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Hydrothermal karst cavities in a Devonian carbonate reservoir analogue (Rhenish Massif, Germany): Implications for geothermal energy potential

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Deep geothermal reservoirs can provide renewable energy for electricity and heat generation [1]. In the Rhine-Ruhr area of western Germany, where Europe's largest district heating network is located, up to 1,300 m thick carbonates of Devonian age are available in ≥ 4,000 m depth [2, 3]. Near the surface, these rocks contain karst cavities, which host some of Germany´s longest caves [4, 5]. At reservoir depth, abundant karstification may significantly increase the geothermal reservoir potential [6] (Figure 1).

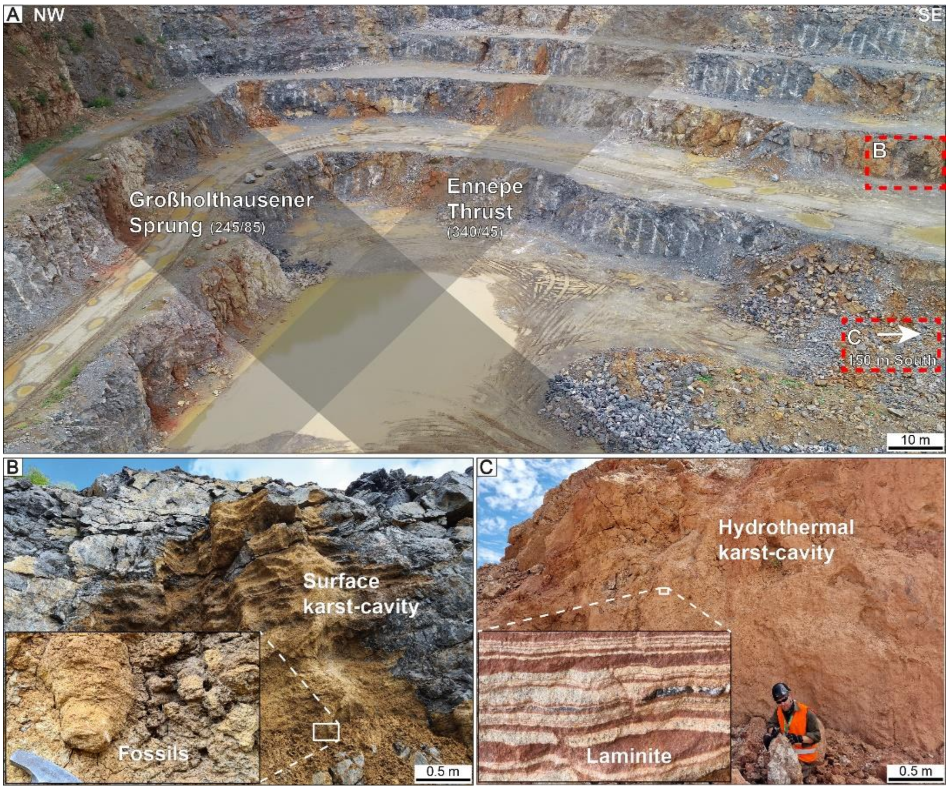

Figure 1: (A) Drone image displaying the WSW-ENE (340/45) striking Ennepe Thrust (Variscan) and NNW-SSE (245/85) striking Großholthausener Sprung (Post-Variscan) in Steltenberg Quarry. (B) Surface karst structures with karstified walls including fossils. (C) Hydrothermal karst cavity with laminated cement/sediment infill at the southern quarry wall.

In the Munich area (southern Germany) deep-seated karstified Upper Jurassic rocks are widely used for the city´s district heating network [7]. Most deep-seated geothermal systems are located at a depth of 1,000 m or more at temperatures over 60 °C [8]. Therefore, it is important to assess deep-seated karstified structures elsewhere to assess their geothermal reservoir potential. In the Rhine-Ruhr area, these could have the potential to be used as an alternative renewable energy resource.

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This study aims at the geological characterization of deep-seated (hydrothermal) karst cavities in Steltenberg Quarry (western Germany) where Middle/Upper Devonian carbonates (Massenkalk limestone) are present in the vicinity of two regional fault zones [9, 10]. We applied state of the art petrographical, geochemical, palaeothermometrical methods, and U-Pb dating. Here we present the first U-Pb age data of deep-seated hydrothermal karst precipitates in Germany, which formed at the Permian-Triassic boundary (252.4 ± 8.6 My, Table 1). The U-Pb age data of calcite cement veins (LMC 8), which were cutting the near-surface karst cavities before they got dissolved, points to an Oligocene maximum age (30.0 ± 2.81 My) of the karst cavities.

Table 2: Geochemical (carbon, oxygen, strontium isotopes), palaeothermometry (clumped isotopes, fluid-inclusions), and U-Pb age data of some relevant phases from Steltenberg Quarry.

Phase	**δ^{13}C (‰)**			**δ^{18}O (‰)**			**^{87}Sr/^{86}Sr (± 2 σ)**		**Δ_{47} (°C)**	**Primary T_h (°C)**	**U-PB age (My)**
	min.	max.	mean	min.	max.	mean	min.	max.	(±SD)		(±SD)
LMC 10	-6.4	-5.6	-6.0	-9.2	-7.5	-8.2	no data	no data	no data	no gas phase	no data
LMC 9	-5.3	-3.6	-4.3	-5.8	-5.0	-5.4	0.709386 (5)	0.709386 (5)	23 (8)	no gas phase	no data
LMC 8	-2.9	-1.5	-2.2	-3.8	-3.4	-3.6	0.711656 (5)	0.711656 (5)	73 (1)	164-196 (n = 5)	30.0 (2.81)
Laminite 1	-3.0	-2.1	-2.6	-4.5	-0.4	-2.3	0.709028 (5)	0.714721 (6)	93 (18)	207-221 (n = 9)	252.4 (8.6)
MK Fossils	2.8	3.0	2.8	-7.7	-7.1	-7.3	0.707915 (5)	0.707915 (5)	no data	no data	388.8 (5.4)
MK lime-stone matrix	2.4	3.2	2.8	-9.9	-5.2	-7.1	0.708027 (5)	0.708879 (5)	85 (41)	no data	no data

Contributor statement

Mathias Mueller: Project administration, fieldwork, data curation, investigation, visualization, writing – original draft; Benjamin F. Walter: Fieldwork, data curation, investigation, review and edit; Aratz Beranoaguirre: Data curation, review and edit; Manfred Heinelt: Fieldwork, review and edit; Adrian Immenhauser: Project administration, fieldwork, review and edit.

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