Geochemistry and microbiology of geothermal aerosols in Iceland: implications for biosignatures in the plumes of Enceladus

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The plumes of Enceladus offer a unique opportunity to determine if life currently exists within the moon's likely habitable subsurface ocean. Cassini's encounters with the plumes have implied that plume micron-sized ice grains originate as aerosolised ocean fluid, produced by vigorous bubbling of hydrothermal gases at the liquid-vapor interface. We investigated the chemistry and microbial content of aerosol plumes originating from actively bubbling and geysering geothermal springs in Iceland, to better understand the potential for biosignature entrainment in the plumes of Enceladus. Geothermal springs provide excellent natural laboratories for studying plume aerosols, with bubbling of hydrothermal gases, anoxic fluids with chemistries relevant to Enceladus, and microbial communities adapted to these chemical conditions. In contrast to plume aerosols at Enceladus, geothermal aerosols on Earth emerge from accessible fluid reservoirs, offering the opportunity to fully interpret biosignatures in the context of known biological activity that produced them.

We collected samples of spring waters and aerosols across the Geysir and Ölkelduháls geothermal fields in southern Iceland. These locations were selected to encompass contrasting aerosolisation regimes: periodically erupting geyser plumes (Strokkur) vs. constantly bubbling springs (Ölkelduháls). Our data show that geothermal springs can be prolific local sources of aerosols in the 1-10 µm range, with aerosol fluxes tightly controlled by gas dynamics. Geochemical analyses reveal that spring aerosols are preferentially depleted in silicon and sulfur relative to source fluids. Microbial abundances within aerosols in the immediate vicinity of springs were elevated 2-3 orders of magnitude above background, indicating that microbial biomass can be ejected by bubbling of hydrothermal gases. However, aerosol size distributions at Ölkelduháls were influenced by distance from the spring, with the largest measured droplets (≤ 10.0 µm diameter) decreasing to background levels within 10 m. If biomass tends to associate with the largest droplets, it may quickly fall out and therefore not be dispersed. Because the Enceladus plumes are stratified by size, understanding size-dependent variations in aerosol biomass content will lead to better predictions of possible biosignature content of ice-grains ejected to the altitude of spacecraft fly-throughs. Our findings will enable new perspectives on Cassini plume fly-through data and can be leveraged to predict plume behaviour and composition at other planetary bodies with possible plumes, such as Europa.