Thermal Modeling of Gravel and Sand at Different Saturation Levels. J. Pokuri[1], K. M. Bushick[2], A. V. Viswanathan[2], J. T. Elam[3], A. R. Oliver[4], N. C. Brownstein[5], R. E. Tedder[6], [1]Green Hope High School, Cary, NC 27519. [2]Durham Academy Upper School, Durham NC 27705. [3]Durham School of the Arts, Durham NC 27701. [4]Duke University, Durham NC 27705. [5]Carrboro High School, Carrboro, NC 27516, [6] Saint Andrew's School, Middletown, DE 19709

Introduction: The key component to life on earth is liquid water. Consequently it can be expected that liquid water on other planets could potentially mean the presence of alien life. A planet that has received particular attention in recent decades is Mars because scientists suspect it may currently have significant amounts of groundwater [1]. By studying sediments similar to those found on Mars, we can identify areas where there may be liquid water on or below the surface of the planet. The focus of our investigation is to determine the relationship of thermal inertia on two sediments- sand and gravel- at different levels of saturation.

Thermal inertia in this study is defined by the ability of fine gravel to absorb and conduct heat throughout the day and retain it at night. By stimulating this diurnal and nocturnal occurrence in a controlled setting, we were able to collect the thermal inertia data of sand and gravel. This data was instrumental in constructing a thermal model.

The thermal model provides a visual aid showing the heating and cooling curves of sand and gravel at different levels of saturation. By comparing our data and thermal models with infrared data of Mars taken by orbiting satellites, we can hope to identify potential places where water lies on or below the surface of the planet[2].

Analytical Approach: To emulate conditions and sediments on Mars, we designed a heavily controlled experiment. We obtained a large amount of sediments from the Eno River in Durham, NC and sifted the deposits to separate the gravel from the sand. In compliance to NASA guidelines, we sifted enough sediment to fill four buckets 10cm tall and 20cm wide with sand and gravel (two buckets apiece). During the setup, we positioned a 630 watt/m^2 heat lamp 50cm above the center of the buckets at a 10º angle from the vertical, this lamp was used because it was similar to the 590 watt/m^2 maximimum that Mars experiences. The infrared thermometers were then mounted on tripods 0.5m away from the sample also at a 10º angle from the vertical. The measure of the infrared thermometer was set to Celsius. The setup can be seen in Figure 1.

During the experiment, all temperatures were taken in 30-second increments. First we took three initial measurements without the heat lamp turned on to get a baseline close to the ambient temperature. Then we turned on the heat lamp and proceeded to record the temperature shown on the infrared thermometer every 30 seconds. We continued to record temperatures until the sediment started to stabilize which was defined as a change of less than +/- 1°C for five minutes. After stabilization occurred, the heat lamp was turned off and measurements were once again taken every 30 seconds until the sediment stabilized.

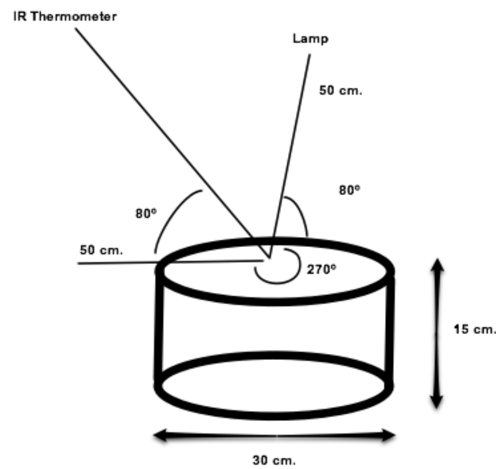

Figure 1: Diagram of the set up used to collect data and minimize inaccurate data

The objective of our experiment was to measure and model the thermal inertia of sand and gravel that were dry, saturated within 8 cm below the surface, 6cm below the surface, 4cm below the surface, 2 cm below the surface, and completely saturated. In order to perform the saturated tests, the pre-determined sediment was placed in the bucket and was then saturated with water. The dry sediment was then placed on the saturated sediment until a height of 10cm was achieved. At the end of each data cycle, the wet sediments were placed in an oven to dry.

These procedures were repeated many times for each saturation level and were averaged out in order to obtain the most accurate results possible. At the end of the entire data collection process, a thermal model was made to compare the thermal curves of the different saturation levels.

Results: After compiling all the data, graphs of the thermal inertia of sand and gravel were created. Logger Pro 3 was used to distinguish that the heating curves follow a natural logarithmic function and the cooling curves follow a natural exponential function.

The thermal inertia graphs show that the more saturated the sediments are, the less their maximum temperature will be but will be achieved at a shorter amount of time. The graphs differ because both sediments start at the same temperature, but the gravel curves peak at about three degrees higher than their respective sand curves. Both sediments stabilize after the cooling at approximately the same temperature. The heating and cooling curves for the sand are shown in Figure 2 and for the gravel are shown in Figure 3.

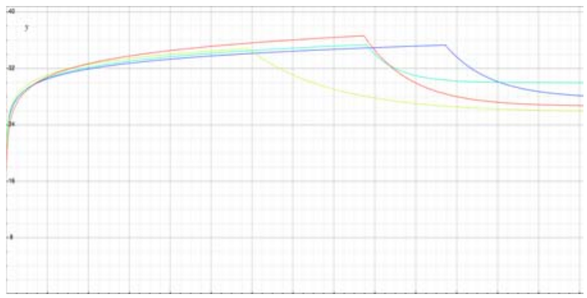

Figure 2: *Thermal behavior of sand at different levels of saturation: dry (red), saturated within 8 cm below the surface (turquoise), 6cm below the surface (blue), and 4cm below the surface (green).*

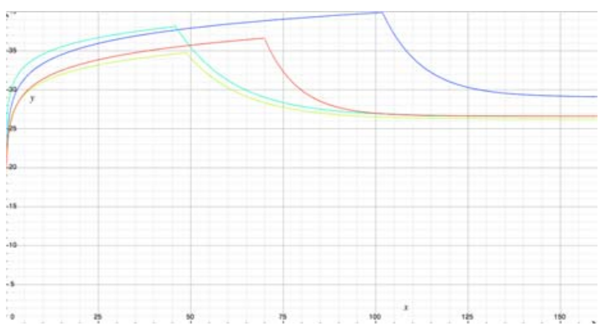

Figure 3: *Thermal behavior of gravel at different levels of saturation: dry (blue), saturated within 8 cm below the surface (turquoise), 6cm below the surface (red), and 4cm below the surface (green).*

Discussion: Taking into consideration the fact that water has a very high specific heat, we had hypothesized that as the water content and level of saturation increased, the sediment samples would achieve thermal stability faster and at a lower temperature.

The data from the sand samples turned out to follow our hypothesis with no irregularities. The data from the gravel was less predictable. While the temperatures at which each sample stabilized did end up in proportional order, the time at which it reached this stabilization did not. The runs from the gravel samples with 2 cm of saturation reached a stable temperature in much less time than they were relatively hypothesized to take.

There are many reasons why the gravel samples yielded less clear and less expected results. One of the biggest factors is that the infrared thermometer was measuring a small spot of the entire sample, which was not homogenous like the sand. This variance within the sample could account for much of the unsteady data; the small bumps along the curve. The time to stabilization may be accounted for by reevaluation of the parameters for stabilization, as much of the data, especially from the dry gravel run, could be truncated if stabilization was considered to be within 2 Cº or 3 Cº instead of 1 Cº.

Overall, the data from both sediments confirm that the temperature and time (omitting the 2 cm gravel data) of thermal stabilization is proportional to the amount of water saturation and the depth at which the saturation occurs. However it should be noted that to an extent, the larger sediment sizes result in less accurate and continuous data. This is an important consideration when dealing with remote sensing data.

Future Work: We would like to expand our experiment by conducting more comprehensive tests regarding evaporation. To study this process, we could weigh the sediment samples before and after each trial to evaluate how much of the water is being evaporated. These discrepancies will allow us to more accurately estimate the depth of groundwater on Mars, if the situation ever arises, by comparing our findings with data taken at the particular location of interest.

Additionally, we could increase the sediment sample size in order to test for the thermal inertia of sediments saturated at below 10cm depth. This way we could distinguish a depth where the maximum temperature of the thermal curve ceases to decrease and thus we would identify the range of depth groundwater under Mars needs to be for detection by satellite.

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