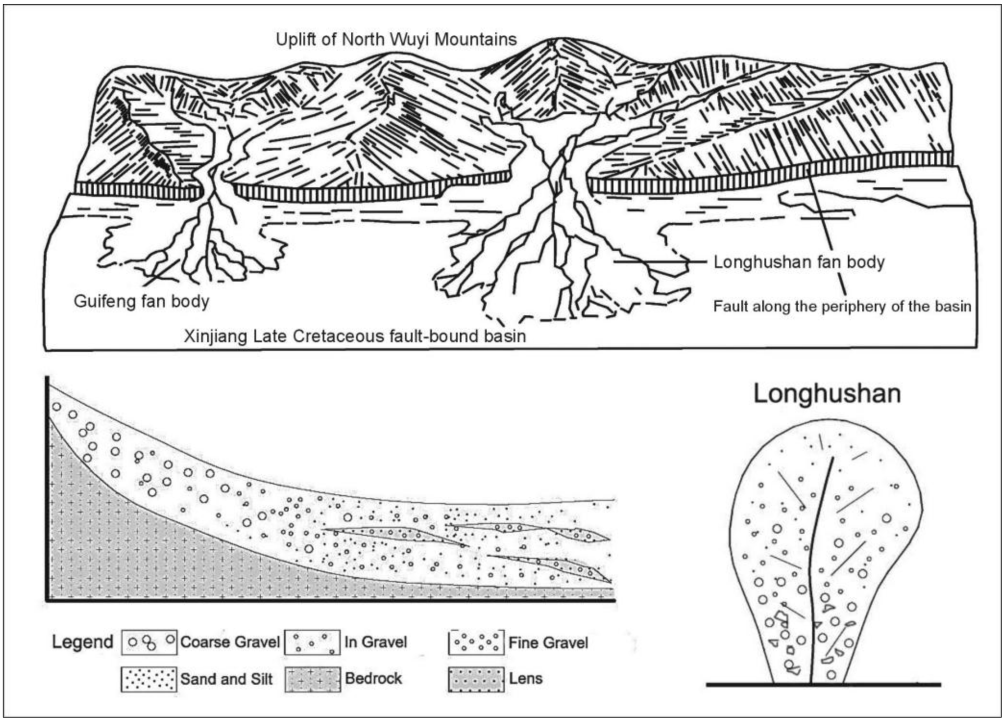

Fig. 2. Setting and structure of alluvial-proluvial fan of Longhushan
(modified after Ding and Yin, 2009; He and Ren, 2009).

Tab. 1. Upper Cretaceous red beds stratigraphy of the Xijiang Basin
(Application Documents..., 2011).

Geological age	Lithostratigraphy and thickness			Lithology	Tectonic environment	Geomorphologic features
Late Cretaceous	Guifeng Group	Lianhe Formation (>1600 m)	K_2lh	Purplish red conglomerate, sandy conglomerate, fine sandstone, siltstone	Extensional basin	Red-bed hills or lowland
		Tangbian Formation (462 m)	K_2t	Calcareous fine sandstone, siltstone		Danxia landform
		Hekou Formation (687 m)	K_2h	Purplish red conglomerate, sandy conglomerate, pebbly sandstone, intercalated with sandstone and siltstone		

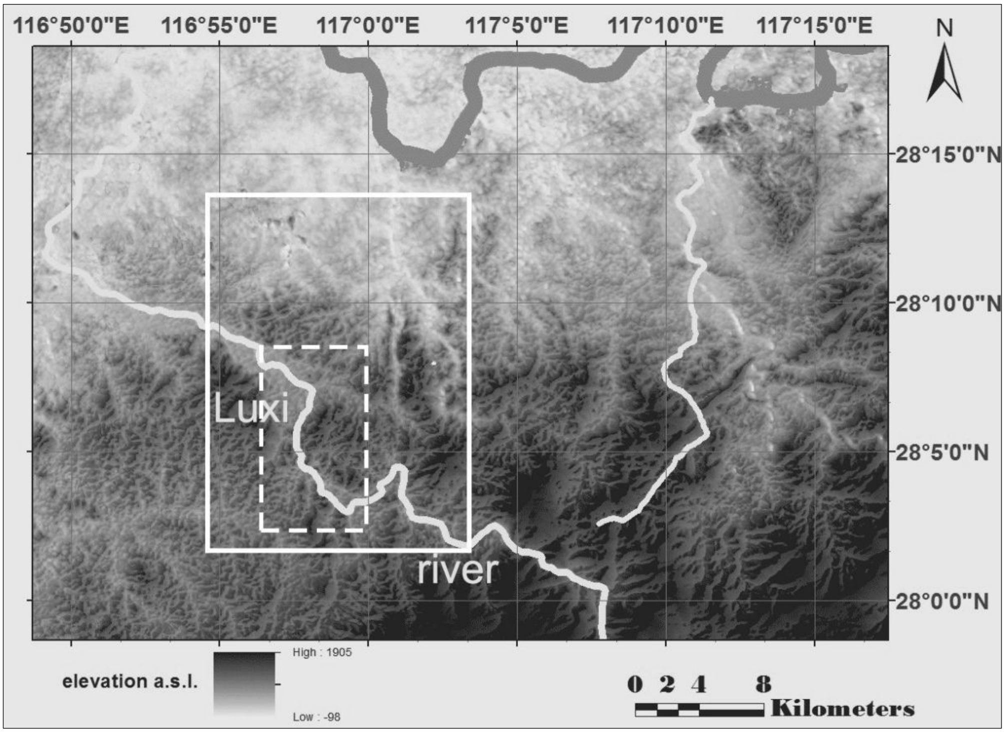

Fig.3. Digital elevation map of Longhushan Geopark derived from Aster GDEM. Big solid white box is the core zone with most concentrated Danxia landform. Small dash line box is the cliff burial site, with 202 hanging coffin sites on the western bank of the river.

The Luxi River is a meandering river, 286 km long, running through the Longhushan Geopark along a length of some 48 km (Fig. 3). The channel is flanked by steep cliffs. Some large caves along western bank of the Luxi River, from a few tens to more than 100 m long, were used by ancient Chinese residents 2600 years ago as a natural burial places (holy tombs), forming the renowned Asian cliff burial culture. These are also known as 'hanging coffins', popular also in Indonesia and the Philippines at the same time period. The large caves occur almost exclusively along the western bank of the river and are seldom found on the eastern bank. The reason for this spatial distribution is still a mystery.

This study aims to test if the regional fault system influences the pattern of Danxia mountains and to explain spatial distribution of large caves on the western bank of the Luxi River from a geological perspective. In order to focus on the Danxia landform, research was carried out in the core zone of the Geopark (Fig. 3).

Study approach and methods

Regional geologic maps (1:200,000 and 1:50,000) and geomorphologic maps (1:50,000 and 1:10,000) were prepared by visual interpretation of satellite imagery data (LANDSAT-7 ETM) and digital elevation models (ASTER DEMs). The ETM image is composed of 6 VNIR and SWIR bands, with the resolution of 30 m, and the panchromatic band 8, with the resolution of 15 m. The ASTER image has 3 VNIR bands, with the resolution of 15 m, and 6 SWIR bands with the resolution of 30 m. The GCPs collected in the field were also used for georeferencing, performed using Environment for Visualizing Images (ENVI) version 4.4 software (RSI) and ArcGIS 10 (ESRI). Different input datasets and processing methods were applied (GIS-based analysis, lineament extraction, raster calculations, etc.).

Field investigation

Outcrop scale measurements of bedding and fracture orientation were conducted for structural geology study. The distribution of fracture and the orientation of bedding planes influence hydraulic conductivity, rock mass permeability and groundwater circulation pathways. Cavernous tafoni-type weathering is a common and conspicuous global feature (Bradley et al., 1978; Brandmeier et al., 2011). In Longhushan, cavernous weathering is a very common phenomenon. The size of the caves varies from centimetres to tens of meters. Along the two banks of the Luxi River there are caves developed in Danxia mountains, but the large caves which can accommodate coffins occur only along the western bank of the meander. It is hypothesized that the spatial concentration of these big caves is related to tectonic structures influencing preferential weathering. Therefore, orientation of fractures and bedding planes of the Danxia mountains along the western and eastern bank of the Luxi River were measured.

Results and discussion

A rose diagram of lineaments identified in the study area indicates the predominant ENE, NNE, and NW trending clusters (Fig. 4, 5), consistent with the orientation of main faults through the Xinjiang Basin. This indicates that the main faults not only define the geometry of the Xinjiang Basin but also control the orientation of the Danxia mountains.

Shallow groundwater generally flows in the direction similar to the topographic gradient. Field data show that the bedding planes in the Danxia mountains on the western and eastern banks of the Luxi River are both gently dipping to the east or southeast (Fig. 6). The bedding and fracture planes can become important preferential flowpaths for groundwater and stimulate the development of large caves along the down-dip of the bedding plane, or at the intersection of the fractures (Fig. 7).

The preferential formation of caves on the down-dip side of the bedding planes (along either down-dip side of true dip or apparent dip, Fig. 7) or at the intersection of fractures is due to greater discharge of groundwater. Therefore, the large caves could have only developed at the western bank of the Luxi River, which is the lower part of the topographic gradient of Danxia mountains, rather than at the eastern bank.

In Longhushan, cavernous weathering is ubiquitous which is due to multi-genesis. The size of the caves varies from centimeters to tens of meters. Cavernous tafoni-type weathering is a common and conspicuous global feature (Bradley et al., 1978; Smith, 1978; Brandmeier et al. 2011). Besides the salt-weathering interpretation in sandstone areas proposed by other studies and the preferential groundwater erosion from this study, lithological variation influences the wavy rock wall surfaces, with concave pits formed along silty mudstone layers and lenses. Then, exfoliation processes on Danxia rocks reshape the geometry of the caves. Inception of some other types of surficial caves exploits stratification and is followed by lateral widening due to repeated wetting-drying cycles along the walls.

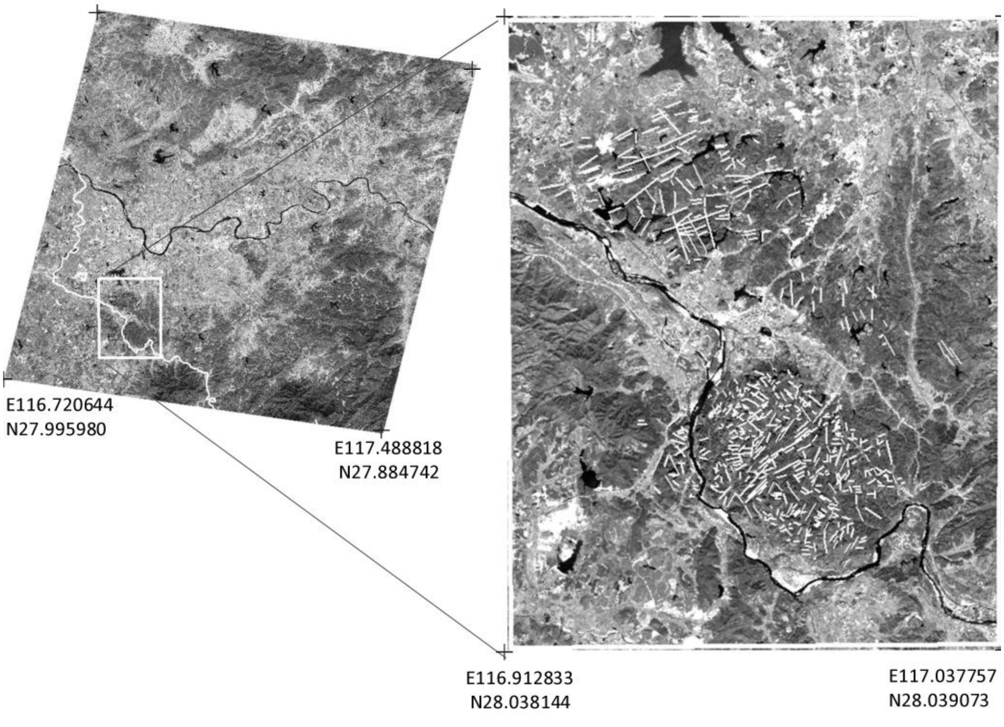

Fig. 4. Lineaments pattern of the study area extracted from remotely sensed images.

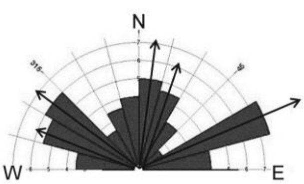

Fig. 5. Rose diagram depicting the distribution of regional lineaments.

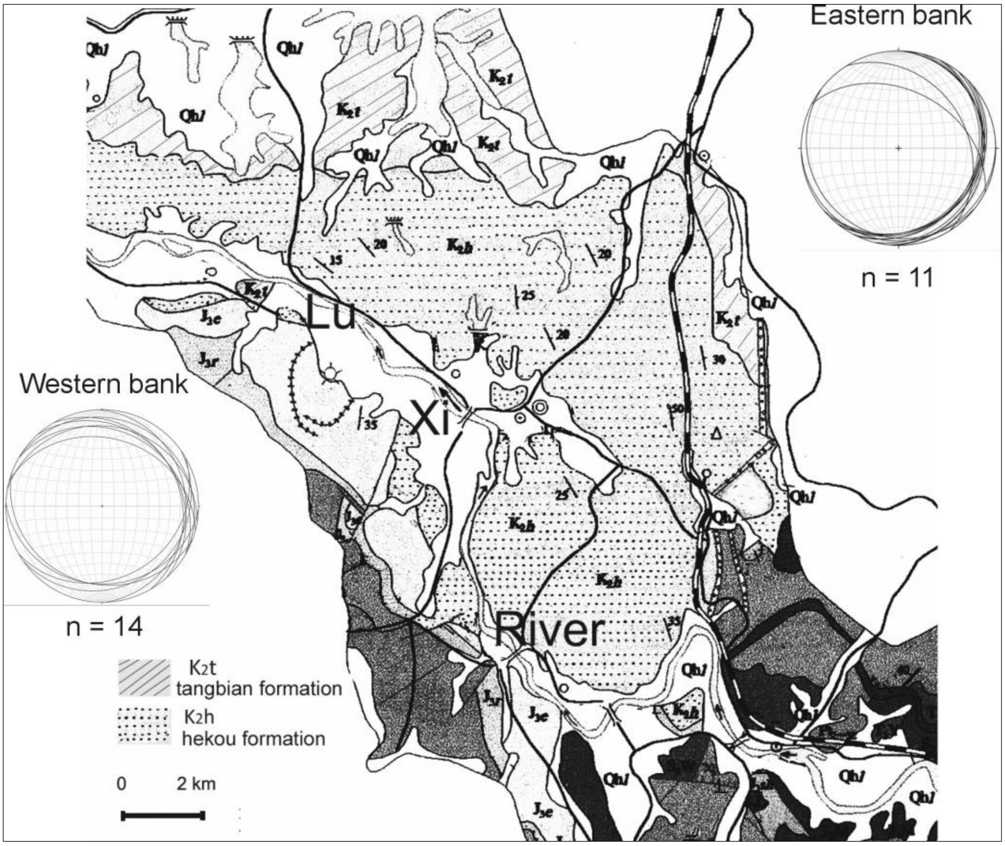

Fig.6. Regional geological sketch map of the partial Luxi River in Longhushan. Equal-area, lower-hemisphere plot of bedding planes of measured Danxia mountains along western and eastern bank of the Luxi River respectively.

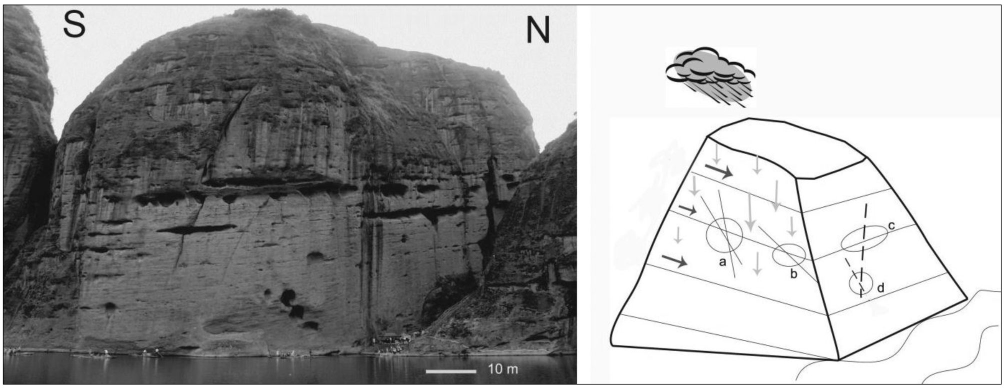

Fig. 7. Outcrop sketch of large scale caves developed in a Danxia mountain at the western bank of the Luxi River. Cartoon depicts the orientation of bedding and fracture-controlled preferential weathering sites in the gently-tilted Danxia mountain. a, b, c, d represent the location of the caves at the down-dip side of the bedding plane and fracture intersections.

Conclusions

The study has revealed that regional main faults not only control the basin pattern in the large scale but also influence the orientation of the Danxia peaks. Most Danxia mountains are aligned in ENE, NNE and NW direction. This is seen in the lineaments extracted from remotely sensed images. Tectonic deformation riddles the upper crust with fractures, which provides pathways for water flow and thus promotes weathering. This in turn causes rapid incision and erosion of the more permeable parts in the Danxia mountains. The bedding and fracture orientations favour preferential weathering and erosion at the down-dip of the bedding planes and at the intersection of fractures. This explains the concentrated spatial distribution of large caves along the western bank of the meander in the study area. Our study proposes that tectonic structures are among important controlling factors, contributing to the development of Danxia landform.

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Integrated system of measured dangerous rock objects in National park Bohemian Switzerland

Abstract: Rock-mass falls and boulder falls pose a considerable hazard in the Bohemian Switzerland National Park. Each year at least a few events involving more than 1 m^3 of rock are recorded. Remedial measures include induced rock falls, stabilisation using wall clamps into firm rock at depth, by concrete frames and construction of safety nets, fences and barriers. Most hazardous objects are monitored using different methods of data collection. An integrated system of measured dangerous rock objects is being developed and includes an interactive map showing the level of potential hazard at particular localities.

Geological setting and problem

Elbe Sandstones is a general name for sedimentary formations on both sides of the River Elbe valley. These sandstones were deposited during 10 or 12 million years between the Cenomanian and Coniacian, mostly during the middle Turonian. Sandstones formations were originally about 1000 meters thick, but this thickness was reduced by erosion associated with the emergence of the Elbe sandstones tectonic block in the late Cretaceous, and during reactivation of old faults in the Cenozoic (Mikuláš et al. 2007), under the influence of Saxon tectonics. The Elbe Sandstones belong to the north-western part of the Bohemian Cretaceous Basin, which was influenced in its establishment by fault zones in the bedrock. An intra-basinal part of a palaeodrainage system went with the slope of the Elbe fault zone and was strongly influenced by the coupled Jizera fault zone heading N-NE. Runoff followed the Lusatian fault zone and the Železné hory fault zone. The result of later paleostress was the subsidence of fault-bounded depocenters of the Bohemian Cretaceous Basin and the emergence of new source areas (Uličný et al. 2009).

This highly complicated geological history led to the creation of a dense joint system in sandstone rock formations. Erosion in thick-bedded sandstones, with predisposition set by joints, has evoked block erosion. On high platforms there occur huge unstable rock blocks of a size more than hundreds cubic meters. Possible fall of these blocks poses great danger to human lives and may cause considerable damage of infrastructure. In the Bohemian Switzerland National Park, potentially dangerous rock objects are monitored at about 500 localities. They are subject to handheld and automatic measurements, with or without remote data transfer.

Rock falls in the Bohemian Switzerland National Park

Within the National Park there are many small rock-falls less than 2 m^3 in size and a few rock-falls involving more than 2 m^3 each year (Fig. 1, 2). For example, in 2012 three falls near roads displacing more than 1 m^3 were registered, while in the year 2010 four falls involving more than 5 m^3 occurred. In the end of 19th century a rock fall in the village of Hřensko brought about catastrophic results. More than 200 m^3 of rock mass fell onto a hotel causing serious damage to the building. Nowadays we are able to predict instability of big sandstone blocks and we manage sanitations to avoid such catastrophic rock falls. Only rock blocks, which are dangerous to infrastructure or to human lives, can be secured, whereas others are left to natural processes. This means that we measure unstable boulders above roads and hiking trails, and rocks in the National Park domain that pose hazard to buildings. Sanitations of small dangerous objects, with maximum size up to 20 m^3, are managed by the rock squad of the National Park, usually by induced rock fall. Bigger objects are secured by specialized companies, usually by extraction of the most unstable parts, by stabilisation using wall clamps into firm rock at depth, by concrete frames and constructions of safety nets, fences and barriers (Fig. 3).

In the Bohemian Switzerland National Park there exist several types of data connected with rock dynamics. These datasets are used for safety management, early warning and planning of sanitations of unstable blocks. The first dataset is Digital Terrain Model, created using LiDAR technology with the pixel size of 1 m (Trommler 2007). This Digital Terrain Model will be used as a base layer map of the system. The next data derives from field geological mapping focused on engineering geology problems, such as stability of rock blocks (Šebesta et al. 1999). Dangerous rock objects are subdivided into five groups of dangerousness by minimum time interval of potential collapse, from red triangles for objects, which are imminently unstable,

Fig. 1. Small rockfall at Kyjov, 1 m^3 (Photo: J. Šafránek, 2012).

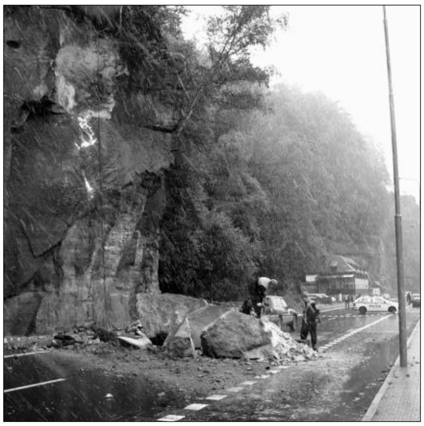

Fig. 2. Big rockfall in Hřensko, 20 m^3 (Photo: Z. Vařilová, 2009).

Fig. 3. Concrete frame, wall clamp and dynamic barrier in Hřensko (Photo: Arcadis GT a.s., 2012).

with the possibility of collapse in days, to green triangles for objects that are stable for the minimum of hundreds of years (Stemberk, Zvelebil 2001).

Very important is the dataset collected during the last decade by members of Department of Geology – Rock Squad. This handheld data represent relative movements of unstable rock blocks and give us the first view in analysing of each unstable compartment. In the Bohemian Switzerland National Park more than 700 points are measured at about 400 localities. The objective of the Rock Squad is to measure each point in the maximum interval of two weeks. These measurements are accomplished through the use of dilatometers, by which it is possible to measure with the accuracy of hundredths of a millimetre (Fig. 4). Other data come from automatic monitoring systems with remote data transfer, which measure relative movements of rock blocks with high level of risk for visitors and citizens of Hřensko. For data transfer standard GSM provider is used. The last type of data collected in the National Park goes from automatic monitoring systems without remote data transfer, gathered from data-loggers by members of the Rock Squad at an interval of one month. This system is used for measuring unstable blocks above the route connecting Janov and Hřensko, or for measuring movements on Pravčická brána rock arch.

Integrated System of Measured Dangerous Objects

An integrated system of dangerous objects will be presented on an interactive map with measured objects marked by coloured triangles (Fig. 5), where colour indicates the current level of hazardousness, from non/low to high (grey – green – yellow – orange – red colour, respectively). Each triangle represents one rock object, or a locality with one or more measured points. Click on a triangle summons context menu with options GRAPH, SITUATION, DATA and INPUT. Selecting GRAPH shows a graph of measured parameters in time, such as relative movement and temperature. In situation where each object should have more than one measuring points, graphs show movements for each point and there is one graph for air temperature. Selecting SITUATION summons photography, map or drawing of the whole dangerous object or locality, with imprinted points of measuring. Selecting DATA shows spreadsheet of measured data at each point on a dangerous object or locality, with columns for date, temperature, movement and variations between current and last measurement. Selecting INPUT allows members of the Rock Squad to input handheld measurements or automatically gathered measurements from data-loggers. Automatic monitoring with remote data transfer is updated in real-time. The system will be also connected with internet and GSM and in cases of exceeding limits designed for each dangerous object it will send warning through SMS or email.

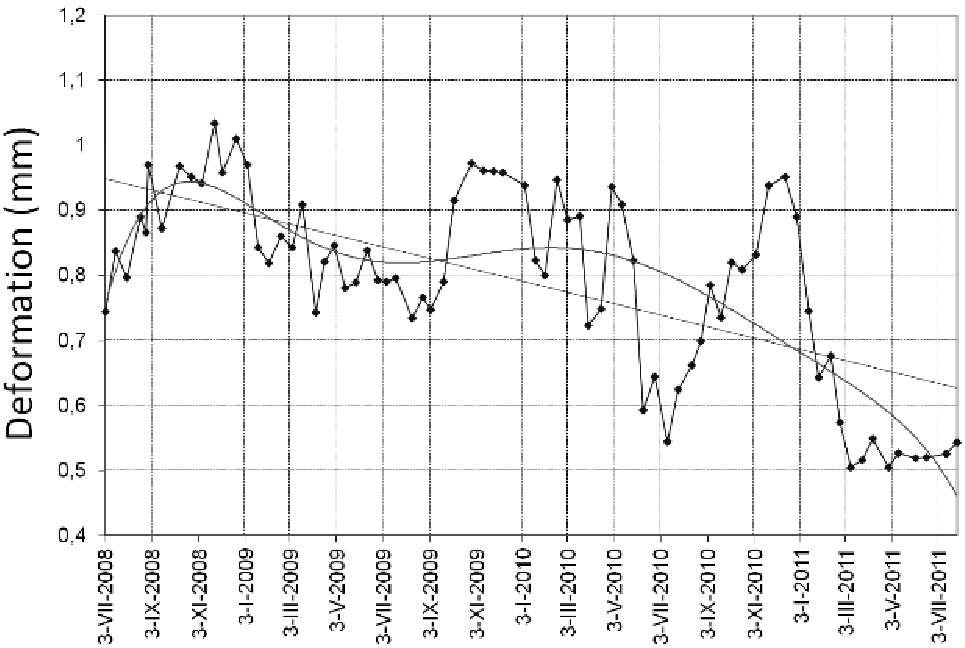

Fig. 4. Chart of handheld dilatometer measurements.

Outlook

The main goal of this project is to make data collection more efficient, to integrate these datasets into one system, to compare gathered data and, in addition, the system should be open for future applications of different monitoring methods, different measuring or collecting modes, and even for different types of data.

A different output will be a simplified map with DTM and topography layers. Dangerous objects are also viewed as in the example (Fig. 5), but right-clicking would not summon context menu on danger icon. Users will see map with dangerous objects marked by coloured triangles. The main reason behind this approach is to simplify interpretation of deformations. Data measured and set into the database by field workers will be connected with an integrated system and will be available to interpretation in shorter time and interpreted data will be more 'real-time'. The next goal is to create web application of early warning system that should be connected to police, fire department or local government. Another goal of this project is to create process for collecting, archiving and analysing data and datasets from different kinds of measurements into one system.

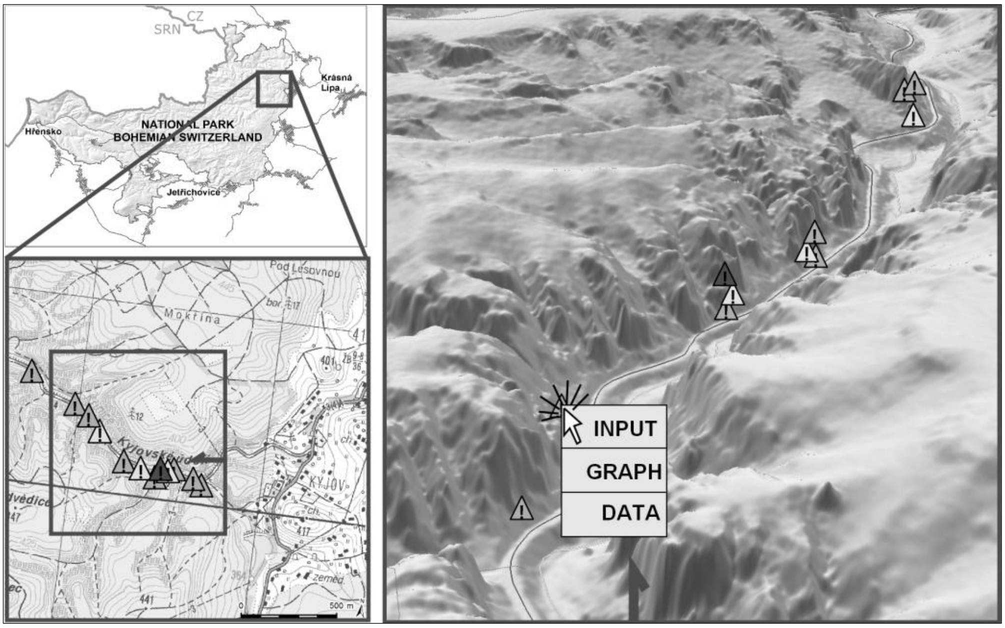

Fig. 5. Layout of Integrated System of Measured Objects in the Bohemian Switzerland National Park.

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Hygrophilous tall herb communities in the Stołowe Mts, against their diversity in the Sudetes (Poland)

Abstract: The differentiation of hygrophilous tall herb communities in the Stołowe Mts seems to be known sufficiently well, in spite of that only some relevés were published. In the Stołowe Mts only two communities have been distinguished so far – *Geranio phaei-Urticetum dioicae* and *Petasitetum albi*. The wide phytosociological investigation carried out by authors in 2011 in many localities of hygrophilous tall herb communities in the Sudetes and their foreland brings new information in this area. Results of analyses revealed that four different hygrophilous tall herb communities should be distinguished within the area of the Stołowe Mts. According to proposal of Michl et al. (2010) communities occurring in the Stołowe Mts do not belong to *Adenostylion alliariae*, which is limited to the subalpine zone, but to two other alliances: *Rumicion alpini* and *Arunco dioici-Petasition albi*.

Introduction

The syntaxonomy of hygrophilous tall herb communities in the Sudetes is still unclear. The primary source of knowledge about plant communities in Poland (Matuszkiewicz 2001) lists seven associations occurring in this mountain range. On the other hand new synthesis concerning tall herb communities in central and northern part of Europe (Michl et al. 2010), suggests that most of differences between these communities are only of local character. Our research carried out in 2011 focused on explaining these discrepancies.

Methods

In 2011, 152 relevés of hygrophilous tall herb communities were collected in the Sudetes and their foreland, according to Braun-Blanquet approach (Mueller-Dombois & Ellenberg 2003) and stored in a TURBOVEG database (Hennekens & Schaminée 2001). The area of the relevés was adapted to these proposed by Chytrý & Otypková (2003). All relevés were classified using the TWINSPAN method (Roleček et al. 2009) embedded within the JUICE program (Tichý 2002). A Total Inertia method was used as a measure of cluster heterogeneity (Tichý et al. 2007). Diagnostic species for particular vegetation units were determined using the phi coefficient as a measure of fidelity (Chytrý et al. 2002) in a synoptic table. The phi coefficient was used for clusters of equalized size (Tichý & Chytrý 2006). Only species with both a significant concentration in particular vegetation units (using the Fisher's exact test and the significance level $P < 0.5$) and phi coefficient ≥ 0.30 were considered to be a diagnostic species.

Within known stands of hygrophilous tall herb communities in the Stołowe Mts we selected 5 sites. On each site 3 phytosociological relevés were made. The literature of the subject and unpublished data was used as well, to reflect the full diversity of investigated phytocoenoses (Pender & Macicka-Pawlik 1996, Świerkosz et al. 2002, Świerkosz, unpbl.).

Character species of *Mulgedio-Aconitetea* Hadač et Klika et Hadač 1944 and syntaxonomical nomenclature follows Michl et al. (2010). Vascular plants nomenclature is in accordance with Mirek et al. (2002).

Results

Investigated communities of hygrophilous tall herbs in the Stołowe Mts belong to four different types of phytocoenoses.

Ass. *Prenanthetum purpureae* Bolleter 1921 (Table 1) is known from the most exposed places and from the springs within the spruce forest at higher altitudes, mainly around Szczeliniec Wielki Mt. It is easy to identify due to common and abundant occurrence of *Cicerbita alpina*, *Streptopus amplexifolius* and *Dactylorhiza fuchsii* (Reczyńska & Świerkosz 2012). On the other investigated stands in the Sudetes also *Aconitum variegatum, Lunaria rediviva* and *Chrysosplenium alternifolium* seem to be differentiating for this association, in opposite to *Petasitetum albi* Zlatnik 1928, in which the patches have been included earlier. The association is probably widely distributed in the Sudetes – vegetation plots with occurrence of above mentioned species were recorded from the Izerskie Mts, the Orlickie Mts and the Śnieżnik Massif. Most of them were observed at altitude between 700 and 1000 m a.s.l.

Ass. *Petasitetum albi* Zlatnik 1928, is a community of shady habitats at lower altitudes, with domination of *Petasites albus* and with occurrence of many *Querco-Fagetea* Br.-Bl. et Vlieg. 1937 species such as *Asarum europaeum*, *Carex sylvatica*, *Ajuga reptans*, *Viola reichenbachiana*, *Mercurialis perennis*, *Mycelis muralis*, *Sanicula europaea* and others (Table 2). The community is very common in lower mountain ranges in the Sudetes, such as the Krucze Mts, the Sowie Mts, the Złote Mts and in the Izerskie Foothills.

Ass. *Geranio phaei-Urticetum dioicae* Hadač et al. 1969 was recognized in the vicinity of Pasterka, Radków and Jakubowice villages (Świerkosz et al. 2002). Its characteristic species is *Geranium phaeum*. The phytocoenoses belonging to this association are clearly synanthropic in character, with occurrence of many nitrophilous species, such as *Urtica dioica*, *Aegopodium podagraria, Galium aparine, Geum urbanum, Glechoma hederacea* and *Artemisia vulgaris* (Table 3).

Tab. 1. Ass. *Prenanthetum purpureae* Bolleter 1921 in the Stołowe Mts.

Relevé no.	Layer	1	2	3	4	5	6	7	8	9	10	11	12
Date (year/month/day)		2011-07-19											
Relevé area (m^2)		24	25	25	25	25	25	25	25	16	25	25	25
Altitude (m a.s.l.)		780	775	765	775	755	775	770	760	750	760	775	750
Aspect (degrees)		360	360	360	45	315	45	270	315	315	0	45	0
Slope (degrees)		2	2	2	2	5	5	10	2	2	0	2	0
Cover shrub layer (%)		2	0	0	0	0	0	0	0	0	0	0	0
Cover herb layer (%)		90	70	90	80	90	100	60	100	100	90	90	100
No. of species		34	29	24	28	23	28	20	26	29	26	31	34
D. Ass. *Prenanthetum purpureae*													
Streptopus amplexifolius	c	1	1	+	+	+	.	.	r	1	+	+	.
Cicerbita alpina	c	2	1	2	1	1	1	2	+	.	.	.	.
Prenanthes purpurea	c	+	+	+	.	+	.	+	.	.	.	.	+
Dactylorhiza fuchsii	c	.	.	.	+	.	+	.	.	.	1	+	1
Ch. Cl. *Mulgedio-Aconitetea*													
Chaerophyllum hirsutum	c	2	1	1	1	2	2	1	2	3	1	1	1
Calamagrostis villosa	c	+	+	+	2	+	2	+	r	+	+	1	1
Stellaria nemorum	c	1	2	1	1	2	1	+	1	.	.	+	.
Petasites albus	c	2	1	2	.	2	.	2	1	2	3	.	.
Veratrum lobelianum	c	.	1	.	2	+	1	.	1	+	.	1	2
Ranunculus lanuginosus	c	.	.	+	+	+	1	.	1	.	r	1	.
Polygonatum verticillatum	c	.	+	+	.	.	.	1	.	+	+	+	.
Myosotis nemorosa	c	.	.	.	.	.	1	.	r	+	.	+	.
Rosa pendulina	b	.	.	+	.	.	.	.	.	.	.	.	.
Ch. Cl. *Querco-Fagetea*													
Galeobdolon luteum	c	1	+	2	1	1	+	2	.	.	+	+	.
Fagus sylvatica	c	+	+	+	1	+	.	.	.	.	.	+	r
Stachys sylvatica	c	+	.	+	.	1	+	.	1	.	+	.	.
Acer pseudoplatanus	c	r	r	r	r	.	.	.	.	.	.	.	+
Lysimachia nemorum	c	.	+	.	1	.	.	.	.	.	+	1	+
Paris quadrifolia	c	r	.	.	.	.	.	r	r	.	+	.	+
Carex remota	c	+	.	.	.	.	+	.	.	.	.	+	+
Anemone nemorosa	c	.	+	.	.	r	.	.	r	+	.	.	.
Veronica montana	c	.	.	r	+	r	.	.	+	.	.	.	.
Dentaria enneaphyllos	c	+	.	.	.	.	.	.	.	.	+	.	.
Epilobium montanum	c	+	.	.	.	.	.	.	.	.	.	.	.
Impatiens noli-tangere	c	.	.	.	.	.	+	.	.	.	.	+	.
Accompanying species													
Oxalis acetosella	c	1	1	1	1	r	+	+	+	+	1	1	+
Athyrium filix-femina	c	2	2	1	2	2	1	1	2	1	+	3	.
Senecio ovalis	c	+	+	+	+	+	1	+	+	+	.	+	.
Equisetum sylvaticum	c	+	r	.	1	.	1	.	+	1	+	+	2
Crepis paludosa	c	.	+	.	1	r	1	.	1	+	1	2	+
Chrysosplenium alternifolium	c	.	.	+	+	+	+	.	1	+	.	+	+
Sorbus aucuparia	c	+	r	.	+	.	.	r	.	+	.	r	r
Dryopteris dilatata	c	+	.	+	+	+	.	+	.	+	.	.	.
Cardamine amara	c	.	.	.	.	.	.	.	+	+	r	+	+
Cirsium oleraceum	c	.	.	.	.	.	+	.	2	1	2	.	2

Remark: shortened table – accompanying species with less than 5 occurrences and moss species were omitted.

Tab. 2. Ass. *Petasitetum albi* Zlatnik 1928 in the Stołowe Mts.

Relevé no.	1	2	3	4	5	6	7	8	9	10
Date (month/day)	06.10	06.06	06.06	06.06	06.06	06.06	06.06	06.06	06.06	07.05
Date (year)	1998	1996	1996	1996	1996	1996	1996	1996	1996	2002
Relevé area (m^2)	25	20	20	20	10	15	20	8	20	30
Altitude (m a.s.l.)	720	750	750	740	740	740	740	750	740	705
Cover shrub layer (%)	.	.	.	+	.	.	10	.	+	.
Cover herb layer (%)	100	100	100	100	100	100	100	100	100	100
Cover moss layer (%)	.	.	20	.	.	.	.	.	.	5
No. of species	20	14	12	15	11	11	21	10	16	14
Ch. Ass. *Petasitetum albi*										
Petasites albus	4	5	5	4	5	5	4	5	4	5
Ch. Cl. *Mulgedio-Aconitetea*										
Chaerophyllum hirsutum	1	.	+	1	+	+	+	+	+	r
Stellaria nemorum	.	.	+	1	+	+	+	+	1	+
Calamagrostis villosa	+	+	+	+	+	.	.	.	.	.
Polygonatum verticillatum	.	.	.	+	+	+	+	.	.	.
Veratrum lobelianum	.	.	+	.	.	.	.	+	+	.
Ranunculus lanuginosus	.	+	.	.	.	.	+	.	+	.
Valeriana sambucifolia	.	.	.	.	.	+	+	.	.	.
Thalictrum aquilegifolium	.	.	1	.	.	.	.	.	+	.
Sporadic: *Anthriscus nitida* 6 (+); *Ranunculus platanifolius* 1 (+); *Streptopus amplexifolius* 2 (+).										
Ch. Cl. *Querco-Fagetea*										
Impatiens noli-tangere	.	.	.	+	.	+	+	+	1	.
Galeobdolon luteum	.	+	.	.	+	.	.	.	+	+
Acer pseudoplatanus c	+	.	.	+	.	.	+	.	+	.
Prenanthes purpurea	.	+	.	+	.	.	+	.	.	.
Anemone nemorosa	+	.	+	.	.	.	+	.	.	.
Mercurialis perennis	+	.	.	.	.	.	.	.	1	+
Fraxinus excelsior b	.	.	.	.	.	.	+	.	+	.
Sporadic: *Acer platanoides* b 7 (+); *Carex sylvatica* 1 (+); *Dryopteris filix-mas* 10 (+); *Euphorbia dulcis* 7 (+); *Fagus sylvatica* c 10 (+); *Festuca gigantea* 9 (+); *Galium odoratum* 10 (+); *Lathraea squamaria* 4 (+); *Stachys sylvatica* 7 (+).										
Accompanying species										
Senecio ovalis	+	+	.	1	+	+	+	.	+	.
Oxalis acetosella	.	.	+	+	+	.	+	.	.	+
Aegopodium podagraria	1	1	.	.	.	+	+	.	+	+
Urtica dioica	.	.	.	+	.	+	+	+	+	+
Cirsium oleraceum	1	.	.	.	.	+	+	+	.	.
Athyrium filix-femina	+	.	+	.	.	.	.	.	+	+
Equisetum sylvaticum	.	.	.	+	1	.	.	+	.	.
Cardamine amara	.	.	+	.	+	.	.	+	.	.
Crepis paludosa	+	.	+	.	.	.	.	.	.	.
Cardaminopsis halleri	+	.	.	.	.	.	.	.	.	+
Ranunculus repens	+	.	.	.	+	.	.	.	.	.
Equisetum arvense	+	+	.	.	.	.	.	.	.	.
Rubus idaeus	+	+	.	.	.	.	.	.	.	.
Phyteuma spicatum	+	+	.	.	.	.	.	.	.	.

Sporadic species: *Caltha palustris* 8 (+); *Carex canescens* 2 (+); *Dryopteris carthusiana* 2 (+); *Fragaria vesca* 1 (+); *Heracleum sphondylium* 7 (+); *Juncus effusus* 2 (+); *Mnium stellare* d 3 (2); *Phleum pratense* 1 (+); *Rhizomnium punctatum* d 10 (+); *Sambucus racemosa* b 7 (+); *Sorbus aucuparia* b 4 (+); *Veronica chamaedrys* 4 (+).

Tab. 3. Ass. *Geranio phaei-Urticetum dioicae* Hadač et al. 1969 in the Stołowe Mts.

No. of relevé	1	2	3	4	5
Date (month/day)	6.04	6.04	6.04	6.04	7.05
Year	1995	1995	1995	1995	1996
Relevé area (m2)	25	20	20	20	10
Altitude (m a.s.l.)	680	680	670	680	700
Aspect	NE	NE	NE	(S)	.
Slope (degrees)	10	5	10	5	.
Cover shrub layer (%)	.	.	+	.	.
Cover herb layer (%)	100	100	100	100	100
Cover moss layer (%)	.	.	.	.	+
No. of species	14	10	18	14	21
Ch. Ass. *Geranio phaei-Urticetum dioicae*					
Geranium phaeum	3	3	3	3	3
Ch. Cl. *Mulgedio-Aconitetea*					
Anthriscus nitida	2	1	2	2	+
Valeriana sambucifolia	.	.	+	.	.
Ranunculus lanuginosus	.	.	.	+	.
Stellaria nemorum	.	.	.	.	+
Ch. Cl. *Artemisietea vulgaris*					
Urtica dioica	2	3	3	2	3
Aegopodium podagraria	+	2	2	1	1
Chaerophyllum aromaticum	.	.	.	1	2
Agropyron repens					r
Glechoma hederacea	.	.	.	.	+
Ch. Cl. *Querco-Fagetea*					
Primula elatior	1	+	+	+	+
Galeobdolon luteum	1	1	+	.	.
Viola reichenbachiana	+	+	+	.	.
Anemone nemorosa	+	.	+	.	+
Mercurialis perennis	.	.	+	1	.
Dryopteris filix-mas	+	+	.	.	.
Moehringia trinervia	+	.	+	.	.
Sporadic: *Acer pseudoplatanus* c 3 (+); *Anemone ranunculoides* 5 (r); *Epilobium montanum* 5 (+); *Impatiens noli-tangere* 5 (+); *Poa nemoralis* 5 (+); *Ulmus glabra* 3 b (+).					
Accompanying species					
Senecio ovalis	2	+	1	2	1
Oxalis acetosella	+	+	+	.	.
Phyteuma spicatum	+	.	+	.	.
Deschampsia cespitosa	.	.	+	.	+
Dactylis glomerata	.	.	.	+	r
Alchemilla monticola	.	.	.	+	+

Sporadic: *Brachythecium velutinum* 5 (+); *Cirsium oleraceum* 4(+); *Geum rivale* 3 (+); *Mnium hornum* d 4 (+); *Quercus robur* c 4 (+); *Poa annua* 1 (+); *Veronica chamaedrys* 4 (+); *Taraxacum sect. Vulgaria* 5 (+).

The last one is the community of *Petasites hybridus-Primula elatior*, preliminary recognized during our analyses of data collected from the Sudetes . These phytocoenoses have been included so far in *Phalarido-Petasitetum hybridi* Schwickerath 1933, what turned out to be incorrect because of their different species composition with occurrence of many *Mulgedio-Aconitetea* species, such as *Anthriscus nitida, Geranium sylvaticum, Petasites albus, Chaerophyllum hirsutum, Stellaria nemorum* and *Myosotis nemorosa*.

Sample relevé No. 276: Date 11.07.1996; Relevé area 25 m^2; Aspect W; Slope 10^o; Altitude 535 m a.s.l.; Cover herb layer 100%; Cover moss layer 10%; No. of species 18.
Petasites hybridus 5; *Impatiens noli-tangere* 1, *Primula elatior* +, *Myosotis nemorosa* +, *Petasites albus* +, *Cardaminopsis halleri* +, *Chaerophyllum hirsutum* +, *Stellaria nemorum* +, *Urtica dioica* +, *Aegopodium podagraria* +, *Chaerophyllum aromaticum* +, *Stachys sylvatica* +, *Epilobium montanum* +, *Alchemilla monticola* +, *Cirsium oleraceum* +, *Heracleum sphondylium* +, *Lathyrus pratensis* r, *Rumex obtusifolius* r.

Discussion

Despite the fact differentiation of hygrophilous tall herb communities in the Sudetes seemed to be known sufficiently well it turned out that patterns of distribution and differentiation of tall herb communities in this area tend to be more complicated and need further studies. Currently, eight separate syntaxonomical units can be distinguished in the Sudetes and four of them occur in the Stołowe Mts. In the latter mountain range, two communities are in accordance with classification proposed by Michl et al. (2010) partially, the third one (*Petasitetum alibi*) represents old syntaxonomical unit and the fourth one represents probably a new community which has not been recognized earlier and needs more material to be described. According to proposal of Michl et al. (2010) associations occurring in the Stołowe Mts do not belong to *Adenostylion alliariae*, which is limited to the subalpine zone, but should be included in two other alliances: *Rumicion alpini* Rübel ex Scharfetter 1938 (*Geranio phaei-Urticetum dioicae*) and *Arunco dioici-Petasition albi* Br.-Bl. & Sutter 1977 (*Petasitetum albi* and *Prenanthetum purpureae*). Syntaxonomic position of comm. *Petasites hybridus-Primula elatior* needs further study.

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Role of gravitational processes in the shaping of sandstone rock forms in low mountains: Świętokrzyskie (Holy Cross) Mountains, central Poland, case study

Abstract: Some 80 sites of natural rock forms built of Palaeozoic quartzitic sandstones and sandstones as well as Mesozoic sandstones were recorded in the Świętokrzyskie (Holy Cross) Mts. Three types of gravitational rock movements were connected with their development: deep disintegration of rock massifs, movements of sandstone boulders and movements of slope covers. This study proves that the second type of movement developed in the conditions of subarctic climate (occurrence of perennial frozen bodies and permafrost retreat), in the Late Pleistocene or earlier, e.g. during warmer periods of the Early Vistulian. An important factor controlling slope deformation is the occurrence of clay-marl series below the sandstone series.

Introduction and settings

The Świętokrzyskie (Holy Cross) Mountains are situated in Central Poland. In geological terms this region is the most elevated element of the Mid-Polish Anticlinorium. It is composed of the Palaeozoic massif shaped during the Late Palaeozoic tectonic movements, and the Permian-Mesozoic cover that surrounds the outcrop area of sedimentary Palaeozoic rocks (Fig. 1). Its morphology is characterised by the occurrence of low mountain and hill ranges ranging 350–600 m a.s.l., standing several tens to more than 100 m above the surrounding plains (Urban and G g ol, 2008). Generally, the relief of the region is rock-controlled. It is an effect of morphological evolution in a warm climate of the Neogene and moderate and cold climate (glacial and periglacial conditions) of the Pleistocene.

Some 80 sites of natural sandstone rock forms have been recorded and studied in this region (Fig. 1). The rock forms are situated usually in the ridge and near-ridge positions. Their height varies from 1–2 m to slightly more than 10 m (usually 4–5 m); lateral extension of groups varies from several tens of meters to 2 km. The rock forms usually represent cliffs and 'rock pulpits', occasionally pillars. They are built of various lihological types of sandstones of different age (Alexandrowicz, 1990, Alexandrowicz and Urban, 2005) (Fig. 1): (a) Upper Cambrian, hard quartzitic sandstones; (b) Lower Devonian quartzitic sandstones and sandstones; (c) Lower Triassic sandstones; (d) Lower Jurassic rather soft sandstones. The rock group Skałki pod Adamowem, built of the Lower Jurassic sandstone and constituting a range of crags (cliffs, 'rock pulpits', occasionally 'mushrooms') c. 2 km long, which crown the slope, is shown as an example in this paper (Fig. 2).

Generally, the rock forms were developed during the last Pleistocene glacial period – Vistulian (Weichselian) This is suggested through their occurrence in the area covered and morphologically deformed by ice-sheets of South-Polish (Cromerian) and partly Mid-Polish (Saalian) glacials (Lindner, 1972). Therefore, the gravitational mass movements typical of periglacial zone, such as creeping-solifluction were most probably responsible for stripping of rock surfaces (Alexandrowicz and Urban, 2005; Urban, 2005). However, one former concept postulated the principal role of aeolian erosion in their development (Lindner, 1972). The predominant role of slope processes is suggested by blockfields on slopes of the Łysogóry Range (Klatka, 1962; Jaśkowski et al., 2002), which are still bare, as well as remnants of such blockfields and debris covers in the slopes formed of other sandstones (Lindner, 1996). However, the role of gravity in the development and shaping of the natural rock forms is more complex than limited only to stripping of rock surfaces (formations). Gravitational movements of rock blocks and boulders are described and interpreted in this paper.

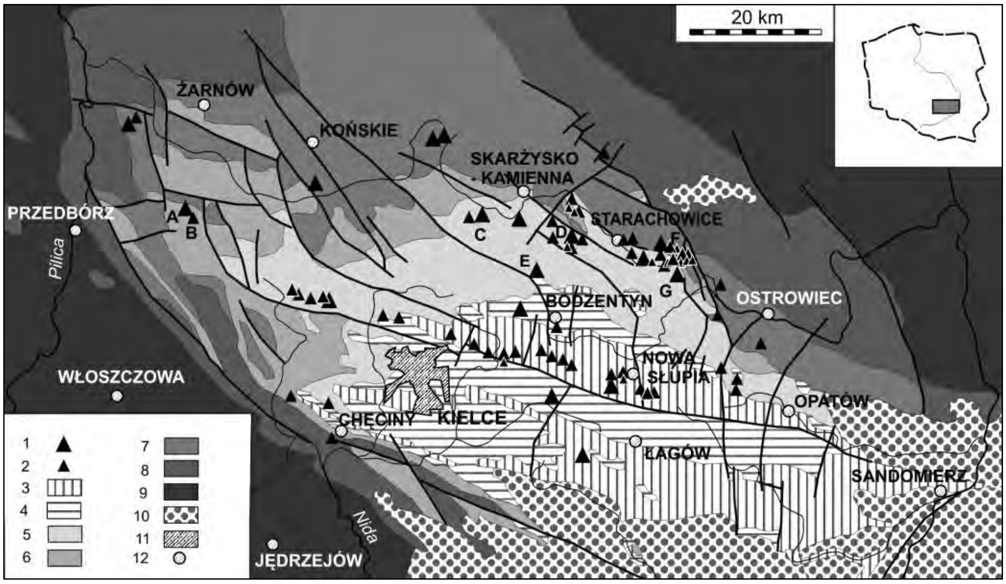

Fig. 1. Distribution of natural rock forms in the Świętokrzyskie Mts. Explanations: 1 – large group of rock forms; 2 – single crag or small group of crags; 3 – Cambrian, Ordovician and Silurian; 4 – Devonian and Carboniferous; 5 – Permian and Lower Triassic; 6 – Middle and Upper Triassic; 7 – Lower and Middle Jurassic; 8 – Upper Jurassic; 9 – Cretaceous; 10 – Cenozoic; 11 – Kielce town, capital of the Province; 12 – other town. Sites of rock forms' occurrence mentioned in the text: A – Piekiełko Szkuckie, B – Szkucin-Tumany, C – Piekło Dalejowskie, D – Biały Kamień, E – Kamień Michniowski, F – Skałki pod Adamowem, G – Ruda.

Observations and laboratory analyses

The effects of gravitational movements related to rock forms were described on the basis of the following observations and analyses:

- observations of ridge and slope morphology (morphological profiles of slopes),
- measurements of spatial position of rock boulders (compass measurements of joints and bedding planes),
- analysis of morphology and genesis of non-karst caves,
- ERT (electrical resistivity tomography) profiles (in cooperation with T. Pánek, P. Tábořík, J. Hradecký from the University in Ostrava, Czech Republic),
- analysis of archive descriptions of borehole logs.
- studies of lithology (granulometry and petrography) and structures as well as OSL and radiocarbon datings of slope covers,

Types of gravitational slope and rock movements

The analysis of borehole logs as well as ERT profiles proves that the sandstone complexes forming natural crags and cliffs are several meters to several tens of meters (usually up to 30 m) thick and they are underlain by clay-claystone-siltstone-heterolithic series. In the example of the Skałki pod Adamowem site (Fig. 2), the sandstone complex is nearly horizontal and 15–20 m thick. It probably overlies clay-claystone series of similar thickness.

Three general types of gravitational slope failures and rock movements can be distinguished:

- deep disintegration of rock massifs,
- movements of sandstone boulders,
- downslope movements of slope covers.

Deep disintegration of rock massifs consists in widening of joint fissures propagated deeply into the rock massif and connected with spreading or lowering type of movement, occasionally slight rotation. These processes are manifested by deformations of hill ridges or table-like hills, producing trenches and crevice type caves. However, in contrast to the Beskidy Mts. (higher mountains situated south of the Świętokrzyskie Mts., where landslide play crucial role in the shaping of slopes – see e.g. Margielewski, 2006), in slopes of the Świętokrzyskie Mts. no landforms typical of slides *sensu* Dikau et al (1996) have been recorded. This means that the initial deep disintegration of rock massifs has not been finalised by rapid slope failures (Detailed analysis of these deep structures and processes will be a matter of another paper).

Instead of landslides, movements of individual rock boulders (among which the largest reach 6–7 m high and 10 m in diameter) are very common gravitational processes in the Świętokrzyskie Mts. The most frequent type of boulder movement

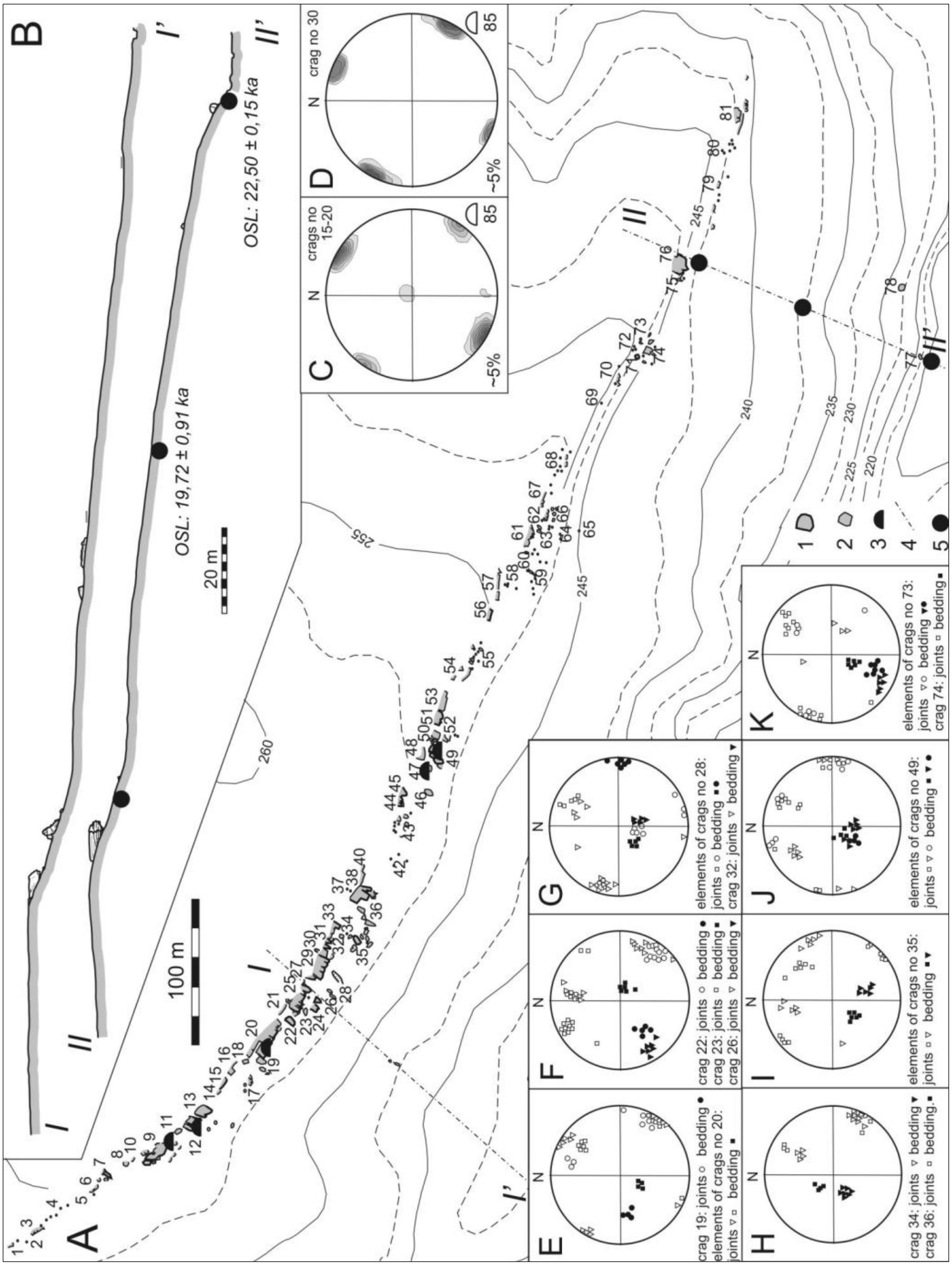

Fig. 2. Skałki pod Adamowem rock group: A – map; B – cross-sections I–I' and II–II'; C, D – contour diagrams of normals to joints and bedding planes (projection on upper hemisphere) of *in situ* rock forms; E–K – pole point (directional) diagrams of normals to joints and bedding planes (projection on upper hemisphere) of *ex situ* rock forms (the term "crags" means here a group of boulders). Explanations: 1 – rock form higher than 2 m, 2 small rock form, 3 – non-karst cave, 4 – cross-section, 5 – artificial trenches.

is toppling combined with downslope translation. The angle of blocks' tilt is usually similar or slightly higher than slope dipping (10–30º), whereas the translation distance varies from several to several tens of meters. However, inclinations reaching 70º and translation longer than one hundred meters are also observed. Another frequent deformation of blocks is their lowering and slight translation downslope (without toppling). Reverse rotation (in relation to slope) around the horizontal axis (somewhere combined with rotation around vertical axis) is less frequent, and usually refers to blocks adjoined to *in situ* rock massifs. The most characteristic example of such movement is the Kamień Michniowski site (Fig. 1), where horizontal rotation (50–60º) of large block and its sinistral rotation around vertical axis (70º) gave rise to the formation of the Jaskinia Ponurego Cave (25 m long), the longest non-karst cave in the Świętokrzyskie Mts.

An analysis of large rock groups situated on slopes of various aspect indicates that slight dextral rotation of boulders is more frequent on the slopes facing south-west, while the sinistral rotation is rather typical of slopes facing south-east.

At some sites large boulders *ex situ* represent a substantial part of rock landforms (e.g. Piekło Dalejowskie, Biały Kamień, Ruda, Piekiełko Szkuckie, Szkucin Tumany – Fig. 1). In these strongly disintegrated rock groups the most distant 'wandering boulders' are situated 100–200 m far from the central part of a site, within a very gently inclined (even less than 5º) footslope. Such rock groups are often characterised by apparent and thick clay (silt-marl-clay) series in their substratum.

In the example of the Skałki pod Adamowem site (Fig. 2 A, B), the most distant boulders are situated nearly 200 m downslope from the rock range. Most of measured boulders display toppling type of movement concordant to the slope dip (Fig. 2 D–K: boulders in crags no. 20, 22, 26, 28, 32, 34, 35, 49, 73, 74). However, dextral rotation combined with tilting discordant to the slope dip is also observed (crags no. 23, 35, 49).

The material of slope covers in the vicinity of the rock forms is usually represented by diamictons composed of sand and sandstone debris. It is massive, matrix or clast supported. Clasts are usually randomly oriented and angular. Apart from sand-debris covers, aeolian sands occur in some places, particularly as fills of narrow passages in between rock outcrops. OSL datings of both types of material indicate the Late Glacial and the Early Holocene as the time of last bleaching of quartz grains (i.e. substantial movements of slope covers). At the Skałki pod Adamowem site, two OSL datings of slope diamictons yielded ages c. 20–22 ka – the climatic pessimum of the Plenivistulian. At the Piekiełko Szkuckie site, the passage between shifted rock forms is filled by aeolian sand yielding OSL date c. 15 ka.

Discussion

The frequency and distance of boulder translation depend on geological structure of slopes. Strictly, they are controlled by the thickness of a sandstone complex as well as thickness and lithology of their basement, rather than by slope angle. It is illustrated by gently dipping slopes, related to strongly disintegrated rock groups overlying plastic rocks (clays etc.) as direct substratum. Therefore, gravitational disintegration of rock groups during the coldest periods of the Pleistocene (when basement rocks were totally frozen) is rather impossible. However, their movements in the Holocene environment seems also hardly probable and there are no signs of such recent movements (see also Jaśkowski et al., 2002).

On the other hand, the formation (transformation) of slope covers was related to the growth of their plasticity, i.e. solifluction-creeping generated by seasonal ice thawing or other saturation with water. The datings indicate the climatic pessimum of the Plenivistulian and the Late Pleistocene as the time of these processes. The predominance of toppling and translation of *ex situ* rock forms, especially smaller ones (i.e. typical boulders), suggests connection or at least coincidence of these movements with transformation of slope covers.

In consequence, the most probable time of gravitational disintegration of groups of natural rock outcrops (also movements of single rock forms) was the period of gradual permafrost retreat and formation of perennial frozen bodies. As evidenced by ERT cross-sections presented by Schrott and Sass (2008) and Kneisel (2010), in such environments the occurrence of frozen bodies in subarctic climate is very sensitive to local conditions: slope dip, aspect and specific elements on the slope, such as rock boulders. So, it is very probable that the boulders created local conditions for the occurrence of such frozen ground bodies, which acted as 'anchors' during boulder movement. In consequence, respectively to slope aspect, moving boulders were undergoing clockwise rotation on slopes facing south-west and counter-clockwise rotation on slopes facing south-east. Such phenomenon is observed at many studied sites (also at the Skałki pod Adamowem site – Fig. 2).

The most suitable period for such movements of boulders seems to be the climate warming after the last Pleniglacial pessimum and subsequent growth of humidity (increase in precipitation) during the Late Pleistocene (see e.g. Śnieżko, 1995; Pawelec, 2006). However, the processes of gravitational disintegration of rock outcrops could have developed also during warmer periods preceding the Plenivistulian coldest period, as well as in the Early Plenivistulian and Early Vistulian or even during the Mid-Polish glacial period.

Conclusions

1. Gravitational movements have played an important role in the formation and evolution of the sandstone rock formations in the Świętokrzyskie Mts.
2. They are quite different than mass movements typical of mountainous areas, e.g. the Carpathians. In the Świętokrzyskie Mts. typical landslides do not occur, although deep slope deformations represent structures resembling the preparatory stages of the Carpathian landslides.
3. An important geological factor conditioning slope deformation of groups of rock forms is the occurrence of clay-marl series below the sandstone in the geological sequence.
4. The most suitable conditions for slope deformations occurred during the time of subarctic climate characterised by the occurrence of perennial frozen bodies and permafrost retreat, e.g. in the Late Pleistocene, or earlier, during warmer periods of the Early Vistulian and the Early Plenivistulian or even Mid-Polish glaciation.

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Dating speleothems in sandstone, non-karst caves – methodological aspects and practical application, Polish Outer Carpathians case study

Abstract: The aim of project has been to test methods of speleothem dating in non-karstic caves formed due to gravitational slope movements in the Polish Outer Carpathians built of siliciclastic rocks. Two laboratory methods were applied: radiocarbon (^{14}C) datings and U-series datings. Both methods yielded the values indicating the Late Pleistocene-Holocene ages. However, the obtained U-series datings were usually much higher ('older') than radiocarbon ones of the same samples. This suggests that preconditions necessary for successful application of at least one method were not fulfilled. Radiocarbon datings seem to be more reliable, however, the feature limiting their interpretation is the reservoir effect, which cannot be reliably assessed in this study.

Introduction

Gravitational mass movements have been one of the most common processes controlling morphogenesis of the Outer Carpathians, built of flysch, siliciclastic-clayey rocks of the Late Jurassic-Early Miocene age. The chronology of landslide phases can be reconstructed by dating of forms/sediments genetically connected with these phenomena, such as landslide peat-bogs, material buried by colluvia or landslide dam lake deposits (Alexandrowicz, 1996; Margielewski, 2006) as well as non-karst, gravitationally induced caves. The studies of peat-bogs filling landslide depressions are the most efficient and advanced in the Polish Outer Carpathians (POC). Lakes formed due to valley damming by slope failures as well as findings of organic material within colluvia are rare in the POC. In such situations, dating of secondary formations in caves connected with mass movements on mountain slopes seems to be an adequate method to reconstruct phases of these movements.

Two general types of caves are genetically related to gravitational slope movements: caves formed due to fracture opening preceding the crucial phase of slope disintegration – a landslide, and caves formed within landslide body-colluvium (Margielewski, Urban, 2003). The dating of formation or modification of both types of caves, reflected in the development of the secondary formations in caves, can indicate ages or at least the marginal dates of gravitational slope failures. This paper presents a discussion on results of datings of samples analysed by radiocarbon (^{14}C) and U-series methods, verified by palynological analysis.

Occurrence and types of secondary formations in Polish Outer Carpathian caves

Secondary formations of speleothem type are principally rare phenomena in non-karst caves occurring in flysch rocks forming the POC. Among more than 1200 caves recorded in this region, they have been found in several tens. They are frequent in caves developed in the Cergowa Sandstone in the Beskid Niski Mts, which are characterised by calcite-dolomite cement. These speleothems represent typical carbonate cave formations: flowstones, draperies, stalagmites, stalactites, occasionally corraloids (Urban et al., 2007 b, 2012). In caves formed in other types of sandstone these secondary formations are smaller, rare and represent following types: (1) non-carbonate, moderately hard to soft, small stalactites and tooth-like forms as well as coatings, (2) non-carbonate, very hard coatings and small coralloids, (3) crusts and coatings of microcrystalline gypsum and calcite, (4) agglomerations of small carbonate coralloids, (5) blankets of carbonate moonmilk, (6) crusts of sparry and glassy gypsum crystals (7) typical, but small carbonate dripstones, flowstones and helictites. They were found in several caves in the Beskid Śl ski Mts, Beskid Żywiecki Mts, Beskid S decki Mts, Beskid Wyspowy Mts and the Pogórze Beskidzkie (Urban et al. 2007a, 2007b, 2012; Gradziński et al., 2010).

Material and laboratory analyses

Considering the occurrence of carbonate minerals, most samples for datings were taken in two caves formed in the Cergowa Sandstone in the vicinity of Dukla town, Beskid Niski Mts., most abounding in the carbonate speleothems: Jaskinia Słowiańska-Drwali and Jaskinia Wodna w Piotrusiu. Additional samples were collecred in the Jaskinia Pod Bukiem, Jaskinia Gdzie Samolot Spadł and the rock walls near the Jaskinia Klubowa and Jaskinia Słowiańska-Drwali (Table 1). Some of them are characterised by intervowen fabric representing calcite pseudomorphosis after aragonite (JPB-1, GSS-3, lower, older part of UJK-1), while some are built of calcite displaying travertine fabric – porous, fine crystalline and contaminated with clay and detrital material (GSS-1, GSS-2). Phreatic calcite crust and typical flow-stone filling the crevice in the Cergowa Sandstone outcropped in the Klenczany quarry, Beskid Wyspowy Mts., were also used for analyses. Besides, small calcite speleothems from the Jaskinia Miecharska Cave, Beskid Śl s ki Mts., formed in the siliceous-clayey Godula beds (Urban 2007 a) were sampled.

Apart from carbonate material, some amount of organic material sufficient to radiocarbon dating were found in two non-carbonate stalactites from the caves Jaskinia Wiślańska (sample JW2/07) and Jaskinia Miecharska (MIECH-8).

The conventional radiocarbon (^{14}C) datings were conducted in three laboratories: Radiocarbon Laboratory of the Silesian University of Technology in Gliwice, Poland, Radiocarbon Laboratory of the National Academy of Sciences of Belarus in Minsk, Belarus and Laboratory of Absolute Chronology in Skała, Poland. Six AMS radiocarbon datings were made in Beta Analytic Inc., Miami, Florida, USA. U-series datings have been performed at the Institute of Geological Sciences, Polish Academy of Sciences, Warsaw, Poland.

Results

The radiocarbon conventional dates range 14.56 (± 0,08)– 0.96 (±0.06) ka BP, whereas calibrated dates vary from 18.01 ka cal BP to 0.73 ka cal BP (Table 1). In every speleothems sampled along their axis, the dates are in accordance with growth of these formations.

In the case of samples representing carbonate speleothems, the 'reservoir effect' must be taken into account. Genty et al. (1999) calculated the average 'dcp' value (percentage of carbon originated from rocks or solutions, not directly from the atmosphere) for several Holocene speleothems at 9–18% and mentioned a speleothem of 'dcp' approaching 35%. Vogel and Kronfeld (1997) assumed the age correction yielding ca 1.5 ka for the Late Pleistocene stalagmites. Beck et al. (2001) assessed this correction at 1.45 ka for the 11–16 ka ago. Pazdur (1987) estimated the age correction for carbonate tufas in southern Poland at 0.5–6 ka. Goslar et al. (2000) estimated this value for the stalagmite from Slovakia at 2.3–2.7 ka. 'Dcp' yielding 6% was calculated in the Moravian Karst (Bruthans et al. 2012).

The initial ^{14}C activity in speleothems is conditioned by soil processes, water circulation and type and structure of rock basement. In an open system of dissolution, when seepage waters are in contact with soil and delivery of CO_2 is provided, the process of replacement of 'dead carbon' by biogenic carbon is efficient, so 'dcp' is low (Genty et al. 1999). In the non-karst caves of the POC, formed due to massif disintegration, rather low 'dcp' may be expected. So, the ages calculated using 'dcp' equaling 15% ' are presented in Table 1.

The U-series ages range from 4.9 (±1.3) ka to 21 (±2) ka, plus two extraordinary datings of phreatic calcite filling crevices in Klenczany quarry and yielding nearly 200 ka (Table 1). However, 42% samples (8 from 19) could not be interpreted due to high contamination with detrital thorium component – marked by $^{230}Th/^{232}Th$ ratios. Most samples, except SD 8 and SD 9, are characterized by low uranium content at the level typical for Krakow area. Some samples have an extremely low U content, e.g. 0.02 ppm for SD 4 sample.

Many samples of carbonate speleothems were dated with both radiocarbon and U-series methods, or the speleothems were sampled for each method close to each other along the growth axis. Comparing radiocarbon and U-series datings two groups of samples may be distinguished. Most samples yield radiocarbon ages lower than U-series ages, the reverse relationship was noted two times only. In the case of SD-8 sample, the difference is large, the ^{14}C age being 6–10 ka older than U-series age. In the case of the second sample representing this group, SD-9, these ages are much closer each to other (Tab. 1).

Discussion

Simple comparison of radiocarbon and U-series ages shows differences larger than the uncertainty ranges of the methods. This clearly shows that preconditions necessary for successful application of at least one method were not fulfilled. Two features strongly suggest higher applicability of radiocarbon datings. The first is the distinct accordance between the age ranking of radiocarbon dates and spatial growth of speleothems (disregarding the shift caused by reservoir effect). The correctness of radiocarbon datings is also confirmed in general by palynological analysis (Table 1).

Also the general similarity (Holocene age) of radiocarbon datings between carbonate speleothems and datings of organic matter originated from non-carbonate secondary formations (samples MIECH-8, JW2/07) suggests correctness of the radiocarbon datings. Similar three datings representing the Holocene (10.2 ka to 2.1 ka) have already been obtained from the organic matter in the non-carbonate speleothems in the Jaskinia Miecharska cave (Urban et al., 2007 a). Furthermore, studies of peat bog deposits in landslide terrains in the Outer Carpathians confirm intensification of mass movements during the Late Glacial and the Holocene (Alexandrowicz, 1996; Margielewski, 1998, 2006).

While discussing the limitations of radiocarbon datings, two main difficulties emerge. The first one, reservoir effect, was already discussed. The second problem is the kind of chemical system which the speleothem represented since its formation: open or closed system, understood similarly to Borsato et al. (2003), discussing the U-series datings interpretation. It strictly concerns the possibility to re-

Table 1. Selected results of radiocarbon, U-series and palynological analyses.
Explanation: DC – datings impossible due to high amount of detrital Th contamination.

Sample	Mineralogy	Sample no.: U-series; ^{14}C	U [ppm]	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$	Age U/Th [ka]	Conv. age ^{14}C BP [ka]	Age ^{14}C cal BP (range 95%) [ka]	Conv. age ^{14}C BP after "bcp" correction [ka]	Age ^{14}C cal BP after "bcp" correction [ka]	Palynological analysis	d^{13}C (‰, PDB); d^{18}O (‰, PDB)
Jaskinia Słowiańska-Drwali Cave													
SD 1	Calcite (aragonite)	GdS-1203						7..94±0.11	7.13 – 7.11 (0.8%) 7.08 – 6.56 (93.8%) 6.55 – 6.51 (0.8%)	6.59±0.11	7.67–7.27 (95.4%)		-7.28; -8.36
SD 2 s-1	calcite	W 2857; GdS-1332	0.066±0.003	1.01±0.07	0.09±0.01	13	DC	6.74±0.09	7.76–7.43 (95.4%)	5.39±0.09	6.39–6.37 (1.0%) 6.32–5.93 (94.4%)		8.92; -7.44
SD 2 s-2	calcite	W 2858	0.053±0.002	1.24±0.07	0.16±0.02	3	DC					Neoholocene, SB	-8.85; -7.46
SD 2 s-3B	calcite	GdS-1331						3.63±0.07	4.42–4.07 (91.7%) 4.04–3.99 (3.7%)	2.28±0.07	2.50–2.05 (95.4%)		-10.10; -7.55
SD 2 s-5	calcite	GdS-1334						2.04±0.06	2.29–2.20 (1.3%) 2.15–1.86 (94.1%)	0.69±0.06	0.73–0.54 (95.4%)		-9.98; -7.03
SD 4 s-1	calcite	W 2859; GdS-1329	0.026±0.002	1.11±0.09	0.14±0.02	>100	16.3±3.0	4.20±0.09	4.96–4.51 (93.8 %)	2.85±0.09	3.24–2.77 (95.4%)	Neoholocene, SB	-9.25; -7.25
SD 4 s-2	calcite	W 2860	0.042±0.002	1.32±0.08	0.12±0.02	>100	14.0±1.9						-10.01; -7.88
SD 4 s-3	calcite	GdS-1333						3.10±0.08	3,48–3,07 (95.4%)	1.75±0.08	1.88–1.51 (95.4%)	Neoholocene, SB	-10.75; -7.49
SD 4 s-5	calcite	GdS-1330						0.96±0.06	0,98–0,73 (95.4%)				-10.10; -7.33
SD 8	aragonite	W 2832; GdS-578	6.2±0.5	1.53±0.05	0.074±0.005	900	8.3±0.7	14.56±0.08	18.01–17.36 (92.9%) 17.33–17.25 (2.5%)	13.21±0.08	16.45–14.85 (95.4%)		-0,79; -6.95
SD 9	calcite (aragonite)	W 2829; GdS-1216	11.1±0.2	1.86±0.02	0.069±0.001	350	7.68±0.15	9.42±0.06	11.07 – 10.95 (7.7%) 10.87–10.85 (0.7%) 10.80–10.49 (86.7% 10.45 – 10.44 (0.3%)	8.07±0.06	9.30–8.65 (95.4%)		-4,18; -6.99
Rock wall near the Jaskinia Słowiańska-Drwali Cave													
CREST-1	calcite	W 2783; GdS-1214	0.031±0.003	1.22±0.13	0.12±0.03	37	14±4.0	3.18±0.05	3.56– 3.32 (91.8%) 3.29– 3.26 (3.6%)	1.83±0.05	1.88–1.61 (95.4%)		-10.11; -7.08
Rock wall near theJaskinia Klubowa Cave													
UJK 1 s-1	calcite	W 2865	0.098±0.003	1.06±0.04	2.64±0.08	7	DC						
UJK 1 s-2	calcite	W 2827	0.002±0.001	3.3±0.9	1.06±0.17	3	DC						-9.80; -7.47
Jaskinia w Piotrusiu Cave													
JWP 1s-1	calcite	GdC-651						6.86±0.04	7.82–7.60 (95,4%)	5.51±0.04	6.41–6.27 (80.1%) 6.25–6.20 (15.3%)		-8.13; -8.20
JWP 1s-2	calcite											Early Holocene?	
JWP-1s-3	calcite	W 2867	0.186±0.005	1.19±0.05	0.18±0.01	20	21±2.0	6,01±0.04	6,95–6,74 (95,4%)	4.66±0.04	5.58–5.54 (4.5%) 5.48–5.30 (50.9%)		-8.33; -7.75
JWP-2s-1	calcite	311826						9.92 ±0.04	11.40 –11.24	8.57±0.04	9.63–9.47 (95.4%)		

JWP-2s-3	calcite	311827						5.35 ±0.03	6.27–6.24 6.21–6.17 6.16–6.10 6.08–6.00	4.00±0.03	4.53–4.41 (95.4%)		
JWP-2s-4	calcite	311828						3.24 ±0.03	3.55–3.52 3.51–3.50 3.49–3.39	1.89±0.03	1.92–1.91 (1.1%) 1.90–1.73 (94.3%)		
JWP-2s-5	calcite	311829						1.85 ±0.03	1.87–1.71	0.50±0.03	0.62–0.61 (2.0%)		-7.49; -7.79
JWP 7s-1	calcite	W 2861; GdS-1320	0.071±0.002	1.18±0.06	0.13±0.01	44	15.0±1.6	8.84 ±0.10	10.20–9.59 (95.4%)	7.49±0.10	8.45–8.10 (90.8%) 8.09–8.03 (4.6%)		
JWP 7s-2	calcite	W 2862	0.085±0.004	1.12±0.07	0.12±0.02	2	DC					Early Holocene?	
JWP 7s-3	calcite	W 2863; GdS-1321	0.116±0.005	1.28±0.07	0.07±0.01	2	DC	5.79±0.09	6.83–6.39 (95.4%)	4.44±0.09	5.31–4.85 (95.4%)		
JWP 7s-7	calcite	GdS-1374						4.28±0.14	5.30–4.40 (95.4%)	2.93±0.14	3.45–2.75 (95.4%)	Neoholocene, SB-SA	
JWP 7s-8	calcite	GdS-1325						4,46±0.09	5,32–4,85 (95.4 %)	3.11±0.09	3.60–3.00 (95.4%)		
Jaskinia pod Bukiem Cave													
JPB – 1	calcite	GdS-580						11.39±0.06	13.40–13.12 (95.4%)	10.04±0.06	11.95–11.20 (56.4%)		-9.43; -9.31
Jaskinia Gdzie Samolot Spadł Cave													
GSS – 1	calcite (aragonite)	W 2831	0.017±0.001	1.24±0.13	1.1±0.1	2	DC						-8.81; -7.62
GSS – 2	calcite	W 2866	0.088±0.005	0.99±0.07	0.24±0.03	2	DC						-9.26; -7.94
GSS – 3	calcite	GdS-1215						8.07±0.08	9.26–9.16 (7.3%) 9.15–8.64 (88.1%)	6.72±0.08	7.69–7.43 (95.4%)		-10.47; -8.62
Klenczany quarry (fissure filled with calcite)													
KLEN - 1	calcite	W 2784	0.043±0.003	1.49±0.12	0.04±0.01	34	4.9±1.3						-11.93; -8.67
KLEN2s-2	calcite	W 2830	0.36±0.02	1.60±0.07	0.89±0.04	440	186+16,-15						-3.12; -8.68
KLENs2-1	calcite	W 2828	0.249±0.007	1.73±0.04	0.92±0.02	1800	199 +9, -8						-0.92; -9.11
Jaskinia Miecharska Cave													
MIECH-1	calcite	W 2864; GdA-2137	0.129±0.005	2.10±0.08	0.13±0.01	56	15.0±1.0	8.95 ±0.03	10.21–10.11 (94.7%) 10.07–9.92 (0.7%)	7.61±0.03	8.42– 8.35 (95.4%)		-1.76; -7.34
MIECH-3	calcite	311825						12.59±0.05	14.08–14.63	11.24±0.05	13.80–13.70 (2.3%) 13.50–13.00 (93.1%)		-3.30; -7.71
MIECH-8	organic	MKL-1251							7.67–7.28	no BCP			
Jaskinia Wiślańska Cave													
JW2/07	organic	GdA-2169						2.48±0.02	2,72–2.46 2.39–2,37	no BCP			

place carbon atoms-isotopes during the time spanning since its formation and sampling. In the study case of speleothems in the Carpathian caves, chronological ranking of ages seems to be not dependent on structural-mineralogical variations. It is proved by SD-4 speleothem displaying 'normal', chronological datings, despite the difference in microstructure of its lower, older part, and the upper, younger part.

Discussing the reliability and correctness of U-series dating at least three methodological basic requirements must be taken into account (Borsato et al. 2003): a) amount of uranium, b) amount of detrital thorium at the initial time, c) secondary alterations of the speleothem.

(a) Low uranium activity increases the uncertainty of final result. In analyzed samples from the Outer Carpathians this amount varies from 0.002±0.001 ppm to 11.1±0.2 ppm; in 5 samples (23%) is less than 0.005 ppm (Table 1).

(b) At the initial time, the sample must not contain detrital thorium. It is assumed that the samples characterized by $^{230}Th/^{232}Th$ ratio higher than 20 can be regarded as not contaminated by initial thorium. However, especially for samples of young speleothems characterized by low uranium content, the contamination problem is important. In the case of carbonate speleothems from the Carpathian caves it seems to be the crucial limitation of this method – 42% samples yield the $^{230}Th/^{232}Th$ ratios lower than 20, whereas these ratios for the other 5 samples (23%) was less than 100. Detrital thorium contamination of speleothems in the Carpathian caves is caused by lithology of host rocks and is related to the origin of caves due to gravitational disintegration of massif. The latter stimulates fast water seepage and, consequently, transport of clayey contaminats from regolith to caves. This differentiates the studied speleothems from the carbonate rock environment in which speleothems usually form.

(c) Calcite sample has to be in a closed system since its formation. It means that ^{230}Th and ^{234}U isotopes cannot be added or removed from the sample since crystallization. Checking if this third requirement is fulfilled needs observations of speleothems' microstructures. The studied speleothems commonly display neomorphism or mineral alteration. Large and 'clean' calcite flowstones and stalagmites from the Jaskinia Wodna w Piotrusiu Cave and the upper part of the Jaskinia Słowiańska-Drwali Cave reveal agradational recrystallisation and bear small clayey-iron-detrital inserts. Other samples from these caves are still partly aragonitic or bear traces of this mineral. Some other calcite samples are porous, fine crystalline and contaminated with clay and detrital material.

These features suggest that the majority of studied speleothems can represent open systems in terms of uranium-thorium circulation (as interpreted by Borsato et al., 2003). Borsato et al. (2003) suggested thorium introduction into the speleothems as the process typical of open systems. $^{230}Th/^{234}U$ ratios higher than 1 measured for some samples suggest that such epigenetic, secondary contamination of speleothems in the Carpathian caves was probable. In the case of specific environments of Carpathian caves this process may have been facilitated by the same factors producing initial contamination, which enabled thorium transport, as fast water seepage, common occurrence of clayey material and organic ligands (originated in forest soils) in this water.

The majority of U-series datings of studied speleothems in caves of the Outer Carpathians are much older than radiocarbon ones. Similar tendency was noticed by Bruthans et al. (2012) in the caves of the Bohemian Paradise. Similarly to the speleothems in the Carpathians, samples form the Bohemian Paradise were characterised by low uranium content and high content of detrital thorium, as well as apparent secondary alteration (weathering) of the speleothems. Also Goslar et al. (2000) stressed frequent situations where radiocarbon ages were too low or U-series ages were too high.

Two samples yielding U-series datings lower than radiocarbon ones, SD-8 and SD-9, are characterised by very high uranium content, low contamination with detrital thorium and the occurrence of aragonite or its remnants. These samples show also relatively high $\delta^{13}C$ values (Table 1), typical of large kinetic isotopic fractionation during the CO_2 escape from the solution. These processes could have been also responsible for high uranium content. Both samples clearly confirm the significance of such factors as the amount of uranium and contamination of detrital thorium in controlling of correctness of U-series datings.

The U-series datings of two samples of phreatic calcite from Klenczany quarry, which cannot be examined by radiocarbon method might be regarded as reliable and correct. Similar ages for calcite from this quarry were obtained by Gradziński et al. (2012).

Conclusions

Large differences between two methods of datings: radiocarbon and U-series ones, obtained for the same carbonate speleothems from POC do not make possible to ‘fit’ them and to compare. The radiocarbon ages of carbonate speleothems seem to be more reliable due to their accordance with the growth of the speleothems, palynological data, radiocarbon datings of organic matter and ages of slope failures recorded in peat-bogs in the landslide terrain.

The most important features limiting the usage of U-series analysis for dating speleothems in the studied caves are the small amount of uranium, in contrast with usually large contamination with detrital thorium. This contamination could have originated at the initial stage, during speleothem development, however, introduction of thorium during the epigenetic alterations of speleothems is probable. In such cases, most speleothems represent open systems in relation to the processes responsible for the results of U-series analysis, while they tend to be closed systems in terms of radiocarbon datings.

The most important feature limiting the interpretation of results of radiocarbon analysis is still the reservoir effect, which cannot be reliably assessed by comparison of radiocarbon and U-series datings obtained in this study.

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Stability complex deterioration of a Rock Arch – case history of the Pravčická brána

Abstract: The set of diverse methods, including field geological and geophysical survey, geochemistry, monitoring of deformation and temperature regime, was used for non-destructive exploration of the Pravčická brána Rock Arch, with focus on the inner block structure, intensity of weathering and natural dynamics. Results of this comprehensive study provide valuable information helping to identify potentially hazardous parts and assess the current level of stability.

Introduction

The Pravčická brána Rock Arch (PBA) has developed on massive Cretaceous sandstones in the NW part of the Czech Republic. PBA occupies the top part of the well pronounced rock rib (Fig. 1). The arch with its length of 26.5 m and height of 16 m is the largest sandstone rock arch of Europe, and the symbol of the Bohemian Switzerland National Park (BSNP). Due to its geometry and exposure to external influence, including anthropogenic factors during the last 200–250 years, it is currently threatened not only by the stress posed by its own weight, but also by dynamic effects of volumetric changes together with physical and chemical weathering. There have been serious fears about arch lifetime as early as from the 1990s. The initial evaluation of the stability of the rock body were based only on short-term data series of control monitoring and a low level knowledge of rock mass parameters (Zvelebil et al., 2002), and yielded indicators of low stability of the arch regarding different models of deformation kinematics and stress loading. The main problem of all the additional studies needed was the nature-preserve status at the locality, which have been banning all destructive activities including usual rock sampling or destructive exploratory methods.

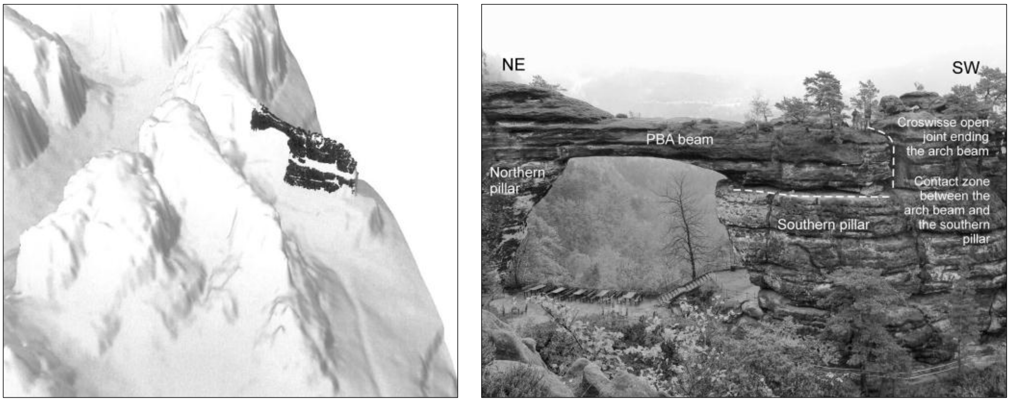

Fig. 1. Pravčická brána Rock Arch. Perspective view from west, DMT of the PBA and surroundings (Dresden University of Technology, ©NASA (SRTM), BSNP databases) (left); a view of the western side of the arch (photo by Z. Vařilová) (right).

Methodology

The new comprehensive study (2002–2010) reported here was designed to fully respect the protective conditions of the locality, to make follow-up activities possible in future, and to monitor any possible negative changes in the rock massif. It had to employ only nature-friendly methods and combine them to answer the questions about interior of the rock arch, its deformation kinematics, and factors and conditions influencing the former (see Fig. 2). The study methods ranged from detailed field documentation to monitoring temperature and deformation regimes of the rock, including application of a geophysical survey, geochemical survey and control monitoring of displacements. Laboratory testing was carried out for basic strength parameters, salt efflorescence and weathered rock and debris. Main operating factors were monitored simultaneously, particularly changes in external temperature, propagation of thermal wave inwards rock mass, degree of sunlight and chemical composition of rainfall and rock percolating solutions. Rock arch laser scanning outputs served as a basis for displaying and modelling the results of the methods used.

The status of the rock mass as a whole and its fabric were characterised by several independent geophysical parameters that very well complement the sporadic results of laboratory tests. The geophysical survey focused on the potentially hazardous parts and points of instability, with attention given to the arch block structure to verify lines of the main joints and to identify new failures and inhomogeneities within the rock massif. Special attention was paid to the south pillar exhibiting worn surface, with special regard to way of draining the area and any intense salt weathering displayed. The selected option combined geophysical methods, i.e. ground penetrating radar (GPR), seismic measurements (tomography) on a repeating basis, resistivity tomography (ERT) and dipole electromagnetic profiling (DEMP).

Particular attention was paid to the processes of salt weathering studied from the aspect of their spatial and temporal distribution complemented with the geochemical characteristics of three main ‘stages’ of the studied system. The composition of atmospheric precipitation was used as the external input (source of anthropogenic influence) and further compared with the composition of infiltrated solutions sampled in the form of seepage water. Last but not least, the chemical composition of salt efflorescences was considered as a final product. The main attention was paid to comparing pH and concentration of major solutes including the acidifiers (SO_4, NO_3, NH_4^+). Impact of acidification on the geological environment and displayed physicochemical weathering running through the near-surface zone of rock massifs was assessed (partial results in Vařilová et al., 2011a). Destruction of case-hardened surfaces and salt efflorescence presence were also studied in time and in terms of distribution depending on height and exposure (more in Přikryl et al., 2007; Vařilová et al., 2011b). Samples of salt efflorescence and sandstone affected by weathering were examined using laboratory methods, i.e. X-ray diffraction to determine the main phase and chemical composition of salts, ion-exchange chromatography to determine water-soluble salts present in the pores below the surface, and SEM/EDS analyses for microscale description of structural characteristics of case-hardened surfaces and salt efflorescence (partial results in Vařilová et al., 2011b).

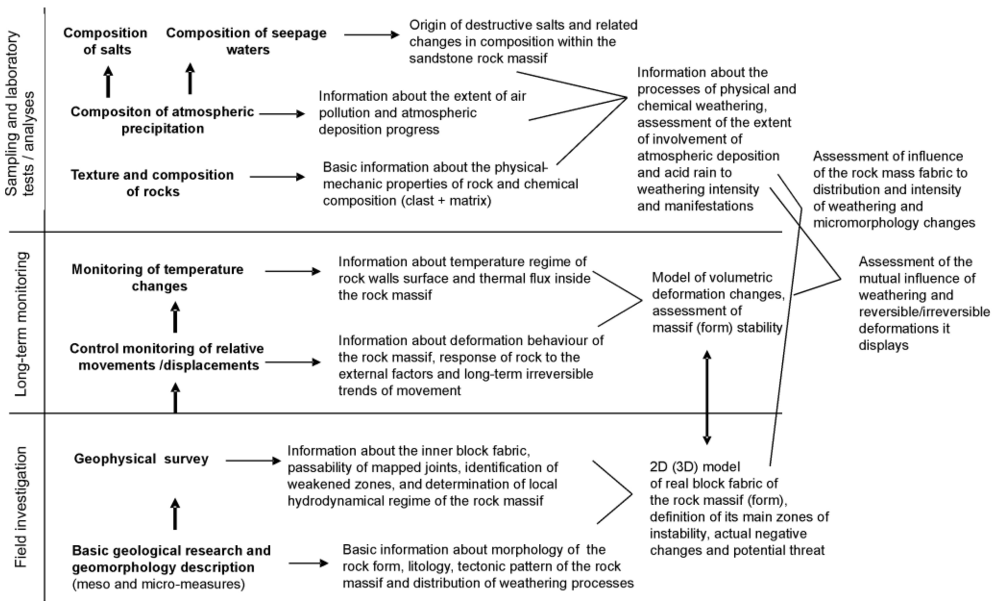

Fig. 2. Diagram showing the methodology procedure applied within the comprehensive research of the Pravčická brána Rock Arch PBA body has been built. The methods ranged from common to highly specialised ways of research, the latter providing information to complement the initial basic research and expand into the field of determining interactions.

Control monitoring of deformation behaviour of the rock arch was carried out using a combination of all the methods applied throughout the BSNP area as a part of rock collapse prevention schemes (Vařilová and Zvelebil, 2005; Zvelebil et al., 2005), with monitoring by a portable rod dilatometer at 6 sites over the period of 14 days. The previous activities were supplemented by an automatic remote monitoring system with online data transfer that contained 12 metering sensors with dilatation and temperature reading carried out every 5 minutes. Evaluating the time series of movements (together with air temperatures) included not only time-tested standard qualitatively-empirical methods, but new procedures based on the theory of complex systems – ones never applied on the locality (e.g. graphic correlograms, phase portraits and the Visual Recurrence Analysis method – Vařilová et al., 2011).

In parallel with deformation monitoring, regular measurements of temperature changes in the body of PBA were carried out, employing temperature sensors at three depths of the rock massif (10, 45 and 90 cm) that were installed from the western and eastern sides in the top level of the rock ridge corresponding to that of the arch beam. Time temperature recording was used for numerical modelling of the depth range and the phase shift of quasi-periodic (daily and annual) temperature changes (partial results in Vlčko et al., 2009 and Brček et al., 2010).

Massif fabric and low strength distribution

From the lithological aspect, the least resistant is the horizontal conglomerate layer forming a contact zone between the arch beam and the southern pillar. Geophysical measurements (seismic tomography, together with repeated GPR and DEMP) demonstrated areas of significant weakening in the interior of the rock mass along the arch vault and a trend of increasing weathering towards the rock massif, especially from its underside.

The body of the arch also generally exhibits a relatively low seismic velocity that does not exceed 2500 m/s (locally value up to 500 m/s near the surface of rock massif or crack zone), which points to the sandstone being affected by weathering, as further suggested via low strength values found in laboratory. Geomorphologic resistance of the body is, on the contrary, positively influenced by the secondary opal rock crust that forms surface protection of the sandstone with relatively disintegrating tendency. Secondary impairment of the function of this 'protective' crust was documented in the zones of crystallisation of salts.

Zones of secondary disintegration were found within the PBA body by repeated usage of geophysical methods (GPR). Discovery of several sub-vertical fissures in both pillars as well as in the arch beam itself (the most fresh is not older than 6 years), were assessed to be of the highest significance. Primary and secondary joints define the inner block fabric of the sandstone massif and present the basic predisposition to instability. Moreover, the distribution of moisture in the body of the arch is generally influenced by a large volume of interconnected and capillary pores (Přikryl et al., 2007) and the existence of sub-vertical fissures and micro-fissures that serve as preferential paths of gravitational infiltration of precipitation and melting water under a gradual weakening of surroundings of these (e.g. Young et al., 2009). The sandstone capacity of easily absorbing water and its very quick evaporation, the latter being evidenced by geophysical measurements (DEMP), causes locally the salt recrystallization processes to run much faster, compared to the less exposed parts of the rock ridge. Exposed to sunlight and prevailing southwest winds, the northern pillar wall under the vault is a typical place of the saturation with solutions alternates drying of the near-surface portion of the rocks in a cyclical manner, with intensive salt weathering causing damage to the near-surface parts. Weathering processes are also influenced by the thermal quasi-cycles and the temperature gradient. Measurements indicate that almost 50% decrease in daily temperature changes and thermal stress occurs within PBA just in the near-surface parts of the rock massif.

Inside the arch body, stress is redistributed due to progressive disintegration and weakening of individual portions of the rock massif through weathering. This is an important finding from the perspective of stability compared with the processes of near-surface weathering that operate mostly in the form of flaking, spalling and granular disintegration.

Deformation model

The total deformation identified by long-term monitoring (from 1993 to 2010) is evaluated to minor reversible movements (max. 0.62 mm/16.5 year) which do not represent direct danger for the PBA body. Nevertheless, the data obtained provide very important information about the kinematics of movements and how they are influenced by the exposure and microclimatic conditions.

Control monitoring has demonstrated slow irreversible body movements manifested as the decline of the western side of arch beam (0.53 mm/14.5 years at the point of cliff) and sub-horizontal (shear) displacement towards the south on the eastern side of the arch beam (3.31 mm/16.5 years at the point of cliff, and 0.62 mm/16.5 years on the southern crosswise open joint ending the arch beam), as well as conspicuous reversible quasi-cyclical movements associated with changes in temperature at the level of days up to years. Average seasonal amplitude at 6 monitored sites (calculated by nonlinear visual analysis of data from dilatometric measuring) ranges between 0.87–2.81 mm/15 years, which reflects morphology and extreme exposure of the PBA body. Higher average seasonal amplitude of movement was detected on the western side of the beam (2.81 mm/15 year), compared to the eastern side (1.81 mm/15 year).

More processes should be added to the initial model of the quasi-cyclic loading of the arch top beam by bending up with parallel longitudinal arching due to the action of change in volume in the north-south direction (described firstly by Zvelebil et al., 2002). The eastern and the western part of the PBA body behave differently in both reversible and irreversible deformation modes. Effects of external temperature (which causes the spatial asymmetry) produce not only flexural stress but partly also torsion stress of the beam. In addition, the many times repeated daily and seasonal strain-stress pulses (due to temperature fluctuations) lead to gradual reduction of strength in strained parts of the sandstone massif and cumulative folding of micro deformations.

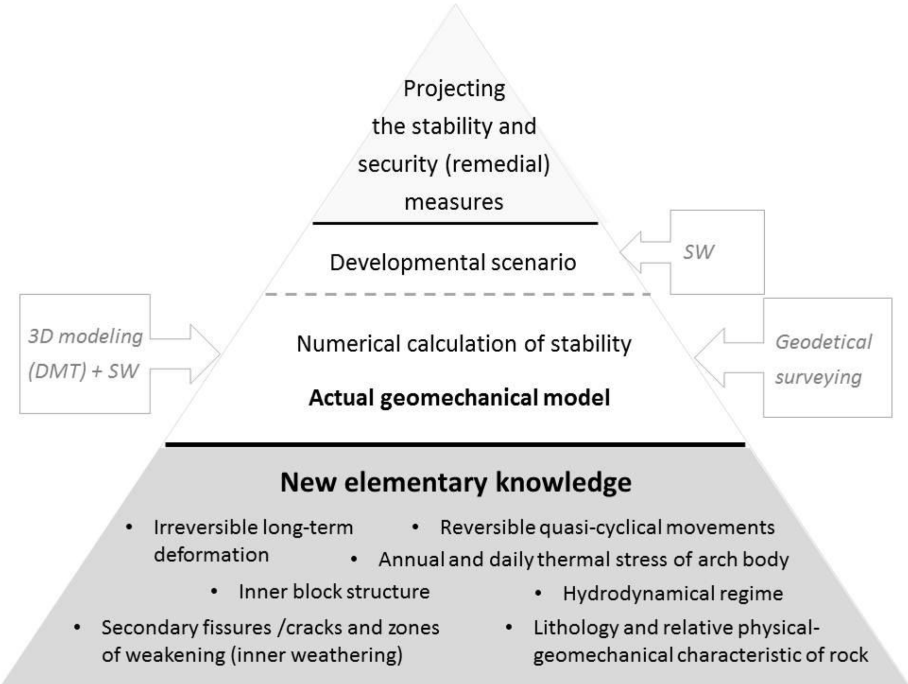

Fig. 3. Results of this comprehensive study constitute the basement for a subsequent modelling of instability progress and potential design of remediation.

Conclusions

New stability risks were discovered, e.g. associated with intense tectonic impairment of the rock massif, involving episodic aquifers, and the mode of selective weathering that so far was not being considered. Weathering processes are not only causing damage to the near-surface parts, but also weaken the strength of the internal parts of the massif with a major influence on the overall stability of the object.

The collected information was used to develop a structural deformation model of the PBA, including description of the nature of disintegration and assessment of the extent and the involvement of external factors (including anthropogenic influences). The results of this comprehensive study provide valuable information about the current condition of the rock body. The gained knowledge helps to identify potentially hazardous parts and is to be used not only for modelling future development, but also for projecting the most suitable remedial and safety measures in the study area.

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Weathering and conservation of sandstone heritage: the biological dimension

Abstract: Many examples of the world's cultural and natural heritage are carved in sandstone, and thus understanding how sandstone surfaces deteriorate is important for heritage conservation. Communities of organisms, including higher and lower plants and microbial biofilms, often play key roles in sandstone deterioration, and may also be capable of protecting and remediating deteriorating stonework. Our recent research in the UK and South Africa indicates that biota play many protective roles, although sandstone is also prone to high rates of biodeterioration from lichens and surface biofilms in some settings. Using a case study in Belfast, Northern Ireland, we demonstrate the structure of biofilm communities through molecular techniques (TRFLP and pyrosequencing), and illustrate the important function these biofilms play in influencing surface moisture regimes and stone deterioration. Further information on the structure and function of biotic communities on sandstone surfaces across a wider range of environments is now needed in order to assess the global importance of biology to sandstone heritage conservation.

Sandstone heritage

There are many examples of both natural and cultural heritage sites involving sandstone. For example, the Geopark of Zhangjiajie in China is largely valued for its dramatic pinnacles and towers developed within a sandstone massif. Similarly, the world heritage site of the Acacus Mountains, in Libya, whilst listed largely for its rock art, is characterized by dramatically sculpted sandstone terrain. Many globally important cultural heritage sites also contain sandstone, such as the ruins of Angkor Wat in Cambodia, which contain many sandstone carvings and buildings as well as those constructed of laterite. Of course, many heritage sites contain equally valuable natural and cultural elements, as exemplified by the Golden Gate Highlands National Park in South Africa, where sandstone not only underpins the dramatic landscape and relief, but also provides the canvas for the painted rock art left by the San people (Mol and Viles, 2010). Sandstone is prone to rapid and dramatic weathering, and whilst this weathering provides much of the beauty of the landscapes, it can also reduce the longevity of heritage carved in sandstone. Sandstone, because of its relatively porous nature, also provides an attractive surface for biological colonization, and thus most sandstone walls and surfaces (even in hostile environments such as the Dry Valleys of Antarctica) are inhabited by some form of life (such as epilithic and endolithic biofilms). Weathering and biological colonization of sandstone surfaces are inextricably interlinked, and the aim of this paper is to evaluate the ways in which biology may enhance or retard weathering and how it might be used as a conservation strategy.

Biology and sandstone heritage conservation: threat or opportunity?

Figure 1 illustrates the threats and opportunities that biology might introduce to the conservation of sandstone heritage sites (both natural and cultural). Looking at biology as a threat, there are many examples of deteriorating species known to produce rapid weathering. In the Golden Gate Highlands National Park, South Africa, for example, the lichen *Lecidea aff sarcogynoides* produces clear pits within sandstone surfaces (both on walls and on natural exposures). On the death of these lichens, the pit is exposed and further accelerated weathering may occur. How the lichens produce these pits is unclear, but it probably involves a combination of biophysical and biochemical alterations. The literature is replete with examples of biodeteriorogenic species, although there are only a few studies which attempt to produce a relative assessment of the rate and severity of biodeterioration vs other weathering processes which might affect bare surfaces.

Far fewer studies have been made of the potential bioprotective role of biology, although some lichens are known to produce a protective patina and recent trials have been carried out of the role of soil and turf as 'soft capping' to protect ruined wall heads (Lee et al., 2010). As well as actively and passively influencing deterioration and weathering, biology can also have other impacts on heritage conservation. For example, rampant plant growth can cover whole tracts of sandstone surfaces, obscuring any valuable and interesting natural relief and cultural carvings. Furthermore, growth of both higher plants and microorganic biofilms has an aesthetic impact, and can be thought undesirable on some surfaces (where it can be classed as 'soiling'). For example, at Angkor Wat, after biocide treatment to remove naturally occurring lichen growths Warscheid and Leisen (2011) note that very unattractive black growths of bacteria and algae rapidly colonized. The visual effect was unpleasant, and these biofilms were also found to cause rapid biodeterioration.

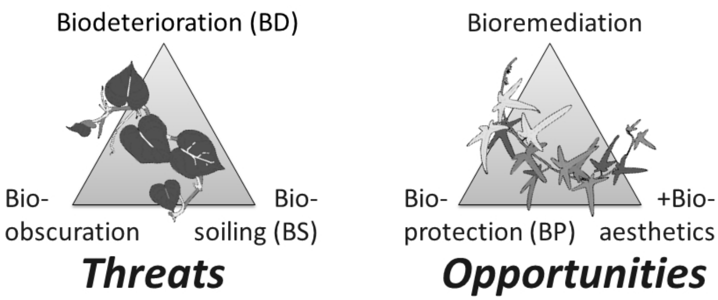

Fig. 1. Conceptual model of threats and opportunities of biology for sandstone heritage conservation.

The relative balance of biodeterioration and bioprotection and of threats and opportunities in general will vary hugely across different climatic areas (Table 1). For example, in arid areas where biodiversity is low, biological soiling is minimal, bioprotection possible, and biodeterioration by endolithic growths likely to be very important. Endolithic growth, i.e. organisms that directly bore into the surface, is common in hostile climates where avoidance of high UV radiation and search for water and moderate environmental conditions encourages biota to grow inside rocks. In comparison, the thick biofilms encouraged by moist conditions in the temperate zone may provide a very different balance of threats and opportunities. Viles and Cutler (2012) have proposed a conceptual model for the impacts of disturbance (such as rapid climate change) on biodeterioration and bioprotection of sandstone heritage. Whilst requiring further testing, this model may be a useful way of understanding threats and opportunities for conservation and managing them under dynamic future conditions.

Tab. 1. Biota on sandstone heritage, weathering and climate.

Zone	Biodiversity	Bio-soiling	Bioprotection	Biodeterioration
Arid	Low	Minimal	Possible	Endoliths
Mediterranean	Medium	Patchy	Patina	Endoliths + wetting/drying
Temperate	Medium	Patchy to general	Thick biofilms	Multiple processes
Humid tropical	High	General	Thick biofilms	Biochemical

Case study – evaluating the nature and roles of green algal biofilms on sandstone heritage in Belfast under climate change

As part of a recent, interdisciplinary project we have investigated two main questions about green biofilms on sandstone heritage buildings in Belfast, Northern Ireland. Firstly, what is growing on the walls? Using molecular techniques we have identified the eukaryotic microorganisms (algae and fungi) growing within such biofilms and how species diversity varies across and between buildings. Secondly, are the green biofilms a threat or an opportunity? We have used resistivity survey techniques and Equotip hardness testing to infer the impacts of green algal biofilms on moisture regimes and weathering on sandstone heritage walls. Our study covered six buildings across Belfast, most of which are mainly constructed with sandstone, but some of which utilize limestone and brick. Crescent Church is built of Scrabo and Locharbriggs sandstone, All Souls' Church of Scrabo sandstone and Doulting Limestone, Fitzroy Church of Scrabo sandstone, Ewert Building of Giffnock sandstone, the Lanyon building of Dungannon sandstone and other materials, and the

Queen's University Geography Department building of brick and Portland limestone.

For the first question 54 samples were taken with sterile adhesive tape, following the protocols described in Cutler et al. (in Press). DNA was extracted using a modified CTAB method and then amplified using PCR. TRFLP was used to describe the community structure, and 3 pooled samples (form Fitzroy, Lanyon and Ewert buildings) were then subjected to pyrosequencing to identify the algae and fungi present. Once the data was obtained, Shannon diversity indices were calculated and non-metric multidimensional scaling (NMDS) used to represent relationships between community composition and sample location. For the second question 15 blocks covered with patchy biofilms were sampled for greening (with a spectrophotometer) and surface hardness (with an Equotip) on a sample of green and non-green patches. More detailed assessments were made on 4 patchily covered vertical transects for which 2d resistivity profiles were also obtained using Geotom equipment. The Geotom resistivity equipment allows non-invasive estimation of moisture contents to a depth of several centimetres inside walls (in this case, c. 30cm).

Results

Algal diversity levels were found to be very similar across all sandstone samples, regardless of the building sampled, the inclination of the surface, height above ground level, material type or surface finish. Fungal diversity was similarly uniform across sandstone samples, except for a significant difference between ashlar (smooth) and rough finished surfaces, where the diversity on ashlar was significantly higher than that on rougher surfaces. NMDS results showed that algal communities were much more uniform across all buildings (although different on the Portland limestone from the Geography building), whereas fungal communities varied between Fitzroy and Crescent churches and the other buildings sampled. Pyrosequencing found 124 algal taxa, most of which were very rare, and 351 fungal taxa, 95% of which from Ascomycota.

The block and transect survey results showed that green covered areas on sandstone blocks were generally harder and less variable in hardness than areas without a green biofilm. Using hardness and variability in hardness as proxies for the degree of weathering (lower hardness and more variable hardness is hypothesized to be associated with more weathered surfaces), these results show no evidence for green algal biofilms causing enhanced deterioration of sandstone surfaces. Resistivity surveys indicate no consistent relationship between greening on the surface and moisture regimes inside the stone, but some transects show evidence that green areas can retard moisture ingress. Further details are given in Cutler et al., (Accepted).

Climate change models predict wetter winters for Northern Ireland and increased numbers of very wet spells. Such wetter conditions will enhance the likelihood of green algal biofilm colonization and growth on heritage sandstone surfaces. Whilst our results do not give any serious cause for concern about green algal biofilms in Belfast in terms of their contribution to biodeterioration, more rapid and widespread green soiling may be perceived to look unpleasant and give the appearance that buildings are uncared for. Of course, if climate change results in a different biotic community with different impacts on the stone surface, then biodeterioration (or conversely bioprotection) impacts may become more pronounced. Follow-up surveys will be necessary in Belfast to monitor the changing situation. We advocate the use of a similar methodology to characterize the nature and impacts of biota on other sandstone heritage surfaces around the world in order to provide a balanced assessment of their roles now and under the changing climatic conditions over the next 50–100 years.

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Pollen spectra in the upper mineral horizons of Podzols in the Stołowe Mountains

Abstract: We report the results of investigating pollen distribution in Podzols. Based on palynological data we were able to confirm polygenetic character of two lithologically different layers in the examined soils: (1) surface layer with the dominance of birch and admixture of alder, hazel and pine, as well as with presence of *Calluna*, pointing to human activity, and (2) subsurface layer with significant share of lime and hazel, but also with beech, hornbeam and oak, suggestive of Atlantic/Subboreal periods.

Introduction and aim of study

Podzols with thick forest humus (mor-type) are good objects for palaeobotanical investigation, despite the fact that palynological studies are carried out preferably in peat or lake sediments (Hicks and Hyvärinen, 1999). Moist, acidic and anaerobic environment limits the microbial decomposition and promotes survival of sporomorphs in some wet Podzols, while in the oxygenated soils containing carbonates sporomorphs are under rapid biological corrosion. Generally, the fertile forest soils with a mull-type humus are considered to be unsuitable for pollen analysis (Tobolski, 1980). Pollen analysis is also often applied in the buried soils, whose development was halted by the covering alluvial, colluvial, or aeolian sediments.

Several papers have shown that pollen analysis can be an effective tool for palaeogeographical reconstructions of soil origin (Havinga, 1963, 1974; Nalepka, 1999) and slope covers formation (Sageidet, 2009, Van Mourik, 1999). Previous studies in the Stołowe Mountains suggested lithological discontinuity of mineral substrate of Podzols. This is why an attempt was made to confirm the heterogeneity of soil profile and to identify the conditions under which the sandy surface layer may have formed, based on qualitative and quantitative analysis of pollen in E and Bh horizons.

Materials and methods

Three areas were chosen in the Stolowe Mountains: Białe Skały area, Narożnik massif and Skalne Grzyby area. In each particular area a soil toposequence was established from the upper slope to the footslope. The soil pits were located at the altitude from 810 to 727 m a.s.l. Soils were described and sampled according to Guidelines for soil profile description (2006) and classified according to the international classification system (IUSS Working Group WRB, 2006).

For pollen analysis small (1,5 cm^3) undisturbed soil samples were taken from soil horizons in the following order: A, E and Bh/Bhs, in selected profiles. Samples were treated with fluoric acid and next steps of the chemical treatment were performed following Moore et al. (1991). Pollen were identified using optical microscope with a magnification of 400–1000x. A total of 16 tree and shrub species and 30 species of herbaceous plants were identified. The taxa were divided into 4 groups: coniferous trees, deciduous trees and shrubs, perennials and herbaceous plants, and cryptogams. Due to the significant number of the sporomorphs, whose identification was not possible, a separate group of unmarked taxa was distinguished.

Results and discussion

Two lithologically different layers were distinguished in the soil profiles: (1) an upper cover, hosting eluvial AE and E horizons, (2) a solifluction layer, comprising mainly the Bh and Bs horizons (Fig. 1). Upper soil mineral horizons have single-grain structure, weak to moderate stratification features, skeleton content below 15%, and usually sandy texture. These layers meet requirements of *albic* diagnostic horizons. Deeper illuvial layers (B) were clearly distinguished by fine-earth fraction presence, expressed by sandy loam and loamy sand textures. The structure of soil mass varied between platy and platy-subangular, medium to strong. Also the content of rock fragments was higher and reached 70–80%. Illuvial horizons meet requirements of *spodic* diagnostic horizon. Most of the soils (11 pedons) were classified as Albic Podzols or Stagnic Albic Placic Podzols, other two as Regosols and one as Histic Stagnosol.

A total number of 16 tree and shrub species and 30 species of herbaceous plants were identified in 4 groups. However, a sufficient amount of sporomorphs, allowing the pollen analysis, was present only in some soil samples. The state of preservation of pollen grains and spores was also variable. Some grains had corroded cell walls or were preserved only in fragments – mainly in the near-surface soil layers. Charcoal particles were also found in three samples.

The surface horizons of Podzols were dominated by tree pollen (from 69 to 92% of the total number of sporomorphs found), with a clear dominance of birch (19–40%) and alder pollen, and variable admixture of hazel and pine (Fig. 2). These four species accounted for 57 to 77% of total pollen grains. A considerable share of birch in all analyzed sites was surprising, since birch is considered to be a pioneer species,

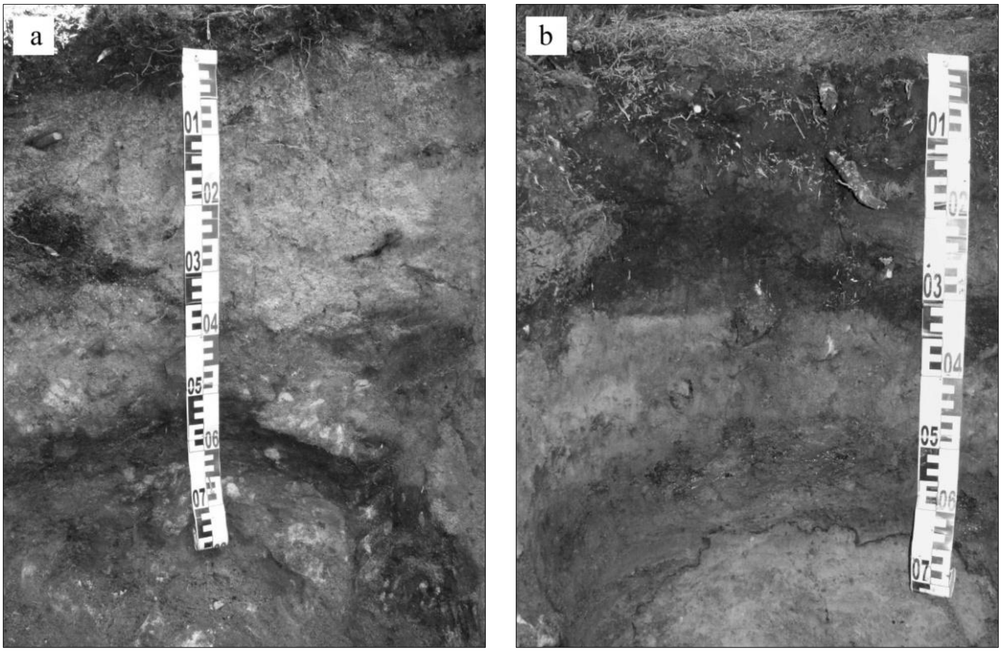

Fig. 1. Podzol profiles with lithological discontinuity: (a) thick sandy, loose layer over a dense, skeletic horizon; (b) impermeable *placic* horizon causes water stagnation in the upper head of soil profile.

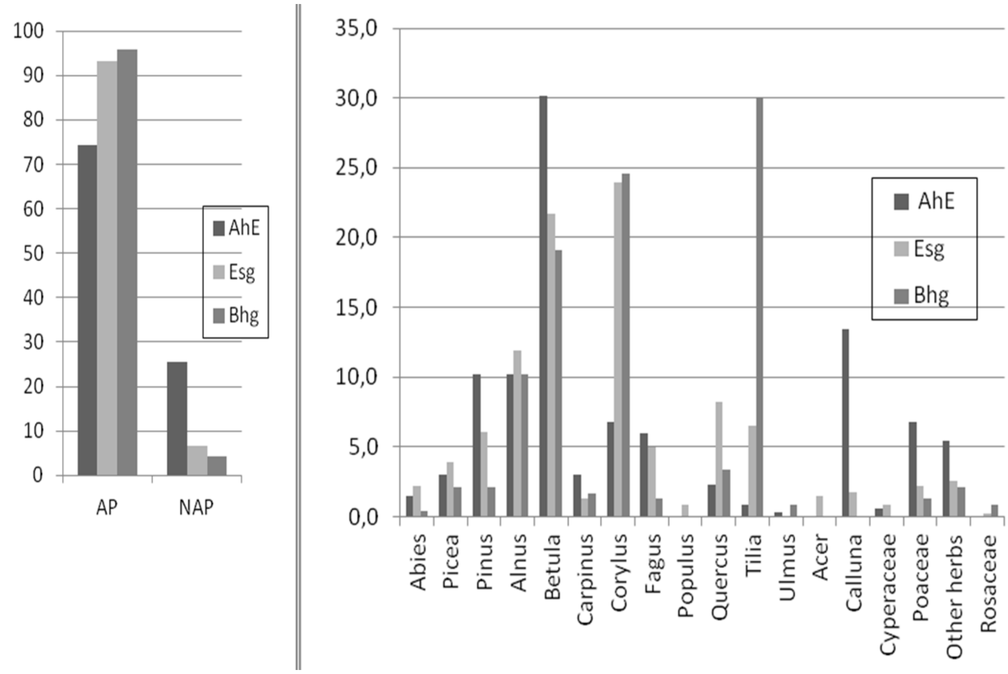

Fig. 2. Percentage concentrations of pollen (trees and herbaceous sporomorphs) in AhE, Esg and Bhg horizons. The arboreal (AP) and non-arboreal (NAP) pollen sum in examined soil horizons.

entering open areas, uncovered due to severe storms, fire or an excessive mass-thinning. In pollen spectra, also *Calluna* is well distinguishable, which may be correlated with human activity (Valde-Nowak and Bronowicki, 1999) in this area or with natural fire events. These suggestions are confirmed by the presence of wood charcoal (dated age: 1035 BP) in the form of a continuous layers or dispersed in the sandy material of surface horizons. These layers are therefore interpreted to be relatively young superficial layers, formed recently by the deposition of material from erosion running under more humid climate, as confirmed by regular and fairly large admixture of alder pollen.

Contrasting pollen structure was present in the subsurface horizon Bhg in the profile BBS2. Samples from this layer were absolutely dominated by tree pollen – up to 95%, and contained a significant share of lime (30% of total tree pollen) and hazel (25%), but also beech, hornbeam and oak (at least 7% of each species). Forests with linden trees are represented in pollen spectra since the mid-Boreal period. However, the share of other species typical for the warm broadleaf forest, including beech, provides a basis for determining the period of formation of this layer at the turn of the Atlantic and Subboreal periods, which is complimentary to the biostratigraphic findings from the Wielkie Torfowisko Batorowskie peatbog (Marek, 1998). The absolute dominance of deciduous tree species with a minimal admixture of grass in the forest floor suggests that these stands were developed on 'brown earths' (Cambisols) or 'rusty soils' (Brunic Arenosols), but not the Podzols. The contemporary subsurface Bh horizons of Podzols were then the surface mineral layers (humus horizons). The results of palynological analyses suggest that at least some of the Podzols in the Stołowe Mountains are relatively young polygenetic Holocene soils, and their development is related to the widespread formation of the cover sand layer.

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Temporal and spatial variability of microclimate in sandstone landscape: detailed field measurement

Abstract: Microclimate is an important driver of species occurrence and vegetation cover in landscapes with complex relief such as sandstone areas, but attempts to measure the characteristics of these microclimates are rather scant. We performed detailed and long-term measurement of near-ground surface temperature and soil moisture in six different valleys using newly developed tools (TMS1). The results reveal a buffering effect of valleys and that temperatures are significantly colder on valley floors during the growing season while temperatures were similar or even higher during the winter season than on slopes and crests.

Importance of microclimate in complex landscape

Even as microclimate influences the distribution of many species on a small spatial scale, it also could significantly shape large-scale patterns of species distribution as it forms sheltered localities at both ends of the climatic gradient. The importance of such refugia or microclimatic conditions, per se, as buffers of recent climate change, and especially in relation to rising global temperatures, is also being recognized (e.g., Ashcroft 2010). The effect of microclimate is markedly manifested in landscape with such complex relief as seen in sandstone areas, where erosion has modeled unique compositions of stone blocks, deep gorges and canyons, stone walls and slope crests. Microclimate there is often mentioned in relation to the presence of Atlantic (oceanic), montane or even alpine species (Sádlo et al. 2007). Their occurrences are traditionally and logically ascribed to temperature inversion in deep gorges caused by low irradiation and inflow of cold air. Short-term studies of individual profiles of several valleys have proven the existence of temperature inversion under specific weather conditions, such as clear sky or a warm frontal system (Beer 2007, Sklenář et al. 2007). These studies also have shown the opposite effect, however, with valley floors being warmer than valley slopes and crests. This points to a buffering effect of deep valleys, which could reduce and delay temperature fluctuations.

Methods

We performed continuous, long-term (more than 1 year) field measurement of microclimate, detailed in respect to both time and spatial scales. We focused on environmental conditions near the ground, as the most important part of the life cycles of both plants and small animals plays out near the soil's surface. For this purpose, we used a newly developed, affordable and autonomous station, the TMS1 (TOMST s.r.o., Prague, Czech Republic). Each TMS1 station allows continuous (every 30 min in our study) measurement of 4 parameters for a period of at least 1 year. Three temperature sensors (MAXIM/DALLAS, 0.0625 °C resolution and ±0.5 °C accuracy) measure temperatures directly at the soil surface, 10 cm below and 15 cm above the surface. One moisture sensor based on the time domain transmission (TDT) technology measures soil moisture in the first 15 cm below ground. About 300 TMS1 stations were installed during 2009 along an elevation gradient in 6 valleys of sandstone landscape in the Bohemian Switzerland National Park (Czech Republic). Individual stations were placed at regular distances along valley floors and on several profiles perpendicular to the valley floor in the strata determined to be the same relative height above the floor.

We performed detailed temperature and moisture measurement in order to describe both daily and seasonal dynamics of microclimate. We obtained more than 20 million individual records annually (not all stations operated through the entire year).

Preliminary results

Preliminary results based on our analyses of this large dataset support the idea of valleys as buffers of climate fluctuation on a seasonal time scale. The bottoms of the valleys are significantly colder than are their slopes and slope crests during the vegetation period (Fig. 1). They are not significantly colder during the winter (Fig. 2), however, and even show a higher average minimum temperature than do the remaining parts of these valleys. Very probably, that is due to a lower exchange of heat fluxes of the sheltered ground surface and longer lasting snow cover. Daily temperature fluctuation also decreases if we proceed from the top to the bottom of the valley height gradient. The long-term measurements also confirmed higher soil moisture at the bottom of the valleys during both the vegetation and winter periods. Differences between the valleys are small, but the deeper gorges tend to have lower average temperature at the bottom. On the other hand, a comparison of microclimate to standard meteorological data measured at the center of the study area indicates high capacity for the topography and vegetation cover to modify mesoclimate temperatures. We recorded differences up to ±10 °C in the daily average aboveground temperature (Fig. 3). This huge microclimatic variability has important consequences for predicting the impacts of climate change. While large-scale shifts in species distribution are predicted, our measurements indicate that small-scale heterogeneity will allow species to adjust to climate change by shifting to suitable habitats within their current ranges.

Furthermore, the large number of measured points allows extrapolation of microclimate across the landscape, and detailed measurement focused on localities of rare and/or endangered species provides important information about their habitat requirements. This knowledge strengthens our ability to predict species distribution in the face of ongoing climate change.

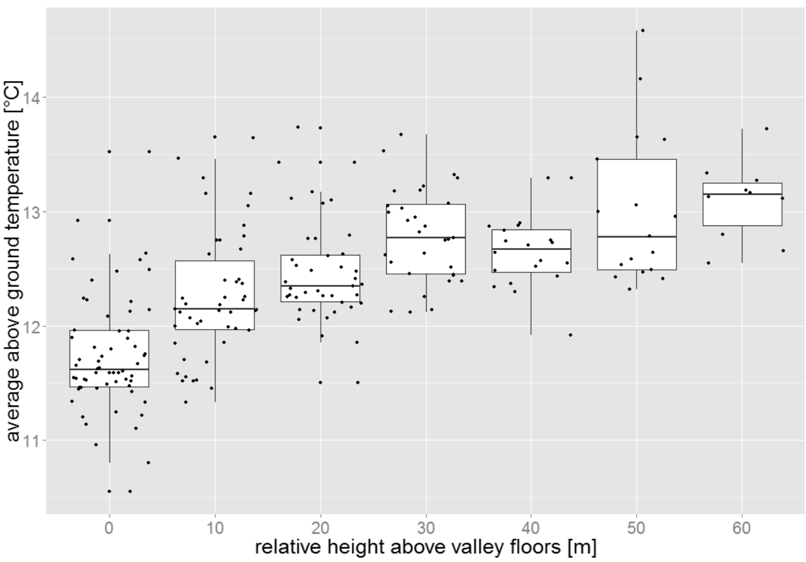

Fig. 1. Monthly average temperature (15 cm above ground surface) in relation to relative height of the measurement point to the valley floor, data for vegetation period (1 May – 31 Oct 2010, n = 233).

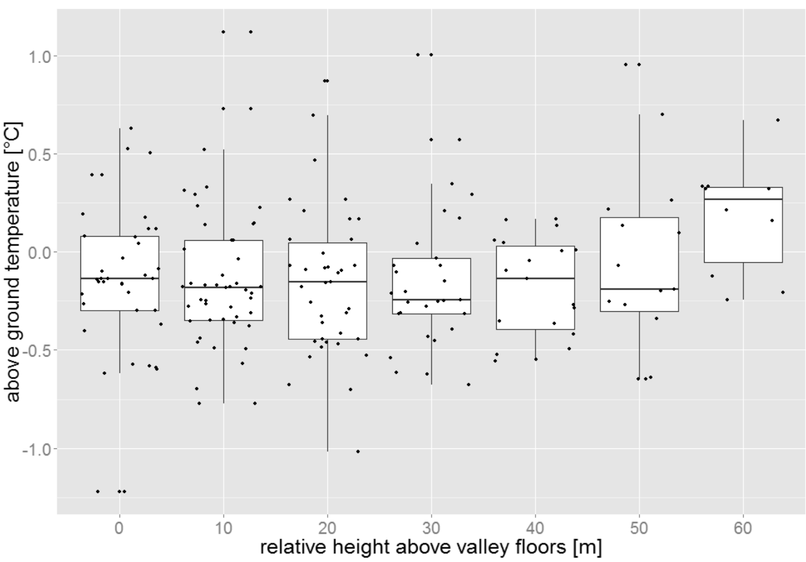

Fig. 2. Monthly average temperature (15 cm above ground surface) in relation to relative height of the measurement point to the valley floor, data for winter period (15 Nov 2010 – 31 Mar 2011, n = 235).

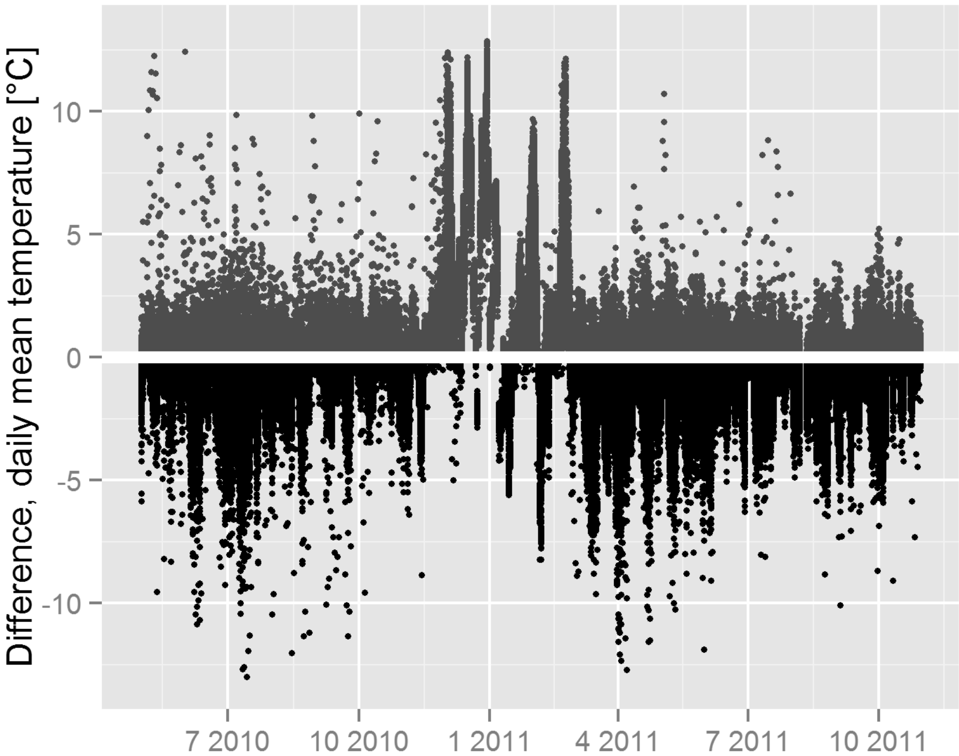

Fig. 3. Differences in average daily temperature measured at each locality 15 cm above ground using TMS1 unit and mesoclimate data represented by standard meteorological station (2 m above ground in meteorological screen).

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Influence of structural features on the course of river channels – the Stołowe Mountains case study

Abstract: The objective of this study was to examine the relationships between bedrock characteristics and the course and nature of river channels in the Stołowe Mountains (SW Poland). We examined whether stream courses follow tectonic discontinuities and are related to the strength of the substrate. Research was carried out along valleys intersecting the southern escarpment of the main plateau. Field observations were supplemented by the study of rock strength using Schmidt hammer. Streams preferentially exploit NW-SE tectonic lines and leave the plateau using areas of lower rock strength.

Introduction

The Stołowe Mountains are a unique part of the Polish territory – they are the only tableland area in the country. In terms of geology, the range constitutes the central part of Intra-Sudetic Depression, filled with thick nearly-horizontal layers of Cretaceous deposits – marls, mudstones and sandstones. This lithology is reflected in the relief of this area. Well-developed stair-like system of flat surfaces separated by steep cliffs is clearly visible on several altitude levels, which are characterized by diverse strength of the substrate. Hydrological network of the Stołowe Mts. seems adjusted to the geological structure and channel courses are assumed to be determined by the structure of the substrate. However, no detailed studies defining the relationships between surface features and the course of the river channels have been ever performed, especially in the sections where they rivers cross marginal escarpments In these sections, in many cases, different fluvial processes like erosion, deposition or transport are intensified.

The objectives of the study included the examination of the relationship between substrate structural determinants and the course and morphology of streams channels. We examined whether the course of streams is somehow adjusted to tectonic discontinuities, and is justified by the strength of the substrate.

Study area

The study area is located within the southern escarpment of the Stołowe Mountains and extends from the Lisia Pass (790 m a.s.l) to Batorów, reaching the peak at Mt Narożnik (851 m a.s.l). The eastern section follows the precipices of

Wielkie Urwisko Batorowskie (c. 700 m a.s.l) (Fig. 1.). The investigated area is located within the Stołowe Mountains National Park. In this part of the mountains, the dominant substrate is the Middle and Upper Turonian fine-grained series that includes mudstones and marls. Only the highest, top parts are made of the most durable Late Turonian sandstones. They developed in the form of almost horizontal layers of varying resistance to destruction, as well as of different sediment grain size and degree of sorting, the type of binder, different content of silica and calcium carbonate, different stratification, strike and dip oflayers, their thickness, and what is important for further consideration – variable joint density (Jerzykiewicz, 1968).

The streams of the Stołowe Mountains, particularly the ones draining the southern part of the region, are characterized by diverse channel morphology at different reaches. Sections formed in slope deposits, where water flows between boulders and blocks of rock, are dominant in the upper and middle sections of most streams. They have the form of boulder channels and are most spectacular in places, where they cross the cliffed escarpment. Numerous boulders and residual blocks constitute the local accumulation bases and may cause water damming. Channels of alluvial character occur below the cliffs, in areas with low inclination. Sections of rocky channels are sparse and up to 30 m in length (Migoń et al., 2011).

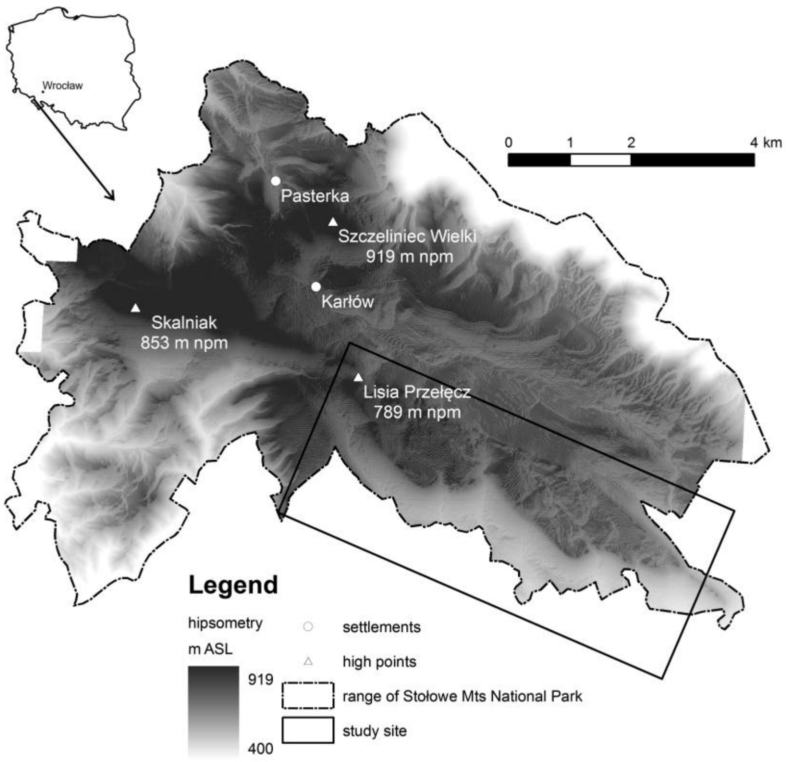

Fig. 1. Hipsometry of the Stołowe Mountains National Park; study area marked by black rectangle.

Material and methods

We applied two specific research methods. Sclerometer (Schmidt hammer) was used to test the strength of sandstone outcrops over the Narożnik – Urwisko Batorowskie transect. In accordance with the established procedure (Day and Goudie, 1977; Selby, 1980), for the measurement we selected smooth vertical surfaces, affected by weathering as little as possible. 63 research plots were chosen At each of them 35 readings were taken. For further statistical analysis we rejected five lowest values, assuming that they may result from local decline in substrate strength caused by mineral composition or enhanced rock weathering. Similar approach was applied earlier by Remisz (2007). In addition, Rock Mass Strength classification (Selby, 1980) was used. However, the original RMS classification was modified and the range of possible values was calculated based on extreme values recorded only during this study. This procedure provided two end-member strength classes, which formed the frame for the construction of local rock strength scale. This resulted in five-class strength classification (Fig. 2).

Geomorphological mapping and the review of cartographic materials were carried out for selected sections of river channels, where bedrock channels developed (Fig 2). Analyses focused on Złotnowski, Kamienny, Bobrówka and Mostowa Woda streams, which are located along the southern escarpment of the Stołowe Mts. ArcGis software was used to elaborate hypsometric maps on the basis of 5x5 m raster model that had previously been developed using LIDAR data. We compared the course of stream channels with the network of tectonic discontinuities. Information about the latter is based on studies by Pulinowa (1989) and Wojewoda et al. (2011). Hydrographic network was generated from 50 meter elevation model (DTM) developed in the Department of Cartography at the University of Wroclaw. The contemporary system of streams was examined for bedrock channels within the escarpment, with the regard to rock strength classes.

Results

In general, the southern part of the Stołowe Mountains is drained towards the south-east. However, this direction is not constant. Having reached the cliff, streams frequently change their direction to more or less southward at the distance of about 0.5–1 km. In this way, they cross the escarpment at right angles. These places are not located at random. We found that there is a correlation between the strength of sandstone outcrops of the southern cliff and the course of the river channels. This is particularly evident in the Urwisko Batorowskie section, which is cut by Mostowa Woda and Bobrówka streams along with their tributaries. These streams use the cliff recesses related to the reduced resistance (both cases in the first

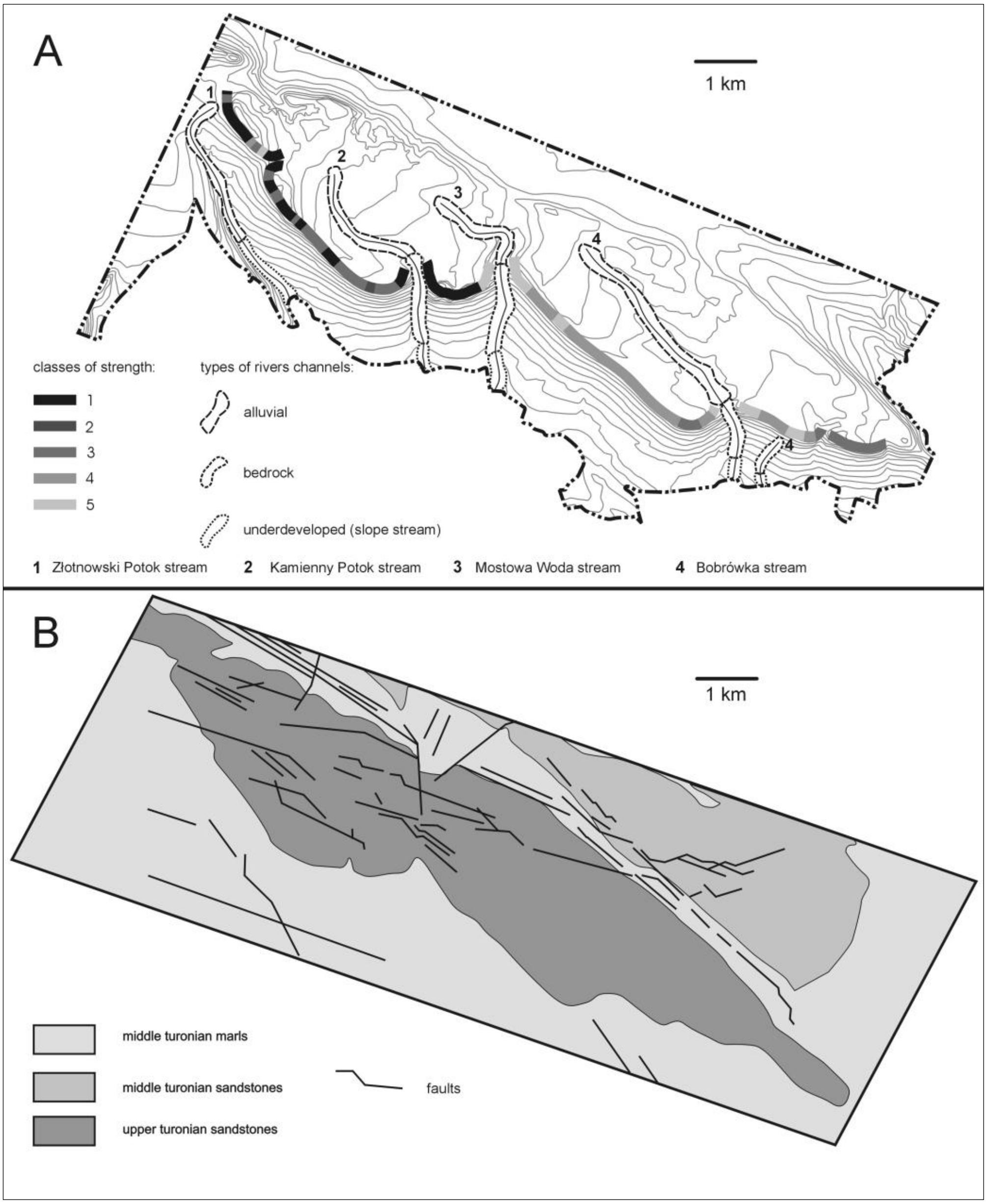

Fig. 2. River channel types and rock strength (modified Selby's RMS approach: 1 – the strongest rock, 5 – the weakest rock) along the southern escarpment of the Stołowe Mts (A), in relation to geology and the most important tectonic discontinuities (B), based on Wojewoda et al. (2011).

class of rock strength – Fig. 2). We found the relationship between tectonic discontinuities and the course of streams for the cliff section from the Lisia Pass to the Skały Puchacza rocks. The Kamienny stream and episodic rivers in the Narożnik and Skała Józefa rock area use tectonic discontinuities, although the strength measured with Schmidt hammer is high (class V) at these sites.

No permanent stream uses discontinuity below Mt Narożnik because water departs here in the direction of surface tilt, i.e. to the southeast. Below the cliffs, in the area of contact zone between fine-grained sedimentary rocks and sandstones there is a plenty of springs feeding short tributaries of the Złotowski, Kamienny, Mostowa Woda nad Bobrówka streams. River network here becomes denser and streams change again their direction from S to SE.

Discussion

The course of streams on the southern side of the Stołowe Mountains massif is highly diverse. Springs are located in the elevated area of tableland (on mesas). In the upper reaches, streams flow in poorly developed initial channels within the flat surfaces of the tableland. In places where streams reach the cliff, the nature of channels changes to the bouldery one. Their directions turn to perpendicular to the cliff and the gradient increases. Below the cliff the inclination is reduced and channels assume alluvial character and the direction is again to the south-east (Migoń et al., 2011). Such variability and location of channels suggests some relationships between the stream network and tectonic discontinuities. It should be emphasized that the Stołowe Mountains is a special area where the spatial distribution of tectonic elements shapes the relief and guides the geomorphic evolution (Pulinowa, 1989). However, the relationships between the course of streams and tectonics of the massif, understood as a system of medium and large discontinuities within the sedimentation basin, have not been the subject of greater interest so far. Only Pulinowa (1989) outlined some general relationship between these factors. The literature overview delivers also an example of the Czerwona Woda valley suspected to use a fault zone (Wojewoda et al., 2011). Despite numerous studies on rock strength (e.g. Synowiec, 2002; Migoń and Zwiernik, 2006; Remisz, 2007), identification of the relationship between cliff strength and the course of boulder sections of the streams channels has not been investigated.

According to Pulinowa (1989), tectonic lines of NW-SE extension define morphological edges of the tableland and have controlled the inception of the hydrographic network of the Stołowe Mountains. The results presented here confirm this observation. Kamienny, Bobrówka and Mostowa Woda streams run in this direction below and above the cliff. However, bouldery sections of the analysed stream channels run perpendicularly to the edge of the tableland. These fragments are in accordance with discontinuities that cross the syncline axis, in NE-SW direction. They play a secondary role in morphogenesis and usually form less elevated areas and passes (Pulinowa, 1989). Some significance for the course of the river system should also be attributed to medium scale joints. They contributed to subsidence in the north-eastern part of Mt Narożnik (Pulinowa, 1989). However, no constant stream was noticed during field studies and water occurs there only periodically.

Our observations give no clear proof that streams run down the cliff in places where the substrate strength is reduced. The majority of streams does so, only the case of Kamienny stream is different. Dry valleys crossing the cliff in places typified by high strength were also noticed. But one cannot conclude for such a state of affairs only on the basis of measurements with Schmidt hammer. Application of Selby's RMS classification seems to be more useful in such instances. It takes into account not only the strength of the substrate measured with a hammer, but also the location, direction and density of discontinuities. This can be crucial for discussion about the controls on the hydrographic network. Remisz (2007) performed such a classification for the southern part of the cliff and concluded that structural factors have a decisive impact on the final value of the cliff resistance. After application of RMS classification, it turned out that places where streams cross the escarpments are characterized by lower final score, regardless of the results of Schmidt hammer measurements.

Conclusions

1. The main direction of valleys crossing the southern cliff of the Stołowe Mountains follows that of fault lines running in NW-SE direction, in the zones of tectonic discontinuities.
2. The direction of boulder-filled channel sections is adjusted to the course of subordinate NE-SW discontinuities.
3. Morphology and spatial pattern of channel sections along all streams on the southern side of the massif are similar to one another.
4. Rock mass strength values at cliff/valley intersections are lower compared to those obtained at other sites within the cliff. According to Selby's classification, sandstones building the cliff have high and medium resistance. In places where the continuity of the cliff is interrupted, the rock mass strength is reduced in a noticeable way.
5. Tectonic and structural factors may overlap, favouring concentration of surface runoff in specific areas. At the same time, concentration of water may cause further lowering of rock resistance.
6. There are two possible explanations for the observed drainage pattern. Streams may use zones of decreased bedrock resistance of rock base, hence more probe to erosion, but it is also possible that the decreasing resistance of rock results from streams activity. So far, to give a strong favour to one of these hypotheses does not seem possible.

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What is the relationship between vegetation in sandstone deep valley and basic measured microclimatic parameters in the Bohemian Switzerland

Abstract

Geomorphology and microclimate have fundamental effect on the diversity of the habitats and strongly influence species diversity. To know how the microclimate dynamics works in the terrain composed of deep sandstone valleys is crucial for understanding vegetation composition (e.g. Härtel, 2002; Härtel and Marková, 2005). The vegetation on the nutrition poor substrate is affected more by abiotic stress conditions than biological causes (Brown et al., 1996). Species diversity of sandstone landscapes is determined by the combination of sharp ecological gradients, mainly by moisture and temperature (Gutzerová and Herben, 1998). In deep valleys we could find conditions similar to mountain and alpine habitats and peat bogs.

Climate inversion was described by several authors (Kuwagata and Kimura, 1995; Geiger et al., 2009; Bourne et al., 2010; Gillies et al., 2010). In the area of the Czech Republic and its neighborhood several studies have been carried out (Sklenář et al., 2007; Kopecký, 1998; Beer et al., 2001, 2007). The majority of them has been performed with short-time measurements or with low frequency of measurements because of instruments limitation. The results show the presence of inversion under conditions of high atmospheric pressure. The inverse climate creates more stable and colder climate on the bottom of the valleys (e.g. Beer, 2007; Sklenář et al., 2007). The decisive factors for climate dynamics are potential direct radiation (Gutzerová and Herben, 1998, Whiteman, 1982), wind (Whiteman, 1982; Kuwagata and Kimura, 1995), and vegetation cover (Stoutjesdijk and Barkman, 1992). The relationship between vegetation and microclimate parameters measured by a sufficient number of quality measurements has still not been attempted in the area of Czech sandstone landscapes.

Since 2009 we have realized long-term microclimatic measurements of moisture and temperature with 400 sensors and have collected phytosociological reléves close to sensors in six selected valleys in the area of Bohemian Switzerland National Park, which is a typical example of landscape with high geomorphological

and climatic diversity (Härtel et al., 2007). Studied vegetation is mainly hold in non-intervention regime, however, in the past the majority of natural forest communities of *Dicrano-Pinion* and *Piceion excelsae* has been replaced by spruce monocultures. In this part we present relationship between vegetation and basic climatic features (absolute temperature minimum, temperature minimum in different months, average temperature, minimum of moisture etc.) derived from large datasets of temperature measurements. The strongest effect these climate parameters have on composition of the herb layer and natural regeneration processes of the main tree species.

The main aim of our project is to a create microclimatic-vegetation model of the sandstone landscape based on a set of phytosociological reléves and long-term microclimatic measurements of moisture and temperature with sensors. The basic model will be created for the area of six selected valleys, and using the exact digital terrain model from LiDAR surface scanning this model will be extrapolated to a major part of the Bohemian Switzerland NP. The final model will use pretensions of selected species to environmental conditions to predict their optimal habitat in different parts of the National Park (similarly as Elith et al., 2006 or Meynard and Quinn, 2007) and will be verified by field research by recording the presence/absence of species in optimal habitats predicted by the model.

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Silver fir restitution in Stołowe Mountains National Park

Abstract

Forests cover about 90% of the Stołowe Mountains National Park area. Most of them are coniferous forests, with Norway spruce as the dominant species (about 78% of the forest area). About 200 years ago the Stołowe Mountains, similarly to the rest of the Sudetes, were covered by mixed and broadleaf forests with beech (about 50% of the all forest area), Silver fir (18–20%), spruce (2 %) and some other tree species such as sycamore maple or scotch elm.

In the 17th and 18th century the dynamic development of colonization and glass- and steel works caused mass cutting of natural forest. Huge amounts of wood were needed, hence beech and fir became unpopular species because of their slow growth and only fast growing spruce was planted or sowed. It is important that seeds from different part of Europe were used, from spruce population not necessarily adjusted to the Stołowe Mountains climatic and soil conditions.

Now, within the Stołowe Mountains National Park forests consist of spruce (72%) and some other tree species like beech (11%), larch (5%), sycamore (2%) and only 0.2% of Silver fir. The National Park service, from the first day of National Park existence, is trying to rebuild these artificial forests. Especially Silver fir is under special protection in the Stołowe Mountains NP and the programme of its restitution was established. The main activities are:

- protection of all adult fir trees (about 6000 grown fir trees remain in National Park forests),
- special protection of very rare fir natural renewal,
- breeding and planting of silver fir seedlings.

Since the Silver fir restitution programme has just begun, a considerable work is to be done to make fir an important component of forests in the Stołowe Mountains. But there is a long way ahead to reach the 18% contribution of fir in National Park forests, which is the ultimate goal.

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My Remembering to Kudowa – Sandstone Landscape III

Let's try to write a poem now
as well as I could say.
I like to do this step by step
and hope it grows o.k. ☺

At home from long time journey way,
from the north of Austria,
let's have for me a remembrance view
to the time from Kudowa.

The rocky land we spoke about,
these sandstone landscape views,
"transcripted" from the scientists:
and we noticed many news.

From "bouldering" to boulders there,
so crazily placed as here:
this travelling in older times,
Yes, it was a good idea. ☺

The mountains here are all split deep
in gorges filled with snow.
We climbed on top on sunshine days.
Who counts this rocky row?

Much forests all around the scene,
big boulders "sliding slow" –
but only seen in geology time
and fare away from "go".

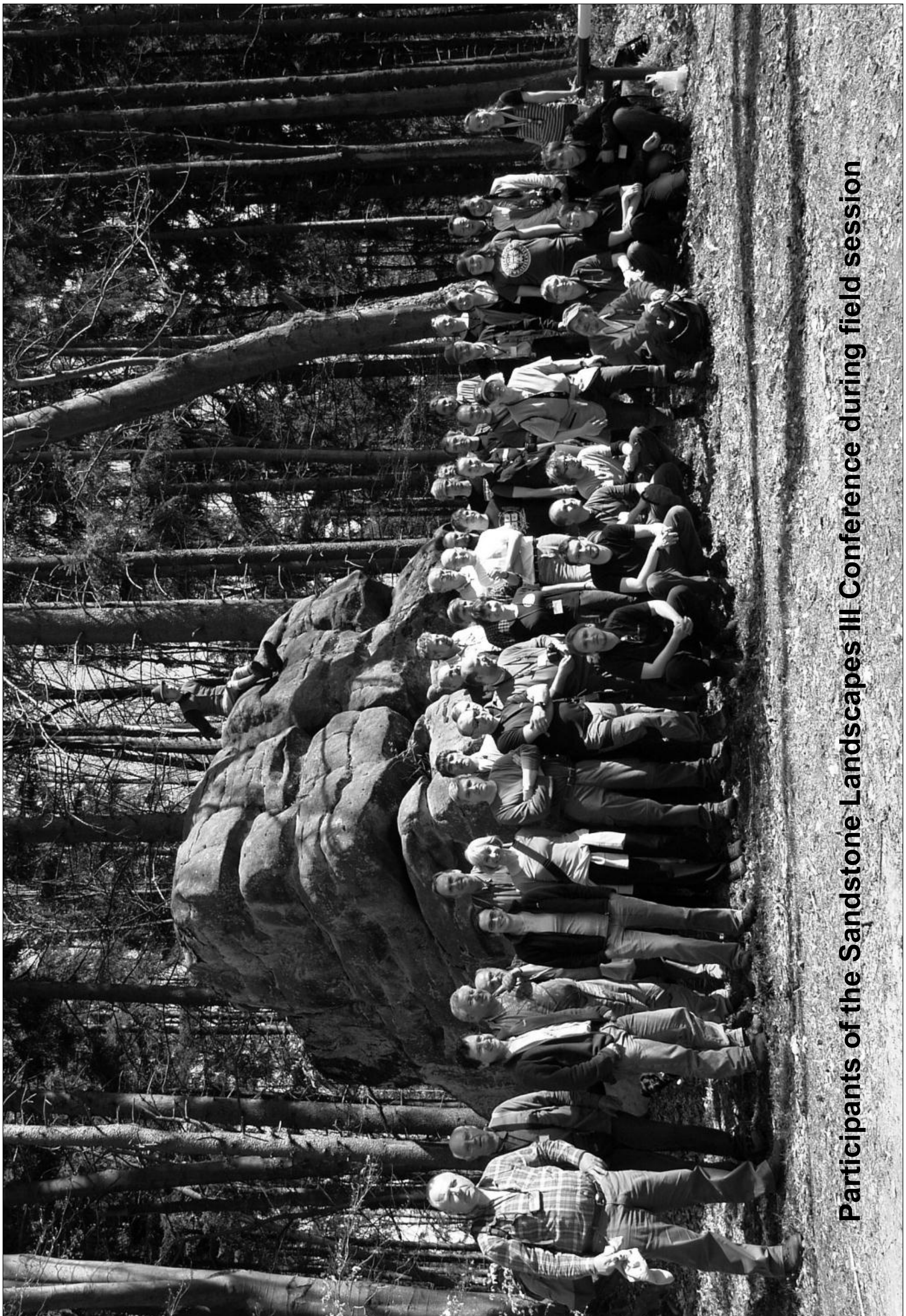
These mighty table mountain cliffs
are yellow, gray ore white.
On meadows stones are "wandering":
remember to the guide.

These hiking tours just up and down
on stony stairs for all.
Tonight a fun made dinner time
in our dining hall.

Remember to the running dog,
the falcons flying wide,
the stony hen on boulder's top –
all this with photo light.

Interesting days in Polish land,
the scientific talks,
the pretty old town Kudowa
with sunshine during walks.

Gunhild Bähr, Wien 2012



Participants of the Sandstone Landscapes III Conference during field session