Supporting information for

**Were springline carbonates in the Kurkur-Dungul area (Southern Egypt) deposited during glacial periods?**

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**Supplementary contents:**

* Supplementary Text (lithofacies description): **TEXT S-1**
* Supplementary Tables: **Table S1 to S3**
* Supplementary Data (EarthChem file): **DATA S-1**
* Supplementary Figures: **Figure S1 to S11**

**Supplementary figure and table captions**

**Fig. S1** Generalized stratigraphy of the Kurkur–Dungul area (based on Issawi 1968).

**Fig. S2** Satellite map of the studied area showing the position of the sampled locations.

**Fig. S3** Position of the sampled tufa deposits with the indication of the sampling points.

**Fig. S4** Field photographs showing the macromorphology of the studied deposits at Kurkur Oasis. a) densely-packed Intraclastic rudstone (FA5) consists of rounded to sub-rounded, fine to coarse-grained pisoids (0.5 to 3 mm in diameter) showing normal grading (coarsening upwards) and imbricated-structure at top part, forming sheets to channelized bodies, Kurkur Oasis, site 1; b) FA5 rudstone displaying cross-bedding to normal grading, Kurkur Oasis, site 1; c) FA1 peloidal tufa including brecciated lithic fragments of the older bedrock, Kurkur Oasis, site 2; d) vertically-aligned plant casts of rush and reed stalks in growth position (FA4), Kurkur Oasis, site 3; e) porous FA5/FA4 accumulation consisting of phytoclastic (horizontally-aligned) and phytohermal (vertically-aligned) casts, Kurkur Oasis, site 3; f) example of FA4 phytohermal tufa from Kurkur Oasis, site 3; g) example of FA4 phytohermal tufa from Kurkur Oasis, site 4; h – j) highly porous FA4 tufa with plant stems and tree trunks preserved as empty moulds, Kurkur Oasis, site 5; k) concentric spherical-shaped FA2, Kurkur Oasis, site 5; l) small-scale concentric spheroidal-shaped crystalline boundstone FA2, Kurkur Oasis, site 5.

**Fig. S5** Field photographs showing the macromorphology of the studied deposits at Gebel El–Digm area. a) tufa deposits unconformably overlie the Dakhla Shale, Gebel El–Digm, site 1; b, c) FA4 deposits rich in casts of plant stems and branches, Gebel El–Digm, sites 1 and 2, the pen for scale is 12 cm; d - f) thin laminated FA3 tufa having pillow-like structures and displaying porous inner core in cross section containing rich phytoherms, whereas the cortex is wavy, convolute-laminated (1–2 mm-thick each) showing exfoliated structure, Gebel El–Digm, site 3.

**Fig. S6** Field photographs showing the macromorphology of the studied deposits at Dineigil Oasis. a – c) Coated plants tufa rich in vertical (FA4) and horizontal (FA5) positions casts, molds, fossil leaves, some still preserve its organic composition. It is unconformable deposit on the Kurkur Formation along the slope of the Sinn El–Kaddab Scarp.

**Fig. S7** Field photographs showing the macromorphology of the studied deposits at Dungul Oasis and Gebel Kalabsha. a, b) tufa accumulations covering the thin-bedded limestone of the Garra Formation, Dungul Oasis, sites 1, 2; c - e) phytohermal FA4 deposits, rich in vertical mammillated plant casts and chaotic-order branch’s moulds at top, Dungul Oasis, sites 1, 2; f) thin-bedded tabular FA1 tufa with local FA6 lenses and no plant remains, Dungul Oasis, sites 3, 4; g) hard, blocky massive rocks, grey to yellowish grey, with no plant remains, Dungul Oasis, site 5; h, i) fractures filled with clean crystalline calcite deposits (FA7) at Gebel Kalabsha.

**Fig. S8** Photomicrographs showing the microfacies features of the studied tufa rocks. a) Clotted peloidal mudstone with fenestral and voids; b) Clotted peloidal mudstone; c) Crystalline dendrite boundstone organized in laminae of feather-like calcite crystals; d) wavy Laminated boundstones with alternation with light microsparitic and dark micritic peloidal laminae; e) hemidomic laminated clotted boundstones coating sub-spherical to elliptical cavities (phytoclasts);f) Intraclastic packstone of peloids (some with micritic cortex), pellets and linear fragments cemented with a microsparitc light calcite;g) example of irregular Micritic dendrite formed with peloidal clots and surrounded by microsparitic calcite cements; h) detail of circular-elliptical to linear sections of filaments (black) surrounded by light microsparitic coatings.

**Fig. S9** Correlation between the δ13C and δ18O values at: a) Dineigil Oasis; b) Gebel El-Digm (sites 1–3); c) Dungul Oasis (sites 1–5).

**Fig. S10** Areal distribution of 13Ctufa, 18Otufa, T47 and calculated 18Owater values from this study and 13Ctufa, 18Otufa from literature**:** Dakhla Oasis (Kieniewicz and Smith 2009; Jimenez 2014), Kharga Oasis, Refuf Pass and Wadi Midauwara (Smith *et al.* 2004a; Jimenez 2014), Farafra Oasis (Wanas 2012), Petrified Forest, New Cairo, Egypt (Hassan 2015), Crystal Mountain (Jimenez 2014). The dashed square is our study area. The 13Ctufa, 18Otufa values are average values from the sites.

**Fig. S11** Correlation between the U/Th age data and elevation of the studied tufa samples.

**Table S1** Description of the locations and coordinates, elevation and thickness of the deposits.

**Table S2** Summary of the identified lithofacies and their related depositional environments.

**Table S3** Stable carbon and oxygen isotopic composition of all analysed tufa and calcite samples and their microfacies types. The 230Th ages of the dated tufa samples are indicated for comparison.

**Supplementary References**

Alçiçek, M.C., Alçiçek, H., Altunel, E., Arenas, C., Bons, P., Brogi, A., Capezzuoli, E., de Riese, T., Della Porta, G., Gandin, A., Guo, L., Jones, B., Karabacak, V., Kershaw, S., Liotta, D., Mindszenty, A., Pedley, M., Ronchi, P., Swennen, R., Temiz, U. 2017. Comment on “First records of syn-diagenetic non-tectonic folding in Quaternary thermogene travertines caused by hydrothermal incremental veining” by Billi et al. Tectonophysics 700–701 (2017) 60–79. *Tectonophysics,* **721**, 491–500

Arenas-Abad, C., Vázquez-Urbez, M., Pardo-Tirapu, G., Sancho-Marcén, C. 2010. Fluvial and associated carbonate deposits. In: Alonso-Zarza, A., Tanner, L.H. (Eds.) Carbonates in continental settings: processes, facies and application. *Dev. Sedimentol*., **61**, 133–175

Bastianini, L., Rogerson, M., Mercedes-Martin, R., Prior, T.J., Cesar, E.A., Mayes, W.M. 2019. What Causes Carbonates to Form “Shrubby” Morphologies? An Anthropocene Limestone Case Study. *Front. Earth Sci.*, **7:236**, doi:10.3389/feart.2019.00236

Capezzuoli, E., Gandin, A., Pedley, M. 2014. Decoding tufa and travertine (fresh water carbonates) in the sedimentary record: the state of the art. *Sedimentology,* **61**, 1–21

Chafetz, H.S., Folk, R.L. 1984. Travertines – depositional morphology and the bacterially constructed constituents. *J. Sed. Petrol.,* **54**, 289–316

Chafetz, H.S., Guidry, S.A. 1999. Bacterial shrubs, crystal shrubs, and ray-crystal shrubs: bacterial vs. abiotic precipitation. *Sed. Geol.,* **126**, 57–74

Della Porta, G. 2015. Carbonate build-ups in lacustrine, hydrothermal and fluvial settings: comparing depositional geometry, fabric types and geochemical signature. In: Bosence, D.W.J., Gibbons, K.A., Le Heron, D.P., Morgan, W.A., Pritchard, T., Vining, B.A. (Eds.), Microbial Carbonates in Space and Time: Implications for Global Exploration and Production, vol. 418. Geological *Society, London, Special Publications* 17–68

Dupraz, C., Reid, R.P., Braissant, O., Decho, A.W., Norman, R.S., Visscher, P.T. 2009. Processes of carbonate precipitation in modern microbial mats. *Earth-Science Reviews,* **96** (3), 141–162

Erthal, M.M., Capezzuoli, E., Mancini, A., Claes, H., Soete, J., Swennen, R. 2017. Shrub morpho-types as indicator for the water flow energy - Tivoli travertine case (Central Italy). *Sedimentary Geology,* **347**, 79–99

Ford, T.D., Pedley, H.M. 1996. A review of tufa and travertine deposits of the world. *Earth Sci. Rev*., **41**, 117–175

Gandin, A., Capezzuoli, E. 2014. Travertine: Distinctive depositional fabrics of carbonates from thermal spring systems. *Sedimentology,* **61**, 264–290

Gradziñski, M. 2010. Factors controlling growth of modern tufa: results of a field experiment. In: Tufas, Speleothems and Stromatolites: Unravelling the Physical and Microbial Controls (Eds M. Pedley and M. Rogerson), *Geol. Soc. London Spec. Publ*., **336**, 143–191

Gradziñski, M., Wroblewski, W., Dulinski, M., Hercman, H. 2014. Earthquake-affected development of a travertine ridge. *Sedimentology,* **61**, 238–263

Guo, L., Riding, R. 1992. Aragonite laminae in hot water travertine crusts, Rapolano Terme, Italy. *Sedimentology,* **39**, 1067–1079

Guo, L., Riding, R. 1998. Hot-spring travertine facies and sequences, Late Pleistocene, Rapolano Terme, Italy. *Sedimentology,* **45**, 163–180

Hassan, K.M. 2015. Stable isotopic signatures of the modern land snail *Eremina desertorum* from a low-latitude (hot) dry desert – A study from the Petrified Forest, New Cairo, Egypt. *Chemie der Erde,* **75**, 65–72

Issawi, B. 1968. The geology of Kurkur Dungul area. General Egyptian organization for geological research and mining. *Geol. Surv. Pap.,* **46**, 1–102

Jimenez, G. 2014. Travertine from Egypt’s Western Desert: a Terrestrial Record of North African Paleohydrology and Paleoclimate during the Late Pleistocene (Master’s thesis) University of New Mexico, 95 p.

Jones, B., Renaut, R.W. 1995. Non crystallographic calcite dendrites from hot-spring deposits at Lake Bogoria, Kenya*. J. Sediment. Res*., **65**, 154–169

Jones, B., Renaut, R.W. 2010. Calcareous spring deposits in continental settings. In: *Developments in Sedimentology: Carbonates in Continental Settings: Facies, Environments and Processes* (Eds A.M. Alonso-Zarza and L.H. Tanner), 177–224. Elsevier, Amsterdam

Jones, B., Renaut, R.W., Rosen, M.R. 2000. Trigonal dendritic calcite crystals forming from hot spring waters at Waikite, North Island, New Zealand. *J. Sediment. Res*., **70**, 586–603.

Kieniewicz, J.M., Smith, J.R. 2009. Paleoenvironmental reconstruction and water balance of a mid-Pleistocene pluvial lake, Dakhleh Oasis, Egypt. *Geol. Soc. of America Bull.,* **121**, 7–8, 1154–1171

Koban, C.G., Schweigert, G. 1993. Microbial Origin of travertine fabrics – two examples from southern Germany (Pleistocene Stuttgart travertines and Miocene Riedoschingen travertine). *Facies,* **29**, 251–264

Love, K.M., Chafetz, H.S. 1988. Diagenesis of laminated travertine crusts, Arbuckle Mountains, Oklahoma. *Journal of Sedimentary Research,* **58**, 441–445

Merz-Preiß, M., Riding, R. 1999. Cyanobacterial tufa calcification in two freshwater streams: ambient environment, chemical thresholds and biological processes. *Sed. Geol*., **126**, 103–124

Monty, C.L.V. 1976. The origin and development of crypalgal fabric. In: Stromatolites (Ed. by M. R. Walter), Elsevier Amsterdam, *Develop. in Sedimentology,* **20**, 193–249

Nicoll, K., Sallam, E.S. 2017. Paleospring tufa deposition in the Kurkur Oasis region and implications for tributary integration with the River Nile in southern Egypt. *J. of African Earth Sci.,* **136**, 239–251

Ordóñez, S., Garcia del Cura, M.A. 1983. Recent and Tertiary fluvial carbonates in Central Spain. *Spec. Publ. Int. Assoc. Sedimentology,* **6**, 485–497

Pedley, H.M. 1990. Classification and environmental models of cool freshwater tufas. *Sed. Geol.,* **68**, 143–154

Pedley, M. 2009. Tufas and travertines of the Mediterranean region: a testing ground for freshwater carbonate concepts and developments. *Sedimentology,* **56**, 221–246

Pedley, H.M., Rogerson, M., Middleton, R. 2009. The growth and morphology of freshwater calcite precipitates from in vitro mesocosm flume experiments. *Sedimentology,* **56**, 511–527

Pentecost, A. 2005. Travertine. Springer-Verlag, Berlin/Heidelberg, 445 p.

Pentecost, A., Whitton, B.A. 2000. Limestone. In: Whitton, B. A. & Potts, M. (eds) The ecology of cyanobacteria. Kluwer Academic Publisher, Netherland, 257–279

Rainey, D.K., Jones, B. 2009. Abiotic versus biotic controls on the development of the Fairmont Hot Springs carbonate deposit, British Columbia, Canada. *Sedimentology,* **56**, 1832–1857

Reitner, J., Neuweiler, F., Gautret, P. 1995. Modern and fossil automicrites: implications for mud mound genesis. In: Reitner, J., Neuweiler, F. (Eds.), A Polygenetic Spectrum of Fine-Grained Carbonate Buildups. *Facies,* **32**, 4–17

Shiraishi, F., Reimer, A., Bissett, A., Beer, D. de, Arp, G. 2008. Microbial effects on biofilm calcification, ambient water chemistry and stable isotope records in a highly supersaturated setting (Westerhöfer Bach, Germany). *Palaeogeogr., Palaeoclim., Palaeoecol.,* **262**, 91–106

Smith, J.R., Giegengack, R., Schwarcz, H.P. 2004a Constraints on Pleistocene pluvial climates through stable-isotope analysis of fossil-spring tufas and associated gastropods, Kharga Oasis, Egypt. *Palaeogeogr., Palaeoclim., Palaeoecol.,* **206**, 157–175

Vázquez-Urbez, M., Arenas, C., Pardo, G. 2012. A sedimentary facies model for stepped, fluvial tufa systems in the Iberian Range (Spain): the Quaternary Piedra and Mesa valleys. *Sedimentology,* **59** (2), 502–526

Wanas, H.A. 2012. Pseudospherulitic fibrous calcite from the Quaternary shallow lacustrine carbonates of the Farafra Oasis, Western desert, Egypt: A primary precipitate with possible bacterial influence. *J. of African Earth Sci.,* **65**, 105–114