The role of Fungi in the precipitation of calcite: Relationship between fungal filaments, nanofibres, and needle fibre calcite.

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Abstract

Fungi are known to be involved in biogeochemical cycles in numerous ways. In particular, they are recognized as key players in organic matter recycling, as nutrient suppliers via mineral weathering, as well as large producers of oxalic acid and metal-oxalate. However, little is known about their contribution to the genesis of other types of minerals such as calcium carbonate ($CaCO_3$). Yet, $CaCO_3$ are ubiquitous minerals in many ecosystems and play an essential role in the biogeochemical cycles of both carbon (C) and calcium (Ca). $CaCO_3$ may be physicochemical or biogenic in origin and numerous organisms have been recognized to control or induce calcite biomineralization. While fungi have often been suspected to be involved in this process, only scarce information support this hypothesis.

This Ph.D. thesis aims at investigating this disregarded aspect of fungal impact on biogeochemical cycles by exploring their possible implication in the formation of a particular type of secondary $CaCO_3$ deposit ubiquitously observed in soils and caves from calcareous environments. In caves, these deposits are known as *moonmilk*, whereas in soils, they are known as *Needle Fibre Calcite* (NFC – *sensu lato*). However, they both correspond to the same microscopic assemblage of two distinct and unusual habits of calcite: NFC (*sensu stricto)* and nanofibres. Both features are acicular habits of calcite displaying different dimensions. Whether these habits are physicochemical or biogenic in origin has been under discussion for a long time.

Observations of natural samples using microscopic techniques (electron microscopy and micromorphology) and EDX microanalyses have demonstrated several interesting relationships between NFC, nanofibres, and organic features. First, it has shown that nanofibres can be either organic or mineral in nature. Second, both nanofibres and NFC display strong structural analogies with fungal hyphal features, supporting their fungal origin. Furthermore, laboratory experiments have confirmed the fungal origin of nanofibres through an enzymatic digestion of fungal hyphae. Indeed, structures made of nanofibres with similar features as those observed in natural samples have been produced. Finally, calcium enrichments have been measured in both cell walls and intrahyphal inclusions of hyphae from rhizomorphs sampled in the natural environment. These results point out an involvement of calcium sequestration in nanofibres and/or NFC genesis.

Several aspects need further investigation, in particular the understanding of the physiological processes involved in hyphal calcite nucleation. However, the results obtained during this study have allowed the confirmation of the implication of fungi in the formation of both NFC and nanofibres. These findings are of great importance regarding global biogeochemical cycles as they bring new insights into the coupled C and Ca cycles. Conventionally, fungi are considered to be involved in organic matter mineralization and mineral weathering. In this study, we demonstrate that they must also be considered as major agents in mineral genesis, in particular $CaCO_3$. This is a completely new perspective in geomycology regarding the role of fungi in the short-term (or biological) C cycle. Indeed, the presence of these secondary $CaCO_3$ precipitations represents a bypass in the shortterm carbon cycle, as soil inorganic C is not readily returned to the atmosphere.