Engineering geological research of andesite alteration related to the revitalization of the Šášov Castle (Central Slovakia)

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Inžinierskogeologický výskum alterácie andezitu súvisiaci s revitalizáciou hradu Šášov (Stredné Slovensko)

Abstract: An architectural study of the revitalization of the Šášov castle in the neovolcanic Štiavnické vrchy Mts. initiated a revision of the castle buildings. The building stone showed high post-volcanic alteration (hydrothermal and/or by weathering) or total disintegration in some parts of the walls. It must be replaced, because the safety of the ruins determines a sustainable development of this historical site. The castle hill rocks and the main building stone are both Neogene andesites, but not necessarily identical – the building stone came probably from several sources and the original source of the building stone was not the question. Suitable replacement material was searched for in a local quarry. Andesites at different weathering levels were taken to test the impact of alteration upon the rock properties and their suitability for the castle remediation. Expandable clay minerals were considered important for the rock weakening and weathering resistivity. Mineral composition was analysed by X-ray diffractometry. Powdered samples were used for the determination of the particle density and Enslin-Neff tests. The dry bulk density, total porosity, He-effective porosity, and the uniaxial compressive strength (UCS) were determined only on cylindrical rock cores of the quarry andesite. The "sound" building stone consists of feldspars (andesine > orthoclase), amorphous phases and a small amount of augite and quartz. Its alteration is manifested by the falling content of amorphous phases, augite and feldspars, by increasing smectite (up to 28%) and secondary carbonates (up to 22 %), as well as by the color change due to increasing iron oxyhydroxides. Mineralogical composition showed acceptable differences compared to the sound quarry rock. There, higher alteration levels show higher water adsorption and increasing macroporosity, as well, which could be explained by a hypothesis: the basic macroporosity is of syngenetic origin, but, cyclic wetting and drying of the smectite together with freezing water in the pores probably open new cracks and enable rock weathering into weak phases, new-formed smectite included; open porosity resulting from their erosion multiplies the interface area and accelerates the weathering. For increasing porosity leads to a striking drop in UCS, only a sound rock from the deeper parts of the quarry can be recommended for the castle revitalization.

Key words: building stone, andesite, alteration, smectite, porosity, uniaxial compressive strength

1. INTRODUCTION

The content of clay and clay minerals in indurated sedimentary rocks determines their weathering-and-erosion resistance. This is obvious on rock cuts (especially in flysh), on building stones and rock sculptures in exterior (sandstones with different clay content), but also in the geomorphology (soft land forms on claystones, steeper slopes on sandstones). Visser & Mirwald (1998) studied the vulnerability of historic sculptures made of calcareous sandstone due to weather/climate conditions. They pointed out clay minerals as critical components. Also other works refer to a direct relation between the clay minerals in the rock and the decrease in the weathering resistance (Soukupová et al., 2002; Šrámek, 1997; Kundig et al., 1977). The influence of the type of the clay minerals upon the strength and weathering resistance is evident in claystones (Reuter et al., 1980; Nüesch, 1999; Ondrášik et al., 2002 and others) and in volcanic rocks (Vavrová et al., 2002), less in limestones, where detritic clay can be seen only as the non-soluble residuum after an acidic dissolution. But even the weathering resistance of limestones is decreasing with increasing clay content. Clay minerals retard a big amount of water in the inter- and intragranular spaces and the expanding volume of the freezing water leads to a frost destruction of the rock. However, expansive clay minerals have the most destructive effect (May, 1994): if minerals like smectite, vermiculite or mixed-layers are within the weathering products, additional stresses occur due to the repeated expansion/swelling and contraction of the clay minerals by cyclic wetting (stress phase) and drying (tensile stress phase). This is a difference compared to the volume changes during freeze-and-thaw cycles in winter, where no significant tensile stresses are expected (Šimková et al., 2012). Standard laboratory tests used in the engineering geology do not pay attention to the presence of clay minerals in rocks. Most tests

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Fig. 1. South view of the Šášov castle ruins and the neovolcanic rock mass.
Obr. 1. Pohľad z juhu na zrúcaninu hradu Šášov a neovulkanický skalný masív.

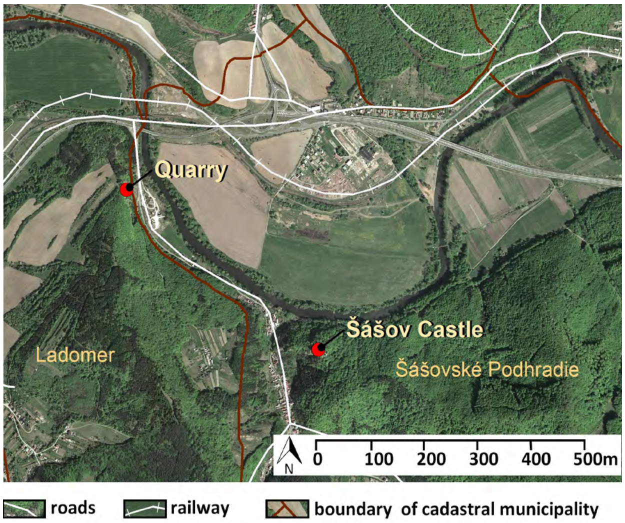
are based on freezing the water-saturated samples and/or on the stresses due to the crystallisation of new mineral phases from the added solution. The only notice on clay minerals can be found in the technical standards for the road construction: partly weathered crushed volcanic rocks can be applied in the load-bearing sub-base of the road if they do not contain clay (clay minerals). A revitalization-oriented study of the ruins of the medieval Šášov castle and a local quarry in Šášovské Podhradie village provided an opportunity to study how alteration and the presence of swelling/expansive clay minerals in rocks influence their physical properties and weathering resistance. Volcanic rocks were chosen because the highest content of swelling clay minerals was expected there due to hydrothermal alteration processes preceding their weathering.

2. ŠÁŠOV CASTLE – HISTORY AND REVITALIZATION STUDY

The medieval Šášov castle (Fig.1) above the Šášovské Podhradie village (Central Slovakia, Fig. 2) is a national cultural heritage site. A strategic position on a hill overlooking the village and the Hron River was a reason for its construction. The most important dates in the castle history are: 1253 – early Gothic construction, 1490 – reconstruction and extension in the Renaissance style, 1677 – destruction in attacks, the castle turned into abandoned ruins (Hoššo, 1981). Since 1970 small rescue works were carried out. An engineering geological mapping of the castle rock mass in the scale 1:500, together with the inventory of the state of all castle buildings were done in 1994: some collapses of walls followed major tectonic lines in the castle rock mass opening due to slow slope movements, building stone and the binder were weathered (Vlčko et al., 1994). At the beginning of the 21st century an architectural study of the revitalization possibilities was presented (Adamcová, 2006) based on suggestive reconstruction and neoplasm, two basic methods used in architectural conservation. The reconstruction of the period style is impossible due to the lack of information about the historical architectural background, and the current unstable state of the ruins. The revitalization main idea is based on a legend about the first owner of the castle – a clown. The architectural study adapted this place to a new spot, where theatre, arts and nature meet through numerous stages for outdoor theatre and concerts, partly open air galleries, spotting places and view-points to "cheer up" the visitors (Fig. 3). It tried to avoid solutions, where the existing ruins would serve as a holding base for new constructions. Own carrier systems should be fully independent from the ruined walls and only "inserted" into the existing ruins. In spite of this, a professional conservation of the remaining walls cannot be avoided, so a brief revision of the castle condition was done in 2009, 15 years after the inventory. The most dramatic destruction was found in the so called Round Tower: a seriously cracked wall over a tensile joint in the rock mass collapsed. But in general, changes in the wall crowns were quite negligible. All levels of weathering were present in the lower wall parts (Fig. 4-5), leading to cavities and overhangs. A characteristic macro-porosity of the weathered building stone was observed, too.

3. STUDIED ROCKS

The village Šášovské Podhradie is located in the Neogene volcanic Štiavnické vrchy Mts. The castle hill is built of the Upper Badenian leucocratic pyroxene andesites and related hyaloclastite breccias of the Turček Formation (Lexa, 1986; Konečný et al., 1998[a]). The rocks are also affected by tectonic disintegration as the castle hill is situated next to a major fault (Fig. 6). Andesite is the prevailing rock type both in the castle subgrade (with a whole range of transitions to volcanic glass, tuff and breccias) and in the building stone of the castle. The castle hill rock mass was not necessarily the only source, however, the original building stone source was not the question of the research. Replacement material for the weathered building



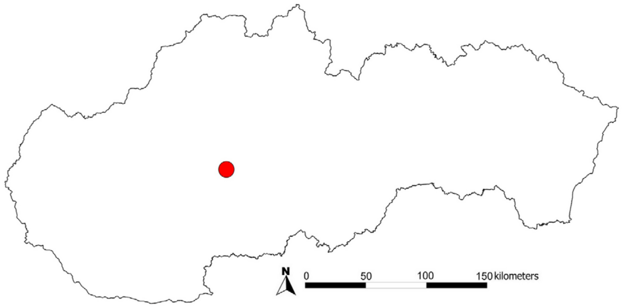


Fig. 2. Situation map of the studied site: Šášov Castle and the quarry.

Obr. 2. Situačná mapa študovanej lokality: hrad Šášov a kameňolom.

stone was searched for. In order to test the suitability for the castle remediation, a pyroxene andesite from an abandoned local quarry 1.5 km N-NW from the castle, from the same geological unit and of the same age, was studied. A lava flow of basaltic andesites (Pannonian) together with their tuffs and tuffitic breccias (Pannonian) in the upper part of the quarry outcrop belong to the Šibeničný vrch complex of the Štiavnické vrchy Mts. (Konečný et al., 1998[a,] 1998[b]) (Fig. 6). It can be assumed that a certain part of the building stone comes from the quarry due to the short distance. Samples showing different alteration levels were taken from the castle (1 relatively sound and 1 highly altered and disintegrated) and from the quarry (4 levels, from sound to "altered III") to test the impact of alteration upon the rock properties and the suitability for the castle remediation (Fig. 7-9).

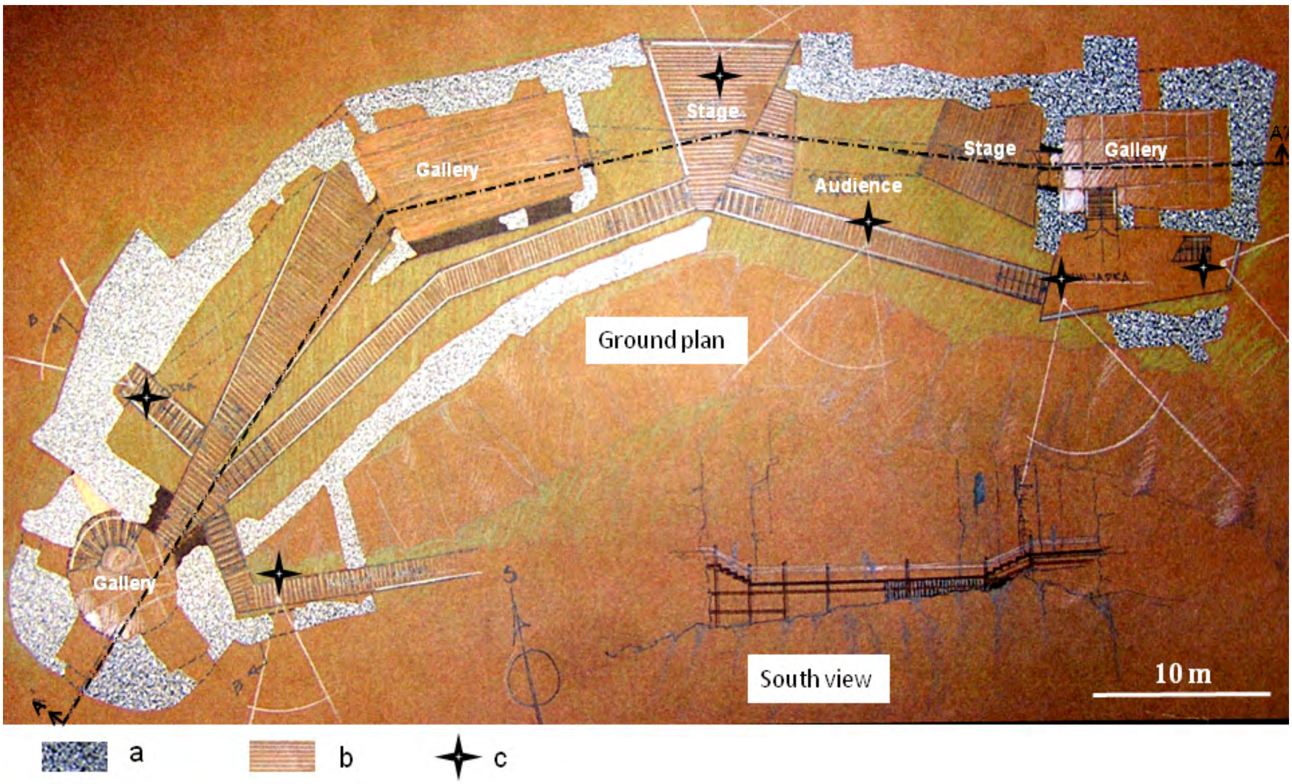


Fig. 3. Architectural study of the castle revitalization – bird's eye view and one segment of the south view: a) ruins of the castle walls; b) walkway; c) scenic view point; detail of the archival document, material and color suffering of time.

Obr. 3. Architektonická štúdia revitalizácie hradu – pôdorys a časť pohľadu z juhu: a) ruiny hradných múrov; b) chodník; c) scénický vyhliadkový bod; výrez z archívneho dokumentu, materiál a farby poznačené časom.

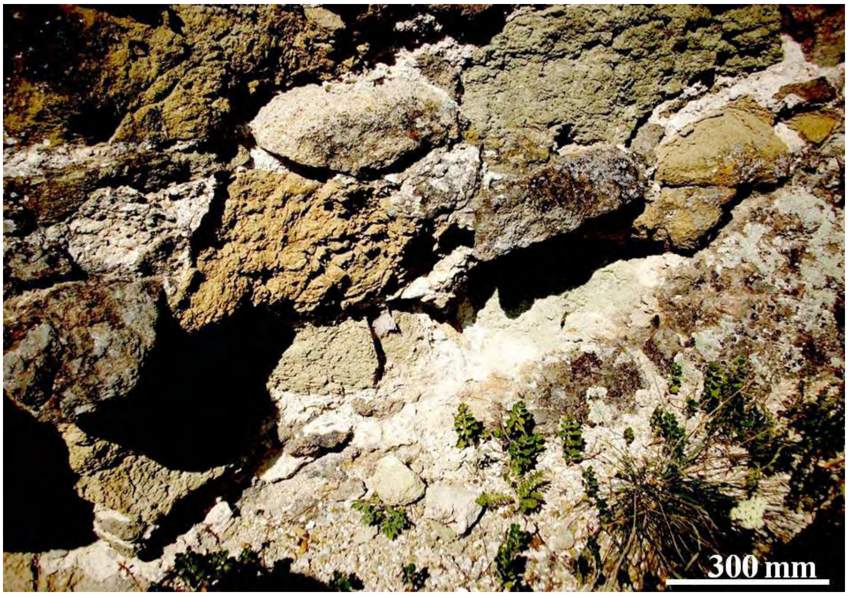


Fig. 4. Building stone of different alteration levels in the lower part of the wall: from color change to total disintegration, wall overhangs.
Obr. 4. Stavebný kameň v rôznom stupni alterácie v dolnej časti múrov: od zmeny farby až po úplný rozpad, previsy.

4. METHODS OF LABORATORY RESEARCH

Quantitative X-ray diffractometer analyses (XRD) was done at ETH Zürich, the zinc oxide (ZnO) was used as the internal standard to determine the percentage of the amorphous phase in the analysed samples. ZnO was calcined at 700 °C, micronized to fraction < 0,020 mm and added to the samples (also micronized to <0,020 mm) in the ratio sample:ZnO = 90:10 (mass %). The batches were homogenized in a pulverisette. Randomly oriented, front-loaded powder specimens were prepared and analysed using the Philips PW 1820 instrument (CuKα, range 2-70°2θ, step size 0.02°, counting time 4 s). The powder diffraction files were processed by the software BGMN®/AutoQuan by Rietveld analysis (Bergmann & Kleeberg, 1998). The information about the internal standard proportion (10 wt.%) was provided to the software to calculate the amorphous phase amount in the samples.

For the determination of the particle density r_s (g.cm^{-3}) ("real density" according to STN EN 1936: 2007), rocks were grinded to powder and tested in the helium Stereopycnometer according to the manual (Quantachrome Instruments, 2005), results were checked by a standard glass pycnometer method (STN EN 1936: 2007). This rock powder was used also for the Enslin-Neff water adsorption tests (DIN 18 132: 1995, Fig. 10) applied in an innovative way with the following idea: water adsorption of the rock powder does not depend on the porosity of the tested rock, because the original porosity was eliminated by grinding. Increasing water adsorption of rock powders of similar grain size distribution by the Enslin-Neff method must be only due

Fig. 5. Highly altered building stone: yellowish color, disintegration into small grains along many fine cracks. Length of the block ca. 500 mm.
Obr. 5. Intenzívne alterovaný stavebný kameň: nažltlá farba, rozpad na drobné zrná pozdĺž množstva jemných prasklín. Dĺžka bloku cca 500 mm.

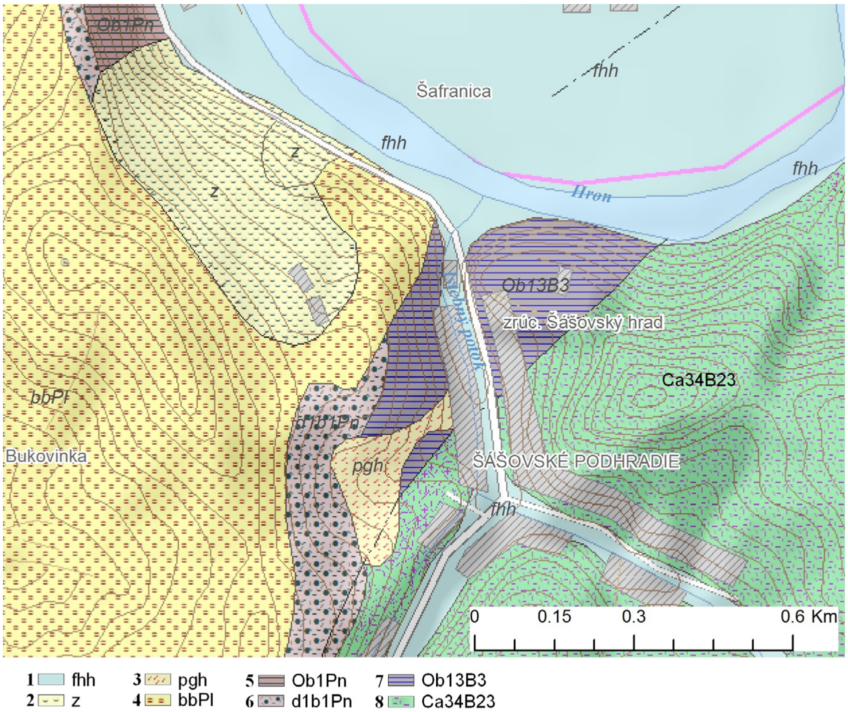


Fig. 6. Geological map of the studied area (http://mapserver.geology.sk/gm50js/ [2014-04-10]): 1) fluvial deposits (Holocene); 2) landslides (Pleistocene/Holocene); 3) slope deposits (Pleistocene); 4) sand, clayey sand, gravel (Pliocene); 5) lava flows of basalts and basaltic andesites (Pannonian); 6) freatomagmatic tuffs and tuffitic breccias of basalts or basaltic andesites (Pannonian); 7) lava flows of basic leucocratic andesites (Badenien); 8) biotite-amfibolite-pyroxene andesites (Badenien); zrúc. Šášovský hrad = Šášov Castle ruins.

Obr. 6. Geologická mapa študovanej oblasti (http://mapserver.geology.sk/gm50js/ [2014-04-10]): 1) fluviálne sedimenty (holocén); 2) zosuvy (pleistocén/holocén); 3) deluviálne sedimenty (pleistocén); 4) piesky, ílovité piesky, štrky (pliocén); 5) lávové prúdy bazaltov alebo bazaltických andezitov (panón); 6) freatomagmatické tufy a tufobrekcie bazaltov a bazaltických andezitov (panón); 7) lávové prúdy bázických leukokratných andezitov (báden); 8) biotiticko-amfibolicko-pyroxénické andezity (báden).

Fig. 7. The potential source of the replacement building material – an old local andesite quarry. Gradual transition of the massive pyroxene andesite upwards into porous blocky lava breccias with a cover of pyroclastic rocks the top.

Obr. 7. Potenciálny zdroj náhradného stavebného kameňa – starý miestny andezitový lom. Masívny pyroxénický andezit prechádza smerom nahor do pórovitých lávových brekcií, navrchu s pokryvom pyroklastických hornín.

Fig. 8. Quarry andesite blocks: relatively sound on the left, altered II on the right. Drillholes diameter is 34.75 mm.

Obr. 8. Bloky andezitu z lomu: relatívne zdravý vľavo, vpravo alterovaný – stupeň II. Priemer návrtov je 34,75 mm.

to higher content of swelling clay minerals, and this method could indicate their amount. In the standard tests of the water absorption by porous rocks (STN EN 13 755:2008, STN EN 1925: 2002), it is impossible to distinguish between the impact of porosity and clay minerals.

Cores 34.75 mm in diameter, ca. 60 mm high (58.5 to 59.6 mm exactly) were drilled from the quarry rock blocks. The volume V of the partly irregular cores was determined by weighing under water (Archimedes law) for the dry bulk density ρ_d determination whereby a thin Parafilm-M® of known density ρ_p=0.992 g.cm^{-3} was applied instead of the standard liquid application of the paraffin cover. The volume V (cm^3) was calculated from the equation

$$V = \frac{m_{1p} - m_{2p}}{\rho_{wT}} - \frac{m_{1p} - m_1}{\rho_p}$$

where m_1 (g) is the mass of the dry sample, m_{1p} (g) is the mass of the dry sample with Parafilm-M® cover, m_{2p} (g) is the mass of the sample with the cover under water, ρ_{wT} (g.cm^{-3}) is the water density at the temperature T, value can be found in tables. Dry bulk density was calculated as $\rho_d = m_1 / V$ (g.cm^{-3}). Total porosity n (%) was calculated as $n = 1 - (\rho_d - \rho_s)$. The helium-effective porosity n_{He} (%) was determined by He-Stereopycnometer (Quantachrome Instruments, 2005), the method was published by Adamcová (2012). Finally, the uniaxial compressive strength (UCS) was tested by the Point Load Tester (Bieniawski, 1975). Due to the protection of the cultural heritage by law, no bigger building stones were available from the castle for drilling cores, i. e. only the mineral composition could be compared to the quarry rock.

5. RESULTS AND DISCUSSION

Plagioclase phenocrysts are visible in the fine groundmass of the relatively sound andesite building stone of dark grey color (designation 2.5Y 4/1 of the Munsell Color Charts (2011) from the castle. According to XRD, this is mostly the plagioclase andesine (54.1 ± 2.5 %), but also orthoclase is present (16.5 ± 1.1 %). The macroscopic dark mineral is augite (4.7 ± 0.7 %). Small amount of quartz (3.5 ± 0.4 %) was detected by XRD,

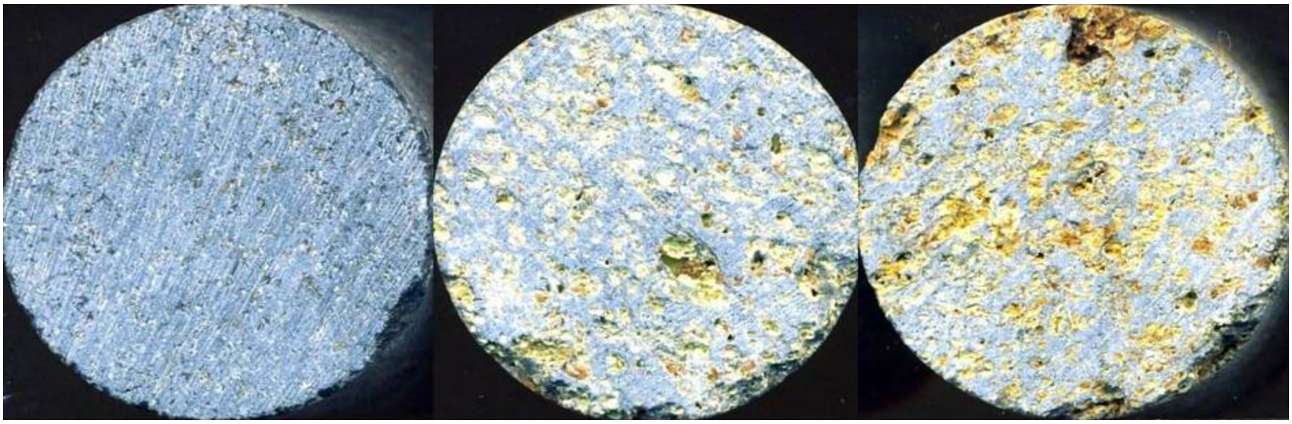


Fig. 9. The different alteration levels of the quarry andesite with different porosity, part of it is primary: sound – left, altered I – center, altered II – right; diameter of cores is 34.75 mm. No regular cores were possible from the III. alteration level.

Obr. 9. Rôzne stupne alterácie andezitu z lomu s rôznou pórovitosťou, časť z nej je primárna. Zdravý – vľavo, alterovaný I, – stred, alterovaný II – vpravo; priemer vrtných jadier je 34,75 mm. Z III. stupňa alterácie nebolo možné zhotoviť pravidelné jadrá.

as well, the rest are amorphous phases (21.2 ± 3.0 %) (Fig. 11). Smectite is the main alteration product of the post-volcanic alteration (i.e. post-volcanic hydrothermal alteration processes and/or weathering) found in the highly altered and disintegrated sample of the building stone – up to 28.1 ± 2.7 %. The feldspars (andesine and orthoclase) are still present, but augite was reduced below 1 %. New mineral phases were detected: aragonite and calcite (Fig. 12) from secondary hydrothermal veins in the rock. The rest are amorphous phases and quartz. Relative contents are given in Fig. 13. Also magnetite was separated by a magnet (quantification from the XRD plot failed) indicating that the disintegrated building stone may come from a different source than the studied "sound" building stone with no signs of magnetite. Amorphous phases include the unstable volcanic glass, but also the Fe-oxyhydroxides resulting from the alteration of mafic minerals (augite, magnetite) due to the oxidation of Fe^{2+}. The presence of iron oxyhydroxides is evident from the color change to light olive brown (2.5Y 5/3) and brownish yellow (10YR 6/8).

The sound quarry rock is medium gray (N 5 according to Munsell Color Charts, 2011). Its mineral composition is partly different from the studied sound castle building stone (Fig. 11). No orthoclase, but magnetite (3.8 ± 0.4 %) is present there. Augite content is 6.1 ± 0.7 %, quartz only in traces (0.6 ± 0.3 %). Magnetite could be simply separated from the rock powder by a magnet, as well. Andesine is the major mineral phase in the sound quarry rock (50.9 ± 2.1 %), and again, smectite is the main alteration product in the altered quarry sample (with 17.7 ± 2.0 % in the "altered III" sample) (Fig. 14 and 15). Feldspars are usually the most critical phase producing smectite when weathered. However, volcanic glass (within amorphous phases creating 38.6 ± 2.2 % of the sound rock), augite and magnetite seem to be the most unstable components of this rock according to the quantitative XRD analysis. The content of andesine in the sound sample (50.9 ± 2.1 %) is lower than in the "altered I" (58.3 ± 2.5 %) and "altered II" (56.7 ± 2.0 %) samples (Fig. 15). This could be due to primary differences in the mineral composition of the very variable volcanic rock. But it is to point out that these are only relative contents in %, not absolute ones. Any leaching and erosion of the less resistant alteration products would increase the relative contents of the remaining mineral phases. This could mean that the feldspars are normally weathering, but the soft alteration products are significantly leached/eroded and removed. With the alteration, secondary phases appear and their content is increasing (smectite up to 17.7 ± 2.0 %), while the contents of amorphous phases, augite and magnetite are decreasing.

Fig. 10. Enslin-Neff test. Conus of the rock powder in the center of the water-saturated porous plate enabling suction and absorption of water.
Obr. 10. Skúška Enslin-Neff. Kužeľ horninového prášku v strede frity nasýtenej vodou, ktorá umožňuje vzlínanie a absorpciu vody.

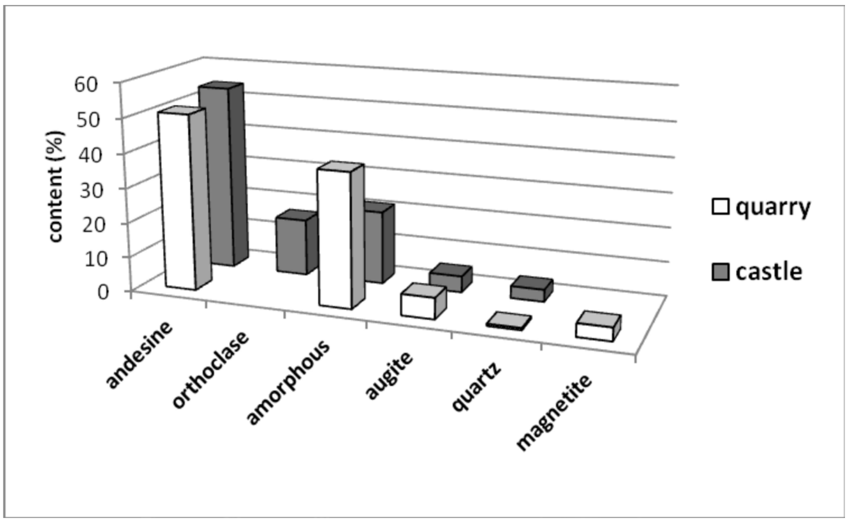


Fig. 11. Comparison of the mineral composition of the relatively sound castle building stone and the quarry andesite. Andesine = isomorphic middle member of the albite-anorthite (plagioclase) feldspars.
Obr. 11. Porovnanie minerálneho zloženia relatívne zdravého stavebného kameňa z hradu a andezitu z lomu. Andezín = izomorfný stredný člen albit-anortitového radu živcov (plagioklas).

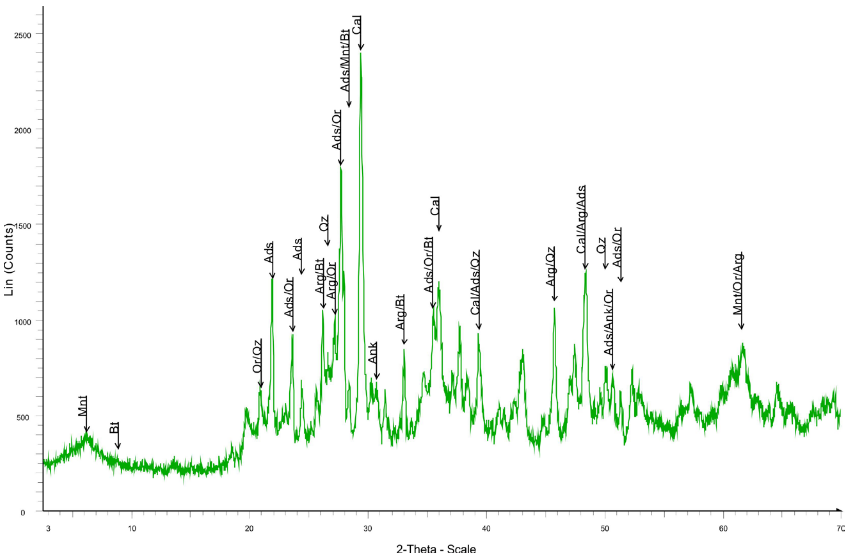


Fig. 12. XRD spectrum of the highly altered and totally disintegrated building stone. Elevated bases on the right side of the spectra indicate the presence of amorphous phases (volcanic glass). Ads – andesine, the other mineral abbreviations are used according to Whitney & Evans (2010).
Obr. 12. RTG-difraktometrický záznam práškových vzoriek vysoko alterovaného a úplne rozpadnutého stavebného kameňa. Zvýšená báza pravej časti naznačuje prítomnosť amorfných fáz (vulkanické sklo). Ads – andezín, ostatné skratky minerálov sú použité podľa Whitney & Evans (2010).

Iron oxyhydroxides could not be quantified, but their presence changed the rock color from medium gray (N 5 according to Munsell Color Charts, 2011) to light olive gray (5 Y 5/2) with a stain of brownish yellow to yellowish red color (10 YR 6/8 to 5 YR 5/6).

The quarry rock available in bigger blocks (important for core drilling) was used for the illustration of the alteration impact upon the rock properties. While results of mineralogical analyses are shown also for the alteration level III, it was impossible to prepare regular cores from so highly altered rock – it was breaking already during drilling. Therefore, tests of physical properties were not carried out on those samples; Fig. 16 and 17 show the changes from the sound rock up to "altered II", the alteration level was indicated by the smectite content. With successive mineralogical changes, the particle density is slightly decreasing, indicating the alteration of heavy minerals. And, as expected, the water adsorption by Enslin-Neff is clearly increasing with the increasing smectite content – the method developed for soils was proven as an indicator test of the increasing content of expanding clay minerals in hard rocks, as well. Both measured total and helium-effective porosities are also increasing, which corresponds well with the visual check of the macro-porosity. All these changes resulted in the rock weakening. The UCS by PLT dropped dramatically from 270 MPa of the sound rock to 51 MPa of the "altered II" sample. As already explained, comparative tests of physical properties could not be carried out on the building stone from the castle, because the ruins are protected by law and drilling was not allowed.

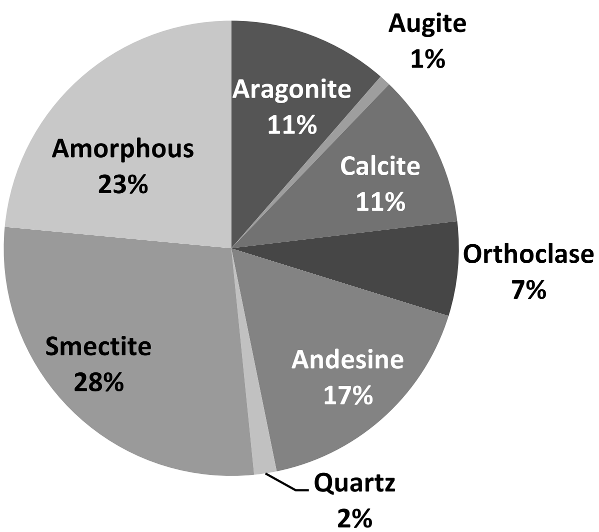


Fig. 13. Mineral composition of a totally disintegrated castle building stone.
Obr. 13. Minerálne zloženie úplne rozpadnutého stavebného kameňa z hradu.

6. CONCLUSIONS

Impact of the andesite alteration upon the physical properties was studied on the potential replacement building stone necessary for the revitalisation of the Šášov castle ruins. It comes from a local quarry in the Šášovské Podhradie village. The original castle building material is heterogeneous, the building stone comes probably from several sources and/or underwent different post-volcanic alteration processes. Therefore, small mineral differences compared to the quarry andesite are less important. Looking at the alteration, certain hydrothermal mineralisation (aragonite and calcite, probably secondary veins) was detected in the highly weathered and disintegrated andesite building stone from the Šášov castle. But, the post-volcanic alteration (hydrothermal and/or weathering) of studied andesites produced also weak secondary phases dominated by smectite and including significant amount of iron oxyhydroxides at both sites – the Šášov castle walls and the local quarry. The soft secondary phases could be partly leached and eroded by the precipitations and would contribute to the increasing porosity. The engineering geological tests showed that higher porosity is accompanied by a dramatic reduction of the uniaxial strength, and by the weakening of the rock, because big empty pores are easily collapsing under load. The primary macro-porosity of studied andesites is of syngenetic character and may vary from place to place. For the assessment of the alteration impact upon the porosity, following well-known

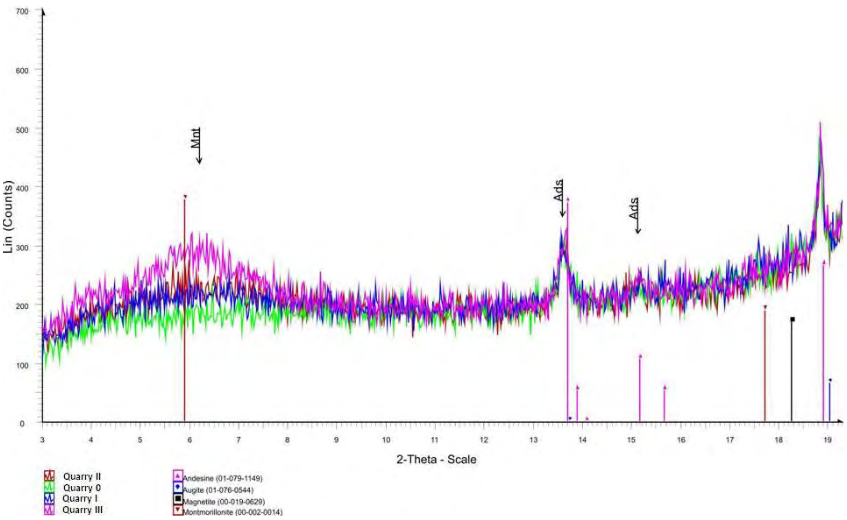


Fig. 14. Detail of the smectite part of the XRD spectra; smectite content increasing with the alteration. Quarry andesite of different alteration levels, powder samples.

Obr. 14. Detail smektitovej oblasti RTG spektra; obsah smektitu stúpa s alteráciou. Andezit z lomu v rôznom stupni alterácie, práškové vzorky.

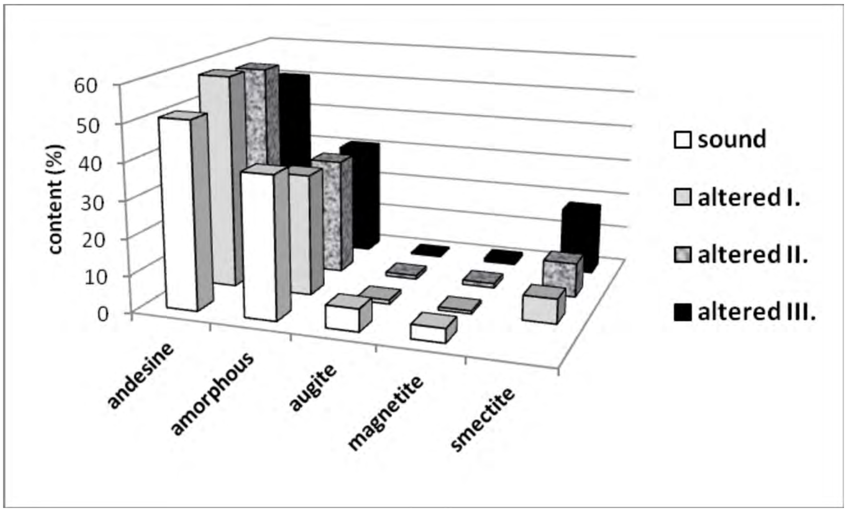


Fig. 15. Alteration-caused mineral changes of the quarry andesite with significant increase of the smectite content.

Obr. 15. Minerálne zmeny andezitu z lomu spôsobené alteráciou, s významným nárastom obsahu smektitu.

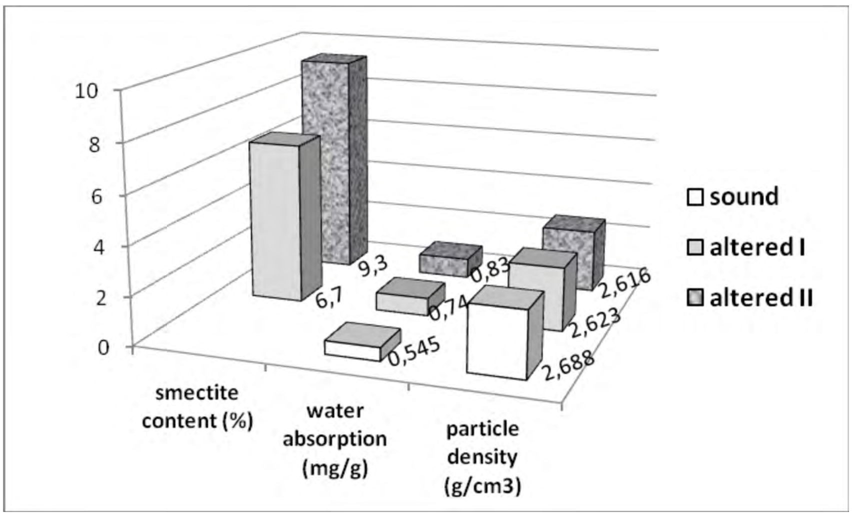


Fig. 16. Increasing content of smectite is accompanied by higher water absorption in the Enslin-Neff test and slightly lower particle density due to alteration of heavier mineral phases.

Obr. 16. Stúpajúci obsah smektitu sprevádza vyššia absorpcia vody pri skúške Enslin-Neff a mierne nižšia merná hmotnosť v dôsledku alterácie ťažších minerálnych fáz.

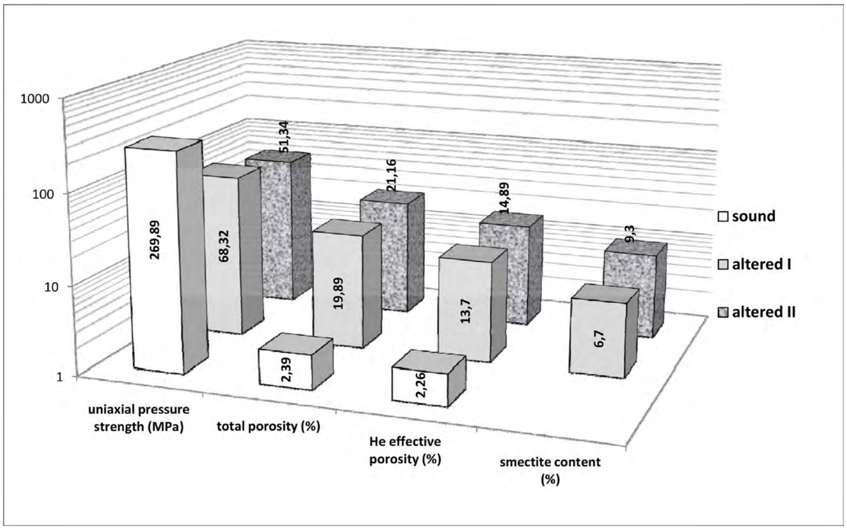


Fig. 17. Impact of alteration upon the physical properties (quarry andesite). The marked drop of strength is the most important change.
Obr. 17. Vplyv alterácie na fyzikálne vlastnosti (andezit z lomu). Markantný pokles pevnosti je najvýznamnejšia zmena.

facts were considered: 1. higher water uptake will follow if the porosity and/or the smectite content increases; 2. water in pores may be seasonally freezing with relevant volume increase producing stress in rock pores, therefore freeze-thaw cycles weaken the rock by new cracks, i. e. new-formed porosity; 3. water adsorbed by the expandable smectite causes volume increase of the clayey fill of the pores and exhibits an additional stress on the pore walls (swelling pressure); 4. expandable clay minerals produce tensile stresses during drying and shrinking – like smectite in the cohesive pore fill, i. e. a cyclic wetting-drying contributes to the weakening of the rock bonds and porosity increase.

The theoretical consideration supported by mineralogical outputs resulted in a hypothesis that smectite is contributing to the progressive weathering in following way: primary porosity (from micro to macro scale) enables the penetration of weathering agents, generating the first erodible secondary phases, clay minerals included; next, the porosity is increasing due to the partial erosion of secondary phases, due to freezing of water in the old and new-formed effective pores and due to cracking the rock by cyclic pressure and tensile stress by wetting and drying of the smectite; in this way, weathering agents reach deeper parts of the rock, the interface area is multiplied which accelerates the weathering progress producing more of the secondary minerals, smectite included ; their easy erodibility leads to higher porosity and weakening of the rock – till the total disintegration. There is probably a coupled effect of the porosity and the smectite content. With every weathering step the number of pores and the amount of new-formed clay minerals are multiplied. Therefore, the weathering progress in a partly weathered/altered building stone containing expandable clay minerals may be much faster than in a sound rock. Even if an experimental confirmation of the coupled effect of smectite and porosity is still missing, much more attention should be paid to the clay mineral content in the building stone because of this theoretical danger. Enslin-Neff test of the water absorption by rock powders can be recommended at least for a quick qualitative comparison of the building stone suitability in the practice.

From that conclusion, an explanation for the bad condition of some parts of the castle walls was driven. Those parts that had been obviously constructed from a more weathered/altered and less resistant stone available at or near the surface, and their disintegration was faster. When sounder parts of a deposit were opened, the building stone was more resistant against weathering. Plaster relicts on castle walls are of big importance, protecting the building stone from weathering. Concerning the castle preservation, water (combined with frost or swelling/shrinking clay minerals) is the main enemy, causing degradation. Castle ruins should be prevented from the infiltrating precipitation water by roofing where possible, and by the conservation of the wall crowns. Stone from the sound parts of the local quarry can be taken as a replacement material for any castle reconstruction. The sound andesite of low porosity and absenting swelling clay minerals promises better durability and good mechanical properties – UCS over 200 MPa. The quarry could be one of the several original sources of the castle building stone – the probability is high because of the small distance that would be an advantage also for the castle revitalization project.

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Resumé: Ruiny hradu Šášov (obr. 1) na strednom Slovensku (obr. 2) sú národnou kultúrnou pamiatkou. Architektonická štúdia jeho revitalizácie, nadväzujúca na legendu o šašovi, navrhovala v areáli hradu okrem vyhliadkových bodov celý rad objektov, kde by sa mohli konať divadelné predstavenia, koncerty a výstavy pre zábavu návštevníkov (obr. 3). Hoci boli navrhnuté prevažne ľahké samonosné konštrukcie, stabilita a bezpečnosť hradných múrov podmieňujú rozvoj tejto historickej lokality, čo iniciovalo revíziu stavu hradných objektov. Na viacerých miestach bol zistený výrazne horší stav hradných stien, kde bol stavebný kameň silne zvetraný, miestami až dezintegrovaný (obr. 4 a 5). Na sanačné, prípadne rekonštrukčné práce bude potrebné nájsť vhodný zdroj stavebného kameňa. Pozornosť sa sústredila na najbližší opustený andezitový lom cca 1,5 km S-SZ od hradu, na okraji obce Šášovské Podhradie (obr. 2 a 7), keďže v stavebnom kameni hradu prevažuje tiež andezit. (Stavebný kameň na hrade je pomerne heterogénny a môže pochádzať z viacerých zdrojov, ich identifikácia nebola predmetom výskumu. Vzhľadom na blízkosť lomu je však pravdepodobnosť, že sa jedná o jeden z pôvodných zdrojov, vysoká.) Geologická charakteristika lokality je na obr. 6. Boli odobrané bloky horniny relatívne zdravej i v rôznom stupni post-vulkanickej alterácie (hydrotermálnej a/alebo zvetrávania) (obr. 8 a 9) na výskum vplyvu alterácie a s ňou súvisiacich sekundárnych napučiavajúcich ílových minerálov na fyzikálne vlastnosti horniny a odolnosť voči zvetrávaniu, ako aj na overenie vhodnosti pre sanačné či rekonštrukčné práce na hrade. Minerálne zloženie bolo hodnotené na základe RTG difrakčnej analýzy (kvalitatívnej i kvantitatívnej). Práškové vzorky boli použité aj na určenie mernej hmotnosti a absorpcie vody metódou Enslin-Nef (obr. 10). Na vrtných jadrách bola stanovená objemová hmotnosť suchej horniny slúžiaca na výpočet celkovej pórovitosti, tiež otvorená pórovitosť efektívna pre hélium a nakoniec pevnosť pri bodovom zaťažení a z nej pevnosť v jednoosovom tlaku. Študovaný relatívne zdravý stavebný kameň z hradu je andezit tmavosivej farby s jemnozrnnými výrastlicami andezínu, ktorý je v zložení dominantný (54,1 %), prítomný je aj ortoklas (16,5 %), zvyšok tvoria amorfné fázy (21,2 %), augit (4,7 %) a malé množstvo kremeňa (3,5 %) (obr. 11). Hlavným produktom post-vulkanickej alterácie (hydrotermálnej a/alebo zvetrávania) je smektit, ktorý tvoril až 28,1 % vysoko alterovaného a dezintegrovaného stavebného kameňa. Živce sú naďalej prítomné, augit bol zredukovaný pod 1 % a zistené boli nové minerály – aragonit a kalcit (obr. 12), zrejme z hydrotermálnych žiliek v hornine. Zvyšok sú amorfné fázy a kremeň, relatívne obsahy sú na obr. 13. Magnetom bol vyseparovaný aj magnetit, ktorý sa však z RTG záznamov nepodarilo kvantifikovať. Ten naznačuje, že stavebný kameň môže pochádzať z rôznych zdrojov, lebo v zdravom nebol magnetit zistený. Amorfné fázy zahŕňajú nestabilné vulkanické sklo, ale aj oxihydroxidy železa (napr. zo zvetraného augitu a magnetitu), ktoré charakteristicky sfarbujú zvetranú horninu do žlta až hrdzava. Relatívne zdravá hornina z lomu je stredne sivej farby a jej minerálne zloženie sa mierne líši od študovaného kameňa z hradu: neobsahuje ortoklas a zistený bol magnetit (3,8 %). Hlavný minerál andezín tvorí 50,9 %. Prekvapivý vyšší obsah andezínu v alterovaných blokoch ako v zdravom (obr. 15) môže byť spôsobený rozdielmi v pôvodnej láve, no treba zdôrazniť, že sa jedná o relatívne, nie absolútne obsahy. Akýkoľvek odnos mäkkých produktov alterácie (vylúhovanie, erózia) spôsobí nárast relatívnych obsahov zvyšných minerálov v horninovom prášku. Preto je možné, že andezín zvetráva, ale pre odnos produktov sa to neprejaví ako pokles relatívneho

obsahu tak, ako sa to ukazuje u amorfných fáz a augitu, ktorých alterácia je intenzívnejšie. Postup alterácie je sprevádzaný nárastom obsahu smektitu (až do 17.7 %) (obr. 14 a 15) a oxihydroxidov železa, ktoré menia farbu horniny do hnedožlta až žltočervena. Práve obsah smektitu bol vodítkom pre stanovenie stupňa alterácie vybraných blokov horniny. Väčšie bloky horniny z lomu, z ktorých sa dal pripraviť dostatočný počet vrtných jadier, boli použité na ilustráciu vplyvu alerácie na fyzikálne vlastnosti andezitu (hornina v III. stupni alterácia sa lámala, preto bolo určené iba minerálne zloženie). Zmeny minerálneho zloženia s rastúcim stupňom alterácie sprevádza aj mierny pokles mernej hmotnosti ρ_s (g.cm^{-3}), čo indikuje alteráciu ťažších minerálov, a zreteľný nárast adsorpcie vody metódou Enslin-Neff (obr. 16) ako dôsledok vyššieho obsahu smektitu. Inovatívne aplikovaná metóda, pôvodne určená pre zeminy, sa teda osvedčila aj pre skalné horniny ako metóda na indikáciu prítomnosti napučiavajúcich ílových minerálov. Postupne rastie pórovitosť, celková aj efektívna pre hélium, a s ňou výrazne klesá pevnosť v tlaku – z 270 MPa u zdravej horniny až na 51 MPa (obr. 17) v II. stupni alterácie. (Porovnávacie skúšky fyzikálnych vlastností nebolo možné vykonať na stavebnom kameni z hradu, ktorý je pamiatkovo chánený a poškodzovanie múrov je neprípustné.) Primárna makropórovitosť študovaného andezitu je syngenetická a môže sa meniť od miesta k miestu. Pri uvažovaní, ako mohla ovplyvniť alterácia pórovitosť, sa vychádzalo z nasledujúcich známych faktov: 1. nasiakavosť horniny stúpa s vyššou pórovitosťou a/alebo s vyšším obsahom smektitu; 2. voda v póroch sezónne zamŕza, zväčšuje objem a tlačí na steny póru, cyklické zamŕzanie/rozmŕzanie preto oslabuje horniny tvorbou nových puklín – nárast pórovitosti; 3. absorpcia vody vo výplni pórov s obsahom smektitu vyvolá na steny póru dodatočný tlak z napučiavania; 4. pri vysúšaní kohezívnej výplne póru s obsahom smektitu dôjde k zmrašťovaniu a ťahovým napätiam na stenách póru, cyklické vlhčenie a sušenie ďalej oslabí horninu. Teoretické úvahy podporené mineralogickými analýzami viedli k hypotéze, že hoci pórovitosť zohráva pri zvetrávaní stavebného kameňa významnejšiu úlohu, v horninách bohatých na živce prispieva smektit ako produkt alterácie k progresu zvetrávania tým, že umožňuje nárast pórovitosti (1. trhaním horniny pri sýtení vodou a vysúšaní, 2. ľahkou erodovateľnosťou a možným odnosom z horniny), vyššia pórovitosť zas vedie k prenikaniu zvetrávania hlbšie do horniny za vzniku väšieho množstva smektitu a zvetrávanie postupne akceleruje, prepojenosť účinkov pórovitosti a smektitu určuje intenzitu zvetrávania. V rovnakých podmienkach potom navetraná hornina zvetráva oveľa intenzívnejšie ako zdravá. Hoci nie sú k dispozícii priame dôkazy, teoretické nebezpečenstvo tu je, preto je pri posudzovaní kvality stavebného kameňa potrebné venovať pozornosť obsahu napučiavajúcich ílových minerálov (to sa doteraz v praxi nerobilo a nepredpisujú to ani technické normy pre stavebný kameň). Preto murivo, ktoré bolo zrejme už v čase výstavby hradu Šášov viac alterované, zvetralo rýchlejšie. Hlavným nepriateľom hradu Šášov je teda voda pôsobiaca najmä v póroch a spôsobujúca objemové zmeny pri mraze, ale aj pri zmenách vlhkosti smektitu. Pri sanácii hradných ruín je potrebné zakonzervovať koruny múrov a prestrešiť objekty, kde je to možné. Stavebný kameň pred ďalším zvetrávaním čiastočne chránia aj zvyšky omietky na múroch. Zdravý andezit z opusteného miestneho lomu, ktorý má nízku pórovitosť a pevnosť v tlaku vyše 200 MPa, je vhodný ako náhradný stavebný kameň na prípadné opravy či rekonštrukcie. Na lacnú kontrolu obsahu smektitu v stavebnom kameni sa hodí jednoduchá porovnávacia skúška absorpcie vody podľa Enslina-Neffa na horninovom prášku, ktorá na rozdiel od skúšok nasiakavosti eliminuje vplyv pórovitosti na výsledok a odráža práve obsah napúčavých ílových minerálov.