

**INDUCED THERMOLUMINESCENCE AS A METHOD FOR DATING RECENT VOLCANISM: VARIABILITIES WITHIN THE BLUE DRAGON FLOW AT CRATERS OF THE MOON, IDAHO, USA.** A. Sehlke<sup>1</sup>, D. W. G. Sears<sup>2</sup>, H. Sears<sup>2</sup>, S. S. Hughes<sup>3</sup> and the FINESSE Team. <sup>1</sup>NASA Ames Research Center/USRA, Moffett Field CA, 94035, USA (alexander.sehlke@nasa.gov), <sup>2</sup>NASA Ames Research Center/BAERI, Moffett Field CA, 94035, USA; <sup>3</sup>Dept. of Geosciences, Idaho State University, Pocatello, ID

**Introduction:** Over the past two years, we demonstrated that a suite of mainly tholeiitic basalts that had erupted about 2.2 ka to nearly 500 ka ago in the eastern Snake River Plain (Idaho) and the the Big Island of Hawaii showed a correlation between induced thermoluminescence (TL) and age of the rock [1,2]. However, our correlations show considerable scatter consistent with petrographic changes in the feldspar, the major TL-producing mineral in these rocks, such as crystallization of amorphous phases to produce feldspar or the diffusional loss of incompatible elements, such as Fe, that quench TL in feldspars.

In the present study, our aim is to isolate the influence of changes in modal abundances of luminescing phases and their crystallization history from age and compositional variability by investigating the induced TL properties of basaltic lava emplaced in a single lava flow for the Blue Dragon lava flow. Once the origin and mechanism contributing to the scatter in induced TL to age relationship is identified and can be corrected for, the TL method, which is low-weight, low-power, low data-rate, would be suitable in spacecraft use as a dating method.

**Methods:** *Field site and sample collection.* We collected 28 samples within a single ~2.75 km long lava flow belonging to the Blue Dragon lava that erupted about 2.2 ka ago at the Craters of the Moon National Monument and Preserve, Idaho. Samples types included flow lobes, pahoehoe ropes, channel levees, and lava that had completely transitioned from a pahoehoe to a morphology, indicating differences in cooling history and crystallinity [3,4].

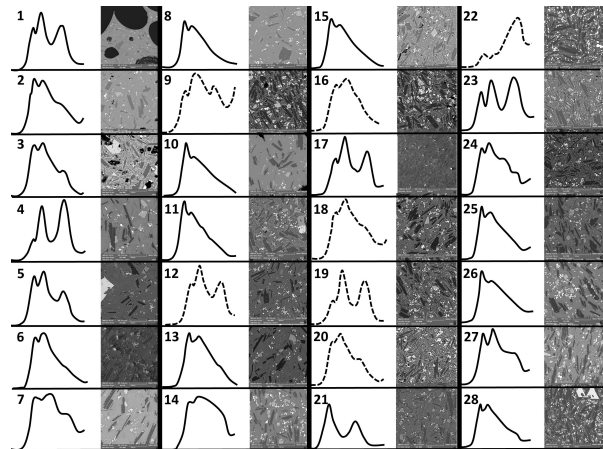
Mineralogy and crystal abundances were determined by electron beam microprobe analyses and back-scattered electron image processing, respectively.

*Laboratory measurements of induced TL.* Fresh samples were taken about 5 cm below the surface, gently crushed using stainless steel and agate pestles and mortars until they passed through a 250  $\mu\text{m}$  sieve. Four milligram aliquots were then placed in copper pans for TL measurement. Modified commercial Daybreak Nuclear and Medical Inc. thermoluminescence equipment was used to obtain TL data in the form of plots of light emitted versus laboratory heating temperature. The resulting plots are referred to as "glow curves". Five glow curves were recorded for each sample, one in the natural

state, three after exposure to a standard dose of beta radiation, and one in the drained state. Dhajala meteorite was used for normalization to enable interlaboratory comparison.

**Results:** Identified phases in our samples are  $\text{An}_{62\pm 4}$ ,  $\text{Fo}_{52\pm 4}$ , Fe-Ti-Spinel, Apatite, and residual glass. The composition of the mineral phases is more or less constant throughout the entire length of the flow; the FeO-content of the anorthite ranges between ~0.5 and 0.8 mol%. Regarding the sample texture observed in BSE imagery, our samples generally showed a quench crystal matrix on the micrometer scale.

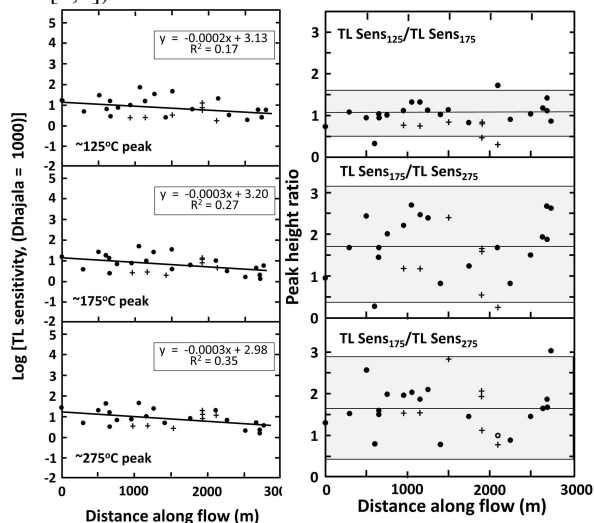
The glow curves for all of these 28 samples are plotted in Figure 1 along with back-scattered electron (BSE) images. We observed a variety of complex shapes in the glow curves and in peak intensities. Also evident is the existence of three robust peaks at 125°C, ~175°C and ~275°C.



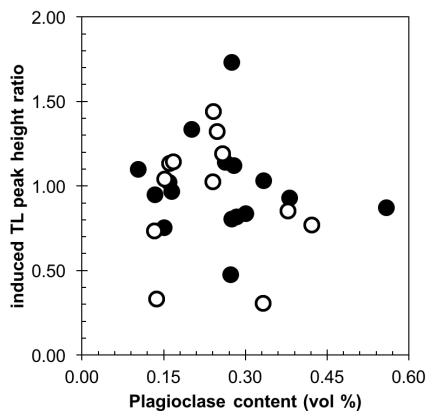
**Figure 1:** Glow curves collected for all 28 samples and their back scattered electron (BSE) images. Three distinct peaks are identified, 125°C, ~175°C and ~275°C. Solid lines represent samples collected from the channel interior, dashed lines indicate samples recovered from channel levees.

For each of the three peaks we plotted peak heights as TL sensitivity normalized to Dhajala (left hand plot) and peak ratios (right hand plot) with increasing flow distance in Figure 2. For all three peaks we see a correlation between induced TL intensity and flow distance in which TL drops by about an order of magnitude over the length of the flow. The trends for each peak appear very similar and the  $R^2$  value increases from the 125°C to the 175°C to the 275°C peak. However, they are not

statistically significant. Additionally, the scatter along the flow, which spans more than one order of magnitude, is comparable to the scatter observed in our previous studies of young (<50 ka) Idaho and Hawaiian basalts [1,2]).



**Figure 2:** (Left) Decrease in induced TL as a function of distance along flow and (b) peak height ratios of induced TL with increasing flow distance (the grey envelopes on the peak ratio plots are  $2\sigma$  standard errors). Dots represent samples collected inside the lava channel, and + symbols represent samples collected from the levees.



**Figure 3:** Peak height ratio (125°C/175°C) against plagioclase content. Open dots represent samples without quench crystals, whereas black dots are samples where quench crystals were observed.

Insight into the processes affecting the TL properties of geological samples can often be obtained by considering peak-height ratios (Figure 2 right hand plot). While all show considerable scatter, the 125/175 ratio shows considerably less scatter than the 125/275 and 175/275 plots.

In Figure 3 we compare the 125/175 ratio to the modal plagioclase content of the basalts in order to explore the idea that the 125°C peak reflects plagioclase

content and the 175°C peak removes the effect of sample heterogeneity. We also indicate which samples contain quench crystals (solid dots). We do not see any significant trends in this plot.

**Discussion:** It is usually safe to assume that the mineral responsible for the TL in a feldspar-bearing rock is feldspar. This assumption dates from the nineteenth century and was found to be true for meteorite classes. In this case, based on meteorite data, we suggest that the 125°C peak is due to low-temperature (ordered) plagioclase, the 175°C peak is due to high-temperature (disordered) feldspar and the 275°C peak is due to calcic phases. The variety of glow curve shapes is therefore a result of mixing these phases in various proportions. The BSE images (Figure 1) are not picking up this variation since (1) high and low feldspar are not distinguishable this way and (2) TL could be produced by phases below the resolution of the SEM. The peak height ratios are consistent with this interpretation; the 125°C and 175°C peaks are present in the same phase but the 275°C peak is decoupled and can show independent variations. So is the lack of correlation between the 125/175 ratio and modal plagioclase (Figure 3).

The decrease in TL sensitivity with distance along the flow (Figure 2, left), if real, might suggest that the TL is being produced by submicron feldspar in the glass which is converting to non-luminescent (or weakly-luminescent) feldspar along the flow. Thus, some of the apparent correlations between TL and age observed in previous work might be an artifact of sampling location; “old flows” sample close to the vent while “young samples” sample further from the vent. However, our field notes do not support this idea.

The bottom line is that while we are making progress in understanding TL and the crystallization behavior of basalts, we have still not characterized the cause of scatter in our data sufficient to make dating a possibility. Our next step is to obtain cathodoluminescence data for our samples in order to check for luminescent phases other than feldspar. One possibility is that spinel is playing a major part in determining the TL properties of these rocks.

**Acknowledgements:** This research is supported by the NASA Postdoctoral Program (administered by USRA) and FINESSE (Field Investigation to Enable Solar System Science and Exploration, PI J.L. Heldmann), a SSERVI research grant to NASA Ames Research Center.

**References:** [1] Sears D. W. G. et al. (2016) *J. Geophys. Res. Solid Earth* 122 (2), 906-922. [2] Sears D. W. G. et al. (2017) *J. Volcanol. Geotherm. Res.* 349, 74-82. [3] Sehlke et al. (2014) *Bull. Volc.* 76:876. [4] Robert et al. (2014) *Bull. Volc.* 76:824.