

**REMOTE SENSING OF LAKE SANDVATN, ICELAND: ANALOG FOR GALE CRATER, MARS.** R. V. Patterson<sup>1</sup>, E. B. Rampe<sup>2</sup>, M. T. Thorpe<sup>3</sup>, C. C. Bedford<sup>2,4</sup>, O. C. Gadea<sup>1</sup>, M. L. Meier<sup>5</sup>, <sup>1</sup>University of Houston, Houston, Texas (rvpatter@cougarnet.uh.edu), <sup>2</sup>NASA Johnson Space Center, <sup>3</sup>Jacobs at NASA JSC, <sup>4</sup>Lunar and Planetary Institute, USRA, <sup>5</sup>University of Idaho.

**Introduction:** Lake Sandvatn, Iceland is a paleoclimate analog [1, 2] for Gale crater, Mars, that exhibits lacustrine sedimentation adjacent to a fluvial-deltaic complex [3, 4]. NASA's *Curiosity* rover has traversed nearly 27 km (as of sol 3349) of Gale crater and encountered a myriad of sedimentary rocks formed through a combination of fluvial, lacustrine, and aeolian processes [3-5]. Varied provenances of the region include subalkaline basalt, trachybasalt, a K-rich source, and an evolved Si-rich source [6, 12]. This study leverages the versatility of hyperspectral ASTER satellite data to characterize mineral phase distribution and abundances of rock units within the Lake Sandvatn catchment in order to better understand the active setting of the ancient Gale crater lake.

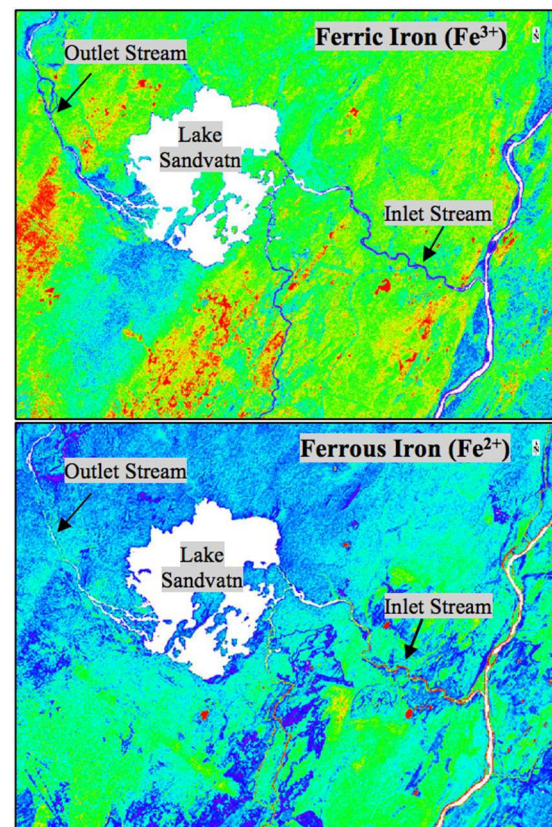
**Methodology:** ASTER data file (AST\_L1T\_00306122007130336\_20150519213452\_5864) over Lake Sandvatn, Iceland, was utilized due to the low cloud coverage (<5%) and central location of the lake within the data footprint. The image was converted from radiance to reflectance data using the QUAC tool on ENVI. Visible to near infrared (VNIR) and short-wave infrared (SWIR) bands (0.556 to 2.4  $\mu\text{m}$ ) were stacked to create a composite with 15 m/pixel spatial resolution. In order to isolate the pixels containing mostly geologic materials, a Normalized Difference Vegetation Index (NDVI) of  $\left( \frac{\text{NIR}-\text{red}}{\text{NIR}+\text{red}} \right)$  and Normalized Difference Water Index (NDWI) of  $\left( \frac{\text{green}-\text{SWIR}}{\text{green}+\text{SWIR}} \right)$  were used to identify and remove water and vegetation pixels. Color composites were created using band math as outlined in [7]. Ferric iron was determined by the ratioing of ASTER bands  $\frac{\text{Band 2 (0.630 to 0.690 } \mu\text{m})}{\text{Band 1 (0.520 to 0.600 } \mu\text{m})}$ . Ferrous iron was determined by the following band operation:  $\frac{\text{Band 5 (2.145 to 2.185 } \mu\text{m})}{\text{Band 3 (0.760 to 0.860 } \mu\text{m})} + \frac{\text{Band 1}}{\text{Band 2}}$  [7].

**Preliminary Results:** Understanding the spatial distribution of iron species is important when examining primarily basaltic terrain in an aqueous sedimentary environment (e.g., Gale crater, Jezero crater, and Lake Sandvatn [2, 3, 10, 13]). For example, species-specific iron mapping may indicate the presence of groundwater hydrothermal alteration through the detection of certain Fe-bearing minerals [7,11].

**Ferric iron.** Ferric iron ( $\text{Fe}^{3+}$ ) is most prominent in areas where basaltic host rock is exposed (Fig.1). High abundance areas of  $\text{Fe}^{3+}$  spatially trend to the NE-SW.

Stream banks and flood plains show lowest abundances of  $\text{Fe}^{3+}$ .

**Ferrous iron.** Ferrous iron ( $\text{Fe}^{2+}$ ) is largely absent from the region surrounding Lake Sandvatn, except for a few areas of high abundance (Fig. 1). These  $\text{Fe}^{2+}$ -rich zones are correlated to the inner banks of the inlet stream SE of Sandvatn, as well as punctuated circular areas on the east side of the lake.



**Figure 1.** Ferric (top) and ferrous iron (bottom) color ramp images of Lake Sandvatn, its inlet and outlet channels, and the surrounding topography. Warmer colors indicate higher abundances. 1:44,009 scale. North is up.

**Conclusions:** Certain igneous ferric minerals (e.g., magnetite) are significant carriers of the  $\text{Fe}^{3+}$  species in the upper mantle [8] from which these basalts originated [9], and potentially the leading cause of high  $\text{Fe}^{3+}$  abundance. If secondary ferric minerals (e.g., hematite) are present, they may indicate hydrothermal alteration during the water-rock interaction or chemical weathering of Fe-rich basaltic country rock in the damp Icelandic environment.

At present, it is unclear why ferrous iron occurs in highest abundances within the inner banks of the eastern

inlet stream, although future field work in summer 2022 will address this question. The seemingly random circular areas of ferrous iron abundance correspond to telephone wires and transformers along the Icelandic roads in the region, are not of geologic significance, and will be masked out of future imagery.

**Future Work:** Thermal emissivity imagery of Sandvatn will be used to perform linear spectral unmixing on select pixels from the same ASTER image (Fig. 2). No image stacking will occur, so the thermal infrared (TIR) (8.291 to 11.318  $\mu\text{m}$ ) data will remain at 90 m/pixel resolution. Linear spectral unmixing will determine respective percentages of spectral endmembers within the TIR range in each pixel selected throughout the catchment area. Since water and vegetation will not be removed from the TIR imagery due to the coarse spatial resolution, endmembers should include water and lichen in addition to common igneous minerals previously identified in the Lake Sandvatn region [2]. Endmembers will be provided by the ASTER EcoStress spectral library (<https://speclib.jpl.nasa.gov/>). Unmixing results will be compared to the mineralogy along the *Curiosity* rover traverse to help interpret mineralogical changes observed (e.g., Fe-oxide and oxyhydroxide detections).

This work will be directly relevant to field operations performed by the Digging Iceland Geology for Mars Analog Research Science (DIGMARS) group.

Mineralogical and geochemical data from Lake Sandvatn sediments collected by DIGMARS [2] will also be compared to *Curiosity* rover findings.

Hematite discovered by *Curiosity* is hypothesized to relate to alteration phases [13], which is not supported by the preliminary findings at Lake Sandvatn [2]. Additional analytical methods, including mineral abundance maps and linear spectral unmixing within the Lake Sandvatn catchment, will bolster our understanding of the history of liquid water at the ancient Gale crater lake.

**References:** [1] Thorpe M. T. et al. (2019) *Geochimica et Cosmochimica Acta*, 263, 140-166. [2] Thorpe M. T. et al. (2022) *LPSC LIII*. [3] Grotzinger J. P. et al. (2015) *Science*, 350, 6257. [4] Rivera-Hernandez F. et al. (2020) *JGR Planets*, 125, 2. [5] Edgar L. A. et al. (2017) *Sedimentology*, 65(1), 96-122. [6] Carr M. H. (1973) *JGR*, 78, 4049-4062. [7] van der Meer F. D. et al. (2020) *Remote Sensing of Environment*, 148, 124-133. [8] Forst D. J. and McCammon C. A. (2008) *Annu. Rev. Earth Plant. Sci.* 36, 389-420. [9] Benediktsson I. O. et al. (2022) *European Glacial Landscapes*, 95-101. [10] Goudge et al. (2015) *JGR: Planets*, 120 (4). [11] Zamyad M. et al. (2019) *Journal of the Indian Society of Remote Sensing*, 47, 1817-1830. [12] Bedford C. C. (2019) *GCA*, 246, 234-266. [13] Rampe E. B. et al. (2020) *JGR Planets*, 125 (9).



**Figure 2.** ASTER color composite (RGB: 3N, 2, 1) with pixel selection locations for future linear spectral unmixing analysis. 1:44,009 scale. North is up.