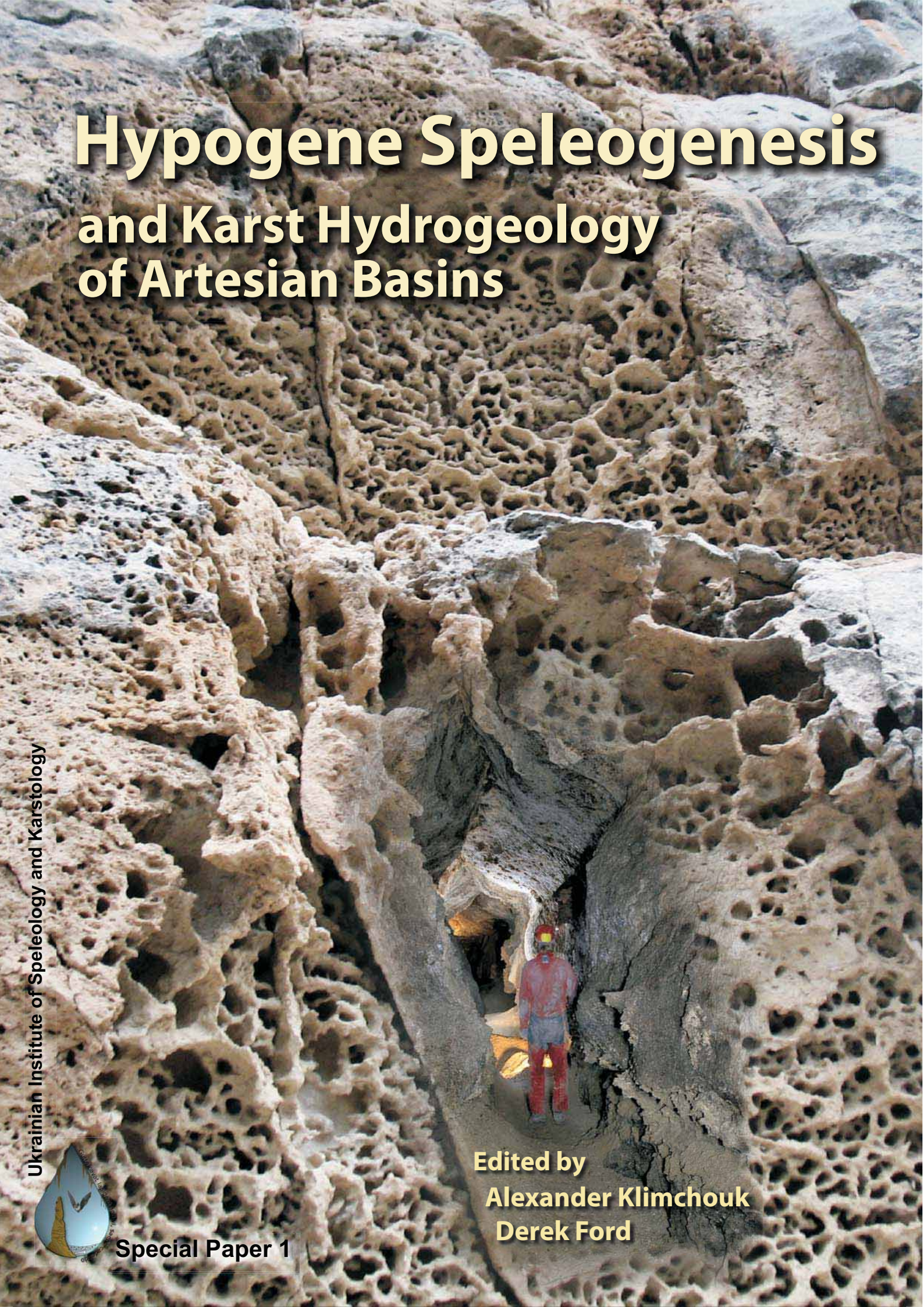
Hypogene Speleogenesis and Karst Hydrogeology of Artesian Basins



Edited by
Alexander Klimchouk
Derek Ford

Ukrainian Institute of Speleology and Karstology

Special Paper 1

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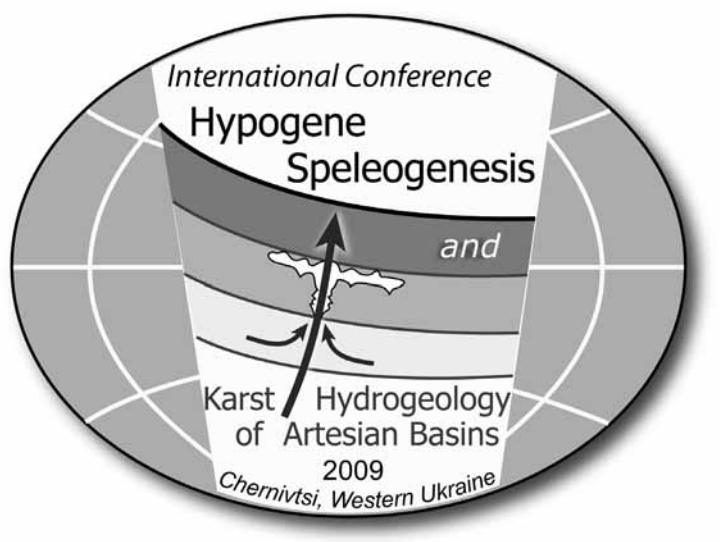
Proceedings of the conference held May 13 through 17, 2009 in Chernivtsi, Ukraine



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Front cover: Tafoni on a limestone escarpment in the Crimea Piedmont (background) and a passage in Slavka Cave, Western Ukraine (inset). Photos and collage by A.Klimchouk

Back cover: Hypogenic morphology in gypsum caves of the Western Ukraine. Photos and collage by A.Klimchouk

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CONTENTS

HYPOGENE KARSTIFICATION IN SAUDI ARABIA (LAYLA LAKE SINKHOLES, AIN HEETH CAVE)

Stephan Kempe[1], Heiko Dirks[2], and Ingo Bauer[1]

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The Arabian plate is tilted towards the East. In its western reaches the crystalline basement is exposed, while towards the east increasingly younger deposits crop out, beginning with the Paleozoic (e.g., Thompson, 2000). Therefore, bands of unfolded sedimentary formations can be followed from the NE to the S throughout much of Saudi Arabia (Figure 1). In this series, harder layers form prominent escarpments like those of the middle Jurassic and lower Cretaceous limestone. In between, the upper Jurassic Heeth Formation, composed of anhydrite, forms a flat area that is visible from space due to its bright color. The anhydrite, ca. 150 m thick, forms an aquiclude for the groundwater below. It therefore flows eastward toward the Persian Golf following the general dip (e.g., Dirks, 2007).

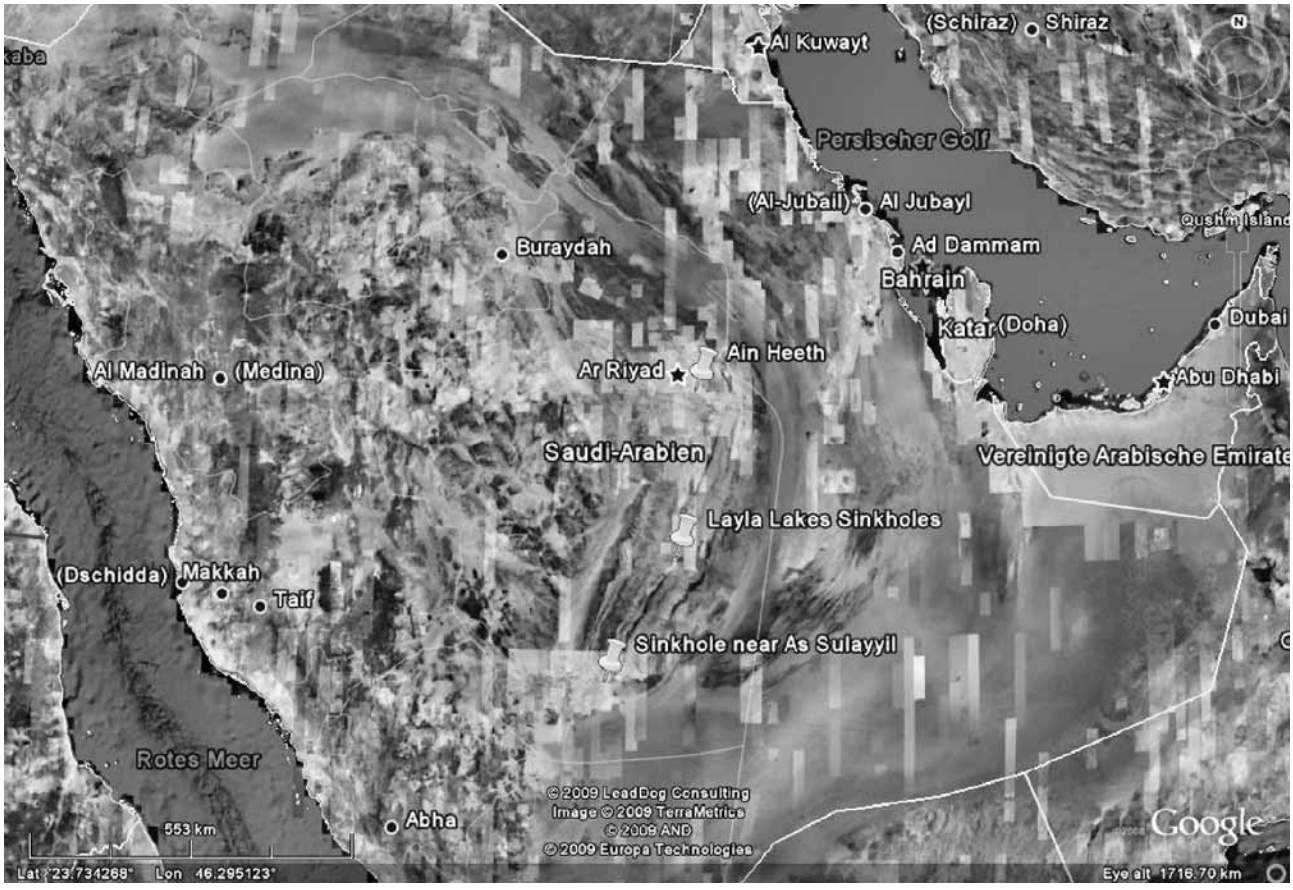

Figure 1. Google Earth picture of Saudi Arabia, with the exposure of the crystalline base in the west of the country and the successively younger Paleozoic, Mesozoic and Tertiary Sediments to the east curving roughly North-South.

Figure 2. Recently subsiding sink hole at As Sulayyil (Foto S.Kempe).

Figure 3. A picture of water sport formerly possible in the Layla Lakes in central Saudi Arabia.

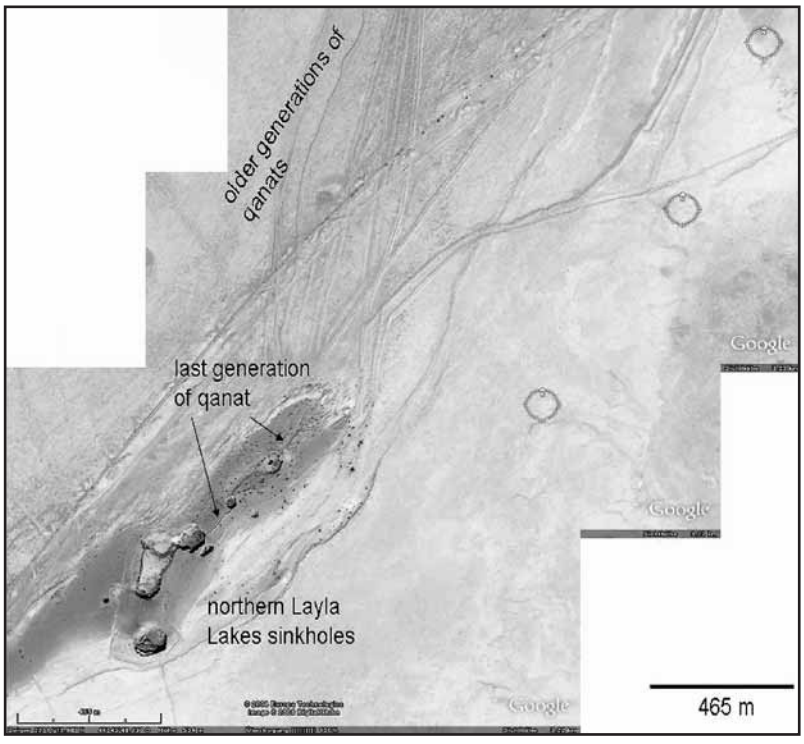

Figure 4. Google Earth composite, showing the northern sinkholes of the former Layla Lakes in the south and the system of older and more recent Qanats (underground aqueducts) leading from the lakes to the former farming community of As Sayh 6 km to the north that used the natural outflow water of the Layla Lakes.

Locally, the Heeth Formation is, however, punctured by karst sinkholes formed above hypogene caves. One of these areas is around the town of As Sulayyil, 500 km south of Riyadh, where several sinkholes have opened up. At least two have recently been filled by the farmers, but one rather recent one (at Umm Sulaim; N20.42414° E45.66311°), 47 m long and 27 m wide and about 1 m deep, was venting hot and humid air through fresh circumferential and radial cracks, apparently rising from the deeper underlying aquifer (Figure 2).

The most prominent of such features are, however, the former Layla Lakes at 22.17°N 46.70°E. This sinkhole group originally contained 17 lakes (Ministry, 1984) (Figure 3). They served as natural outlets of the underlying aquifer. Apparently enough water discharged to feed several qanats and to sustain irrigated agriculture and date farming in the center of Arabia for a long time (Figure 4). Beginning in the late 1980's water was first pumped out of the lakes and then the groundwater was tapped by deep wells. This led to a quick drop in the water table and dried up the lakes by the mid 1990's, terminating the period of sustainable usage of this local water resource. The water table lowering revealed 19 sinkholes (Kempe and Dirks, 2008), some of them composites of several subsidence centers (Figure 5). The largest is 1.1 km long, 0.4 km wide and about 40 m deep (Figure 6). Others are less than 10 m across and rather recent (Figure 7). The bottom of the former lakes and the flats around them are composed of thick layers of fine-grained lake chalks (the Quaternary Layla Lake Formation; Kempe and Dirks, 2008) that show signs of further subsidence, partly due to their drying out and possibly partly by further subsidence above hypogene cavities at the bottom of the Heeth Formation. The most striking feature of these sinkholes is the several meters thick tufa covering the vertical walls of the sinkholes (Figures 8, 9). It formed sub-aqueously and is entirely composed of gypsum. Morphologically the tufa displays thick bulbous forms at the bottom, changing to conical forms at middle depth and to gour-, gutter-, or shovel-like forms near to the former lake surface. The mineralogy and morphology of this tufa appear to be singular worldwide (Kempe and Dirks, 2008).

The rapid groundwater consumption also made the lower parts of the deepest cave in Saudi Arabia accessible. This is the former well of Ain Heeth (also Dahl Hit) near Al-Kharj ca. 35 km south of Riyadh (24.48582N, 46.99708E). It is a >160 m deep cave with a gaping entrance (Figure 10) at the type location of the Heeth Formation, which is composed of laminated and autobrecciated anhydrite. The cave apparently formed by upward solution of the groundwater body in a hypogene setting *sensu* Klimchouk (2007, Figure 16). In the 1930's the cave was a spring, allowing the deep groundwater to flow out freely. In the 1980's the cave formed a pool, often visited by locals for picnics. Then a pump house was installed

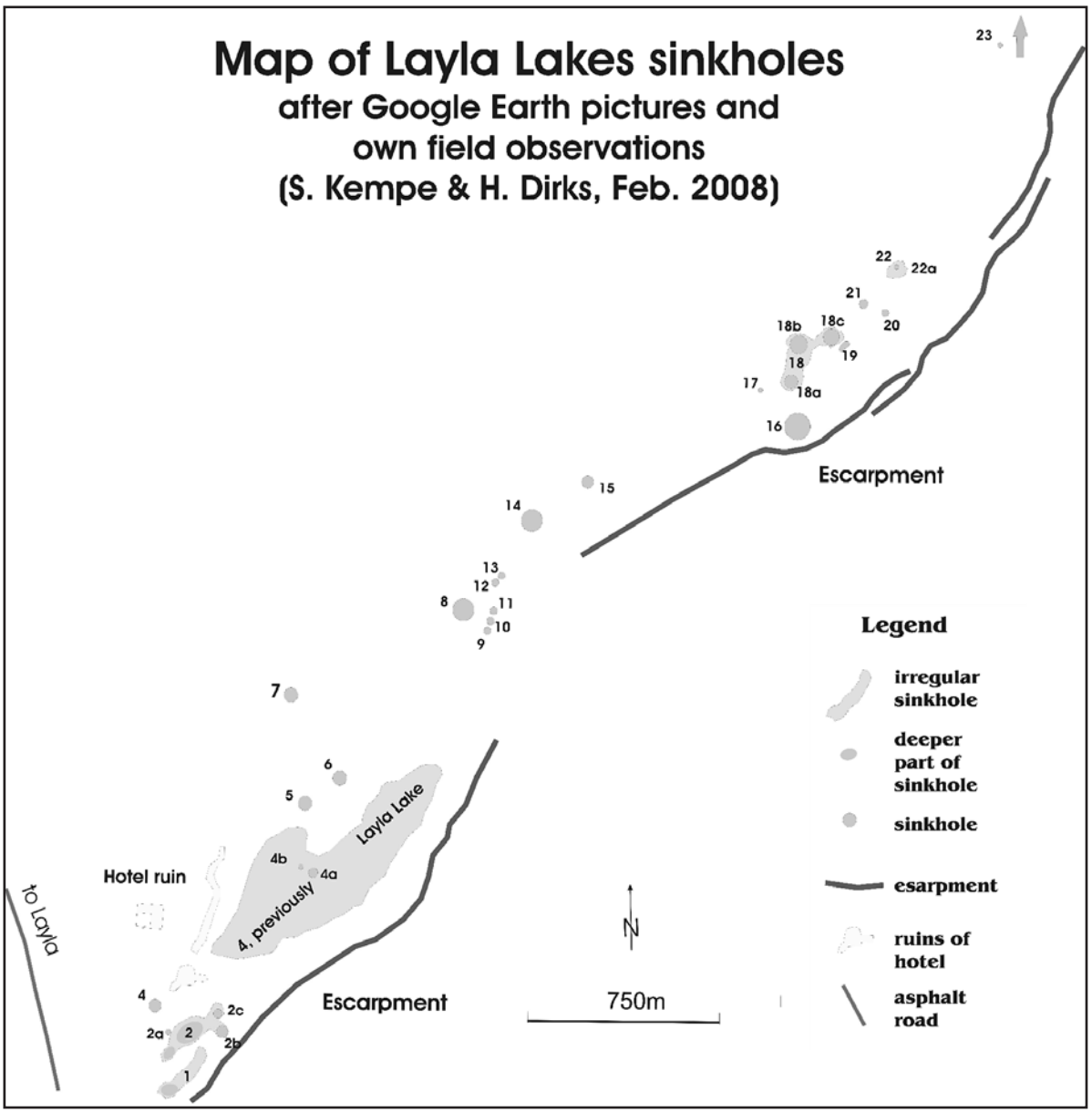

Figure 5. Map of the current sinkholes of the Layla Lakes area (modified after Kempe and Dirks, 2008).

Figure 6. View into the largest of the Layla Lakes sinkhole (No. 4) (Foto S.Kempe).

Figure 7. One of the smaller sinkholes in the Layla Lakes area (Foto H.Dirks).

and the water was used locally. Then deep wells in the surrounding area tapped the underlying aquifer. In 2002, the lake had receded to a depth of 137 m (pers. comm. Greg Gregory) and divers explored a large chamber and a horizontal, slowly descending passage at its bottom. During the visits by the authors on February 19th, 2008, the large chamber (up to 70 m long and 20 m wide) at a depth of ca. 145 m was accessible, with the groundwater surface forming a lake at its bottom (Figure 11). The horizontal passage apparently was not yet free of water. The cave walls show the morphology typical of convective cave formation in a phreatic setting in gypsum (Figure 12) (e.g., Kempe, 2008). Descending steeply over the boulders of the cave floor, one passes through almost all of the Heeth Formation, thus making it the only outcrop where it can be studied in detail. Above the entrance of the cave the transgressive contact of lower Cretaceous marl and platy limestone is well displayed.

Further sinkholes are also reported from the area north of Riyadh but have not yet been investigated by the authors.

Thus the Heeth Anhydrite Formation appears to experience hypogene karstifiction in several (at least four) areas along its roughly N-S striking outcrop. The lowered ground water level now allows us to study these features

Figure 8. Gypsum tufa grew in sublacustrine positions on the walls of the sinkholes, forming gour- and cup-like structures in the upper section of the water column (Foto S.Kempe.).

Figure 9. In the lower part of the water column, more compact, inverted cone-like gypsum tufa forms grew (Foto H.Dirks).

Figure 10. Entrance of Ain Heeth (note S.Kempe for scale; Foto H.Dirks).

for the first time without needing to dive. On the other hand, the drying-out of the Layla Lake sediments causes substantial fracture formation around the former lakes. Furthermore, the loss of buoyancy caused by the groundwater lowering may destabilize the breccia pipes below the sinkholes with the potential of intensifying sinkhole subsidence and accelerating sinkhole formation. Near As Sulayyil a sinkhole appears to be just opening up, providing a connection through its breccia pipe with the aquifer below the Heeth formation as is evidenced by the emanation of warm and moist air. Overall the situation can be compared to the setting of the "Schlotten" in the South-Harz. These cavities formed also underneath anhydrite deposits (Zechstein) in a deep phreatic setting by water rising from the underlying Zechstein Kalk (e.g., Kempe, 1996) (Figure 13).

Figure 11. Surface of the ground water in Ain Heeth at a depth of ca. 145 m (Foto S.Kempe).

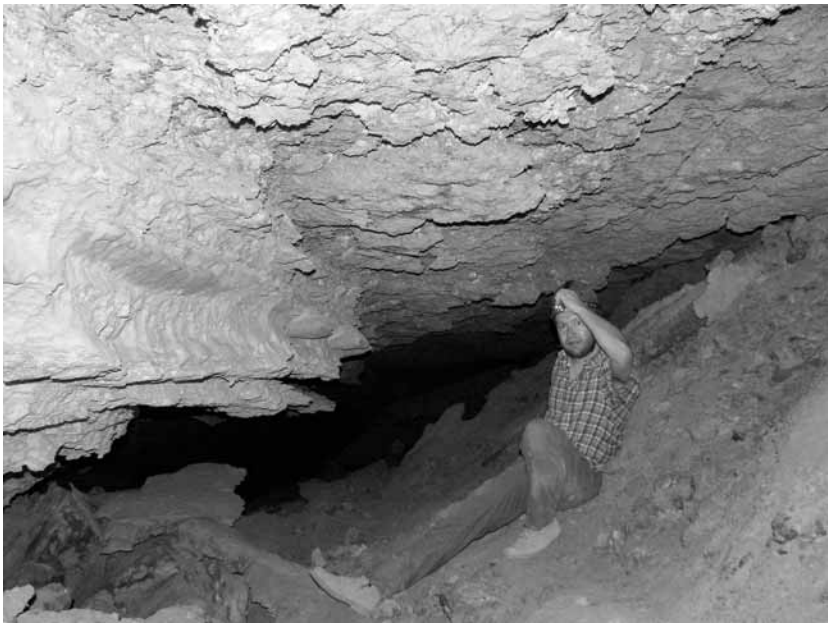

Figure 12. Morphology of the cave walls and ceiling is typical for cave genesis driven by density convection and identical to South Harz gypsum cave morphology (Foto S.Kempe).

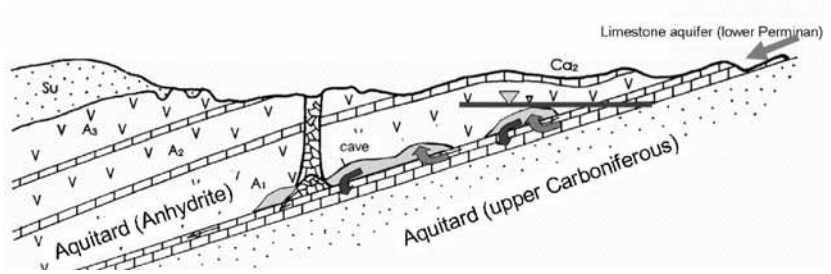

Figure 13. Sketch of hypogene cave formation in the South Harz, where water rising from the underlying Zechsteinkalk aquifer forms caves in the overlying Werra-Anhydrite (modified after Kempe, 1996).

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