On peculiar properties of Winter Air Circulation in Kulogorskaya Cave System

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Summary: The caves of the Kulogorskaya cave system show distinct seasonal ventilation patterns, where all known entrances serve as “lower” entrances for the ventilation system. The caves are covered by approximately 15 meters of gypsum rock, followed by 3 meters of broken carbonates and up to 3.5 meters of quaternary sediments. The surface above the cave system is densely covered with sinkholes, but all of them are turf-covered and do not exhibit visible aerodynamic activity. This raises the question of the nature of the upper entrances to the cave ventilation system. Our research suggests that in the Kulogorskaya cave system the upper entrances to the ventilation system are the turf-covered sinkholes having air permeability due to the presence of a "corrosive randkluft”: a 5 -15 mm space between the vertical walls of the sinkholes and the filling material. The existence of such cavities was found when one of the sinkholes was excavated to form an artificial entrance (the Well) to the remote part of the cave. The Well is larger in cross-section than the “randkluft” and in the winter plays the role of a lower entrance, despite its geometrical position as an upper entrance. To prove the existence of air circulation via sinkholes we measured the soil temperature at sinkholes and found positive temperature anomalies which cannot be explained by the geometry of the sinkhole alone.

Introduction

The Kulogorskaya Cave system is situated in the Pinega district of the Archangelsk region in the northern part of Russia. The cave system is studied by Speleologists from Archangelsk, St. Petersburg, Moscow, Tver and other cities under the guidance of the Archangelsk Speleological Association “Labirinth”.

The climate of the area is quite cold. The annual average air temperature is +0.2 °C, the annual average precipitation is 560 mm. The winter is 140 days long, from November till March; the coldest month is January with an average temperature of -13 °C. The summer spans from end of June to the beginning of August, the hottest month is July, with an average temperature of +15.4 °C. The air temperature in the static zone inside caves is +2.5 °C.

The Kulogorskaya cave system is developed in gypsum rock which forms a plateau. All natural cave entrances are located at the bottom of the plateau ledge. The geological cross-section of the plateau consists of about 15 meters of gypsum rock, followed by 3 meters of broken carbonates and up to 3.5 meters of quaternary sediments (figure 1).

The average number of sinkholes above the cave system is around 3000-4000 per km^2, sometimes exceeding 10000. Almost all sinkholes are tuft-covered. None of the sinkholes show any visible signs of aerodynamic activity. There are 7 known caves in the area, with a total length above 22 km.

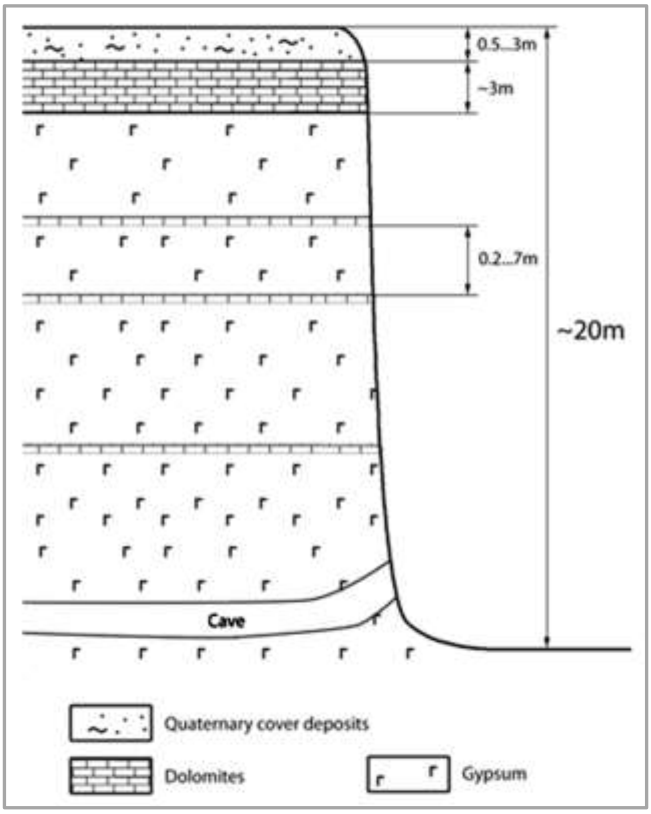

Fig. 1: Geological conditions.

Besides the natural entrances to the caves, there is an artificial one. In 1990 one of the sinkholes was excavated and the Well was build, connecting the surface with a remote part of the K-13 cave. It is about 20 m deep and has a minimal cross-section of 0.6x0.6 m at the bottom.

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The cave system shows a distinct seasonal ventilation pattern, where all known entrances serve as a "lower" entrance for the ventilation system, inhaling air in winter and exhaling in summer. Such a circulation system is common for open karst, however in the region of Kulogorskaya cave system there are no open air vents from the cave to the surface. This raises the question, what serves as an upper entrance for the cave circulation system?

Even more interesting is the aerodynamic situation around the Well. Although it is built as an upper entrance to the cave system, in winter it inhales cold air. No opposite air flow was observed inside the Well.

Vertical air filtration

Seasonal air circulation patterns, observable at natural cave entrances, require other entrance(s) to serve as upper entrance for the circulation system. More than 30 years of research suggest that the total number of sink-holes with bare gypsum rock in the area is not more than 10. And even they do not show any visible signs of air flow.

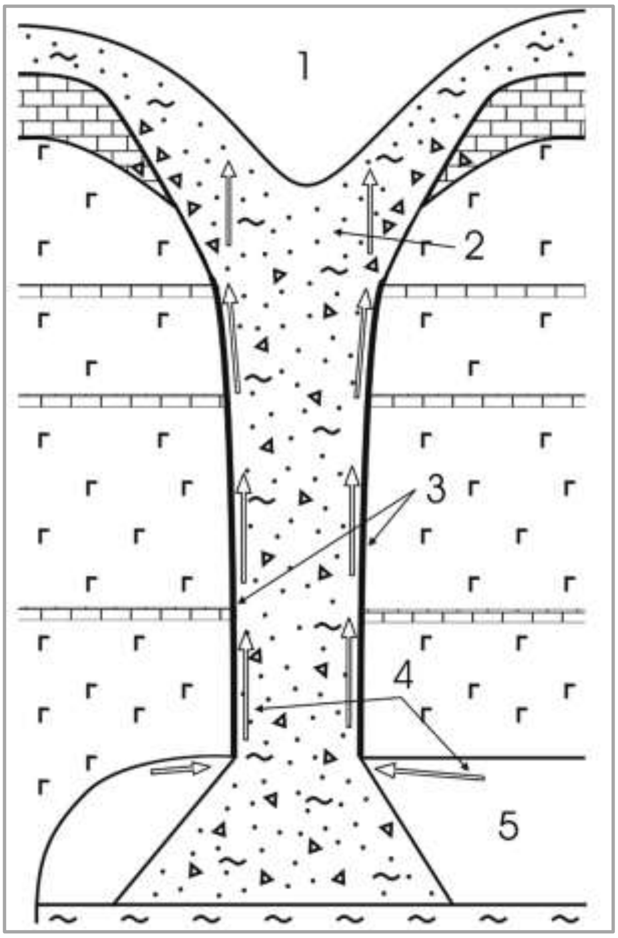

Fig. 2: Winter air circulation at sinkhole
1 – sinkhole, 2 – zone of air filtration,
3 – randkluft, 4 – air flow, 5 – cave.

So, the question of the upper entrance for the cave air circulation system remained open till the construction of the Well in 1990. For the construction the sinkhole and the tube below where excavated. The tube was found to be filled with a mixture of quaternary sediments and broken carbonates. It was also found, that between gypsum walls of tube and filling material there is an air-filled space 5-15 mm wide, which we call "corrosive randkluft". The walls of the randkluft were covered with grains of sand, likely to be transported by the water during spring snow melt.

Such a randkluft can provide air flow from the cave to the depth of 3 to 4 m at the sinkhole bottom. The air can penetrate the remaining layer of well-washed sandy loam.

We believe, that a large number of such randklufts below sinkholes serve as upper entrances for air circulation (fig. 2).

The reason of randkluft existence is likely to be the high rate of gypsum rock dissolution.

Air circulation and the Well

In autumn the area around the Well is separated from the lower entrance by high levels of water in the Siphon area. At this time a separate air circulation system starts working around the Well.

However, when water levels decrease in winter both systems continue to operate independently of each other, with both, the natural entrance and the Well working as "lower entrances" for air (figure 3).

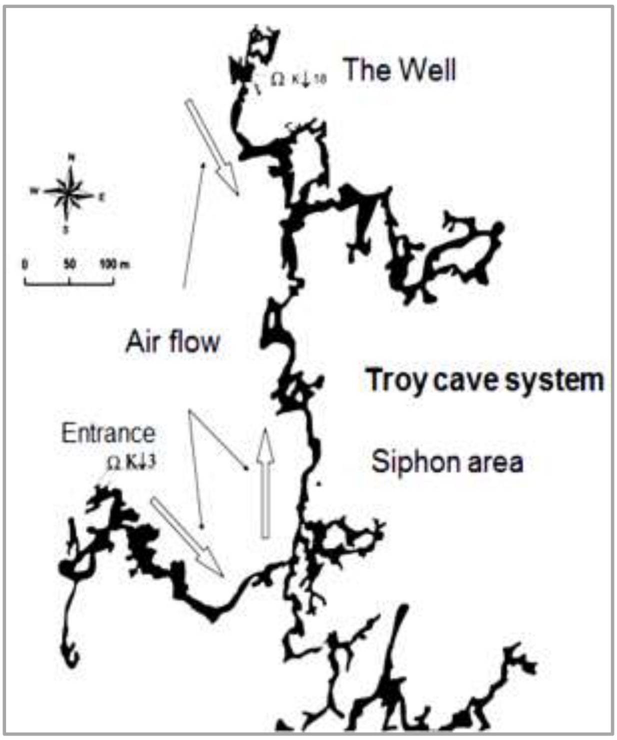

Fig. 3: Winter air circulation in K-13 (Troy) cave.

This situation can be explained as follows. When the outside air temperature drops below the temperature of the rock (2.5 °C) the cold air displaces warm air inside the volume of the Well. So, the cold air reaches the level of the cave and the pressure of the cold air column inside the Well pushes air into the cave. At the same time, the temperature of air located in the narrow vertical slits of randklufts is determined by the temperature of the rock, so that air is lighter than the cold outside air (and the air located in the well) and is displaced upward (figure 4).

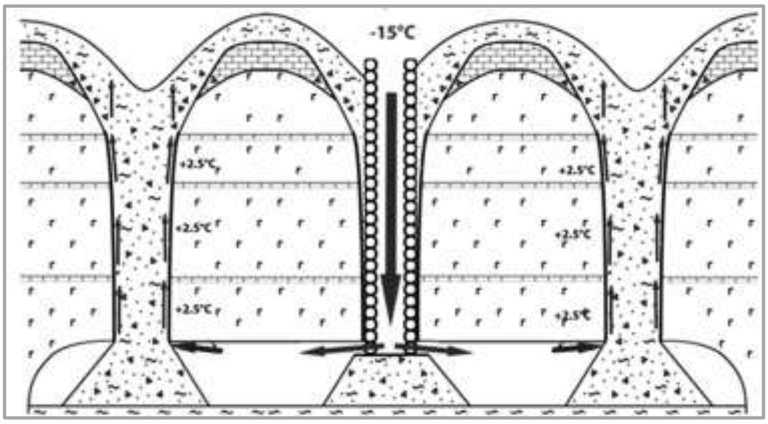

Fig: 4: Winter airflow in the Well.

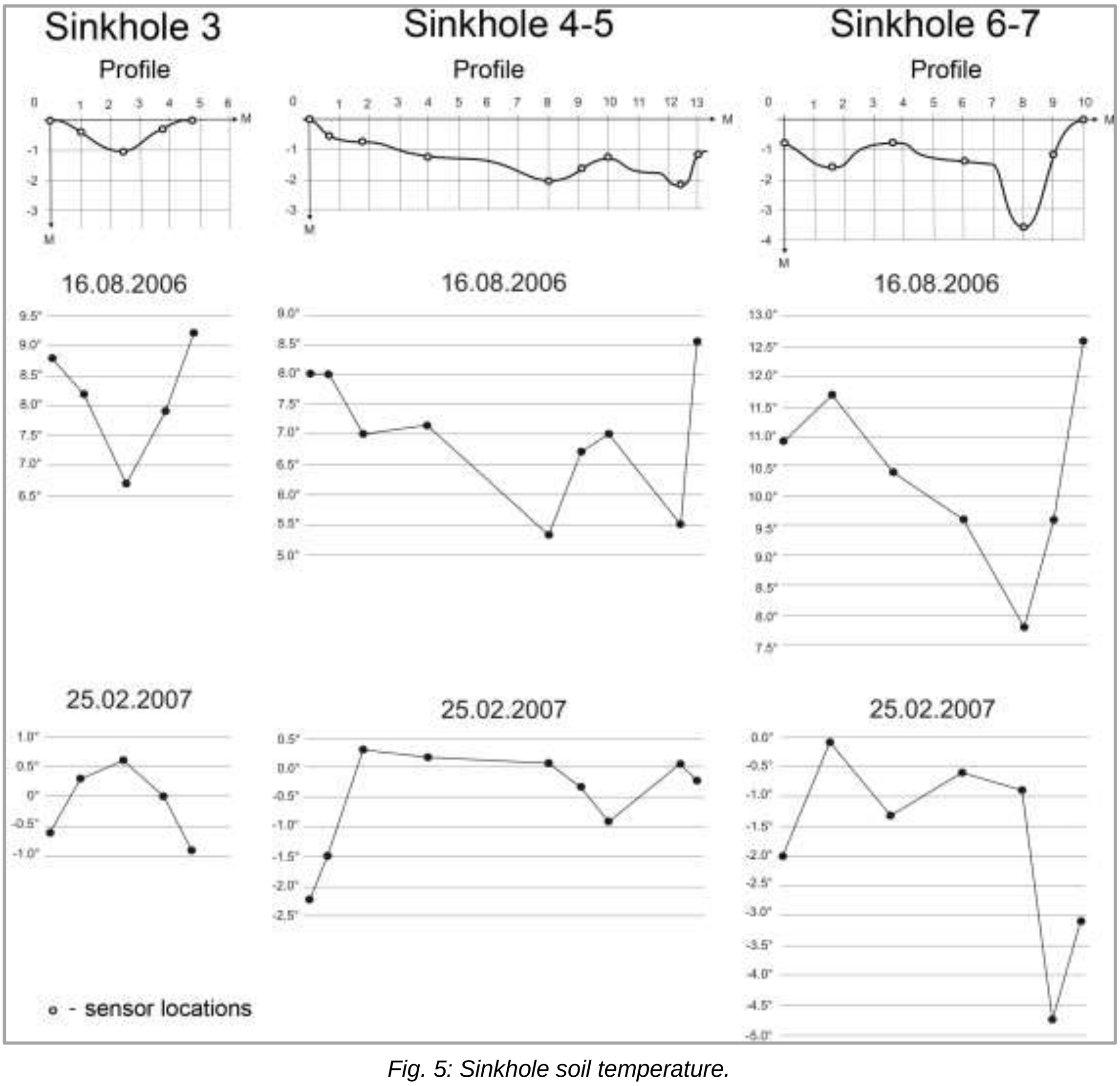

Fig. 5: Sinkhole soil temperature.

Sinkhole temperature measurements

Since the speed of air flow inside the cave is below a measureable level and direct observations in randklufts are not possible, other means are required to test our hypothesis.

One of the consequences of air infiltration at the sinkhole bottom should be an increase of soil temperature both in winter, when warmer air from the cave is exhaled, and in summer, when hot air from the atmosphere is inhaled.

In order to check this we equipped about 20 sinkholes with temperature sensors and made a series of measurements in different seasons.

For measurements we have used KTY83-110 positive temperature coefficient thermo resistors [1]. The sensor resistance is first calibrated at 0 °C using a snow-water mix, and then the temperature can be derived from the resistance reading using coefficients provided in the datasheet. The low price of the sensor allowed us to equip many stationary measurement points inside and outside the caves. The sensors for measuring sinkhole soil temperature where buried at a depth of 0.3 m.

Most of the sinkholes show temperature profiles which are not correlated with the sinkhole geometry or other external features. Fig. 5 shows profiles of some sinkholes and temperatures measured during summer (16.08.2006) and winter (25.02.2007). Outside air temperatures at the days of measurements were +14 °C 16.08.2006 and -15°C 25.02.2007, respectively. The sky was cloudy, so temperature anomalies cannot be due to uneven heating by the sun.

A characteristic feature of a ventilating sinkhole in the summer may be a higher temperature at the sinkhole bottom relative to a nearby, less deep sinkhole (see crater number 7). In winter, the picture is less clear, probably because of a much smaller difference between the temperature of the air entering from the cave below (2.5 °C) and the soil temperature under a layer of snow (from -0.1 to -3.1 °C). However, sinkholes number 4 and 5 show abnormally high temperatures at the bottom and even at the slopes, regardless of depth, which in our opinion is the evidence of heating of these sites by air-heat flux, originating from the cave. The example of sinkhole № 3 shows that in the winter the heating of the bottom of the sinkhole is independent of its size and depth, but is likely to be determined by the degree of vertical permeability of the soil at a given point.

Conclusions

We have shown that turf-covered sinkholes play an active role in the ventilation of the cave system in the Kulogori area.

Air permeability of sinkholes is provided by corrosive randklufts. Existence of randklufts seems to be caused by the high speed of gypsum dissolution.

The comparatively larger cross-section of the Well and obstructed air exchange with the natural entrance explains the existence of two independent air circulation systems in Troy cave.

One can expect the same air filtration mechanism to work in any region with similar conditions.

References

KTY83 series Silicon temperature sensors. Product datasheet.
http://www.nxp.com/documents/data_sheet/KTY83_SER.pdf