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Cover photo : Keir Vaughan-Taylor on Lake 2, Koonalda Cave, Nullarbor Plain. (Photo by Kevin Moore)

Back Cover : The Khan and Beagum in Kubla Khan Cave Tasmania (Photo by Garry K. Smith)

World-Wide Largest Biosphere Reserve On Sulphate Karst And The Schlotten Caves – Endangered Geo- And Biodivesity Hotspots In The South Harz, Germany

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Abstract

The karst area at the South Harz Mountains (Central Germany) is a landscape with a unique character based on its geology. It features small-scale diversity of semi-natural structures and is important for the conservation of certain species. The South Harz area forms a 100 km long continuous belt of evaporitic rock from the Upper Permian (Zechstein) stretching from Osterode (Lower Saxony, Göttingen district) via the Nordhausen district (Thuringia) to the south-eastern edge of the Harz Mountains north of Sangerhausen (Saxony-Anhalt). The most important characteristics are the large areas of outcropping gypsum rocks, the largest and thickest anywhere in Central Europe. The solubility of gypsum in combination with high levels of precipitation has created intense karstification with an amazing diversity of gypsum karst features in a geologically short period of time. Amongst the about 170 caves are the largest anhydrite caves of Europe outside the Russian Platform. This is unique world-wide for sulphate karst areas. Only small areas of the landscape are effectively protected. Quarrying for gypsum, anhydrite and dolomite threatens core areas of the landscape. This also endangers the sustainable development of the South Harz Mountain region. Protection in form of a large-scale biosphere reserve is only given in Saxony-Anhalt – the only one of its kind world-wide. This illustrates the under-representation of sulphate-karsts in the global network of protected areas and sites.

Keywords: South Harz, karst landscape protection, evaporate karst, gypsum, anhydrite, world heritage

1. Introduction

The landscape of the South Harz is dominated by gypsum karst, forming one of the largest continuous gypsum karst areas in Europe (Kempe 1996). It occupies a narrow belt extending through the States of Lower Saxony, Thuringia and Saxony-Anhalt (Federal Republic of Germany) from Osterode am Harz in the West to Sangerhausen in the East. This sulphate belt has developed a remarkable density and variety of karst phenomena throughout the Pleistocene and Holocene. Karstification occurs mostly in the gypsified anhydrite layers of the Upper Permian, i.e. the anhydrite members A1, A2, A3 of the Werra, Staßfurt and Leine Zechstein (Upper Permian) salinar series, respectively. Dolomite and limestone outcrops complement the karst area. This outstanding landscape is worthy of preservation and several important sections are legally protected. However, the area and its outstanding importance is not well known internationally.

2. Epikarst and Biodiversity Hotspot

The most pronounced features of the South Harz karst landscape are more than 20,000 sinkholes in addition to countless uvalas, ponors and karstic springs, periodic lakes, about 170 caves and other karst phenomena plus many archaeological sites. All are confined in the small spaces of the individual gypsum outcrops. These natural conditions are a vast mosaic of closely interconnected but diverse habitats, including dry meadows, beech forests on sulphate rocks and dolomite (*Hordelymo-Fagetum lathyretosum*), gypsum escarpments, stony terrain, spring bogs and water-filled fens. The South Harz gypsum karst area is also an important habitat for many bat species and the European Wildcat (*Felis sylvestris*).

The highly structured surface and its dry soils limits housing development, agriculture and forestry. Many parts of the karst are therefore in a semi-natural state. Calcareous beech woodlands are particularly worth protecting and dominate the flora together with dry calcareous grasslands. In addition, the north-western Atlantic and south-eastern continental climate

zones overlap in the Lower Saxony part of the gypsum karst. The geological conditions, especially the diversity of different karst types and climatic conditions, allow a specific large biodiversity. This has been the main reason why the German Federal Agency for Nature Conservation (BfN) has added this area to a list of 30 biological hotspots under the name of **"South Harz Zechstein Belt, Kyffhäuser and Hainleite"**. Even though, only parts of the landscape are protected.

3. Hypokarst and Mining

Since the 16th century, copper shale miners in the area of Mansfeld have known phreatic anhydrite caves without natural entrances in the subsurface and named them "Schlotten" (Kempe 2014). They are mostly situated in the Mansfeld Basin within the Zechstein anhydrite, but some underlie the Biosphere Reserve and are open for restricted public visits. TheseSchlotten-type caves are the largest anhydrite caves in

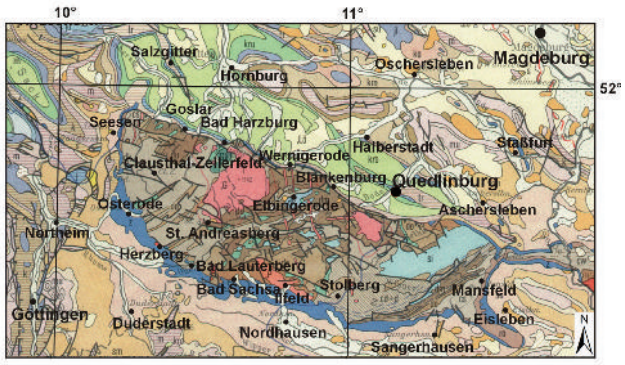

Figure 1. Geological map of the South Harz Zechstein belt between Osterode and Sangerhausen plus the Schlotten cave area near Eisleben and Mansfeld. Graphics: Geopark Harz . Braunschweiger Land . Ostfalen, modified by Stefan Mohr.

Figure 2. Sachsenstein sulphate cliff near Bad Sachsa. Photo: Detlef Tront.

Figure 3. Beech forest on gypsum in the Höllstein area near Walkenried. Photo: Hans-Georg Mendel.

Figure 4. The Wimmelburger Fluchtwegschlotte, one of the largest Schlotten cave rooms near Eisleben. Photo: Klaus Stedingk.

Europe outside the Russian Platform. The most famous of them are the "Wimmelburger Schlotten" near Eisleben. Four geological and geochemical preconditions are required to form these caves: Inflow of sulphate-poor and carbonate-rich groundwater via a locally fractured limestone karst aquifer, superposition by an impermeable rock (in this case anhydrite),presence of steeply inclined fault zones in the anhydrite yielding the initial permeability, and development of a secondary calcium-sulphate solubility due to carbonate precipitation near the boundary between limestone and anhydrite. The water input derives from meteoric precipitation sinking into a jointed limestone aquifer. The easily soluble, but impermeable anhydrite forms the upper boundary of the caves and induces the formation of a pressurised aquifer between limestone and anhydrite. Anhydrite is generally impermeable because tectonic fissures are quickly closed again by a volume increase during the gypsification. The Mansfelder Schlotten can be classified as strata-boundary caves between limestone and anhydrite rock. The cavities start to develop along horizontal shear zones with sigmoidal joints. When the carbonate-rich water meets the anhydrite rock at such a fault, the solubility equilibrium changes, and fine-grained carbonates precipitate. By this process, the water gains a secondary calcium-sulphate solubility and large hypogene cavities develop by slow, density-driven convection. The karst water regime is a siphon-drainage system (Kupetz and Knolle 2015).

4. Landscape History

The fens and lakes in the South Harz gypsum karst sinkholes are excellent archives for the reconstruction of vegetation, land use and emission rates over millennia. Pollen is preserved very well due to the anoxic conditions in bogs especially in the hypolimnion of lakes. Studies of the varved sediments of the Lake Jues sinkhole in Herzberg provided a well-dated, continuous and highly sensitive environmental and climatic reconstruction of the Holocene for the mid-latitudes in Central Europe. The results serve as an important link between the better investigated neighbouring regions. This sinkhole is one of the largest of its type in Germany and collapsed during a Laacher See volcanic event ~ 13,000 BP. Tephra from this event was found at the base of Jues sinkhole (Meischner and Grüger 2008).

Climate shifts, mainly in phase with those recorded from other European regions, are inferred from changing limnological conditions and terrestrial vegetation. Significant changes occurred at 11,600 yrs BP (Preboreal warming), between 10,600 and 10,100 yrs BP (Boreal cooling), and between 8,400 and 4,550 yrs BP (warm and dry interval of the Atlantic). From 4,550 yrs BP the climate became gradually cooler, wetter and more oceanic. This trend was interrupted by warmer and dryer phases between 3,440 and 2,850 yrs BP and probably between 2,500 and 2,250 yrs BP (Voigt *et al.* 2008).

Figure 5. Gypsum quarry destroying the Zechstein landscape south of Walkenried. Photo: Reiner Cornelius.

Palynological studies provide reconstruction of vegetation and settlement history from the Preboreal throughout the Holocene. Deciduous primeval forests dominated by oaks (*Quercus*) spread from the beginning of the Holocene at 10,020 a BP. From 7,600 a BP on in the Neolithic period first settlements and arable farming began to affect the forests. Floral change again took place during Bronze Age when the beech (*Fagus*) superseded the primordial tree species. This process bearing significant ecological effects. Biomass and biodiversity of arthropods declined in the forests, since the number and biomass of foliage-feeding invertebrates associated with oak exceed those associated with the beech (Alexander *et al.* 2006).

Based on the landscape features and ecological qualities, there also exists a wealth of archaeological sites in the South Harz Zechstein belt. The Einhornhöhle cave near Herzberg-Scharzfeld, a cave bear site with Neanderthal tool findings has been known since prehistoric times. More recently the Lichtensteinhöhle cave near Osterode am Harz has become known. It can be dated to the Late Bronze Age by archaeological findings (Flindt and Hummel 2015) and comprises among others, a rich bat fauna. The tree-dwelling stenoecious Bechstein's bat had been the most frequent bat species in Holocene oak forests but was a rare species in the beech forests of the Late Bronze Age cultural landscape (Rupp 2017).

The beech declined in the Middle Ages when humans exploited large areas due to a demand for charcoal for mining. The extraction of metals started more than 4,000 years ago. Geochemical investigations of fens in karst sinkholes in the South Harz allow detection of the emissions produced by mining, as the high portion of low density organic material with very low background concentrations of heavy metals, and the near-neutral pH-values in most of these mires prevent migration of heavy metals. Emission of dust and other harmful elements can be correlated with changes in vegetation (after Hettwer *et al.* 2002).

Biosphärenreservat
Karstlandschaft
Südharz

Figure 6. Signet of the only Biosphere Reserve on sulphate rocks worldwide.

5. Threats and Chances

Unfortunately, parts of this landscape have already been destroyed. In many places gypsum, anhydrite and dolomite is quarried predominantly by globally operating business groups. Every year, millions of tons are processed for construction materials, such as gypsum wallboards, plaster, etc., and karst phenomena with their characteristic flora and fauna are irreversibly lost. Valuable natural heritage and long-term development prospects for the region are sacrificed for short-term jobs and profits. But this must not happen any more, since natural gypsum can be substituted by synthetic, especially gypsum from flue gas desulphurisation (FGD) in nearly all fields of application. FGD gypsum is a waste product of smoke desulfurization. Not all of this gypsum is used for the building industry and must be locally stored or even deposited. Phosphogypsum also can be used as a substitute material for natural gypsum in different technical fields (Yang *et al.* 2015).

Gypsum karst areas, which are now being unnecessarily destroyed, developed over hundreds of thousands of years and represent geosites and biotopes with a significant ecological importance for biodiversity, groundwater systems and the defining landscape elements in Europe. Compensatory measures such as restoration can never substitute primary ecotopes that evolved over a geological and rather than a biological time frame. Restoration would take centuries and the geomorphological structure of this unique habitat and also the karst phenomena would be irrecoverably lost. Because of the current tempo of species extinction, due to climate change, ecological niches like the gypsum karst become indispensable. For this reason sustainable production in the case of utilisation of synthetic gypsum instead of natural gypsum is an economic advantage, resource efficient and above all a guarantee for the protection of biodiversity and landscape ecology in Europe (Röhl 2003).

6. Protection by World Heritage Status?

The environmental and speleological NGOs in Lower Saxony, Thuringia and Saxony-Anhalt vigorously object to the issuing of new extraction permits. In order to ensure the long-term protection of the gypsum karst landscape they demand the establishment of a cross-boundary UNESCO Biosphere Reserve, designated "Karstlandschaft Südharz", and the nomination of more gypsum karst areas as Natura 2000 sites also in Lower Saxony and Thuringia. The environmental NGOs have lodged a complaint with the EU, because important gypsum areas comprising habitat types and species worth of protection have not been nominated for protection in the interest of the continued gypsum mining.

The South Harz gypsum karst is part of the Geopark Harz . Braunschweiger Land . Ostfalen since 2002, UNESCO Global Geopark since 2015 and was declared a German National Geosite in 2006. For more geo-tourist information see also http://www.karstwanderweg.de.

So far, Saxony-Anhalt has been the only German state to consistently protect its share of the gypsum karst belt as a Biosphere Reserve. Declared in 2009, it has an area of 30,034 ha and ranges from Stolberg in the West to Sangerhausen in the East. There is no other Biosphere Reserve in a gypsum karst area in the world.

Sulphate karst areas are massively under-represented in the global network of protected areas and sites. Following Guidelines 4 and 9 (IUCN 1997) and Recommendation 4 from IUCN (2008), parties whose territories include karst terrains situated on evaporite rocks should consider the potential of their sites for natural World Heritage recognition, and this consideration should be started for the gypsum karst landscape described above.

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