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How Heating and Convection Contributes to Natural Disasters

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From the beginning I have sought to write a unit which is both exciting for my students, but yet has practical application in the curriculum we now teach. Presently, the "changing earth" is part of the K-4 science curriculum set up by the City of New Haven. Usually this includes discussion of weather, tides, the effect of the moon, and some discussion of earthquakes, volcanoes, and plate tectonics. Earlier I had considered centering the unit on volcanoes, and earthquakes. I guess it is the dramatic view of lava from a volcano, and the sight of buildings falling and the ground splitting that accounts for students' continued fascination with these kinds of events. It is because of this fascination which I have witnessed with my own students that I had chosen to center my unit on these particular types of disasters. However, another consideration - that of relevancy to my students kept nagging at me. As the testing of students broadens it will very shortly encompass both science and social studies. It therefore became apparent that the unit should embrace some scientific knowledge which would be age appropriate to my third graders. They and I have seen the cliché volcano made with baking soda. I hope that the unit is more than just a bag of science tricks. It was my good fortune that the seminar leader suggested that the concept of convection, that is the rising and falling of material due to heat, is at the core of not only volcanoes, earthquakes, and plate tectonics, but also has relevance when speaking of hurricanes, tornadoes, the earth's winds, and other processes. If students could grasp this one principle they would be able to better understand and connect these earthly occurrences under the concept of convection.

In dealing with the wide range of disasters that are included within the unit I suggest that each could be viewed as an independent subtopic and could be taught independently. This would allow for the teaching of the unit at various times throughout the year since at present the time allowed for science is not consistent. A discussion of various disasters could be strung out throughout the school year and yet have some continuity.

The outline of the unit is as follows:

I. Heating and Cooling Basics

- A. How does the application of heat affect materials?
- B. What is convection?

II. The Interior of the Earth

- A. What is the internal structure of the Earth?
- B. What is the source of heating inside the Earth?
- C. What is plate tectonics?
- D. How does convection lead to Earthquakes?
- E. How does convection lead to Volcanoes?

III. The Exterior of the Earth

- A. How do heat and water power convection?
- B. How does convection cause our weather?
- C. How do thunderstorms, hurricanes and tornadoes develop?

Heating and Cooling Basics

How does the application of heat affect materials?

As I begin the unit I would like to deal with the basic concept of convection which is the primary concept that ties the unit together. It is crucial for students to understand that when something is heated such as air it is less dense than cooler air so it rises. This kind of rising and falling is at the heart of our weather. Similarly temperature differences in the ocean result in ocean currents which mix Earth's huge mass of water. Likewise, the huge layer of rock called the mantle rises and falls, driving plate tectonics and causing earthquakes and volcanoes. Fluid motion occurs in solids, liquids, and gases. The mantle flows over a long time but it is not (primarily) molten; it is solid. The term "convection" is appropriate to all these situations and the notion of heated water rising up and falling back down is the type of cyclical movement they need to grasp.

Applying heat to water and air makes them expand. There are a couple of often

used demonstrations that can make this concept more tangible to children. One is to stretch the opening of a balloon over a flask of water. Heat the flask or place it in warm water and students will see that the balloon will expand due to the expansion of air within the flask. In response to students questions about why this happens I have found it useful to tell them that all matter such as water and air is made of small particles called molecules. At a cool temperature the molecules stay close together and move very little. However when heat is applied the molecules react by pulling away and expanding outward and their movement quickens. As the molecules spread out the air becomes less dense and so it rises.

Another good illustration of this is to have students pretend that they are molecules. As they stand together in a group side by side they would be simulating molecules at room temperature. Remember that the molecules are always in motion. Suggest to the children that they are now being heated up. As molecules they would begin to move round increasing their speed and widening the space between their neighbors and themselves. If the heating source were then removed the molecules (students) would begin to slow down and get closer to one another until they were standing next to one another. 1

What makes convection work is heat energy. Energy is the fuel that makes things happen. Energy is partially defined as the ability to do work. It can be found in a number of different forms. It can be chemical energy, electrical energy, heat (thermal) energy, light energy, or nuclear energy.

There are two types of energy: stored energy (potential) and moving energy (kinetic). If we have a battery we have potential energy. If we use that energy to power a flashlight we now have kinetic energy. Energy can be transferred into another sort of energy but it cannot be created and it cannot be destroyed. Energy always existed in one form or another. Heat is a form of energy and it can move in three ways: conduction (from hot to cold by vibration of molecules; convection (from warm to cool by fluid movement) and radiation (energy carried by light or electromagnetic radiation) which is how the Earth receives the energy from the Sun. 2

What is convection?

In the most basic term convection is the transfer of heat from a high temperature object to a low temperature object. According to scientific laws heat cannot pass from a cold object to a warm object. Convection takes place because heated materials rise because of their lower density and cool materials fall. A heated fluid will rise and then fall to be reheated again. Of course the rising and convection cannot occur without gravity. Sometimes fluids can become trapped in the cycle of heating, rising, cooling, and then falling and when that happens the circulation is called a convection cell. This pattern of rising and falling air is constantly happening in and around the Earth. Students can see this by heating some water and throwing in some rice or small macaroni. The heated water wants to expand and so rises up to the top. It then cools and falls back down toward the heat source below the bottom of the pot. Convection is critical in driving the Earth's weather. Convection is able to take some of the excess heat from the Earth's surface and send it into the higher levels of the atmosphere where it is released, and this helps keep the earth's temperature stable. Without convection the temperature of the Earth would be an average of 125º F rather than the normal 59ºF.3 Convection in the atmosphere and inside the Earth plays an important role in keeping the temperature on the Earth within a range that is capable of supporting human life.

The Interior of the Earth

Convection is not only occurring at the surface of the Earth but inside as well. How is it possible?

What is the internal structure of the Earth?

The Earth's interior consists of a very thin and brittle crust, the mantle, and the core. The outermost layer of the Earth is called the crust. It is a thin layer of rock that covers the globe. There are two kinds of crust. There is the oceanic crust which lies under the oceans and the continental crust which comprises the continents. One of the main differences between the two is their density. The lighter continental crust lays higher on the earth's surface and accounts for the land masses, and mountains. The heavier oceanic crust sits lower on the planet and forms the natural basins for the vast oceans which cover the Earth.

Also of importance beside the density of the two crusts is their thickness. The heavier oceanic crust is relatively thin only about 7 miles. The lighter continental crust while thicker is lighter in density so it can be supported by the material underneath. The continental crust averages about 20 miles thick but can be up to 40 miles thick in certain places especially where there are mountain ranges.4

Below the crust is the mantle. The mantle is divided into two sections. The upper part of the mantle and the crust make up what is known as the lithosphere. Both of these parts are rigid and cooler in comparison to the material below in the lower part of the mantle or asthenosphere. The asthenosphere or "soft" area is between 100 and 200 kilometers below the Earth's surface and the temperature is near the melting point. The entire mantle beneath the lithosphere acts like plastic that is pliable enough to make land masses or plates move across it.5

The core is made of two distinct parts. The inner core is a solid mass which is surrounded by the outer core which is mostly liquid. While the core and mantle are about equal in thickness, the core forms only 15% of the Earth's volume whereas the mantle covers about 84% of its volume and 63% of its mass. The remaining 1% is the crust.6

What is the source of heat inside the Earth?

The heat within the Earth is the result of the natural process that occurred during the planet's development. The Earth formed from a cloud of a swirling mass of particles and gas some 4.57 billion years ago. As the Earth took shape gravitation pulled some of the denser pieces to the core. As the process continued it created tremendous amounts of heat which caused less dense material to rise and form layers. Therefore the core is a dense solid mass of almost pure iron. The heat from inside the Earth is the result of leftover heat from the process of "accretion" during which the Earth absorbed the orbital energy of colliding/sticking bodies (like asteroids) and from the decay of radioactive elements like uranium, thorium, and a heavy isotope of potassium. Thus half of the Earth's internal heat supply comes from radioactive decay and half comes from primordial heat left over from the planet's formation. As the Earth assumed a shape closer to what it is today it was covered by a low-density crust, oceans, and an atmosphere. 7

What is plate tectonics?

This theory was first suggested by Alfed Wegener a German meteorologist in his 1915 book *: The Origin of Continents and Oceans* . In his book Wegener discussed his puzzlement concerning the fact that he had collected similar fossils and rocks on different continents. How could this be unless all of the continents had once been joined together in a supercontinent he called Pangaea. His speculation was not new because Sir Francis Bacon had written in 1620 that it was obviously apparent from looking at maps that the South American coast line fit side by side with the coast of Africa. Despite these curious observations this theory of continental drift was deemed crazy primarily because Wegener could not account for how the continents could break off and slide away from each other. Many years later when studies showed that a portion of the ocean floor was spreading, Wegener's ideas didn't sound so foolish. By 1960 scientists began to put together the "plate tectonic theory".8

As previously stated the Earth's outer surface is covered with a thin crust. This crust lies on top of the asthenosphere which has been compared to a plastic like material. By plastic it is not meant to conjure up the idea of a rigid material but something almost of the order of silly putty which is solid but pliable. The idea of mantle convection - that there are convection cells of hot rock circulating beneath the Earth's crust and causing the crust to split and move about - was first proposed by an English geologist named Arthur Holmes around 1929.

Plate tectonic theory says Earth's crust is broken into 12 major plates all moving relative to each other. The 12 major plates are the result of the stiff lithosphere cracking as it slips and slides on top of the putty-like asthenosphere. The rising and falling (convection) of mantle rock helps to propel the plates. The example which is most of used is comparing the crust and lithosphere to the shell of an egg. If it is cracked it breaks into small pieces or plates but it sits on the moving white of the egg which most resembles the asthenosphere. Most of the activity whether earthquakes or volcanism occur at the edge of the boundaries of the plates.

How do cooling and convection inside the Earth lead to Earthquakes?

We have already discussed the idea of convection, which is the rising of heated fluid and the falling of cooled fluid. Within the Earth the process takes place in the asthenosphere. The explanation of this movement is referred to as Mantle Convection Theory. The theory states that within Earth's mantle there is rock rising and falling in a circular fashion. The convection currents result from different temperatures in mantle materials. These hot upwellings and cold downwellings avoid each other and set up a pattern. At first it was believed that this material rises in the asthenosphere and moves laterally across under the lithosphere moving the plates like they are on a conveyor belt. It seemed that the spreading seafloor was what set the plates in continual motion. The older heavier edge of the plate on the other side would sink or "subduct" as the ocean floor spread apart. Now scientists believe the reverse seems to be the catalyst for the plates moving. The "subducting" edge of the plate sinks down and is gradually absorbed back into the mantle dragging along the rest of the plate.

While the exact cause of plate movement cannot be positively certain there is no doubt that the plates often bump into one another and move in different directions. It is from this bumping and jostling that earthquakes occur. There are three different kinds of plate boundaries: convergent, divergent, and transform. Most geological activity takes place on these boundaries all over the world.

Convergent boundaries are places where the boundaries of plates are moving toward each other and bump or crash into each other resulting in the destruction of the Earth's crust. Here is where the greatest earthquakes in the world occur. If two continental plates collide the edges of the plates will buckle and form mountains. If an oceanic plate and a continental plate crash the dense oceanic plate will dip under the edge of the other. This process is called subduction. An example of this can be seen along the coast of South America where the oceanic Nazca Plate crashed into and is diving beneath South America. The result of this crash was the formation of the Andes Mountains.

Remember that oceanic plates will subduct (be drawn down) into the mantle because of their greater density but a continent cannot subduct because of its lighter density. Thus oceanic plates will recycle themselves by returning to the molten asthenosphere while continents are never destroyed but will reconfigure themselves as they move about and slam into other continents.

Divergent boundaries are places where the plates are moving apart and new crust is being created. As the plates separate the block between them usually sinks into the softer plastic like interior of the asthenosphere. The falling land forms a valley or rift. Then magma seeps up and fills in the cracks. This is what is happening between the South American plate and the African plate. As the plates separate new crust is forming along these faults. When it was first noticed that a new sea-floor was being made scientist wondered if the Earth was going to get larger. That didn't happen because as the new sea-floor is created the old is subducted back down into the mantle where it is recycled.

Transform boundaries are places where plates slide by each other. The plates slide by each other in a horizontal motion and because the edges of the plates are usually uneven there is the potential for large eruptions such as that occurring near the San Andreas Fault in California. One of the strongest earthquakes along this fault was the 1906 San Francisco Earthquake.

How do cooling and convection inside the Earth lead to Volcanoes?

Most of the Earth's volcanoes form where the ocean plates are separating from each other (divergent boundaries). These spreading center volcanoes are caused when the oceanic plates are pulled back and oceanic rifts occur. We can see this in the case of the Mid-Atlantic ridge where the sea floor is spreading apart. Over 80% of the Earth's magma comes out of the Earth in the oceans. As the plate pulls apart some of the asthenosphere liquefies and rises to fill in the gap.9

The classic volcanic cone which we are use to seeing occurs in 7% to 13% of the time at a subduction zone.10 Just the process of the plate diving back into the mantle involves a tremendous amount of energy which results in Earth's greatest earthquakes. While these volcanoes, such as Vesuvius, are spectacular, they produce far less magma than the oceanic volcanoes.

Transform faults in which the boundaries of plates slide past each other have little or no association with volcanism. The horizontal sliding does not allow a rift to develop where magma could be released.

Sometimes volcanoes occur in the middle of a plate. To account for these volcanoes scientist have suggested the plume theory. In this theory a hot narrow plume of mantle rises from the very hot core-mantle boundary and when it reaches the surface it forms what is called a hot spot. At the hotspot, mantle rock melts when it gets close to the surface (where pressure is lower and it's easier to melt). The melted rock or magma will then erupt and build a volcano. If the eruptions take place on a moving plate it will develop a long line of volcanic islands like the Hawaiian Islands.

An eruption can last a few minutes, hours, or even days. The eruption can consist of oozing lava, or perhaps a spectacular explosion. This all depends on the type of magma that the volcano extrudes. Magma can have different viscosity or resistance to flow depending on its content of silica, and also depending on its temperature. In other words high viscosity means the lava is thick and may trap gases and build up pressure leading to a dangerous explosion. Low viscosity means that the lava is thin and can flow freely without trapping rocks or gases; an eruption with this sort of lava will be calmer.

There are a number of types of eruptions. An eruption of lava with high viscosity will be very damaging resulting in what are called a Vulcanian or Plinian type of eruption. A low viscosity eruption will result in a calmer event which would be either Icelandic, Hawaiian, or Strombolian.

There are a number of types of volcanoes but I have chosen to limit discussion to 3 main types based on their eruption patterns and their general form. Their eruption pattern is determined largely by the type of magma (called lava if it reaches the surface) they produce. They are the, Shield Volcano, Scoria Cone, and Stratovolcano.

The Shield volcano has very gentle slopes that convex upward. They are broad, low profile volcanoes. Their shape comes from the fact that they are built by Icelandic or Hawaiian type (low viscosity) eruptions (Mauna Loa, Haleakala).

The Scoria cone has straight sides with steep slopes and a large summit crater. They are also called cinder cones and are the most common type of volcano. They are developed as a result of Strombolian-type eruptions where the magma that is released is of medium viscosity. (Paricutin Volcano and Stromboli Volcano)

The Stratovolcano has gentle lower slopes but the upper portion usually rises steeply with a small summit crater. They are also known as composite cones. They are the most picturesque and most deadly volcanoes and are associated with explosive plinian eruptions. Their lava is high-viscosity so it tends to solidify and form a protective cap. (Mt. Fuji, Mt. St. Helens, and Mt .Kilimanjaro)

The Exterior of the Earth

How do heat and water power convection?

So far we have considered energy that flows from the interior of the Earth to its surface. This energy is capable of doing some extraordinary things like causing earthquakes and volcanoes. However, the amount of heat generated from the Earth's interior is nothing compared to the energy that is radiated from the sun and reaches the Earth on a daily basis. Only a fraction of the energy radiated by the sun reaches the Earth and yet that is more than 5,300 times greater than the flow of energy from the interior of the Earth.11 Water has the unique ability to store heat and because it is so plentiful on the earth it is capable of transferring large amounts of heat around the planet. It is the heat stored in water that changes it into water vapor and begins the water or hydrologic cycle. When water evaporates it changes to a gas and absorbs heat. When the water vapor changes back to water through condensation it releases heat. As water freezes to ice, molecules slow down and heat is released. Likewise, when ice melts heat is absorbed and the molecules speed up and move apart from one another. This process of sublimation and deposition is another cycle that continues all over the Earth. All of this keeps the Earth from experiencing extreme ranges in temperature.

How does convection help to create our weather?

The hydrologic cycle is continuously running. As it's heated by the sun, water evaporates from bodies of water and also through transpiration plants add water into the atmosphere. The vapor attaches itself to small particles of dust in the atmosphere and gathers as clouds. As the clouds become heavier the vapor condenses and falls to Earth as rain or snow depending on the temperature of the surrounding air.

As previously stated the surface and near-surface waters of the oceans absorb a large quantity of solar energy. Through tides and winds some of this heat is also distributed into the deeper and dense regions of the ocean. Winds drive the oceans down to a depth of about 325 (100m).12 This helps to bring warmth to the polar regions of the Earth.

The prevailing winds and climate zones are also affected by convection. The earth receives most of the sun's rays along the equator because it hits that area most directly while it just skims the poles. The air around the equator is heated and rises and begins to float toward the poles while at the same time cool air is dragged down toward the equator. This circular motion sets up convection cells above the Earth (similar to those within the Earth's mantle) that distribute warm air around the globe. If not for the rotation of the Earth the rising air from the region of the equator would sink down near the poles. There would be one convection cell from the Equator going to the North Pole and one going from the Equator to the South Pole.

However while this air exchange goes on the Earth is also turning and this pushes the air sideways. The Coriolis Effect, as it is called, makes the air mass move to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The bottom of convection cells drive prevailing winds, and where cells meet leads to the jet streams. For example the Trade Winds are cooling air which is falling and returning to the warmer equator. Instead of reaching the poles the warm air was deflected so far east that it cooled before reaching the subtropic latitude. Thus the Earth's rotation causes the convection process to take the form of three convection cells in each hemisphere. As they fall the Trade Winds are deflected to the right in the Northern Hemisphere and thus push westward.

How does convection help develop thunderstorms, hurricanes, and tornadoes?

A heated rising air mass is another form of convection. When air rises it goes to lower pressure and expands, and the expansion causes its temperature to drop; when the temperature is low enough water vapor in it will condense into liquid water. Thunderstorms begin as the water vapor in the rising air mass condenses and releases more heat which makes the air rise higher, and thus draws in more moist air. Most thunderstorms form in late afternoons during the summer when the temperature of the ground and lower atmosphere are warmest. The early development of a thunderstorm requires that there is a continuous supply of rising warm moist air. When the water drops become too heavy they begin to fall and pull in some cooler air. What follows is a cycle of continuous updrafts and downdrafts which make for the more violent part of the storm. As the rain falls and downdrafts pull in more cool air the heat is cut off and the downdrafts dominate and updrafts dissipate along with the thunderstorm.

To show students the effect that temperature has on air movement have students cut a 2 inch diameter (6 cm) spiral from a piece of tissue paper. Cut a piece of thread and tape it to the center of the spiral. Turn on a desk lamp pointing it upward. Hold the thread and the spiral over the lamp about 4 inches (10cm) above the light. The result is that the tissue spiral will begin to turn. The heat from the light made the air above the light move faster and spread out, and the cooler air rushed in to take the place of the warmer air and so the spiral turns. This movement is called convection.

Hurricanes occur in the North Atlantic and North Pacific oceans. Hurricanes that strike the eastern part of the United States usually begin their development as storms in the western region of Africa or the Caribbean. Hurricanes follow a set of stages in from their formation to their dissipation. Initially a hurricane is a *tropical disturbance* of moist upwellings with a light circulation. The surface low pressure strengthens and a storm begins to develop. The surface air flows into the center which acts like a chimney, pumping, warm, moist air rapidly upward where it cools and condenses water thus releasing great amounts of heat. This re-warmed air strengthens the updrafts ands draws in more warm moist air from below. As the speed increases it is categorized as a *tropical depression* . If the wind speed reaches greater than 39 mi/hr but less than 74 mi/hr it becomes a *tropical storm* and receives a name. The tropical storm will only become a hurricane if the wind speed reaches greater than 74 mi/hr.13

The most feared type of storm in the world is the tornado. Most tornados occur as the result of large (supercell) thunderstorms. Warm moist upwellings of air develop into a thunderstorm. The rotation of the column of air appears to happen when winds at two different altitudes blow at two different speeds causing wind shear. This causes a horizontal rotation of the column of air. If this column of air gets caught in a supercell updraft the updraft tightens the spin (much like a skater spins faster when arms are pulled close to the body) and a funnel cloud is created.14

So we have seen that convection - the rising of a heated fluid and falling of a cooled fluid forms the basis of the dynamic nature of the planet. Hopefully, students will come to see that the planet they live on is in continual motion. Not only are things moving above the surface but a tremendous amount of movement is going on underneath their feet deep below us. It is amazing that such a seemingly simple thing as rising and falling has so much importance for life on our planet.

Lesson Plan #1

Reading: Magic Tree House Book : *Vacation Under the Volcano* by Mary Pope Osborne

There are other books in the series which go along with this unit. Check out the student bibliography.

Objective: to recognize fiction and nonfiction information in a historical fiction book

Materials: Magic Tree House Book: *Vacation Under the Volcano*

Summary: In this story the main characters Annie and Jack travel back in time to Pompeii just as Mt. Vesuvius is about to erupt, and they must find a In the process the characters introduce some basic facts about ancient life in Pompeii and about earthquakes.

Graphic organizer that consists of two columns one labeled fictional details and the other factual details.

Procedure:

1. Students will have read the story in class.
2. Teacher will review characteristics of historical fiction (telling a story where the setting and some characters, and/or events are historically accurate)
3. Have students orally offer suggestions about what aspects of *Vacation Under the Volcano* is fiction and nonfiction.
4. Have students fill in their graphic organizers - if possible let them work in teams.
6. Discuss with students why the author sets her books in historical settings?
Does this make the story more interesting to them? Would they get more out of just reading a nonfiction book about earthquakes? Did it help them to understand what the

people in Pompeii experienced?
5. Create a classroom chart of their findings. Emphasize to students that they must understand where the fictional parts are so they aren't misinformed.

Lesson Plan #2 Writing

Objective: Students will be able to write a journal entry that might have been written by someone near Mt. Vesuvius when it erupted in 79 A.D.

There are some web sites that have copies (translations of the letters of Pliny the Younger concerning the death of his uncle, Pliny the Elder during the eruption of Mt. Vesuvius in 79 A.D. Older students might be able to read them or for younger children the teacher can use the letters as a shared reading opportunity.

See Living with a Volcano in your backyard- An Educator's Guide U.S. Geological Survey GIP 19, www.vulcan.wr.usgs.gov/Outreach/Publications/GIP19/framework.html

Materials: copies of the two letters from Pliny the Younger to Tacitus,

This lesson would occur later in the unit concerning volcanoes when students should have a general understanding of volcanoes. This eruption would be studied as a historically significant eruption and the devastating affect it had on the people who lived near it.

Writing journal entries for characters is something most 2nd, 3rd and higher students will have experience for Connecticut's Mastery Tests.

Procedure:

1. Students will be given a copy of the two letters of Pliny the Younger concerning the death of his uncle in the eruption of Mt. Vesuvius.
2. The teacher will read the accounts in a shared reading lesson, making sure to review vocabulary, and student's comprehension.
3. Students will write a journal they might have written if they were one of the few survivors of the eruption of Mt. Vesuvius.

4. Students may also draw a picture to illustrate their entry and share both with their classmates.

Lesson Plan #3 Viscosity Study

(taken from http://www.nps.gov/archive/crmo/chap2d.htm)

Obj. Students will be able to describe the liquids in terms of their viscosity

Students will be able to explain how heat affects a liquid's viscosity.

Students will understand the difference between a basaltic lava which is runny and

rhyolite lava which is thicker.

Materials: smooth surface like a cookie sheet or white board, water, honey, vegetable oil, heat source, refrigeration if possible, chart to record findings.

1. On one side of the smooth surface draw a line and label it "A" and on the bottom label the other side "B".
2. Pretend that the liquids are different lavas at varying temperatures. Record the temperature, and time that it takes for the liquids to travel from side "A" to side "B". Also record if the liquid is highly viscous (thick) or low viscous (runny).
3. You can also record whether the liquids would be high in silica (high viscosity) or little silica (low viscosity.
4. Note how temperature affected viscosity. Did the honey noticeably cool as it slid down the surface? If so did it look differently at the bottom than it did on top?
5. Did any of the materials look ropey- like pahoehoe?
6. If you extend the experiment and refrigerate some of the materials would the honey crystallize and become like jagged aa lava?

Notes

1. acting like molecules

2. Ahrens, Meteorology Today, 28-29

3. http://www.weatherquestion.com/What_is_convection.htm

4. Abbott, Natural Disasters, 29-30

5. Abbott, Natural Disasters, 29-30

6. Abbott, Natural Disasters, 28-30

7. Abbott, Natural Disasters, 26-30

8. Abbott, Natural Disasters, 51-52

9. Abbott, Natural Disasters, 175

10. Abbott, Natural Disaster, 175

11. Abbott, Natural Disasters, 39

12. Abbott, Natural Disasters, 281

13. Abbott, Natural Disasters, 33-37

14. Abbott, Natural Disasters, 334-327

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