

Electronic supplement for the paper:

K. Žák, D. K. Richter, M. Filippi, R. Živor, M. Deininger, A. Mangini and D. Scholz.: Coarsely crystalline cryogenic cave carbonate – a new archive to estimate the Last Glacial minimum permafrost depth in Central Europe.

Examples of in situ occurrences of coarsely crystalline cryogenic cave carbonate and its different morphological forms



Fig. S1. General view of the typical occurrence of the CCC – white aggregates on the cave bottom. Heilenbecker Höhle, Germany. Photo by M. Filippi.



Fig. S2. The CCC trapped on the cave wall. Na Javorce Cave, Czech Republic. Photo by M. Filippi.

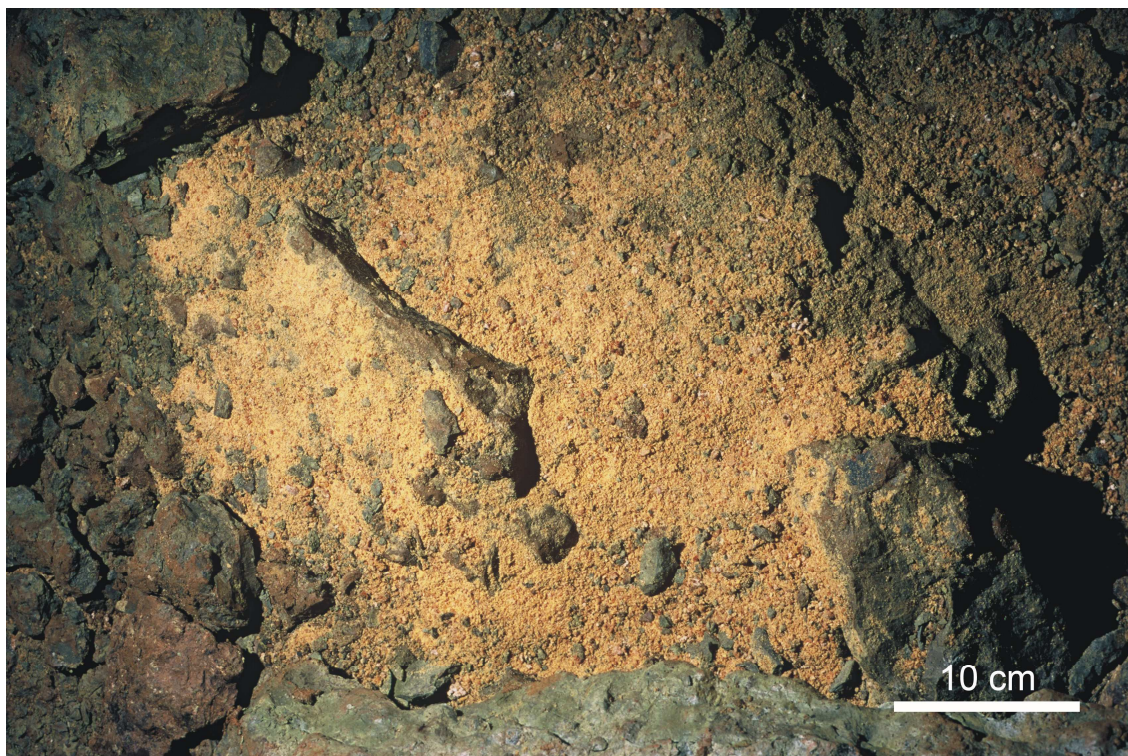


Fig. S3. Detailed view on accumulation of the loose CCC on the cave bottom. BUML Cave, Czech Republic. Photo by P. Zajíček.



Fig. S4. Loose CCC on the limestone block surface at the cave bottom. Studeného Vetra Cave, Slovakia. Photo by M. Majer.



Fig. S5. Loose CCC on the surface of limestone blocks. Malachitdom, Germany. Photo by M. Filippi.



Fig. S6. Detailed view on the loose CCC covering the clay sediments on the cave bottom. Portálová Cave, Czech Republic. Photo by M. Majer



Fig. S7. A rosette aggregate of the CCC. Javoříčko Caves, Czech Republic. Photo by K. Žák.



Fig. S8. Irregularly developed CCC crystals and their aggregates. Hačova Cave, Slovakia. Photo by J. Brožek.



Fig. S9. Different CCC types (simple crystal, skeletal aggregates and globular form). Portálová Cave, Czech Republic. Photo by M. Filippi.



Fig. S10. "Raft-like" CCC aggregate. Javoříčko Caves, Czech Republic. Photo by M. Filipi.



Fig. S11. "Raft-like" CCC aggregate. Na Javorce Cave, Czech Republic. Photo by M. Filipi.



Fig. S12. Two-generation crystalline "raft-like" CCC aggregate. Na Javorce Cave, Czech Republic. Photo by M. Filippi.

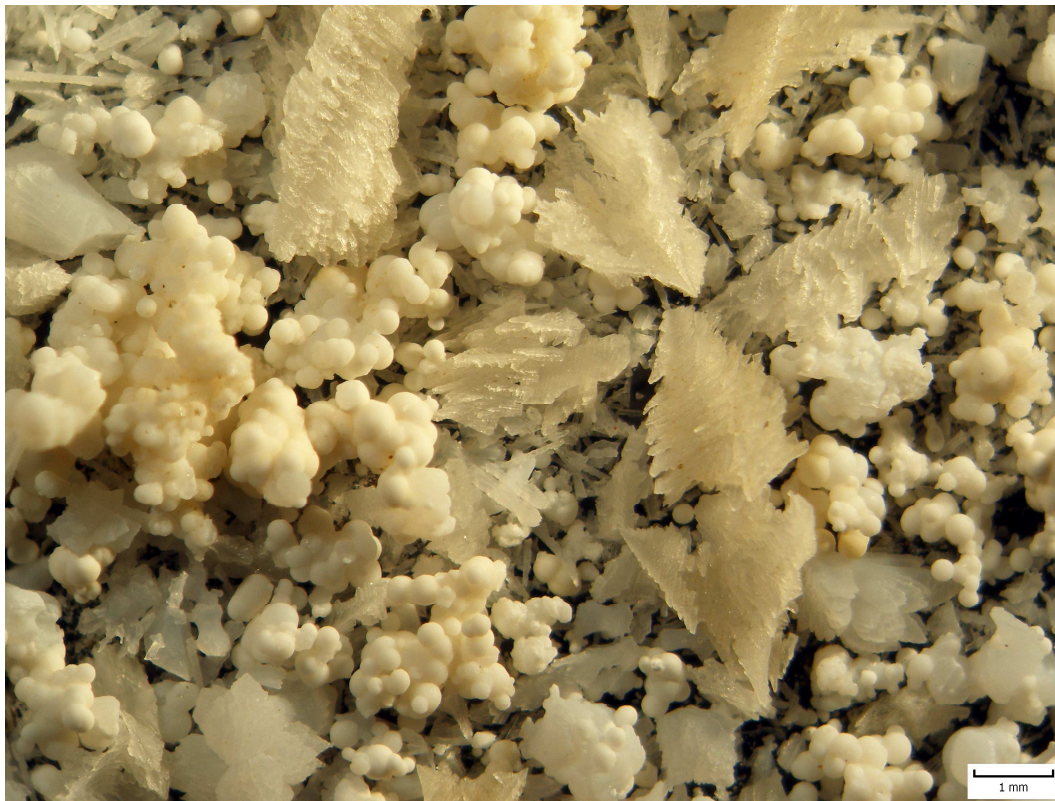


Fig. S13. Mixed skeletal and globular types of the CCC. Studeného Vetra Cave, Slovakia. Photo by M. Filippi.



Fig. S14. Globular (hemispheric) CCC on the limestone block at the cave bottom. Malachitdom, Germany. Photo by M. Filippi.

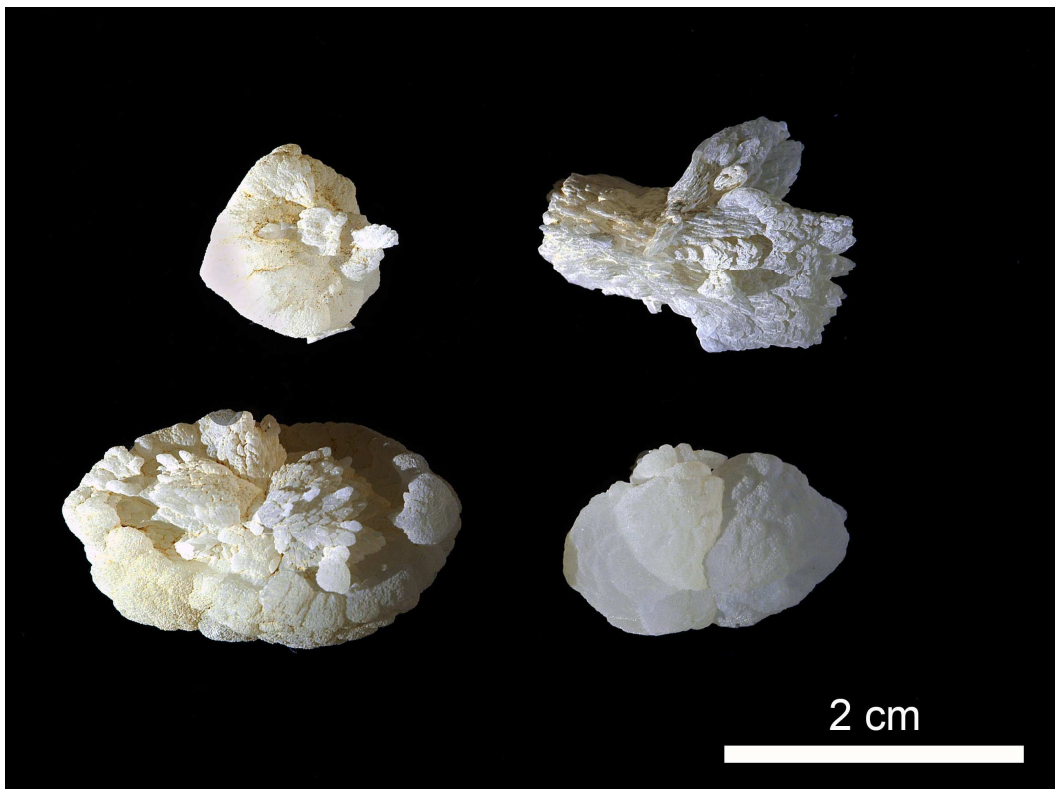


Fig. S15. Globular types of the CCC. Studeného Vetra Cave, Slovakia. Photo by J. Brožek.

Table S1. Characteristics of the studied caves. The U-series ages were obtained from three different laboratories: Heidelberg Academy of Sciences, Heidelberg (H), Institute of Geological Sciences of Polish Academy of Sciences, Warsaw (W), Max-Planck-Institute for Chemistry, Mainz (M). The MAAT temperatures of each area are derived from the closest meteorological stations, the cave air temperatures are based on one or several single measurements.

Cave number Cave name Country	Entrance position (deg. N, E) elevation (m a.s.l.)	Basic cave description (cave ventilation).	Cave length (m) Vertical extent (m) MAAT surface (°C) Cave air T (°C)	CCC number of sites, depth below surface	CCC age (U-series, ka BP)	References, dating laboratories
1 Apostelhöhle Germany	51°23' 41" 8°40'02" 501	Complex maze of narrow, mostly vertical cavities in massive Devonian limestone, one narrow entrance (limited ventilation).	ca. 1 000 106 9.0 8.0	two sites, 83 m and 93 m below entrance, ca. 50 - 60 m below the slope	408+42-31 83.5±1.4 37.53±0.31 35.59±0.42	CCC description and dating: Richter et al. (2010b), dat. lab: H
2 Dechenhöhle Germany	51°21' 57" 7°38'40" 175	Mostly subhorizontal corridors in massive Devonian limestone, located at shallow depth, originally several entrances (moderate ventilation).	870 ca. 10-11 10.0 10.0-11.0 (show cave)	one site ca. 20 m	not dated yet	CCC description: Richter and Niggemann (2005)
3 Glaseishöhle Germany	47°30' 44" 12°54' 42" 2 230	Alpine cave dominated by cavities extended in the vertical direction in Triassic limestone (strong ventilation).	2 267 229 ca 0.0 1.0–2.0	one site 229 m	not dated yet	CCC description: Richter et al. (2009c)
4 Großen Sunderner Höhle Germany	51°18' 45" 8°00' 48" 280	Mostly water-level controlled cave with a large chamber at the crossing of fault-oriented corridors in Carboniferous limestone (moderate ventilation).	250 42 ca. 9.5 similar to MAAT	one site 28 m	not dated yet	CCC description: Richter et al. (2009a)
5 Heilenbecker Höhle Germany	51°17' 35" 7°20' 34" 204	Complex cave of multistage origin, mostly developed as epiphreatic maze in layered Devonian limestone, narrow entrance (limited ventilation).	3 822 41 10.0 9.0	one site about 25 m	31.25±0.50	CCC description: Richter et al. (2008); dating: Richter et al. (2009b); dat. lab: H
6 Herbst-labyrinth - Adventhöhle Germany	50°41' 17" 8°12' 23" 420	Extensive cave system, mostly sub-horizontal, large, water-level controlled corridors in Devonian limestone (limited ventilation). CCC in Rätselhalle (Site 1) and Weihnachtsbaum-Halle (Site 2).	5 800 80 9.3 9.3	two sites both are 30 to 40 m below surface	Site 1: 29.17±0.48 28.70±1.50 Site 2: 23.96±0.18 23.59±0.30	CCC description and dating: Rätselhalle - Kempe et al. (2006) and Richter et al. (2010a), Weihnachtsbaum-Halle: Richter et al. (2011); dat. lab: H
7 Malachitdom Germany	51°27' 56" 8°42' 02" 424	Inclined cave in Devonian limestone with a large dome formed by corrosion, phreatic morphology, discovered by a quarry (limited ventilation).	296 58 9.0 8.0	two sites ca 45 and 50 m below original surface	15.61±0.20 14.84±0.13 14.48±0.12	CCC description: Erlenmeyer and Schudelski (1992), Schmidt (1992), Richter and Niggemann (2005), dating: Richter and Riechelmann (2008); dat. lab: H

8	51°21' 00" 8°24' 00" 448	Cave system in Devonian limestone with three epiphreatic subhorizontal levels (CCC occurs in a main corridor of the middle level, limited ventilation).	622 18 ca. 9.5 9.5	one site 10 m below the surface	not dated yet	CCC description: Richter and Niggemann (2005)
9	52° 12' 16" 9° 17' 16" 276	Epiphreatic cave system in Jurassic limestone with long subhorizontal water-level controlled corridors (limited ventilation).	1 127 20 9.0 9.0	two sites 30 to 40 m below the surface	66.4±0.5 62.0±0.4 61.6±0.4 53.7±0.3 12.0±0.1 11.9±0.1	CCC description and dating: this work and Richter et al. (under review), dating lab: M
10	49°56' 37" 14°07' 42" 246	Cave with phreatic morphology developed in layered Devonian limestone with a large dome accessible only via long and narrow corridors (limited ventilation).	274 31 ca. 8.5 similar to MAAT (no precise data)	one site 45 m	33.77±1.77 25.95±1.53	CCC description and dating: Žák et al. (2004); dating lab: W
11	49°40' 13" 16°54' 49" 445	Extensive cave system in Devonian limestone, developed at several levels (limited ventilation).	ca. 4 000 108 ca. 8 similar to MAAT	two sites approx. 30 m	38.09±0.60 37.84±0.73 34.60±0.41	CCC description: Žák et al. (2011), dating: this work; dating lab: H
12	49°56' 17" 14° 10' 59" 330	Complicated extensive system of narrow shafts and corridors formed in layered Devonian limestone (limited ventilation).	1 634 129 ca. 8 similar to MAAT (no precise data)	three sites site 1: 45 m site 2: 60 m site 3: 65 m	Site 1: 50.04±0.59 28.56±0.17 Site 2: 14.98±0.17 Site 3: 9.191±0.072	CCC description: Žák et al. (2011), dating: this work; dating lab: H
13	49°54' 56" 14°03' 48" 402	Cave system in massive Devonian limestone developed by corrosion along faults, communication with surface only via narrow chimneys, discovered by a quarry (limited ventilation).	ca. 200 32 ca. 8 similar to MAAT (no precise data)	one site 60 m	34.26±0.72	CCC description: Žák et al. (2011), dating: this work; dating lab: H
14	49°56' 58" 14°07' 15" 242	Smaller cave system in layered Devonian limestone, almost completely sediment-filled, the CCC site was discovered by excavation of corridors (limited ventilation).	ca. 180 17 ca 8.5 similar to MAAT (no precise data)	one site 28 m	34.45±0.34 34.01±0.38	CCC description: Žák et al. (2011), dating: this work; dating lab: H
15	48°31' 04" 17°23' 33" 690	Morphologically complex cave developed in Triassic limestone, located in a hilly range (moderate ventilation).	660 73 7.7 average 6.8, locally down to 5.8	one site 45 m	47.58±0.55	CCC description: Šmída (2010), Žák et al. (2011), dating: this work; dating lab: H
16	49° 13' 00" 20°07' 20" 1 767	Large mountain cave system with only one CCC site. The deepest CCC site known so far (moderate ventilation).	ca. 26 000 451 1.0 1.0-3.5	one site 285 m below the closest surface	17.13±0.12	CCC description: Žák et al. (2011), dating: this work, dating lab: H

17	48°51' 45" 20°18' 50" 995	Extensive complex, multi-level cave system developed in Triassic limestone, with large galleries and chambers, formed by allochthonous water streams (could have strong ventilation in the past).	22 027 194 4.7 4.9	two sites both at ca. 120 m	23.43±1.05 22.61±1.44 21.16±2.66	CCC description: Tulis and Novotný (1989), Hill and Forti (1997), description and dating: Žák et al. (2004); dating lab: W
18	48°55' 35" 19°39' 19" 1 678	Pre-Quaternary cave system located in Triassic limestone with large domes, fossilized in the mountain range (limited ventilation).	1 518 107 0.8 ca. 2.5	two sites both at ca. 50-60 m	180.0±6.3 104.0±2.9 79.7±2.3	CCC description and dating: Žák et al. (2009a); dating lab: W
19	49°13' 33" 20°10' 16" 1 522	An extensive cave system in Triassic limestone with relatively large corridors (moderate ventilation).	870 50 1.9 2.8-3.0	one site ca. 50 m	15.74±0.47	CCC description: Orvošová and Vlček (2012); dating this work; dating lab: H
20	50°51' 33" 20°29' 56" 257	Extensive cave system, mostly phreatic, developed in Devonian limestones under a small hill in a relatively flat country (limited ventilation).	3 670 59 ca. 6.0-7.0 (no precise data)	ca. 12 sites 33-43 m	61.0±1.8 53.0±1.5 40.0±1.3 38.8±1.4 36.0±1.2	CCC description: Durakiewicz et al. (1995), description and dating: Žák et al. (2004), dating lab: W

Table S2. New U-series data on coarsely crystalline CCC obtained in Heidelberg. All ages are reported in years BP (Before Present, relative to 1950). The errors are 2σ .

Lab. No.	Field No.	Sample location and description	$\delta^{234}\text{U}$ (initial) (‰)	^{238}U ($\mu\text{g/g}$)	^{232}Th (ng/g)	^{230}Th (pg/g)	Age uncorr. (ka)	Age corrected (ka)
5217	PORT1	Portálová Cave, Czech Republic, crystals and crystal aggregates	898.2 ± 6.5	8.6785 ± 0.0087	4.226 ± 0.022	74.59 ± 0.57	34.46	34.45\pm0.34
5281	PORT2	Portálová Cave, Czech Republic, the same site, hemispheres	887.3 ± 5.3	6.5312 ± 0.0065	4.152 ± 0.032	55.19 ± 0.52	34.02	34.01\pm0.38
5218	CJVK1	Na Javorce Cave, Czech Republic, Karakorum Section, flat rafts formed by clear yellowish crystals	1297.7 ± 4.0	5.2694 ± 0.0053	80.97 ± 0.31	46.79 ± 0.23	28.75	28.56\pm0.17
5282	CJVK2	Na Javorce Cave, Czech Republic, the same site as CJVK1, flat rafts formed by white porous crystals	1364.7 ± 9.2	2.1741 ± 0.0054	28.89 ± 0.18	32.16 ± 0.27	50.18	50.04\pm0.59
5256	CJVK3	Na Javorce Cave, Czech Republic, Půda Section (the deeper one), cave rafts, white	2304.6 ± 5.7	2.4009 ± 0.0024	30.60 ± 0.21	16.97 ± 0.19	15.09	14.98\pm0.17
5257	MJAV1	Javoříčko Caves, Czech Republic, Olomouc Chamber, rafts formed by yellowish crystals	1144.7 ± 10.4	0.32932 ± 0.00066	8.627 ± 0.055	3.493 ± 0.056	38.17	37.84\pm0.73
5283	MJAV2	Javoříčko Caves, Czech Republic, Olomouc Chamber, rafts, another site	1179.3 ± 7.7	0.5128 ± 0.0010	26.81 ± 0.14	5.578 ± 0.073	38.75	38.09\pm0.60
5219	SHAC1	Hačova Cave, Slovakia, brownish crystals, partly skeletal aggregates	466.4 ± 5.2	0.9385 ± 0.0019	0.9655 ± 0.0039	8.122 ± 0.070	47.60	47.58\pm0.55
5224	MEST1	Mesačný Tieň Cave, Slovakia, white crystal aggregates	183.9 ± 1.7	14.250 ± 0.014	41.27 ± 0.14	40.38 ± 0.25	17.20	17.13\pm0.12
5515	NOVO1	Novoroční Cave, Czech Republic, one large white crystal aggregate	1451.8 ± 9.5	0.96340 ± 0.00190	1.946 ± 0.018	10.700 ± 0.190	34.28	34.26\pm0.72
5516	VERJ1	Verných Cave, Slovakia, crystal aggregates, partly also cave rafts	1240.4 ± 9.6	1.1873 ± 0.0012	34.230 ± 0.340	6.020 ± 0.160	16.10	15.74\pm0.47
5522	CJVK18	Na Javorce Cave, Czech Republic, cavity below the Půda Section (the deepest one), small white crystal aggregates	6955.9 ± 11.3	1.7141 ± 0.0017	21.65 ± 0.10	18.25 ± 0.14	9.236	9.191\pm0.072
5523	MJAV3	Javoříčko Cave, Czech Republic, Ivošovy Caves section, large, brown-colored aggregates	1558.7 ± 14.8	1.6121 ± 0.0016	15.758 ± 0.085	18.88 ± 0.16	34.70	34.60\pm0.41

Table S3. New U-series data on coarsely crystalline CCC for the Riesenberghöhle, Germany, obtained in Mainz. All ages are reported in years BP (Before Present, relative to 1950). The errors are 2σ .

Sample (Riesenberghöhle)	^{238}U ($\mu\text{g/g}$)	^{232}Th (ng/g)	$(^{234}\text{U}/^{238}\text{U})$	$(^{230}\text{Th}/^{238}\text{U})$	Age uncorrected (ka)	Age corrected (ka)
"Zopfsinter" RieSe	2.75 ± 0.02	1.55 ± 0.02	1.7873 ± 0.0029	0.7163 ± 0.0028	53.7 \pm 0.3	53.7\pm0.3
"Zopfsinter-1", white	0.564 ± 0.005	2.20 ± 0.03	1.6201 ± 0.0029	0.7634 ± 0.0039	66.5 \pm 0.5	66.4\pm0.5
"Zopfsinter-1", brown	1.67 ± 0.01	2.69 ± 0.03	1.5620 ± 0.0029	0.1625 ± 0.0011	11.9 \pm 0.1	11.9\pm0.1
"Zopfsinter-2", white	1.41 ± 0.01	0.80 ± 0.01	1.5294 ± 0.0023	0.6784 ± 0.0030	61.6 \pm 0.4	61.6\pm0.4
Rhombohedral "Sinter-1", white	1.35 ± 0.01	2.89 ± 0.03	1.5254 ± 0.0025	0.6800 ± 0.0031	62.0 \pm 0.4	62.0\pm0.4
Rhombohedral "Sinter-1", brown	1.65 ± 0.01	7.23 ± 0.08	1.5626 ± 0.0026	0.1630 ± 0.0010	12.0 \pm 0.1	12.0\pm0.1