

Living in the subsurface: local adaptations that define a global biome

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Microorganisms pervade subsurface environments, creating one of the largest and most diverse biomes on planet Earth. Life penetrates kilometers deep into the heterogeneous crust, anywhere where water is present, where temperature remains sufficiently low, and porosity is sufficiently high to accommodate cells. Metabolic and nutrient resources available to subsurface microorganisms vary considerably by location. Shallow sites and those with significant hydrological recharge maintain geochemical connection to surface biomes, whereas deep and isolated aquifers require residents to survive with local energy sources. Life within these isolated biomes requires novel adaptative strategies for metabolism, genome content (or lack thereof), and growth mode. I will discuss our efforts to understand these strategies in the Deep Mine Microbial Observatory (DeMMO) within the Sanford Underground Research Facility (SURF), South Dakota, USA. This network of flowing boreholes within a former mine, tap fracture fluids up to 1.5 km deep and have been isolated from the surface for 10s to 1000s of years. We find microbial communities that are distinct by site and broadly stable through time. Metabolically, we find widespread capabilities for mineral-fueled metabolisms from genomics and *in situ* colonization experiments, in accordance with our thermodynamic predictions of energy yield. Genomic content here appears bimodal: apparently to either streamline size or maximize opportunity. Combined with long-term sequence-based monitoring of microbial ecology, we can evaluate population level variability in the context of genomic traits. Further, our ongoing approaches to assess microbial activity using imaging and dual DNA/RNA amplicon sequencing reveal widespread ultralow activity cells with relatively few, but specific, more active cells and taxa. These results may be characteristic of life in isolated, oligotrophic environments and have implications for habitability more broadly. Taken together, these findings point to microbial populations uniquely adapted to the environmental extremes presented by the deep subsurface. I will contrast these results to those found in shallow oligotrophic environments with higher surface connectivity such as caves, and a broader array of global subsurface locales. By taking a holistic view of subsurface geochemistry and geomicrobiology, we are illuminating life strategies that may be representative of subsurface populations on our planet and potentially others.