Rebecca DZOMBAK Report rcvd. 9.6.18
APS Lewis & Clark Astrobiology grant
Project: Iceland as an analogue for unvegetated Precambrian soils during oxygenation of the atmosphere

*Note: This progress report was delayed because the previous summer/fall's weather in Iceland would not allow for fieldwork during times when I was available. Fieldwork was carried out 31 July – 08 August 2018.*

## PROJECT REPORT

*Abstract.* The co-evolution of life and the atmosphere during the Precambrian was the most significant upheaval in Earth's history, and yet it remains poorly understood. Paleosols (fossilized soils) are one of our most valuable records for these changes; as soils form relatively quickly on Earth's surface and are essentially in constant contact with the atmosphere, they can offer a more direct record of redox conditions than deep marine rocks. However, in order to interpret these paleosol records, we must strive to understand the biosphere at the time of their formation, and how nutrients may have been cycled. Precambrian paleosols are typically basalt-parented and formed long before the evolution of land plants. Iceland, with its volcanic-dominated landscapes largely devoid of vegetation, can serve as an ideal analogue for Precambrian terrestrial environments. Modern soils (both unvegetated and populated by mosses), soil crusts, and basalts were sampled to explore nutrient availability and weathering patterns in this unique environment. These samples (n = 100) will serve as both Precambrian and early terrestrial ecosystem analogues, allowing us to explore biosignatures left by microbial mats and early terrestrial plants (mosses), typical weathering patterns for unvegetated basalt, and nutrient cycling (Fe, P, C).

*Introduction.* Although the rise of oxygen ca. 2.4 billion years ago is one of the most pivotal events in Earth's history, constraints on its timing and correlation with the evolution of photosynthesis remain ambiguous. While both paleosols and marine records contribute to our understanding of this event, paleosols can directly reflect atmospheric oxygenation via an onset of oxidative weathering, whereas shales reflect changes in the ocean's oxidation state. Understanding the geochemistry of these paleosols depends in part on understanding how nutrients appear and behave in similar, modern soils; hence, the need for analogue landscapes. Additionally, better understanding nutrient cycling and potential bioavailability in analogue soils will aid in understanding Precambrian marine productivity, as continental weathering and subsequent riverine transport is key in delivering essential nutrients to the oceans.

There are a handful (ca. 20) of well-constrained Precambrian paleosols around the world; of these, most – if not all – are parented by basalts of varying compositions. They are also unvegetated, having formed before the evolution of land plants. It is possible that they hosted microbial mats (similar to modern cyanobacteria-dominated biological soil crusts), although remnant microbial structures in soils of this age are exceptionally rare. An analogue landscape, then, would be dominated by volcanic material and have essentially no vegetation.

*Sampling & Methods.* Iceland is an island dominated by its volcanism; basalt flows cover the vast majority of its surface, aging from modern to (older). Due to intense deforestation by the Vikings hundreds of years ago, it



lacks any natural forest; vegetation in non-agricultural areas is limited to early-succession plants such as mosses and grasses. However, when Vikings deforested the land, they also cultivated much of it, making many valleys too influenced by anthropogenic activity to sample as an analogue landscape. Sampling was therefore limited to areas with no obvious sign of recent human activity (e.g., fences, ditches, rows of plants); moderately to heavily grazed areas were also avoided. Sampling primarily targeted soils with no vegetation or moss/lichen/soil crust only, although several soils with grasses were sampled for comparison. Samples of basalts both with and without lichens/mosses were also gathered for weathering rind analysis. Because of the sampling target goals, many of the soils collected were Inceptisols (showing only the beginnings of horizonation). A 1m soil auger was used; this depth was appropriate for most soils due to their immaturity, but several were deeper than 1m and so the depth profile is incomplete. In these cases, the soil was mature enough to have developed a clear B horizon within sampling distance, so they are still useful for this work. Parent material (basalt) was sampled for each soil profile. Soils were described fully in the field; however, due to the augering method, field pH data were not collected. (USDA soil pH lab techniques will be used to approximate soil pH at different horizons.)

The sampling path (see Fig. 1) went from Reyjkavik along the southern/southeastern coast to Höfn, inland, back along the coast, and finally up to Snæfellsnes peninsula on the western coast. Eleven soils were collected (a depth profile for each, marked by a star on Fig. 1), along with miscellaneous other useful samples (e.g., basalts hosting different mosses and lichens, soil crusts). Landscapes of varying ages/maturity were sampled, with the freshest being basalt rubble fields, grading into moss-covered basalt, and ending with fairly mature, clay-rich red volcanic soils. Active depositional environments hosting volcanic materials were also sampled (floodplains), though these were very immature with soils lacking strong horizonation. The moss-covered basalt fields (Fig. 2) were of particular interest because of the rapidity of moss succession; an entire landscape could be coated in moss in as little as a year. Additionally, we came across many wetlands/peaty soils, often accompanied by springs with unique biology (bright orange filamentous bacteria) – some geothermally influenced, others apparently not. Finally, several areas featured large, fresh scoria cones, completely lacking vegetation, as well as some with lichens only. These were sampled for weathering rind analysis.

This combination of unique microenvironments increased the versatility of Iceland as an analogue for early terrestrial systems, exceeding my expectations for what I might capture. Certainly, new questions and opportunities were raised throughout this sampling trip. I plan on returning to pursue some of these new research paths.

The samples arrived recently and processing has begun. All soils are weighed and dried at 55C, then homogenized to <70um. Samples with adequate volume have an aliquot frozen prior to drying. Bulk geochemistry will either be carried out by ALS Minerals in Vancouver, BC, or in-house in a new facility, using a four-acid digestion and analysis via ICP-MS. Soil $C_{org}$ contents will be measured on a Costech Elemental Analyzer, following a 5% HCl acidification procedure. A sequential extraction procedure is used to target four functional groups of iron (magnetite, oxides, carbonates, and poorly crystalline/labile Fe), with a separate method for extracting iron in sulfides. Phosphate will be measured via UV-VIS. An undergraduate researcher will be involved in this work.

In addition to serving as standalone analogue soils, the data collected during this work contribute to my ongoing effort to geochemically characterize B horizons from a large variety of parent materials/climates/soil orders. These Icelandic soils fill two important niches: high-latitude soils (likely sensitive to climate change) and unvegetated soils, as the rest of the dataset is currently limited to lower latitudes and vegetated regions. These soils may serve as important indicators of how key elements cycle differently in vegetated vs. unvegetated environments, as well as in colder, slower-weathering biomes.
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*Figure 1. Map of sampling locations in Iceland. Eleven soil profiles were sampled, with 100 total samples taken.*

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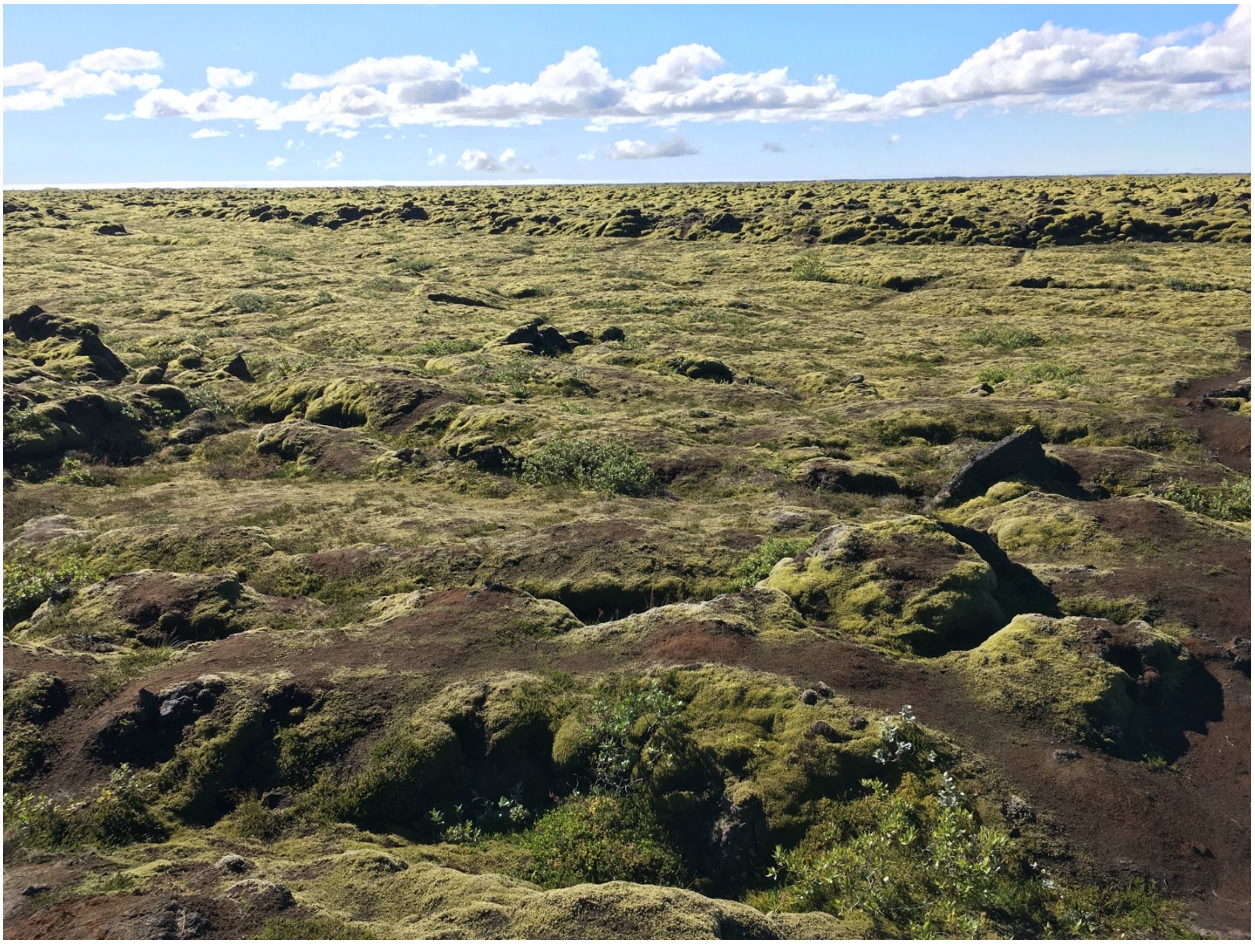

*Figure 2. Recent basalt flow and rubble in southern Iceland. Although the flows cover large areas (tens of square kilometers) and are very recent, the mosses have completely covered this primordial-looking landscape.*