Sand or Rock? Finding Out from 1,000 km

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Remote sensing is a term invented to include techniques used by astronomers for centuries: the detailed investigation of objects beyond reach. Remote sensing now includes the use of sensors in areas of the electromagnetic spectrum outside the visual and their application not just to astronomical objects but places where a scientist *could* visit but getting there or studying a wide-enough area is impractical.

Remote sensing frequently relies on "ground truth" measurements made by a scientist at the sites of interest to validate the results obtained by the remote sensors, which are frequently mounted on aircraft or spacecraft. This activity explores a phenomenon familiar to students that is directly applied in spacecraft investigations of solid objects in the solar system.

It is difficult, when looking down on a surface from great heights, to determine the physical state of that surface. Is it solid, like Half Dome in Yosemite? Is it sandy, like the dunes in the Sahara? Measurements made in a portion of the electromagnetic spectrum called the thermal infrared permit scientists to determine remotely the state of the surface in question.

The thermal infrared is the portion of the spectrum we sense as heat. Thermometers are heat sensors familiar to everyone and will be used for measurements of sample surfaces. Infrared (IR) thermometers, working much like instruments on spacecraft, can now be purchased inexpensively and used for remote sensing experiments in the schoolyard laboratory.

This activity quantifies an experience many students have had visiting a beach, or even playing in a sandbox. A summer afternoon walk, barefoot, across sand can burn one's feet. Often people take a few steps and then bury their feet in the cooler subsurface sand

as they make their way across the beach. After sunset, the surface sand cools rapidly and buried feet are warmed by the deeper sand that has not cooled off yet. Stopping to rest on an empty fire ring, the beach walker notices how warm the concrete ring is long after the Sun has gone down. Students explore these effects using laboratory thermometers, and can use an IR thermometer if one is available.

OBJECTIVE: Observe how measurements made with instruments can be interpreted based on observations made with personal experience. Make "ground truth" measurements and observe how remote sensing measurements compare and that they can be used to investigate places where *in situ* measurements are difficult or impossible to make. In the course of this experiment, students will investigate the physical state of two surfaces and understand the application of these techniques to spacecraft investigations of surfaces in the solar system.

APPARATUS:
(1) **Cement stepping stone** for a walkway. This is one of the materials whose thermal characteristics will be compared. Available for a few dollars from a home improvement store.
(2) **Loose sand** having color similar to the cement stepping stone. The mass of sand should be greater than or equal to the mass of the stepping stone. Sand is available for a few dollars from a home improvement store.
(3) **Cardboard** folded and taped/glued to hold the sand in the same shape/size/depth as the block. A plastic bag or sheet can prevent sand leakage. In fact, any low-wall (to minimize shading) insulating container can be used. Pizza boxes may fortuitously match the size of a cement stepping stone. Alternatively, a suitable solid, dimension-matching "stone" can be made: mix cement and sand from a home improvement store with water in a plastic bag. Place the bag in a reinforced pizza box serving as a form.
(4) Four **laboratory thermometers** (that can be read to 1°C)
(5) Three scraps of **foam rubber**
(6) **Graph paper**
(7) **Non-contact = infrared (IR) thermometer** (optional). A non-contact thermometer measures the thermal infrared radiation emitted by an object. IR thermometers can be found with internet searches using "IR thermometer" and "temperature gun". Potential sources include http://www.ebay.com/ and
 http://www.tempgun.com/order.html .
(8) **Meter stick or tape measure or camera tripod or home-made spacer** (optional) for repeatable placement of the IR thermometer.
(9) Twin **desk lamps with equal-wattage tungsten bulbs** (optional, to do this experiment indoors during inclement weather). Fluorescent and LED lamps do not emit enough heat (they're too efficient generating light!) to warm the sand and stone surfaces.

ADVANCE PLANNING AND PREPARATION: Plan to collect the data for this experiment on one day and to analyze it on a second day. Acquiring a useful set of data will span most of a school day. The measurements take a few minutes each, perhaps

twice during each school period, and can be made by students in each period, independent of measurements made in other periods. On the first day your syllabus can be organized to permit measurement breaks between regular activities. On the second day, students in each class period can combine all of the data, plot it, and draw conclusions from their analyses.

Construct a cardboard tray, or find some other low-wall insulating container, that will hold sand with a depth equal to the thickness of the stepping stone. The tray should be the same size, or have larger dimensions than the stepping stone. Line the tray with a plastic bag or sheet to prevent sand leakage (the sand should not be in the bag).

The essence of remote sensing is making measurements at a distance. For this experiment, the thermal infrared emissions from the samples are measured with the non-contact IR thermometer. Students compare remote sensing measurements with the measurements made *in situ* with the laboratory thermometers.

To make successful remote measurements, the IR thermometer must only measure the temperatures of the sample surfaces, not the surroundings of the samples (Figure 1). To do this, measure the maximum diameter of a circle that will fit in the smaller of your sand or stepping stone samples. Find the field of view (aspect ratio) of the sensitivity cone in the IR thermometer specifications. The ratio quoted indicates the diameter of the field of view in terms of the distance of the sensor from the object being measured. For example, 1:1 means that at a distance of 1 meter the sensor is viewing a circle one meter in diameter. To better mimic remote sensing, a ratio of 1:6 or 1:8 is more realistic so the IR thermometer can be held at a greater distance from the surface while measuring the temperature of the sample.

Knowing the IR thermometer field of view ratio in advance, determine a distance for the students to use for their not-so-remote sensing measurements. You may wish to prepare a cardboard or wooden spacer, or even a chain of paper clips, to use.

[The distance of the object being measured and the field of view of the IR thermometer affect the "filling" of the sensor. It is better to overfill the sensor – make sure the sensor "sees" only the object, not any of its surroundings – than to underfill it. Underfilling the sensor confuses the reading by combining the temperature of the surface of interest with the temperature of the surrounding base material. (Think of measuring a candle flame with the room in the background. The heat of the flame is mostly "averaged out" by the cooler background of the room.) Underfilling can be dealt with during data analysis, but the process is involved and not directly applicable to the demonstration.]

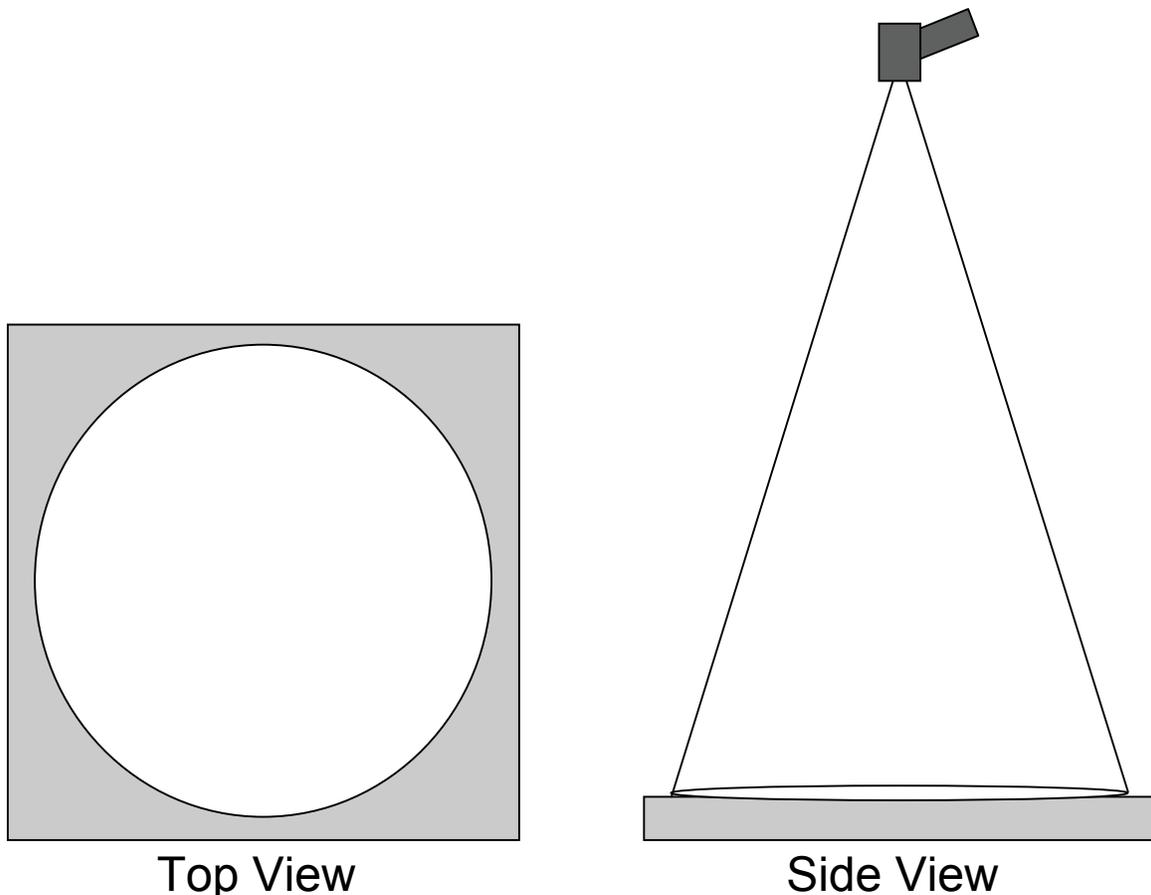|	
Top View	Side View

Fig. 1. The top view shows a measurement circle inscribed in a square sample of material, with extra room around it. The circle represents the area measured by the IR thermometer, located at the top of the side view. The side view illustrates the placement of the IR thermometer, centered over the sample. The aspect ratio in this side view is about 1:1.5 (the height of the IR thermometer is about 1.5 times the diameter of the circle).   An aspect ratio of 1:4 would place the IR thermometer at a height four times the diameter of the circle above the sample.

Store the stepping stone and sand-filled tray under the same conditions overnight (preferably outside and cold) prior to the day of the experiment. This starts the two samples at equal temperatures.

Scout a location for the samples where they will not be molested during the day of the experiment and will receive direct sunlight until early afternoon. Plan to record temperatures as the samples warm and as they cool.

PROCEDURE: To initiate the experiment, place the samples in direct sunlight. If the day is cloudy and the experiment cannot be postponed, move the samples indoors and use twin desk lamps with twin tungsten light bulbs, one aimed at each sample. Distances and light projection angles should be equal (just as sunlight would be for both samples).

To make subsurface measurements, insert a thermometer, bulb first, to the bottom of the sand tray near its center, beneath the whole layer of sand. To avoid breaking the thermometer under the stepping stone, place a piece of foam rubber on the ground, lay the thermometer on top of the foam rubber, and then gently place the stepping stone into direct contact on top of the thermometer, near the stone's center.

Initiate surface measurements by placing thermometers on each surface. Lay a piece of foam rubber on top of each thermometer and then gently place a book on top of the foam. This holds the thermometer bulbs in direct contact with the stone and sand surfaces, permitting the thermometers to equalize temperatures with the surfaces for accurate readings. The thermometers have equalized with the surfaces when their indicating fluid (dyed alcohol or mercury) no longer changes position. This should take less than a minute to occur. Record the subsurface temperatures and the surface temperatures. Then remove the upper thermometers, foam, and books.

With the meter stick (or spacer), hold the IR thermometer a measured, repeatable distance perpendicular to the sand surface and then the block surface (keep the meter stick out of the field of view of the thermometer during measurements). The IR thermometer should be placed so that its measurement circle's diameter comfortably fits inside the areas covered by both the sand and the stepping stone surfaces.

After the initial set of measurements with the IR thermometer and lab thermometers use all five thermometers to measure six temperatures (two bases, two surfaces in contact, two surfaces remotely measured) every 30 minutes or so. The number of measurements is subject to the duration of a classroom period and the rate of change of the surface temperatures. Each measurement should be recorded with the time of measurement. Remove the surface thermometers between measurements so insolation continues. Be sure students allow time for the surface thermometers to equilibrate (likely less than a minute) with the surfaces each time.

At a convenient time (late morning or early afternoon), make a final set of measurements of the sun-warmed stepping stone and sand. Then shade them or move them into the shade and continue regular measurements through the end of the (school) day as the samples cool. Combine all the measurements made during the day for analysis in class the next day.

THE UNDERLYING PRINCIPLES: Heat and light radiated by the Sun are absorbed by the top surface of the stepping stone and transferred through the solid stone by conduction. The stone is a poor conductor of heat and warms slowly. Because it has high thermal inertia it retains the heat it acquired long after insolation has ceased, radiating heat from its surface and warming the surrounding air.

Heat is transferred more efficiently through the sand – the difference between the stone and the sand is the gaps between sand grains that, on Earth, are filled with air and on most other solid solar system bodies are "filled" with vacuum. The sand grains, because of the gaps between them, have much more total surface area presented than does the

solid stepping stone. (The surface area of any gaps in the stepping stone is going to be smaller than for unconsolidated sand.) The greater surface area permits the sand to absorb and release heat more rapidly than the stepping stone.

The top layer of sand absorbs heat and light radiated by the Sun. The top layer transmits that heat to lower layers by both conduction to sand grains in contact, radiation to adjacent grains, and convection – air warmed by the sand warms adjacent grains. Cooling works in a similar fashion, with the top layer grains radiating to the sky. Lower grains both conduct and radiate to upper grains and warm the air between grains. The air then escapes and mixes with and warms the open atmosphere. In a vacuum, the process works by radiation and conduction, without convection.

The IR thermometer measures the amount of thermal infrared radiation in wavelengths from 8 – 14 micrometers (this is well beyond the wavelengths of visible light which span about 0.4 – 0.7 micrometers) and is calibrated to provide a temperature based on the amount of IR radiation detected. Spacecraft instruments often look at a wider range of the infrared spectrum to determine the amount of IR radiation emitted by the surface. An instrument, usually a spectrometer or a radiometer with a set of filters (at pre-determined wavelengths across the infrared spectral range of interest) is used. The data collected are combined to generate a curve of intensity vs. wavelength which usually is a close match to a "blackbody" curve. Knowing where the peak of the surface's intensity curve falls permits the determination of its temperature. Variations from a blackbody curve can also be interpreted, giving additional information about the surface.

[Reminder: A blackbody perfectly absorbs and emits all wavelengths of electromagnetic radiation. The spectrum of a blackbody, that is, a plot of intensity vs. wavelength (or frequency), has a distinctive "hump" shape: at short wavelengths intensity rises rapidly to a peak before slowly dropping down again towards longer wavelengths. The height and wavelength of the peak change with temperature; knowing the position of the peak intensity permits a blackbody's temperature to be deduced. The tungsten filament in a light bulb and stars (especially the hotter white and bluish ones) have spectra that are close to the spectrum of a true blackbody. For additional background, the basic properties of a blackbody are explained in most encyclopedias and introductory physics texts.]

DISCUSSION: The behaviors of the warming and cooling curves of the sand and the stone are different. The sand warms and cools quickly on its surface. In the example charted below (Figure 2), warming data collected in the morning by a student shows the sand starting cool (and cooler than the stepping stone) but warming rapidly both on the surface and at depth. The temperature of the top sand surface is notable.

The stepping stone started warmer (perhaps its storage area was warmer than the sand's prior to starting the experiment) and warmed further with insolation, but neither the top surface nor the bottom surface warmed as much as the sand. The difference between top and bottom is much less for the stepping stone than for the sand. Had data taking

continued with both samples in the shade, the stepping stone would have retained its warmth far longer than the sand.
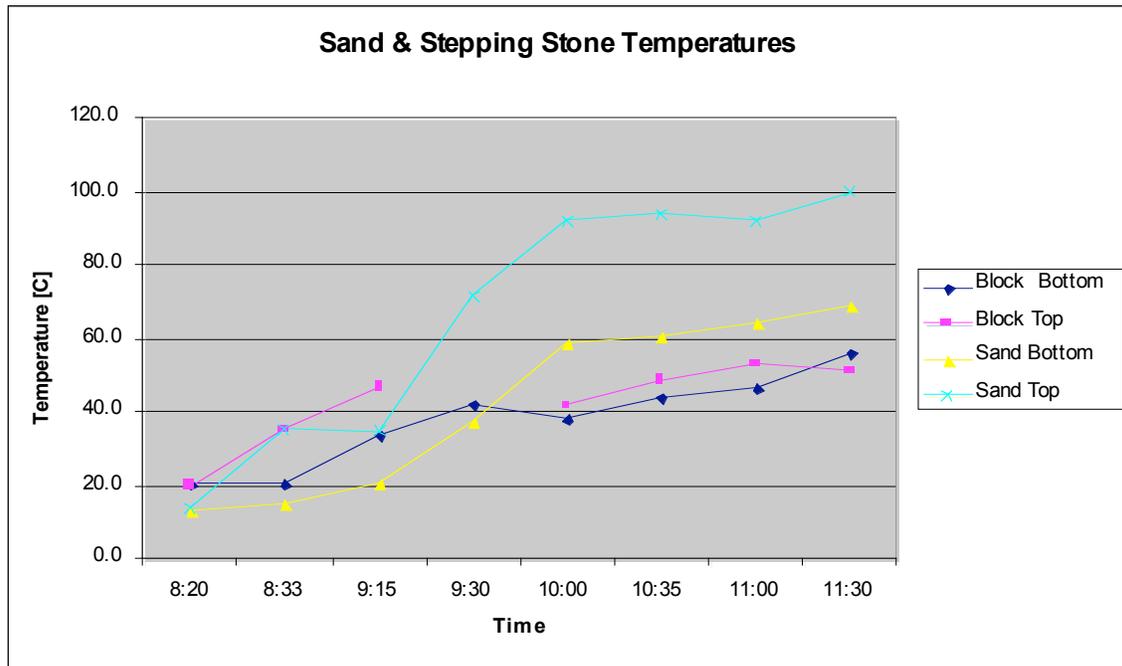

Fig. 2. Temperature measurements of the top and bottom surfaces of the sand sample and the stepping stone (block). The stepping stone is always cooler than the sand. These are real data acquired by a student. Note the apparent mis-reading of the thermometer on some occasions and the uneven timing of measurements.

With this experiment as an analog, we can assume that rapidly warming or cooling surfaces on other planets are covered by fragmented or loose, sandy material. Surfaces that warm and cool slowly are solid or perhaps have only a very thin layer of sandy material on top of the solid material.

Planetary scientists prefer to observe the warming phase of a planetary surface after a full (local) night of cooling. It is more diagnostic. This matches the exposure of the samples to sunlight at the beginning of the experiment. The after-sunset cooling curve on a planetary surface is useful and was matched by the shading done in the experiment.

The image pair from Mars, in Figure 3, illustrates the interpretation of thermal data. While temperature curves are not presented, the startling differences and similarities in the images permit planetary scientists to map in images whose finest details are larger than a football field (100 m per pixel) the distribution of rocks and dust. The daytime image shows dusty areas as warmer, and therefore bright; rocks are slow to warm and don't stand out during the day. The nighttime image shows dusty areas as darker because they cool quickly. Rocks retain longer the warmth they acquired during the day and appear relatively bright in the infrared at night. Note the rocky areas of ejecta around the

fresher craters and their rocky inner walls. Dust fills the bottoms of some craters, perhaps blown in from the surrounding plains by Martian windstorms.
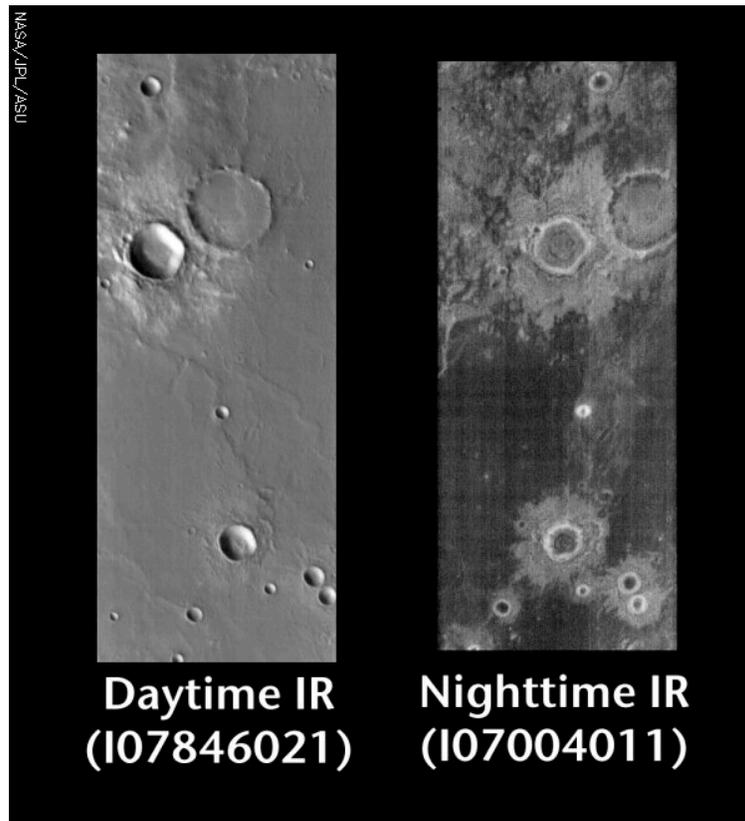

Fig. 3. Ancient and more recent craters are presented in this pair of images acquired by the Mars Odyssey spacecraft's Thermal Emission Imaging System (THEMIS). The daytime image records a combination of topography, physical shape, and thermal characteristics of the surface. Sun-facing slopes are warmed while shadowed slopes stay cool, presenting in the IR an appearance similar to the view in visible light. At night the effects of direct sunlight and shadowing disappear quickly, leaving warm rocks appearing bright and the rapidly cooling dust appearing dark. Each THEMIS image is 320 picture elements (pixels) across its width. By contrast, the IR thermometer used in this activity is a single pixel instrument. Image courtesy NASA/JPL/Arizona State University.

EXTENSION: Test a wide variety of materials. Compare the effects of material grain size, color, and reflectivity, and how wet and dry materials behave. Experiment with additional blocks and sand of different grades or with other materials. Try diatomaceous earth, flour, rice, kitty litter, dry pet food, fish tank or construction gravel of various sizes; any materials with differing colors and consistencies. Cold breakfast cereals in flakes or puffs can be compared to the same cereal bound into a "solid" with melted margarine and marshmallows (for example, Rice Krispies© and Rice Krispies Treats©. Wrap them in cellophane during insolation to keep them clean and you can eat the samples when you're done!). Experiment with good insulators like solid Styrofoam, "popcorn" Styrofoam, and foam rubber and test good conductors like scraps and shavings of iron and aluminum.

Sand, diatomaceous earth, and construction gravel can be purchased from home improvement stores. Flour, rice, cold cereals, dry pet food, and kitty litter can be found at grocery stores. Fish tank gravel, dry pet food, and kitty litter can be found at pet shops. Shipping and some hardware stores will have good insulators and a junkyard, metal supplier, hardware store or your school's or district's machine shop can supply metal samples.

FOR MORE INFORMATION:

An early version of this activity was developed by the author for NASA's Cassini Program. It may be found at http://saturn.jpl.nasa.gov/education/pdfs/Sand_Or_Rock.pdf. Day/night infrared images of Mars (including Figure 3) can be found at
http://themis.asu.edu/zoom-20040624A
http://themis.asu.edu/zoom-20040614A
http://themis.asu.edu/zoom-20040616A
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http://themis.asu.edu/zoom-20040621A

ACKNOWLEDGMENT:

Sample Student Data Sheet

Temperature Measurements, °C

Time of Measurement	Sand			Stone		
	Bottom	Top	IR (Top)	Bottom	Top	IR (Top)

Using the data table above, collect and then plot temperature vs. time for all three measurements of each material. Interpret the results.