University of Idaho

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Multispectral Imaging of Halema'uma'u Lava Lake, HI: Emissivity of Flowing Basalt in the Visible to Near-Infrared Range

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Visible near-infrared brightness is proportional to glass abundance in solid basalt - What impact does heat in active vents have on the data?

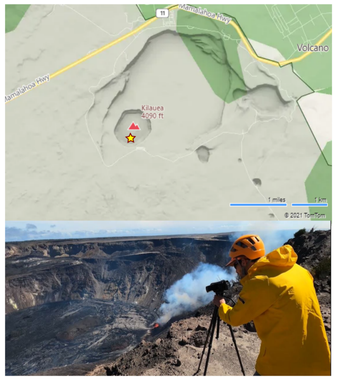


Figure 1. The two spectrometers were placed on the southern rim (yellow star on upper image) on the 85th day of the eruption, March 15th. Observations were made periodically between 10:30 AM and 12:15 PM on Oct. 7th, 2021. Temperature was measured with a handheld FLIR Systems SC620 camera with a 45° horizontal field of view and a resolution of 640 × 480 pixels

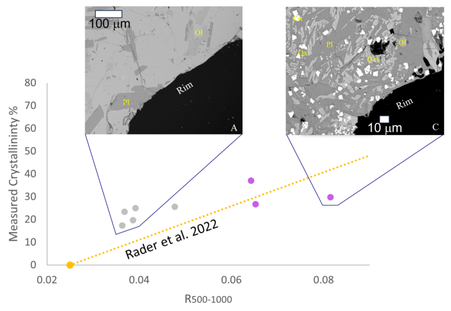


Figure 2. Glassy basalt has been shown to have lower reflectance between 500-1000 nm due to the low crystal content. Example images of glassy (left) and crystaline (right) SEM images overlain on the values of reflectance and crystallinity from Jordan Craters, OR (Reeder et al., *in review*).

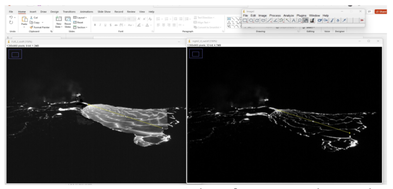


Figure 4. Images were taken from a similar angle and distance from the target at the same time. Slight offset between images was minimized in ImageJ using the StackReg plugin.

Figure 3. The MicaSense RedEdge - M sensor is a 5-band off-the-shelf instrument utilized primarily by agriculture. The sensor's low cost, UAV-compatibility, simplicity, and simultaneous capture for all bands makes it an attractive choice for deployment during an active eruption. The wavelengths for each band are in the chart to the right.

Despite the challenges, daytime VNIR reflectance images show variation in part due to roughness, temperature, and glass content

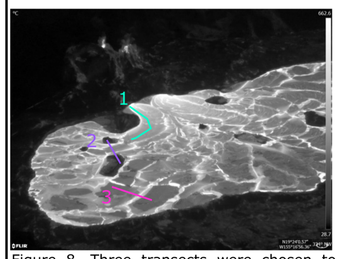


Figure 8. Three transects were chosen to evaluate the range of temperatures and crustal evolution on the lava lake. Transect 1 in teal looks at progressive cooling and thickening of the crust from the vent. Purple transect 2 looks at the reflectance of the older floating islands. The third transect (pink) looks at thicker plates separated by a hot spreading center.

Transect 1
Simple cooling of crust

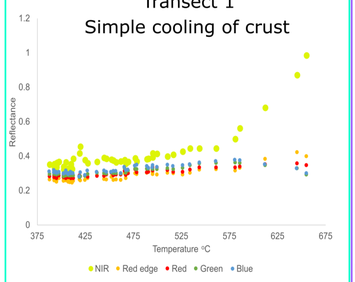
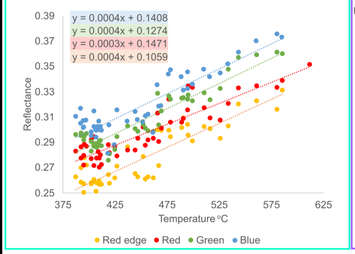
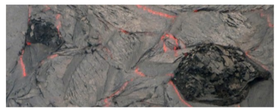


Figure 9. Temperatures above ~550°C exponentially influenced the near-infrared (NIR) band. The other wavelengths were weakly influenced with a positive linear relationship. Neither surface texture or crystallinity is likely to vary along this transect thus it provides a baseline brightness related to temperature which can be corrected on more complicated features.



Transect 2
Rough, old, cold islands



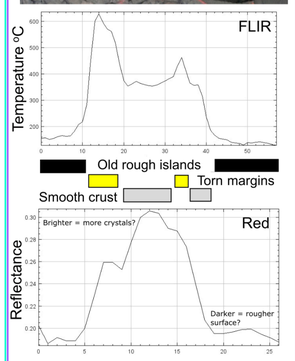
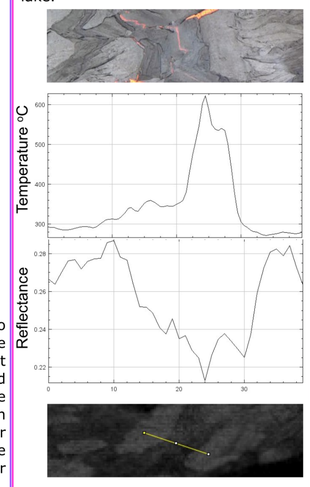


Figure 10. Active channel between two older islands illustrates that surface roughness and glass content overwhelms temperature. The red band shows darker reflectance for the hotter margins compared to the thin crust, suggesting a glassier composition. The islands may be darker because of glassiness or roughness.

Transect 3
Thin vrs thicker crust

Figure 11. Transect across older thicker and cooler on the outside and hotter in the middle, shows the newer crust reflecting less light possibly because it is glassier and has yet to crystallize. Sampling could confirm this hypothesis but was not possible due to the inaccesible nature of the lake.



Conclusions:

1. The radiance of hot lava increased linearly between temperatures of 375- 650 °C in wavelenths of 475-717 nm.

2. The MicaSense RedEdge-M sensor accurately measured the blackbody radiance for the Red (668 nm) band at 500 - 675 °C.

3. The sensor measured radiance > blackbody of the lava (emissivity >> 1), which is interpreted as an over-influence of sub-pixel-sized hot spots as opposed to true emissivity.

4. Within a single image, regions of similar thermal makeup can be compared for non-thermal effects to radiance and reflectance.

Blackbody Furnace Test shows RedEdge-M accurately measures radiance in the Red band

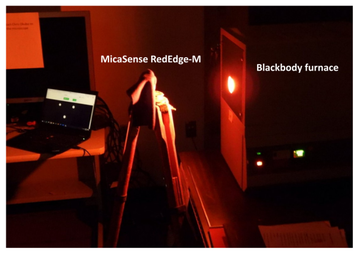


Figure 5. Temperatures from 500-675°C were measured at the USGS Flagstaff Astrogeology center in a dark room.

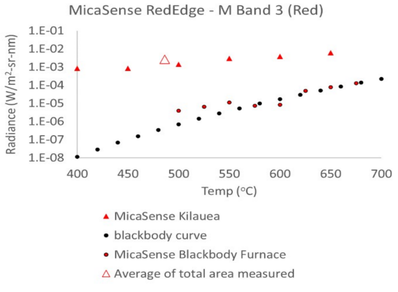
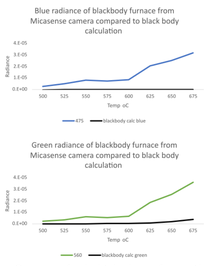


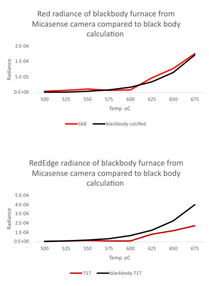
Figure 6. Radiance from the Kilauea lava lake taken at night (red filled triangles) indicate higher radiance than the blackbody (black circles). If the emissivity of lava in the thermal range is <0.9, then FLIR-derived temperatures may be too low, causing a rightward shift of the MicaSense Kilauea data.

Micasense reads too high

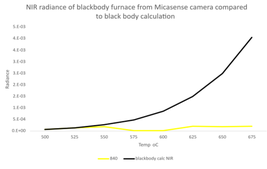


Common for light-leakage from other bands in off-the-shelf imagers.

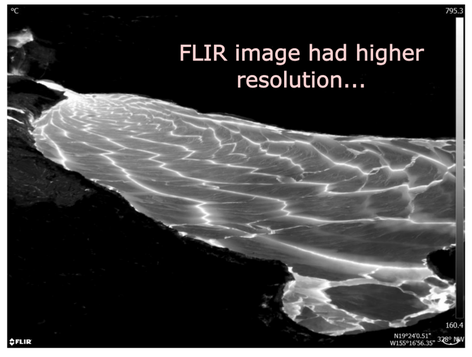
Micasense reads close to blackbody

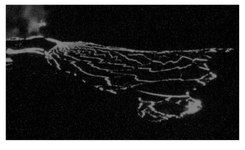


Micasense reads too low



Common for typical IR-blocking coatings on lenses in off-the-shelf imagers.





... than the Micasense images

Figure 7. The Micasense had a wider range of values per pixel than the FLIR and since the dyranimc range of radiance was so high, the radiance output for a single pixel was skewed to higher values. **Making calculating emissivity from this dataset impossible.**

Improved real-time viscosity measurements

Implications for monitoring - with further calibration, this technique may provide a real-time estimate of crystal content without the need for dangerous, expensive, and time-consuming sampling for petrologic data. Crystal estimates would be useful for improved accuracy in lava flow models and targeted sampling for glass or phenocrysts.

Petrology on planetary lavas from a distance

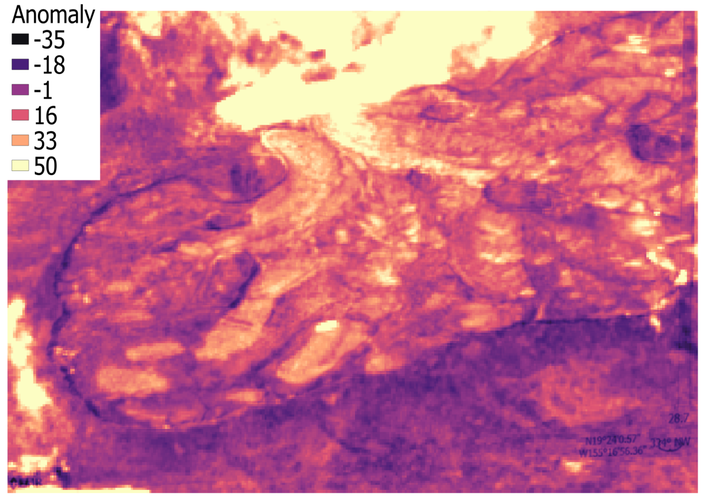
Improved remote petrology on lavas may allow for a better understanding of the petrogenesis and emplacement environment of active or very hot planetary surfaces such as Io or Venus. Further, this method has the potential to interpret VNIR data from exoplanets that may be lava worlds.

Need to isolate roughness from crystallinity

Further experiments and study is needed to confirm that the overall brightness of molten and recently-molten lava is due to crystallinity. Molten rock doped with crystals but with similar surface textures is the next step in isolating this effect.

Usefulness of an image that shows crystallinity

Figure 12. The image below is a thermally-corrected (magnitude of daytime reflectance above or below the trend line in Fig. 9) average reflectance map which may indicate regions of high glass content or increased surface roughness (dark spots) or regions of high crystallinity and smoother surface roughness (lighter spots). Images like these could be produced to monitor active eruptions or provide targeted sampling maps when glassiness or regions of high crystallinity are needed.



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