The natural caves in the geotope cluster Werdenfels Country (Southern Bavaria, Germany) and their importance for geotourism

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Zusammenfassung

Die natürlichen Höhlen des Werdenfelser Landes entstanden vorwiegend in verkarstungsfähigen Gesteinseinheiten, die Bestandteile eines ca. 7 km mächtigen Sedimentstapels sind. Dieser wurde in der Spätphase des ca. 250 Millionen Jahre dauernden Alpidischen Zyklus dem europäischen Kontinentalrand überschoben und ist seit dem mittleren Tertiär subaerisch exponiert. Nach Erläuterung verschiedener Höhlenbildungsprozesse erfolgt eine chronologische Auflistung der geologischen Formationen, in denen Höhlen vorhanden sind; begleitet von Hinweisen, wo sie zu finden und wie sie in der Formation ausgeprägt sind. Einige Höhlen, die für Touristen und/oder Speläologen Bedeutung erlangten, werden näher charakterisiert. Abschließend werden die Vorgänge erklärt, die zur Entstehung der seltenen Primärhöhlen führten.

1. Geographical and geological setting

Werdenfels Country and its geotopes are situated at the northern margin of the Northern Calcareous Alps and its foreland (Fig. 1). The tectonic units present there consist, from the top downwards, of the Inntal-, Lechtal- and Allgäu-nappes, the NCA-Border-zone as well as the Penninic and Helvetic nappes (Behrmann & Tanner 2006), which are partially covered by Quarternary and Holocene deposits. The pre-Quarternary units are attributable to the products of a Wilson Cycle, which was accomplished here by the opening and closure of the Alpine Tethys, situated between the continents Europe and Africa. This process lasted ca. 250 Ma and resulted in the deposition of an up to 7 km thick carbonate-dominated deepening upward first order megasequence (BGLA 1996: 220-230), which – from late Cretaceous onwards – was intensely folded, faulted, exhumed and thrusted northward onto the European foreland by several tectogeneses (Auer & Eisbacher 2003). Subaerial exposition and erosion of the nappe pile occurred since the Middle Tertiary and caused karstification of its calcareous formations (Uhlig 1954). These parts contain the bulk of the natural caves present in the Werdenfels Country. Predominantly secondary caves exist: they originated due to chemical dissolution of limestone, magnesian limestone and gypsum. Other processes, which resulted here in the formation of caves, comprise brecciation at intersecting faults, physical erosion, gravitational collapse and chemical precipitation; therefore, caves also exist in formations not appropriate to karstification. Primary caves are developed rarely.

In the following, the formations hosting caves are shortly described and a few of these objects, which are of touristic and/or speleological importance, are characterized.

2. Formations containing secondary caves

2.1. Reifling Formation (Ladinian) (Nittel 2006)

Deposits of the distal part of the frontal slope of the Wetterstein Carbonate Platform, consisting of calcareous, horizontally and nodular layered strata with chert-intercalations. A few caves are established in the uppermost part of the Reifling Formation close to the stratigraphic contact to the Wetterstein Limestone. The caves, which occur in the the upper part of the Höllental, originated by enhanced erosion of solid rock, less resistant to weathering agents than the stratigraphic cover.

2.2. Wetterstein Limestone (latest Anisian to earliest Carnian) (Petschick 1983, Nittel 2006)

Carbonate platform, consisting of lagoon-, reef- and proximal reef-slope-deposits. The main geographic occurrences of caves hosted in this formation are the Zugspitzplatt, Leutascher Platt, Höllentalcirque and Reintal. In these areas, the cave-register of the Munich Association of Speleologists specifies ca. 200 objects, which are classified as shafts, ice-filled caves, niches as well as dry and water-carrying caves, due to their connectivity with the karst groundwater regime. In general, the caves originated at intersecting faults due to karstification and selective erosion. According to own observations at Zugspitzplatt, the maximum diameter of shaft-entrances measures up to 12 m (Fig. 2); the forces of erosion are best visualized at some of the smaller sized shafts, which bear natural stone-bridges in fragile state. The complex endokarst systems of several caves, comprising a network of shafts, domes, open fractures and canyons, were explored and mapped (Alstetter et al. 2004); shaft „Finkenschacht“ was in-

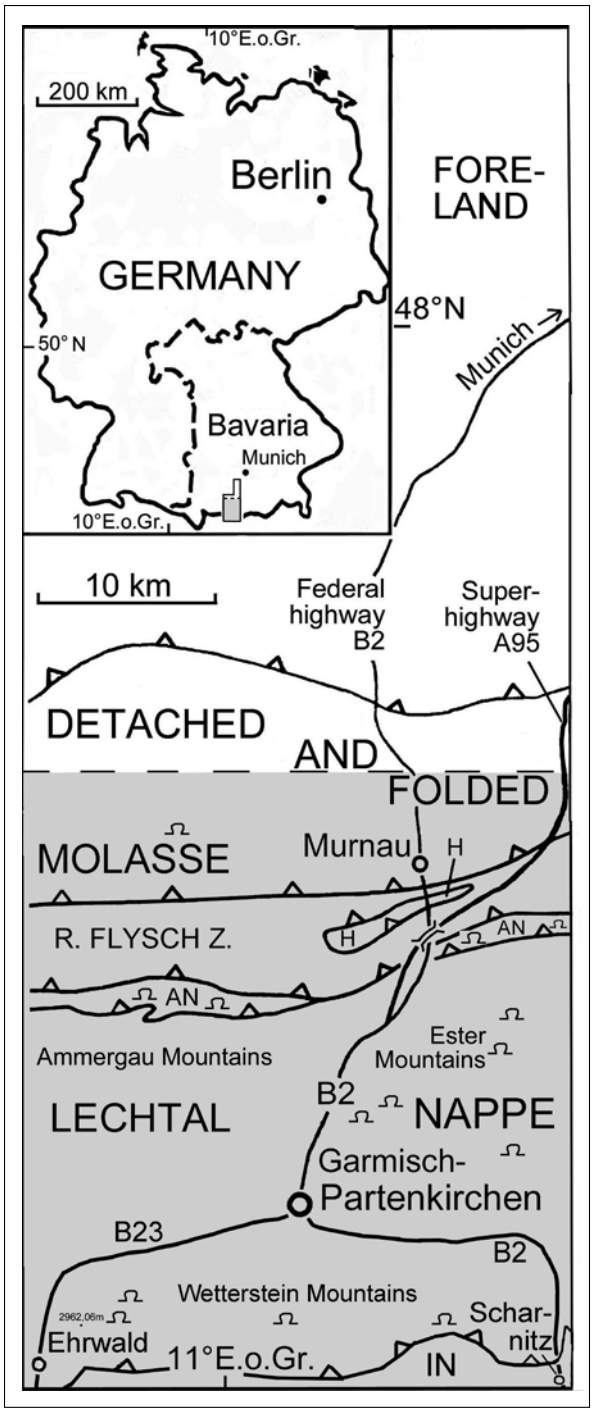

Fig. 1: Geographic and geological setting of the geotope cluster Werdenfels Country (gray shading). Omega-symbol: important sites of natural caves. Abbreviations: H.: Helvetic Zone; R. Flysch Z.: Rhenodanubian Flysch Zone; AN: Allgäu Nappe; IN: Inntal Nappe. Triangles point to the tectonic footwall.

Abb. 1: Geografische Lage und geologischer Rahmen der Geotoplandschaft Werdenfels (grau schattiert). Omega-Symbol: wichtige Höhlengebiete. Abkürzungen: H.: Helvetische Zone; R. Flysch Z.: Rhenodanubische Flysch Zone; AN: Allgäu Decke; IN: Inntal Decke. Dreiecke zeigen ins tektonisch Liegende.

Fig. 2: Partially ice plombed entrance of a large and deep shaft, developed in Wetterstein Limestone (latest Anisian to earliest Carnian). s0 114/32. View S. Location: Zugspitzplatt at elevation 2481 m, GPS-data: N47 24.500 E10 58.733.

Abb. 2: Teilweise eisplombierter Eingang eines breiten und tiefen Höhlenschachts, angelegt im Wettersteinkalk (oberstes Anis bis unterstes Karn). s0 114/32. Blickrichtung nach S. Lage: Zugspitzplatt auf Höhe 2481 m, GPS-Daten: N47 24.500 E10 58.733.

spected by speleologists down to 131 m (Triller 1982: 65). Shaft-entrances located too close to winter-ski-runs at Zugspitzplatt are secured to minimize hazards.

2.3. Raibl Formation (Carnian) (Hornung et al. 2007)

Clastic basin deposits, covered by a carbonate platform development, consisting of limestone, dolostone and gypsum layers. The exposed parts of the upper Raibl Formation, which additionally reveal massive autoclastic sedimentary breccias, are characterized by many small caves and niches, which originated due to chemical dissolution and physical erosion. Geosite „Bärenhöhle", situated close to the village of Wallgau, is made well accessible for tourists (Fig. 3).

2.4. Hauptdolomit (Latest Carnian to Norian) (BGLA 1996)

Back reef deposits made up of dolostones with locally bituminous intercalations (Seefeld Formation). Faint traces of dolomite karst - in the form of small niches - are developed in magnesian limestone. At the well known geo- and archaeo-site „Veste" near the village of Ohlstadt, also several tectonic caves are present. One of them probably marks a transpressional shear fracture.

2.5. Plattenkalk (late Norian) (BGLA 1996)

It conprises the upper part of the afore mentioned back reef deposits and consists of slightly marly limestone layers. The main geographic occurrences of caves hosted by that formation are situated in the Ester Moun-

tains. At the western margin at geosite „Kuhfluchtfälle“, several caves end in a fractured and karstified steep rock face; intermittent cascades appear there, when the caves are active. The geosite is topped by the object „Frickenhöhle“, situated shortly above at 1252 m. Its complex endokarst system was explored to a length of ca. 2900 m; its difference in elevation is 78 m; it reveals siphons, cascades, sintercurtains, speleothems, halls and ponds (Behrens et al. 1996). The cave is active only during phases of very intense and persistent rainfall: e. g. on May-22-1999 (Bayer. Landesamt für Wasserwirtschaft 2003). At the eastern margin of Ester Mountains, the length of the joint- and fault-controlled cave „Angerlloch“ (Fig. 4) comes up to 626 m; beside the afore mentioned endokarst features, it contains water table markers and considerable amounts of fluvioglacial sand and gravel. Due to aesthetic appearence of and easy access to this object, a conflict of interest arose between cave-tourism and nature protection; because of the presence of rare and endangered flora and fauna, adapted to special habitat-conditions concerning darkness, humidity and temperature, the cave‘s entrance is locked yearly from October to April (Behrens et al. 1996) by a secure gate.

Fig. 3: Geotope „Bärenhöhle“, hosted in the Raibl Formation (Carnian). The niches are characterized by cellular and alveolar patterns of weathering. View N. Location: 1,4 km WSW Wallgau at elevation 940 m.

Abb. 3: Geotop „Bärenhöhle“, angelegt in der Raibler Formation (Karn). Die Felsnischen sind durch Zellular- und Alveolarverwitterungsmuster gekennzeichnet. Blickrichtung nach N. Ort: 1,4 km WSW Wallgau auf 940 m Höhe.

2.6. Kössen Formation (Rhaetian) (BGLA 1996):

Basin and rise deposits consisting of massive as well as horizontally and nodular layered limestones, which locally are interstratified with marlstone. Geosite „Der Stein“ above Lake Kochel hosts several fault-bounded caves, which originated by karstification and physical erosion.

2.7. Hierlatz-Limestone Formation (Liassic) (BGLA 1996)

Massive, varicoloured limestone deposited on submarine rises. Geosite „Bärenhöhle“ is a fault-controlled cave and originated by karstification and gravitational collapse. The hight of the cave-entrance is ca. 22 m. The object is situated close to the village of Oberammergau and represents an attractive and appreciated point for tourists.

2.8. Zementmergel Formation (late Cretaceous) (BGLA 1996)

Flysch deposits, which are made up of cherty and marly limestone layers. Cave „Schatzloch“ is of tectonic origin. Access to this geosite is signposted at local hiking trails. A myth tells that at several times gold has been found there by a stranger from Venice. This story was transferred into a dialectic poem and was visualized in the village of Bad Kohlgrub as a painting in fresco.

2.9. Freschen Formation (late Aptian to Albian) (Engelbrecht 2010)

Medium to coarse grained, glauconitic, phosphatic and calcareous quartzsandstone layers deposited at the Grünten Ramp of the Helvetic Carbonate Platform. A cave was opened up by mining activity at the hump „Langer Köchel“, situated in the nature preserve area „Murnau-Eschenloher Moos“. The fault controlled cave originated by physical erosion and was later partially filled with fluvioglacial calcareous mud. The object, situated at the western margin of a mining pond, is flooded.

2.10. „Breccias“ of Längenfeld and Kreuzeck (Late Tertiary) (Vaché 1960)

Proximal fluvial conglomerates consisting predominantly of limestone pebbles and boulders („Herrgot-

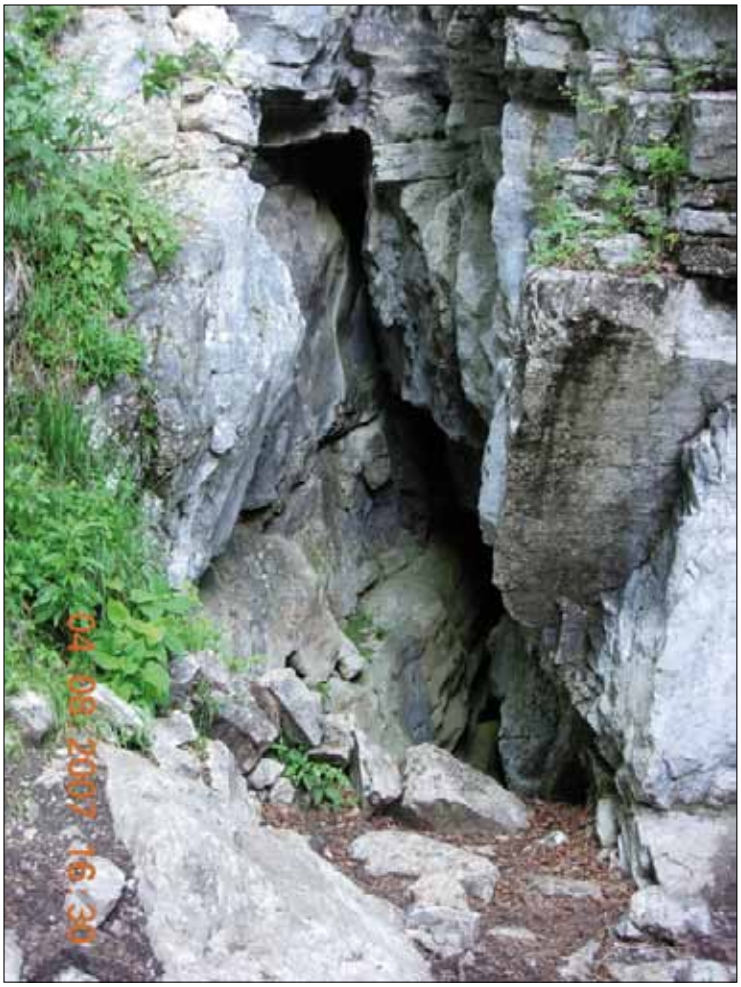

Fig. 4: Geotope „Angerlloch" situated in Plattenkalk (late Norian). s0 179/24. View N. Location: At the eastern margin of Ester Mountains at elevation 940m in the Obernachtal.

Abb. 4: Geotop „Angerlloch", angelegt im Plattenkalk (oberes Nor). s0 179/24. Blickrichtung nach N. Ort: Am Ostrand des Estergebirges auf 940m Höhe im Obernachtal.

tsbeton"). Numerous large niches characterize several steep nagelfluh-faces („Schwalbenwände") at Kreuzeck (1651 m) and contribute to the beauty and individuality of that alpine landscape.

2.11. Temporary ice-caves (recent)

They occur at the runouts of snow avalanches at the base of steep rock faces. In springtime, the gaps and voids between rock-substratum and compacted snow widen, when running water undercuts and hollows out firn. One of these temporary objects is known at geosite Partnachursprung (karst spring), situated in the Reintal. The roof of that cave – consisting of ca. 600 m³ ice – collapsed on Sept.-13-1999 and buried two hikers (Wehrle 2002).

3. Geological formations hosting primary caves:

3.1. Wetterstein Limestone

The central reef area and adjacent zones made up of sedimentary breccias and reef-detritus locally contain meter-sized fossil caves: the voids of them were draped by mm-laminated dolostone-limestone-encrustations („Großoolithe"), which originated under vadose conditions during temporary sea level drop and subsidence stop: late-diagenetic sinter, chemically precipitated from migrating pore-fluids, filled the voids by forming concentric scale-aggregates (Nittel 2006).

3.2. Rock fall deposits (Holocene)

It consists of angular rock fragments, which accumulated at the runouts below rock fall scars. The caves originated, as m³-sized boulders piled up chaotically and created large voids in between them. According to own observations, the main occurrences of that type of cave are rock-slide deposits at Zugspitzplatt, Eibsee and in the Reintal (geosite „Steingerümpel").

3.3. Calcareous sinter and tufa deposits (Holocene to recent)

They occur at cascades and at cold water springs, which originate at geological boundaries characterized by permeability-contrasts; for instance at the stratigraphic contact between permeable, coarse grained fluvioglacial detritus and semipermeable sandstones and marlstones of the Molasse. This situation is given at geosite „Schleierfälle" in the nature preserve area „Ammerleite": it is situated at the steep western slope of river Ammer, where outlets of several cold-water springs are present. Calcareous sinter and tufa deposits accumulate actually by physical lime-precipitation and by coeval biomineralization. The caves form syngenetically: sinter-curtains steadily grow downward from overhangs and lock up the niches below.

Conclusions

Several objects of the natural caves present in the Werdenfels Country deserve the predicate natural monument and contribute to the scientific, aesthetic and touristic values of this geotope cluster. The necessity exists to create a complete register of natural caves of that area.

Ergebnisse: Einigen natürlichen Höhlen, die im Werdenfelser Land vorhanden sind, gebührt das Prädikat Naturdenkmal. Sie tragen zur wissenschaftlichen, ästhetischen und touristischen Bedeutung dieser Geotoplandschaft bei. Es besteht die Notwendigkeit, ein vollständiges Höhlenregister dieses Gebietes zu erstellen.

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