**Introduction:** The interaction between hot lava and ground ice on Mars produces a variety of landforms that could provide important insight into the nature and extent of water on Mars [1-5]. Quantifying these interactions relies on numerical models that have been difficult to validate under appropriate conditions. A remarkable outcrop of a sill that intruded into lake sediments in the western Idaho provides a rare opportunity to rigorously test these models.

**Field Site.** The sill is part of the Miocene Columbia River Basalt CRB flood basalt province. It is about 0.5-m thick with about 1 m of lake sediments exposed above and below the sill (Fig. 1). The sediments are related to the Clarkia fossil beds that preserve leaves, pollen, and other organic material in exquisite detail [6]. This pristine organic material allows the application of an established geothermometer developed by the petroleum industry [e.g., 7,8].

**Pollen Geothermometry:** The color of pollen and other organic material is an indicator of the maximum temperature that the host sediments were subjected to, a concept often referred to as “thermal maturity.” Initially translucent pollen grains, upon heating, turn to yellow and progressively darker shades of brown, eventually blackening completely near 300° C. The reactions causing these color changes are irreversible and the pollen materials are not greatly affected by other geologic processes – as long as the environment remains anoxic. However, the reactions take place quickly, allowing the pollen color to be used to record even rapid thermal events.

**Calibration.** While the geothermometry methods are well established, the do need to be calibrated for specific types of organic materials. Pollen of the same species as in the intruded lake sediments were collected from nearby localities and subjected to controlled heating in the laboratory. The opacity of the heated pollen were quantified with digital imaging equipment. It was discovered that certain types of pollen (bisaccate sacs) provided more reliable correlations with temperature than other pollen. Figure 2 shows the laboratory results for the sacs and the curve fitted to the data.

**Observed Temperature Profiles.** Samples were collected every few cm along a vertical profile. The pollen were extracted and their color measured using the same equipment as for the laboratory calibration. The resulting profiles of the maximum temperature the sediments were exposed to are shown in Figure 3. The temperature profile is remarkable in that it is essentially a constant at 250-300 °C, both above and below the sill. These results place challenging constraints for current numerical models of lava-water interaction.
Testing Models: The set of models tested to date assume that conduction with phase changes is the dominant heat transfer processes between the lava and the wet sediments. The baseline model is an extension of the Keszthelyi and Denlinger [9] model first created to explain the initial cooling of pahoehoe surfaces. The model uses a simple finite-difference algorithm but includes temperature-dependent thermal properties for the lava with a simple crystallization model governing the release of latent heat (versus glass formation). The effect of vesicles, important for pahoehoe flows, can be ignored for this avesicular sill.

The lake sediments are assumed to be 40% water by volume with the silicate portion having thermophysical properties similar to basalt. This is a relatively low water content for uncompactsed lake sediments [e.g., 10]. The water is assumed to boil at 100 °C or ~300 °C (corresponding to pressures of 0.1 or ~7 MPa) and the water vapor is instantaneously removed from the system. This simplification of the behavior of the vapor phase has proven adequate to reasonably reproduce the effect of the cooling by rain [11].

Discussion: These results indicate that the baseline model cannot be trusted to provide useful simulations of the interaction between groundwater (or ice) and lava. Other models incorporating the same physics will be equally untrustworthy. The problem is the simplifying assumption that the steam that is generated is instantaneously removed. Instead, it is more likely that the steam travels a modest distance before cooling and recondensing. A 2-phase circulation system is then set up, forming a “heat pipe.” This process produces a very constant temperature profile across the 2-phase region [e.g., 12]. However, to fit the field data, the steam should be at 250-300 °C, requiring a pressure ~7 MPa. This corresponds to hydrostatic pressure at a depth of hundreds of meters under a mix of sediments and water. Estimates of the lake depth range from 100-150 m, but the nature of the sediments indicates that this location was near the margin of the lake. This suggests that the heat pipe mechanism is viable only if the steam were raised to a pressure significantly above hydrostatic. The similarity of the temperature profiles above and below the sill may be a challenge to reproduce via the heat pipe mechanism. Until we complete our modeling of the heat pipe process it is unclear if additional or different processes need to be called upon to explain the field observations.

This project concludes with the determination that existing models for the interaction between lava and subsurface volatiles are inadequate and future studies are necessary to understand this dynamic environment.

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