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WINTER MICROCLIMATIC REGIME OF LOW-ALTITUDE SCREE SLOPES AND ITS RELATION TO TOPOGRAPHY: CASE STUDY FROM THE CESKE STREDOHORI MTS. (N CZECH REPUBLIC)

ABSTRACT: RASKA P., KIRCHNER K. & RASKA M., *Winter microclimatic regime of low-altitude scree slopes and its relation to topography: case study from the Ceske Stredohori Mts. (N Czech Republic)*. (IT ISSN 0391-9838, 2011).

Many low- to mid-altitude Central-European scree slopes display microclimatic regimes with thermal anomalies throughout the year. These anomalies favour stenoecious species, some of them considered to be glacial relics. In this study, we present a pilot study focusing on the evaluation of topographical factors (elementary landforms, slope profile, clast size) that predispose the formation of different microclimatic regimes at screes that have similar physico-geographical characteristics. We carried out detailed geomorphologic mapping at four scree slopes in the Ceske Stredohori Mts. (Northern Czech Republic). The mapping was supplemented with snow cover monitoring, observations of microclimate-induced features (ice holes with cold air exhalation and vents of warm air), and temperature measurements from the prolonged winter period of 2007-2008.

The results showed distinct differences in the microclimatic regime of the four study sites. A concave foot slope built by large boulders was the major factor inducing cold exhalations and the persistence of ice and snow. Slope inclination and vegetation patterns played a limited role. Warm vents within the upper part of the screes were strictly related to specific landforms (terminal lobes and elevations) and to mid-size clasts. The results are discussed using a geomorphologic evaluation of sites in the region that display thermal anomalies. The regional analyses indicate that the warm vents are mainly located on the southern slopes (due to higher incoming solar radiation) and at higher altitudes. The screes with cold air exhalations (freezing screes) are located at lower altitudes and on slopes with different orientations.

KEY WORDS: Scree, Microclimate, Thermal regime, Topography, Ceske Stredohori Mts.

ABSTRACT (in Czech): RASKA P., KIRCHNER K. & RASKA M., *Zimní mikroklimatický režim nízko položených suťových svahů a jeho vztah k topografii: příkladová studie z Českého středohoří (S Česko)*. (IT ISSN 0391-9838, 2011).

Mnoho středoevropských suťových akumulací lokalizovaných v nízkých až středních nadmořských výškách vykazuje mikroklimatický režim s teplotními anomáliemi v průběhu roku. Tyto anomálie jsou výhodné pro stenoekní druhy, z nichž některé jsou považovány za glaciální relikty. V tomto článku prezentujeme výsledky studie zaměřené na zhodnocení topografických faktorů (elementární formy reliéfu, profil svahu, velikost klastů), které predisponují vznik rozdílných mikroklimatických režimů na sutích, které jinak mají podobné fyzicko-geografické charakteristiky. Provedli jsme detailní geomorfologické mapování čtyř suťových akumulací v Českém středohoří (s. Čechy). Mapování bylo doplněno monitoringem rozsahu a výšky sněhové pokrývky, pozorováním mikroklimaticky podmíněných jevů (ledové jámy s chladnými exhalacemi, ventaroly - vývěry teplého vzduchu) a teplotním měřením v zimním období let 2007-2008.

Výsledky ukazují významné rozdíly v mikroklimatickém režimu čtyř studovaných lokalit. Konkávní úpatí sutí s přítomností velkých klastů bylo hlavním faktorem podmiňujícím chladné exhalace a persistenci ledu a sněhu. Sklon svahu a prostorový vzor vegetačního krytu hrály pouze omezenou roli. Ventaroly v horních částech sutí byly silně vázány na specifické formy reliéfu (terminální laloky suťových splazů a elevace) a na středně velké klasty. Výsledky výzkumu jsou diskutovány ve vztahu ke geomorfologickému hodnocení lokalit s teplotními anomáliemi v širším regionu. Regionální analýza indikuje, že ventaroly se nacházejí převážně na jižně exponovanych svazích (díky vyššímu příjmu slunečního záření) a v relativně vyšších nadmořských výškách. Sutě s chladnými exhalacemi (příp. podmrzající sutě) jsou lokalizovány v relativně nižších nadmořských výškách a bez zřejmého vztahu k expozici vůči světovým stranám.

KEY WORDS (in Czech): Suť, mikroklima, Teplotní režim, Topografie, České Středohoří.

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INTRODUCTION

Scree slopes are typical landforms occurring in Central-European highlands. Screes are built by the accumulation of stones of different shapes and sizes, and they are generally formed as a result of the in situ weathering of solid bedrock, the accumulation of rock falls, or a combination of both. Several studies have pointed out that there is a specific microclimatic regime on these slopes, which is typical of scree slopes at much higher altitudes and latitudes (i.e., those with permafrost conditions; Gude & *alii*, 2003; Zacharda & *alii*, 2007). The specific microclimatic regime of mid- to low-altitude screes is caused by air circulation in the surface layer and the interior, resulting in the relative thermal inertia of scree slopes (Kubát, 1999). The warmer air accumulates in upper part of a scree and is released during the winter through a venting system (exhalation) that limits the preservation of snow cover. In contrast, during the cold months the cold air accumulates in the basal part of the scree slopes and is released from foot slope lobes or from so-called ice holes (see fig. 2A), creating a stable cold environment. In some cases, this regime allows the preservation or creation of permafrost-like conditions (so-called freezing screes). Such screes and their different parts represent the environment for several stenoecious species, some of them relicts from glacial periods (e.g., Zacharda, 2000).

Most studies have focused on the biogeographical observation of these screes (e.g., Molenda, 1996; Růžička, 1999; Zacharda & *alii*, 2005) based on analyses of thermal regimes using dataloggers (Gude & Molenda, 2000; Zacharda & *alii*, 2007) and, more recently, on the identification of underlying permafrost-like conditions using geophysical tools (Otto, Sass, 2006). Following these microclimatic studies, different models have been established to explain the regime, including those suggested by Balch (1900), Kubát (1971), Wakonigg (1996), Harris & Pedersen (1998), or Herz & *alii* (2003). Focusing on low-altitude screes, Zacharda & *alii* (2007) showed that the microclimatic regime is more complicated and that it changes throughout the year.

In comparison with microclimatic and geophysical measurements, there is a limited number of studies dealing with the geomorphic preconditions of the microclimatic regime of screes. Gude & *alii* (2003) summarised the main preconditions for the formation of the microclimatic regime, which include (a) a steep slope, (b) a thick layer of blocks with an open void system and (c) sparse vegetation cover. Cílek (2000) and Kirchner & *alii* (2007) studied the geomorphology of scree slopes from a palaeogeographical point of view, and they suggested implications concerning the environmental changes of these slopes. Hétu & Gray (2000) presented another example of geomorphologic considerations of environmental change of scree slopes. However, their study was carried out in an environment that differed from that in the Central-European highlands. There are numerous studies that focus closely on the geomorphology of scree slopes (e.g., Czudek & Demek, 1976; Schrott, 1999; Curry & Morris, 2004), but these studies lack significant microclimatic or biological links that would contribute to the general knowledge of recent Central-European scree slope environments. Many studies that focus on relationship of geomorphology (topography) to microclimate in higher altitudes and/or latitudes are inspiring methodically, and they reveal the modes of air circulation and thermal regimes of scree slopes, taluses and rock glaciers (e.g., Ishikawa & Hirakawa, 2000; Herz & *alii*, 2003; Delaloye & Lambiel, 2005; Lewkowicz & Bonnaventure, 2008; Lambiel & Pieracci, 2008; Juliussen & Humlum, 2008; Gadek & Kedzia, 2008). However, the implications of these studies for low- and mid-altitude scree slopes are limited for the two following reasons. First, the climate of these areas (solar radiation, ambient air temperature, snow precipitation) is different, and it influences the microclimatic regime of individual landforms, including screes. Second, scree slopes in lower altitudes are mostly surrounded by forest vegetation that (i) influences the incoming solar radiation and temperatures and (ii) increases the biogeomorphic effects on surface dynamics in comparison with climate-controlled dynamics in mountain regions (e.g., Hales & Roering, 2005; Matsuoka, 2008).

Major gaps in understanding of Central-European scree slopes include the role of surface dynamics (e.g., rolling, bouncing, sliding), biogeomorphic effects (e.g., animal trampling and the effects of woody debris), and the influence of anthropogenic transformation (cf. Balej & *alii*, 2008). The significance of these gaps increases with the geomorphic variability of scree localities, which represent the source of our recent understanding. At the same time, it was shown already that the understanding to geomorphologic processes is a key factor for certain aspects of the effective environmental management (e.g. Panizza, 1996). Without a detailed geomorphological studies focused on the above mentioned issues, considerations of the conservation and management of biogeographically significant scree slopes, especially those that are freezing or displaying thermal anomalies, are far from convincing.

In this study, we focus on the winter microclimatic regime of four low-altitude scree slopes in the Ceske Stredohori Mts. (Czech Middle Mts., Böhmische Mittelgebirge) in Northern Czechia. We characterise the winter microclimatic regime by means of temperature measurements with dataloggers, snow cover monitoring, and observations of microclimate-induced features. The results are discussed using the topography analyses of these sites based on geomorphologic mapping supplemented with geodetic measurements. Our main research aims were (i) to analyse the winter microclimatic (thermal and snow cover) regime of the study sites and (ii) to evaluate the role of (micro)topography in this regime. The issue to be discussed was whether different microclimatic regimes evolve at localities (sites) with similar physico-geographic conditions (e.g., exposition, altitude, geology), and what role (micro)topography played in these differences.

STUDY AREA

The study area (see fig. 1) is situated in Northern Czech Republic, where the Elbe River has formed a deep, incised valley through the Ceske Stredohori Mountains, a 60-km long, SW-NE trending neovolcanic range (Cajz, 2000). During the Quaternary period, the geomorphic characteristics of the volcanic range were diversified due to tectonic movements and the differing resistance of rocks. These conditions controlled the incision of water streams and the denudation of slopes (Král, 1966; Kalvoda & Balatka, 1995). Located in the centre of the volcanic range, the study area is represented by a wide steep slope, which was inclined westwards to the Elbe River and by a valley of its tributary, the Prucelsky brook.

The climate of the study area is moderate with average annual temperatures between 6 and 7°C. The average number of days with rain exceeding 1 mm is 110. Snow cover is present 60-70 days per year with an inter-seasonal average maximum depth of about 40 cm. In this respect, the monitored winter season is below average as were the last ten years in comparison with the normal period of 1961-1990. The main slope of the study area is covered with abundant scree accumulations, and the four studied screes are located within this area (figs. 1 and 2). The screes are composed of clasts of basaltic rocks varying in size, shape and age. The general physico-geographical conditions of the study sites, such as exposition, altitude, inclination (i.e., incoming solar radiation), and surrounding vegetation (i.e., effects of environmental change along the ecotones) are comparable. The differences among them are apparent at a detailed topographical scale. The basic characteristics of the study sites and the methods used for each of them are summarised in table 1.

METHODS

1. *Geomorphological analyses*

Geomorphological methods were used to evaluate the topography-microclimate relationship at two scales. We ap-

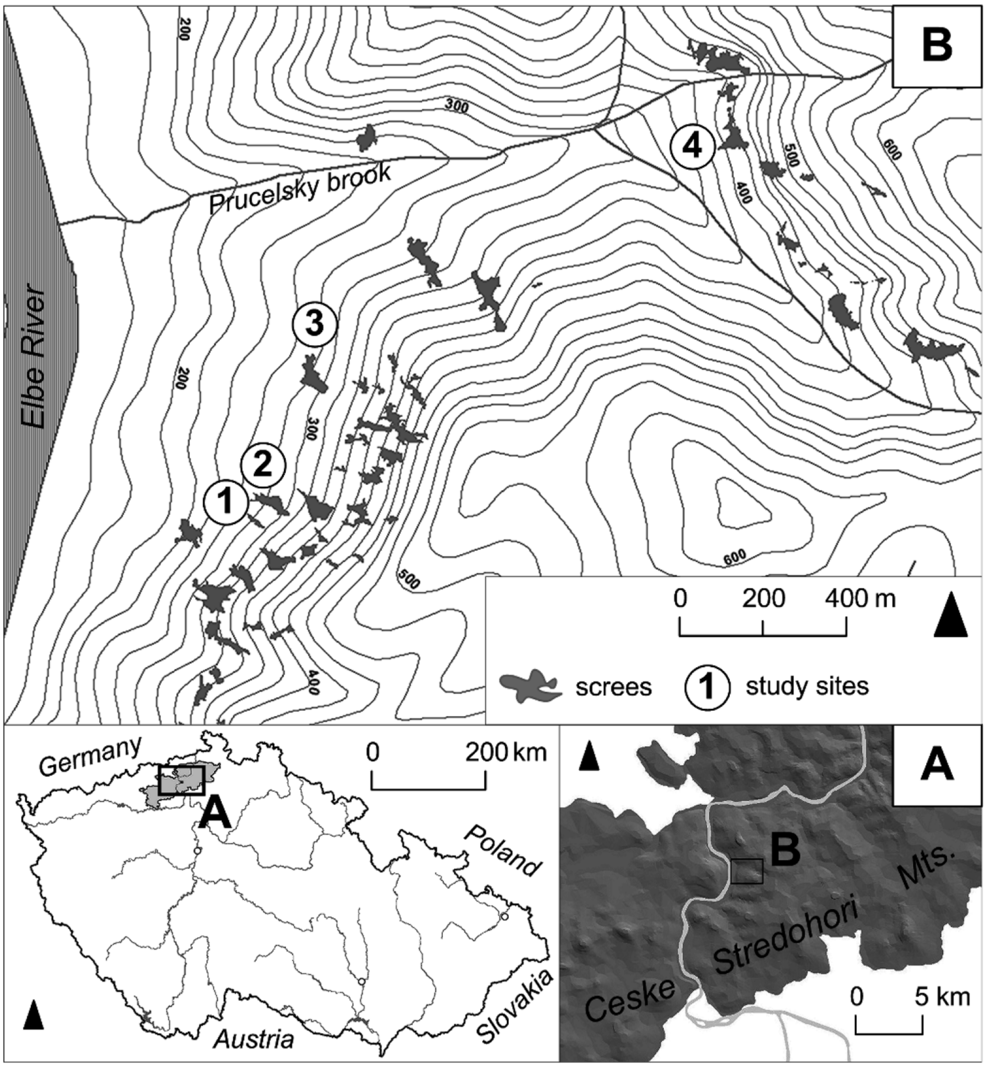


FIG. 1 - The study area in the Ceske Stredohori Mts., Czech Republic.

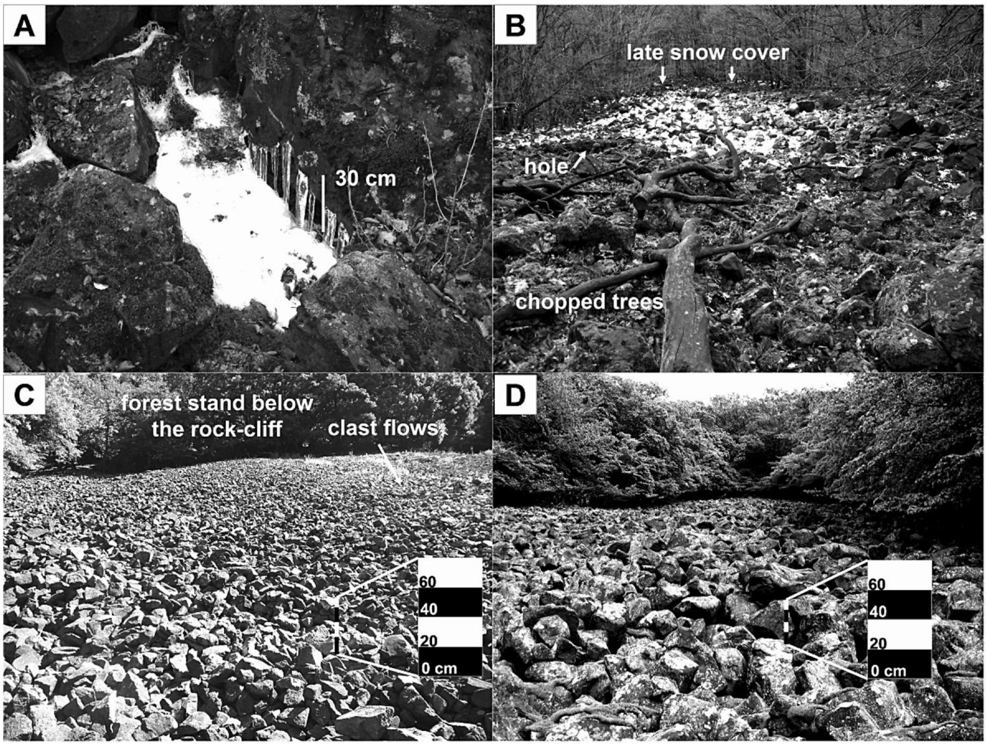


FIG. 2 - (A) Ice and snow in the ice hole at locality 3. (B) Downslope view of locality 1 during the period of last snow cover. (C) Locality 4 with small clast size. (D) Homogeneous boulder cover at locality 2.

plied the geomorphologic mapping (Demek & *alii*, 1972) of major landforms supplemented with the extraction of slope profiles at all four screes. During mapping, special attention was paid to micro-scale landforms (up to 10^2 m) that were possibly related to microclimatic variations (e.g., debris and clast flows, ice holes and ridges with lobes). The slope profiles were constructed to reveal the major changes in slope inclination and curvature. The results of these methods were compared with observations of microclimate-related features (see Section 2 in Methods).

TABLE 1 - Basic characteristics of the study localities

No	Shape	Clast size [cm]	Vegetation	Previous studies	Methods applied
1	stream	variable clasts (30-50, locally >100)	wide ecotone, flowers, mosses, woody debris		GTS, MM, SC, OMF, GM
2	oval	boulders (up to 100, often >100)	mosses, lichens		OMF, GM
3	frontal	boulders (around 50, locally >100)	trees, mosses, lichens, flowers, woody debris	Mareš (1959) and Kubát (1971). Mid-July T in 1969 (air 26°C, ice hole 2°C)	OMF, GM
4	complex	variable clasts (clast flows <10, boulders >100)	trees, flowers, woody debris	Raška (2010a)	OMF, GM

Explanation: T = temperature; GTS = geodetic measurement with total station; MM = microclimatic measurement; SC = snow cover mapping and snow depth measurement; OMF = observation of microclimatic features (ice holes and vents or warm funnels); GM = geomorphologic mapping and analyses of landforms.

The scree in locality 1 (fig. 1B), which was monitored with temperature dataloggers, was analysed in detail using the total station measurement. The aim of this measurement was to obtain precise data for topography analyses at the level of individual landforms. The measurement was carried out using a Trimble 5603 DR200+ total station, which offers contact-less (prism-less) distance measuring. We obtained 3D coordinates of 1,175 points from automatised prism-less measurement, 27 from manual measurement (supplementary points) and another 6 that served as orientation points. Applied over an area of 806 m^2, the final density of the points was 1.49 per square metre. The point cloud was filtered to exclude off-terrain points using a robust method of adjustment computing (cf. Kraus & Pfeifer, 1998). Finally, we analysed the dataset in ESRI ArcGIS 9.2 (3D Analyst). Based on an interpolation of the contour theme and the digital terrain model, we analysed the slope inclination and curvature of the scree, and we used these results to re-evaluate the geomorphologic mapping of landforms at the study site.

Where necessary, other methods for determining landform genesis were applied. These methods comprised sedimentological analyses of fine-grained clast flow (locality 4, fig. 1C), using the triangular diagram and C_{40} index (Sneed & Folk, 1958; Graham & Midgley, 2000) and a dendrogeomorphological indication of processes on scree slopes (rock-cliffs) (e.g., Bollschweiler & *alii*, 2008).

2. *Microclimatic monitoring*

We used dataloggers (MINIKIN TH, Environmental Measuring Systems, Czechia) with internal thermistors and humidity sensors to measure ground surface temperature (GST) at the upper and lower parts of the scree accumulation (fig. 5B). The temperature logging accuracy of the sensors was ±0.2°C. The humidity measurements (accuracy ±2 %) were taken into consideration as supplementary information about the thermal regime. The dataloggers were arranged in voids in the first layer of clasts (depth of ca. 20-30 cm) for a prolonged winter period from December 8 (2007) to April 18 (2008) with a logging interval of 1 hour. Both dataloggers were installed in protective sheets, enabling the air to circulate and preventing permanent contact between the dataloggers and the snow-melt water. Basic statistical analyses were applied to the dataset obtained from the measurements, including the running standard deviation (to determine the stability or lability of the microclimatic regime) and the determination of temperature fluctuation types (cf. Ishikawa, 2003).

The presence of microclimatic features (e.g., ice holes and vents) as well as the presence, spatial distribution and depth of the snow cover were observed and documented by digital photos. To express the spatial distribution of snow cover, we chose five phases from the entire monitored period. We transformed the oblique photographs, and we implemented them in a digital terrain model to enable an assessment of the approximate spatial distribution of snow cover patches in each phase. We used a small ruler to measure snow depth at the scree. Because the location and internal heterogeneity (different conditions for snow preservation) at locality 1 did not enable a relevant continual snow cover depth measurement, we used only the maximal value for each period of snow cover presence.

RESULTS

1. Topography of study sites

The geomorphologic mapping revealed various elementary landforms present at the studied localities (see fig. 3A). These landforms can be divided into the following groups. The first group is represented by landforms that predispose the basic topography of the scree (e.g., ridges, depressions, planar slopes, terraces). The presence and character of these landforms are preconditioned by the palaeotopography and surface morphology of solid bedrock. This factor is apparent in downslope depressions, which often continue to the forested surroundings of the scree. This type of landform was present at all four localities. The dynamics of these landforms were low and mostly occurred at the surface layer. Besides the occasional sliding and rolling of large boulders, the movement of the

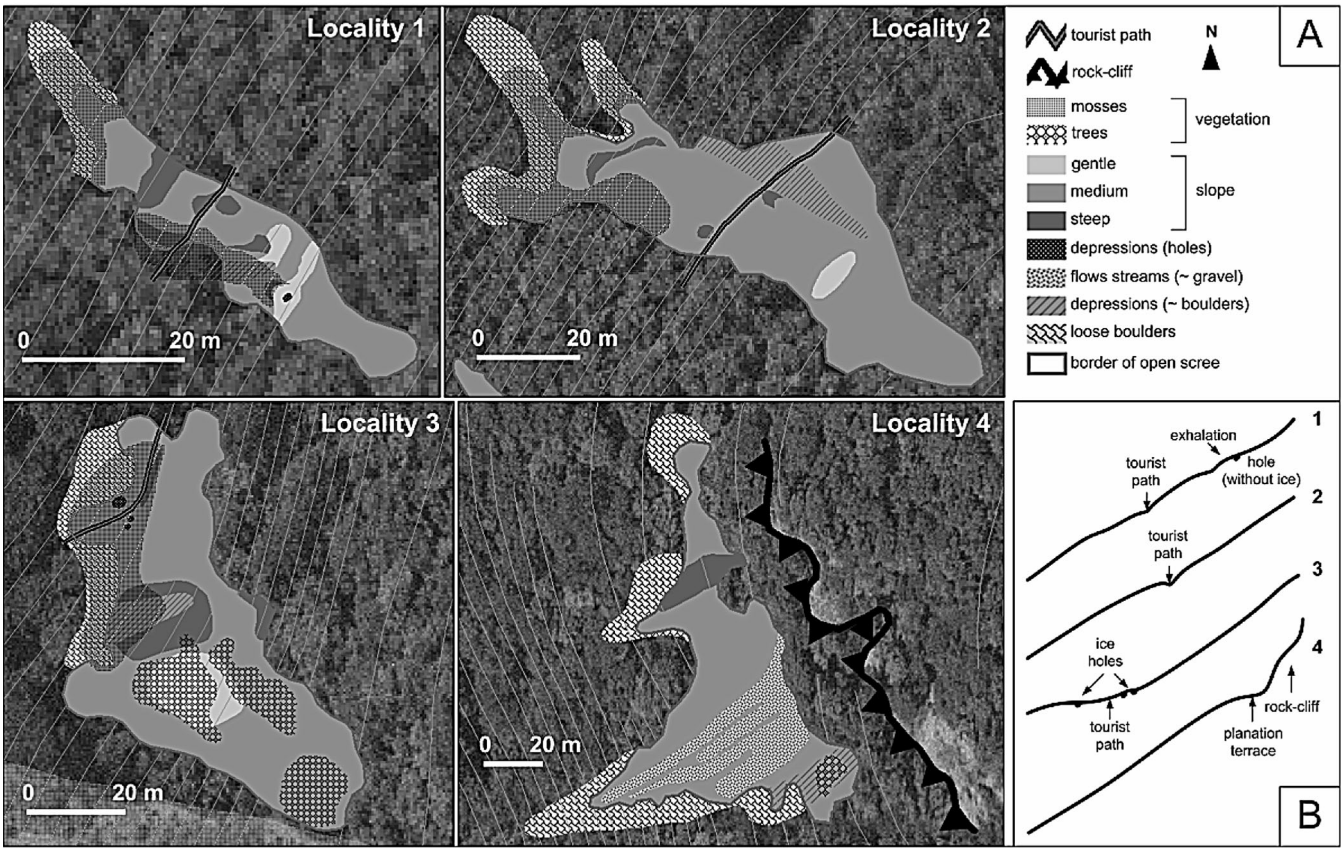


FIG. 3 - Geomorphologic maps of study sites.

clasts was caused by fallen (or chopped-down) trees (see fig. 2B) and animal trampling (mostly hordes of *Ovis musimon*), which is also typical of the dynamics of landforms in the second group.

The second group comprises landforms that resulted from surface dynamics caused by both natural and human-induced processes. These landforms increase the internal heterogeneity of scree slopes. The most frequent are small accumulations of boulders in the form of lobes (expressed as small, round areas of steep slope in fig. 3). Three localities (1-3) have been directly modified by human action as is apparent from a tourist path that crosses the central and footslope parts of the scree. Locality 4 represents the only scree with a preserved rock-cliff, clast flows and debris flows. As we assumed that the active flows might be related to the rock-cliff dynamics, we analysed the rock-fall activity using the dendrogeomorphological methods. We assessed the presence of surface scars on 67 trees standing below the rock-cliff in three distance intervals: 26 trees stood up to 2 m from the cliff; 19 stood from 2 to 5 m from the cliff; and 22 stood more than 5 m from the cliff. A total of 22 of the nearest trees were hit by rock-fall, followed by 15 and 10 in the second and third distance intervals, respectively. The identification of past rock-fall events was limited because the locality was subject to nature conservation, and only the small fallen trees could be analysed using destructive methods. We took sample discs from two young fallen trees. Visual analyses of sample discs showed the presence of scars going back up to 18 years. These results clearly prove rock-fall activity in the site. In addition to the rock fall activity, the debris flows were identified in the destroyed parts of the rock-cliff.

A specific sub-type of the second group of landforms is represented by those that are possibly microclimate related. Three holes with a diameter of about 1 m were present in the foot slope at locality 3. Another hole was formed in the upper part of the scree at locality 1. Locality 4 was typical of small clast flows that have similar morphologic characteristics, such as frost coated clast flows known from colder regions (Hétu & Gray, 2000). Therefore, we carried out a sedimentological measurement to analyse the origin of these clast flows. The analyses of 60 particles sampled in three longitudinal segments of the 3-m long clast flow showed a sorting of grains resulting in a finer and more homogeneous material present in the terminal lobe and coarse, heterogeneous clasts in the channel and source segment. The distribution of grains above and below the C_{40} line was, however, nearly equal, indicating the absence of frost weathering in the origin of the clast flow.

The extracted slope profiles showed significant differences among the studied scree slopes (fig. 3B). We distinguished the following three types of profiles: (a) linear to slightly undulating (localities 1 and 2), (b) slightly undulating with oncave this (i.e. convex) was a nispunt; all the abstract, diss.......... and conclusion duok the concave footslope, which is right foot slope (locality 3), and (c) linear with rock-cliff. The screes with profile types (a) and (c) continued downslope with loose boulders forming boulder streams.

2. Winter microclimatic regime

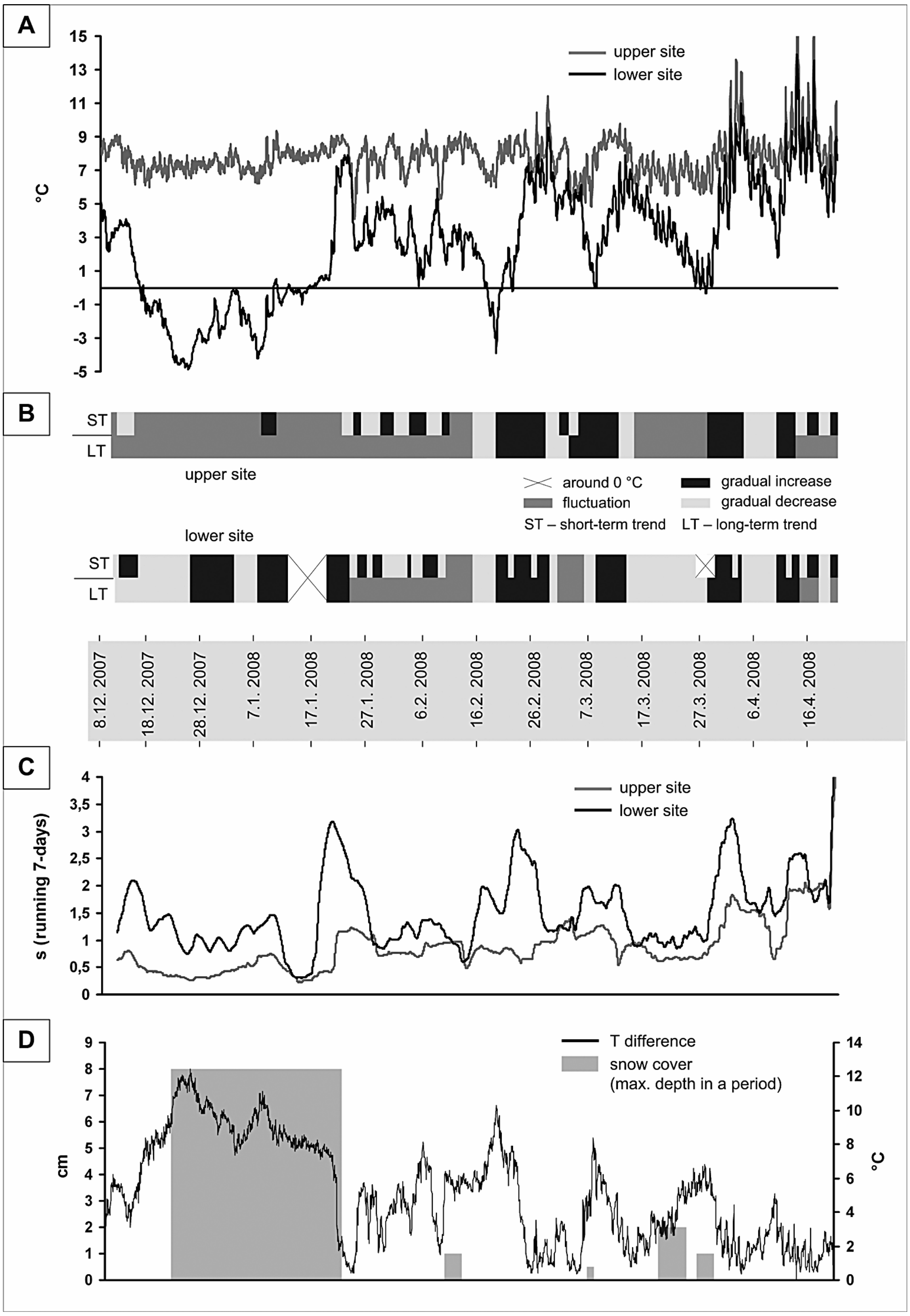
The results of the temperature measurements for the upper and lower logging sites at study locality 1 are shown in fig. 4A. The entire logging period can be divided into three phases. The first phase (December 8 to January 20) had the greatest differences in temperature between the upper and lower sites. The growing differences in temperature are apparent from the beginning of the logging period, i.e., before the first snow. This indicates the role of ambient air temperature in the internal, thermal regime of the scree. The following phase (January 21 to March 30) displayed more closely related temperatures, but some discontinuous differences were still apparent. In contrast to the previous two phases, the last phase (March 31 to April 18) demonstrated an almost identical development of temperatures at both logging sites.

Figures 4B and 4C provide a more detailed representation of the thermal regimes at both logging sites. Fig. 4C indicates a higher fluctuation of temperatures at the lower logging site caused by a faster reaction to air temperature changes. In contrast, the moderately fluctuating temperature at the upper logging site was due to the presence of a vent documented by snow cover mapping. Fig. 4B displays the differences in fluctuation regimes at both logging localities according to the types proposed by Ishikawa (2003) and adjusted by the authors to distinguish short-term and long-term trends.

The development of snow cover at locality 1 indicates that there were several different phases regarding the spatial extent of snow cover (fig. 5A) and its maximum depth (fig. 4D). The maximum depth of the snow (8 cm) was related to a continuous presence of snow cover during the 30-day period a few weeks after the beginning of the measurement. After this period, snow cover occurred in brief episodes with depths less than 3 cm. The last snow melted at the end of March 2008. The snow cover mapping also proved the presence of a vent at the upper part of the scree slope. The triangle-shaped vent (ca. 15 m^2 in extent) was present throughout the first period of snow cover. During the second period of episodic snow cover, snow was present in the form of small patches. The only exceptions were the larger accumulations adjacent to the former position of the vent. As supplementary data, the humidity regime at both logging sites demonstrated high values largely reaching the maximum possible humidity.

Observations of microclimate-related features were carried out at all four study sites. In accordance with former studies, we focused on the presence of exhalations (warm air vents), which are located mainly in the upper parts of screes, and on ice holes, which are usually located in the lower parts of scree slopes. We also looked for the presence of cold/warm air venting on other landforms in various parts of the screes (lobes, ridges and depressions). The presence or absence of observed features is summarised in table 2.

FIG. 4 - Microclimatic regime during the prolonged winter period at study site 1 (see fig. 1). (A) Temperatures at the upper and lower sites of the scree slope. (B) Types of temperature change according to Ishikawa (2003). (C) 7-day running standard deviation of temperatures at the upper and lower sites of the scree slope. (D) Differences in temperatures at the upper and lower sites of the scree slope and maximum depth of snow cover in each snow period.



DISCUSSION

1. The landform-microclimate relation within a single scree slope

The results of the microclimatic analyses carried out at locality 1 show that the regime of this scree has some features that are known from other sites, where the air circulation favours thermal anomalies throughout the year. We detected no ice holes or late (spring to summer) snow in the lower part of the scree or in the ice holes. In contrast, the vent (exhalation) of warm air evolved during the early snow cover period. We compared the data of thermal regime, snow cover occurrence and topography to determine the leading processes in the formation of the microclimatic regime of the locality.

Both the thermal regime and snow cover occurrence may be divided into three phases (see Section in Zesult 2).

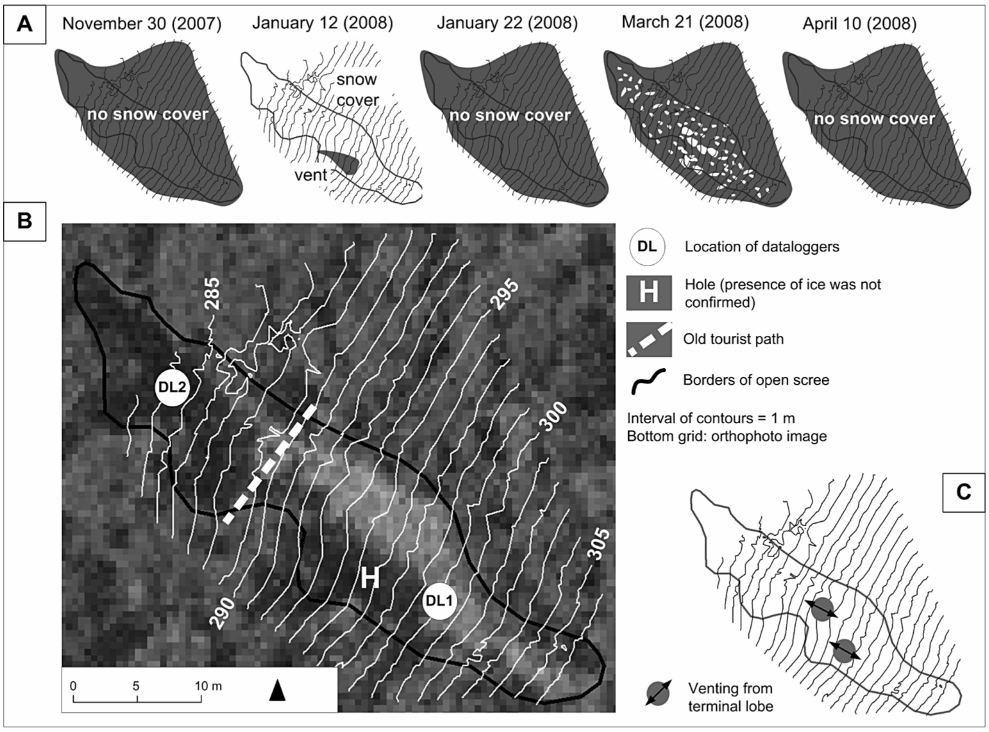


FIG. 5 - Spatial distribution of snow cover during the winter season and topography of study site 1 (see fig. 1). (A) Spatial distribution of snow cover. (B) Microtopography and positions of dataloggers. (C) Location of winter warm air vents.

TABLE 2 - Presence of microclimate-related features at study sites

Site process/ form	Nov 30 (2007) V	Nov 30 (2007) IH	Jan 12 (2008) V	Jan 12 (2008) IH	Jan 22 (2008) V	Jan 22 (2008) IH	Mar 21 (2008) V	Mar 21 (2008) IH	Apr 10 (2008) V	Apr 10 (2008) IH
1			x							
2										
3				x		x		x		x
4										

Explanation: site: number of study site according to Fig. 1B, V: vent at the upper part of a scree slope, IH: ice hole at the lower part of a scree slope (possibly also hole at individual terminal lobe), x: presence at the site.

These phases are based on differences in ground surface temperatures at the two logging sites in the case of thermal regime and on the variability of snow cover and snow depth. The thermal and snow cover phases corresponded in their time delimitation. This fact implies that there is a correlation between temperature and snow cover regime.

The microclimatic regime of the locality and its driving forces are explained in the following sequence:

(1) The first phase of high temperature differences at the logging sites relates to the continual snow cover at the scree. The relative spatial continuity of snow cover is due to mid-size clasts and the presence of organic material partly filling the voids in the surface layer of the scree. The vent evolved during this phase in the upper part of the scree, where the slopes of a terminal lobe (the lobe is expressed as a steep slope below the hole in fig. 3A, locality 1) adjoin the downslope depression. Nevertheless, fig. 4A shows that the differences between the thermal regimes at the upper and lower logging sites were apparent before the first snow cover. This result indicates that the ambient air temperature was the very first factor to induce the winter microclimatic regime at this locality.

(2) The exhalation of warm air, which had accumulated in the system of voids, was accelerated by long-term snow cover during the first phase of the thermal regime. The warmer air in the upper part of the scree slope prevented the preservation of snow cover, which was then limited to its surroundings. As the air in the voids was cooled by surface snow and descended into the deeper voids, it pushed the warm and less dense air to exit the scree at the nearest suitable location. The exhalation from the terminal lobe had both vertical and horizontal components and was close to a combination of the Balch effect (Balch, 1900) and the chimney effect (Kubát, 1971). According to Zacharda & *alii* (2007), the modes of air circulation patterns in low-altitude screes in the region may change during the year. Our results suggest that besides these changes in circulation patterns, the modes may also act together and influence each other.

(3) The second phase, with low temperature differences, correlates with episodic low-depth snow cover (the second phase of snow cover development). The highest volume of warm air from deeper voids was released during the first phase of the microclimatic regime. Other minor exhalations of warm air were possible via the void system in the surface layer of the scree because there was only a sporadic occurrence of snow cover.

(4) Finally, the third phase, with negligible temperature differences, was related only to the period of snow cover absence. Such a distinct relation between thermal regime and snow cover contrasts with findings from other regions

of higher altitudes (e.g., Julián & Chueca, 2007; Gadek & Kedzia, 2008).

2. The topography-microclimate relation - variances among the scree slopes

The relationship between the microclimatic regime indicated by specific features (ice holes and vents) and topography is explained using the profiles and geomorphologic maps of the elementary landforms of the studied scree slopes. The (micro)topography, the clast shape and size were the only significant geomorphic variables at the studied localities. In the following sections, the topography-microclimate relation is discussed from viewpoints of both temporal (section 2.1) and spatial (section 2.2) distribution.

2.1 *Linkages between geomorphic evolution and microclimatic regime*

The evolution of variable microclimatic regimes at the studied localities can be ascribed to their differential geomorphic evolution. The cascading sequence showing linkages from geomorphic evolution, topographic diversity and dominant geomorphic processes to microclimatic effects and its influence on recent dynamics of studied localities is described in the fig. 6. Firstly, the localities are distinguished according to their relative age. Significant differences have been detected between relative age of locality 4, on one hand, and other three localities, on the other hand (Raška, 2010b). The initial evolutional stages of all localities correspond to incision landslide model suggested by Palmquist & Bible (1980). The incision of the Elbe River and of its tributary, the Prucelsky brook, exposed high rock cliffs (rockwalls) composed of basaltic rocks. Initial evolution of these rock cliffs corresponds to transportational slopes of Selby (1982) with slightly varying ratio between the rockwall retreat and downslope transport. The recent topography of studied screes, however, indicates temporal succession in dominance of the rockwall retreat and downslope transport modes. The frontal and complex screes at localities 3 and 4 represent relics of rockwall retreat. Limited secondary movement of these screes was influenced by decrease in slope gradient at the foot slope (locality 3) and young stage of geomorphic evolution (locality 4). In contrast, elongated (oval and stream) screes at localities 1 and 2 were subject to concentration of clasts in slope depression after the destruction of rock cliffs.

The complete scree catena, including all topographical segments (see fig. 6), is preserved only at locality 4. This locality has the highest average slope inclination and the high disintegrated rock cliff together with limited extent of trees below the rock cliff are the factors resulting in high cliff instability index (cf. Magaldi & *alii*, 2007). The scree displays most intense surface dynamics, including active rockfalls and dry debris flows (cf. Raška, 2010a). These processes, in turn, influence distribution of clasts with different size and shape. Dry debris flows composed of smaller angular clasts limit evolution of air circulation pattern at this locality. The other localities, which have significantly lower average slope inclination, are formed by open scree segment and loose boulder streams. The higher relative age of these localities is indicated by total destruction of rock cliffs (cf. Hétu & Gray, 2000), and by predominance of boulders on the surface. Prevalence of boulders is traditionally ascribed to long-term sieve effect (Carniel & Scheidegger, 1974) and was confirmed in the studied region as well (Raška, 2010a). Boulders move separately by rolling and sliding, but the talus creep of a whole scree or its parts has to be taken into consideration. The openwork structure of boulder accumulations at localities 1, 2 and 3 predispose evolution of air circulation pattern and microclimate at all. Nevertheless, the type of microclimatic regime and its effects visible as ice holes and warm air vents during the winter period depends on clast size and slope profile (see section 2.2).

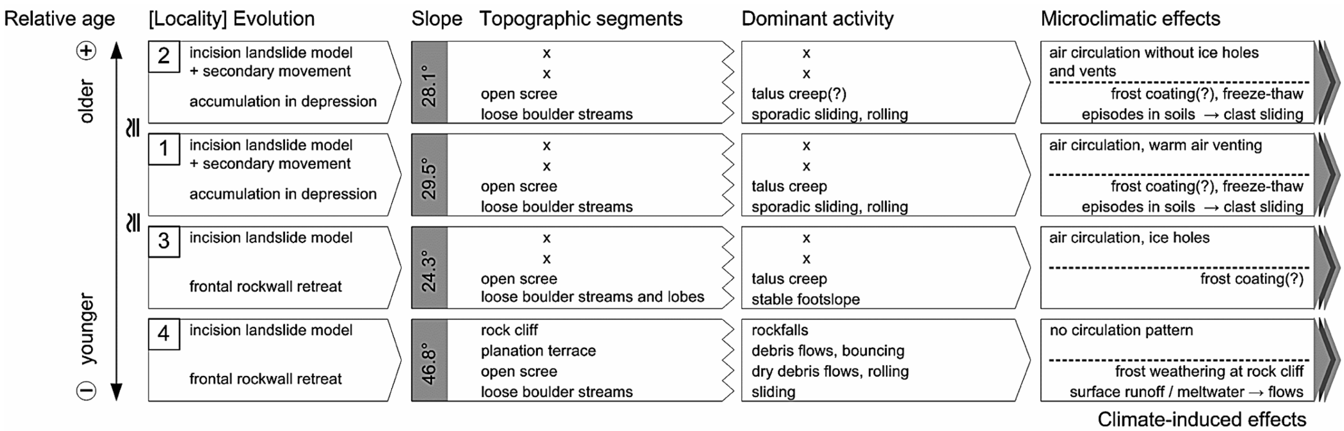


FIG. 6 - Spatiotemporal succession showing the linkages between geomorphic evolution, recent geomorphic processes and microclimatic effects at four studied scree slopes.

Note: the number of locality is in the square at the top-left; differences in relative age of the scree slope 3, 1 and 2 are not significant; secondary movement - subsequent intensive downslope movement of accumulation; slope - average slope inclination derived from DEM (dataset scale 1:10000).

2.2 *Factors influencing the presence of microclimate-induced features*

The ice holes developed only at locality 3, which has a concave foot slope accumulation built by large boulders. The presence of ice and snow in the hole at locality 1 was not proved during the research. The results only partly correspond to general conditions for the formation of freezing screes suggested by Gude & *alii* (2003; see introduction). The entire foot slope segment of locality 3 is covered with trees, flowers and mosses, and its inclination is similar to other studied sites without ice holes (sites sand 2). The presence of large boulders (blocks) with an open void system was only a valid factor for locality 3. Nevertheless, large boulders with a homogeneous matrix were present at locality 2, where none of the microclimate-related features evolved during the monitored period. The absence of microclimate-related features was similar to locality 4, which was built mostly by finer clasts and had a dynamic surface layer.

In contrast, the vent evolved only at locality 1, which had heterogeneous and predominantly mid-sized clasts covered by fallen leaves, mosses, flowers and woody debris. The role of clast size has been discussed by Kubát (1999), Cílek (2000) and Zacharda & *alii* (2007), who have noted that large clasts (boulders) favour air circulation within the scree. Our results, however, suggest that this relationship is more complex. The boulders are favourable to the formation of ice holes, but they may limit the development of vents in the upper parts of screes. Large voids between boulders prevent the formation of spatially continuous snow cover, and the warm air accumulated in deeper voids is not forced to exhale from a compact vent. This was the case of site 2, which had a deep, open void system and surface voids that were often more than 20 cm in diameter. The snow at the locality persisted only on the tops of the boulders, leaving the voids free. This resulted in the continual interaction of internal and ambient air temperature at the scree slope.

Regional insight into the topography-microclimate relationship is offered by a statistical evaluation of more localities. At the beginning of the 1970s, Kubát (1971) published a list of scree slope sites with the presence of ice holes and warm air vents (exhalations). This list is important because it is the only summary of sites made before the intensification of regional human impacts that could possibly influence the climatic variability of these sites. We assessed the altitude and orientation of 28 scree slopes sites located in Northern Czech Republic.

Figure 7 shows the altitudinal position of the sites represented by the lowest point of the scree and the peak of the slope. The column graph indicates the general orientation of the screes (northward, southward and east-west). The altitude graph shows that screes with ice holes are located at lower altitudes than the vents (exhalations). All of the ice holes are located at the foot slopes of screes or at screes with a foot slope position within a slope. While the presence of ice holes seems not to be conditioned by the orientation of slopes, screes with vents (exhalations) are

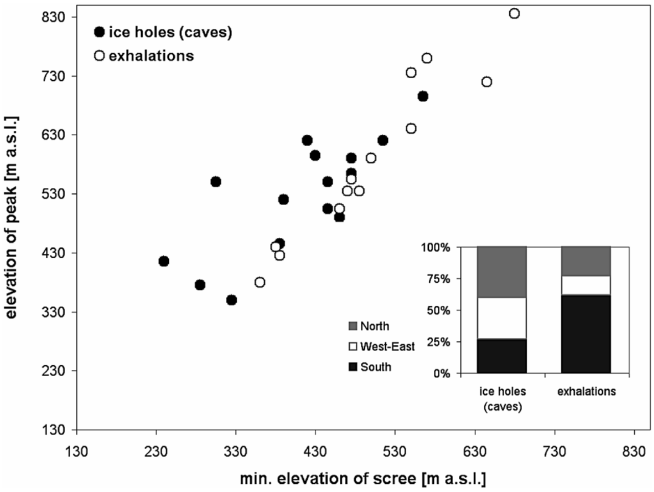


FIG. 7 - Geomorphic position of screes (localities in Northern Czechia) with specific microclimatic regime. Source: localities from Kubát (1971), geomorphic position by authors.

predominantly located on southern slopes. The reason is the higher incoming radiation, resulting in the oscillation of ambient air temperatures in the upper part of the scree (i.e., the part without vegetation cover). The ambient air temperature influences the internal air temperature of the scree and predisposes the formation of vents on topographically suitable locations (e.g., having appropriate clast sizes, lobes and elevations). In contrast, the ice holes are less influenced by ambient air temperatures as the incoming radiation is limited by vegetation from both direct (mosses, flowers, trees) and indirect (treetops) effects.

CONCLUSIONS

The present study offered analyses of winter microclimatic regimes at biogeographically significant low-altitude scree slopes in the Central-European highlands (Ceske Stredohori Mts.), and it discussed the relationship of the microclimatic regime to the topography at the studied sites. The sites were comparable in their general topography, all of them having approximately similar orientation, slope inclination and altitude. The regional climate and vegetation cover (European beech) was also comparable. Therefore, we focused on the variables that represented the topographical diversity of screes (slope profiles, elementary landforms, size of clasts). The results of geomorphologic mapping and microclimatic measurements (thermal regime) and observations (snow cover occurrence) were evaluated in a regional context using the assessment of all the known localities in the region.

Our results show that general factors that were formerly considered the most important for the formation of specific scree microclimatic regimes with thermal anomalies have to be reassessed. The most important factor influencing the formation of ice holes, which indicate possible sporadic permafrost in deep layers of scree, is the slope profile. All of the ice holes were formed at the scree slopes with concave foot slope accumulation. Such positions are usually preconditioned by the palaeotopography of the site. The limiting role of vegetation in the formation of ice holes is minor and needs to be discussed further according to the present species or Raunkiær´s plant life-forms. Large boulders are the predisposing factor for the formation of ice holes. The factors influencing the formation of air circulation in the upper parts of screes (e.g., warm air vents) are quite different from those mentioned above. A major role is played by the general slope topography (orientation, slope inclination), as well as by elementary landforms present on the scree. During the snow cover period, the warm air is exhaled from the tops and sides of the lobes. The geomorphic mapping indicated that such elevations adjoin downslope depressions, which are typical of cold air accumulation and flow. The role of clast size is more difficult to assess. Small clasts did not allow the formation of open void systems with intense accumulation of internal air, whereas large boulders prevented the formation of continuous snow cover. Future study, therefore, should determine precisely the clast size categories allowing or preventing the persistence of spatially continuous snow cover.

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