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Genesis, types and evolution of crevice-type caves in the flysch belt of the Western Carpathians (Czech Republic)

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ABSTRACT

Crevice-type caves are among the least investigated natural phenomena connected with the development of slope failures. These caves present complex and peculiar underground systems with their own development and resulting landforms. We investigated eight caves in the Czech part of the Outer Western Carpathians to determine their genesis, types and evolution. Crevice formation is predisposed according to the lithological, tectonic and morphological characteristics of the landslide body, including the position and location of bedding planes, joints and faults. We performed several analyses, including speleological mapping, evaluation of high-resolution topography above the caves, geophysical (ERT) measurements and structural investigations within cave passages. In accordance with these analyses, various mechanisms responsible for cave development were revealed. An intra-bed translation is responsible for the creation of regularly shaped passages with flat ceilings. Toppling as well as back and horizontal rotation of rock blocks determine the specific morphology and shapes of passages. A relatively novel aspect of the current study is the identification of the subsidence of massive rock wedges due to the widening of cracks. All of these mechanisms control the specific morphological characteristics within crevices, e.g., typical shapes of passages, cave level ordering and ceiling types. Some of these processes also influence topography above the caves. Finally, the different phases of evolution of these caves were determined.

1. Introduction

Caves are among the most distinctive forms of pseudokarst phenomena (Halliday, 2007). Crevice-type caves (CTCs) are formed during the evolution of rock landslides — so-called “rockslide caves” (Panoš, 2001). These caves occur in various rock types such as clastic sediments (Wagner et al., 1990; Pánek et al., 2010), limestones (Self, 1990; Pánek et al., 2009), and granites and gneisses (Vítek, 1978). Although CTCs occur worldwide, investigations evaluating their genesis, evolution and morphology are almost entirely absent from the international literature. Margielewski and Urban (2003) considered the crevices to be initial forms of landslide development. Most commonly, CTCs accompany the evolution of deep-seated gravitational slope deformations (DSGSDs), i.e., types of large-scale and relatively short-displacement mass movements affecting large volumes of rock massifs (Němčok, 1972; Dramis and Sorriso-Valvo, 1994; Agliardi et al., 2001) and reaching depths of at least 30 m (Hutchinson, 1988). However, as indicated by Margielewski (2009), crevices can also be produced within structurally predisposed landslides of shallow and intermediate depths (<30 m according to Hutchinson, 1988). CTCs very often disintegrate incoherent flysch rocks, i.e., sandstones and conglomerates with intercalations of shales (Wagner et al., 1990; Margielewski and Urban, 2003), and their particular morphology is controlled by the type of mass movement, the stage of landslide progression and their position within the landslide body (Wagner et al., 1990; Baroň, 2000; Margielewski and Urban, 2003; Margielewski et al., 2007).

This paper presents CTCs as a distinctive morphological phenomenon of rock landslides based on examples from the flysch belt of the Western Outer Carpathians (WOC), the Czech Republic (Fig. 1). We continue the work of Margielewski and Urban (2003) and Pánek et al. (2010), but we extend the findings of CTCs to their morphological peculiarities, evolution and overall position within relaxed flysch massifs. We have selected eight CTCs according to their extension (depth and length). Using detailed morphological, structural and geophysical information from the CTCs, this study aims to (i) characterize the lithological, tectonic and morphological conditions predisposing CTC development, (ii) describe the various mechanisms leading to CTC progression and decipher their consequences for the superficial morphology and evolution of CTC, and, finally, (iii) describe relationships between the development of underground cavities and the consequent configuration of surface topography.

2. Regional setting

All research sites are situated in the easternmost part of the Czech Republic (Fig. 1), where the WOC are divided into several geomorphic regions: Slovenské Beskydy Mts., Moravskoslezské Beskydy Mts. and

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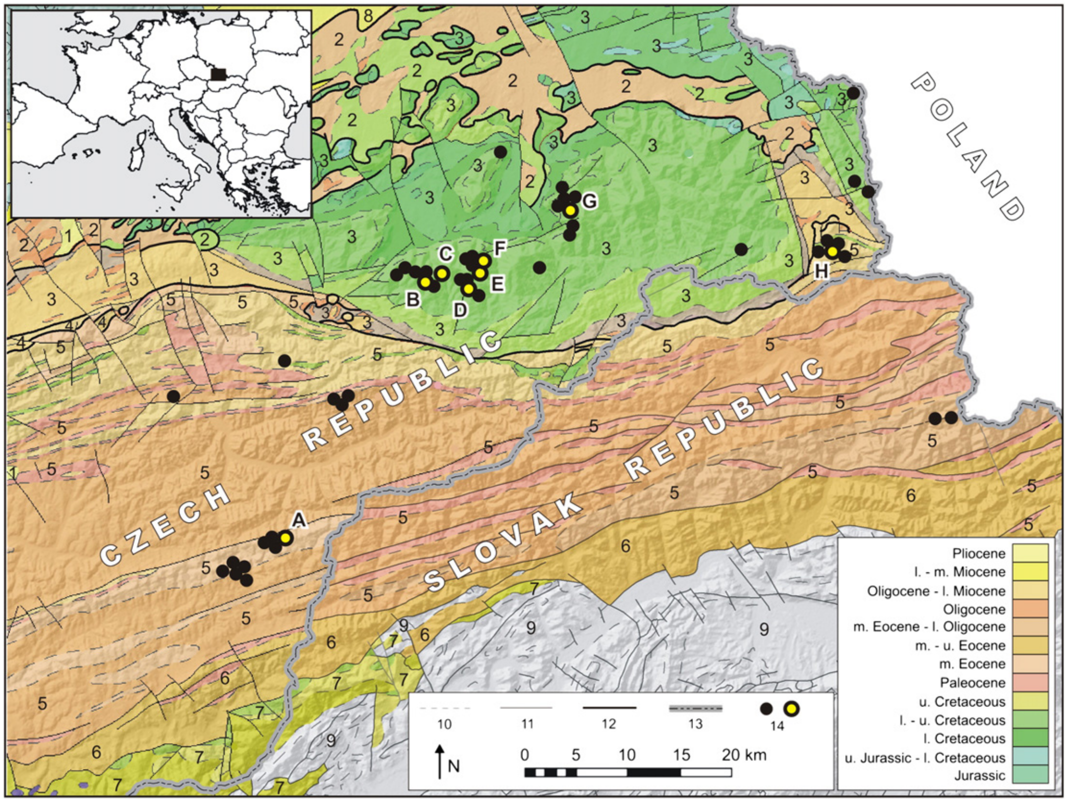

Fig. 1. Geology of the study area with crevice-type cave locations (made by Veronika Smolková): (1) postorogenic sediments (Pliocene); (2) flysch formations of the Subsilesian Unit (Outer group of nappes, upper Cretaceous–lower Miocene); (3) flysch formations of the Silesian Unit (Outer group of nappes, upper Jurassic–lower Miocene); (4) flysch formations of the Fore–Magura Unit (Outer group of nappes, upper Cretaceous–lower Miocene); (5) flysch formations of the Raca Unit (Magura group of nappes, lower Cretaceous–lower Oligocene); (6) flysch formations of the Bystrica Unit (Magura group of nappes, Paleocene–Eocene); (7) flysch formations of the Bile Karpaty Unit (Magura group of nappes, upper Cretaceous–Paleocene, with middle Miocene volcanism); (8) sediments of the Carpathian Neogene foredeep (lower to middle Miocene); (9) Pieniny Klippen Belt and Inner Western Carpathians; (10) lithological boundaries; (11) faults; (12) main thrust faults; (13) state boundaries; (14) crevice-type caves, studied caves: A — Velryba cave, B — Salajka cave, C — Cyrilka cave, D — Čertova díra cave, E — Kněhyňská jeskyně cave, F — Kyklop cave, G — Velká Ondrášova jeskyně cave, H — Na Gírové I cave. Source of geological data: Biely (1996); Cháb et al. (2007); elevation data: SRTM3 v.2.

Javorníky Mts. (Demek and Mackovčin, 2006). The WOC were formed almost exclusively by flysch Mesozoic and Paleogene sediments that were folded and thrusted more than 50 km onto the foredeep in a northerly direction during the early and middle Miocene Alpine orogeny phases (Menčík et al., 1983; Lexa et al., 2000; Krejčí et al., 2004). The following two groups of nappes are distinguished within the study region: the Magura group of nappes (the Rača Unit: Slovenské Beskydy Mts. and Javorníky Mts.) and the Outer group of nappes (Silesian Unit: Moravskoslezské Beskydy Mts.) (Fig. 1). The strata consist of thick-bedded sandstones and conglomerates (quartz grains with a mica and glauconitic detrital admixture and calcific cement) and thin-bedded intercalations of shales with a predominant illite and kaolinite clay mineral content (Menčík et al., 1983; Eliáš, 2000). Regarding the dip of strata, ridges are often formed asymmetrically and are characterized as monoclinal ridges and cuestas (Menčík et al., 1983). This is typically demonstrated, particularly within the Silesian Unit, by characteristic steep northern slopes and long, gentle southern slopes predisposed by bedding planes (Krejčí et al., 2004). One of the study sites (the Velryba Cave, Javorníky Mts.) is situated on a ridge formed with an anticlinal structure. The flysch massif of the WOC is strongly disrupted by joints and faults often trending in the E–W, N–S, NE–SW and WNW–ESE directions (Menčík et al., 1983; Krejčí et al., 2002).

Anisotropic flysch rock mass is strongly affected by mass movements in regions with high levels of annual precipitation (>1000 mm), such as the study region. The study area with the highest local relief (up to 600 m), the Silesian Unit (Moravskoslezské Beskydy Mts.), is affected by numerous DSGSDs, structurally predisposed translational and rotational landslides and to a lesser extent debris flows (Margielewski and Urban, 2003; Krejčí et al., 2004; Margielewski, 2006a; Šilhán and Pánek, 2010; Pánek et al., 2011a). CTC were recognized as important geomorphic elements of gravitationally deformed slopes in the WOC in the 1960s and 1970s (Wagner et al., 1990). To date, there are 120 registered non-karstic caves in the Czech part of the WOC (Hromas, 2009); Fig. 1 shows the locations of the most remarkable examples.

3. Methods

The research design of this study was selected in order to (i) survey the extent of CTCs with documentation of their morphological peculiarities, (ii) determine the types of mass movements responsible for their genesis and (iii) describe the evolutional attributes of crevices within relaxed rock massifs.

Due to inaccessibility and the difficulty of collecting high-resolution measurements within narrow crevice passages, survey methodology was largely limited to the use of a measuring tape and a geological compass. In such circumstances, we used older maps of CTCs published by Wagner et al. (1990). These maps were updated and revised using a DISTO Leica A3 speleological laser rangefinder improved with a DistoX component. The surface topography above cave systems was measured with high precision with a geodetic total station.

The method of Margielewski and Urban (2003) was used to determine the mass movement types responsible for the genesis of individual CTCs. This methodology relies on the fact that changes in the dip and direction of discontinuities between in situ rock mass and gravitationally transported blocks reveal particular slope processes, e.g., translation or horizontal and vertical rotations of rock packets. This assumption is