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PIPING IN LOESS-LIKE AND LOESS-DERIVED SOILS: CASE STUDY OF HALENKOVICE SITE, CZECH REPUBLIC

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Abstract: The soil piping that occurs on luvisols in the vicinity of the village of Halenkovice was studied for 5 years. These piping phenomena can only be found where arable land meets the forest or a belt of shrubbery. If there is a scarp in the locality, which usually changes from 6° in the field to approximately 30° in the forest, soil pipes are more likely to occur. Before the scarp, the slope flattens out and it is almost horizontal. This factor makes it possible for the overland flow to seep into the slope. This seepage results in soil piping, which is formed in loess loam and colluvial deposits. There are about 15 sites in the vicinity of the village of Halenkovice, where soil piping occurs. In one of them, Halenkovice 1 (an area of 900 m^2) we closely studied 47 partial cavities. Their internal volume is 3.8 m^3. The volume of the sink holes is 23 m^3. There are two types of soil pipes – vertical, which on average tend to be shorter (40 cm) and lead the water under the surface, and soil pipes parallel with the slope, which are on average 81 cm long. Water flows through the pipes during a thaw or precipitation, which often takes away the top soil. The intensity of this process depends on the intensity of precipitation, which occurs outside the growing season, when there are no crops in the fields.

Key words: soil piping; subsurface flow, Outer Western Carpathians, Czech Republic.

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INTRODUCTION

The soil piping phenomena occurs in a range of areas, from the periglacial to the pluvial tropics (Farifteh & Soeters, 1999), in agricultural regions (García-Ruiz *et al.*, 1997), and also in towns (*e.g.*, Khomenko, 2006).

Jones *et al.* (1997) claim that more than one third of British farmland may be affected by piping. Major manifestations of soil piping in loess-derived soils, although limited by land-use, can be found in places such as Belgium where it covers 1,000 km^2 (Verachtert *et al.*, 2010). In Hungary, soil piping covers more than two thirds of all cultivated land (Gábris *et al.*, 2003) and in the Ukraine the area endangered by piping covers 50,000 km^2 (Faulkner 2006).

García-Ruiz *et al.* (1997) describe the process that takes place in irrigated terraced fields, where the piping has not been stopped in time. The ceilings of pipe cavities often collapse, thus forming sink holes. The caved-in fertile soil is washed away and the sink hole opens space for further erosion.

The main factors contributing to the formation of soil pipes include:

– running water that comes from precipitation, thawing snow, irrigation, or some un-natural event such as a burst commercial water pipes. Its critical volume varies, depending on the region and geological settings. Jones *et al.* (1997) state that piping occurs in Britain in locations with average annual rainfall exceeding 1,250 mm. In the Basilicata River basin (Italy), the annual rainfall only reaches around 650 mm (Farifteh & Soeters, 1999) and on the Chinese loess plains it is no more than 499 mm due to the fact that the precipitation events are less frequent but more intensive (Zhu, 1997).

– a slope, or hydraulic gradient. Most pipes are formed in gentle slopes. In the top part of the slope water seeps into the ground and flows through a subsurface pipe network. The pipe outlet is often situated at the foot of the hill slope. García-Ruiz *et al.* (1997) state that the irrigated fields in Spain affected by soil piping had a gradient not exceeding 7°. The gradient of loess hill slopes in North-Eastern Hungary where soil piping occurs is around 12° (Gábris *et al.* 2003). According to Farifteh and Soeters (1999), there is faster outflow on steep slopes, which results in lower infiltration.

Other factors contributing to the formation and development of soil pipes include the presence of a network of cracks and fissures (García-Ruiz *et al.*, 1997; Farifteh & Soeters, 1999). Underground erosion may be increased by the removal of shrubs and root systems. The holes, after the root removal, cause cracking of the soil and accelerate the movement of water (Farifteh & Soeters, 1999). Formation of pipe cavities is also assisted by other existing macropores, such as animal burrows (García-Ruiz *et al.*, 1997).

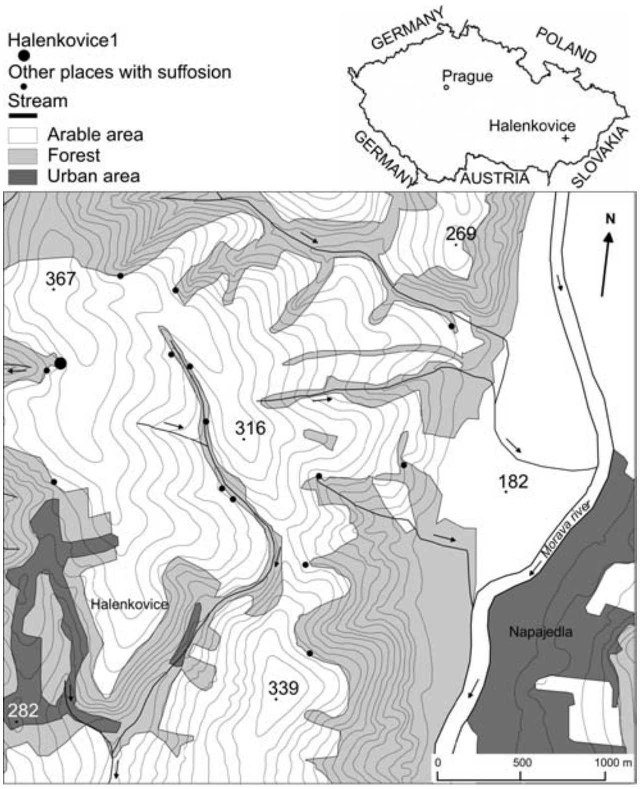

Fig. 1. The vicinity of Halenkovice village with marked locality Halenkovice 1 and other localities where soil pipes have been found

Our attention is drawn to the presence of soil pipes in the terrain by tunnel outlets or collapsed ceilings. As the whole process takes place underground, and the tunnels are very difficult to get into, pipe phenomena usually cannot be exactly localised (*e.g.*, Holden *et al.*, 2002 used ground-penetrating radar for the exploration of subsurface flow).

In this work, we focused on studying the soil piping phenomena in the vicinity of the village of Halenkovice (Czech Republic) in the region of the Outer Western Carpathians. We also attempted to present a scenario of the origin and development of soil piping at this locality.

STUDY AREA

The area under study is situated in the eastern part of the Czech Republic between 49°09’ and 49°12’ north and 17°27’ and 17°30’ east, near the village of Halenkovice. In the vicinity there are 14 other sites with documented soil pipes (see Fig. 1).

The surface bedrock is Tertiary flysch in the Palaeocene and Miocene Magura Nappe system dominated by the Vsetín Beds. These strata are a mixture of claystone, siltstone, sandstone and conglomerate. The rocks are generally weak and produce a relatively thick colluvium (Krejčí *et al.*, 2002). The entire area is covered with loess in an irregular way with the thickness fluctuating from several tens of centimetres in the upper parts up to 10 m at the lee side in the east of the study area.

Table 1

Precipitation and snow cover (Košíky station)

Year	Precip. total (mm)	Maximum snow cover (cm)	End of snow cover	Beginning of snow cover
1999	602	22	14.2.	19.11.
2000	551	17	27.1.	30.12.
2001	685	20	24.2.	25.11.
2002	637	36	27.1.	11.11.
2003	542	7	15.2.	16.12.
2004	663	26	14.3.	20.11.
2005	751	39	18.3.	18.11.
2006	693	53	23.3.	3.11.
2007	887	18	23.3.	6.11.
2008	612	4	20.3.	19.11.
2009	772	15	3.3.	3.11.

The soil cover consists of luvisols which have developed on weathered flysch as well as on loess. Their thickness does not exceed 1 m. The illuvial horizon “B” is up to 70 cm thick and gradually moves into the subsurface loess or the colluvia of the Tertiary flysch.

The whole area of the flysch Carpathians is highly prone to landslides (Krejčí *et al.*, 2002; Bíl & Muller, 2008). The soil piping phenomena in this area and in the wider area of the Carpathians have been given hardly any attention, with a few exceptions (*e.g.*, Kirchner, 1987; Kos *et al.*, 2000; Baroň *et al.*, 2003; Holúbek, 2008). These are mostly smaller examples that are linked to arable land and are often filled in by farmers.

The mean annual temperature in the area was 7–9°C and the annual precipitation reached 600–800 mm during the 1961–2000 period. Rainfall in March to April amounted to 40–50 mm, with snow cover recorded for five to ten days in early March on average. Snow cover was usually not recorded in April (Tolasz, 2007). In addition to this long-term data, we also had at our disposal daily data from a meteorological station, five kilometres away in Košíky (Table 1).

The highest precipitation recorded over the long term is in June and July, with 26% of the total. On the other hand, the least abundant months are January and February, with only 10 % of the total annual precipitation.

Location under study

The Halenkovice 1 location is 90 ×10 m large and it is situated near a local road between the villages of Halenkovice and Žlutava (Fig. 2). Above the road there is a field with an average gradient of 6°, and the distance between the field and the topographic water divide is 165 m. The road is cut into the slope, creating a terrace scarp. Its vertical distance above the road surface is 2 m, with the gradient of 35°. The surface is covered with shrubs (mainly *Prunus spinosa* L.). Piping phenomena are located on the boundary between the field and the terrace scarp. In this almost flat location, the

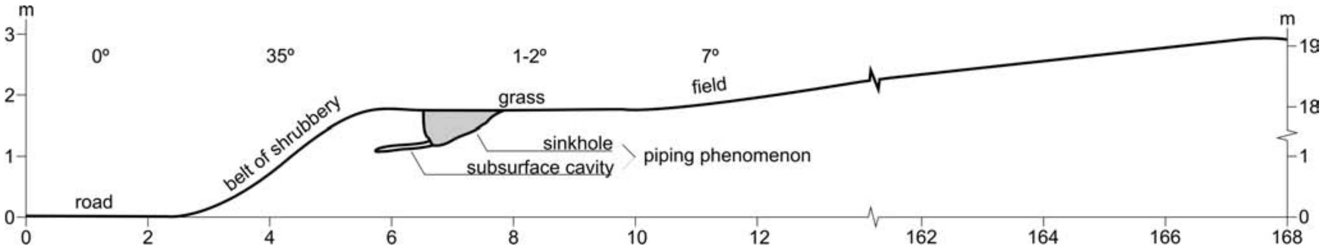

Fig. 2. Schematic profile of Halenkovice1 location, indicating the land use and slope

field is not ploughed right to its edge, so there are grass and shrubs growing there. This is the very place where the sinkholes – entries to the tunnels – are situated. The tunnels are mostly oriented towards the road and the outlets are in the slope of the road cutting.

During rain, the eroded soil is discharged through the outlet of the tunnels onto the road. The soil not only comes from the walls of the tunnel, but also from the field, which is washed away by surface erosion and transported through the tunnels.

Other locations where soil piping occurs are limited to gully edges and headwater catchments.

This work describes 47 independent piping phenomena in one location, which were closely monitored and labelled as Halenkovice 1. Within the vicinity of 3 km there are 14 more locations affected by soil piping (Fig. 1).

Fig. 3. Using smoke bombs to detect connectivity of soil pipes. A pipe outlet is in the foreground, smoke is rising from the opening sinkhole on the slope in the background

METHODS

The field mapping phase was completed in 2003 and all soil piping phenomena were documented. This was followed by monitoring (2005–2010), which consisted of regularly measuring changes in the shapes of soil piping and subsequently drawing them into the plans. It is relatively easy to monitor changes on the surface. However, changes in the length and volume of sub-surface cavities are difficult to measure. When the cavity was short, its length was measured directly. When it was longer, the length of the cavity was measured with the help of a rod pushed inside. Specifically, what was measured was the distance between the orthogonal projection from the opening upper edge to the bottom of the sinkhole and the end of the cavity. In most cases the cavities were linear and had a constant gradient. If this was not the case, a comment was added that the outlet was uncertain.

Several experiments were conducted in order to study the connections among individual cavities and tunnels, including a flooding experiment and a smoke experiment. Flooding was done with the help of water dyed with Brilliant Blue FCF (E133) colouring, and the discharge in the terrace wall was monitored. The smoke experiment comprised of putting a smoke bomb inside an opening of one of the tunnels, and higher up on the slope, monitoring places where orange smoke emerged on the surface (Fig. 3). Both methods seem suitable for monitoring how the subsurface tunnels interconnect.

Sediment catchers were installed to monitor the activities inside the cavities. Polystyrene blocks (2 × 2 cm) fixed in the soil with pins were used for the same purpose, as well as spra-yed belts of reflex paint along the perimeter of the tunnels.

RESULTS

Eight measurements were conducted in the Halenkovice 1 location between 2005 and 2010. Some singular pipes appeared during the monitoring, as well as some complete piping phenomena. Others disappeared.

Pipes can be divided into two categories:

– predominantly vertical cavities, which are formed on the surface and lead steeply down (at an angle of 50 to 90°). It is mainly this type of pipe, through which water penetrates underground;

– pipes parallel with the surface, which are formed in the bottom of sinkholes and continue towards the cut. Their gradient does not exceed 10° (Fig. 4).

The pipe lengths in both categories vary, but on average, horizontal pipes that carry water through the body of the slope towards the gully (Table 2) tend to be longer. The diameter of the inlet pipe openings starts at 3 cm, with the largest opening being 56 cm. The diameters of the pipe outlets ranged from 6 to 48 cm.

The depth of the sinkholes fluctuated from 30 to 130 cm. We found that pipes were often arranged in one line in the di-

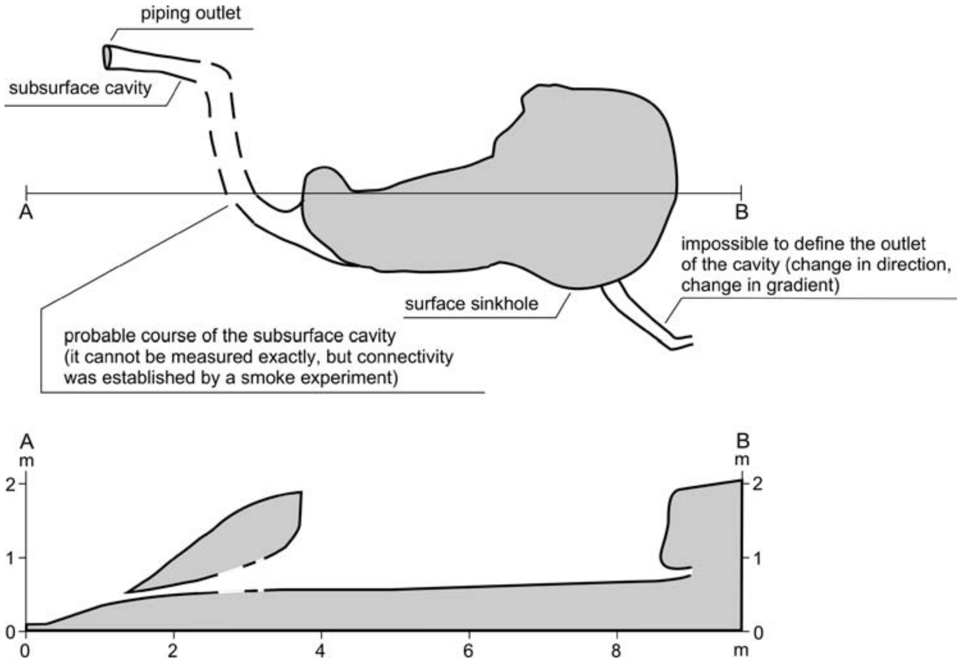

Fig. 4. Layout and cross-section of Halenkovice 1 shows the development of the second type of cavity – a tunnel oriented from the bottom of the sinkhole under a slight angle towards the wall of the cut. Dashed lines indicate a probable continuation of the cavity, which could not be measured, but has been established by the flooding or smoke experiments

rection of the gradient of the slope, without being connected underground. We believe, however, that there is connectivity among the pipes and that water flows through them.

The internal volume of the tunnels of 47 monitored cavities (Table 3) was estimated to be 3.8 m^3 as of November 20th, 2009. The volume of the surface sinkholes caused by soil piping was 23 m^3.

Changes in the shapes of soil pipes

Soil tunnels do not only extend their length, but they can also be seemingly shortened. This occurs when the passage is blocked by the transported material or by a cave-in. The tunnel can open up again later. The water can however continue to flow through the obstacles, such as a cave-in. This cannot be detected by measurements, but only by the flooding experiment.

Monitoring the transporting activity inside the cavities (sediment catchers in the bottom, changes in the position of polystyrene blocks and the disappearing of sprayed belts) led us to believe that water flows through the pipes when it rains with enough power to carry away soil and erode the tunnel walls.

The dimensions of pipes were measured at regular intervals in order to discover whether there was some relationship between precipitation and the development of soil pipes. Each measurement specified the total length of all pipes, the number of new pipes, and the average enlargement of the existing pipes (calculated per pipe).

Table 2

Pipe lengths (cm) in both categories at Halenkovice1 on November 20th, 2009

	Pipe types	
	Vertical	Parallel
N	24	38
Length (cm)		
Average	40	81
Maximum	145	433
3rd quartile	48	85
Median	30	36
1st quartile	18	22
Minimum	5	10

Table 3

Overview of pipes monitored during the whole measurement period. Changes in their numbers on various dates point to formation of cavities

Monitoring	Number of pipes
29.01.2008	23
13.03.2008	34
29.04.2008	36
3.06.2008	38
30.07.2008	40
14.03.2009	43
9.10.2009	47
20.11.2009	47

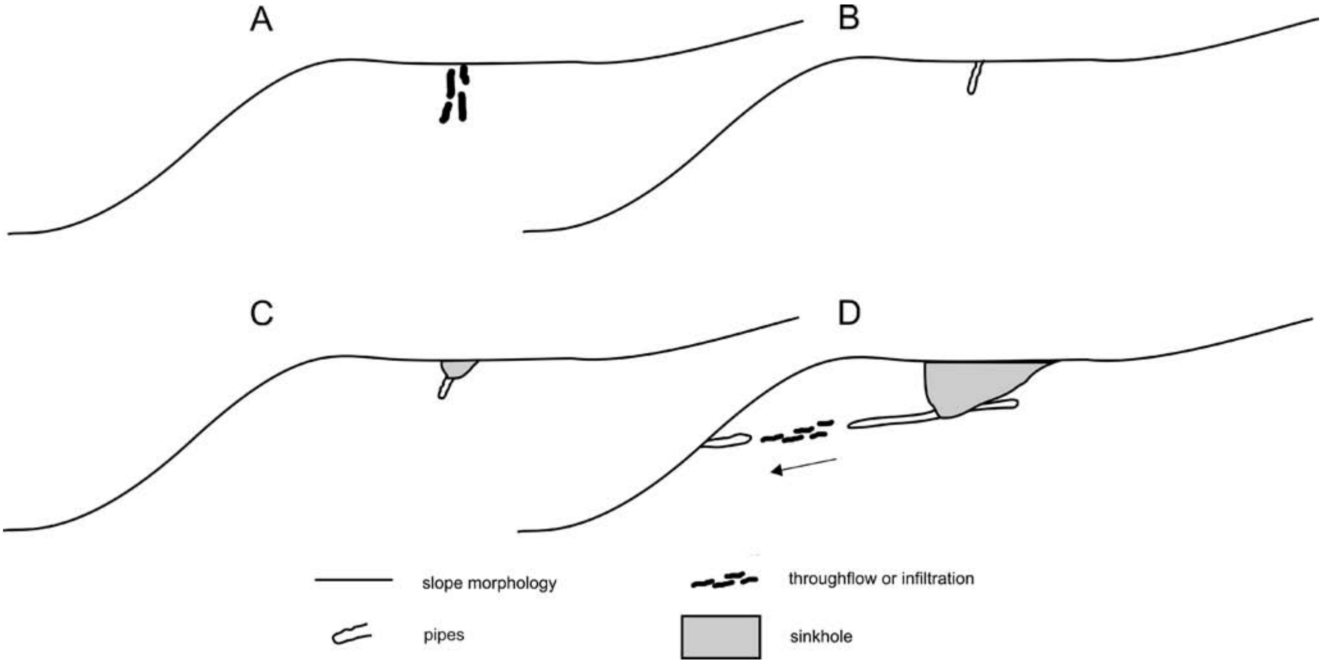

Fig. 5. A conceptual model of the process of soil pipe formation at Halenkovice 1 (A). In places with appropriate conditions, seeping water forms a primary tube (B), from which a sinkhole develops (C). Once the sinkhole stops deepening, running water creates a pipe at its bottom, through which the water flows to the wall of the road cutting (D)

It was not possible to prove a direct relationship between precipitation, the total length of all pipes and the number of new pipes. Newly formed pipes may not be noticed immediately after their emergence. They may be covered with leaves or wood waste (after pruning shrubs) and, therefore, it is possible that they were not included in the study until one of the next measurements.

The development of soil pipes probably depends on reaching a certain threshold in the intensity of rainfall. This value cannot be defined yet since the series of observations were taken over a relatively short period. Demonstrably the greatest increase in the number of new pipes occurred in the period from February 29th to March 1th, when hurricane Emma hit Central Europe (http://en.wikipedia.org/wiki/Emma_ (windstorm)). During the storm, from 2/29–3/1, precipitation reached 39 mm. This figure is not extreme for this location, but the impact was so dramatic since it occurred during the period when there was no longer snow cover and not yet any crops in the fields. The impact of extreme rainfall in summer is moderated by vegetation and mild precipitation also does not cause much damage.

The origin and development of piping phenomena at Halenkovice 1

The soil piping process has been observed to be as follows:

– mainly in the early months of the year after snow melts and the surface of unsown fields is exposed to surface erosion. It is not prevented by any growing crops, so water from melting snow and precipitation carries away surface material, mainly arable soil.

– in the bottom part of the slope before the scarp, where a belt of shrubs usually starts, water is less likely to be transported and so material is collected there. These sediments – often mixed with fallen leaves – are an indicator of seepage, as water flow stops.

– when seepage occurs in grassy terrain, small cavities are formed that are almost vertical. Due to surface erosion they gradually widen and transform into a sinkhole. As soon as a cavity or a sinkhole stops deepening, water continues in the direction of the original slope gradient (Fig. 5).

– water movement towards the erosion base probably also increases its erodibility again and the soil piping process begins – forming cavities and tunnels.

– outflows can often be observed at the foot of the gully, either in the form of water logging, or directly as outlet channels, sometimes with alluvial cones, which are evidence of the ongoing erosion inside the cavities.

– in the final stage, the cavities will cave in. Further development depends on land use. If it is a gully, the whole process is left to run its own course and it is possible to see how soil pipes develop into systems of side gullies. On farmland, primary sinkholes are already filled with material such as wood waste. Root systems of trees usually maintain the stability of the ceiling, so in gullies the transition from soil piping to erosion develops more slowly.

This combination of factors described in the studied location, Halenkovice 1, makes it possible to identify places prone to soil piping erosion. In this area, 14 further examples of soil piping erosion were actually found, with similar morphometric characteristics.

These are the common characteristics for all locations in the vicinity of the village of Halenkovice:

– occurrence is limited to the borderline of arable soil and shrubbery (or the edge of the forest);

– a relatively mild gradient of slope (around 6°) passes into a terrace scarp (with the gradient a minimum of 30° and a vertical distance of at least 150 cm). The scarp is either a gully or a cutting made for a road;

– the terrain flattens out between both parts of the slope, which is where water seepage can occur.

DISCUSSION AND CONCLUSIONS

The critical factors that predetermined the subsurface erosion in Halenkovice 1 was the melting snow and intensive rains in the spring when the arable soil was exposed and prone to surface erosion due to surface flow. The soil piping, however, could not occur here without a suitable geological subsoil consisting of loess and colluvial deposits and without the appropriate morphology of the slope. As stated above, seepage of water must occur before the scarp in the lower part of a slope, so that the flow can continue further underground. If the water flow was not stopped, it would continue over the edge of the cut, where a gully would be formed. This commonly happens in places either with a steeper slope gradient or without a belt of shrubbery, to slow down the flow.

Although the specified piping phenomena are relatively small and thus their direct economic impact is rather low, attention should be given to them because they often develop into erosion furrows and they may be associated with the occurrence of more dangerous phenomena. Especially, piping tends to initiate landslides (*e.g.*, Brand *et al.*, 1986; Uchida *et al.*, 2001) and gullies (*e.g.*, Stankoviansky & Barka, 2007).

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