Rožnovský, J., Litschmann, T., (eds): Mendel a bioklimatologie. Brno, 3. – 5. 9. 2014,
ISBN 978-80-210-6983-1

The thermal regime of ice pits of the Boreč hill

Luboš Türkott[1]; Eva Martinčíková[2]; Vera Potop[1]

[1]Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, Department of Agroecology and Biometeorology, Prague, Czech Republic, turkott@af.czu.cz
[2]Institute of Computer Science, Academy of Sciences of the Czech Republic, Prague, Czech Republic

Abstract

The ecological stability of the sites with stenoec organisms is important factor for maintaining them at given location. Phonolite system of the Boreč hill creates a unique labyrinth of vents. Thermal anomalies occur during the year in the fissure system and create specific microclimate. Flow direction is given by the temperature gradient inside and outside of the system. The lower part of fissure system is located in the debris fields, while the upper part on top of the hill. Phonolite rocks are cooled down by air streaming from the debris fields during the winter. Direction of the air flow changes in the spring and summer. The cold air is exhaled from these vents on the lower parts of system and creates ice pits with the typical vegetation.

Key words: ice pit, air temperature, Boreč hill, ventarole

Introduction

The occurrence of ice caves in the world is quite abundant. Ice decoration of the karst formations is largely described. Ice caves and ice pits can also emerge in pseudo-karst areas. In the Czech Republic several sites with ice pits are described. Kubát (1972, 1974) describes the exhalation with the formation of ice pits in the Giant Mountains on the Velká kotelní jáma, Malý Šišák and Malá čertova zahrádka. Váně (1992) observed strong emissions at Lake Mountain near Klášterec nad Ohří. The highest incidence of this phenomenon in the Czech Republic can be found in the Czech Central Mountains. Czech Central

Mountains is the largest volcanic area in the country. Geologically consists mainly of basalt, in a smaller amount of trachytic and andezit rock. Outflow of magma into the softer layers and their subsequent erosion formed the shapes of so-called lakonits - one of these is the Boreč hill. In this pile of phonolite (449 m above sea level) can be found a large system of fissures called ventarols. According to Váně (1992), the fissures were created thanks to the high viscosity of the lava flow, which is characteristic for this type of rock. Fissures are formed both parallel and perpendicular to the surface. Sufficient height difference and continuity of fracture system, which has one outfall at the bottom part of the hill and the second at its top, creates air flow inside the system. Several possible causes of the airflow in ventarols are described. The most common are follows: (1) Balch effect (Balch, 1900; Zacharda, 2007) the influence of gravity on air flow according to its specific weight; (2) chimney effect (Kubát, 1974 Wakonigg, 1996); (3) interaction with the atmosphere according to the current synoptic situation (Váně, 1992); (4) the influence of latent heat based on consumption and releasing of latent heat during evaporation and condensation (Wakonigg, 1996); (5) impact of geothermal energy (Schwarz, 1959). Váně (1992) assumes that the direction and strength of the airflow inside the system depends on the temperature gradient. Air vents at the top of the Boreč hill are especially noticeable in winter, when vapor is exhaled and during the snow periods, when the snow is melted by the warm air. Water vapor condenses on the vegetation around vents and creates frosting. The air is inhaled in the scree slope at the bottom of the hill. Direction of the air flow in fracture system turns back with increasing ambient air temperature and ventarols on top of the hill start to inhale the air. Cold air is blown out in the scree at the foot of the hill and land creates ice pits that can be observed until late spring or early summer. The temperature of the turning point (i.e. changes of the airflow direction) is variable over time. The drop in winter temperature in the system significantly decreases when the hill cools. Therefore, in early spring the direction of the airflow changes, when the temperature of the ambient air is around 12 °C, compared to that in the autumn around 16 °C, because the hill accumulates heat during the summer (Pospíšilová, 2013).

Ecological stability of these systems provides unique conditions suitable for stenoec organisms that benefit of the warm and humid air at the top of the hill in the cold period of the year. The most representative species is inconspicuous liverwort *Targionia hypophylla* L., a thermophilic species widespread in regions with a Mediterranean climate. There is only one locality in the Czech Republic, where *Targionia hypophylla* L. can be found - on the top of the Boreč hill. It is a relic of the Tertiary flora, which survived an ice age and is maintained only thanks to special microclimatic conditions that are caused by the convection in ventarols.

Its developmental stages and the life cycle are bound by the direction of flow in the fracture system. *Targionia hypophylla* L. vegetates at the period, when the warm and humid air is exhaled in its vicinity and the water vapor condensates in the ventarol vents. This occurs outside the growing season of the vast majority of plant species. The main growing season of *Targionia hypophylla* L. is from autumn to spring (Türkott, 2013). Vegetation in the lower vent of fracture system inside ice pits is similar to species of damp and cold mountain habitats. Among of vertebrates it is possible to find a number of endangered species (*Salamandra salamandra* and glacial relict invertebrates *Pterostichus negligens).* The occurrence of these stenoec species on the Boreč hill is dependent on the specific climate and microclimate of the site and any unbalanced of these conditions would be risky.

Materials and methods

The research started in 2011 and was performed till 2013. Boreč hill is located in the Lovoš Highlands in Czech Central Mountains. Environmental features were monitored in several points of the fissure system. Data collected from the mobile Tinytag data loggers were used to measure the air temperature in the ice pit at the bottom of the fissure system. The pit is located in the scree slope with a volume of 0.03 m^3. Temperature sensors PT100 were located in the cave. At the same time shielded sensors measured the air temperature at 2 m height above the ground. The temperature was measured every hour of the local time from April 3, 2012 to July 5, 2013. Average daily ambient air temperature, average daily air temperature of ice pits and differences between of air temperature both inside and outside ($\Delta t = t_{ins} - t_{out}$) were calculated. The fluctuations and extreme temperatures during study period were determined. Data were statistically processed in Statistika 12 software.

Results

The airflow in the ice caves changes the direction during the year. The change of the flow direction is called a turning point and it is dependent on the temperature gradient. The turning point can be observed by decreasing variations of the t_{out} and the t_{ins} of the ice cave. The change of the direction does not allow performing regression analysis of the entire data set; it must be divided into shorter periods without the turning point. It is ideal to analyze the data between extreme values close to turning points where the flow is steady and unidirectional. The last turning point was observed on April 16, 2012 and October 7, 2012. The period between these reversals is called the summer flow regime. The t_{out} is significantly higher than the t_{ins} of the fissure system and the air is inhaled to vents on the top of the hill. The flow is driven by the Balch effect, when the heavier cold air flows out of the system through ice pits in the bottom of the hill. Consequently, the ice formations are created in ice pits and they remain here until the summer (Figure 3b). The summer flow regime in 2012, the highest ambient air temperature was 38.3 °C at 5 p.m. local time on 20 August. Whilst the temperature of the air exhaled in the ice cave was 2.3 °C and the highest Δt was -36.0 °C. At this time, the absolute maximum air temperature was exceeded on many climatological stations in the Czech Republic and new temperature (40.4 °C in Dobřichovice) record in the CR was measured. The smallest temperature difference (0.6 °C) between ambient air temperature and the temperature inside of the ice pit was measured during the spring turning point on April 17, 2012 in the morning, when the air temperature was 0.0 °C, and the temperature in the ice pit was -0.6 °C. The highest temperature inside (6.9 °C) of the ice pit in summer flow regime was measured on September 12, 2012 and October 7, 2012 at 10 a.m. and 11 a.m. local time, respectively. The lowest ambient air temperature (-0.5 °C) and the lowest temperature of the ice pit (-1.8 °C) were measured on April 18, 2012 at 6 a.m.

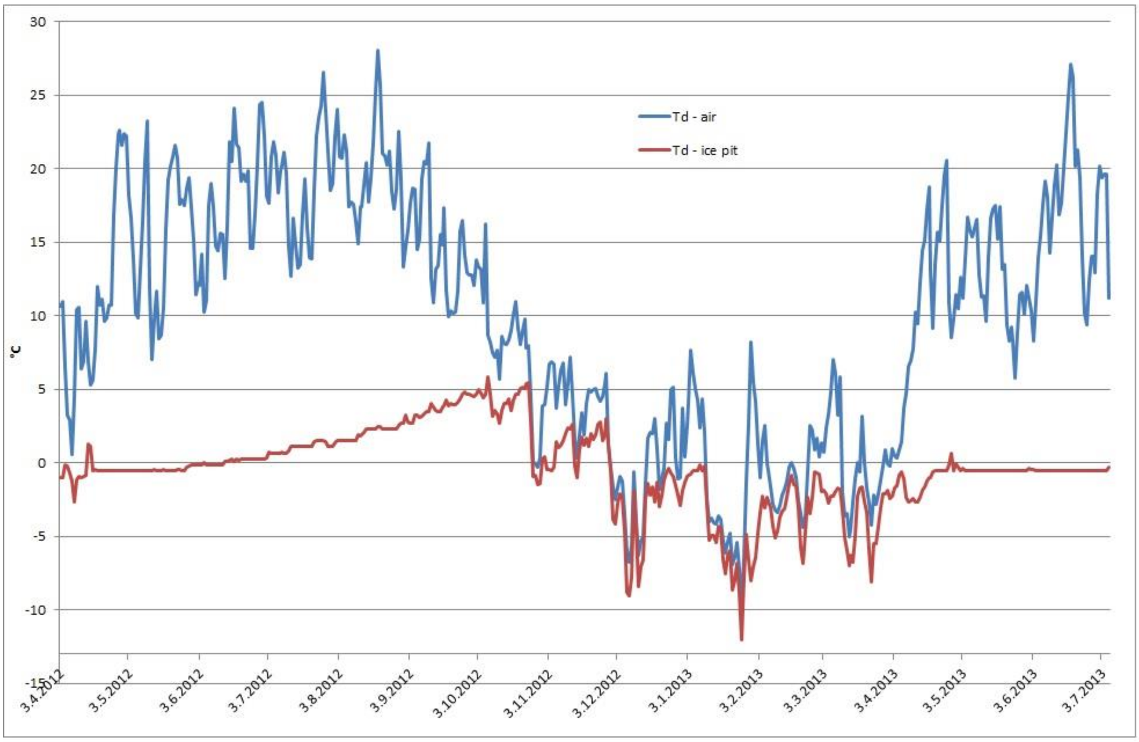

Fig. 1 The average daily ambient air temperature and temperature inside of the ice pit.

The interface period between summer and winter flow regimes to occur so-called mixed regime. In the short time intervals the air flow direction turns back in this period or the flow stops for a particular period of time. Temperature of the turning point is different for spring and autumn season; its temperature decreases during winter as the rock cools down. Therefore, in the early spring lead to change of the flow direction even at the t_{out} was only 12 °C. The fall turning point temperature was around 16 °C, because the rock accumulated the heat during the summer.

Winter flow regime (Fig. 3a) is based on air intake through ice pits and exhalations through vents on the top of the hill. The Δt achieved the highest values in periods of heavy frost, when the flow direction is invariable, upward and exhalations are strong. The driving force of the flow is mainly a chimney effect, supplemented by the influence of the current synoptic situation and latent heat. The temperature of ice pits strongly depends on the ambient air temperature in this period and the difference between them is small. The winter mode measurements took place from October 17, 2012 to April 5, 2013. During the winter flow regime, the highest measured temperature in the ice pit was 5.8 °C (October 21, 24 and 25). The lowest temperature was -14.6 °C (January 26, 2013). The lowest air temperature outside of the ice cave (-12.1 °C) was measured on the same day. On 25 and 26 January 2013 were the coldest days of the winter season 2012/2013 in the Czech Republic.

The ice pit average temperature for the period from April 3, 2012 to July 5, 2013 was -0.4 °C, while the highest and lowest measured temperature were 6.9 °C and -14.6 °C, respectively. The lowest ambient air temperature during the study period was -12.1 °C. The fact that the air exhaled out of the fissure system was colder than the ambient air could indicates a presence of permafrost in the bottom parts of the Boreč hill and the existence of another mechanism of cooling of the exhaled air. Regression analysis indicated a low dependence of the ice pit summer temperature on the ambient air temperature (Figure 2a).

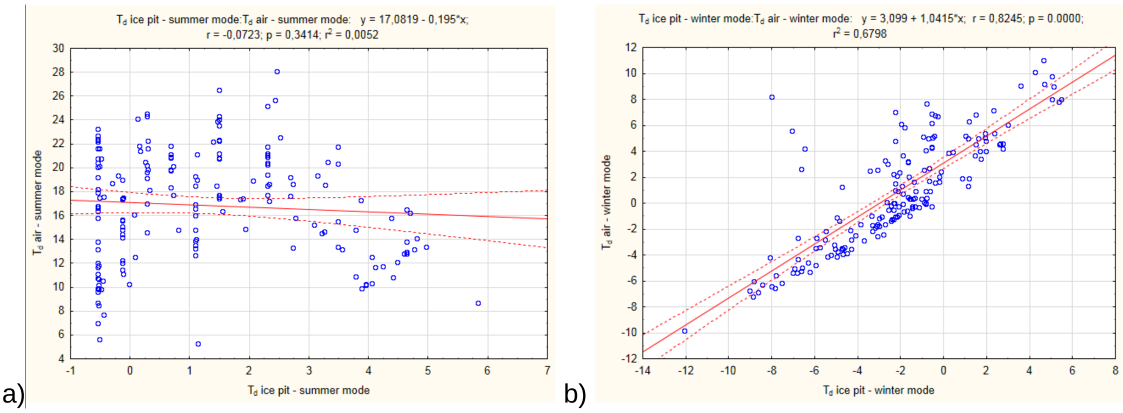

Fig. 2 Graphical representation of data used for statistical calculations of summer (a) and winter (b) air flow regime.

Ice pits temperature strongly depends on the ambient air temperature during the winter. The correlation coefficient (r) was 0.825 and the r^2 fits 0.68 (Fig. 2b).

Fig. 3 Ice pit in winter (a) and summer (b) air flow regime.

Discussion

The average air temperature in the ice pit was -0.4 °C for the measured period. Fialová (2012) stated that the average temperature in one of the ice pits was 0.52 °C and considers the Boreč ice pit is the coldest in compared with others in the Czech Central Mountains. The fact that the lowest temperature measured in the ice pit was lower than the lowest measured ambient air temperature, supposes the existence of permafrost at the bottom of the fracture system. It also confirms the presumption of Režný (1966) and Váně (1992) that ice pits are independent on the air flow dynamic of the whole system to some degree.

Režný (1966) studied fissure ventarols with similar microclimatic regime near Kostelec nad Orlicí. Režný (1966) believes that it is not possible to reveal the structure of the underground ice caves without an underground exploration, but claims that they are not involved in the overall dynamic system. It is assumed that the vents are closed with ice and snow in winter, while in the warm season they are able to emit only a part of undercooled air from the cavities, creating a static counterpart to the main system of fissures with the dynamic regime. Tanaka (2000) examining the microclimate of Nakayama Wind-Hole in Japan claims that in winter the coolness is stored in the scree, while in summer is protected against warming up by the stable stratification.

When the difference between the temperature of ambient air and the temperature inside of the fissure system decreases, the mixed air flow regime was turns up. It leads to frequent changes in air flow direction, and the air flow often completely ceases. As stated by Váně (1992), the whole system can be influenced by the current synoptically conditions. According to Faimon et al. (2011), other characteristics are also very important for the speed and direction of air flow in the system, such as wind strength and direction, orientation of the vent to the wind direction, the presence of vegetation near the vents, humidity – atmospheric and in particular ventarols.

Conclusion

The results of the measurements demonstrated a high storage capacity of the fissure system of the Boreč hill and also the possible existence of permafrost, which can cool down the air exhaled from the ice pits. The air flow in the system is driven by the Balch effect in summer regime and mainly by the chimney effect in winter. The flow direction depends on the temperature gradient between the ambient air and the air in the fissure system. Changing of the flow direction (turning point) varies according to the current temperature of the rock. The lowest temperature in the ice pit for the period from April 3, 2012 to July 5, 2013 was -14.6 °C, which is lower than the lowest measured ambient air temperature (-12.1 °C). The average temperature in the ice pit was -0.4 °C.

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Acknowledgement

This work was supported by Institutional Support Program for Long Term Conceptual Development of Research Institution provided by Ministry of Education, Youth and Sports of the Czech Republic.

Souhrn

Ekologická stabilita lokalit s výskytem stenoekních organismů je důležitým faktorem pro jejich setrvání na daném stanovišti. Puklinový systém znělcové kupy Boreč vytváří unikátní labyrint průduchů, v jejichž vyústění dochází během roku k teplotním anomáliím, které vytvářejí specifické mikroklima. Směr proudění puklinovým systémem je dán gradientem teploty uvnitř a vně systému. Dolní část puklinového systému se nachází v suťových splazech a horní část na vrcholu kopce. V ústí systému byla měřena teplota proudícího vzduchu a byl sledován gradient teploty vydechovaného a vdechovaného vzduchu. Při zimním režimu proudění je vzduch nasáván v suťových splazech, uvnitř systému ohříván a vydechován na vrcholu kopce. Hnací silou proudění je zejména komínový efekt. V tomto období byla zjištěna velmi silná korelace teploty v ledových jamách a teploty vzduchu. Letní režim proudění spočívá v nasávání vzduchu na vrcholu kopce, jeho ochlazování od předpokládaného permafrostu uvnitř kopce a následné exhalaci v ledových jamách suťových splazů. V tomto

případě je hybnou silou Balchův efekt. Nejvyšší rozdíl mezi teplotou vzduchu a teplotou exhalovaného vzduchu v ledových jamách byl 36,0 °C, kdy teplota vzduchu byla 38,3 °C a teplota exhalovaného vzduchu 2,3 °C. Na rozhraní letního a zimního režimu proudění mluvíme o tzv. smíšeném režimu. V krátkých časových intervalech se v tzv. bodech zvratu směr proudění otáčí o 180°, popřípadě proudění na určitou dobu ustává. Teplota jarního a podzimního bodu zvratu byla 12 °C resp. 16. °C. V bodech zvratu je teplotní rozdíl mezi teplotou vzduchu a teplotou uvnitř ledové jámy nejmenší. Průměrná teplota v ledové jámě za období 3.4.2012 až 5.7.2013 byla -0,4 °C, nejvyšší 6,9 °C a nejnižší naměřená teplota byla -14,6 °C. Nejnižší naměřená teplota vzduchu mimo ledovou jámu byla za sledované období -12,1 °C. Fakt, že naměřená minima exhalovaného vzduchu puklinovým systémem dosahují, v porovnání s teplotou vzduchu, nižších hodnot ukazuje na možnou přítomnost permafrostu ve spodních partiích vrchu Boreč a na existenci dalšího mechanismu ochlazujícího exhalovaný vzduchu.

Contact:
Ing. Luboš Türkott, Ph.D.
KAB FAPPZ ČZU v Praze
Kamýcká 129, Praha 6 – Suchdol, 165 21
e-mail: turkott@af.czu.cz
telefon: +420224382783