topic XII

How Are Changes in the Earth's Crust Produced?

Time Emphasis: 13 days

TOPIC OUTLINE		A-1a	A-2a	A-2b	A-2c	B-2a	D-1a
INVESTIGATION		A-1a	A-2a	A-2b	A-2c	B-2a	D-1a
Estimated Time (Periods)		1	2	2	2	2	2
A. Evidence for crustal movement							
A-1 Minor crustal changes	*What Evidence Suggests Minor Changes in the Earth's Crust?*						
A-1.1 Deformed rock strata	A-1.11	■		■			
A-1.2 Displaced fossils	A-1.21	■					
	A-1.22						
A-1.3 Displaced strata	A-1.31						
A-2 Major crustal changes	*What Evidence Suggests Major Changes in the Earth's Crust?*						
A-2.1 Zones of crustal activity	A-2.11		■				
A-2.2 Geosynclines	A-2.21			■			
	A-2.22			■			
A-2.3 Vertical movements	A-2.31						
A-2.4 Ocean floor spreading	A-2.41				■		
	A-2.42				■		
A-2.5 Continental drift	A-2.51						
	A-2.52						
A-2.6 Magnetic poles	A-2.61				■		
B. Earthquakes							
B-1 Wave properties	*What Are Some Properties of Earthquake Waves?*						
B-1.1 Types of waves	B-1.11					■	
B-1.2 Velocities	B-1.21					■	
	B-1.22						
B-1.3 Transmission	B-1.31						
	B-1.32						
B-2 Location of an epicenter	*How Can the Epicenter of an Earthquake Be Located?*						
B-2.1 Epicenter	B-2.11					■	
B-2.2 Origin time	B-2.21					■	

		INVESTIGATION	A-1a	A-2a	A-2b	A-2c	B-2a	D-1a
		Estimated Time (Periods)	1	2	2	2	2	2
TOPIC OUTLINE	C. Model of the earth's crust and interior							
	C-1 Properties	*What Are Some Properties of the Earth's Crust And Interior?*						
	C-1.1 Solid and liquid zones	C-1.11						
	C-1.2 Crustal thickness	C-1.21		■				■
	C-1.3 Crustal composition	C-1.31						
	C-1.4 Density, temperature, and pressure	C-1.41						
	C-1.5 Interior composition	C-1.51						
		C-1.52						
	D. Theories of crustal change							
	D-1 Inferred processes	*What Inferences Can Be Drawn About the Processes Which May Cause Crustal Changes?*						
	D-1.1 Mantle convection cells	D-1.11						■
	D-1.2 Geosynclinal development	D-1.21						■
	D-1.3 Isostasy	D-1.31						■
	D-1.4 Process relationships	D-1.41		■				
PROCESS OF INQUIRY OBJECTIVES	Mathematical Skill	PIO-1		■			■	
	Measurement Skill	PIO-2					■	
	Creating Models	PIO-3	■	■	■		■	■
	Analysis of Error	PIO-4					■	
	Data Analysis	PIO-5		■	■		■	■
TITLES			Evidence of Crustal Movement	Earthquake Watch Analysis	James Hall's Field Trip	The Spreading Sea Floor	Location of an Epicenter	Field Trip Through the Mountains

Multimedia: Check Multimedia Section of Supplement for reference to this topic.

Easy (1)

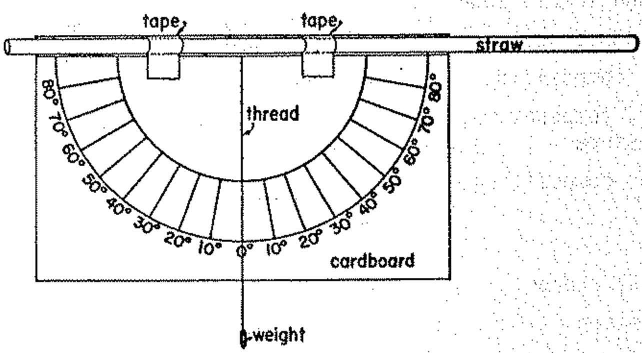
XII-A-1a: EVIDENCE OF CRUSTAL MOVEMENT

QUESTION:

What evidence suggests minor changes in the earth's crust?

MATERIALS:

Color slides and other photographs; specimens of small folds, faults, fossils; geologic maps of New York State and the U. S.; topographic maps; simple compass (for measuring strike); simple clinometer (for measuring dip). See below:



SUGGESTED APPROACH:

1. Students should observe actual evidences of crustal movements in the local area. This is possible in many areas of New York State. Then, these first-hand observations may be supplemented by pictures, specimens, and maps.

2. Conduct a postlab discussion considering such questions as:

   a) Which of the observed changes were rapid? Which were slow?

   b) Did any of the observations lend themselves to more than one interpretation? How could you determine which of the interpretations were most accurate?

PRECAUTIONS:

Try to choose materials, both laboratory and field, that the students can interpret.

MODIFICATIONS:

In lieu of a field trip, plaster or clay models of folds, faults, etc., can be used. There is no substitute, however, for the real thing.

BACKGROUND INFORMATION:

1. Suggestions for field observations:

   a) Tilted rock layers (e.g., Hudson Valley, Orange County, along the Thruway between Utica and Albany, and between Albany and Suffern)

b) Joints and faults

c) Fossils of marine organisms in rock now located high above sea level

d) Fault blocks (e.g., Lake George Valley, Highlands of the Hudson, The Noses fault in the Mohawk Valley, and areas in the Adirondacks)

e) Interviews with persons who remember earthquakes along the St. Lawrence Valley

2. Suggestions for laboratory investigations:

   a) Observations of rock or mineral specimens exhibiting sharp folds

   b) Rock or mineral specimens exhibiting joints that have been recemented together

   c) Clay layers that can be folded by applying horizontal pressure

   d) Photographic slides or movies showing field evidence of crustal movement

REFERENCES:

Geologic pamphlets by the U.S.G.S. or N.Y.S. Geologic Survey on the areas to be visited.

XII-A-1a: EVIDENCE OF CRUSTAL MOVEMENT

QUESTION:

What evidence suggests minor changes in the earth's crust?

INTRODUCTION:

We tend to view our environment as being relatively unchanging. It is possible, however, to find evidence of change, even if the changes themselves are too slow to be seen. In this investigation, you will examine evidence in the field that suggests that at least portions of the earth's crust are undergoing change.

OBJECTIVES:

When you have finished this investigation, you should be able to:

1. identify and interpret evidence that suggests minor changes in the earth's crust.

METHOD:

1. Record any evidence in the area that suggests changes in the earth's crust. Make sketches or take notes since it may not be convenient to revisit the location.

2. Examine the additional information provided to you by your instructor about the area, and, using your field observations, draw interpretations regarding crustal change.

QUESTIONS:

(A-1.11) 1. Describe any evidence for folding, tilting, or faulting of rock strata that you were able to observe. From these observations draw inferences concerning the past history of the area.

(A-1.21) 2. What does the presence of marine fossils in rock found at high elevations suggest to you?

Easy (2)

XII-A-2a: EARTHQUAKE WATCH ANALYSIS

QUESTION:

What evidence suggests major changes in the earth's crust?

MATERIALS:

Completed earthquake watch data, blank world map (supplementary sheet), and student handout sheets.

SUGGESTED APPROACH:

1. Have the students study the completed Earthquake Watch Map and discuss any patterns of earthquake activity that they are able to observe.

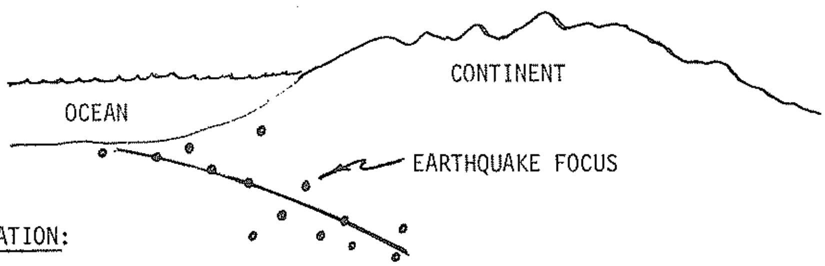
2. Have them compare the earthquake pattterms to the location of mountain ranges and volcanoes.

3. Have the students prepare a vertical cross section of the ocean-continent boundary. On the cross section, have them plot the depths of the earthquake focuses observed, and draw inferences from the pattern which develops.

TYPICAL RESULTS:

1. If a sufficient number of earthquakes is plotted, a clear pattern of the active earthquake belt should result (about 400-500 earthquakes plotted will accomplish this although fewer than 300 are sufficient to illustrate the basic trend).

2. A typical cross section,with depths plotted,should indicate that the earthquakes under continental areas tend to occur at a greater depth than those in oceanic regions. This may be interpreted as a zone of weakness along the crust-mantle interface. If actual depths are plotted, the cross section may look similar to the one below.



BACKGROUND INFORMATION:

The epicenter of an earthquake is the point on the earth's surface directly above the focus.

REFERENCES:

Investigation the Earth, pp. 318-319, Teacher's Guide, pp. 388-389.

XII-A-2a: EARTHQUAKE WATCH ANALYSIS

QUESTION:

What evidence suggests major changes in the earth's crust?

INTRODUCTION:

Occasionally an earthquake occurs that causes widespread damage and is publicized in newspapers, on radio, and television. Earthquakes occur far more frequently than this, although most have a magnitude small enough so that little or no damage occurs. The frequency of occurence of earthquakes, and the areas most susceptible to them should become apparent when you have concluded this investigation.

OBJECTIVES:

When you have finished this investigation,you should be able to:

1. identify regions of high earthquake activity on a world map,

2. relate the world distribution patterns of earthquakes to patterns of volcanic activity and mountain ranges.

3. draw inferences from the pattern of earthquake focus depths and relate them to understandings of the thickness of the earth's crust.

METHOD:

1. Study your completed Earthquake Watch Maps carefully and outline, on your world map (supplementary sheet), areas of high earthquake activity.

2. Outline areas with rugged mountain systems.

3. In a resource book, find information concerning the active volcanic regions in the world, and outline these areas on your map.

4. On a standard size sheet of paper, sketch a coastal area of the world where earthquakes seem to occur frequently. Transfer from the Earthquake Watch Map to your sketch map the approximate locations of as many earthquakes as you are able. Use the following symbols to indicate depth:

Shallow ---- •
Intermediate *
Deep ----- O

If you have the information available, you may want to write the actual depth next to the symbol. When you have plotted a number of locations (30-100), you should prepare a cross section of the area showing both the location and depth of the earthquake focuses. When you have plotted all your points, draw a line representing the average depth to the focuses as you cross the boundary between ocean and continent. Draw inferences from the pattern that evolves.

QUESTIONS:

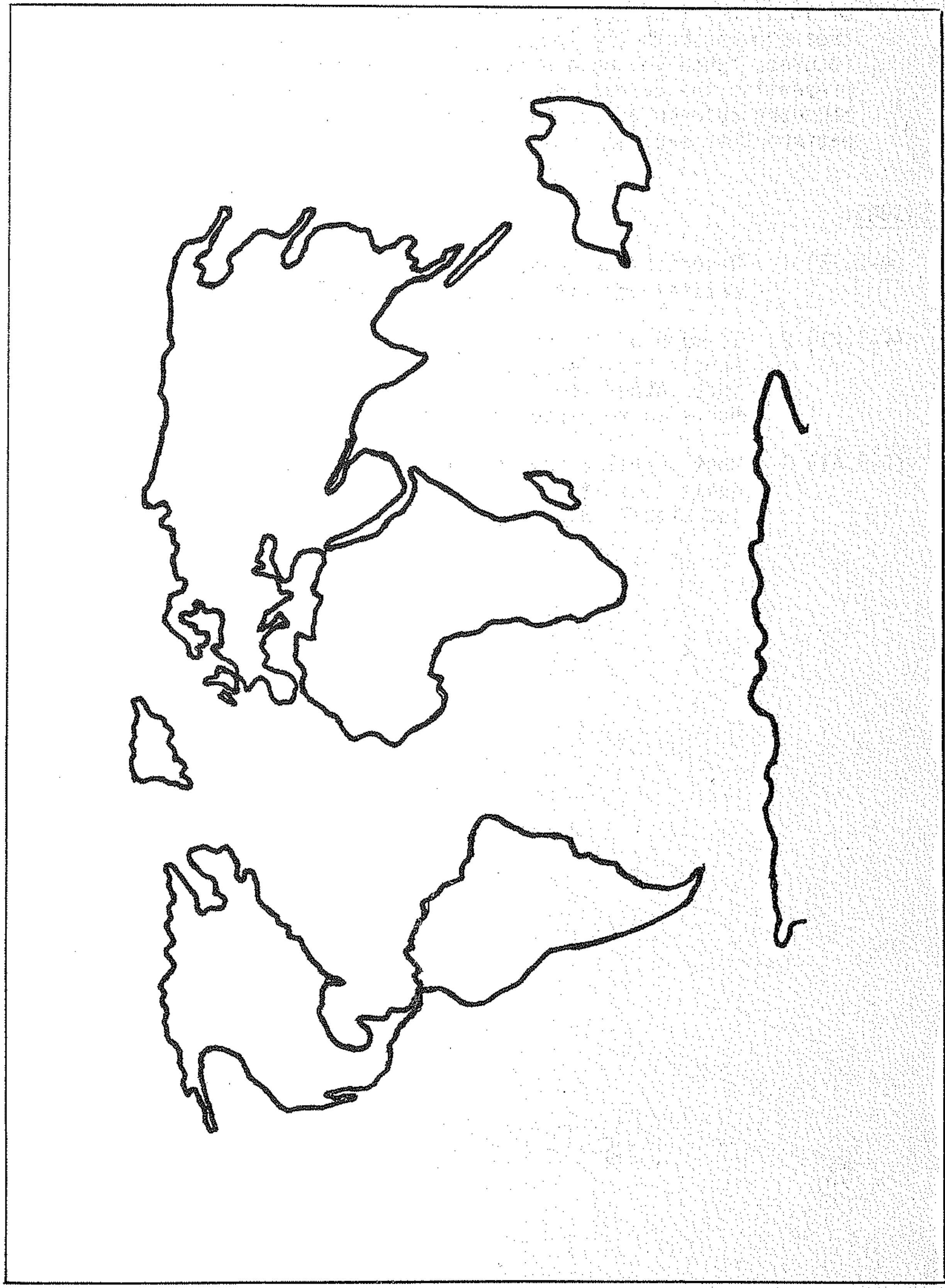
(A-2.11) 1. Describe the zones on the earth's surface where frequent crustal activity can be expected.

(C-1.21) 2. If much of the earthquake activity occurs along the crust-mantle interface, as is sometimes suggested, what can you infer about the thickness of the crust under the continents as compared to the thickness under the oceans.

(D-1.41) 3. What correlations were you able to observe between earthquake activity, volcanic activity, and mountain range locations? How do you think they are related?

Supplementary Sheet

WORLD MAP



XII-A-2b: JAMES HALL'S FIELD TRIP

QUESTION:

What evidence suggests major changes in the earth's crust?

MATERIALS:

Graph paper, supplementary sheet (map and data table), if possible photographs of outcrops near each of the mapped stations if possible.

SUGGESTED APPROACH:

1. Discuss briefly the route along which the stations are located and the evidence provided of outcrops located at the stations. (Use pictures if possible.)
2. Have students use the data to construct a cross section of the sedimentary rock thicknesses from Buffalo to the eastern-most station.
3. Lead students in an interpretation of the evidence relative to the objectives listed. Through questioning, bring out the apparent discrepancy: although most of the sedimentary rocks seem to be of shallow-water origin, the rocks are of tremendous thickness. Lead students in developing possible solutions to the problem. Emphasize the relationship between the geology of the eastern and western portions of New York State.

PRECAUTIONS:

1. Many students seem to want to start both rock Unit I and II at the surface. It may be advisable to permit the student to do this, for he may discover on his own the fact that two rock layers cannot occupy the same space. Be sure that he understands that rock Unit I extends from the surface downward and rock Unit II from the bottom of rock Unit I downward, before he completes the entire investigation.
2. The data are generalized. The units are lumped together to avoid introducing terminology of formations and geologic age. Only the current thicknesses of the rocks are included. This omits the great thicknesses that must have been removed during the Mesozoic and Cenozoic eras.
3. Vertical exaggeration should be discussed. It would be valuable to have a few students make their cross sections to true scale.

TYPICAL RESULTS:

The cross sections will vary in appearance since students will choose different vertical scales. However, this should not affect interpretations. With guidance, students should be able to develop the geosynclinal concept of a shallow sea environment. Briefly summarized, the pressure of the sediments constantly depresses the sea bottom so that a sediment-filled trough is formed with deformation in the areas of greatest pressure.

MODIFICATIONS:

1. Introduce the "field trip" by telling the history of James Hall and, if possible, showing slides of outcrops found along the east-west route of the trip. (See Background Information for a possible script to such a slide set and an outline biography of Hall.)

2. Obtain a USGS basement rock map (cost about $3.50), and compare the cross-sectional profile made in this investigation with it. You will find a trough on the basement map in the Eastern U. S. that corresponds with stations 9 and 10. But which came first, the sediments or the trough?

BACKGROUND INFORMATION:

Teachers may wish to organize a slide field trip with script similar to this one.

James Hall's Field Trip - To Western New York State - 1838

James Hall was born in 1811 at Hingham, Mass., on the shore of Massachusetts Bay, southeast of Boston. He spent his early years here and no doubt became quite familiar with this salt water coastal environment.

Eventually Hall left Hingham and walked overland to Troy, N. Y., where he attended Rensselaer College (now R.P.I.). As he made this journey through western Massachusetts, he must have seen these folded metamorphic rocks of Ordovician and Cambrian age. These rocks are between 500 and 600 million years old.

As he neared the Troy and Albany area he probably observed rocks like these highly folded ones located near the New York-Massachusetts line. They are of Ordovician age, younger than those in western Massachusetts.

One of the problems that must have frustrated Earth Scientists of this time was the thick layers of sand, like these at Glens Falls, N. Y., that covered most of the landscape, hiding from view the bedrock underneath. The concept of continental glaciation had not yet evolved, and would not until 1850 when Louis Agassiz came to teach at Harvard College. About the only bedrock that Hall could have studied in this area were these flat-lying limestones of Ordovician age found along the Hudson River above Glens Falls.

Hall was appointed New York State paleontologist in 1837. In 1838 he organized a field trip from Albany westward across New York State. As he moved west from Albany, he probably studied slightly tipped and deformed rocks like these of Ordovician age near Scotia, just west of Schenectady.

Across the Mohawk River, to the south, but not far from Scotia, he probably observed rocks similar to these that dip slightly to the south and are of Ordovician age.

About 20 miles further west, he could have seen flat-lying rocks of Ordovician age similar to these limestone cliffs exposed along the Mohawk River.

As he proceeded west to Canajoharie he may have been puzzled by these polished and grooved rocks that we now recognize as evidence of continental glaciation. Near Herkimer he may have had opportunity to study rocks similar to these gently tipped limestones and shales, still of Ordovician age.

In the vicinity of Utica, muddy looking, flat-lying, thinly bedded layers of shale about 440-500 million years old may have been observed. These rocks can be traced intermittently westward all the way to the Niagara Gorge at Lewiston.

Hall would not have been able to observe these younger rocks of Silurian age which have been exposed as a result of excavation for a Physics Building on the Syracuse University campus. These thinly-bedded, flat-lying, tan colored rocks are about 50 million years younger than those of Ordovician age which were seen near Utica. These Silurian age rocks can be observed in outcrops from a point just west of Utica to Camillus, just west of Syracuse. One of the fossils common to this rock formation found in the Syracuse area is the Eurypterid. Hall, a paleontologist, probably observed many of these fossils.

As he proceeded west from Camillus, Hall no doubt studied rocks similar to these limestones which outcrop near Batavia and are members of the Devonian period, about 375 million years old. These represent some of the youngest rocks that Hall could have seen on his trip westward.

In the Letchworth State Park area, south of Rochester, along the high banks of the Genesee River, Hall probably did extensive studies of these Devonian age rocks and fossils.

Another outcrop that Hall may have visited is this Devonian age limestone exposed at Indian Falls on Tonawanda Creek about 12 miles west of Batavia.

Near Buffalo, Devonian age limestone can now be seen in limestone quarries where it has been mined for lime and crushed rock. South of Buffalo, Hall may have observed this Devonian age shale rock which is only about 350 million years old.

One of Hall's last stops, and one of the most fascinating was Niagara Falls, where the falls is capped by a layer of Lockport dolostone.

To the south, the Onondaga limestone forms an escarpment which serves to stabilize the level of Lake Erie by forming a resistant lip at the head of the Niagara River.

As a result of this field trip and later ones, Hall was to formulate the theory of geosynclinal mountain building for which he is best known.

REFERENCES:

Investigating the Earth, pp. 312-315, Teacher's Guide, pp. 379-385.

Do Not Print

XII-A-2b: JAMES HALL'S FIELD TRIP

QUESTION:

What evidence suggests major changes in the earth's crust?

INTRODUCTION:

More than 130 years ago, James Hall traveled by foot and horse across New York State collecting geologic evidence for the history of the area. In this investigation, you will use data similar to his. You will study photographs of outcrops taken at the data stations which range from Buffalo to a point east of Albany.

OBJECTIVES:

When you have finished this investigation, you should be able to:

1. interpret the ancient geologic environment of the area between Buffalo and a point east of Albany.

2. relate the geology of the western portion of the state to that of the eastern portion.

METHOD:

1. Study the map, data, and information for the "field trip" route.

2. On graph paper, make a cross section of the sedimentary rock layers from station 1 to 10. Rock Unit I is above Unit II.

3. Discuss with other students the evidence obtained from the cross-sectional profile and the information on the data sheet.

4. Interpret the evidence, and write a probable geologic history of the area between Buffalo and station 10.

QUESTIONS:

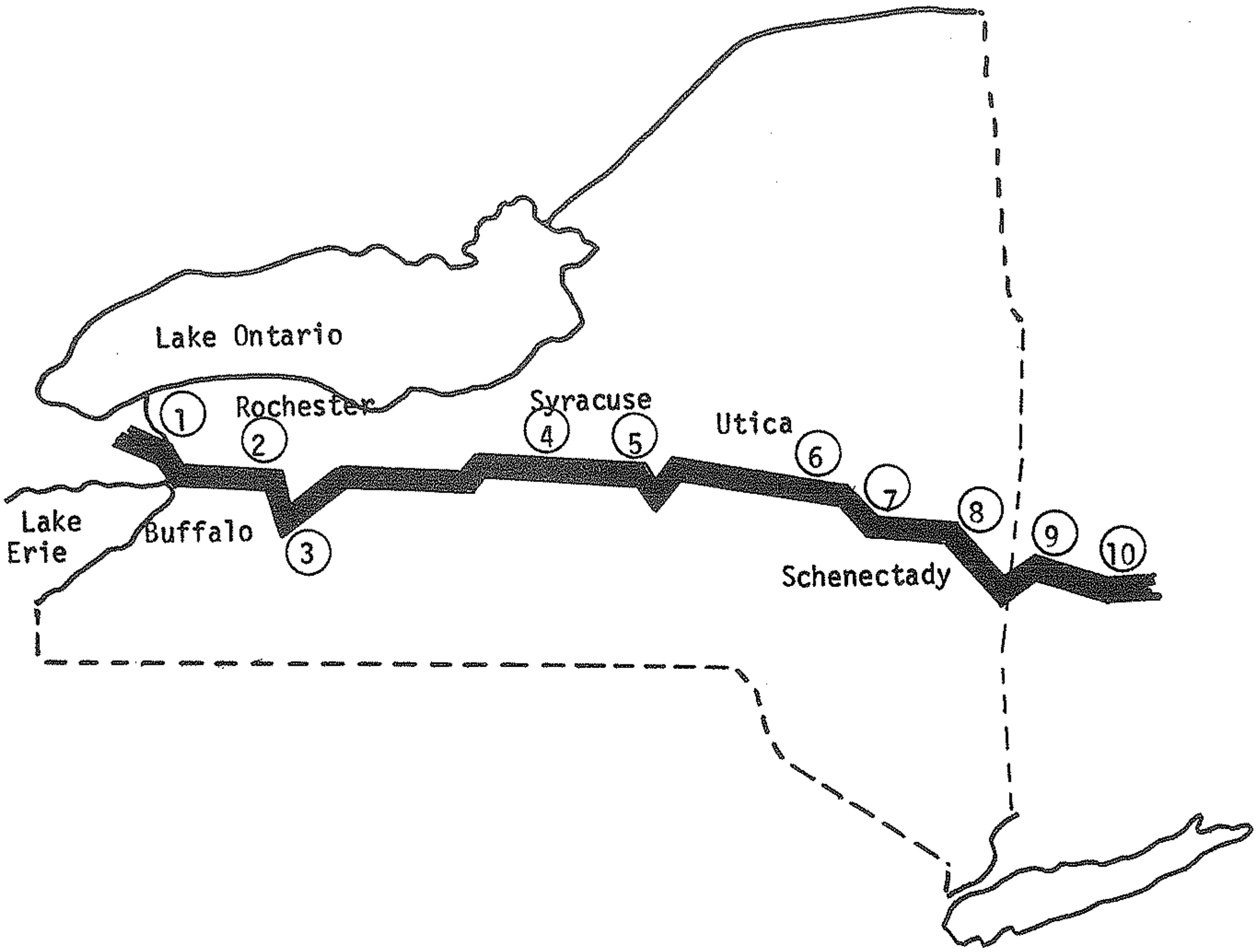
(A-2.21) 1. What evidence indicates that the sedimentary rocks graphed are shallow-water in origin?

(A-2.22) 2. What could explain the extreme thickness of shallow-water deposited sediments?

(A-1.11) 3. How do you explain the difference between rocks at stations 8-10 and those found at stations 1-6?

(A-1.11) 4. What do you think happened to rock Unit I and II at sta-10? Why?

JAMES HALL'S FIELD TRIP



Thickness in Meters of Sedimentary Rocks
Below Surface Along Route Shown on Above Map

Stations	1	2	3	4	5	6	7	8	9	10
Rock Unit I	900	1500	1500	1500	1500	2000	2500	0	0	?
Rock Unit II	300	350	650	3000	3300	3300	3000	3300	3300	?

Adapted from: *Investigationg the Earth*, Teacher's Guide

Rock types found at various stations

1 - Niagara area - horizontal layers
2, 3, & 4 - Flat-lying sedimentary layers
5 - Rocks contain fossil coral
6 - Fossils and thin layers common
7 - Warped sedimentary layers
8 - Rocks contorted and shattered
9 & 10 - Rocks greatly disturbed - evidence of igneous activity

Difficult (2)

XII-A-2c THE SPREADING SEA FLOOR

QUESTION:

What evidence suggests major changes in the earth's crust?

MATERIALS:

Student sheet and Supplementary Sheet.

SUGGESTED APPROACH:

1. Discuss with the students the concept of a magnetic field and the meaning of a magnetic field reversal. Ask how a magnetic field might be "preserved" in molten rock as it solidifies.

2. After making certain that the students understand the method, this exercise can best be done as a homework assignment.

3. After completion of the assignment, discuss with the students:

   A. The meaning of ocean floor spreading.

   B. The rate at which it is thought to be occurring.

   C. How does it relate to other theories such as the geosyncline theory and the continental drift theory.

PRECAUTIONS:

1. Students sometimes have difficulty realizing that the upwelling occurs along the mid-Atlantic Ridge and spills over in both east ahd west directions. Therefore, materials of similar age should be located at approximately equal distances east and west of the ridge. The magnetic reversal pattern serves only to identify rock units of the same age.

2. As in most natural systems, the movement has not been perfectly symetrical, the distance the rock has drifted eastward is consistantly less than the distance it has moved westward, therefore an average must be taken and used for computation.

TYPICAL RESULTS:

NUMBER	1	2	3	4	5	6
Distance West (km.)	40	70	80	104	118	134
Distance East (km.)	28	42	60	74	90	102
Average Distance (km.)	34	56	70	89	104	118
Age From Scale(million yrs.)	2.8	4.4	5.6	7.1	8.4	9.5
Rate of Movement (cm./yr.)	1.21	1.24	1.24	1.25	1.24	1.23

The line drawn by the student for question 1 should be about 1.2 cm. long. Africa should have been in the indicated position (question 2) about 2.0 X 10^8 years ago,

$$\frac{2.4 \times 10^3 \text{ km.}}{1.2 \frac{\text{cm.}}{\text{yr.}}} \times \frac{10^5 \text{ cm.}}{\text{km.}} = 2.0 \times 10^8 \text{ years.}$$

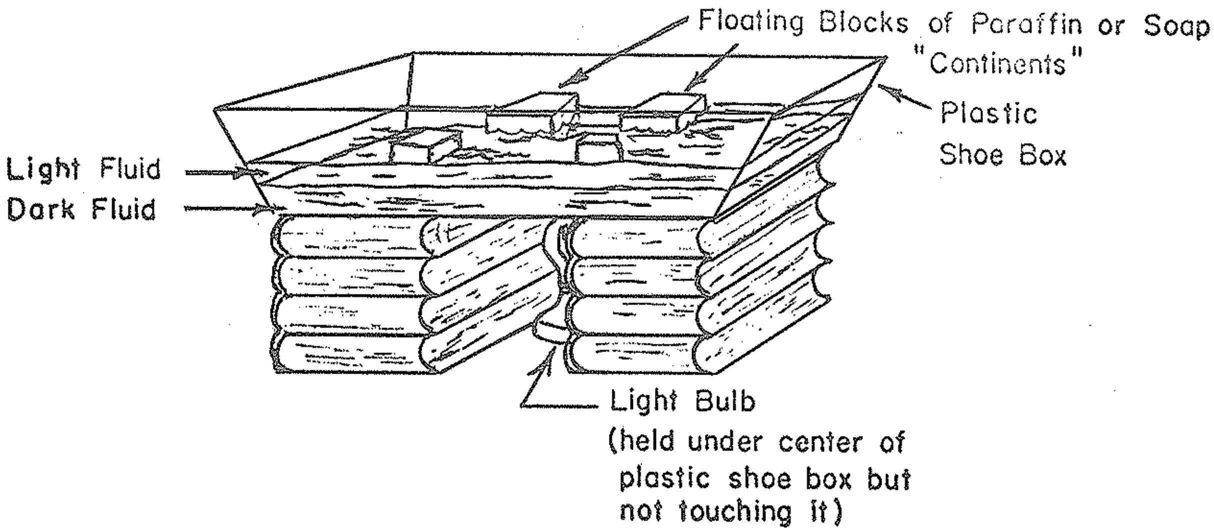
Do Not Print

For question 3, correspondence should be excellent at all points used in calculation. Short intervals may not show up on the general profile because of the amount of material magnetized and the lack of sensitivity of the instrument.

MODIFICATIONS:

Sea floor spreading and the Continental Drift Theory can be demonstrated by using the following technique.

1. Set up the apparatus as shown below.



Note: Pour the lighter fluid very slowly, using a piece of cardboard to break its velocity. Try to maintain a sharp interface between the more dense (dark fluid) and the less dense (light fluid). Density of the fluids can be controlled by storing the dark fluid in the refrigerator and the light fluid in a bucket of warm water, previous to class time.

2. Place a transparent lid on the box with a plastic sheet attached to it and sketch the position of the "continents" as they appear before the light is turned on.

3. Observe the light and dark fluids from the side of the shoe box and sketch the interface between the two.

4. Turn on the light and observe both the interface between the two fluids and the position of the paraffin blocks. Make sketches of each at 5-minute intervals for a period of 20 minutes.

5. Relate what you have seen to continental drift and sea floor spreading.

REFERENCES:

Allan Cox, G. Brent Dalrymple, & Richard R. Doell, "Reversals of the Earth's Magnetic Field," *Scientific American,* Feb. 1967, Vol 216:2, pp. 44-54

Samuel W. Matthews & Robert F. Sisson, "Science Explores the Monsoon Sea," *National Geographic,* Oct. 1967, Vol. 132:4, pp. 554-575

J.D. Phillips, "Magnetic Abnormalities over the Mid-Atlantic Range Near 27°N," *Science,* Aug. 25, 1967, Vol. 157, pp. 920-922

W.C. Pitman, III, & J.R. Heirtzler, *Science,* Vol. 154, 1966, p. 1164

XII-A-2c: THE SPREADING SEA FLOOR

QUESTION:

What evidence suggests major changes in the earth's crust?

INTRODUCTION:

When molten volcanic rocks cool and solidify, the magnetic minerals in them are magnetized in the direction of the earth's magnetic field. They retain that magnetism, thus serving as permanent magnetic memories (much like the magnetic memory elements of a computer) of the direction of the earth's field in the place and at the time they solidified.

In 1906, the French physicist, Bernard Brunhes, found some volcanic rocks that were magnetized, not in the direction of the earth's present field, but in exactly the opposite direction. Brunhes concluded that the field must have reversed. Although his observations and conclusions were accepted by some later workers, the concept of reversals in the earth's magnetic field attracted little attention. In the past few years, however, it has been definitely established that the earth's magnetic field has two stable states; it can point either toward the North Pole, as it does today, or toward the South Pole, and it has repeatedly alternated between the two orientations.

Using a combination of magnetic reversal and atomic dating, we shall attempt to make a model of the earth's floating crust. The rift in the Mid-Atlantic Ranges seems to be a place of upwelling so we will concentrate on it. The research vessel *Chain* of the Woods Hole Oceanographic Institute made crossings of the Mid-Atlantic Ridge in 1966, using an instrument which shows intensity and direction of the magnetic field produced by the rock on the ocean floor. The profiles produced by the *Chain* are shown in Figure 1.

Using radioactive dating techniques (principally potassium-argon), volcanic rocks of the ocean floor in this area were given specific ages. The rock ages are shown in Figure 2.

OBJECTIVES:

When you finish this investigation, you should be able to:

1. interpret evidence that suggests that at least portions of the earth's crust are mobile.

2. given appropriate data, determine a rate of movement of a crustal area.

METHOD:

1. Draw a single vertical line through the first peaks to the west of the main rift in the magnetic profile (Figure 1). Read the distance from the main rift on the scale at the bottom of the page (1 mm. = 2 km.), and record it in the data table below.

PEAK NUMBER	1	2	3	4	5	6
Distance West (km.)						
Distance East (km.)						
Average Distance (km.)						
Age from Scale (million years)						
Rate of Movement (cm./yr.)						

2. Repeat step 1 for each set of peaks you see to the west of the rift, and record under 2, 3, 4, 5, 6.

3. Repeat for each set of peaks east of the rift and record under 1, 2, 3, 4, 5, 6.

4. Find the average distance from the Mid-Atlantic Ridge to each magnetic peak.

5. Using the Time Scale (Figure 2), find the age of the rock at each average distance. Record it on the chart.

6. Assuming that the rock has moved from the central ridge, calculate how many cm./year it moved and complete Chart A.

QUESTIONS:

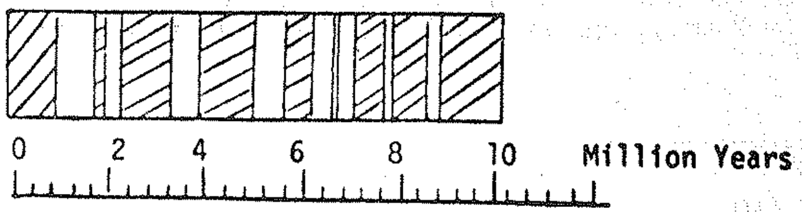
(A-2.41) 1. Describe the age of the nonsedimentary rock found near the oceanic ridge relative to that found farther from the ridge.

2. Draw a line that represents the amount of movement which occurs on one side of the Mid-Atlantic Ridge in one year.

3. If the distance from Africa to the Ridge is 2400 km., how long ago was Africa over the ridge?

(A-2.42)
(A-2.61) 4. Below is a Polarity Reversal Time Scale devised by scientists. Does the polarity of your calculated model correspond to this at all points? (Lined areas

are Normal Polarity; white areas are Reversed Polarity.)



5. Explain in your own words how the work you have done in this lab could lead you to believe in a floating crust theory.

FIGURE 1: ROCK POLARITY ACROSS THE ATLANTIC

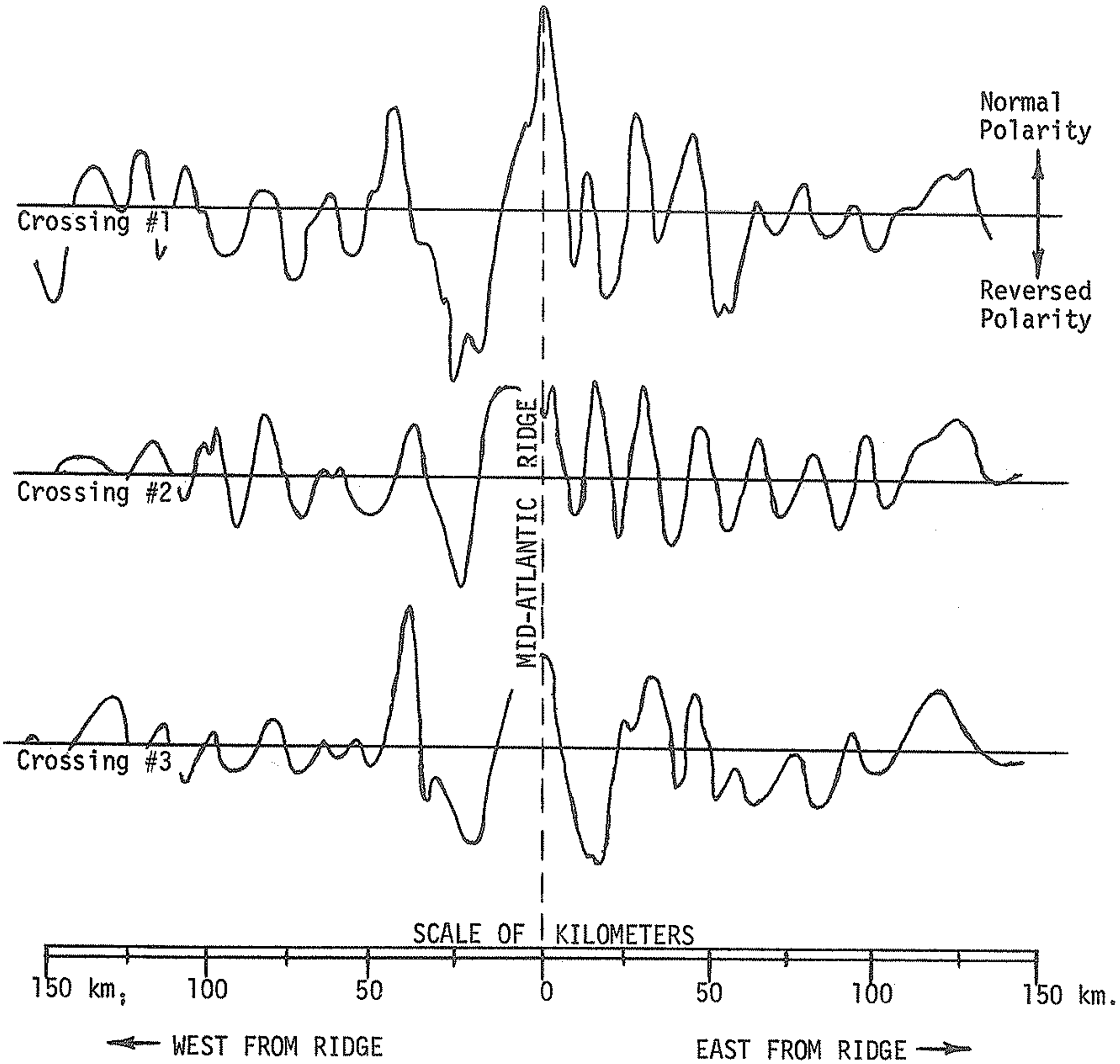
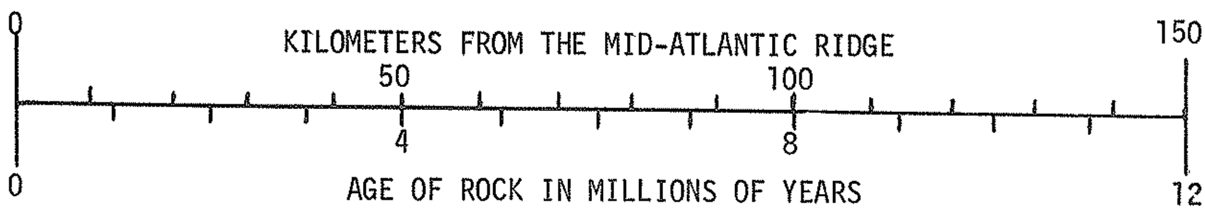


FIGURE 2: ROCK AGE DETERMINATION SCALE



Challenging (2)

XII-B-2a: LOCATION OF AN EPICENTER

p 355 table 16-1

QUESTION:

What are some properties of earthquake waves?

MATERIALS:

Seismogram recordings of the same earthquake from three different stations, graph paper, globes, drawing compasses or string, and marking crayons.

SUGGESTED APPROACH:

1. Discuss with students the characteristics of and the differences between P- and S-waves.
2. Discuss with the students the operation of the S- and P-wave time-travel graph (Supplementary Sheet #1). This may pose some difficulty to the students, so make sure they understand fully how to use it. (See Background Information.)
3. Let them "read" the seismograms and, after having determined the distance to the epicenter for the three stations, let them attempt to locate the epicenter. The latter can be accomplished by constructing intersecting circles on a globe with radii equal to the distances from the epicenter. The intersection of the circles will locate the epicenter. Circles can be drawn either using a compass or string.

PRECAUTIONS:

1. Students may have difficulty drawing the circles on the globes and also in understanding the geometry behind this technique. Some assistance may be needed here.
2. A globe is best for this investigation, since only a small area on a flat projection can be used without getting involved with distortion.

TYPICAL RESULTS:

Because the technique for constructing the circles is difficult to carry out with accuracy, the circles will probably not intersect at a point but rather will indicate a small area, the center of which can be assumed to be the location of the epicenter.

MODIFICATIONS:

Provide seismograms from cities within the U. S. for an earthquake whose epicenter is also located within the U. S. It should then be possible to use a map instead of a globe for locating the epicenter.

BACKGROUND INFORMATION:

The S- and P-wave Time-travel Graph has been constructed by plotting S- and P-wave arrival times, measured at recording stations around the world, versus the known distance of the epicenter from the station receiving the waves. Because the stations were different distances from the epicenter and since the P-wave travels faster than the S-wave, the time gap between arrivals increases with increasing distance from the epicenter.

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XII-B-2a: LOCATION OF AN EPICENTER

QUESTION:

What are some properties of earthquake waves?

INTRODUCTION:

If an earthquake is of sufficient magnitude, the shock will be felt hundreds of miles away. Most earthquakes, however, can only be felt close to the epicenter if at all. Geologists use an instrument called a seismograph to detect earthquakes. This is very sensitive even to weak shocks. From the recorded information of a seismograph, scientists are able to tell how far away the earthquake occurred. When the information from stations in different locations is compared, they can determine the location of the epicenter.

OBJECTIVES:

When you have finished this investigation, you should be able to:

1. Determine from a seismogram the P- and S-wave travel time difference, and with a graph of time vs. distance traveled, determine the distance of the recording station from the epicenter.

2. Locate the epicenter of an earthquake given the distances of three recording stations from the epicenter.

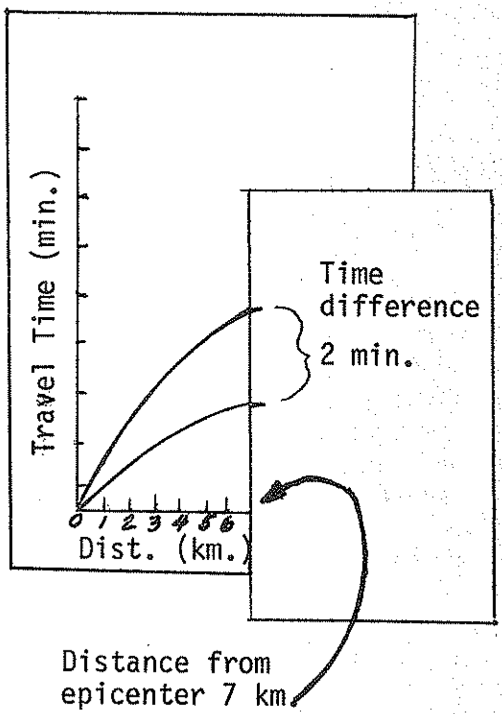
METHOD:

1. Observe the P- and S-waves on the seismograms (Supplementary Sheet #2). Determine the difference between the arrival times of the P- and S-waves on each graph in minutes and seconds.

2. Position a sheet of paper along the time axis of the S- and P-wave Time-travel Graph (Supplementary Sheet #1) and make two marks on the edge representing the P- and S- arrival time difference measured at one of the stations.

3. Slide the paper along the P- and S- curves, keeping the marked edge parallel to the time axis, until the distance between the curves matches the two marks on the edge of the paper (see diagram).

4. Make certain the paper edge is still parallel with the time axis, and then follow the edge down until it intersects the distance axis. The reading at that point will represent the distance the seismograph station was from the epicenter of the earthquake.



5. Repeat the above process for the other two seismograph stations.

6. You now know the location of the three seismograph stations and the distance each is from the earthquake eipcenter. Now devise a method for locating the epicenter on a globe.

QUESTIONS:

(B-1.11) 1. Describe the two major waves that move outward from an earthquake epicenter.

(B-2.11) 2. If the difference in arrival times of P- and S-waves at a station is 4.6 minutes, how far from the epicenter is the station?

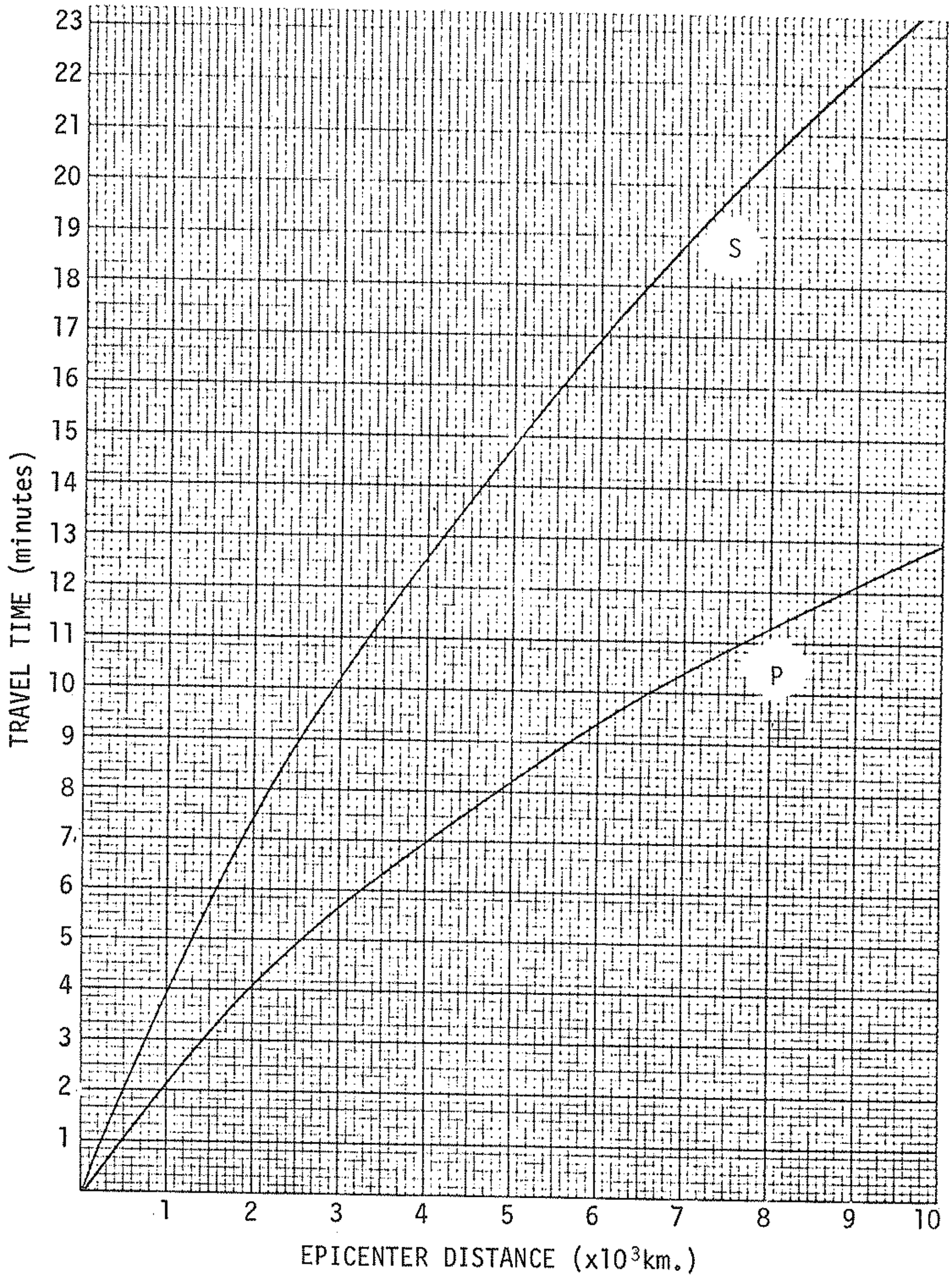
(B-2.21) 3. If a station situated 4000 km. from an epicenter receives a P-wave at 3:20 p. m., what time did the earthquake actually occur?

(B-2.11) 4. Why is the travel-time graph applicable for all earthquakes? What assumptions must be made?

5. Why was it necessary to know the distance from the epicenter for at least three recording stations to be able to locate the epicenter?

(B-1.21) 6. If both the S, shear, wave and P, compressional, wave were traveling through the same medium, which would have the greatest velocity?

Earthquake S- and P-wave Time-travel Graph

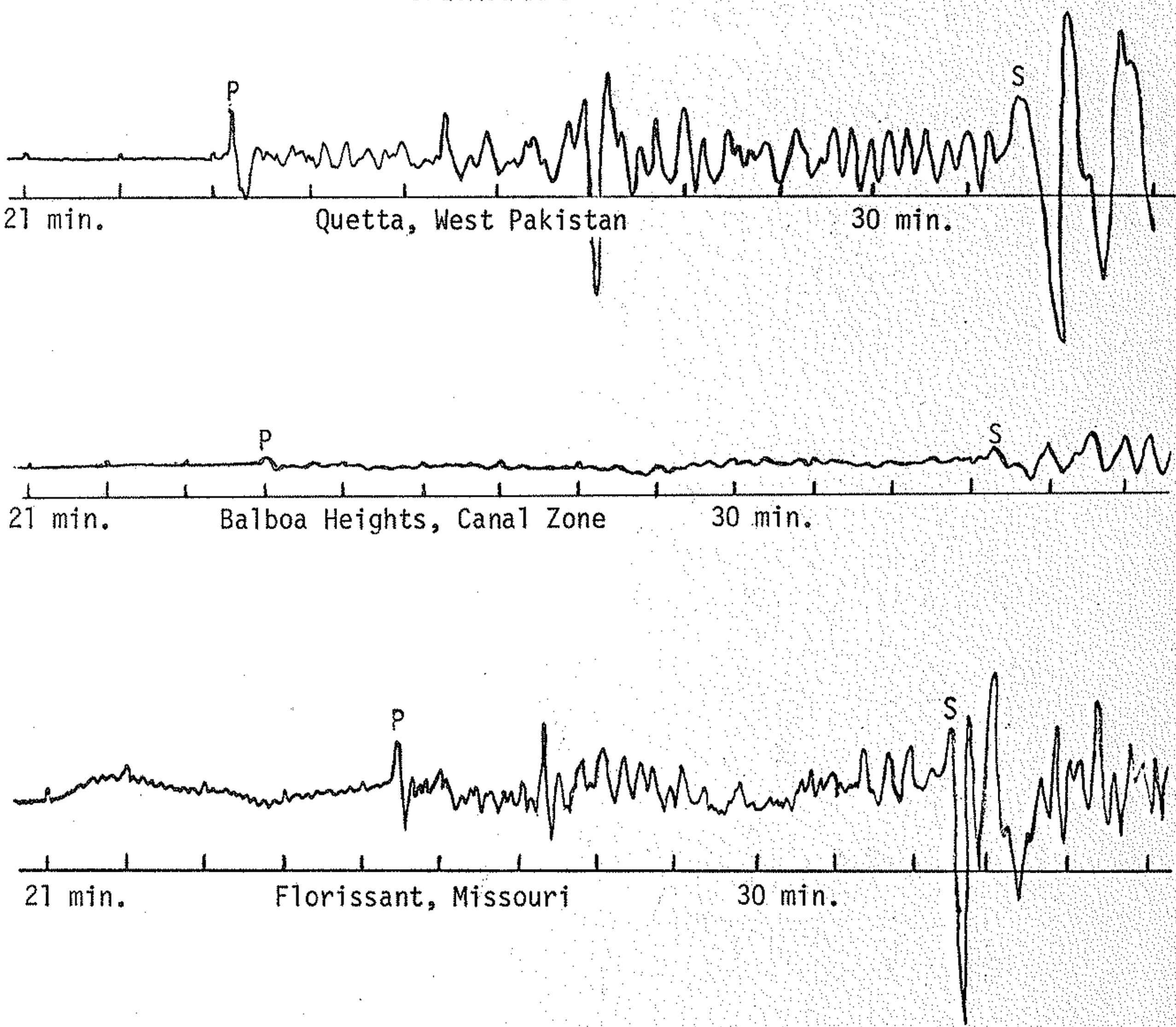


<u>Adapted from</u>:

Investigating the Earth, Laboratory Manual

Do Not Print

SEISMOGRAMS



Adapted from:

Investigating the Earth, Laboratory Manual

Challenging (2)

XII-D-1a: FIELD TRIP THROUGH THE MOUNTAINS

QUESTION:

What inferences can be drawn about the processes which may cause crustal changes?

MATERIALS:

Student handout sheets, including the supplementary sheet; Rocky Mountain or Sierra Nevada Field Trip kits, available from several suppliers (opitional but recommended).

SUGGESTED APPROACH:

1. Show filmstrip or slides for Rocky Mountain or Sierra Nevada Field Trip. Advise students to take notes of interesting features. (Commentary may be taped to maintain pace and save you from trying to read in the dark.)

2. Make certain the students understand that all predicted curves are based on the assumption that the crust material is composed of granite and that at a constant depth of 20 kilometers below sea level there is a crust-mantle interface. The mantle rock represents a more dense form of rock than the granite crust.

3. Have the students complete the graphs by plotting in the actual measured data for each of the curves.

4. In post-lab, discuss the interpretations of the graphs. Assist the students in reaching the conclusion that the mountains must have "granite roots," and that a constant crust-mantle interface at 20 km. below sea level is improbable.

MODIFICATIONS:

1. Sierra Nevada Field Trip - Use the commercial slide kit, and have the students prepare their graphs from the tables below

Location	Distance in Kilometers	Elevation in Meters	Predicted Gravity cm./sec.^{2}	Observed Gravity cm./sec.^{2}
Point Lobas	0	0	979.9	980.2
Near Carmel	5	120	979.9	980.1
Near Salinas	18	17	979.9	979.7
Near San Juan	24	170	979.9	979.8
West of San Juan	30	70	979.9	979.6
Near Hollister	46	100	979.9	979.6
Diablo Range	89	830	979.7	979.8
Cen. Valley	105	30	979.9	979.7
Sierra Foothills	118	83	979.9	979.7
Mother Lode Reg.	132	730	979.7	978.4
Yosemite Valley	163	2600	979.1	978.4
Tuolme	177	3300	978.8	977.6
Tioga Pass	197	3300	978.9	977.6
Mono Lake Area	211	2170	979.2	977.5

a) Data show acceleration of gravity along the route based on the assumption that acceleration of gravity if 979.908 cm./sec.^{2} at 37°N latitude, and that there is a decrease of 0.0308 cm./sec.^{2} per 100 meters of elevation.

b) Data are based on the assumption that the crust-mantle boundary is at 35 km. below sea level.

REFERENCES:

Investigating the Earth, p. 345, Teacher's Guide, pp. 421-433, '65 ESCP Text pp. 14.21 to 14.24

XII-D-1a: FIELD TRIP THROUGH THE MOUNTAINS

QUESTION:

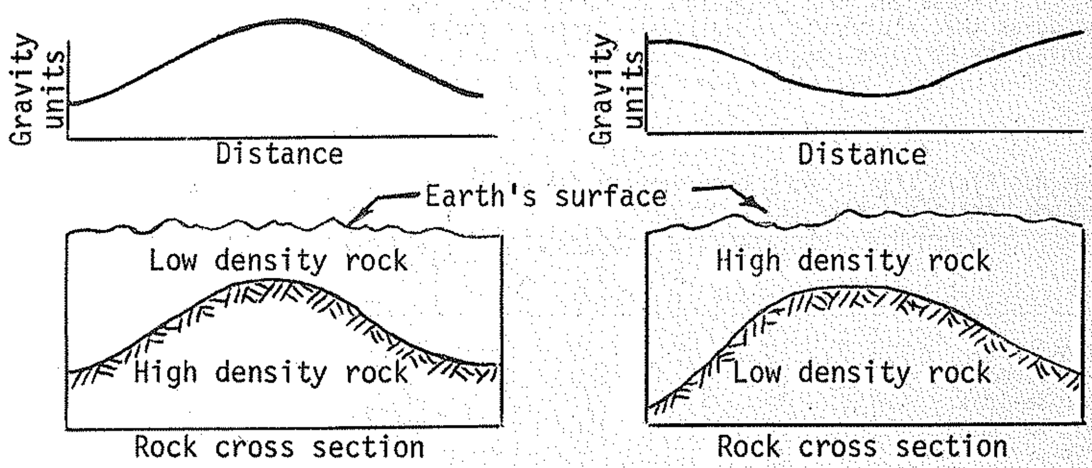
What inferences can be drawn about the processes which may cause crustal changes?

INTRODUCTION:

In this age of space exploration and moon landings, it is difficult to realize the extent of man's lack of knowledge concerning the interior of the earth. We have never sampled the mantle rock which lies below the relatively thin granite crust of the continents. Our knowledge of the nature of this mantle material and its location is based on indirect evidence such as gravity and heat flow measurements.

Gravity Measurement:

Your bathroom scale is actually a gravity-measuring device. The greater the gravitational pull on you, the more the spring in the scale will compress. Geologists use a very sensitive meter to measure extremely small changes in the pull of gravity. They have found that these small changes in gravity are related to the density of the rocks under the surface. Refer to the diagram below.



Heat Flow:

Although the sun is the primary source of energy at the earth's surface, small amounts of heat radiate from the earth's interior. Some of this heat is thought to be produced by the radioactive decay of atoms found in the nonsedimentary rock called granite. If this is the case, you would expect slightly more heat flow to occur in areas under which the rock granite is found.

With this information, you are now ready for a field trip through the mountains.

OBJECTIVES:

When you have finished this investigation, you should be able to:

1. describe how mountains affect the thickness of the earth's crust.

METHOD:

1. Observe the pictures that your teacher has provided for you.

2. Observe the graph of the area (supplementary sheet) over which your field trip has extended.

3. Plot on the graph the actual measured values given in the table below.

Location	Distance from Grand Junction	Gravity	Heat Flow
Bird City	600 km.	978.78 cm./sec.^{2}	4.2 cal./cm.^{2} yr.
Joe's	500	.80	4.3
Last Chance	420	.80	4.5
Denver	310	.41	5.8
?	290	.32	6.0
Idaho Springs	260	.21	6.9
Silver Plume	235	.11	7.1
Loveland Pass	225	.09	7.4
Vail Pass	200	.12	6.9
Vail	180	.14	6.5
Glenwood Springs	90	.25	4.3
New Castle	70	.32	4.5
Grand Junction	0	.59	5.0

4. Draw inferences concerning the depth to the crust-mantle interface based upon your interpretation of the graphs.

5. If you do not agree with the constant 20 km. below sea level as it is drawn on the cross section, sketch on the graph sheet a crust-mantle interface as you think it should be.

QUESTIONS:

1. Why is there a gravity "low" over the mountains even with a constant depth crust-mantle interface? Why a heat flow "high?"

2. What kind of a pattern for gravity and heat flow would you expect if the mountain had deep granite roots?

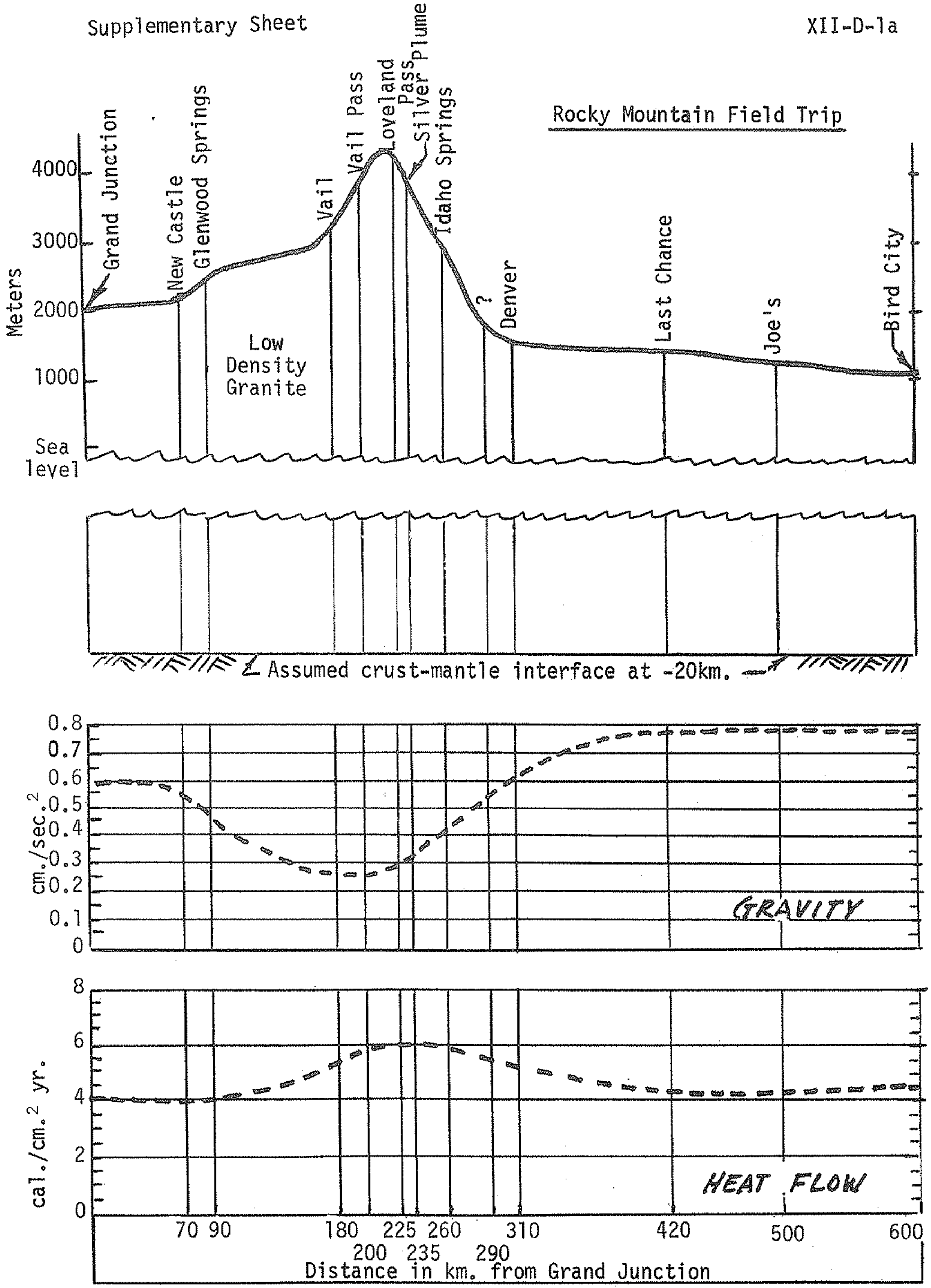
3. How does the actual measured pattern compare with your deep root prediction?

(C-1.21) 4. How does the thickness of the crust under mountains compare with the thickness in adjacent areas?

(D-1.31) 5. Relate the position of the granite mountain in the more dense underlying rock to the position of a floating piece of wood in water.

(D-1.11)
(D-1.21) 6. Describe a mountain building model that would explain the data observed in this investigation.

7. What relationships can you observe between the pictures taken along the field trip route and the scientific data gathered?



Predicted Values assuming the Crust-Mantle Interface to be 20 km. below sea level.