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Tufa in Northern England: depositional facies, carbonate mineral fabrics, and role of biomineralization

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Tufas are widely scattered in northern England, being concentrated in areas of limestone (Carboniferous and Permian), where there are springs, seepages, streams and waterfalls with waters supersatured in respect of calcite. Some deposits are clearly related to faults.
Tufas have been examined in Gordale and Malham (SW Yorkshire), Teesdale and Weardale (Co. Durham), Sunderland (Tyne & Wear) and Great Asby Fell (Cumbria). A variety of tufa types are developed: spring-related pisoids and moss tufa, fluviatile barrage and waterfall tufa, and seepage and spring tufa with microbial oncoids in a paludal setting.
We present preliminary data and observations on tufa in the Teesdale area, which forms along the valley-side adjacent to the River Tees. Locally here, a tiny stream draining agricultural land runs over a sandstone outcrop at the top of a 30 metre high slope; water descends the 30-60 degrees slope, creating tiny waterfalls and pools across an area reaching 10 metres wide, on the way down towards the river. Three main facies are recognizable in the tufa deposits: carbonate crusts, moss tufa and pisoids.
In the upper part of the slope tufa occurs as sub-vertical 0.5-5 cm thick carbonate crusts forming “sheets” with a bulbous external surface covered by a green biofilm, with some insect larvae. Encrustations form upon surfaces of rock exposures and pebbles, and coat plant fragments (leaves, twigs, pine cones).
Tufa precipitation, particularly on mosses, liverworts and leaves (moss tufa), creates a series of rimmed pools, a few decimetres across and centimetres deep. Apart from the presence of moss, which gives the tufa has a vacuolar texture, the main constituents are cyanobacteria and diatoms. The moss tufa deposit may reach a metre or more in height and several metres in width, notably towards the base of the slope, adjacent to the river.
Within the small pools on the slope, pisoids and partially calcified plant remains accumulate. They also occur abundantly in the soil hereabouts, and are gradually being washed down slope. Pisoids vary in size and shape, ranging from rods to sub-spherical forms, up to several cm long or a cm or more in diameter. The external surface is a smooth dull surface of a pale grey-buff colour; the nucleus may be a plant fragment, tufa intraclast or rock fragment.
Microfacies
Teesdale tufa is characterized by three microfacies all contributing to a basic stromatolitic or laminated micro-fabric: dendrolite, dense micrite and palisades of sparite. Laminae consist of an irregular alternation of the three microfacies, which vary in abundance within the main depositional facies.
Dendrolitic layers are characterized of mineralized, upward-branching cyanobacterial filaments, forming bush-like fans. Coarse sparitic layers consist of palisades of bladed calcite spar characterized by rhombohedral terminations. Micritic layers consist of dark-brown dense laminae with some clotted fabric, composed of dark micritic crystals.
In thin-section molds of moss stems are often preserved by a sparitic layer that formed a coating before decay of the moss organic tissues. Cavities are abundant in moss tufa and crusts. They are often empty or in some case filled by detrital particles.
Pisoids under the microscope show a cortex characterized by a concentric structure consisting mainly dense micritic layers alternating with sporadic sparitic and/or dendrolitic layers.
Calcified cyanobacterial filaments or their molds are very evident in the dendrolitic laminae, but also occur in the other microfacies, being incorporated in both the sparite macro-crystals and the micritic layers.
Nanofacies of minerals
The mineral composition of the autochthonous carbonate forming tufa is calcite with a few mole% Mg. Sub-hedral

crystals of calcite, several tens of microns in size, form sparite crystals. Sub-polygonal micro-crystals and elongate fibres a few microns in size compose dense micrite and calcified filaments.
Under extra-high SEM magnifications, all crystal forms seem be made of sub-spherical to rod-like nano-crystals, ranging in size from 100 to 300 nm. Other than cyanobacteria, calcified organic components like diatoms, plant tissues, and extra-cellular polymeric substances (EPS) are mineralized with the same crystal nano-elements.
Conclusions
Tufa formation seems strongly influenced by the inclination of the slope, water energy, the biota, including the biofilm, and the organic matter substrate (mainly EPS); super-saturation of water with respect to calcite is a pre-requisite for precipitation. The inclination of the slope determines the water energy and so the degassing of CO2 which leads to precipitation of carbonate. Photosynthesis by macrophytes, microphytes and cyanobacteria could also contribute to CO2 degassing. EPS degradation processes, particularly those involving heterotrophic micro-organisms which can induce an increase in alkalinity, could be a further mechanism of biomineralization in these tufa carbonates.