Microbially mediated YREE-enriched manganese deposit in the Ytterby mine, Sweden

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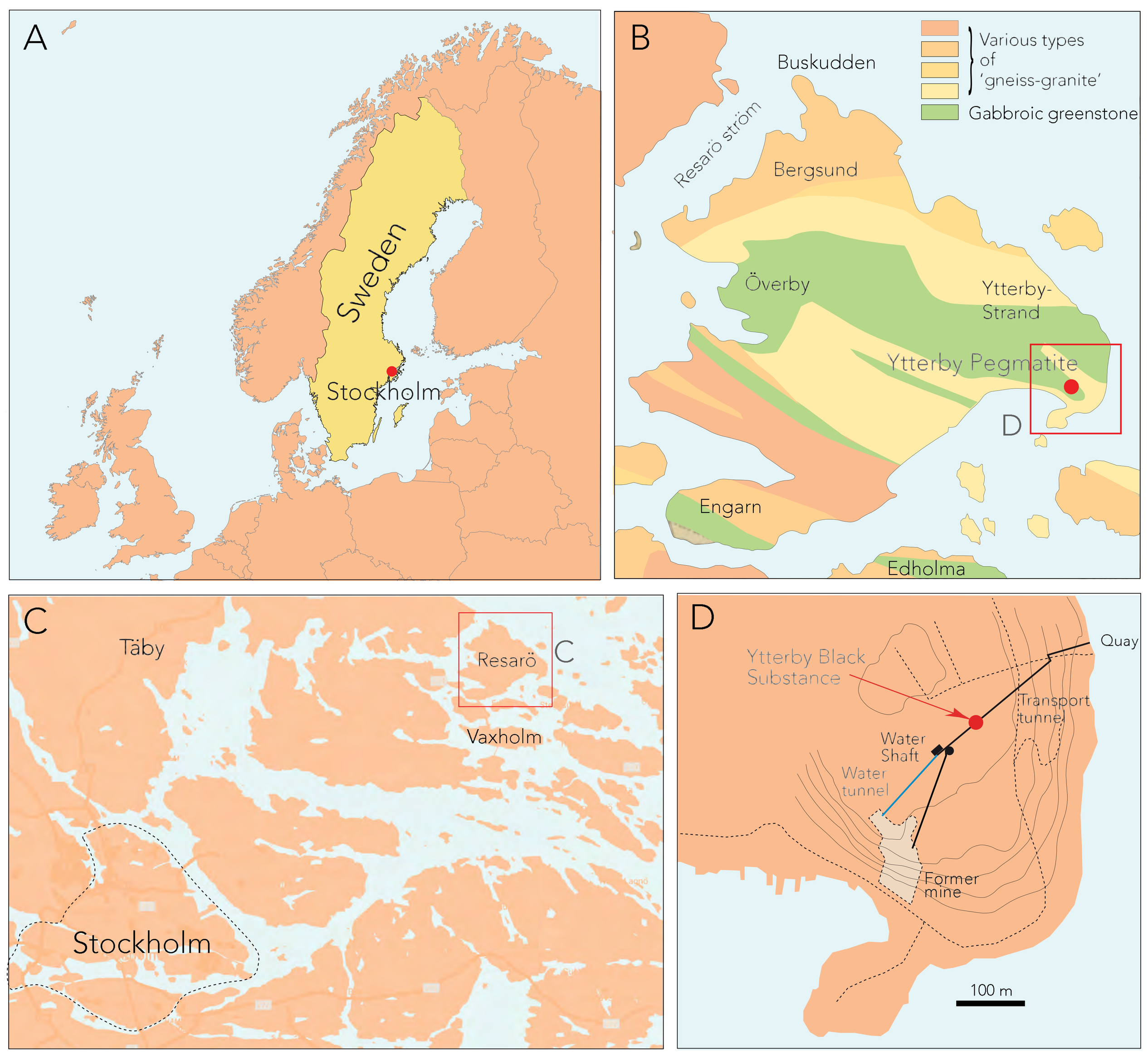
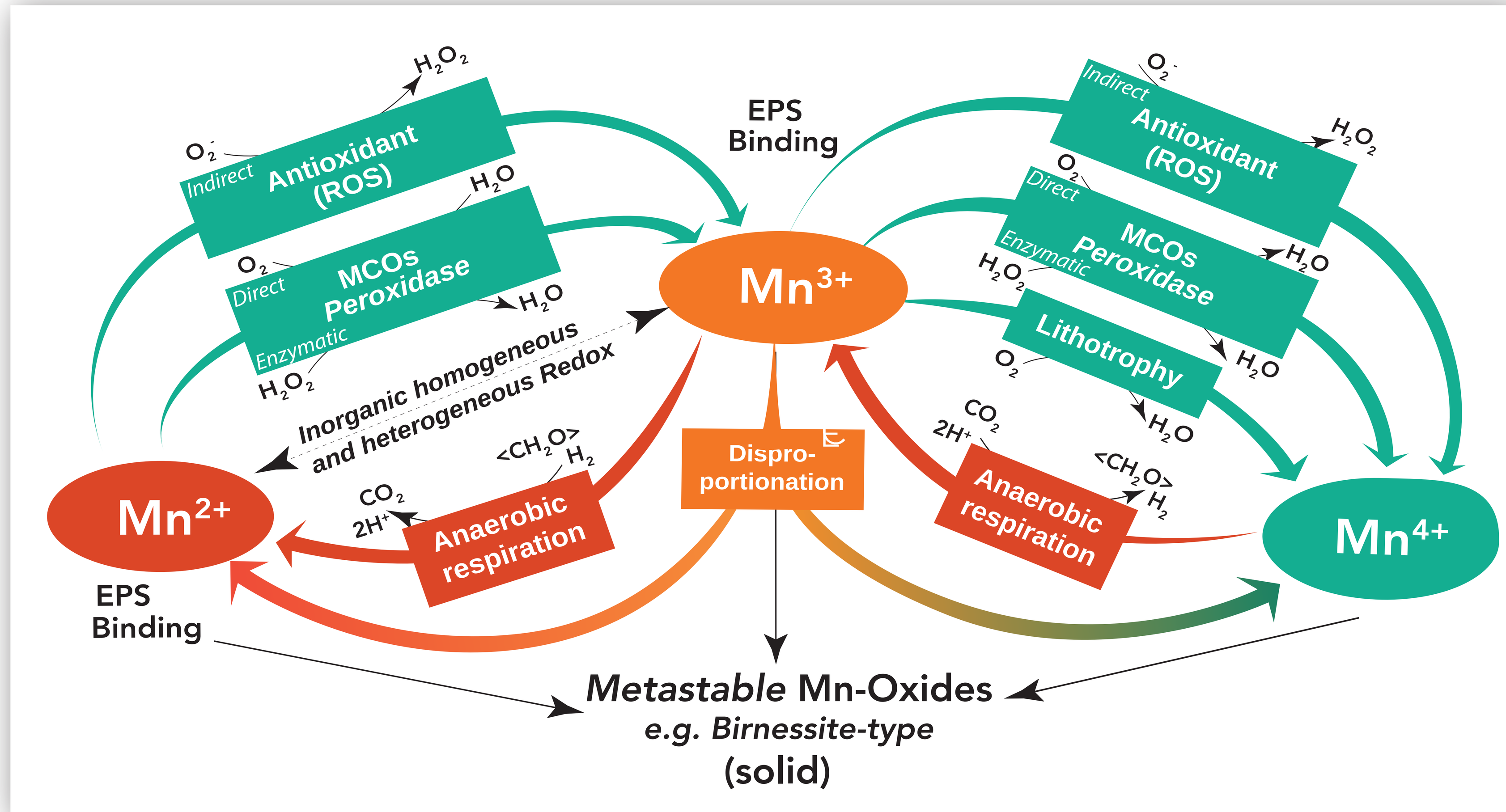
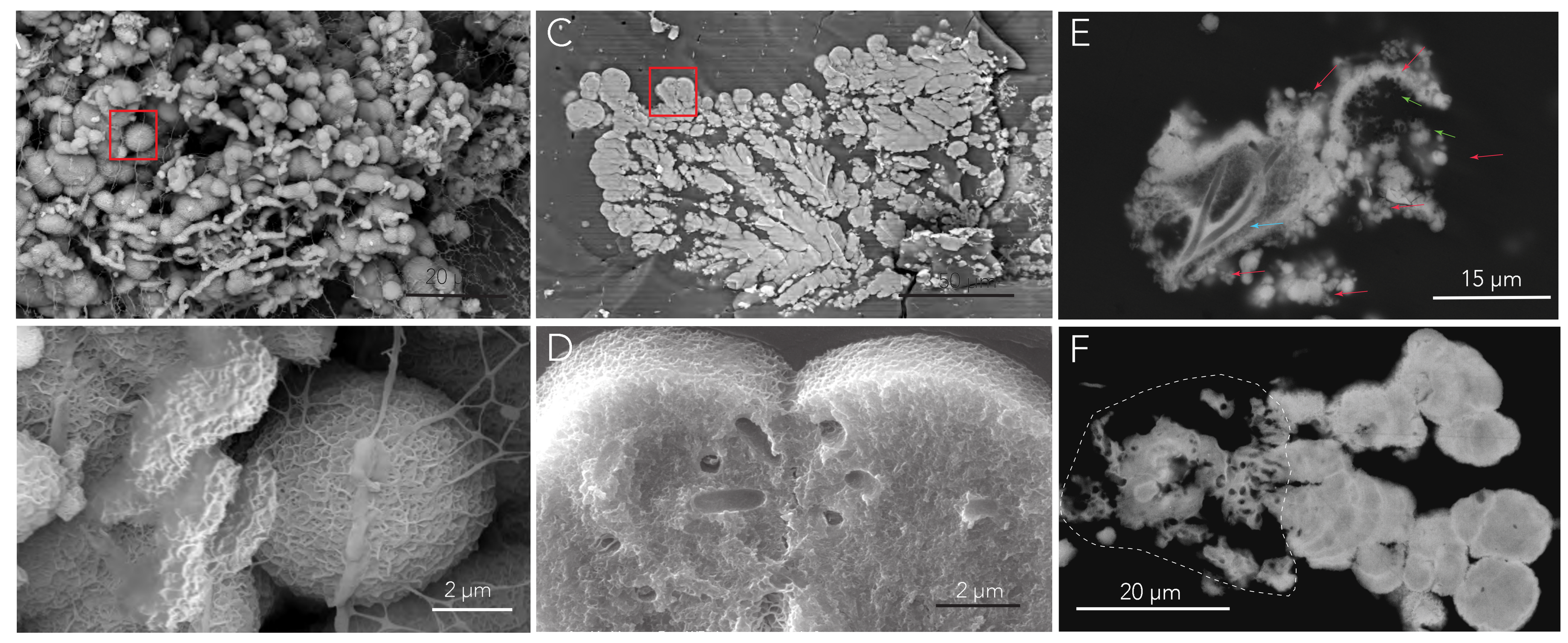
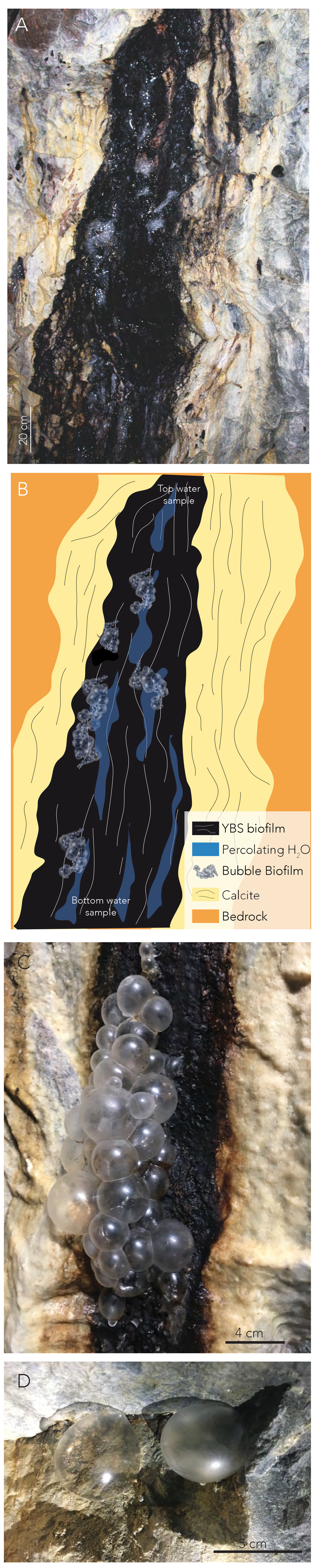


Maps showing the location of the Ytterby mine and the Mn deposit. (C) Map of the Stockholm area with location of Resarö and the Ytterby mine indicated. (D) Map of subterranean tunnels linking the Ytterby mine shaft with a more recently constructed quay to the NE. The Mn oxides (referred to as the Ytterby black substance, YBS) precipitate from water provided by rock fractures that crop out in these tunnels. Modified from Swedish Fortifications Agency (2012).

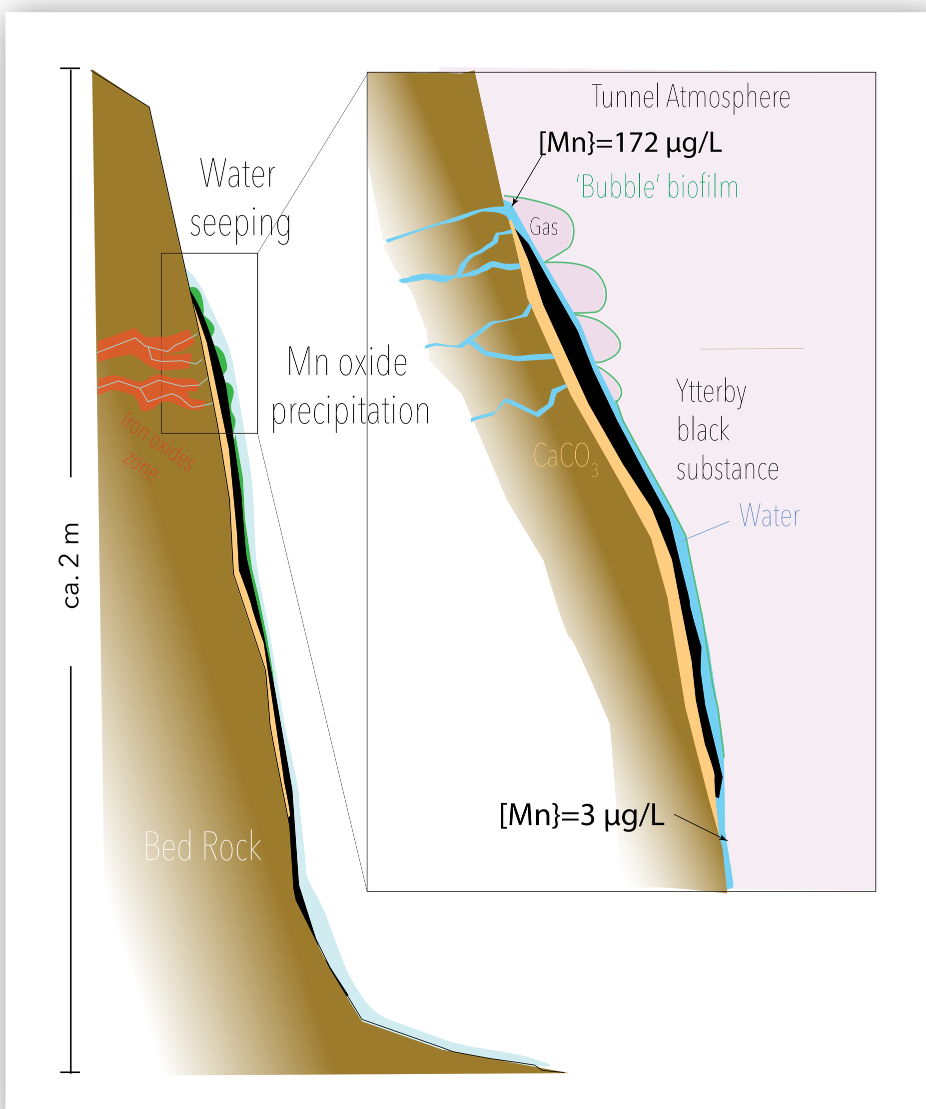


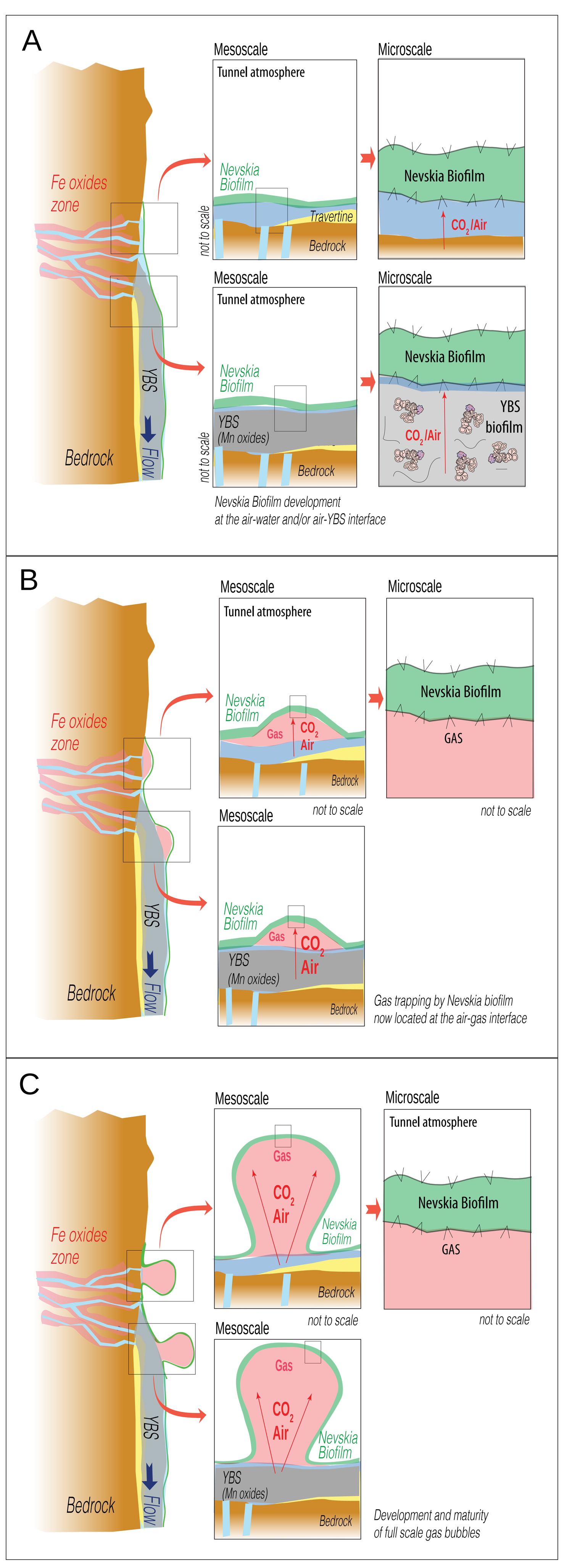


Cryo Scanning Electron Microscope (SEM) images showing microstructures of the Ytterby birnessite-type Mn oxides. (A) Filaments covering microsperolitic/botryoidal Mn oxides. (B) Interwoven nanometre thick sheets forming a reticulate surface texture. (C) Dendritic botryoidal growth pattern. (D) Embedded cell-like structures, (E) Nucleation area showing Mn oxide encrustation of microbial remnants and wad-like Mn oxides. (F) Laminated branches of botryoidal Mn oxides growing on nucleation area (dashed line).

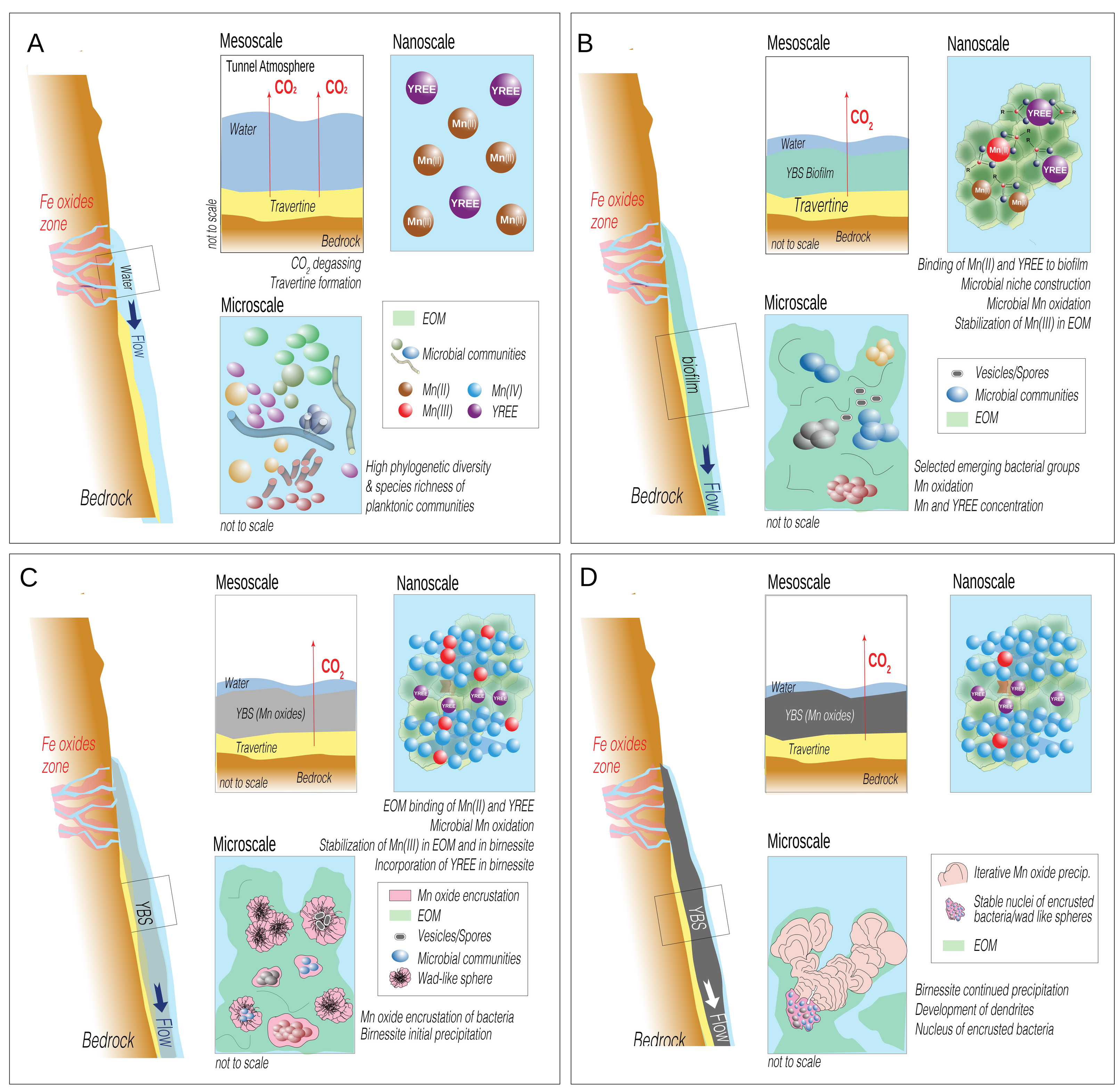


Photograph of the Mn deposit (A) Photograph of the Mn deposit (B) Sketch showing sampling locations, underlying lithified $CaCO_3$ and bubble biofilm. (C) (D) Gas trapped by bubble biofilm





Model for bubble biofilm formation (see text for details).



Model for Ytterby black susbstans (YBS) biofilm formation (see text for details).

Microbially mediated Mn oxides are potentially good candidates for life detection but since production of these minerals involves biogeochemical pathways where abiotic and biotic mechanisms are closely connected, these processes first need to be untangled. The dominant initial Mn phase formed by microbes is a poorly crystalline birnessite-type phyllomanganate. Nano- and microscale structures of these precipitates can potentially be used as biosignatures but that would require profound knowledge of their formation mechanisms. The occurrence of Mn deposits containing this type of mineral is thus of interest for increased understanding of microbial involvement in the Mn cycle. In our research we have access to a subterranean system sustained by epilithic biofilms, which over time have formed rock wall deposits dominated by yttrium and rare earth element enriched birnessite-type Mn oxides. Microbial involvement and the potentially promoting role of biofilms in the formation of these Mn oxides are studied in parallel with analyses of Mn phases produced in vitro by microbes isolated from this system. Microbial niche differentiation of the Mn deposit subsystems (fracture water and biofilms) is investigated to gain insight into differences and potential interplay between the subsystems to understand how they function in aggregate to form the Mn oxides. We find that the microbial communities of the subsystems are phylogenetically significantly different from one another and that the microbial assembly of the feeding water has little impact on the derived biofilms. The signature microbial groups of the Mn oxide producing biofilm (Rhizobiales (e.g., Pedomicrobium), PLTA13 Gammaproteobacteria, Pirellulaceae, Blastocatella and Nitrospira) are not detected in the water feeding the deposit but rather emerge in the biofilm. These bacteria are suited for the extreme nature of the biofilm and seize the opportunity to create their own niche. Two isolated bacterial species (Hydrogenophaga sp., Pedobacter) and one fungus (Cladosporium sp.) are found to mediate Mn oxidation and mineralization of Mn oxides. As far as we know, Pedobacter sp. is previously not known as a Mn oxidizer. Early Mn precipitates are observed at different locations as a function of the mediating species.