MICROBIAL ALTERATION OF VOLCANIC GLASS IN MODERN AND ANCIENT OCEANIC CRUST AS A PROXY FOR STUDIES OF EXTRATERRESTRIAL MATERIAL. N. R. Banerjee1&2, H. Furnes1, K. Muehlenbachs3, and H. Staudigel1, 1Dept. of Earth Science, Univ. of Bergen, Allegt. 41, 5007, Bergen, Norway (banerjee@ualberta.ca), 2Dept. of Earth and Atmospheric Sciences, Univ. of Alberta, Edmonton, Alberta, T6G 2E3, Canada, 3Scripps Institution of Oceanography, Univ. of California, La Jolla, CA, 92093-0225, USA.

Introduction: Over the past decade, studies of volcanic glass preserved in pillow basalts and volcanoclastic tuffs from the oceanic crust have demonstrated the importance of endolithic microbes in the alteration process [1-8]. Microbial alteration features are ubiquitous within the oceanic crust, having been discovered in basalts of all ages, wherever fresh glass is preserved. More recent work in ophiolites (fragments of ancient oceanic crust now exposed on land) has extended the evidence for microbial alteration of oceanic basalts back through the Phanerozoic, beyond the record preserved in the modern oceans [9, 10]. Here we review the evidence for microbial alteration of basaltic glass from modern oceanic crust and Phanerozoic ophiolites and present new data for two Precambrian ophiolites that extend the evidence for microbial alteration of oceanic basalts as far back as the Archean. We describe the use of petrological, geochemical, and microbiological methods for the detection of microbial activity and show how this novel combination of methods can be used to convincingly demonstrate its presence. We further suggest that these techniques could be used to prospect for evidence of past life on Mars.

Modern Oceanic Crust: Petrographic analysis of basaltic glass preserved as pillow rims or within volcanoclastic rocks invariably reveals the presence of microbial alteration textures produced by etching of the glass during microbial colonization. Two textural types of microbial alteration are commonly observed, namely tubular and granular varieties. Tubular textures are the most visually striking and are characterized by micron-scale, tubular to vermicular, channel-like features and branching bodies. These channels are commonly highly convoluted, ramose, and/or twisted. Granular textures appear as solid bands, semicircles or irregular patches of individual and/or coalesced spherical bodies with irregular protrusions into fresh glass. Both textures are observed to extend away from fractures and glass shard boundaries, along which liquid water was once present, into unaltered glass.

Detailed SEM imaging of the microbial alteration textures in thin sections and on grain mounts of freshly exposed surfaces reveal the presence of delicate filament-like structures and material resembling desiccated biofilm. The filaments are commonly observed to be attached to channel walls and display complex morphologies including hollow, filled, and segmented varieties. The filaments are primarily composed of clay minerals similar in composition to palagonite formed during abiogenic alteration of basaltic glass. However, these morphologies do not resemble diagenetic clay minerals or inorganic dissolution features but are suggestive of a biogenic origin.

X-ray element maps collected by electron microprobe show elevated levels of C, N, P, and K associated with the microbial alteration features. These enrichments are highly restricted to the immediate area of microbial attack and quickly diminish away from these areas. The intensity of these signals varies between samples but is present in all cases where microbial alteration textures exist.

Disseminated carbonate in pillow-rim basalt glasses from in situ ocean crust show differences in C isotope ratios from those of the adjacent crystalline cores that likely relate to microbial activity during alteration. Bulk-rock carbon isotope ratios of carbonates in samples of microbially altered volcanic glass are commonly variably depleted by as much as −20‰ [6]. Conversely, crystalline basalt commonly has values bracketed between normal marine carbonate (0‰) and mantle values (−5‰ to −7‰). The generally low δ13C values of carbonates in microbially altered basaltic glass are attributed to metabolic by-products of Bacteria oxidizing dissolved organic matter from pore waters. A few positive δ13C values have been observed in glass samples from slow-spreading ridges where ultramafic rocks are commonly exposed on the seafloor and serpentinization is a dominant process leading to the production of H2. These δ13C enriched carbonates may result from lithotrophic Archaea producing CH4 from H2 and CO2 [6].

We have also treated samples with various nucleic acid stains that specifically bind to DNA and RNA. Our technique combines commonly accepted nucleic acid staining techniques with laser scanning confocal microscopy. The presence of DNA/RNA associated with areas of suspected microbial alteration has been confirmed and suggests the biogenic features may be relatively recent and that the microbes may be currently active in modern oceanic samples.

Phanerozoic Ophiolites: Ophiolites provide an opportunity to prospect for evidence of microbial al-
teration in oceanic basalts of much greater age than found in the modern oceans. One exceptional case is the pillow lavas of the well-preserved Cretaceous Troodos ophiolite in Cyprus. Relic glass is still preserved in the volcanic sequence of the Troodos ophiolite and microbial alteration textures exactly the same as those found in modern oceanic basalts are observed [9]. Since volcanic glass is scarce throughout the rock record, evidence for bioalteration in older ophiolites, such as the Ordovician Solund-Stavfjord ophiolite, is more commonly observed as geochemical fingerprints left behind by microbial activity in the form of elevated levels of the typical biologically important elements C, N, S, P and K. In addition, filaments and biofilms produced by microbes may be fossilized and are identified by their typical morphology. However, perhaps the most robust biomarker appears to be the very light carbon isotope ratios of disseminated carbonate within glassy pillow basalt rims. Analysis of pairs of glassy rims and adjacent crystalline cores consistently produces the familiar bimodal distribution observed in modern samples in which the depleted δ13C values are interpreted as resulting from microbial fractionation.

Precambrian Ophiolites: We have recently searched for biosignatures in the relic glassy rims of pillow lavas from two Precambrian ophiolites: the Middle Proterozoic (1.95 Ga) Jormua ophiolite (Finland), and the Mesoarchean (3.5 Ga) Jamestown ophiolite (South Africa). Both of these ophiolites contain well-preserved pillow structures with easily identifiable chilled selvages that unequivocally demonstrate eruption under water. The Jormua pillow lavas are predominantly basalts that have been metamorphosed to lower amphibolite facies and show the development of a well-defined foliation. The Jamestown ophiolite is dominated by basaltic to ultramafic pillow lavas that are exceptionally well preserved, metamorphosed to zeolite through greenschist facies, and in places virtually undeformed. These characteristics make these ophiolites excellent places to look for evidence of microbial activity in ancient oceanic rocks.

As predicted from our earlier work, the δ13C values of disseminated carbonate in previously glassy pillow lava rims from both the Jormua and Jamestown ophiolites are shifted to lower values (as low as −17‰) when compared to the adjacent crystalline pillow cores. An unexpected finding is the discovery of textural features that strongly resemble fossilised channels, filaments, or biofilm in the undeformed pillow lavas of the Jamestown ophiolite. These textures emanate from healed fractures and have the same size, shape, and distribution as features attributed to microbial activity in modern oceanic samples. Element mapping of these features reveals the presence of organic C along their margins, further supporting a biogenic origin.

Textural relationships and radiogenic dating of metamorphic minerals indicate metamorphism proceeded soon after eruption of the lavas and was likely related to seafloor hydrothermal alteration. We suggest microbial alteration proceeded immediately after pillow formation, in a similar fashion to what invariably can be observed in pillow lavas of modern ocean crust. We regard these features as evidence of biological activity in the Precambrian seas, and that interaction between volcanic glass and microbes was a process already established by Mesoarchean time.

Application to Extraterrestrial Material: A great deal of interest has been focused on recent evidence for palagonite as a major component in the Martian regolith and the possibility that liquid water once existed on the surface of Mars. Our work, which extends the evidence for microbial alteration of pillow basalts back to the Archean, has important implications for the exploration for life on Mars and in our solar system because it shows that robust biosignatures of a presently observable microbial process can be preserved in the geological record. Our techniques could be easily applied to samples returned from Mars and other extraterrestrial bodies where liquid water and conditions suitable for life may have existed. Basalts are commonplace on the surface of Mars and the cratered surface likely hosts countless glassy impact breccias that may have interacted with water in the past. Since basalts are likely to be returned by any extraterrestrial sample return mission they should be assessed for their potential in recording and preserving traces of life.


Acknowledgements: This study was supported by grants from the Norwegian Research Council and the National Sciences and Engineering Research Council of Canada.