**CAN NIR REFLECTANCE DATA FOR ROCKS AND MINERALS BE USED EFFECTIVELY TO PREDICT NIR EMISSIVITY ON VENUS?** G. Y. Kramer[1] and R. R. Herrick[2], [1]Planetary Science Institute, 1700 E. Fort Lowell, Suite 106, Tucson, AZ 85719, gkramer@psi.edu, [2]University of Alaska Fairbanks, 2156 Koyukuk Dr., Fairbanks, Alaska 99775, rrherrick@alaska.edu.

**Introduction:** For decades, knowledge of Venus' surface composition has been limited to XRF, GRS, and reflectance spectra measurements from the Vega and Venera missions, which showed rocks of largely basaltic composition [1-4]. More recently, surface emissivity measured through an atmospheric window at 1.02 µm by the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) on Venus Express has demonstrated a significant variability that can be correlated to different terrain types. For example, compared to the regions interpreted as basaltic plains [e.g., 5,6] tessera terrain have lower emissivity at 1 µm, suggesting they are more silica-rich [7-9]. Other work has suggested that high emissivity areas atop a Venusian shield volcano represent young, unweathered lava flows [10]. So, tessera terrain could be regions where rocks are more felsic or locations of older, mafic rocks, or both. Lower emissivity values may also indicate greater surface roughness [11], an observation which stresses the importance of cross-correlation with other data sets.

One spectral channel has provided a taste of Venus' crustal diversity. By utilizing the spectral windows to the surface (0.85, 0.90, 0.99, 1.02, 1.10, and 1.18 µm) available through Venus' atmosphere [12] the compositional variation of the Venusian crust can be mapped.

**Using reflectance spectra to derive emissivity spectra:** Room-temperature infrared spectra have been collected for decades, yet the NIR range (between 0.7 and 3-5 µm) is (unsurprisingly) limited to reflectance spectra, while the library of emissivity spectra are limited to thermal-IR (>5 µm). Emissivity spectra in the NIR collected under simulated Venusian conditions is just beginning [12,13]. Laboratory spectra of analog materials acquired under controlled conditions specific to a planetary body and its particular environment will ultimately provide the best means to interpret remote sensing data. In the meantime, the existing library of reflectance spectra can be utilized to prepare for and interpret multispectral emission data from Venus, as well as help guide deconvolution models used to unravel mineralogy, weathering products, and surface roughness effects. Kirchhoff's law for opaque material allows us to calculate emissivity (ε) from reflectance (ρ):

$$\varepsilon = 1 - \rho$$

Figure 1 shows images of rocks selected as Venus analogs. These samples were collected from Iceland, and their reflectance spectra measured in the field using a TerraSpec® Halo field spectrometer. The spectra at right are the average of three measurements for each representative surface. The emissivity spectrum was then calculated using the equation above.

*Are spectra measured under Earth-ambient temperatures relevant for Venus temperatures?* Crystal field theory predicts that spectral features, such as band centers for absorptions and emissivity maximums, will vary with temperature. If we could view Venus' surface across a broader spectral range and resolution, precise knowledge of the spectral changes with temperature would be imperative. But with the limitation imposed by these discrete atmospheric windows, the existing library of reflectance data is acceptable. By way of ex-

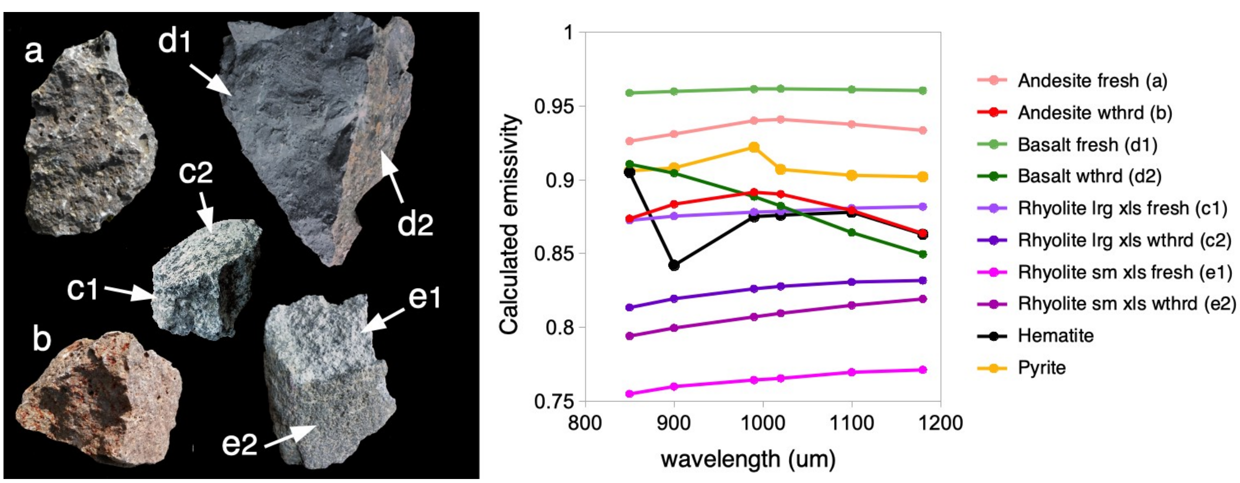


Figure 1: (Left) Venus analog samples collected from Iceland. Arrows point to fresh/weathered surfaces identified in key for spectral plot. (Right) Emissivity spectra of Iceland samples calculated from reflectance spectra using Kirchhoff's law. Spectral channels (tie points) represent locations of known atmospheric windows to Venus' surface. Hematite and pyrite spectra from [12].

ample, the composition of the Moon's surface was mapped using Clementine's UVVIS multispectral camera, which had only five spectral channels between 0.75 and 1 µm, and wasn't even adequately calibrated until after orbital insertion [14].

There are limited available spectra measured at temperatures ranging from 25°C to ~250°C [e.g., 15] and as high as 480°C [16,17]. Silicate rocks and minerals show little change in emissivities and band positions with temperature [16], although diagnostic spectral features can broaden and become attenuated [18-20]. Preliminary work by [17] shows that reflectance values for most of the rocks they measured exhibit little change between 25°C and 470°C. Although measurements of the spectral trends to Venus-like temperatures are limited, existing low-temperature data can be extrapolated, as demonstrated by [19] for variations in the 0.8 to 1.4 µm reflectance spectrum of an olivine (Fo90) from ~100K to 700K.

*Are bidirectional measurements of reflectance spectra relevant for emissivity spectra?* Canonically, directional-hemispherical reflectance spectra are used to derive the directional emissivity spectra that would be measured from Venus. However, most available laboratory and in situ spectra are measured using bidirectional reflectance. Fortunately, converting bidirectional reflectance to emissivity is sufficient for two reasons: (1) the relationship between directional-hemispherical reflectance and bidirectional reflectance values are highly correlated for all emission angles and all wavelengths longer than ~0.6 µm [21] and (2) for dark surfaces, where emissivity >0.7 (expected for most Venus surfaces), emissivity is approximately independent of emission angle [22].

**Expected Venus rock types:** Granitic (felsic) rocks are generally distinct from basaltic (mafic) rocks in the NIR. Emissivity spectra of felsic minerals, like plagioclase and quartz, are low and featureless, and responsible for relatively low (~<0.8) emissivities of granitic rocks (rhyolite, granodiorite, granite). Basaltic rocks have emissivities >0.85 and the diagnostic ~1 and ~2 µm spectral features of the mafic minerals, olivine and pyroxene, present as an increase in emissivity at these wavelengths compared to the continuum. These features are indicative of the presence of Fe, and the location of maximum absorption a function of the crystal lattice structure. Venus' atmospheric windows are well-placed to characterize the 1 µm feature. Ongoing work [12,13,23,24] utilizes the spectral features caused by $Fe^{3+}$ and $Fe^{2+}$, and the inverse correlation between Si and Fe+Mg, to estimate $SiO_2$ abundances and improve rock type identification.

The effect of weathering on the emissivity spectrum of a rock it is dictated by (1) the mineralogy of the fresh rock, (2) the chemistry of the weathering agent (i.e., composition of the atmospheric gases and/or interacting liquids), and (3) the consequent mineralogy of the altered rock. Weathering products like iron oxides or iron sulfides will generally increase emissivity of a felsic rock, but would decrease emissivity of a basalt. The ultimate effect also varies with wavelength, thereby changing the shape of the continuum and making weathering products more distinguishable. Anhydrite is predicted as a weathering product of Ca-bearing silicates, like feldspar and pyroxene [25,26]. The emissivity of anhydrite is near 0.1 [9], so rocks that are extensively altered in this way should be apparent.

In conclusion, the available database of reflectance spectra covers the range of rocks and minerals expected on Venus, and these data can be converted to emissivity spectra to interpret multispectral NIR measurements of Venus' surface. Emissivities and spectral shapes are sufficiently distinct to determine rock type, relative weathering, and potentially grain size variations between rocks of similar composition. Multispectral emissivity measurements in the range of available atmospheric windows is essential to understand the geologic diversity of Venus, its evolutionary history, as well as provide a fundamental context for understanding exoplanets in similar orbital situations.

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