Earth’s Moving Mantle Demonstration*
(Teacher Master)

Objectives: Experiment with thermal convection. Illustrate how thermal energy (heat) can generate motion (flow) in a fluid. The thermal convection in this model is similar to the convection that is inferred for Earth’s mantle. Convection can produce horizontal flow that can cause (or is related to) plate motions. Investigate the viscosity of a fluid and illustrate that Earth’s mantle can be thought of as a solid for short-duration processes (such as the propagation of seismic waves) and as a very viscous fluid for long-duration processes (such as mantle convection and plate tectonic movements).

Materials

1 glass bread loaf dish (1.5 liter)*
2 ceramic coffee cups
1 small Sterno can or 2 small candles
Vegetable oil (about 800–1,000 ml, or 28–34 fl oz)
10 ml (approx. 2 teaspoons) thyme
1 metal spoon
1 box of matches
3 pieces of thin (about 2 mm, or 1/16 in, thick) balsa wood, each 3 × 2 in

*A 2 liter, 20 × 20 cm, or 8 × 8 inch glass dish can be substituted; 2 small Sterno cans or 3 small candles can be used for the extra width of the container.

Thermal convection experiments: Mix the vegetable oil and the thyme (spice) in the glass dish. Stir thoroughly to distribute the flakes of thyme. Arrange glass dish and other materials as shown in figure 1 [appendix]. (Because of the viscosity of the oil and the density of the flakes of thyme, the pieces of thyme are approximately neutrally buoyant. If left unstirred for a long period of time, the thyme will not be evenly distributed in the volume of oil—some of the thyme will tend to float, and some will tend to sink. However, the thyme stays distributed for a sufficient length of time to perform the experiment. If the thyme becomes significantly separated, just stir to mix thoroughly, let the mixture stand without heat until the flakes of thyme are not moving, and begin the experiment again by adding heat.)

1. Observe the oil and spice mixture. With no heat (energy) being added to the system, there should be little or no movement of the liquid. The flakes of thyme will flow with the liquid, showing the direction and velocity of any fluid flow.

2. Light the Sterno can and let the oil heat up for a couple of minutes. (If you don’t wish to use the Sterno as a source of heat, you can use two small candles [figure 2] or a coffee cup with a one-cup electric element heater to heat water in the cup and provide heat to the bottom of the glass dish.) As the oil heats and begins to flow, observe the pattern of fluid flow (circulation) by noting the location of individual flakes of thyme over time (figure 3).

*Adapted from Braile, L. W. (2000). *Explorations in earth science: Thermal convection and viscosity of a fluid.* Retrieved from http://web.ics.purdue.edu/~braile/edumod/convect/convect.htm. Used by permission.

Be sure to view the model several times during the experiment, both from above the dish and from the side of the dish. Draw a sketch of the circulation. (Copies of figure 4 can be used as a base diagram for sketching the flow using arrows.) Is the pattern approximately symmetric on the two sides of the heated area? Where do you observe upward flow? Where do you see downward flow? Where do you observe horizontal flow?

Note that the flow defines a convection cell (actually two cells) in which upward flow above the flame (caused by heating of the fluid that causes expansion and a reduction in density) causes horizontal flow near the surface of the liquid. Cooling of the liquid near the ends of the container increases the density of the liquid and produces sinking and a return horizontal flow toward the center of the container, thus completing a "cycle" of fluid flow in the convection cell. Note that the heat added to the bottom of the container is carried to the surface and distributed primarily by movement of the heated liquid (convection current) rather than by conduction. This type of energy movement is called *thermal convection* because added heat causes the fluid flow (circulation by convection) by lowering the density of the liquid. The difference in temperature between the near surface region of the oil measured above the heat source and near the ends of the glass dish (far from the heat) will be about 2–3 °C and can be observed using a sensitive thermometer. (It is not necessary to heat the oil for a long time, or to a high temperature, to cause convection. The convection will begin shortly after the heat is applied to the bottom of the glass dish. The heating time will be somewhat longer using the candles.)

3. Place the thin pieces of balsa wood on the surface of the liquid as shown in figure 5. Observe the motion of the pieces of wood (representing the relatively rigid parts of plates such as most continental regions) over time. You should see plate separation or divergence (analogous to continental rifting and subsequent sea-floor spreading of the oceanic lithosphere along midocean ridges) at the center of the container where significant upward fluid flow is caused by the heating. (Because of surface tension, the two pieces of wood at the center of the glass dish may tend to "stick together." In this case, use a pencil or other tool to slightly separate the wood. Once the surface tension is reduced, the plates will move with the underlying fluid flow.) Additionally, as time progresses, two of the plates should collide analogous to the continental collision that often accompanies subduction where two plates are moving toward each other (converging).

Convection in Earth: Thermal convection is inferred to exist on a large scale in at least two regions in Earth. The liquid outer core and the upper mantle behave as a solid for seismic wave propagation and as a very viscous fluid for long-duration geologic processes including convection. The heat that causes convection within Earth comes from two sources—original heat from accretion and heat released during radioactive decay of unstable isotopes. Although Earth is about 4.5 billion years old, some heat remains from the accretionary process during its formation because fragments of Earth materials were heated to very high temperatures by impact during formation of the planet, and Earth materials have relatively low thermal conductivity so that significant heat has been retained from the early stages of Earth history. A more important source of heat, however, is the natural, spontaneous, radioactive decay of unstable isotopes of elements that are distributed throughout Earth, particularly in the crust and mantle. These radioactive elements include uranium, thorium, and rubidium. These sources of heat cause Earth's temperature to increase with depth to a temperature of about 5,000 °C in the inner core.

Earth's outer core is inferred to be mostly liquid iron. Convective flow within the outer core not only brings heat to the core-mantle boundary where some of it is transferred into the mantle, but also causes Earth's magnetic field by motions of the electrically conductive inner-core material. Temperatures are hot enough in the upper mantle (≥ 1,200 °C) to cause thermal convection of the highly viscous upper mantle rocks, although the flow velocity is apparently very low—on the order of only centimeters per year. Mantle convection in either the upper mantle or the whole mantle has been suggested (figure 6). The mantle flow is a likely cause of plate tectonic motions. There is still considerable debate about the details of convection in the mantle and the relationship of convection to plate tectonics. For example, there is evidence from the identification of subducted slabs in Earth's upper mantle that lithospheric slabs (subducted plates) sometimes extend (penetrate) to depths greater than the upper mantle (below the mantle transition zone, including the 670 km discontinuity, where seismic wave velocity increases rapidly with depth indicating changes in composition or crystalline structure or "packing" of mantle minerals). Therefore, mantle convection may not be as simple as the upper mantle convection or whole mantle convection models that are illustrated in figure 6. Similarly, the exact relationship of mantle convection to plate motions is not presently known. Mantle convection could be the primary cause of plate tectonics. Alternatively, mantle convection could be a more-passive response to plate motions. In either case, it appears clear that heat within Earth is the ultimate driving force for plate tectonics and mantle convection. For more information on plate tectonics and mantle convection, see almost any recent introductory college-level textbook on geology, such as Press and Siever (1994), Lutgens and Tarbuck (1999), or Skinner and Porter (1999).

References

Atwater, T., *Continental Drift and Plate Tectonics*, videotape, 20 minutes, 1988. (To order, send a check for $15 payable to the "Regents of the University of California" and a request for the 1988 *Continental Drift and Plate Tectonics* videotape to Rick Johnson, Instructional Consultation, UC–Santa Barbara, Santa Barbara, CA 93106.)

Lutgens, F. K., & Tarbuck, E. J. (1999). Plate Tectonics (chap. 5). *Foundations of earth science.* Upper Saddle River, NJ: Prentice Hall.

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Simkin, T., Unger, J. D., Tilling, R. I., Vogt, P. R., & Spall, H. (1994). *This dynamic planet: A world map of volcanoes, earthquakes, impact craters, and plate tectonics* [map, 1:30,000,000 scale]. Smithsonian Institution and US Geological Survey. Retrieved from http://pubs.usgs.gov/pdf/planet.html. [888-ASK-USGS].

Skinner, B., Porter, S., & Botkin, D. (1999). *The blue planet: An introduction to earth system science* (2nd ed.). New York: J. Wiley.

Smithsonian Institution (1989). *Inside Hawaiian volcanoes* [videotape, 25 minutes]. Retrieved from http://nmnhwww.si.edu/gvp/products/inv.htm.

Appendix: Figures 1–6

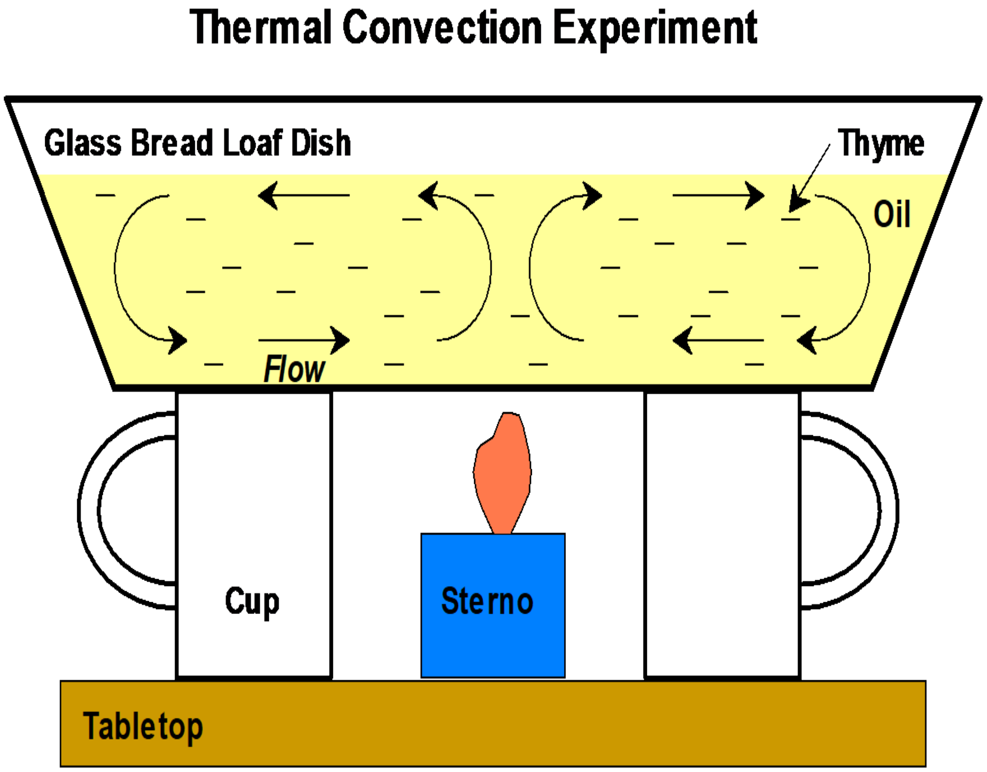

Figure 1. Arrangement of coffee cups, Sterno can, and glass dish on a tabletop (side view) for the thermal convection experiment. Short lines represent flakes of thyme in the oil. Arrows show expected directions of fluid flow defining convection cells after heating of the fluid.

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Figure 2. Alternate setup using two candles instead of the Sterno for heat.

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Figure 3. Close-up photo (side view) of the oil and thyme in the glass dish. Heat from the candles causes the oil and thyme to rise in the middle of the dish (above the candle flames), flow horizontally (away from the center) near the surface of the oil, sink near the cooler edges of the glass dish, and flow horizontally toward the center along the bottom of the dish, thus completing the convection cells.

Thermal Convection Experiment
(template for sketching flow directions)

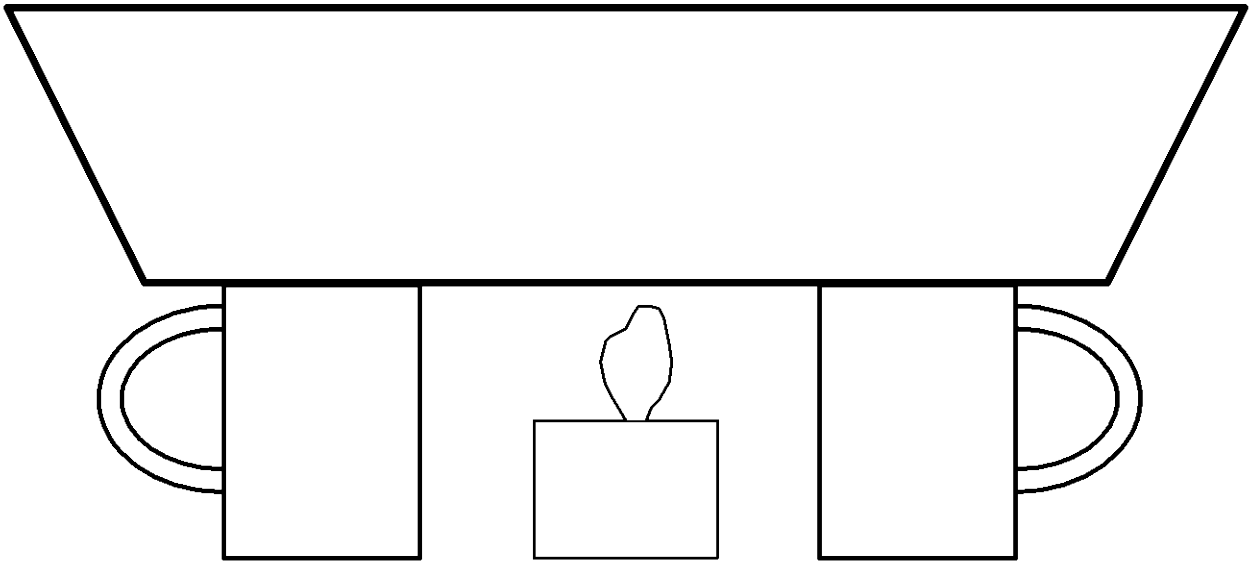


Figure 4. Sketch of fluid flow experiment apparatus. Copies of this figure can be used to record observed directions of fluid flow (using arrows drawn on the diagram) in the oil after convection begins when heat is added.

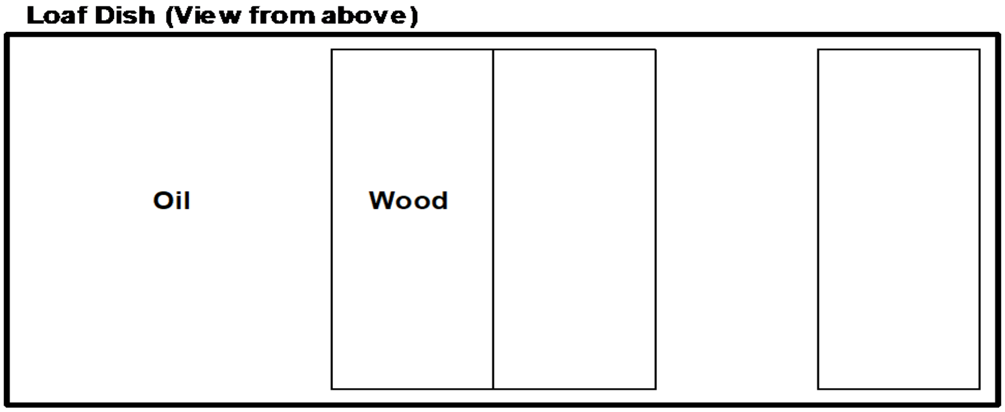
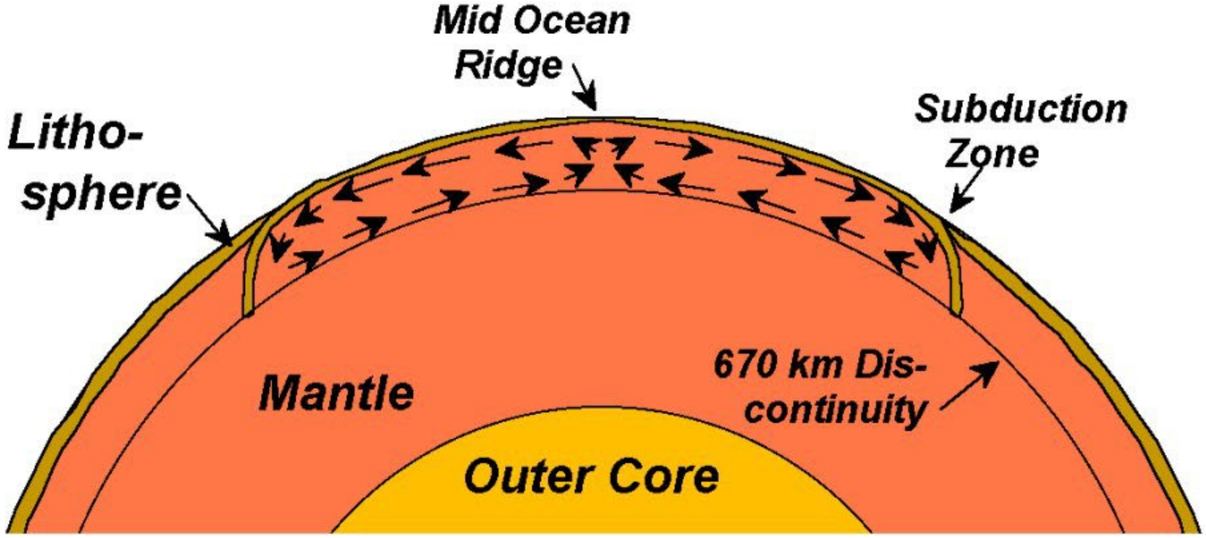


Figure 5. Arrangement of 3 pieces of balsa wood on the surface of the oil (view from above the dish) to illustrate "plate motions."

Upper Mantle Convection



Whole Mantle Convection

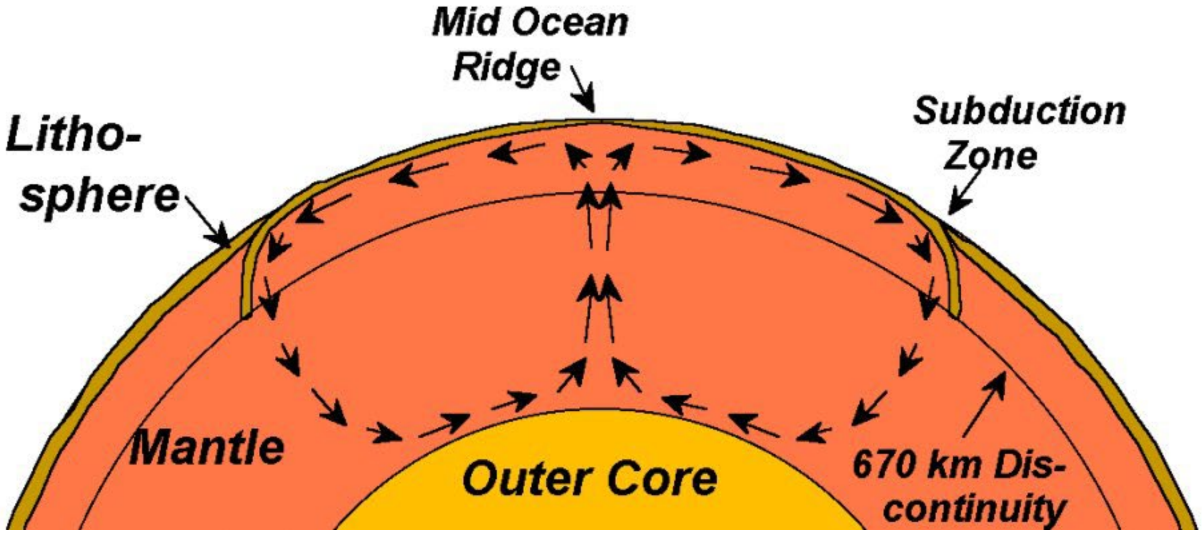


Figure 6. Hypothetical cross-sections through Earth showing possible patterns of convection. Upper diagram: Schematic diagram illustrating convection in Earth's upper mantle. Lower diagram: Schematic diagram illustrating convection in Earth's mantle in which the convection cell and related flow operate throughout the mantle.