USING DIVINER TO IDENTIFY LUNAR PYROCLASTIC DEPOSITS WITH HIGH SCIENCE RETURN AND RESOURCE POTENTIAL FOR LANDED MISSIONS. K. A. Bennett[1], L. M. Pigue[2], L. Gaddis[1], C. C. Allen[3], B. T. Greenhagen[4], D. A. Paige[5], L. Keszthelyi[1], L. R. Ostrach[1], J. J. Hagerty[1], L. A. Edgar[1], R. L. Fergason[1], J. A. Skinner[1]. [1]USGS Astrogeology Science Center (2255 N Gemini Dr., Flagstaff AZ); [2]Northern Arizona University, Flagstaff, AZ; [3]NASA Johnson Space Center (retired), Houston, TX; [4]Johns Hopkins University Applied Physics Laboratory; [5]University of California Los Angeles, Los Angeles CA. (corresponding author email: kbennett@usgs.gov)

Introduction: Explosive volcanic deposits on the Moon are compelling targets, both scientifically and as potential resources. These pyroclastic deposits represent material sourced from the lunar interior, and therefore provide a window into the composition of the lunar mantle. The composition of a pyroclastic deposit reflects how much the parent magma evolved prior to eruption. As magma bodies evolve, elements crystallize and settle out. This fractional crystallization leads to more evolved magmas containing more silica and less iron. Additionally, eruption models indicate that the pyroclastics are from gas-rich magmas that are expected to rise rapidly through the crust in the initial phases of an eruption. These conditions minimize the assimilation of crustal materials, providing a more accurate sample of the melts derived from the mantle. Therefore, the most iron-rich pyroclastic deposits likely represent the least-altered, most primitive material from the lunar interior that are available on the lunar surface.

Pyroclastic material, particularly the iron, titanium, and volatile-rich volcanic glass and crystallized beads [1] formed during a Hawaiian-style eruption, has been hypothesized to be an important potential resource due to its relatively consistent spherical shape and size, which would make processing the particles easier. Additionally, many pyroclastic deposits are glass-rich, which is easier to break down than a fully crystalline rock [2]. Also, iron-rich pyroclastic material has been shown to release the most oxygen of any lunar sample during high-temperature hydrogen reduction experiments [3]. Oxygen is a critical resource that is necessary for creating water and fuel. To target the pyroclastic deposits with the maximum resource potential, it is important to know the iron content of each deposit.

Here we obtain the Christiansen Feature (CF) value and an estimated iron content of lunar pyroclastic deposits to identify the most iron-rich deposits. These deposits are most representative of the lunar interior and the most resource-rich deposits, and therefore their locations are high priority landing sites that have a high science return and resource potential.

Diviner: We use Lunar Reconnaissance Orbiter Diviner Lunar Radiometer Experiment thermal data to obtain the CF value and an estimated iron abundance. The CF value is the wavelength position of the emission maximum near 8 microns, and this compositional indicator can be estimated using Diviner's three channels located near 8 microns [4]. The CF value is dependent on the degree of polymerization of silica. For crystalline materials, shorter CF values indicate minerals like feldspar and higher values indicate pyroxene and olivine. The global Diviner CF map can be used to examine compositional variations on the lunar surface, which is valuable for selecting sites of interest for science and resources.

A strength of the CF parameter is that it is unaffected by the crystallinity of the surface; this is important for pyroclastic deposits because they range from crystalline to glassy. Here we use the global (0-360° lon, ± 60° lat) standard CF map that is publicly available on the PDS (***Figure 1***).

Because the CF wavelength position has been correlated to silicate mineralogy, it can be used to roughly estimate the amount of iron present [5]. Allen et al., 2012 empirically found that the relation between Diviner CF values and FeO wt. % is:

$$\mathrm{FeO} = 74.24 \times \mathrm{CF} - 599.9 \qquad \text{[Eq 1]}$$

Methods: Using the list of 151 pyroclastic deposits (***Figure 1***) compiled by Glaspie et al. [6], in ArcMap we create regions of interest (ROI) within each deposit. We then calculate the average CF value of each ROI and convert this value into FeO wt. % using Equation 1.

Preliminary Results: Thus far we have measured the CF value of 67 pyroclastic deposits. This includes pyroclastic deposits of a variety of sizes, from large regional deposits (~49000 km^2) to small localized deposits (~100s of km^2) [7]. Our preliminary results from this subset of pyroclastic deposits show a range of average CF values from 8.11 to 8.43 μm.

The pyroclastic deposits in our preliminary study that exhibit the highest CF values are Sulpicius Gallus, Mare Vaporum, Taurus-Littrow, Sinus Aestuum, and Rima Bode. These range from 8.43 μm (Sulpicius Gallus) to 8.38 μm (Rima Bode). The highest estimated iron content (Sulpicius Gallus) is 26.0 wt. % FeO. Many of these deposits were designated "black spots" in early telescopic studies because of their very low albedos, later associated with high titanium contents and abundant crystalline beads [8].

Discussion: These preliminary results show that the deposits with the highest CF values are large regional deposits. This is consistent with previous results that have shown that energetic lava fountaining is driven by magmas ascending directly from mantle without stalling and evolving in the crust [e.g., 9]. However, additional more detailed work may be required to verify this as previous studies have found that some pyroclastic deposits contain localized iron-rich areas [10]. This shows that pyroclastic deposits are not always homogeneous and that identifying the most iron-rich pyroclastic material may require more detailed analysis.

Science That Would Be Enabled By A Human Crew At Pyroclastic Deposits: Human presence will enable a faster, more detailed characterization of the local geology, which leads to more representative samples that have a more detailed geologic context. Carefully selected samples from lunar pyroclastic deposits that are representative of the lunar interior would enable petrologic and other studies that could constrain the age of the eruption and provide a detailed composition of the lunar interior at the time of the eruption. These samples could also be used in further tests to understand the chemical and physical properties of pyroclastic material and how it can best be used as a resource.

Astronauts will also be able to dig trenches that can be used to answer outstanding questions related to the stratigraphy of pyroclastic deposits. This includes whether eruptions were sustained or intermittent. Trenches would also reveal subsurface variations, such as variations in grain size or glass content that might result from variations in eruption style.

In situ thermal measurements from handheld instruments and the deployment of heat probes would contribute to our understanding of the unique thermophysical properties associated with pyroclastic deposits. These measurements, along with detailed chemical analyses of returned samples, will provide critical ground truth for the Diviner dataset and the models that are based off of this dataset.

In summary, pyroclastic deposits are valuable targets for future human crews, and the near-global Diviner CF map can help identify pyroclastic material that is most representative of the lunar mantle and that is also a potential resource. Although pyroclastic deposits are concentrated in and near the mare, they are distributed across the Moon and may be co-located with other potential targets of interest. For instance, missions that take place near the South Pole could include an expedition to investigate the Schrodinger pyroclastic deposit (75° S).

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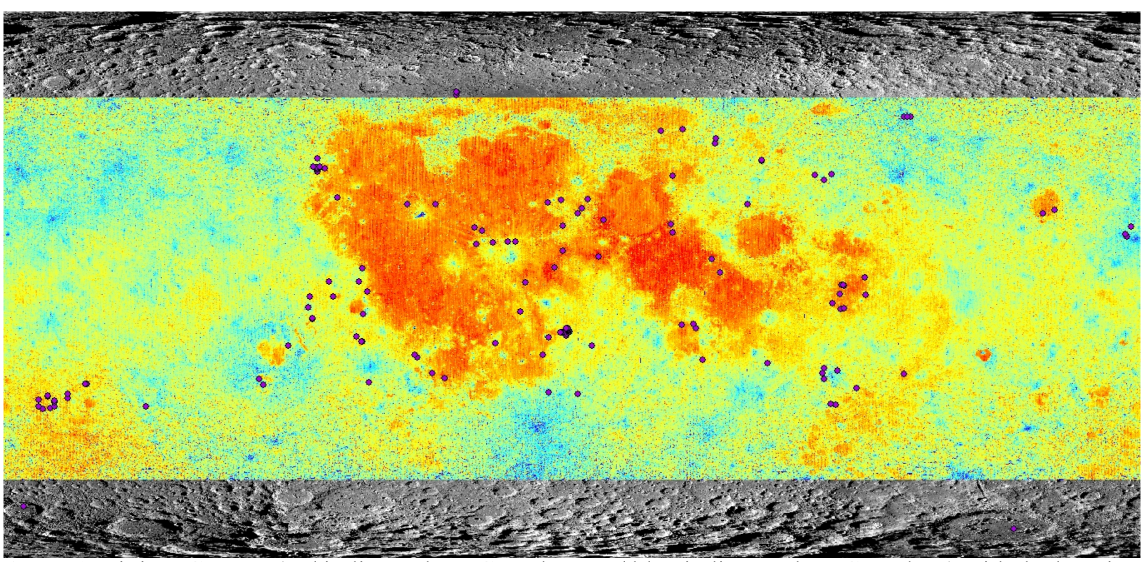

Figure 1: Diviner CF map (red indicates long CF values and blue indicates short CF values) with the locations of all known lunar pyroclastic deposits (purple circles).