Fungi, Metals & Minerals

Pollutant treatment, metal recovery & biodeterioration

Professor Geoffrey Michael Gadd

The most obvious environmental roles of fungi are as decomposers, plant pathogens and symbionts (mycorrhizas, lichens), and in rock and mineral bioweathering, and the maintenance of soil structure due to their filamentous branching growth. They are also familiar as biodeteriorative agents of food and food products, wood, paper and leather, and of the built environment and cultural heritage because of their ability to attack rock and mineral-based substrates, including concrete. Their environmental success is driven by their lifestyle and metabolism.

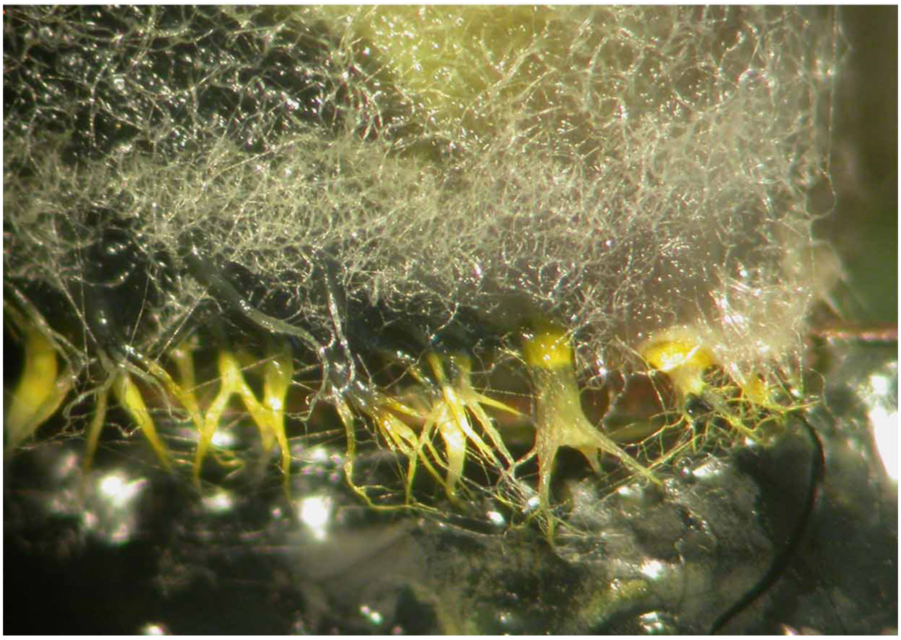

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Figure 1. Colonization and transformation of depleted uranium (DU) by the fungus Hymenoscyphus ericae, a root symbiont of heather. The fungus is forming strands and attacking the DU: the yellow colour indicates the formation and transfer of soluble uranium to the colony. Bar marker = 500 µm.

The filamentous branching growth pattern exhibited by the majority of fungi enables exploration and colonization of the substrate and growth towards new favourable locations. Their organic metabolism, as in their close human relatives, depends on assimilation of carbon sources to make energy and building blocks for growth. It is through these physical and biochemical properties that fungi exert their profound influence on biogeochemical processes in the biosphere, especially when considering soil, rock and mineral surfaces, and the plant root-soil interface. For example, symbiotic mycorrhizal fungi are associated with the roots of ~80% of plant species, are essential for plant health, and are responsible for major mineral transformations and environmental redistributions of inorganic nutrients, e.g. essential metals and phosphate, as well as carbon flow. The ubiquity and significance of lichens, a fungal growth form, as pioneer rock-colonizing organisms in the early stages of mineral soil formation is also well known.

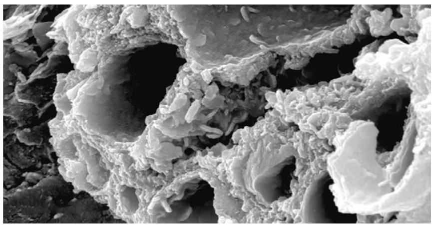

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Figure 2. Uranium phosphate biomineralization formed on the exterior surfaces of cord-like hyphal aggregates of the fungus Beauveria caledonica. Bar marker = 1 µm.

Fungi are dominant members of the soil microbiota and can operate over a wide range of environmental conditions, even in so-called extreme or polluted environments such as those of high acidity or containing organic and metal pollutants. Fungi are also major biodeterioration agents of stone, wood, plaster, cement and other building materials, and important components of rock-inhabiting microbial communities with significant roles in mineral dissolution and mineral formation. This has consequences for the built environment and for cultural heritage, e.g. historic buildings, monuments, statues, gravestones, and frescoes, where effects range from staining and discolouration to pitting, etching, dissolution and spalling (exfoliation) of exterior layers.

What is perhaps not so widely appreciated is that these natural roles of fungi as ecological engineers are also significant for human and ecosystem health in the treatment of pollution from organic and inorganic sources in environmental biotechnology applications such as bioremediation - the application of biological systems to remediate or detoxify environmental pollutants. In addition, fungal properties are receiving growing attention for the biorecovery of useful or valuable elements to aid metal recycling and reclamation, and the development of

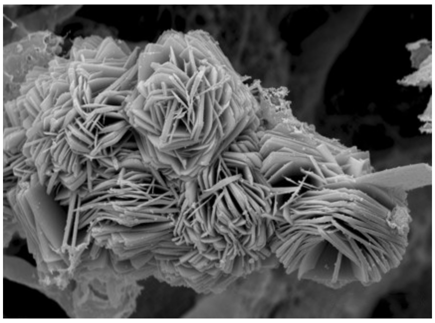

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Figure 3. Uranium phosphate crystals formed on the hyphae of the fungus Aspergillus niger after growth in the presence of soluble uranium and an organic phosphorus source. Bar marker = 500 µm.

new biometal and biomineral products with unusual properties, particularly when formed as nanoparticles.

The ability of fungi to degrade complex natural organic molecules such as lignin, the "woody" component of wood, through excretion of extracellular lignin-degrading enzymes means that they are also capable of degrading a wide variety of potentially toxic xenobiotic molecules that have analogous complex chemical structures. Such xenobiotics can include pesticides, hydrocarbons and even various plastics. Simple soil and composting systems have been successfully developed to treat soil contaminated with substances like pentachlorophenol (PCP) and polynuclear aromatic hydrocarbons (PAHs), the latter being constituents of creosote. Wood-rotting and other fungi have also received attention for the bleaching of dyes and industrial effluents, and the biotreatment of various agricultural wastes such as forestry, pulp and paper by-products, sugar cane bagasse, coffee pulp, sugar beet pulp, apple and tomato pulp, and cyanide.

Metals, unlike organics, cannot be degraded but can be converted by microorganisms to altered chemical states differing in mobility, toxicity and other properties. Fungi transform metals, metalloids and organometallic compounds by a variety of biochemical mechanisms. These have been successfully used worldwide in simple soil biotechnologies, including treatment of selenium-polluted land and drainage water. Biomineralization is the ability of organisms to form minerals and this is receiving growing interest because it can be used for biorecovery of valuable elements in biomineral, elemental, and nanoparticulate forms. The application of microbial systems for metal and metalloid bioprocessing and biorecovery is receiving increasing attention with sustainable environmental concepts becoming new trends in many industries.

Research carried out in the Geomicrobiology Group, University of Dundee explores the mechanisms involved in fungal transformations of metals and minerals, and their importance in the natural and built environment and their potential biotechnological applications in metal bioremediation and/or biorecovery. Fungal biomineralization of metal radionuclides such as cobalt and strontium has been the basis of several studies in the context of radionuclide bioremediation and nuclear decommissioning and has led to development of a biological process for decontamination of concrete surface layers.

With current concern over environmental contamination, and the security and supply of world metal and mineral resources, it can be concluded that fungal capabilities may offer a potentially useful contribution to biotechnological and physico-chemical methods for metal bioremediation and biorecovery.

This article is part of a longer report by Professor Gadd, which will soon be available on our website.

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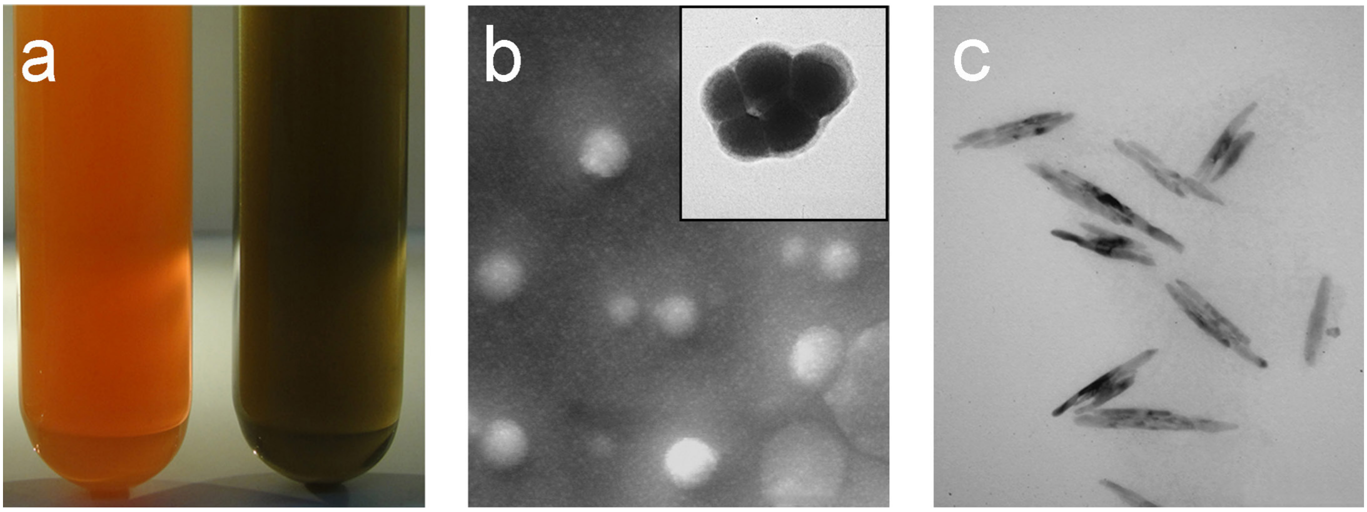

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Fungal production of nanoscale metalloids. (a) suspensions of elemental selenium (red) and elemental tellurium (black) obtained after reduction of sodium selenite or tellurite by biomass-free spent fungal growth medium (b) scanning electron microscopy image of selenium nanoparticles (Bar = 500 nm). The inset is a transmission electron microscopy image of a nanoparticle aggregate (Bar = 200 nm) (c) transmission electron microscopy image of tellurium nanorods (Bar = 400 nm).