MICHAL BÍL, OLDŘICH KREJČÍ, MARTINA BÍLOVÁ, JAN KUBEČEK,
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A CHRONOLOGY OF LANDSLIDING AND ITS IMPACTS ON THE VILLAGE OF HALENKOVICE, OUTER WESTERN CARPATHIANS

BÍL, M., KREJČÍ, O., BÍLOVÁ, M., KUBEČEK, J., SEDONÍK, J., KREJČÍ, V. (2014): A Chronology of Landsliding and its Impacts on the Village of Halenkovice, Outer Western Carpathians. Geografie, 119, No. 4, pp. 342–363. – The article is based on an investigation of landsliding chronology coducted at the village of Halenkovice. (Outer Western Carpathians, Czechia). On the basis of historical data, (chronicles and other archive sources, air photos, old maps), field mapping and interviews of eyewitnesses, we determined six major and seven minor phases of landsliding in the village and its immediate neighborhood for the period 1915–2010. Inactive and active landslides currently cover 20% of the Halenkovice cadastral area. Landslides have strongly affected the development of the village itself. Since 1941, at least 9 houses have been destroyed by landslides, with many other local buildings and roads suffering significant damage. We also documented two examples of periodic reactivation of landslides.
KEY WORDS: Landslide hazard – Halenkovice landslides – Landslide recurrence – Outer Western Carpathians.

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1. Introduction

1.1. A history of landslide research in the Czech Outer Western Carpathians

The history of landslide research and its impacts on the infrastructure in Czechia (the Czech Republic) is connected in particular with its western part (Bohemia), which was densely inhabited in contrast to the east of Czechia (Moravia and the Czech part of Silesia). The first systematic research on landslides in Czechia, specifically from the built-up areas in Prague, north and central Bohemia, began as early as the beginning of the 20th century (e.g. Špůrek 1972).

Due to dispersed settlement built primarily from wood, the majority of the unpaved roads and relatively sparse inhabitation in the Carpathian area, landsliding and its impact were not an area of major concern. The oldest scientific documentation of a landslide which brought about damage to the public infrastructure dates back to 12–13 January 1920 and is from the village of Hošťálková near the town of Vsetín (Dědina 1920, Záruba 1922).

The first railways were planned and built in this area to connect Moravia and Slovakia at the beginning of the 20th century. These activities were accompanied by geotechnical surveys, which soon identified the extreme susceptibility of the flysch rocks to landsliding in the area (Záruba 1938).

1.2. Phases of landsliding

Despite the fact that landslide research has a long tradition in Czechia, there is only one work which has actually attempted to identify eras with higher landslide activity – landslide phases (Špůrek 1967 and other resources cited there). He recognizes a landslide phase as an occurrence of a higher number of landslides in a given area or the acceleration of movement of existing (usually dormant) ones. He focused predominantly on the area of Bohemia. The most prominent phases of landsliding in Bohemia were identified in the periods: 1880–1883, 1897–1900, 1914–1916, 1925–1927, 1939–1941, 1965–1967 (Špůrek 1967). His work was later extended by Rybář (1999) who also focused on the Bohemia region and on a comparison with the situation in East Germany.

The first hint concerning a probable landslide phase in the Czech Carpathians is included in the work of Záruba and Myslivec (1942) who made a brief note concerning additional landslides which might have originated in east Moravia over the period 1924–1929.

The first documented landslide calamity (an event with a large areal impact) hit the Czech Carpathians in 1939–1941. This event, which coincided with landsliding in Bohemia, was described in local works by Krejčí (1943) or Záruba and Myslivec (1942).

Another landslide calamity hit the Western Carpathians at the beginning of the 1960s. The most significant part of this, due to its devastating impact on a number of residential houses, was the Handlová landslide (Slovakia; Nemčok 1982). The calamity in the 1960s was an impulse for the first area mapping of landslides in Czechoslovakia (Matula et al. 1963).

Almost 40 years of relative landslide inactivity have taken place from this point. This area was hit by, in all probability, the most intense landslide calamity in the modern era in July 1997 (Krejčí et al. 2002a). Additional systematic survey of landslide triggering factors and area mapping consequently took place and the landslide risk is a major concern at present. The two most recent phases of landslide activity in 2006 and 2010 were thereby sufficiently documented.

1.3. Historical data delimiting landslide phases

There are numerous written sources according to which our knowledge of landsliding can be enriched. These are first of all local chronicles and additional archive sources. The use of these data (chronicles, old maps and aerial photos) for identification of landslide phases has a long history. They actually helped confirm landslide recurrence in those countries where old aerial photos were available (Guzzetti 2005). These sources, however, cover only part of the 20th century. Additional written sources and maps lead further back into history

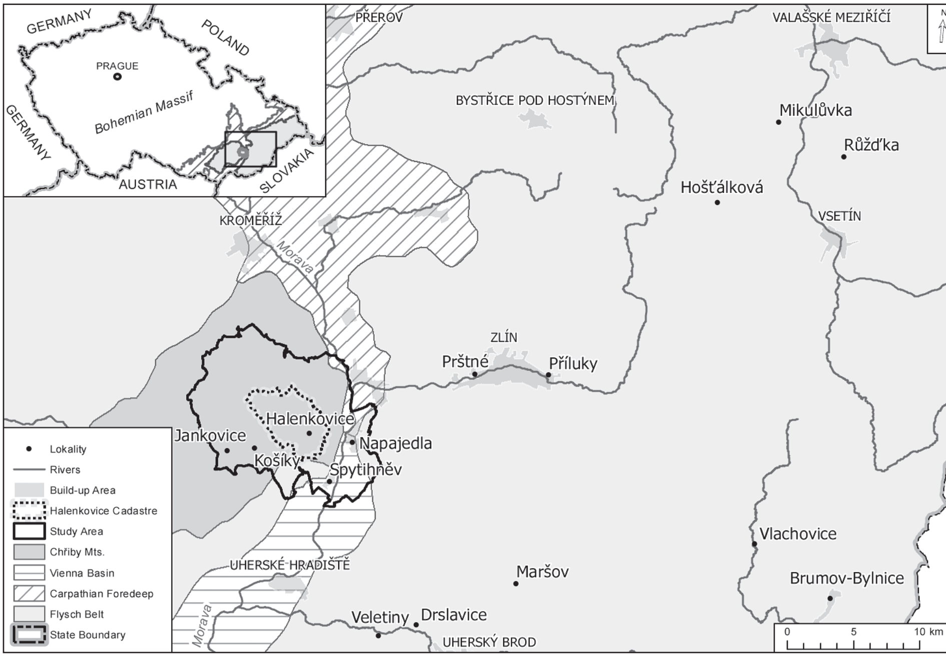

Fig. 1 – Cadastral area of the village of Halenkovice and the neighboring villages which are part of the northern Chřiby mountains region. Additional places (villages and towns) marked as points on the map, are cited later in the text.

(e.g. Ibsen, Brunsden 1996; Calcaterra, Parise, Palma 2003; Tropeano, Turconi 2004; Marchi, Tecca 2006; Devoli, Morales, Høeg 2007; Elliott, Kirschbaum 2007; Raška et al. 2014).

The aim of this work is to identify, on the basis of written sources, aerial photos and other data the landslide phases, the extent, impact and recurrence of slope movements in the village of Halenkovice (15 km west of the town of Zlín), which rank among the most affected villages by landsliding in the Czech part of the Outer Western Carpathians (Fig. 1).

2. Data and Methods

2.1. Digital data

We assembled data on land use and 3D contour lines in order to make an overview of the extent of landslides within the village of Halenkovice (ZABAGED®, ČÚZK). We also collected digital engineering maps (scale 1:10,000) which were made between 1999–2008 within the framework of the ISPROFIN project (Krejčí et al. 2008a, b) to document an antecedent landslide calamity in 1997. Czech Geological Survey carried out a revision of older mapping and a new edition of Landslide inventory maps was issued (www.geology.cz/Mapapplications/Ground instabilities).

2.2. Old maps and aerial photographs

We collected aerial photographs from the archive of the Military Geography and Hydrometeorology Office (MGHO) which covers the years from 1950 up to the present (1950, 1953, 1961, 1973, 1976, 1977, 1982, 1984, 1990, 1991, 2003, 2006 a 2009). Their scale ranges from 1:8,000–1:38,000. Once rectified, we made use of them for identification of destroyed or generally missing houses. All the houses which were not identified on the more recent photos were placed into a map of missing houses. We subsequently consulted these 46 cases with eyewitnesses and the records in the chronicles of Halenkovice and the nearby villages. This procedure was behind the list of damaged or destroyed houses due to landsliding in this area.

Four sheets of 1:10,000 military topographic maps were also acquired from the MGHO. They were mapped under the supervision of the former General Staff of the Czechoslovak Army (GSCA) in 1961 and 1962. These maps are extremely valuable for geomorphologists, as they depict both terrain edges and bulges even of a sub-meter size. We are currently able to identify the landslide morphology from these maps, particularly the frontal parts of the landslides.

The oldest maps which can be used for detection of landslides in Czechia date back to the middle of the 19th century (Stable Cadastre maps). Geological maps of the area were drawn up in 1997 on a scale 1:50,000 (Novák 1997, Havlíček 1997). We used these maps for delimitation of the extent of the Quaternary colluvial cover. Landslides within the Halenkovice area were mapped in the 1960s (Matula et al. 1963), 2003 (Bíl 2003) and 2010 (Krejčí et al. 2010).

2.3. Written records

We used chronicles of the village of Halenkovice and the chronicles of the neighboring villages (Košíky, Jankovice, Spytihněv, Napajedla, Žlutava, Sulimov, Nová Dědina, Kudlovice, Kostelany, Bělov, Vrbka, Lubná) to discover whether or not the landslides identified in the village of Halenkovice were accompanied by other landslides nearby. We also studied all the local newspapers from the Zlín region deposited in the local State District Archives of the Zlín, Kroměříž and Uherské Hradiště districts and the archive of the Bata factory, which has had its seat in the town of Zlín since 1894.

2.4. Interviews

We prepared a lecture for the inhabitants of the village of Halenkovice in January 2013 concerning the history of landsliding in their village. We consequently consulted our findings with the oldest eye-witnesses in order to obtain information about the phases of landsliding and its impact. They also helped us localize damaged houses due to landslides.

2.5. Methods

We used written sources in order to determine the landslide phases in Halenkovice prior to 1997. Špůrek (1972) was among the first who utilized this approach. In his *Historical Catalogue of Slide Phenomena* (Špůrek 1972), he analyzed the available written sources, even the daily press. We used this compilation to study indices on landsliding in close proximity to Halenkovice. Each record was subsequently verified in the local chronicles.

The landslides mapped before 2012 were checked again during the field mapping conducted that same year. This mapping work represented the fourth landslide mapping of the Halenkovice cadaster since 1997 (followed in 2003, 2006 and 2010). This time we also investigated information on bedrock. The results therefore allowed for a connection between individual landslides and underlying geological units.

The landslide database was then investigated in order to link up the individual landslides as much as possible with the dates of their origin or reactivations. This was accomplished by searching in the historical records and interviewing eyewitnesses.

The area of Halenkovice, particularly "Na Díle" landslide (see section 4.2), has been systematically monitored since 1999 and ranks among the most investigated landslide areas within entire Czechia. The statistics and GIS spatial analyses were carried out in the ArcGIS 10.2 (Fig. 2).

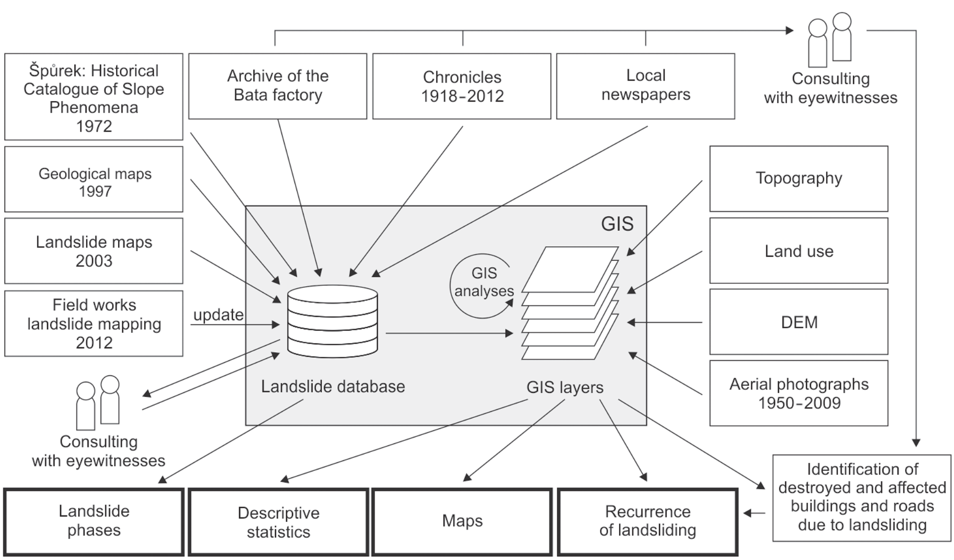

Fig. 2 – Workflow indicating how the database of landslides, list of affected roads and buildings by landslides and landslide phases originated.

3. Halenkovice and its natural environment

3.1. Geography and geomorphology

The village of Halenkovice and the neighboring villages are located in the northern part of the Chřiby Mountains (see Fig. 1) – an approximately 35 km long and up to 10 km wide thrust and fold mountain belt with its main ridge oriented from SW to NE. It is part of the Outer Western Carpathians and is surrounded by depressions with generally lower and flat relief reaching up to 200 m a.s.l. The highest part of the Chřiby Mts. – Brdo (586 m) is located 5 km southwest of the studied area.

Altitudes within the Halenkovice cadaster descend from the north-east (maximum height 410 m) to the south-west (minimum height at the Vrbka floodplain 204 m). The erosion-denudational relief has the character of hilly land from the morphometric point of view. The erosional processes take the form of river erosion, piping (Bíl, Kubeček 2012) and landsliding (Krejčí et al. 2002b). The morphology of the slopes is heavily influenced by the existence of both dormant and active landslides and is therefore both uneven and undulating (Fig. 3).

The long-term average (1961–2000) for annual precipitation amounts is approximately 650 mm. The precipitation is characterized by an annual cycle with the highest precipitation in the summer and the lowest rainfall in the winter. The long-term temperature average is between 8.5–9.0 °C.

Fig. 3 – An example of slopes affected by the existence of dormant landslides. The arrows delimit two 2010 landslides. Photo: Oldřich Krejčí.

3.2. Geological setting of the area

The Carpathian Flysch Belt has a fold-and-thrust structure comprising mostly Cretaceous and Paleogene shales. It is part of the widespread system of young mountain ranges where the nappe structure is typical (Picha, Stráník, Krejčí 2006).

The Carpathian Flysch Belt is represented by the Magura Group of thrust sheets (Hrouda et al. 2009), which consists here of the Rača Unit only (Fig. 4). The flysch sediments of this unit are distinguished in particular by their lithological evolution into the lithostratigraphic members. The oldest one is the Soláň Formation (Fm.). It is represented here by the Lukov Member: thick rhythmical flysch sediments dominated by sandstones, in places with conglomerates, over claystones. The Lukov Member is deeply weathered up to a depth of 10 m and produces unstable sandy colluvium on the slopes. Beloveža Fm. is characterized by rhythmic flysch rocks with non-calcareous claystones and quartz fine-grained sandstones, mostly thin bedded. In certain places Beloveža Fm. contains up to several tens of meters of thick coarse-grained arkose sandstones, which may

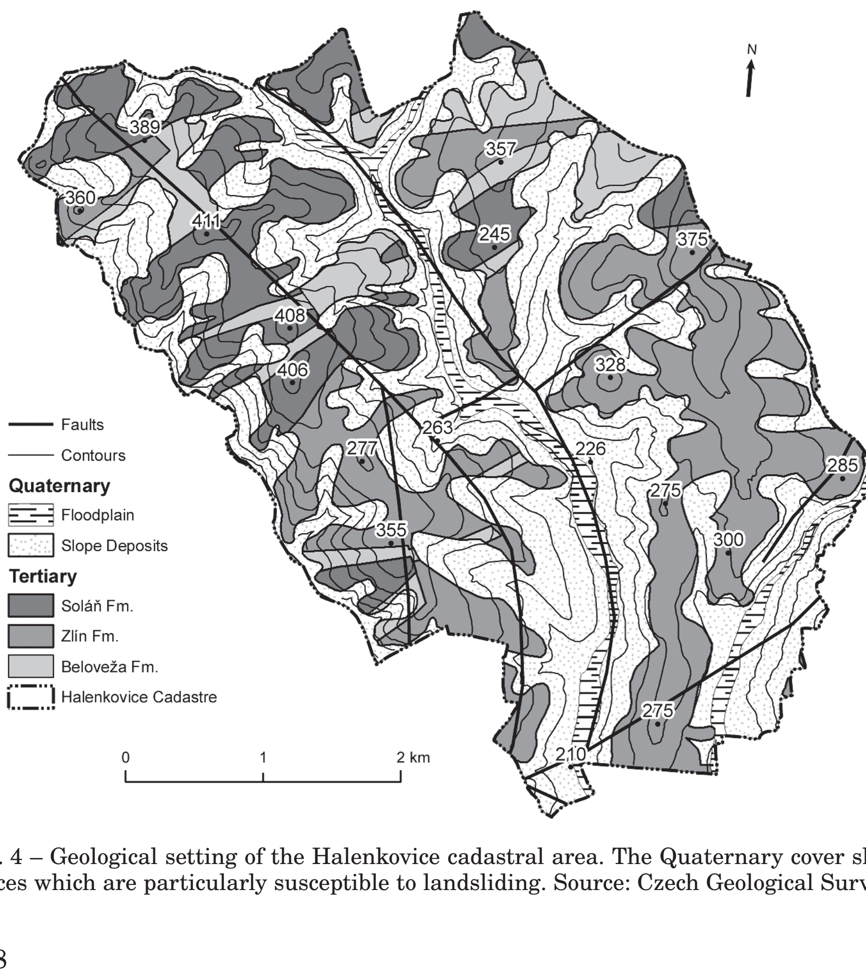

Fig. 4 – Geological setting of the Halenkovice cadastral area. The Quaternary cover shows places which are particularly susceptible to landsliding. Source: Czech Geological Survey.

be accompanied in certain places by brick red claystones. They are extremely susceptible to weathering, form unstable colluvia and predestinate conditions for extensive landslide areas. The members of the Zlín Fm. are characterized by the flysch evolution within deep-water turbidite sedimentation dominated by claystones. Claystones disintegrate into small fragments. They occur in variable thicknesses and often constitute rhythms over 10 m thick along with sandstones.

The area was the subject of erosion and denudation in the Late Miocene after the Flysch Carpathians moved to their present position. The current morphology and river network formed in the Pleistocene and the Holocene.

The Quaternary cover has the form of fluvial sandy gravels in the Vrbka stream floodplain and gravel clasts with loamy matrix on the slopes and loesses. The thickness of the slope sediments is usually between 5–15 m. Colluvial-fluvial sandy loams fill the lower parts of the tributaries, where various processes such as fluvial or slope transport and erosion alternate. The upper parts of the tributaries are incised in the Teritary rocks which outcrop on their narrow beds.

3.3. Tectonics

The extent of the areas affected by the landsliding within the Halenkovice cadaster and its immediate vicinity was in all probability determined by the existence of a system of faults, which originated during the folding of the flysch rocks. Although the faults are not active, they allowed the deep weathering of the flysch rocks up to 17.10 m (Konečný, Müller, Havlín 2009), which was determined by a core borehole in landslide A (see Fig. 5 and onward in the text). Additionally, this area lies close to two more recent geological structures. These are the Hornomoravský úval graben and the Dolnomoravský úval graben (the northernmost foreland part of the Vienna basin, which originated due to a pull apart basin mechanism – Hubatka, Krejčí 1996). They have been active over the last few million years as documented by the uplifted Pliocene sediments and Pleistocene terraces in the Morava river valley (see Fig. 1 and the map of the town of Uherské Hradiště and its surroundings by Havlíček 1997).

4. Results

4.1. Slope deformations in the Halenkovice cadastral area

The area of the Halenkovice cadaster amounts to 20.0 km^2. 120 individual landslides have been mapped out (Fig. 5) with no less than 55 of them having at least one dimension over 50 m. Landslide areas may contain numerous partial landslides of a different type, activity and age.

At least 50 landslides are evidenced as active. The most extensive landslide area (0.95 km^2) flanks the left side of the Halenkovice brook for 2,150 m. Its length (down the slope) is up to 700 m.

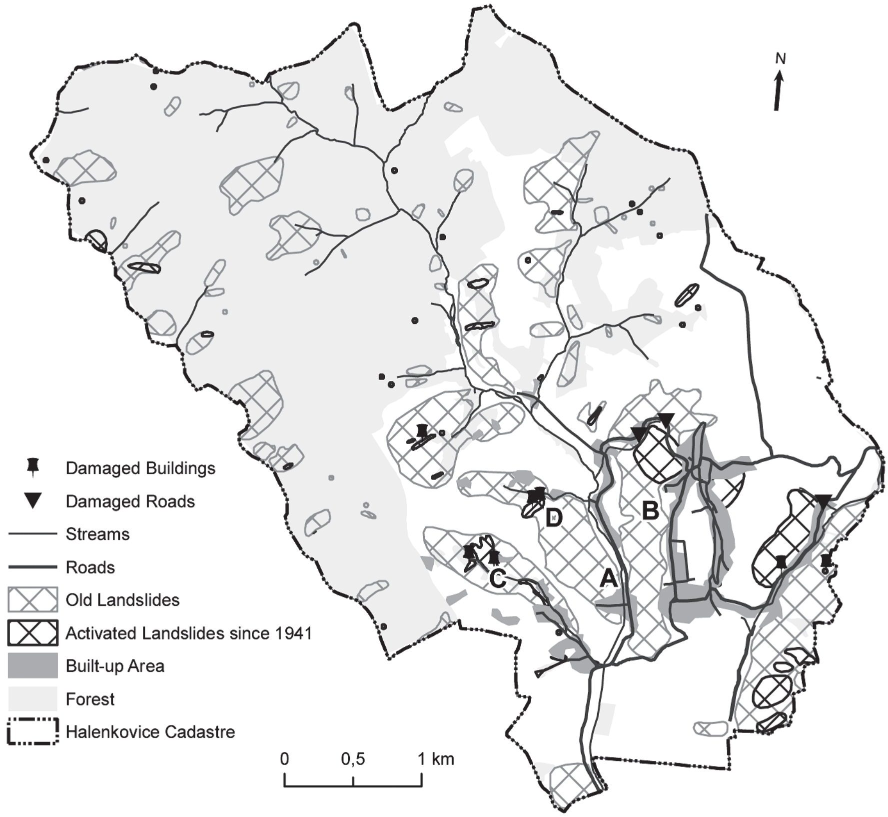

Fig. 5 – Landslides, built-up area, land-use and destroyed infrastructure. The letters A–D show the locations of landslides mentioned in the text. Source: aerial photos, MGDO and landslide mapping.

The area of all the landslides within the Halenkovice cadaster is 4.0 km^2 (20.0% of the cadastral area). The landslide extent for the region of the Western Carpathians is 4.4% on average (Holec et al. 2013). All the landslides are located on the Quaternary cover which has an area of 10.1 km^2. The largest part of the Halenkovice cadaster consists of Zlín Fm. – 12.1 km^2 (60.8%), followed by Soláň Fm. (5.0 km^2; 25.1%) and Beloveža Fm. (2.8 km^2; 14.1%). The average slope is 10.0°. The average slope for all the landslides is 12.7° here, while another area, without the floodplains, has a slope on average 9.7°.

It is evident that the landslides are located here on the deep Quaternary cover. From this point of view, the rest areas on the Quaternary cover where no landslides were mapped are thus easily the most susceptible parts for new landsliding within the entire Halenkovice cadaster.

There were (as of May 2013) 639 buildings in the village of Halenkovice. 300 of them (47%) were located on the landslides (63 on an active landslide and 237 on older ones). Another 20 houses lie on the Quaternary cover, but not directly on the mapped landslides or on the floodplains. If we take only the built-up areas into consideration, the area of the landslides is 19.1%. This is due to the fact that a substantial number of the houses lie on the gentle summit parts. The gardens and orchards cover a large part of the Halenkovice cadaster (the village was renowned for its production of apples and other fruits). The orchards were predominantly planted on steep slopes with a southern and western aspect. If we add this land-use to the built-up area, the area of the landslides on it will rise up to 48%.

4.2. Landslide recurrence

On the basis of the oldest aerial photos of the village of Halenkovice, we identified houses which did not occur on the more recent photos (46 cases). We asked the eyewitnesses, studied the chronicles and discovered that nine houses have been completely destroyed due to landsliding since 1941. The number only concerns residential houses and no other buildings. An unknown number of houses were affected by cracks with this also being observable at present. The number of houses which were removed from the remaining 37 as a result of damage from a landslide cannot be determined. Complete destruction of a house was always an important event, therefore, it was mentioned in the chronicle (the year 1941) or is still remembered among the local people (the year 1970).

Landslide "Na Díle", house No. 46: This is an old slope deformation (area 0.1 km^2), which was delimited in terms of its morphology and boreholes (Fig. 5, letter C). The area of the part reactivated in 1998 is 29,000 m^2. The shear plain is situated at a depth of 16.40 m (Březina, Stach 2001). The landslide was activated in 1941 and 1998, when the houses were affected. Additional documented phases of reactivation without any damage come from 1970, 2006 and 2010, when shallow landslides occurred in the upper part of the active landslide. The landslide activity could also be seen on the 1990 aerial photo.

Residential house No. 46 is situated in close proximity to the active part. According to its inhabitants, the entire area of the landslide was used as arable land and orchards up until March 1941. The landslide was activated in February or March 1941 and widened almost to its present extent during the spring. This resulted in the complete destruction of two houses: No. 335 and No. 46 (see Fig. 6). The landslide divided house No. 46 into two parts. While the barn can be found at its original position today, the residential house was completely destroyed. A new house No. 46 was built 30 m to the E.

The second important phase of landslide reactivation took place in March 1998 and changed the morphology of the slope substantially. The movement of the material downslope was up to 10 m. An eyewitness from No. 46 (Mr. V. Jambor) related the following about the 1998 event: "The soil was oversaturated by water … all the slope was covered by numerous streams and small lakes. When walking on the surface one sank as if walking on a peat bog leaving deep traces behind."

It is a deep-seated landslide (Krejčí et al 2002b) in contrast to shallow landslides and this was in all probability the reason why there was such a delay to the saturation of the underlying weathered rocks. In our opinion this event is

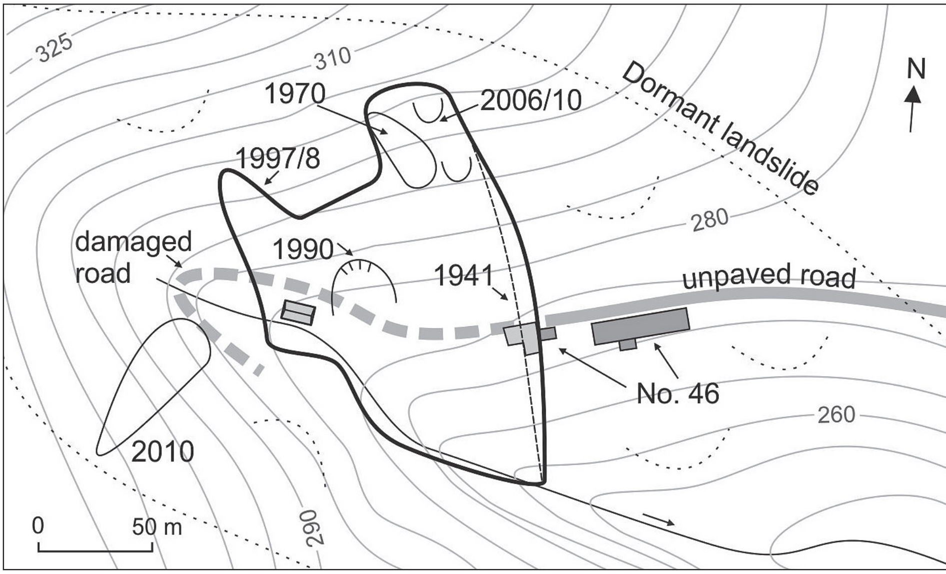

Fig. 6 – Landslide by No. 46. The two destroyed houses are in grey. No. 335 is located to the left, the original No. 46 in the middle and the new No. 46 on the right side. The dates show the places where the rejuvenation was detected. Source: aerial photos, MGHO.

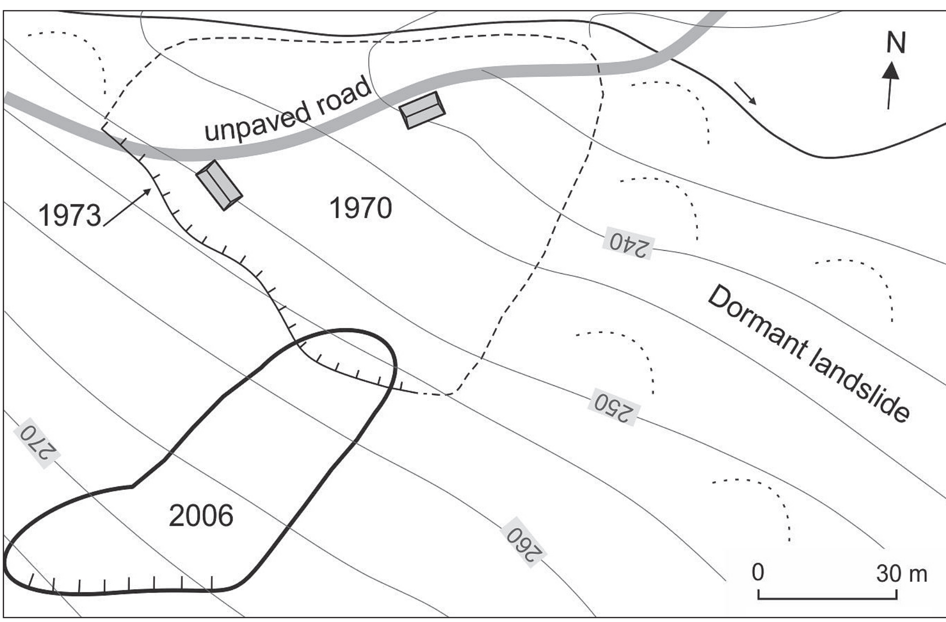

Fig. 7 – A sketch of the "Lipové" landslide. Two residential houses remained on the dormant landslide up until 1970. The extent of the 1970 landslide, particularly the main scarp, can be delimited from the 1973 aerial photo. The approximated border of the 1970 landslide is marked by a dashed line. The uppermost part of the older landslide was activated once again in 2006. Source: aerial photos, MGHO.

directly connected with an extreme episode of rainfall from July 1997. Such a delay for deep-seated landslides is quite common, see Rybář (1999).

The "Lipové" landslide: As a result of rapid snow melting accompanied by rainfall in April 2006 another landslide calamity took place. It primarily affected the area of the southern part of the flysch zone in Moravia (Bíl, Müller 2008). Among the 6 landslides in Halenkovice one was also called "Lipové" (Fig. 5, letter D and Fig. 7). From an interview with eyewitnesses we realized that up until 1970 there were residential houses close to the active landslide. The 2006 event affected the slope in close proximity to the 1970 landslide.

4.3. The oldest landslides

There are at least two landslides whose broad age can be determined based on indirect data. It is well known that the loess cover can be used as a relative proxy to estimate the age of a landslide buried beneath. On the basis of the HP-1 core borehole drilled in 2006, (Konečný, Müller, Havlín 2009) we identified a relict landslide which developed in the colluvium of Zlín Fm. and was subsequently buried under a loess cover. Although the loess was not dated at the locality, the most probable age when it could have sedimented is in the Last Glacial Period (between 28,000–13,000 BP, Frechen, Oches, Kohfeld 2003). The slope deformation which was buried by it (see Fig. 5, letter A), must therefore be older than 13,000 years. This example of an Upper Pleistocene landslide is

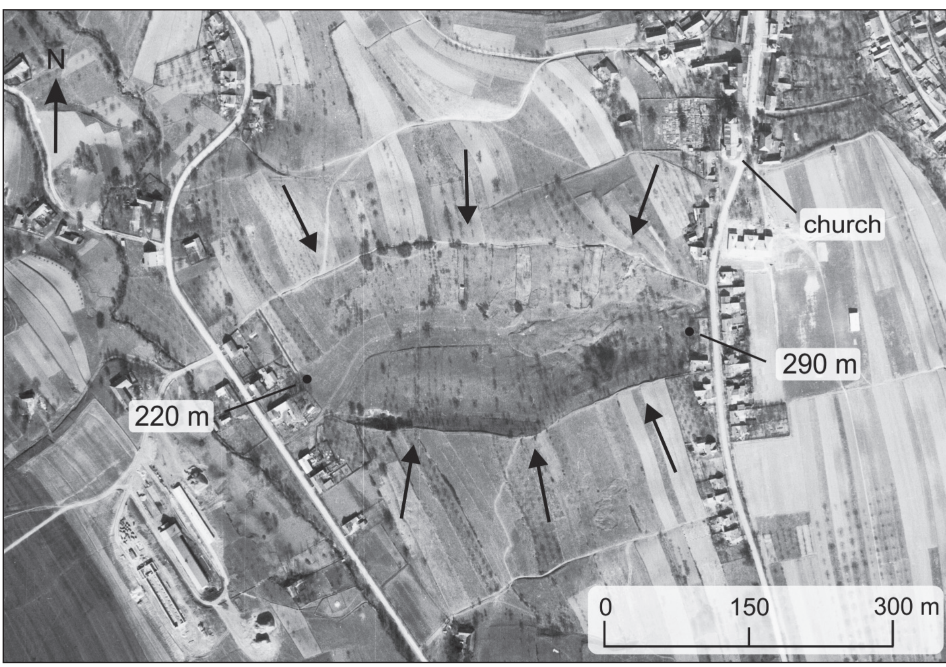

Fig. 8 – A dormant landslide whose accumulation was washed away. The arrows show the border of the slope deformation. Source: aerial photo from March 1961, MGHO.

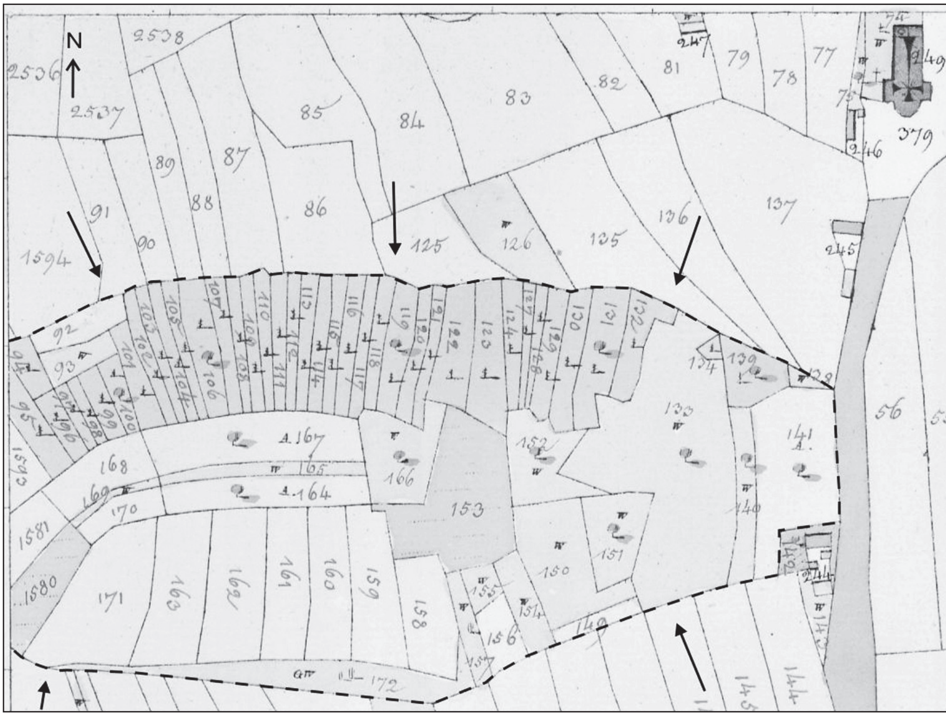

Fig. 9 – Map No. 0663-1-009 of the Stable Cadaster. The dormant landslide, see also Figure 8, can be easily delimited from the shape and the arrangement of the parcels and from the different land use. Source: Archive of the Czech Office for Surveying, Mapping and Cadaster.

not the only one found within the Zlín region. Slopes with sequences of several phases of loess sedimentation, interrupted by landsliding, were also identified in the town of Zlín, in the Dřevnice river valley, on the basis of several boreholes (e.g. Demek 1964, Demek 1966).

Another marker for the presence of a dormant landslide, particularly a deep-seated one, is morphological, that is the missing mass of a slope. A distinct shape which can be easily identified on old maps and aerial photos as a dormant landslide is in the exact middle of the village, with particularly its main scarp still being clearly pronounced (Fig. 5, letter B and Fig. 8).

This landslide was also depicted on a map from the Stable Cadaster which was mapped in the middle of the 19th century. The shape of the main scarp can be seen on the map (Fig. 9) which is also pronounced by a different land-use, where the slopes with the southern aspect were used as orchards and vineyards. The first written references to the village of Halenkovice date back to 1634 (Kašíková 2004). We could speculate that this landslide, lying at the exact middle of the village, originated long before the first settler of the modern era arrived here.

4.4. A chronology of landslide phases in Halenkovice and the vicinity

As we mentioned previously, landslides which did not cause any damage to buildings or the infrastructure were only occasionally recorded. We therefore focused on sources in which a description of such events could be found. The next problem is the fact that the majority of the houses in the Carpathians were built from wood and with only a ground floor. These kinds of buildings can easily be built again unlike those built from bricks.

According to the chronicle of Halenkovice, the first house with a first floor was not built until 1905. The number of residential houses rose from 225 in 1790, 248 (1834), 417 (1921), 532 (1934), 563 (1961), and 620 (1988; Zezula 1989). There were 639 houses in 2013.

4.4.1. Landslide phases since 1915

Here we present comments on landsliding based on a study of historical written sources from the chronicles of the village of Halenkovice and its immediate vicinity (see Fig. 1).

The first documented landslides date back to the autumn of 1915 and hit the villages of Jankovice and Košíky. The same area was hit by landsliding in 1918 (Jankovice) and 1937 (Košíky). The first four landslides were also documented in Halenkovice in April and May 1939. They damaged the local road to Napajedla (Špůrek 1972). This event was also recorded in the broader area in the towns of Napajedla and Uherské Hradiště and also in the villages: Spytihněv, Prštné, Drslavice, and Veletiny (for their localization see Fig. 1).

The first example of landsliding during which residential houses were damaged was recorded in Halenkovice in the spring of 1941. The first phase began in February and March 1941. At least 7 residential houses were destroyed, while another ten houses were seriously damaged. Landslides were also detected in the neighboring villages. There were 7 residential houses destroyed in Košíky and 2 in Jankovice. Additional records about this phase come from Napajedla and the town of Zlín.

A large part of the former Czechoslovakia was hit by landsliding at the beginning of the 1960s (e.g. Matula et al 1963). This event initiated the first areal mapping of slope deformation in Czechoslovakia. There are no written sources about landsliding from Halenkovice from this period. There is only a notice in the chronicle about heavy rains in the summer of 1960 which "… caused erosion on local roads and left potholes up to 1 m deep". The next reference is for June 1961. It describes "lakes of water … on arable land". Up to 12 distinct shapes can be identified from the 1961 aerial photo, which could be a result of landsliding during this period. According to Prokop (in Matula et al. 1963), who completed a map of landslides for this area, there were at least two active landslides in the village of Halenkovice.

Another extremely rainy year was 1965, when landslides hit the villages of Příluky, Maršov and Vlachovice. The rainy season was also recorded in the chronicles of Halenkovice, Spytihněv and Košíky.

Fig. 10 – Example of damage to a road by a landslide in the village of Halenkovice in July 1997 when the road embankment subsided by 1 m. Photo A. Horká.

Another phase of landsliding was recorded in 1970. This event is not mentioned in the local chronicle as it was not written between 1967 and 1973. The landslides must have originated, according to the eyewitnesses, before Easter which was in that year on 29th March. At least 2 residential houses were destroyed (Fig. 7). This event was in all probability local because landslides were only recorded in Košíky and Napajedla.

Czechia, particularly its eastern part (Moravia and Silesia), was hit by an extreme rainfall event in July 1997 during which hundreds of landslides were activated (Krejčí et al. 2002a). At least 7 of them were also recorded in Halenkovice (Kašíková 2004). The landslide "Na Díle" (Krejčí et al. 2002b) was

Table 1 – Landslide phases identified in the village of Halenkovice and the near vicinity

Event	Locality	Landslide phase												
		1915	1918	1937	1939	1940	1941	1942	1960	1965	1970	1997	2006	2010
Active landslides	Halenkovice				4		7				3	7	6	13
	Vicinity	3	5	4	2	3	10	3	3	3	3	7	1	6
Destroyed houses	Halenkovice						7				2			
	Vicinity		4				9	1						

Note: By the vicinity we delimit the cadastral areas of the villages shown on Figure 1. Years when only one landslide was recorded were excluded from the table. The numbers for the years before 1997 come from written sources, aerial photos and interviews.

activated once again. In addition, the main road in the village was interrupted in two places (Fig. 10).

Another phase of landsliding took place during the snow thaw in 2006 (Bíl, Müller 2008). Six active landslides were detected in the village. The last phase, when numerous landslides occurred not only in Halenkovice (13 examples) but in a large number throughout Moravia and Silesia, came about in May 2010 (e.g. Pánek et al. 2011).

Six main years of landsliding (1939, 1941, 1970, 1997, 2006 and 2010), where more landslides were activated (Table 1), can be delimited in the village of Halenkovice and its vicinity according to the written and other sources. The importance among the phases differs. It is probable that the phase in the 1960s was more important than it seems to be from Table 1. More evidence of landsliding comes from the area of the 15 km distant town of Zlín (e.g. Raška, Klimeš, Dubišar, in print).

5. Discussions

5.1. The number of landslides

The overall number of landslides which can be found within the Halenkovice cadaster is 120. Identification of the dates of landslide origins in order to delimit landslides phases is always an issue. Identification of the landslide phases from written sources during the historical era is easier when residential houses or the infrastructure were affected. The varying number of landslides recorded up until 1997 and after this event was in all probability caused by more intensive evidencing of these phenomena at this time.

The exact classification of landslide origin based on aerial photos was influenced by the time span between the respective photos, their quality and the season. The most valuable aerial photo in Halenkovice was taken in March 1961.

During the field mapping (Bíl 2003) we identified 29 active landslides throughout the entire Halenkovice cadaster. Many of them originated in all probability in 1997 and were only occasionally activated in later years. Unfortunately, this number cannot be compared to those presented in Table 1, which demonstrates landslides which were undoubtedly active in the given landslide phase.

Only 7 landslides (from 29 mapped in the field in 2003) were situated outside the forest. We recorded only one landslide, which in all probability originated in a forest (Jankovice in 1922), during the analyses of the written sources. It is therefore probable that the landslides which took place in forests were not recorded at all and the overall number of landslides was therefore strongly underestimated.

We present the assertions of the inhabitants to support the assumption that only the most important events were recorded. The inhabitant Mrs. P. Bieberlová says about this: “I remember that it was simply mentioned among people that this or that house fell down because of an earth movement, but it was not discussed later on.” Mr. V. Jambor, an inhabitant from No. 46, answered the question about the landslide near his house (see Fig. 6): "Due to the fact that the parcels affected did not belong to us, we did not plant trees there, the movement was relatively small and quite far from our house, we did not do anything, but we knew about it. There were more landslides in this area from time to time."

5.2. Landslide recurrence

We found evidence about the landslide recurrence mentioned previously, e.g. by Guzzetti (2005), or recently in close vicinity to the town of Zlín by Raška, KLimeš, Dubišar (in print). Guzzetti (2005) writes about it: "Approximately 89% of all the rainfall induced landslides triggered in the period between 1937 and 1941 were located inside or within 150 meters from a preexisting landslide. Similarly, about 75% of the snow melt induced landslides in January 1997 fell inside the pre-existing landslide deposits, i.e., they were reactivations, or were located within 150 meters of an existing landslide." We demonstrated that landslide reactivation occurred at the same place (Fig. 6) or next to the older landslide (Fig. 7). We also indicated that within the Halenkovice cadaster another 5 landslides were also reactivated within a subsequent phase of landsliding. Landslide recurrence is therefore in all probability a general characteristic of landslides and can be observed at places with different geological settings and terrain morphology.

We also computed the ratio of landslide areas which were active after 1941 to all landslides in Halenkovice (12%, see Fig. 5). The largest landslides in the village in all probability come from the wettest periods in the Holocene as was documented from other parts of the flysch Carpathians (Hradecký, Pánek, Klimová 2007; Klimeš et al. 2009). Moreover, landslide A (Figure 5), found beneath the loess cover, is even older (see section 4.3.). It would seem that the present-day rainfall extremes, particularly those in 1997 or 2006, were still not capable of activating those dormant and large landslides.

5.3. Risk of landsliding

There are a number of regions on the Earth where landslides pose a serious problem to society, accompanied often with numerous causalities. No causalities have been recorded in connection with landsliding over the last 100 years in Czechia. The last record dates back to 1897 in the Giant Mountains (Krkonoše in Czech) where 7 people died as a result of an earth-flow (Pilous 1973). Situations with immediate danger to life when residential houses were destroyed were recorded in e.g. in Růžďka in the Vsetín district in July 1997 (Kirchner et al. 2000) or in the village of Brumov-Bylnice in the spring of 2006 (Klimeš et al 2009). In all the cases the inhabitants abandoned their houses in time.

The 1941 event was in all probability the most devastating in the area of Halenkovice and its surroundings from the view of destroyed houses and affected infrastructure. This event can be compared to the catastrophic landslide which took place in Maršov in January 1967 where nine houses were destroyed (Pašek

1967) or with the villages of Mikulůvka and Růžďka affected by landsliding in July 1997 (Kirchner et al. 2000).

The risk of damage to residential houses still exists in the village of Halenkovice; since 47% (300) of them are situated on landslides and even 10% on active ones (63). Moreover, the risk of road damage due to landslides has recently been identified for a larger region including the village of Halenkovice (Bíl, Kubeček, Andrášik, in print).

6. Conclusions

The results support the previously discovered conclusion concerning the enormous susceptibility of the Flysch Carpathians to landsliding. The intensity and frequency of faulting in the Halenkovice area during the younger Tertiary affected the depths and extent of weathering which resulted in large accumulations of slope sediments. This predisposition in combination with extreme rainfall favored the emergence of landslides.

The landslide hazard poses a continuing danger for the inhabitants and the infrastructure in the area. We also determined the number of houses and roads affected by landsliding and demonstrated the impact of landsliding. A spatial analysis within the inhabited area also revealed that a large proportion of the houses are located in places under risk due to landsliding. Cracks can be observed on a number of the houses and the local residents informed us that the houses have to be repaired regularly. There is consequently a need to come to terms with the presence of landslides and their possible reactivations.

This study provides new information on the extent of slope deformation in the village of Halenkovice and the Northern Chřiby Mts. and can be used e.g. in the process of regional planning by local municipalities. The data and the map can also serve as the foundation for the process of landslide susceptibility map preparation. Similar maps have been recently created in neighboring districts (Klimeš 2008, Havlín 2010).

We identified 6 landslides phases which occurred in Halenkovice and the surroundings since 1915 (1939, 1941, 1970, 1997, 2006 and 2010). It is apparent that apart from the extreme events in 1997, 2006 and 2010, which had a regional impact, the other landslide phases indicated here were of more of a local character.

It will be interesting to investigate phases of landsliding in other Carpathian regions and compare their spatial and temporal concordance with those identified in this study.

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S h r n u t í

VÝVOJ SESOUVÁNÍ A JEHO DOPAD NA OBEC HALENKOVICE, VNĚJŠÍ ZÁPADNÍ KARPATY

Cílem příspěvku je ukázat časový průběh sesouvání v obci Halenkovice (Chřiby, Zlínský kraj) a jeho dopad. V Registru svahových nestabilit ČGS je evidováno 120 sesuvů z této oblasti, z toho 50 aktivních. Plocha sesuvů činí 4,0 km^2, což je 20,0 % rozlohy obce, a tedy významně více, než je průměrná hodnota pro celý region Západních Karpat, která dosahuje jen 4 %. Všechny sesuvy se nacházejí na kvartérním pokryvu, což je dáno hlubokým navětráním flyšových hornin. Z toho pohledu je také ostatní plocha kvartéru, na které nebyly sesuvy dosud prokázány, k sesouvání náchylná. V obci se nachází 639 budov, z toho na sesuvu 300 (47 %, na aktivním 63, na dočasně uklidněném 237).

V podmínkách flyšových Karpat jsou známy dva hlavní faktory vzniku sesuvných kalamit: jarní tání sněhu a intenzivní deště obvykle v letních měsících. Doklady o opakování sesuvů na jednom místě lze získat analýzou leteckých snímků nebo na základě dokumentovaného postižení obytných budov. V článku jsou detailně popsány dva příklady opětovného oživování svahových deformací.

V obci Halenkovice a jejím nejbližším okolí lze vymezit 6 hlavních fází sesouvání (rok 1939, 1941, 1970, 1997, 2006 a 2010) a několik dílčích. První zmínky o sesuvech pocházejí z podzimu 1915. Teprve v roce 1939 je prokázáno, že došlo k sesouvání přímo v Halenkovicích. První případ, kdy sesuvy postihly obytné domy, byl zaznamenán roku 1941. V roce 1970 byly sesuvy zničeny minimálně 3 budovy. V roce 1997 bylo zaznamenáno 7 sesuvů, na 2 místech byla přerušena silnice v obci. V roce 2006 došlo k další fázi sesouvání. Poslední sesuvy v obci byly zaznamenány v květnu roku 2010 (13 sesuvů).

Podíl plochy sesuvů, které byly aktivní od roku 1941 do současnosti, činí pouze 12 %. Z toho plyne, že naprostá většina svahových deformací nebyla aktivována ani extrémními srážkami z let 1997 nebo 2006. Sesuvy zmapované v zastavěném území centra obce nebyly před rokem 1941 aktivní.

Rozlohou největší sesuvy pocházejí s velkou pravděpodobností z nejvlhčích období holocénu, přičemž sesuv nalezený pod sprašovým pokryvem, pochází z přelomu pleistocénu a holocénu. Současné extrémy srážky pouze aktivují místa postižená sesouváním ve vlhkých obdobích holocénu.

Obr. 1 – Vymezení studované oblasti v severní části Chřibů a lokalizace míst, která jsou zmiňována dále v textu.
Obr. 2 – Znázornění postupu prací při sestavení databáze sesuvů, seznamu poškozených objektů a proces vzniku výstupů v GIS.
Obr. 3 – Příklad svahů postižených sesouváním. Šipky ukazují na dva sesuvy z roku 2010. Foto: O. Krejčí.
Obr. 4 – Geologická stavba katastru obce Halenkovice. Místa nejvíce náchylná k sesouvání odpovídají rozsahu kvartérního pokryvu. Zdroj: Česká geologická služba.
Obr. 5 – Sesuvy, zastavěné území a poškozená infrastruktura obce. Písmena A–D označují sesuvy zmíněné v textu. Zdroj: letecké snímky, MGHO a vlastní mapování sesuvů.
Obr. 6 – Sesuv u domu čp. 46. Oba zničené domy jsou znázorněny, čp. 335 je více nalevo, původní čp. 46 ve středu a nový dům s čp. 46 napravo. Data ukazují na místa, kde bylo zaznamenáno oživení sesuvu. Zdroj: letecké snímky, MGHO.
Obr. 7 – Sesuv Lipové. Až do roku 1970 se v místě starého sesuvu nacházely dva obytné domy. Rozsah sesuvu z jara 1970 lze vymezit podle leteckého snímku z roku 1973. Jeho přibližné ohraničení je znázorněno čárkovaně. Nejvyšší část starého sesuvu byla opět aktivována v roce 2006. Zdroj: letecké snímky, MGHO.
Obr. 8 – Fosilní sesuv, jehož akumulační část byla již denudována. Šipky vymezují rozsah sesuvu. Zdroj: letecký snímek z března 1961, MGHO.
Obr. 9 – Stejný sesuv jako na předchozím obrázku, zachycený v mapě stabilního katastru, list 0663-1-009. Mapový podklad: Archiválie Ústředního archivu zeměměřictví a katastru.
Obr. 10 – Příklad silnice z obce Halenkovice zničené sesuvem v červenci 1997, kdy povrch vozovky poklesl o zhruba 1 m. Foto A. Horká.

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