A MINERALOGICAL AND HYDROLOGICAL EVALUATION OF VARIOUS HYDROTHERMAL ENVIRONMENTS AT THE NESJAVELLIR GEOTHERMAL FIELD IN SOUTHWEST ICELAND.

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Introduction: The Hengill Volcanic Complex (HVC) of SW Iceland boasts a wide range of surface hydrothermal conditions, from acid-sulfate fumaroles (pH as low as 0.5), mud pots, and hot springs to near-neutral travertine or silica sinter depositing hot springs (pH as high as 8.3), all likely associated with a deep hydrothermal aquifer with pH ~9 [1] and a high-Fe tholeiitic basaltic substrate (Fe_2O_3T= 13.2%). The Nesjavellir Geothermal Field on the NW side of the HVC [3] hosts a variety of hydrothermal environments in close proximity (Figure 1). At one site, multiple streams with distinct temperatures, pH, and appearances converge in a small area. These include an acidic hot stream (with red microbially coated rocks) and a near-neutral cooler stream with white/yellow coated rocks. The two flow into a third stream, derived from acidic hot springs, fumaroles, and neutral cold springs emerging upstream. Active biomineralization is present in the runoff of both neutral and acidic streams in the area. The characteristics of these environments could provide analogues for the hydrothermal deposits present near Home Plate in the Columbia Hills of Mars [4-5].

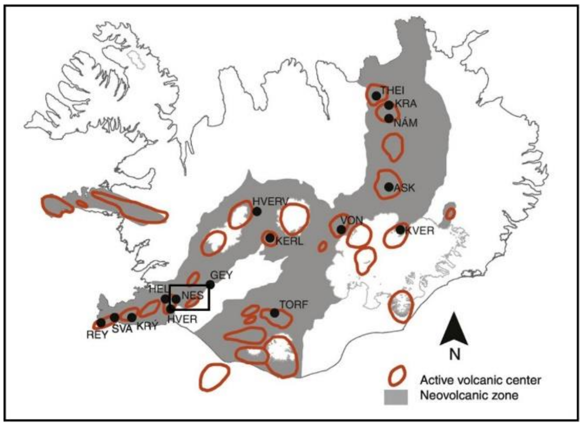

Figure 1- Map of Iceland, with the box outlining the Hengill Volcanic Complex just south of Lake Thingvallavatn. Adapted from [2].

Methods: We visited the Nesjavellir Geothermal Field in August of 2016 and June/July of 2017 and collected surface precipitates, altered soils, water from acidic and near-neutral streams and hot springs, and fresh basalt. Water was tested onsite for pH and temperature, and then analyzed in the field with a Hydrolab sonde to measure temperature, pH, salinity, oxidation-reduction potential (ORP), total dissolved solids (TDS), dissolved oxygen (DO), conductivity, and specific conductivity. Soil and precipitate samples were analyzed using X-Ray Diffraction (XRD) to determine the mineralogy. XRD samples were hand ground using an agate mortar and pestle and analyzed using a Bruker D8 Focus XRD. X-Ray Fluorescence (XRF) samples were powdered using a shatterbox, fused using an M4 fluxer, and analyzed for major and minor elements using a Bruker S4 Pioneer WD-XRF (using the methods of [6]).

Figure 2- The acidic red stream on the left flowing into the near-neutral white stream on the right.

Hydrolab Results: Table 1 shows the Hydrolab results for this site (Figure 2). In September 2016, the red stream had a higher ORP than the white/yellow stream. The red stream's elevated levels decrease downstream as the red stream is

Table 1- Results of field Hydrolab analyses. IN16 samples from 2016, and IN17 from 2017. Yellow = white stream, red = red stream, green = confluence of the streams, blue = bubbling pool between the red and white streams.

Sample	T (*C)	pH	ORP (mV)	Salinity (psu)	DO (mg/L)	Cond. (µS/cm)	Spec. Cond. (mS/cm)	TDS (g/L)
IN1608	22.9	5.65	43.73	0.08	23.25	141.02	0.16	0.10
IN1610	63.5	3.19	476.22	0.30	20.25	788.39	0.61	0.39
IN1613	93.2	2.28	377.22	1.65	10.94	4108.40	3.15	2.02
IN1615	21.29	6.53	88.44	0.08	24.08	155.96	0.17	0.17
IN1709	43.27	5.79	24.93	0.07	0.51	190.57	0.14	0.09
IN1711	10.16	5.82	96.64	0.06	9.78	87.66	0.12	0.08
IN1712	15.14	6.19	119.58	0.17	9.37	288.28	0.35	0.22
IN1714	4.80	6.20	217.37	0.06	11.60	88.49	0.13	0.08
IN1715	24.20	6.13	102.61	0.08	6.88	181.20	0.16	0.10
IN1716	64.70	3.82	258.13	0.14	2.91	391.05	0.28	0.18
IN1717	94.90	2.58	358.83	1.20	2.12	2120.26	2.33	1.49

diluted by more dilute and less oxidizing water. The pH also increases downstream. At the confluence of the white and red streams, conditions more closely reflect the higher volume white stream.

The streams were re-sampled in early July 2017, and had slightly elevated pH for most sites. These slight changes could reveal a seasonal or year-to-year variation in the aqueous conditions.

XRD results: The mineral crust in the white stream (IN1609) is elemental sulfur, and even had a more yellow appearance in 2017. The crust in the red stream (IN1611) yielded no diffraction peaks but had a high background, perhaps indicative of a nanophase iron oxide phase in an otherwise microbial deposit. Sulfides and sulfates are identified in samples collected near the red stream; sulfides near the confluence (IN1612) and both sulfides and sulfates upstream (IN1614). Results can be seen in Table 2.

Table 2- XRD results from the streams and the hot spring of Nesjavellir. P = precipitate, s = soil, XXX = abundant, XX = common, X = rare.

		IN1609	IN1611	IN1612	IN1614
		P	P	S	P
	Temperature (*C)	15	59.3	59.3	68.5
Misc. Phases	Am. Silica				XXX
	Anatase			XX	
	Kaolinite			XXX	
	Nanophase FeO		XXX(?)		
	Sulfur	XXX			XX
Sulfides	Pyrite			X	X
	Marcasite				X
Sulfates	Alunogen				XX
	Rhomboclase				XXX
	Melanterite				X

Discussion: While the red stream itself is oxidizing (high ORP), mineral precipitates upstream (IN1614) include sulfates, elemental sulfur, and sulfides, indicating mixed oxidation states [7], and hydrothermally altered sediment near the confluence of the red and white streams (IN1612) has pyrite (indicating reducing conditions) and kaolinite and anatase, consistent with acid leaching of the soil. The presence of sulfide minerals adjacent to the oxidizing red stream shows that the stream chemistry does not dictate the overall redox conditions of the system, which is locally most likely driven by acid fumarolic steam. The Hydrolab data for the white stream shows a more reducing environment, consistent with the presence of elemental sulfur rather than sulfates.

Mars Comparison: The hydrothermal features at the Nesjavellir Geothermal Field are actively altering high-Fe basalts, and vary widely in pH and ORP over short distances. This leads to a variety of mineral assemblages. Due to the variable conditions in the area, and the alteration of the high-Fe basalt, it is possible to draw some comparisons to environments on Mars.

Similarities can be found with deposits in the Eastern Valley of the Columbia Hills (Figure 3). The deposits are Fe^{3+}-sulfate soils and high-SiO$_2$ soils with possible pyrite and marcasite as hydrothermal alteration products [5]. These deposits would have formed at high water-rock ratios under acid-sulfate conditions, which are probably the result of hydrovolcanism present at Home Plate [5]. The conditions proposed for formation of these soils and products are similar to conditions present in the red stream of the Nesjavellir Geothermal Field, though the specific sulfate minerals identified differ. Further work at the Nesjavellir Geothermal Field will provide greater insight on the origin of the deposits present in the Columbia Hills.

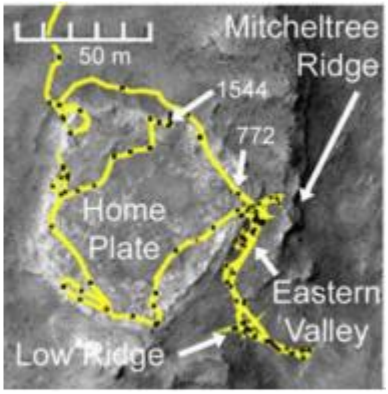

Figure 3- The Home Plate region in the Columbia Hills of Mars. Acid-sulfate deposits are abundant in Eastern Valley. Adapted from [5].

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