Multidisciplinary analysis of a slope failure at the Obří Hrad site in the Šumava Mts.

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In this contribution we describe various scientific techniques, which were used during the research of a multigeneration slope deformation on the archaeological Celtic site of Obří Hrad near Kašperské Hory. Due to a specific local condition, practically no accumulations were left, thus we had to work with other, mostly indirect signs and traces of the older generations of the slope. We have used methods of geomorphology, such as detailed mapping, morphological profiling, rock-strength measurements, etc, of engineering geology and geophysics (geophysical profiling, dilatometric monitoring), of archaeology and inorganic chemistry, in particular the X-ray diffraction analysis, which has helped to determine the origin of morphologically unclear accumulation remnants.

Keywords: slope failure, rockslide, multidisciplinary, X-ray diffraction, slope profile, Šumava Mts.

1 Introduction

In this article, we deal with a multi generation slope deformations on the slopes of the Valy Hill (1,012 m a. s. l.), crowned with a well-known Celtic site of Obří Hrad (**Fig. 1**). The locality is situated in south-western Bohemia, near an old mining town of Kašperské Hory. As the slopes of the spur of the Valy hill are very steep and the dynamics of their reshaping high, as well as the rate of valley floor changing, except for a few remnants there are practically no accumulations of the slope deformations. Thus the direct evidence was for the most part already removed by the activity of the Losenice stream on the narrow valley floor and it was necessary to use less frequent or indirect methods for the slope deformations research.

The very presence of such a large slope deformation is very unusual in rather stable and consolidated crystalline Moldanubicum unit (ZÁRUBA and MENCL 1987). There are several possible conditions, contributing to such a phenomenon:
– strong structural fragmentation, possibly related to a nearby fault zone in the valley
– coincidence of slope and foliation planes orientation (see HARTVICH 2005),
– position of the site on the outer slopes of the Šumava Mts., a significant morphological step securing high energy inputs into the geomorphological processes (HARTVICH 2006),
– overall disposition of the valley plan, resulting into the unique, weakened shape of the spur,
– deep incision of the rivers along the dissected Šumava Mts. outer rim due to backwards erosion connected with the Neogene/Quaternary uplift of the mountains
– high transportation power of these rivers, allowing a fast removal of the collapsed material, thus enabling further sliding,
– finally, possible human influence in the acceleration of already unstable locality.

We think that it was a spatial and temporal coincidence of the above influences that resulted into the extensive slope deformation activity. Throughout the article, we show how various methods contributed to the general hypothesis on the site development.

2 Archaeological research

There are altogether 16 sites with Celtic material findings in Šumava podhůří (Šumava Piedmont), particularly from the Halstatt period there is one settlement and one burial place. As an ex-

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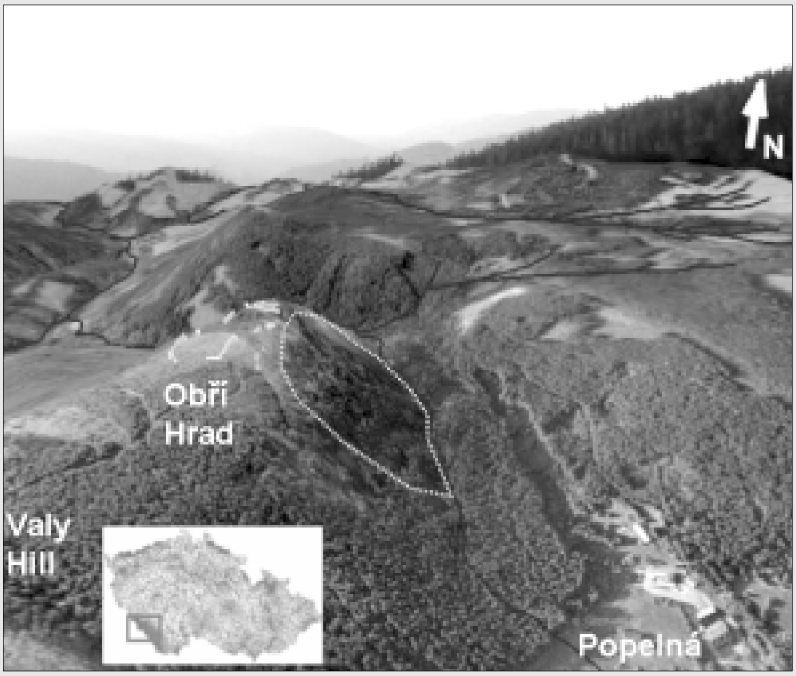


Fig. 1 Aerial view of the site of Obří Hrad. View to the north. Dotted white line indicates the slope with the deformations. Inset: Position of the site within the Czech Republic

ception can be mentioned the fortification of Obří Hrad near Nicov village, which is the only Celtic site within the Šumava Mts. and it is also the highest Celtic heritage site in the Bohemia (ČTVERÁK et al. 2003). This site was first time mentioned by Sedláček in the beginning of the 20. century, detailed site description was done by STREIT (1936). Afterwards, the site has been in focus of research of 6 more archaeologists, and finally, in the years 2002-2003 a combined archaeological and geological research was performed by the authors.

The fortification of Obří Hrad is situated on the northernmost part of the spur of the Valy Hill, its dimensions being approximately 370 m in length and 60-90 m in width, closing the area of about 2,5 ha. The rock outcrops were embedded into the fortifications. The fortification disposition is doubled: there is inner castle (often incorrectly referred to as an acropolis) and outer castle. The fortification of the inner castle is twofold, both belts incorporating the outcrops into the walls. A very unusual and extraordinary is the missing fortification on north-eastern third of the site.

2.1 The research 2002-2003

According the archaeological research, aimed at gathering of the datable material and on the fortification construction techniques, both inner and outer walls are built similarly: dryly laid stone blocks, always with two walls, the space between them was filled with a rock debris. The walls were approximately 3-4 m wide and in the inner castle they still reach over 2 meters in height. The crown of the walls is in some places still over 1 m wide, the width of the foot of the collapsed walls reaches in average 6-7 m.

An important element of each fortification is a gate. Unluckily, no gates were discovered, as the places described by ŠIMEK (1949) have changed and thus cannot be identified. Rather surprising is that Šimek did not describe the „Gate“ outcrop. Generally, it is extremely difficult to identify the entrances in the cases of old, strongly changed fortifications.

The work power, necessary for building of the fortification, was estimated to approximately 150 men, working for 5 months (2 m^3 per person and day), depending also on the level of organization and skill of the workers. Considering this, it is very extraordinary that there were no traces after these builders in the form of the material findings, such as broken tools, lost items, garbage, etc. Despite numerous archaeological researches (including over 100 probes) not a single object or any other material trace was found. However, only recently 18 coins dated approximately to 2.-1. century B.C. were found with the use of the metal detectors. The whole area of the inner castle was searched during our research, however, no other objects were found. Currently, there is a heated discussion between the numismatics on the authenticity of this discovery (doubting not as much the authenticity of the coins, but the locality of their occurrence).

2.2 The purpose of the Celtic fortification

The purpose and function of the building of the Obří Hrad fortification, situated into extremely unsuitable environment, far from any other settlements, is still unresolved. The most likely discussed possibilities were the sacral site, a fortress protecting a goldwashing site, refugium fortress, etc. Also the exact period of the building of the site is not yet completely clear, but according to the construction style and fortification design we can pinpoint the building to the late Hallstatt / Bronze Age period.

There is also a possibility that the location of the site was determined by the very geodynamic activity of the slope. We can assume that the people of that age knew very well the landscape and its behaviour, and thus they would probably notice and were attracted by an active slope site, which could be considered a manifestation of the presence of subterranean gods. In fact, there exists a legend concerning the site, which is connected to the name of the site: Obří Hrad means the „Giant´s Castle“. The story contains a tale that the giants, living on the site, used to throw stones downhill on people. In other words - omitting the culprit - a perfect description of a landslide within the historical age.

There is archaeological evidence that the process of the locality disintegration has began a long time ago:
– some parts of the walls are spread down slope and got mixed with the blockfields,
– at the connection of the outer fortification to the inner citadel there is apparent supportive lock-in, which may have been built to strengthen the toppling wall,
– the rock outcrops, which were incorporated into the fortifications, are currently strongly disintegrated – were they in such state at the time of the building, the builders would try to support them,
– we shall never know for sure whether the north-eastern walls were ever built, but it would be very uncommon if one of the sides would not be protected.

3 Geophysical profiling

In summer 2001, a complex and detailed geophysical profiling on the site of Obří Hrad took place (BENEŠ 2002). The chief purpose of the geophysical profiling was the assessment of the depth, character and distribution of the rock massif disturbation. Several techniques were employed, including gravimetry, geolectric methods, seismic tomography and refraction. There were in total 5 profiles performed, covering mostly the top of the spur, one of them reaching the bottom of the valley. The conlusion from the geophysical research was that the northern spur of the Valy hill, location of the archaeological site, is disturbed into great depth (up to 25 meters), locally covered with thick layer of rock debris and with distinct opening crevasses and pull-zones, which rend the slope prone the mass movement deformations.

Particularly on the tomography and geoelectric resistance measurement is based the interpretation of the massif state. Using the measured profiles, every 5 meters along the profile line the approximate depth of the „sound“ rock was read. Resulting point data were interpolated using kriging algorithm into a raster **(Fig. 2)**.

The validity of the result, i.e. the raster showing the depth of the „undisturbed“ rock, is, of course, influenced by the distribution of the source data and the interpolation formula. The deficit and particularly equal distribution of the data could not be avoided in this case (as we had only profile data), therefore the resulting raster should be used with care, as it cannot be exact due to the data distribution. The kriging then was found the best interpolation method considering the amount and distribution of the profile data (PODOBNIKAR 2007).

As can be seen on the figure, the deepest disintegration of the rock can be found on the NE slope of the spur, just beneath the scarps, where the remnants of the Celtic fortification are missing. On the other hand, the most „solid“ parts of the hill are the south-eastern and north-western edges of the inner citadel. In fact, these are partly covered with outcropping rock and can be considered the most stable parts of the spur. On the margins of these outcrops abruptly end the fortification remnants.

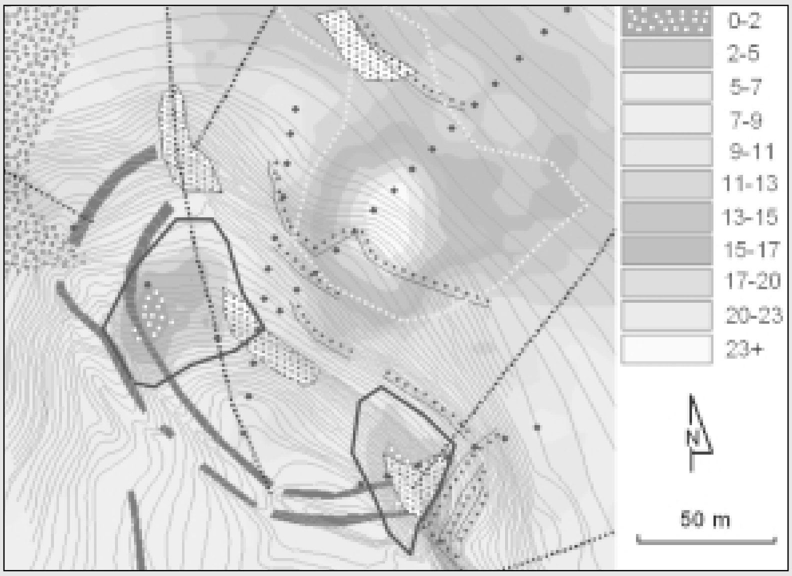


Fig. 2 Interpolated raster showing the depth of the rock disintegration, based on geophysical profiling (see the scale, in meters). Black dotted line – profile paths. White dotted line – zone of deep disintegration. Black solid line – two relatively stable, solid rock blocks in two corners of the inner castle.

4 Geomorphological research

The geomorphological research in the vicinity of the Obří Hrad site has been carried for over 4 years and included a vast number of various methods and techniques. Aside from the detailed geomorphological mapping (1:5,000), covering whole area of the Losenice stream catchment, and special geomorphological mapping (1:500), focused on the most interesting localities, many other methods were employed. From these, we shall discuss following in this article: detailed morphometrical profiling, measurements of the rock strength and site-focused morphological mapping.

4.1 Detailed mapping of the site

The slopes surrounding the northern spur of the Valy hill is regarded as a core area of the geomorphological works in the catchment of the Losenice valley. During several campaigns the site was mapped in the scale 1:500, so that all the relief forms and phenomena were recorded and analysed (**Fig. 3**). Also, several monitoring posts using various techniques were installed on these slopes.

Among the most significant, even determining phenomena for the development and current shape of the slopes are the structurally influenced slope deformations. What is most striking fact, found during the mapping, is that there is very unequal evidence of the slope movements: there are prominent, steep, fresh-looking, step-like scarps just beneath the flat relief of the spur, followed by the slopes, covered with rock blocks and debris. Under the slopes, however, there are practically no accumulations, that would correspond to the scarps above. Further investigation within the river valley floor (including the mapping of the consequences of 2002 flood, see HARTVICH 2007, HARTVICH, LANGHAMMER and VILÍMEK 2007) revealed very high activity of the fluvial transport.

It was calculated that the discharge under the Obří Hrad site may have reached 60-75 m^3/s (HARTVICH 2007), which results into extreme load power within the narrow valley. Thus it is possible to explain the missing accumulations, material from which is currently deposited along the river course. This was confirmed by a dug probe in the Losenice floodplain, which revealed a surprising amount of roughly reworked boulders (up to 50 cm), bearing traces of only short river transport, so that it can be classified as fluvio-deluvial debris.

The majority of the slopes is covered with rock debris, and in several places passing into open block fields. These block fields tend to be rather unstable, with block size up to 3 meters in the longest axis. During the mapping, the chief slope breaklines were also recorded. These served as yet another input into the slope analysis.

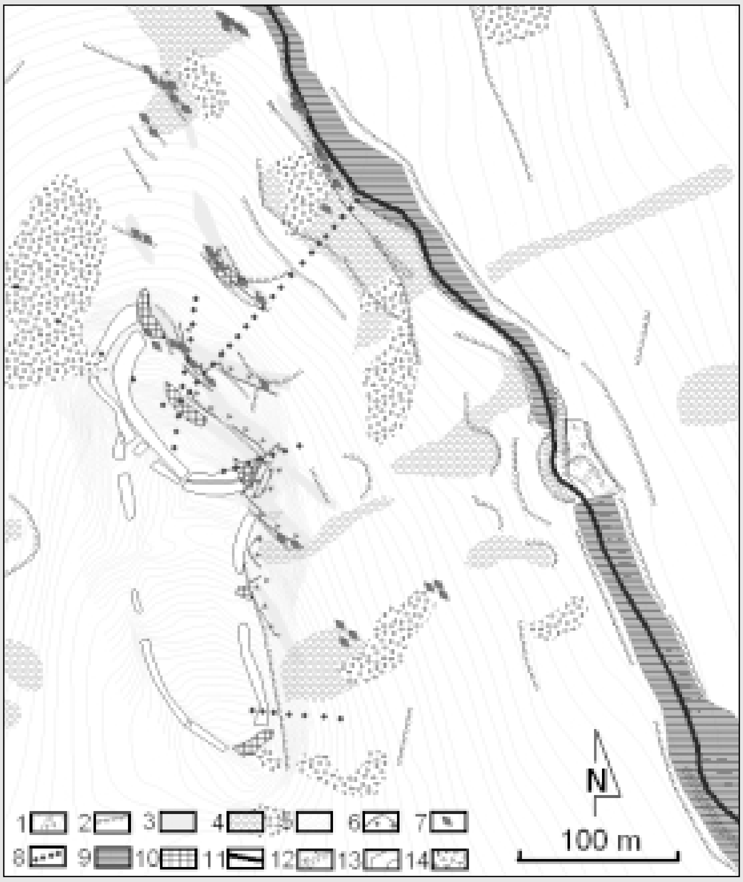


Fig. 3 Map of selected geodynamically significant elements on the eastern slope.
1 – possible remnant of a rockslide on the left bank, 2 – relief breakline, 3 – extension zones, 4 – scattered blockfields, 5 – contour lines, 6 – scarps, 7 – extension depressions, 8 – lines of geophysical profiles, 9 – floodplain, 10 – rock outcrops, 11 – river, 12 – bank lateral erosion, 13 remnants of the Celtic walls, 14 – dense blockfield

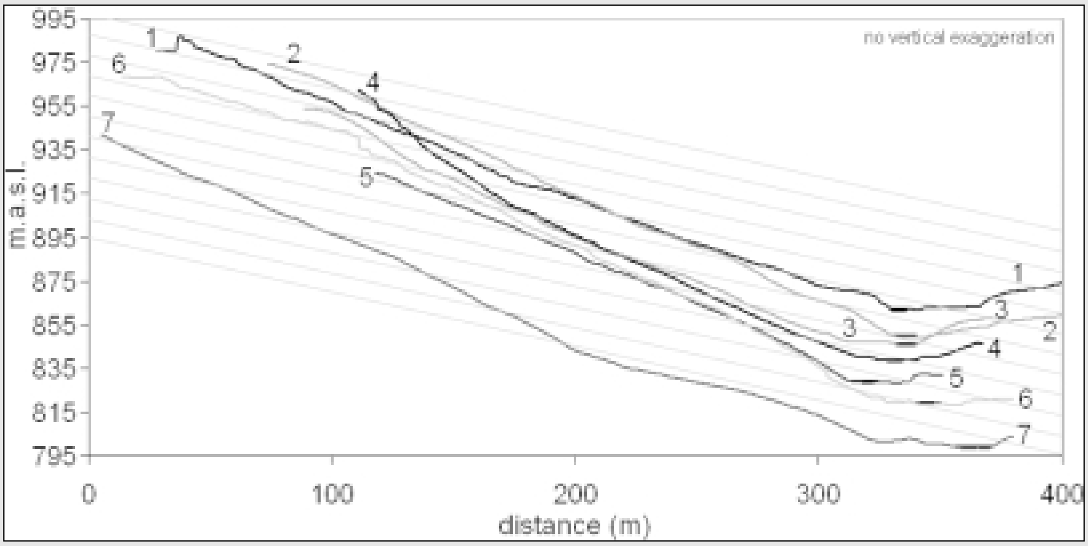


Fig. 4 Seven profiles across the eastern slopes under Obří Hrad site. No vertical exaggeration. Thin grey hachure indicates approximate inclination of the foliation planes

4.2 *Morphometrical profiling*

One of the best ways to gather accurate information on the slope or valley morphology is a construction of transversal profiles. There are several possibilities of their construction, both field techniques and digital data extractions using the DEMs. In this work, we used a laser range finder LaserAce, an optical device allowing measuring both horizontal and vertical distances, with a high accuracy (~ first cm), and at the same time considerably fast and user-friendly. Using this device, we have measured 7 profiles on the northern and eastern slopes of the Obří Hrad spur (**Fig. 4**). The profile paths were situated so that the most significant relief features were covered, particularly such phenomena as the slope breaklines, outcrops, blockfields or scarps.

As was previously described (HARTVICH 2005a), one of the factors, causing the high activity of the slope movements on the eastern slopes of the Valy hill, is the configuration of the slope in respect to the rock structures, particularly the orientation and dip of the foliation planes. Unlike in the case of the most slopes in the vicinity, the Obří Hrad eastern slopes are steeper than the foliation planes, having at the same time similar orientation of the dip (kataclinal overdipped slopes, see MEENTENMEYER and MOODY 2000), as can be seen on the **Fig. 4**. This results into enhanced sliding of the slope material along the tilted planes.

We are not going to discuss each profile separately, there are, however, some common features observable. The profiles tend to have either steeper upper sections, or showing significant steps or cliffs, generally later identified as corresponding to position of the slope deformation scarps. The central portions of the slope are usually almost straight, in average inclined about 25°. The lowermost part of the slopes is generally slightly convex, showing a significant increase in steepness, which is due to direct connection to the activity of the river incision as well as sideward erosion.

In order to trace more subtle morphological properties of the slopes and also to support the suggestions with solid data, a local slope inclination was calculated for each profile. After smoothing of the curve using

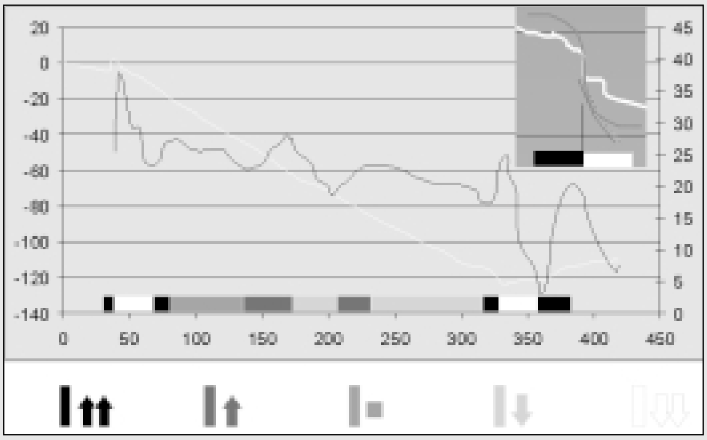
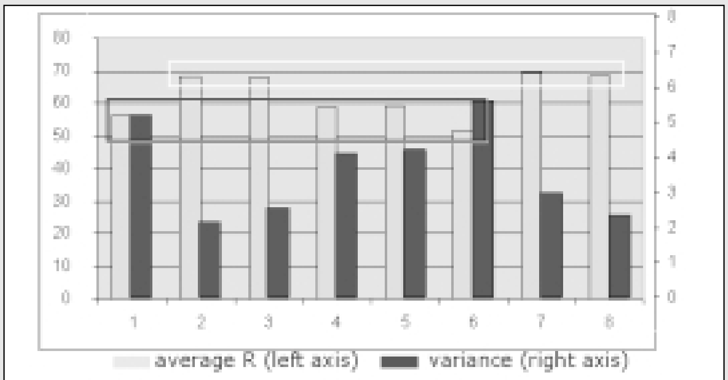


Fig. 5 Fine-tuning of the profile information gathering. Profile (white line) can be made clearer by a smoothened line of local inclination (black line). The segments below show the local trends on the inclination line, which also tells about local curvature: black – very concave, 50% grey – straight slope, white – very concave. The inset shows a position of a possible scarp



Site No.	I	II	III	IV	V	VI	VII	VIII
average R	56,4	68,3	67,9	58,9	59,4	51,7	69,3	68,7
std. deviation	5,2	2,2	2,6	4,1	4,2	5,6	3,0	2,3
maximum	66	74	72	70	65	62	74	72
minimum	44	64	64	52	50	40	60	61
var. coefficient	9,3	3,2	3,7	6,9	6,8	10,8	4,3	3,3

Fig. 6 Elementary statistic table of the rock strength measurement data. It is clear that the dataset fell into two clusters (harder and softer) by both variance and R average

a moving average function, the local trends were observed on each profile. The local trends were classified into five categories, representing convex to concave slope shape (**Fig 5**). The segments of the profiles were drawn into the profile map

The significance of the sequence of the segment type is obvious – a transfer from the convex to concave part of the slope indicates a step in the relief. As can be seen from the **Fig. 4** these steps occur either directly under the flat top of the spur, or in the lower part of the slopes, closely to the river....

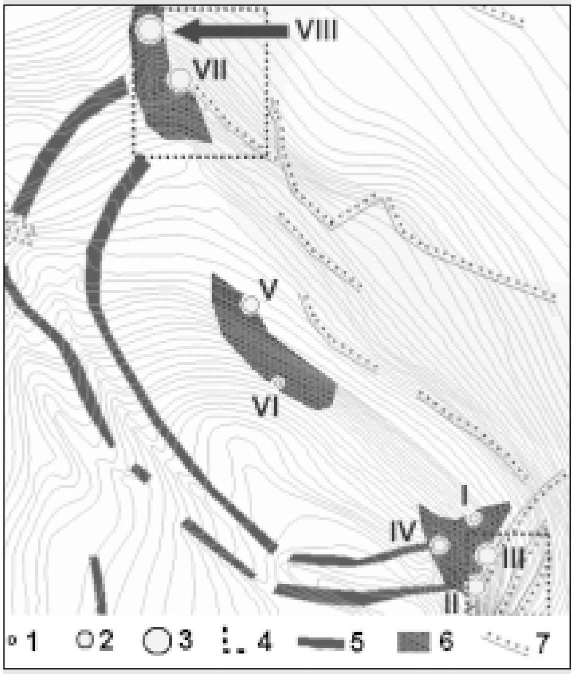


Fig. 7 Map of position of the measured rock strength sites (I-VII)
1-3 size of the circle grows with groving R average, 4 – possible scarp outcrops with the hardest rocks, 5 – Celtic walls, 6 – rock outcrops, 7 scarps according to mapping

4.3 Rock strength measuring

The rock strength measurement was carried out in order to confirm a hypothesis that the prominent rock steps beneath the Obří Hrad site. The rebound value (R) depends on the physical properties of the rock surface, which are changing in dependence of the time, elapsed since the rock face exposure, due to the weathering of the minerals on the surface. Therefore, we inferred that the potential rockslide scarps would appear harder (being exposed for a shorter time) than the other rock faces. It was necessary to take into account specific structural properties of the gneisses – the foliation planes, predisposing the presence of weaker surfaces within the rock, which could influence the results of rock strength measurements. Therefore, all the measured surfaces were selected so that their orientation to the foliation is approximately the same and its influence on the measurement is thus minimized.

The methodics of the measurements was taken over from several works. On each measured surface, 25 measurements were taken – the literature recommendations vary from 9 (BORRELLI et al. 2007) to 50 (SHAKESBY et al. 2006). The measurements were taken at least 15 cm from the plane border and so that they avoided visible cracks or diskontinuities in the rock (AYDIN and BASU 2005). The measured point was smoothened slightly using a grindstone, which decreases the variations of measurements (KATZ et al. 2000) – this fact was verified during the measurements.

In total, eight surfaces were measured, four of which were the presumed scarps, the other common rock surfaces for comparison (**Fig. 6**). The data were analysed statistically, we calculated the standard deviation and variance coefficient, as is suggested by MENTLÍK (2005). The eight datasets fell into two surprisingly different groups, both by the R value and the variance coefficient.

The four harder rock faces, with R close to 70, were the supposed scarps and the inner wall of the rock outcrop „Brána“ („The Gate“), currently measured by automatic extensometers as well as dilatometers (**Fig. 7**). The other four were all the other rock faces, measured for comparison, where the R oscillates between 50-60. In accordance with the literature (SHAKESBY et al. 2006) the variance decreases with growing R value.

5 X-RAY DIFFRACTION ANALYSIS

The x-ray diffraction analysis, a common technique used in inorganic chemistry, was performed on the samples collected along the profile No. 2. The method was employed in order to validate a hypothesis that the remnants of the accumulation on the right bank are accumulations of a slide, originating on the left bank of the river. The idea was that even though both sides of the valley are built by orthogneisses, it might be possible to find differences in the mineral composition along a cross-section across the valley due to facial changes during the metamorphic processes. By comparison of the spectra of the samples we might be able to assess the origin of the accumulation.

5.1 Methodology description

The X-ray powder diffraction (XRD) method was used for identification of the differences among studied samples. First, two samples of different origin were studied by XRD and we have recognized, that X-ray powder patterns of these samples exhibit important differences. These differences are caused by different relative content of main minerals and their crystallinity. Therefore we have used this method for determination of similarity of selected samples.

The URD-6 diffractometer was used. This old device (Freiberg, DDR 1988) was reconstructed and uploaded with a new software. The original hi-voltage generator was replaced by new commercial Seiffert (BRD 2004) generator. The Cu_Ka radiation was used in combination with secondary monochromator. The device was callibrated with use of Al_2O_3 standard (NIST676).

X-ray powder patterns were measured in continuous regime and written by recorder. Both peak positions and the heights of the peaks were used for qualitative and semiquantitative detetrmination respectively. These values were read visualy from the diffractograms.

5.2 Results and their significance

In total, we have analysed 11 samples, but sample No. 7 was omitted – it had too biased spectrum, probably due to the weathering. We shall not describe in detail all the spectra, the quantified results are shown clearly and concisely on **Fig. 8**.

The semiquantitative determination of relative composition of the samples were studied with use of “Reference intensity method of quantitative X-ray diffraction analysis” (DAVIS 1988). The reference intensity ratio (RIR) constants were taken from the same monography. The minerals were identified with use of PDF-1 database (International Centre for Diffraction Data, Pennsylvania). According to the approximate knowledge of mineralogical composition of the samples all the samples were tested for the presence of the following minerals (the number in the parenthesies means the “card number” in PDF database):

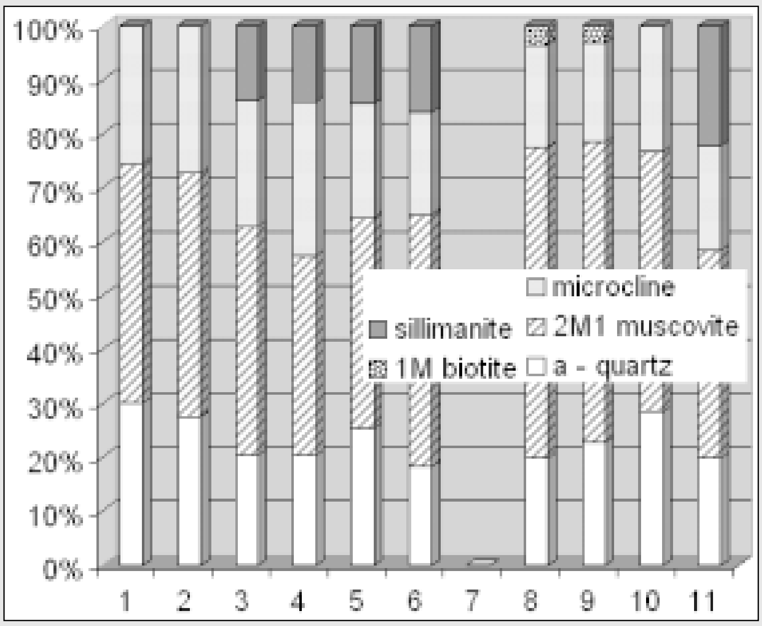


Fig. 8 Relative mineral content in the samples 1 – 11 according to the roentgen diffraction analysis. Notice the similarity between samples 3-5 and sample 6, coming from the accumulation across the river

Microcline (19-932)
Muscovite (6-263)
Orthoclase (31-966)
Muscovite 2M2 (25-649)
alfa-quartz (33-1161)

If we project the results into the profile (**Fig. 9**), interesting features can be observed. Generally, it can be said that the samples 3-5 from the center of the slope are very much alike, and they are also very similar to the sample 6, which was taken from the presumed slide accumulation. The sample No. 11 is also similar, particularly due to the presence of the sillimanite. The content of 1 M biotite differentiates the samples No. 8 and 9. The projection into the profile (**Fig. 9**) might suggest a logical conclusion that the mineral content changes not only horizontally, but also vertically with the respect to the foliation planes.

6 Discussion and interpretation of the results

Throughout the article, we have been collecting evidence, pointing towards considerable activity of the geomorphological processes, including the slope morphology, rock destruction depth and distribution, rock strength variations, archaeological results, floodplain dynamics, scarp shape and position, opening zones presence, as well as the mineral composition throughout the valley cross-section. Now we should compile the sources and connect into a unifying hypothesis.

The spatial distribution of relevant phenomena (**Figs. 2, 4** and **6**) shows certain pattern. The significant mapped scarps, built by the hardest (= least weathered rocks), coincide with the abrupt ending of the remnants of the Celtic walls and also of the rather sound, unweathered rock. The mineral composition, marked by high quartz and microcline content and by missing sillimanite and 1M biotite slightly differs from the other samples.

Further down slope, very deep destruction of the rock surface (up to 25 m) prevails, and yet further the straight, though still considerably steep (between 23˚ and 28˚) slopes are covered with thick debris layers and loose, unstable blockfields. Here, the high content of sillimanite is the best distinguishing factor together with missing 1M biotite. Between profiles 4 and 5, however, there is a step-like scarp outcrop approximately in the middle of the slope, followed by a semicircular depression and a blockfield, thus forming an exception from the otherwise straight slope profiles in this slope segment.

The valley floor is separated from these uncurved slopes by a prominent breakline, indicating the reach of the direct influence of the riverbank erosion, which can be seen on practically all the profiles. The accumulations of the slope deformations are for the most part removed by intensive river activity, with only small remnants of the – probably – younger phases. One of these can be found at the valley bottom where the profile No. 2 passes. Here, from the assumed accumulation scrap, a sample No. 6 for the roentgen analysis was taken, showing very similar content to the samples from the central parts from the left slope (No. 3-5), particularly in the content of sillimanite. At the same, this sample was without 1M biotite, so unlike the other samples (8 and 9), taken from the nearby right bank slope (**Fig. 9**). This could confirm the assumption that the material is really an accumulation remnant, originating on the opposite slopes under the Obří Hrad. Furthermore, we can assume that it was one of the younger phases, because:

1. it came from the middle of the slope, not from upper part,
2. it can be still found near the valley bottom in the reach of flood events,
3. it is still morphologically distinguishable from the rest of slope, from which it is separated by a 2-3 meter high step.

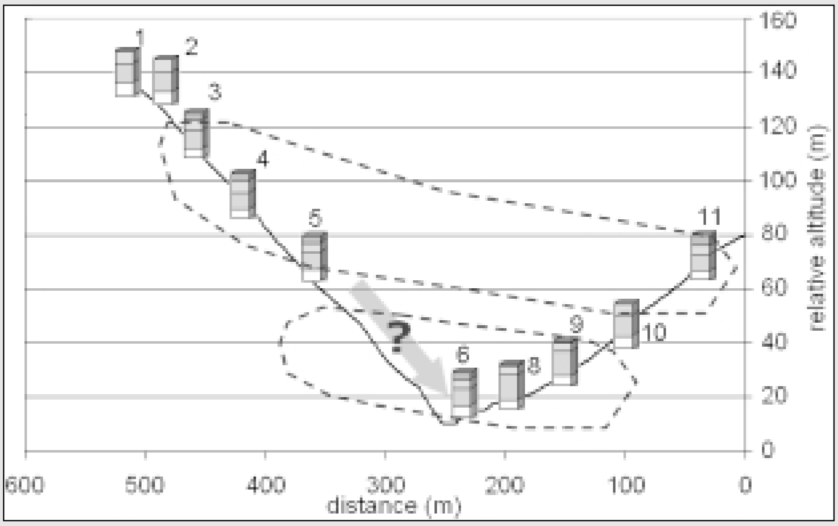


Fig. 9 Position of the samples for the roentgen diffraction analysis along the profile No. 2. The arrow indicates possible origin of the accumulation, from which sample 6 was taken. The dashed lines indicate clusters of the mineralogically most similiar samples

To the approximately same phase should be counted two other, smaller deformations. One of them can be associated with the the above described scarp in the mid-slope. It ends abruptly by a steep step on the end of a blockfield, currently in the direct reach of the river lateral erosion. There are some hints suggesting that it is currently the most active zone of the slope, although the slope movements tend here to be rather shallow and of lesser volume:

1. there are no traces of the accumulation on the valley bottom (small volume was instantly removed),
2. the blockfield is apparently very unstable, as is confirmed by preliminary yields of the extensometric measurements,
3. the preliminary results of the clast analysis in several profiles on the blockfield show significant downslope orientation of the longer axes,
4. the depth and size of the semicircular depression does not allow for large volume of the sliding material.

This younger generation of slope deformations does not reach further than approximately to the middle of the slope, thus its activity does not interfere with the archaeological site. On the other hand, there are the most prominent scarps just under the inner citadel, which can be associated with 1-2 older generations of the sliding (**Fig. 10**). These movements were deeper and probably developed on a strong structural predisposition, which was documented previously (HARTVICH 2005).

The mechanics of the rock sliding is determined by the orientation of the foliation layers, predisposing the shear planes, and deep weathering along the joints of approximately NW-SE direction, documented by the geophysical profiling.

As the luminescence isotope absolute dating has not been performed yet, thus the time pin-pointing of the origin of the rocksliding is based on indirect, relative signs. The rock strength measurements indicated that the scarp faces are significantly younger than comparable rocks (see the chapter Geomorphological attitude), the hardest of all being the inside wall of the outcrop „Brána" („The Gate"). Here, the velocity of the opening of the fissures has been measured for four years, with the fastest movements reaching 4 mm, i.e. approximately 1mm per year, which would - in the case of a constant movement velocity - mean that the opening has been proceeding for roughly 1,000-1,500 years. This would have two consequences:

1. original hypothesis of the archaeologists, that the „Gate" was actually an entrance into the citadel is thus ruled out, for the Celts built the site approximately 2,500 years ago,
2. this is the hardest, therefore youngest rock face - but not by much, the difference in average R being 0,9-2 % (the scarps) and 14,3 – 18,7 % (other rock faces).

Consequently, we can speculate that the three typical scarp faces being slightly older than the assumed age of the gate fissure (1,000-1,500 years) would put the age of the slides somewhere around the age of the building of the Citadel. Taking into account the spatial distribution of the scarps and related phenomena, the missing portion of the fortification and the time coinci-

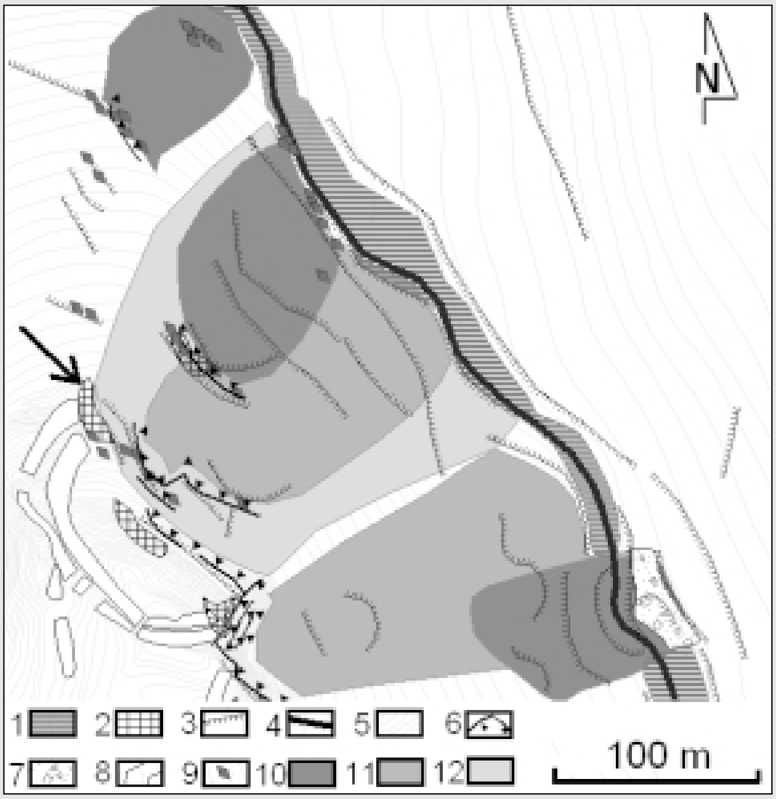


Fig. 10 A synthetic map, showing the position of 2-3 generations of slope deformations on the E and NE slopes of Obří Hrad spur

1 – floodplain, 2 – rock outcrops, 3 – relief breaklines, 4 – river, 5 – contour lines, 6 – slide scarps, 7 – slide accumulation across the river, 8 – remnants of the Celtic fortifications, 9 – extension depressions, 10 – 3rd. slide generation (youngest), 11 and 12 – 1st/2nd generation (older). The arrow indicates the outcrop „Gate" with fast opening fissure

dence, we have in our opinion strong (although indirect) evidence for the conclusion that there was very likely an interaction between the citadel and the slope processes, most likely that part of the – then newly built or unfinished – citadel was damaged by the rockslide.

Such an event would certainly disrupt the continuation of the site development, possibly it might even lead to abandoning of the citadel. This would comply with the lack of archaeological material findings - the site would be never actually used.

Even though the accumulations of this older and larger generation cannot be traced today, there is still some evidence that the activity of these rockslides may persist. As was mentioned, the monitoring on the "Gate" outcrop shows, particularly across an apparently fresh opening, rather high velocities, reaching 1 mm per year. As this opening:

1. is the most significant opening in the outcrop
2. can be traced further from the outcrop
3. the measured movement velocity does not respond on the seasonal influences

Therefore we think that what we measure is very likely but a surface manifestation of a deeply based, creep movement. This can be linked to a so far unexplained area of deep rock disintegration, recorded by the geophysical profiling (see the chapter). If we extend the line of the opening, it continues in the direction 110°-115° (most important structural joint orientation, see HARTVICH 2005b) along a significant step towards the scarps just above this deeply disintegrated area. This coincidence may be seen as an indicator of either re-activation of the larger slides of the 1st generation (reaching almost to the citadel) or their persisting, cyclic creep movement. We do not have yet all the data to confirm this hypothesis; it would require another, possibly extensometric measuring between the scarps and a suitable outcrop down slope.

Finally, there are some more questions, arisen during the analysis of the collected information. We have silently presumed – particularly in the event sequence reconstruction – that the activity of the geomorphological processes is more or less equal throughout the site history. This presumption may be, however, questioned at least from three angles, taking into account:

1. climatic oscillations and changes during the last 3000 years,
2. possible seismic influences (even from a distant event may have influence on strongly disintegrated spur),
3. other disturbances/singular events, such as exceptional floods, landcover changes (related to both the climate and human activity).

It is clear that if we want in the future estimate possible endangerment of the archaeological site, it will be necessary to include at least some information on these phenomena. Some steps had already been taken in order towards observation of the response of the site on particular climatic events: a network of various observation points is under construction, its crucial elements being automatic catchment discharge measurements, data from the nearby climatic station Churáňov, automatic extensometric monitoring and automatic on-site temperature measuring.

7 Conclusion

Using a rather wide range of methods from various scientific disciplines, we were able to assess the position, mechanics, and in a way also relative timescale for 2-3 generations of rockslides on the eastern slopes of the spur of the Valy Hill under the archaeological site of Obří Hrad. The younger generation, which is partly active due to its association with the erosive activity of the Losenice River, reaches only to the middle of the slope and there are still some traces of its accumulation in the narrow valley bottom. On the other hand, the most prominent remainders of the older generations are the scarps and possibly also the missing parts of the Celtic fortifications. This older generation is larger, deeper and is strongly determined by the structural conditions. The material, accumulated on the valley bottom, is already removed by the river activity, which is very intensive particularly during the flood events.

The collaboration between the specialists in different fields allowed complementing the final hypothesis from various points of view, which proved very useful. We concluded (see the discussion) that it is very likely that the older generation of the sliding coincided spatially and probably also temporarily with the Celtic site construction. However, it is necessary to remark that – despite the above mentioned indications – this scenario is a hypothesis, validity of which shall be contested during our further research. Aside from the mentioned luminescence dating of the scarp exposure, we intend to expand the database of the rocks strength measurements, continue in all the three types of on-site monitoring, examine the mechanics of the slide by numerical and photoplastic modelling.

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