

Earth's Interior Structure[©]

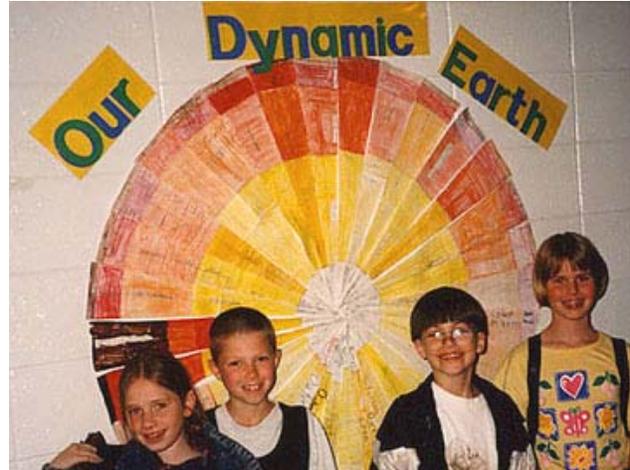
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Educational Objective: Develop understanding of the structure of the Earth's interior (and ultimately, relationships to plate tectonics, occurrence of earthquakes and volcanoes, and the origin of the Earth's magnetic field, etc.) by constructing a scale model of a "slice" of the interior of the Earth and studying the material properties of Earth's interior. The activity also provides useful practice with the concept of scale.

Possible Preparatory Lessons/Activities:

Density

Elasticity and seismic waves

Seismic waves and travel times in the Earth

(evidence from seismic velocities for the existence of the core)

Plate tectonics -- Lithosphere, asthenosphere

Primary chemical layering of the Earth -- Crust, Mantle, Core

Materials:

two 11" x 17" sheets of paper taped together along the short side*

meter stick

pencil

~ 70 cm long string with loop at one end

transparent tape

colored pencils, crayons or felt pens (optional)

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Procedure: Draw a light center line and “width lines” (short dashed lines on “construction detail”, Figure 1) on the 34” x 11” paper (two 11” x 17” sheets of paper taped together) and construct a scale model of a slice (like a “pizza slice”) of the Earth’s interior. The scale is 1:10 million or 1 cm = 100 km (1 cm on the model represents 100 km in the actual Earth), resulting in a slice with a radius of 63.7 cm corresponding to the real Earth’s radius of 6371 km (*10 million times the size of the scale model*). Using the dimensions shown on the “construction detail” drawing (Figure 1) will provide a 15° segment of the Earth’s interior.

Once the surface arc line (draw using the string with a loop and a pencil with the length from the center point to the pencil in the loop being 63.7 cm) and the straight (angle) lines have been drawn, the light pencil lines can be erased. Complete the scale model slice of the Earth by drawing arcs at the appropriate radii corresponding to the Moho, Lithosphere-Asthenosphere, Transition Zone, Core-Mantle, and Outer Core-Inner Core boundaries as given in Table 1 and illustrated on the Earth’s Interior Structure diagram (Figure 2).

For the first two boundaries below the surface (Moho and Lithosphere-Asthenosphere), it is easier to measure downward (0.35 cm and 1.0 cm) from the surface to adjust the length of the string. Note that converting the depth and radius measurements, in kilometers on the Table, to the 1:10 million scale, one can simply move the decimal two places to the left and the number will be in cm. For example, 6371 km is 63.71 cm at the 1:10 million scale (see Table 1). More complete information on the layers of the Earth's interior is given in Table 2.

Label the boundaries and layers of the Earth and (optionally) color the various layers representing spherical shells. Suggested coloring of slices to enhance visibility and imply relative temperature in the Earth’s interior is: inner core - white, outer core - yellow, mantle (below the lithosphere) - orange, upper mantle - red, lithosphere - brown. (See Figure on page 57 in *Seismic Sleuths* to illustrate the relationship of the “slice” to the spherical Earth. A slightly modified diagram from page 57 of *Seismic Sleuths* is shown in Figure 3. Also, see Figure on page 127 of Bolt, 1993). Examples of slices constructed by students are shown in Figures 4 and 5.

A suggested extension of this activity for a classroom is to cut out each of the scale model slices and mount them on the floor or wall. Twenty-four of the slices (using the 15° slice produced by the measurements shown on the attached “construction detail” drawing, Figure 1) can be arranged into a complete circle representing a 1:10 million scale cross section through the entire Earth. Label the main regions: lithosphere, mantle, outer core, inner core. This extension strengthens the scale model concept, aids in visualizing the depths and relative sizes of the various regions of the Earth’s interior, and increases involvement of the students because each student contributes a “slice” to the full model. An example of a “classroom set” of slices of the Earth’s interior is shown in the attached photographs (Figures 6, 7 and 8). In this scale model constructed from each student’s slice, the radius of the resulting circle is 63.7 cm and the various layers are labeled.

The dimensions shown on the “construction detail” drawing (Figure 1) can be modified to make slices of different angles so that a “complete Earth” can be made by a classroom of different

numbers of students, one slice from each student. See Table 3 for measurements for the “width lines” corresponding to different angles of the “slice” and different number of slices (one from each student) that will be needed to make a complete Earth.

Extensions:

1. One of the confusing concepts of Earth structure is the distinction between chemical layering (crust, mantle and core) and mechanical layering (lithosphere, asthenosphere and mesosphere). The scale model illustrates all of these layers on a single diagram. The chemical and mechanical classifications for the upper layers of the Earth are illustrated in Figure 9. Tables 4 and 5 contain the layer depth information for the chemical and mechanical classification.
2. The interior of the Earth is also not quite as simple as the spherical shell models (the 1:10 million scale model and Figures 2 and 6) suggest. The real Earth structure has significant lateral variability, particularly because of plate tectonic processes. A typical Earth structure showing oceanic and continental regions, a mid-ocean ridge spreading center and a subduction zone is illustrated in Figure 10. This schematic model of the upper layers of the Earth is similar to structure inferred for the western coast of South America. See "This Dynamic Earth – The Story of Plate Tectonics" (U.S. Geological Survey) for more information on plate tectonics.
3. An interesting feature of the 1:10 million scale of our model is that the standard unit of length in the metric system was (historically) defined as one ten millionths of the distance along the surface of the Earth from the pole to the equator. Because the scale of our model is 1:10 million, the distance from the pole to the equator on our whole Earth model, made from a classroom set of slices as described above, will be 1 meter. Have the students draw the poles and equator on the model and check the measurement using a string positioned over the Earth's surface.
4. A similar exercise constructing a scale model of the Sun (at a 1:1 billion scale; note difference in scale) can be utilized to reinforce the concept of scale and examine the internal structure of a star. Data for making the scale model are provided in Table 5. Additional information on the interior of the Sun can be found in Beatty and Chaikin (1990), Lang (1996) and Smoluchowski (1983). [A scale model activity for the solar system is described by Braile (1994)]. The students should recognize that the 1:1 billion scale model of the Sun is approximately the same size as the 1:10 million scale model of the Earth. Thus, because of the differences in scale, the Sun has a diameter that is about 100 times larger than the Earth's diameter.

Related Materials:

1. Pizza the Earth activity, pp. 54-55 and Masters 12, 15, 17, and 18 of *Earthquakes (Tremor Troops) - A Teacher's Package for K-6*, FEMA/NSTA, 169 pp., 1988 (note mistake in scale on page 55). The activity is on page 52-53 of the revised (August, 2000) edition of *Tremor Troop* (FEMA 159). Masters 12a, 12b, 15, and 16 are associated with the Pizza the Earth activity.
2. Diagram on p. 57, *Seismic Sleuths*, FEMA/AGU, 364 pp., 1995.
3. "Earth Anatomy" poster (Figure 11); an attractive colored poster illustrating the structure and relative scales of Earth's interior, The Wright Center for Science Education, Tufts University (http://www.tufts.edu/as/wright_center/svl/posters/erth.html). The scale of the slice of the Earth in the poster is close to 1:10 million, but not exactly. As a challenge question, have students determine the scale of the poster by measuring the radius with the meter stick and using Earth's actual radius of 6371 km. The IRIS poster, Exploring the Earth Using Seismology (Figure 12), is a good resource for learning about how seismic waves are used to determine Earth structure.
4. The "3-D Earth" activity (<http://web.ics.purdue.edu/~braile/educindex/educindex.htm>) reinforces the concepts of scale and structure of the interior of the Earth. It also provides a useful, and surprising, demonstration of the relative volumes of the Earth's layers.
5. Chapter 6 on the Earth's Interior in Bolt, B.A., *Earthquakes and Geological Discovery*, Freeman, New York, New York, 229 pp., 1993 (see Figure on p. 143 showing the velocity and density of rocks with depth through the Earth).

*I apologize for the use of non-metric units! However, the availability and low cost of 11" x 17" photocopy paper makes this paper convenient for this activity.

References:

- Beatty, J.K., and A. Chaikin (Eds.), *The New Solar System*, 3rd edition, Sky Publishing Corporation and Cambridge University Press, Cambridge, 326 pp., 1990.
- Bolt, B.A., *Earthquakes and Geological Discovery*, Scientific American Library, W.H. Freeman & Company, New York, 229 pp., 1993.
- Braile, S.J., A journey through the Solar System, *Project SPICA: A Teacher Resource to Enhance Astronomy Education*, p. 53-57, Kendall/Hunt Publishing Co., Dubuque, 1994.
- FEMA/AGU, *Seismic Sleuths – Earthquakes – A Teachers Package on Earthquakes for Grades 7-12*, American Geophysical Union, Washington, DC, 367 pp., 1994.
- Lang, K.R., Unsolved mysteries of the Sun – Part 1, *Sky & Telescope*, p. 38-42, August, 1996.

Lang, K.R., Unsolved mysteries of the Sun – Part 2, *Sky & Telescope*, p. 24-28, September, 1996.

National Science Teachers Association, Earthquakes: *Tremor Troop – A Teacher's Package for K-6 grades*, NSTA Publications, Washington, DC, 169 pp., 1990; revised edition, August 2000.

Smoluchowski, R., *The Solar System*, Scientific American Library, W.H. Freeman & Company, New York., 174 pp., 1983.

U.S. Geological Survey, *This Dynamic Earth – The Story of Plate Tectonics*, USGS Map Distribution Center, PO Box 25286, Denver, CO, 80225, 1-888-ASK-USGS, <http://pubs.usgs.gov/publications/text/dynamic.html>.

Table 1. Measurements for Earth's Interior Structure ("Pie-Slice") Activity.

	Actual Value	Scale Value (1:10 million Scale)
Radius of Earth	6371 km	63.7 cm
Depth* to base of the crust (average)	35 km	0.35 cm
Depth* to base of lithosphere (average)	100 km	1.0 cm
Depth* to base of upper mantle	670 km	6.7 cm
Depth* to core-mantle boundary	2885 km	28.9 cm
Depth* to outer core-inner core boundary	5155 km	51.6 cm

*Measure downwards from the surface after drawing the arc representing the surface at a distance of 63.7 cm from the Earth's center and drawing the diagonal lines completing the "pie-shaped slice" of the Earth.

Table 2. Earth's Interior Structure.

Radius (km)	Depth (km)	Layer	Boundary	Material	Average or Range of Density (g/cm ³)	Average or Range of Compressional Seismic Velocity (km/s)
6371	0	-	<i>Surface</i>	<i>air/solid</i>	~ 1-2.7	~ 2-6
-	-	Crust ¹	-	solid (SiO ₂ -rich)	2.8	6.4
6336	35 ¹	-	<i>Moho (crust-mantle boundary)</i>	<i>solid/solid</i>	-	-
-	-	Upper Mantle	-	solid (Fe and Mg silicate)	3.3	8.0
6271	100 ²	-	<i>Lithosphere-Asthenosphere Boundary</i>	<i>solid/solid</i>	-	-
-	-	Asthenosphere (Upper Mantle)	-	Solid ³ (Fe and Mg silicate)	3.3	7.9
5701	670	-	<i>Transition Zone⁴ (Base of Upper Mantle)</i>	<i>solid</i>	4.2	11.0
-	-	Lower Mantle	-	Solid (Fe and Mg silicate)	5.0	13.0
3486	2885	-	<i>Core-Mantle Boundary</i>	<i>solid/liquid</i>	-	-
-	-	Outer Core	-	liquid iron	11.0	9.0
1216	5155	-	<i>Inner Core Boundary</i>	<i>liquid/solid</i>	-	-
-	-	Inner Core	-	solid iron	13.5	11.0
0	6371	-	<i>Center of Earth</i>	<i>solid iron</i>	13.5	11.0

¹ The thickness of the Earth's crust is actually quite variable ranging from 5-10 km in oceanic regions to 20-70 km for continental crust. The crust-mantle boundary is called the Mohorovicic discontinuity (or 'Moho'), after its discoverer A. Mohorovicic. It separates the chemically-distinct crust (high silica rocks) from the more mafic (high in magnesium and iron content and low silica) mantle. Because of the differences in chemical composition, the seismic velocity is significantly different above and below the Moho.

² The thickness of the lithosphere is somewhat less than 100 km for most oceanic and tectonically active areas and considerably thicker in ancient continental regions. The 100 km value represents a useful average for the whole Earth. Note that the lower lithosphere is part of the upper mantle.

³ Although the mantle is a solid nearly everywhere (as evidenced by the propagation of shear waves through the mantle), within the asthenosphere (just below the lithosphere), the mantle in many regions may be partially molten and behaves as a "soft" layer relative to the more rigid lithosphere above and lower mantle below. The entire mantle consists of Magnesium and Iron rich silicate rock. The mineral olivine (and related high-pressure phases) is most likely a major constituent.

⁴ The transition zone is actually a region from a depth of about 400 to 670 km in which physical properties, such as seismic velocity, change rapidly with depth, primarily in a series of sharp increases corresponding to phase changes in the structure of the Magnesium and Iron rich silicate rock which makes up the mantle.

Table 3. Measurements of Width Lines to Produce Slices of Different Angles for Different Class Sizes.

Angle of Slice (degrees)	Number of Slices (Class Size) to Make a Full Circle	Distance From Center Line to Width Line (see Figure 1)
12	30	6.7 cm
15	24	8.3 cm
20	18	11.1 cm
24	15	13.2 cm

Table 4. Earth's Interior Structure, Surface to Outer Core Depth Range, *Chemical Layering* (Global Averages).

Layer	Radius Range (km)	Depth Range (km)	Characteristics
Crust	6336-6371	0-35	High SiO ₂ content (50-70%)
Mantle	3486-6336	35-2885	Low SiO ₂ content (35-40%)

Table 5. Earth's Interior Structure, Surface to Outer Core Depth Range, *Mechanical Layering* (Global Averages).

Layer	Radius Range (km)*	Depth Range (km)*	Characteristics
Lithosphere	6271-6371	0-100	Relatively cool, brittle, strong
Asthenosphere	6071-6271	100-300	Hot, lower viscosity, weak
Mesosphere	3486-6071	300-2885	Hot, but stronger because of increased pressure

*Depths to boundaries between these layers are variable and not precisely known.

Table 6. Sun's Interior Structure.

Layer	Radius (km)	Radius at 1:1 Billion Scale (cm)	Characteristics
Convective Zone	495,000-695,000	49.5–69.5	Temp at surface ~ 5500°C. In this layer, convection of mass in large to small circulating cells carries heat to the surface. The solar atmosphere (above the convective zone extends millions of kilometers into space).
Radiative Zone	190,000-495,000	19.0-49.5	Heat is moved upward from the core primarily by radiative transfer.
Nuclear Burning Core	0-190,000	0-19.0	Nuclear fusion of Hydrogen to Helium occurs in the core. Temperature 15,600,000°C. Core is only 1.5% of Sun by volume, but comprises almost half of the solar mass.

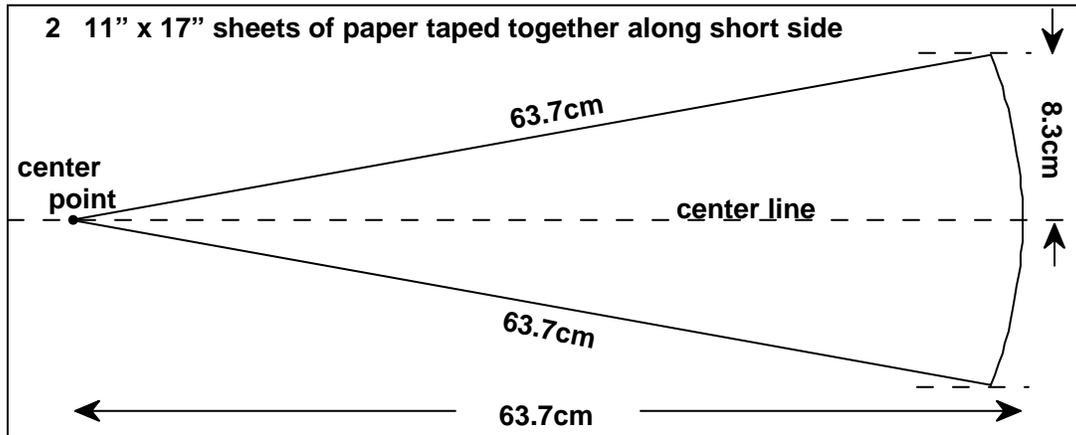


Figure 1. Dashed lines are light pencil lines (draw first) that can be erased after the solid lines of the "slice" are drawn.

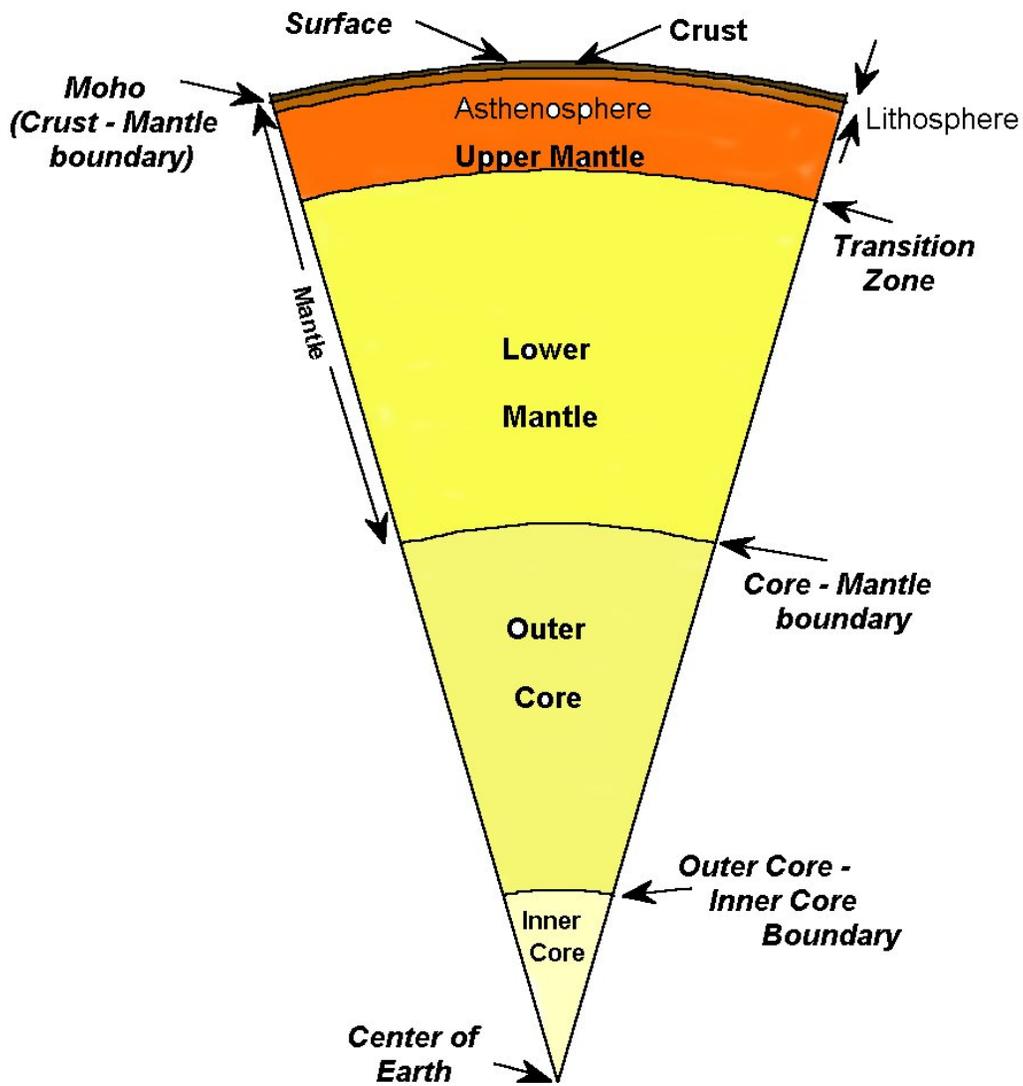


Figure 2. Earth's interior structure. See Table 2 for information about layers (spherical shells) and boundaries.

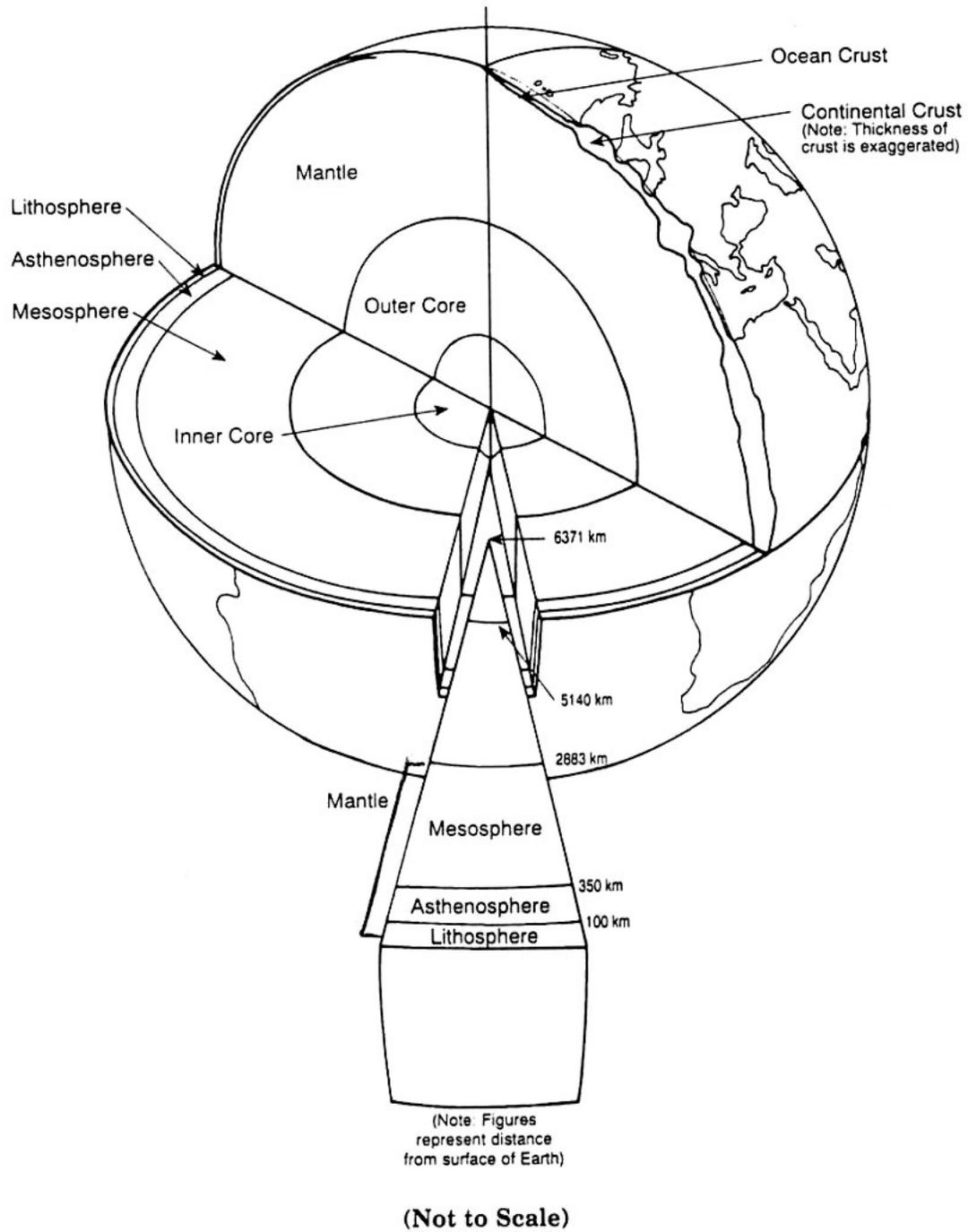


Figure 3. Perspective view of Earth cross section. (Modified from figure on page 57 of *Seismic Sleuths*, FEMA/AGU.)



Figure 4. Students constructing a "slice" of the Earth's interior at 1:10 million scale.



Figure 5. Students constructing a "slice" of the Earth's interior at 1:10 million scale.



Figure 6. Students standing in front of a 1:10 million scale cross section through the Earth constructed from slices drawn by each student in the class.

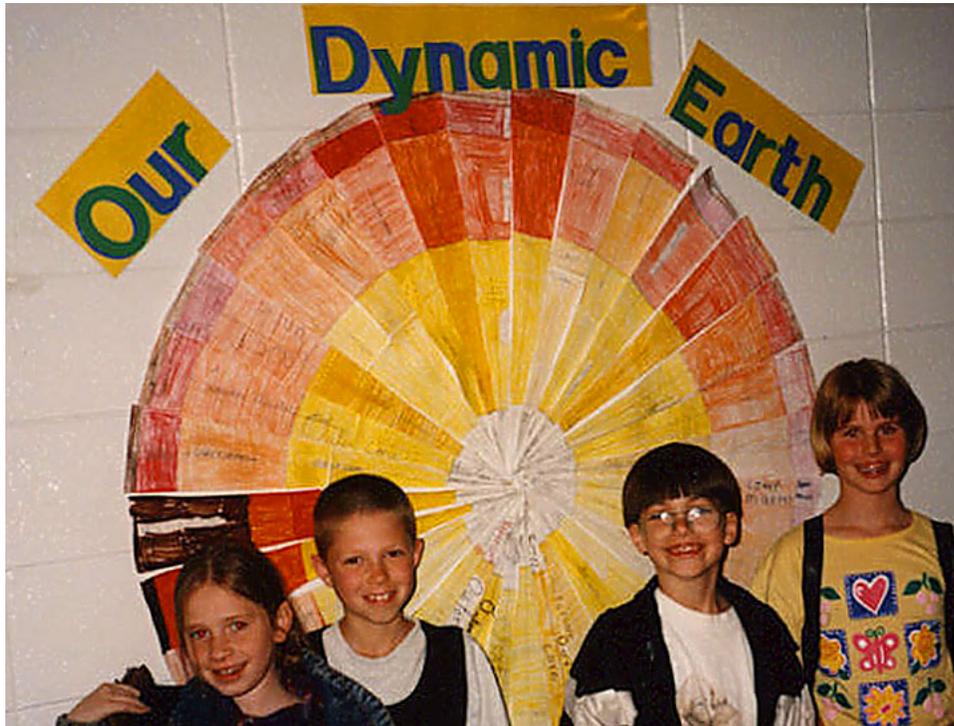


Figure 7. Students standing in front of a 1:10 million scale cross section through the Earth constructed from slices drawn by each student in the class.



Figure 8. Students standing in front of a 1:10 million scale cross section through the Earth constructed from slices drawn by each student in the class.

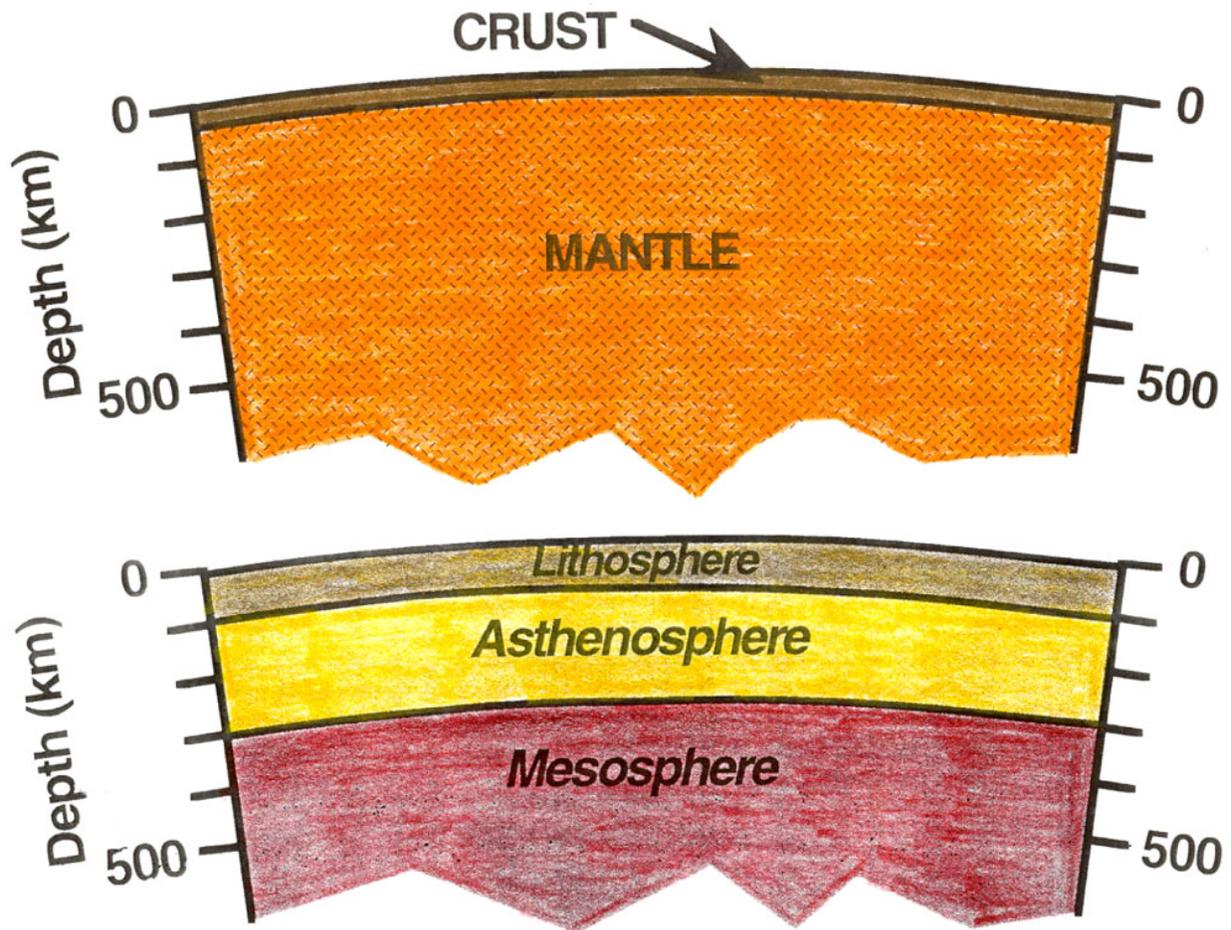


Figure 9. Earth's shallow (0 to 600 km depth) structure showing chemical layer classification (upper diagram) and mechanical layer classification (lower diagram).

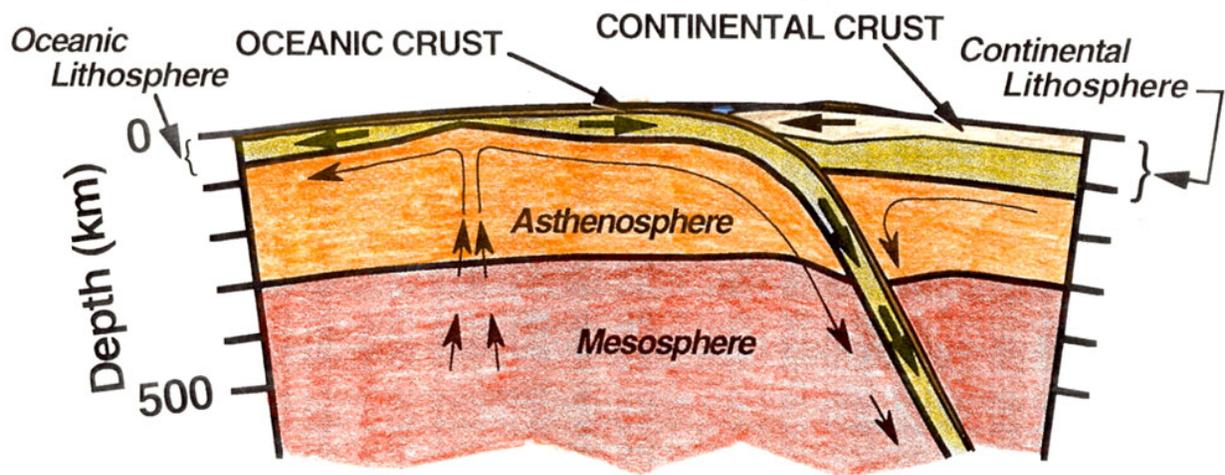


Figure 10. Earth's shallow (0 to 600 km depth) structure, illustrating continental and oceanic plates, a mid-ocean ridge spreading center, a collision zone similar to western South America, and possible upper mantle convection flow patterns. Large arrows indicate directions of plate motion. Small arrows and thin lines indicate possible convective flow. The subducted (underthrust) plates are not easily recognized below about 700 km depth. Plate velocity measurements, the distribution and types of earthquakes, three dimensional seismic velocity variations, and other geophysical observations are used to delineate the distribution of lithosphere and asthenosphere and plate interactions.



Figure 11. Earth Anatomy Poster (http://www.tufts.edu/as/wright_center/svl/posters/erth.html).

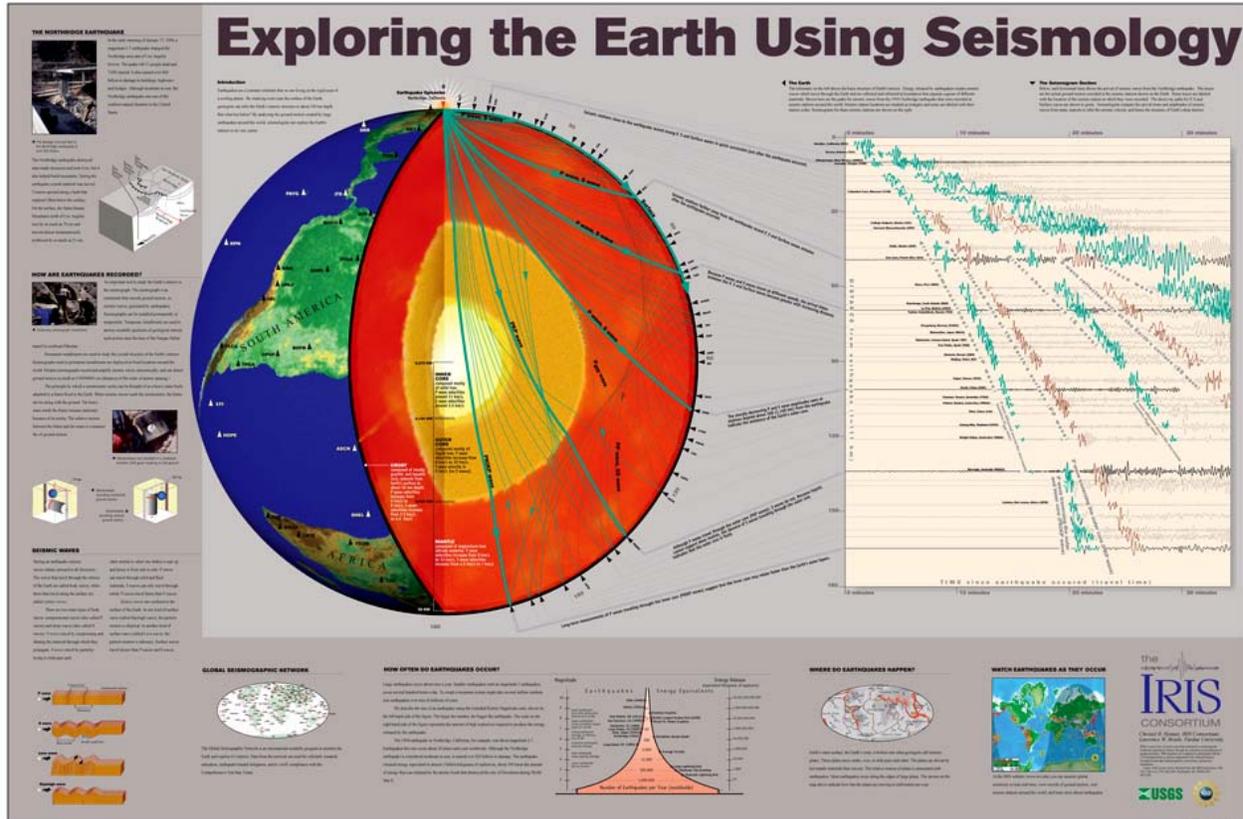


Figure 12. IRIS Poster (<http://www.iris.edu/about/publications.htm#p>).