Tropical Natural History 19(2): 113–116, October 2019

Short Note
Biomediation of Tufa Formation by Silk Capture Nets of Larval Philopotamidae (Insecta: Trichoptera)

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Received: 13 August 2019; Accepted: 24 September 2019

Tufas are unlithified secondary deposits of calcite (crystalline calcium carbonate, $CaCO_3$) formed at ambient temperatures in riverine or lacustrine waters. Tufa frequently supports unique, highly specialised and often endangered communities of organisms[1,2,3,4] and is an important source of palaeo-environmental information[5,6]. Tufa formations are widespread globally but are most frequent about springs and upper water courses in tropical and subtropical karst areas where carbonates produced by solution weathering are reworked through the karst and eventually deposited as tufa. Outgassing of CO_2 from supersaturated $CaCO_3$ solution leads to the precipitation of calcite. Although the reaction is ostensibly simple ($Ca^{2+} + 2HCO_3 \rightarrow CaCO_3 + CO_2$), the outcome is complicated by a 3-phase equilibrium between gas (CO_2), solid ($CaCO_3$) and aqueous solutions of Ca^{2+}, HCO_3^- and $CaCO_3$. Calcite precipitation is also influenced by factors such as water flow rate and the air-water interface area[7] and may be mediated by biotic factors that provide nucleation or entrapment sites for calcite[6,8,9].

Pleistocene[5] and Eocene[10,11] fossil tufas have been found that contain abundant examples of structures interpreted as being calcified remnants of silk larval/pupal cases, retreats and capture nets of aquatic Lepidoptera (Pyralidae), Diptera (Chironomidae) and especially Trichoptera. Insect silk structures have likely contributed historically to tufa-building processes by capturing and sequestering particles of calcite. Similar structures and processes are sometimes observed in contemporary tufa environments but are only occasionally conspicuous[12] when the structures are obviously abundant. This report describes a contemporary waterfall tufa site with very extensive development of calcified silk structures produced by larval Trichoptera that are greatly influencing tufa deposition.

Observations were made at Paeng Din waterfall, Nong Hin District, Loei, Thailand in June, 2019. A small stream issues from a spring at 17.0617N, 101.7464E and flows NE for about 500 m with only light tufa deposition before dropping steeply via a succession of waterfalls, pools and terraces with thick tufa deposits into a forested lower valley. Water temperature (24.0–26.7 °C) and pH (8.5) were fairly constant whereas conductivity varied from 320–426 $\mu Si.cm^{-1}$ (measured on 4 occasions during the previous year). Large numbers of elongate calcified closed tubular structures were observed encrusting steeper inclines (70°–90°) in rapid flows over the edges of terraces (Fig. 1A) or waterfalls (Fig. 1B) and were particularly well developed on

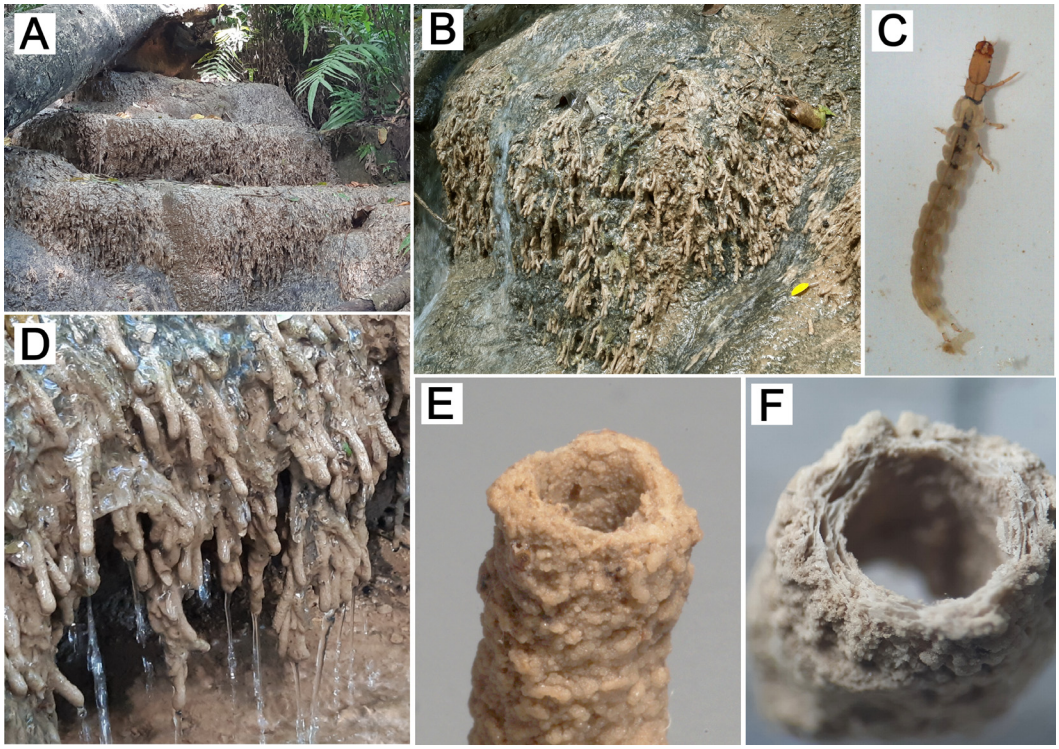

FIGURE 1. Calcite tubes and larval Philopotamidae at Paeng Din waterfall. (A) Tufa terraces with tube accretions on outer walls (B) Tube accretion on a waterfall (C) Philopotamidae larva (D) Tube accretion forming an overhang on a waterfall (E) Tube (broken) showing microcrystalline material of outer wall and lumen (F) Tube (broken) showing membrane layers in outer wall

vertical or overhanging substrate (Fig. 1D). The tubes varied from 1–6 cm in length (mean=3.7±0.3, n=25) and were approximately 6 mm in diameter with a central lumen 3–4 mm in diameter (Fig. 1E). The external wall was about 1 mm thick with an outer surface of fine crystalline or granular material and several inner membranous layers (Fig. 1F) apparently coated with mostly finer material. When tubes were carefully removed from the substrate using a steel ruler numerous small Trichoptera larvae (Fig. 1C) were found although it was not clear if the larvae were within or beneath the tubes. The larvae were identified as belonging to the family Philopotamidae, so-called finger-net caddisflies that spin mesh nets of silk to catch small particles of food that becomes trapped in their nets.

Dropwise addition of 1M HCl to the tubes resulted in intense evolution of a gas (assumed to be CO_2) with most of the bulk material dissolving and leaving only a small amount of sticky deposit in which were very few particulates. It was concluded that the bulk material was probably almost entirely composed of calcite. The sticky deposit was most likely silk as the capture nets of larval Philopotamidae are constructed from several layers of very fine mesh silk[13] that would

have resisted digestion with dilute HCL. It is probably these silk layers that form the membranes visible in Fig. 1F. Calcite entrapment has been reported in silk structures produced, for example, by larvae of Diptera (Simuliidae)[9] and Trichoptera[14] (especially Hydropsychidae) but the overlapping silk membranes of Philopotamidae nets have the smallest mesh opening reported for Trichoptera with effective mesh-size as low as 0.4x0.4 μm[13] and are probably very efficient at trapping and binding microcrystalline calcite. Further deposition of calcite leads to the dense accretions of tubes reported here and appears to contribute to the rounded profile and overhang seen on the walls of tufa terraces (Figs. 1A, 1B, 1C). There can be little doubt that philopotamid capture nets make a significant contribution to tufa formation at this site and provide a striking demonstration of biomediated sedimentation of calcite deposits.

Paeng Din waterfall is a tourist attraction and the delicate tubular structures are almost entirely absent from areas of the site that receive most pressure from visitors who bath in the waters and walk on the tufa barriers and cones (tubes survive only where protected by being on the undersides of small overhangs). Visitor activity not only destroys philopotamid calcite tubes but also severely damages the friable unlithified older deposits of tufa and the tufa biota associated with it. Paeng Din is not unique as many tufa waterfalls in Thailand are subject to massive tourist pressure with unrelenting damage to their geology and to the unique communities inhabiting them. Their biological importance, geological interest and conservation value remain unrecognized.

ACKNOWLEDGEMENTS

I would like to thank Ana Previšić, Pongsak Laudee, Marija Ivković and Simon Vitecek for specimen identification and useful discussion. Thailand Research Fund (DBG6180024) is gratefully acknowledged for supporting the fieldwork that made these incidental observations possible.

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