

COLOR ANALYSIS OF VISIBLE IMAGES FOR ASSESSING SEDIMENT PROVENANCE DURING ORBITAL AND IN SITU PLANETARY EXPLORATION. P. Sinha¹, B. Horgan¹, A. Rudolph¹, R.C. Ewing², E. Rampe³, M.G.A. Lapôtre⁴, M. Nachon², M.T. Thorpe³, C.C. Bedford^{5,3}, K. Mason², E. Champion², P. Gray⁶, E. Reid⁷, M. Faragalli⁷, ¹Purdue Univ. (sinha37@purdue.edu), ²Texas A&M Univ., ³NASA Johnson Space Center, ⁴Stanford Univ., ⁵Lunar and Planetary Institute, USRA ⁶Duke Univ., ⁷Mission Control Space Services.

Introduction: Sediment provenance is the reconstruction of the origin and transport of detrital sediments from source to sink [1]. Studying and tracking sediments allows investigation of distant rock units (e.g., upstream) and helps constrain the various surface processes that influenced the modern or paleo-environment [2,3]. Most rock exposures on Mars are sedimentary [4] and mafic [5], however, it is not well known how different transport pathways, such as glacial, fluvial, and eolian, physically and chemically alter mafic sediments [6,7]. Understanding the cause of physical and chemical variability within a sedimentary system is crucial to interpret the origin and history of sediments encountered by rovers on Mars.

The most common and abundant planetary datasets are visible images, which on rovers are typically acquired in color. In this study, we test the predictive capability of color analysis on visible images to identify mineralogical variability in a mafic sedimentary system. We hypothesize that the chemical and physical variability in sediments with distance from source can be tracked using color analysis, and that this technique can be used to constrain sediment transport pathways and inform rover operations on Mars. To test this hypothesis, we compared sediment/rock colors in rover and aerial images at a Mars analog site in Iceland with their visible and near-infrared (VNIR; 0.3-2.5 μm) spectra and characterized the mineralogy of bedrock and transported sediments.

Field work: The Semi-Autonomous Navigation for Detrital Environments (SAND-E) project uses rover field tests and geological investigations to study the Mars analog glacio-fluvial-eolian landscapes of Iceland. SAND-E aims to develop operations approaches to advance science workflows and maximize science returns. Our 2019 field site, Skjaldbreiðarhraun [8,9], is a glacio-fluvial-eolian sand plain surrounded by volcanic systems dominated by basaltic minerals and glasses. This region is characterized by braided river channels, eolian and fluvial ripples and dunes, wind-sculpted bedrock, wind-deflated rocky plains, and sand drifts similar to martian landscapes [5]. Rock and sediment samples were collected from surrounding bedrock outcrops and from proximal, medial, and distal sites in the outwash plain which increase in distance from Þórisjökull glacier. Ground scientists and engineers under simulation operated the rover, Argo J5, developed by

Mission Control Space Services, Inc., based on inputs (e.g., visual imagery, spectral data, etc.) returned by the rover. Simultaneously, an unmanned aerial system (UAS), simulating Mars Ingenuity Helicopter, collected aerial images that simulate HiRISE's and Ingenuity's imaging resolutions (25 cm/pixel and 3.2 cm/pixel).

Methods: Color analysis is performed using Decorrelation Stretch (DCS) on visible imagery (RGB channels). Mafic sediments at the catchment scale in the field site appear homogenous in natural color, but applying a DCS uses principal component analysis (PCA) so that subtle color differences are stretched to utilize the entire color space [11]. DCS suppresses the effects of albedo and maximizes compositional information. DCS processing is carried out using ENVI software and is extensively used in assessing variability in images from Mars orbiters and rovers [12,13]. We applied DCS to images acquired during SAND-E rover traverses, as well as to a map (41/cm/pixel) of the field site using aerial images from Loftmynd ehf.

VNIR reflectance spectra of the surface and interior of source rocks and dry sediments were collected in the lab using an ASD FieldSpecPro3 spectrometer. Sediment samples were sieved into bins of sizes: <63 μm , 63-125 μm , 125-500 μm , 500-2000 μm , >2000 μm . Source rocks and segregated sediment samples were imaged using a commercial camera for DCS analysis.

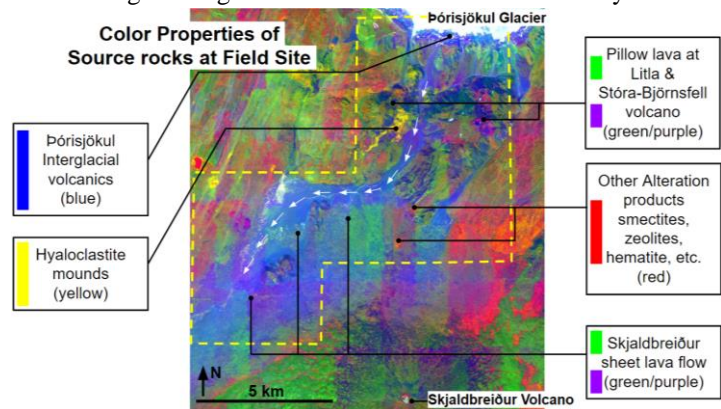


Figure 1: DCS color image of Skjaldbreiðarhraun field site

Comparison of DCS with VNIR spectra: DCS color analysis of the study site's aerial image reveal color variation indicative of mineralogical variability in the basaltic terrain (**Figure 1**). Comparing the DCS colors of source rock images with the mineralogy interpreted from VNIR spectroscopy (**Figure 2**) [14], we learn that blue, green, and purple colors are linked to

primary mafic minerals, where pyroxenes typically appear blue in the DCS and display absorption bands at ~ 1.02 and $2.3 \mu\text{m}$ while olivine exhibits a broad absorption band beyond $1 \mu\text{m}$ and typically appears green/purple; yellow mostly represents palagonites/ altered glass displaying strong hydration bands (1.43 & $1.93 \mu\text{m}$); and red/magenta colors indicate alteration products like smectite, zeolites, and hematite that display absorption bands associated with Fe^{3+} ($0.86 \mu\text{m}$), hydration (1.43 & $1.93 \mu\text{m}$), and hydroxylation with Si, Al, Fe, and Mg (2.1 , 2.22 , 2.27 , & $2.3 \mu\text{m}$).

DCS image of grain-size segregated sediment samples show that coarser sediments are blue/green in color whereas finer fraction is dominated by red and yellow (Figure 2). Both coarse and fine fractions display mafic signatures as absorption bands at $1 \mu\text{m}$ but the fines also display hydration and hydroxylation bands at 1.93 and $2.22 \mu\text{m}$ due to concentration of altered materials.

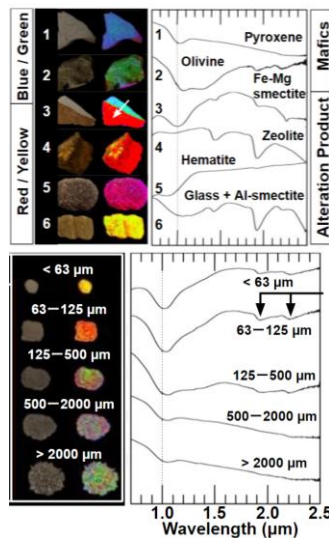


Figure 2: DCS colors and VNIR spectra of source rocks (left) and grain-size segregated sediment sample (right).

Sediment provenance using DCS color analysis: Up north, the Þórisjökull interglacial volcanics are dominantly blue in the DCS, and appear to overly a green unit which is capped by remnants of an oxidized lithic unit in red color. The western

flank of the valley shows yellow hyaloclastite mounds and green pillow lava from Litla-Björnsfell volcano, while Stóra-Björnsfell, on the eastern flank has a purple caldera overlying green color dominated lithics towards the bottom of the cone. In the south, the Skjaldbreiður shield volcano is mostly blue, however, tumuli formed by the shield flow show color variability ranging from green to purple/blue. The bright green patches around Skjaldbreiður's eastern and western slopes are due to vegetation. A caveat to DCS technique is that shadowed regions appear blue and ice that appears white look similar to a bright deposit of fine-grained dust north of our medial site.

We observe that the DCS of exposed bedrock surrounding the outwash plains contains units of all colors, and cobbles representing all of these units can be identified in the rover-scale DCS images (Figure 3). However, in the aerial map (Figure 1), the outwash plain is primarily dominated by blue. Our analysis suggests that

fine-grained altered materials are easily transported downstream/downwind which leaves behind coarser and blue-colored basaltic cobbles sourced from Þórisjökull volcanics to dominate the surface. Within the valley, cobbles around inactive channels appear purple due to oxidation, whereas the cobbles around active channels are blue as fresh supply of cobbles are continuously fed from upstream. The color variability in the outwash plain is likely due to local variations in the basaltic materials and from differences in the local surface density of coarser and finer particles.



Figure 3: Outwash sediment within the rover's workspace.

Application: We observe that DCS-based color analysis is a powerful tool for identifying spectral diversity, and that it has the capability to differentiate primary minerals from alteration minerals, with limited ability to identify minerals within each group (e.g., pyroxene vs. olivine or altered glass vs. hematite vs. smectite). But when this technique is used in tandem with spectral or any other dataset, the combination makes an effective tool to carry out sediment provenance study by characterizing mineralogical variability within a basaltic sedimentary system. Therefore, color analysis can aid in identifying diverse targets for sampling within the rover's workspace. Tactically, DCS colors can be used during operations to link detrital sediments within the rover's vicinity to surrounding bedrock sources in the absence of a significant dust cover. This will enable extending local mineralogical interpretation to surrounding region using orbital dataset at coarser resolution. Correlating observation of surface features from orbit and ground enhances the ability to interpret using orbital datasets. Thus, DCS images enhance our ability to survey, map, optimize rover's traverse and select science targets on relatively dust-free planetary surfaces.

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