Appendix B
Core Lab Activities

Core Lab 1 - Interpreting Historical Geological Events

Introduction

Historical geology involves the study and interpretation of past events in the Earth's geological history. The recognition of the vast amounts of geologic time and the ability to establish the sequence of geological events that have occurred at various places and at different times, are the focus of this laboratory exercise.

Purpose and Outcomes

The students will

- construct and interpret cross-sectional diagrams of the Earth using the concepts:
    - Principle of original horizontality
    - Law of superposition
    - Principle of uniformitarianism
    - Law of cross-cutting relationships
    - Unconformities
    - Faulting
    - Folding
    - Principle of inclusions
    - Contact metamorphism
- apply and assess alternative theoretical models for interpreting knowledge.

Method

Part 1: Introduction to terminology and concepts

In completing this part of the laboratory exercise, students will have to reference Figures 1, 2, and 3. These figures are hypothetical cross-sections of the earth's crust and interior.

A. Principle of Original Horizontality

Sediment, as it is deposited through weathering and erosion, forms nearly horizontal layers. Therefore if beds of sedimentary rocks are folded or inclined at an angle, it can be implied that some form of deformation took place after the sediment was deposited.

1. Indicate from Figure 1 the layers of rocks that this principle applies to:

2. Which rock layer would be the oldest, D or E? Circle the answer.

B. Law of Superposition

In any undeformed sequence of rock layers, a rock layer is relatively older than all rock layers above and relatively younger than all layers below.

3. Of the rock types in Figure 2, A, B, D, and E, which are the youngest and oldest? List in order from oldest to youngest.

Oldest ___ ___ ___ ___ Youngest

Hypothetical Cross-Sections

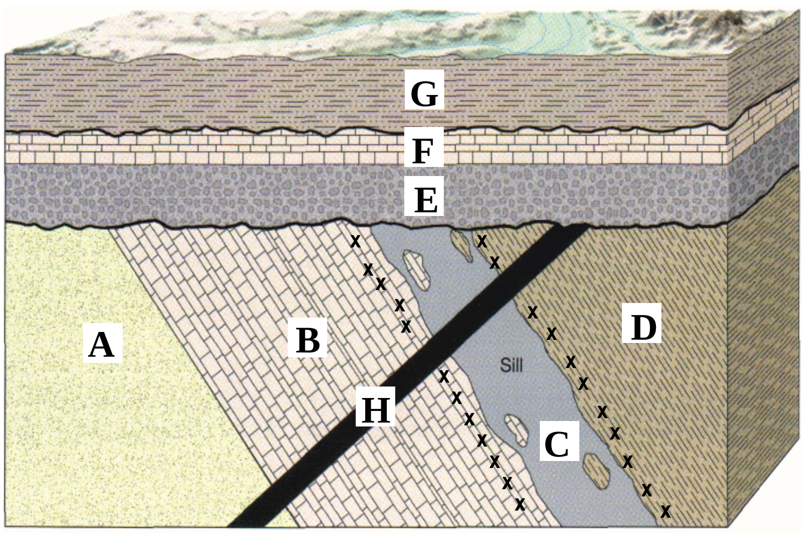


Figure 1

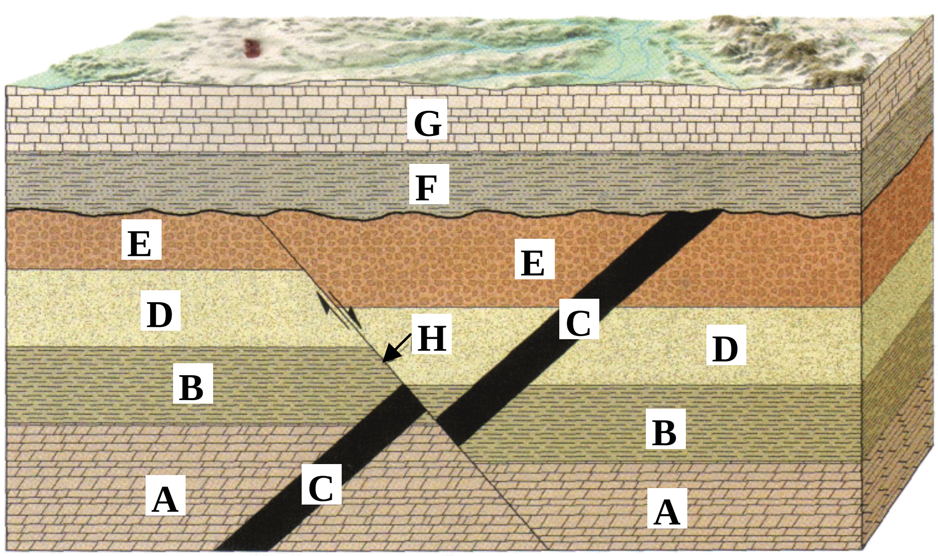


Figure 2

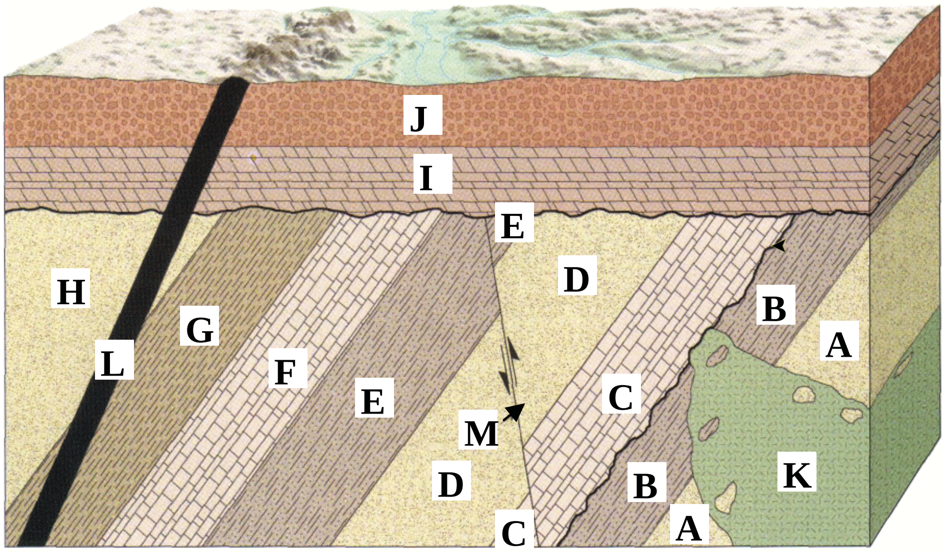


Figure 3

C. Principle of Uniformitarianism

When interpreting rock history by sequencing physical events, it must be recognized that the same external and internal processes happening on Earth today are most similar to the processes that operated in the past.

4. With reference to Figure 1, what physical events can we observe on earth today that most likely occurred similarly in earth's geologic history. List three.

a) ____

b) ____

c) ____

D. Law of cross-cutting Relationships

Whenever molten rock cuts through existing rock or a geologic feature, the intrusive rock is younger than the structure it cuts across.

5. With reference to Figure 2, which letters of two features illustrate this relationship? _____ and _____

6. Would the fault seen in Figure 2 be older or younger than the sedimentary beds, A, B, D, and E?

____

E. Unconformities

As sediment is deposited at a location, there will be an uninterrupted record of the material as it is deposited. However, if there is a break or gap in the sequence of deposition, then this gap in time allows for the development of an erosional surface, clearly visible between rock layers. Such a gap or break in the rock record is an unconformity.

7. Identify the unconformity in each of the illustrations by indicating the letter which identifies the feature.

   a) Figure 1 _______________

   b) Figure 2 _______________

   c) Figure 3 _______________

F. Faulting

Faults involve a break between rock layers where significant movement or displacement of a rock layer has occurred.

8. With reference to Figures 2 and 3, which letter identifies a fault?

   a) Figure 2 _______________

   b) Figure 3 _______________

G. Folding

Rock layers are subjected to tremendous pressures from within earth's crust. These pressures cause rocks to fold, over periods of significant geological time. The time of the folding will always be at least as young as the youngest layers involved in the folding, and older than any undisturbed beds of rocks overlying the folded rock layers.

9. With reference to Figures 1, 2 and 3, which figure(s) may have been exposed to tremendous pressures and displays evidence of folding?

   Figure(s) ___________________________

H. Principle of Inclusions

A piece of one rock unit contained within another is referred to as an inclusion. These features occur when preexisting rock is eroded and becomes part of a younger rock unit.

10. Which figure and rock unit shows this feature?

Figure _____, and rock unit ______.

Figure _____, and rock unit ______.

I. Contact Metamorphism

Contact metamorphism occurs when molten rock comes in contact with preexisting rock. The heat causes a change in the older rock, in which it intrudes.

11. Which symbol in the three Figures represents contact metamorphism? ______________________

12. Indicate the rock unit in each illustration which shows contact metamorphism.

Figure 1, rock unit(s) ____________.

Figure 2, rock unit(s) ____________.

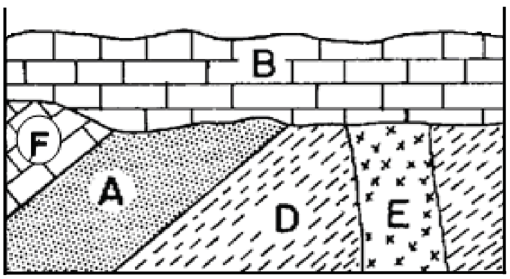
Figure 3, rock unit(s) ____________.

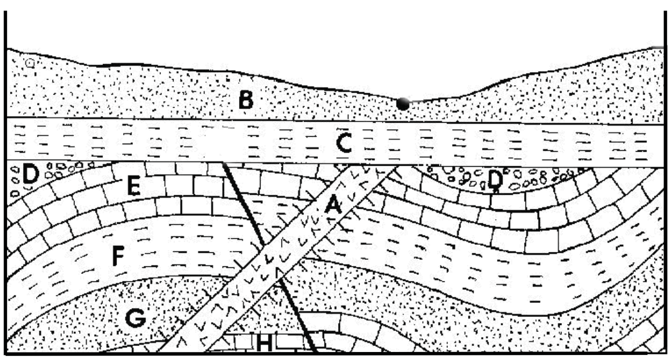
Part 2: Sequencing of Events

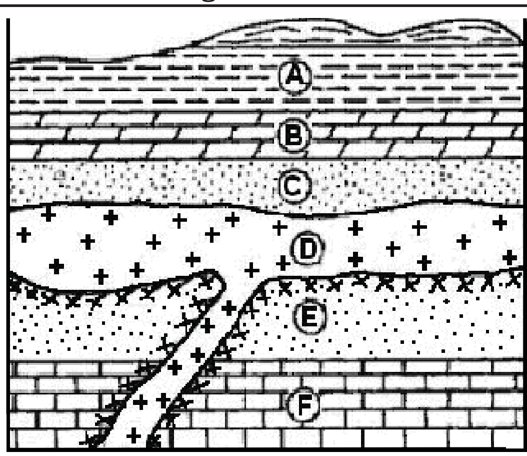
A. List the entire sequence of events, in order from oldest to youngest, as they have occurred in Figure 2. Write the appropriate letter or event in the space below.

Relative Time	Letter	Event
Youngest		
Oldest		

B. Using the geological symbols in Figure 7 as a key, interpret the sequence of events as shown by the diagrams below. Use short descriptive sentences to describe the events from the oldest to the youngest. Describe the events in the space at the right of each figure.

Geologic Cross-Section	Geologic Event
 Figure 4	

Geologic Cross-Section	Geologic Event
 Figure 5	

Geologic Cross-Section	Geologic Event
 Figure 6	

Part 3: Construction of a Geologic Cross-Section

In the space provided, construct a geologic cross-section, using the following information:

- A thick layer of evenly-bedded limestone is deposited in sequence with layers of shale, sandstone and conglomerate.
- All layers are subjected to intense horizontal pressure resulting in folding.
- The folded layers are eroded to the top of the sandstone layer.
- A layer of shale is deposited on top of the eroded surface.
- A basaltic intrusion cuts through all layers and flows on to the surface where it burns all rocks that it comes in contact.
- There is some evidence of surface erosion.

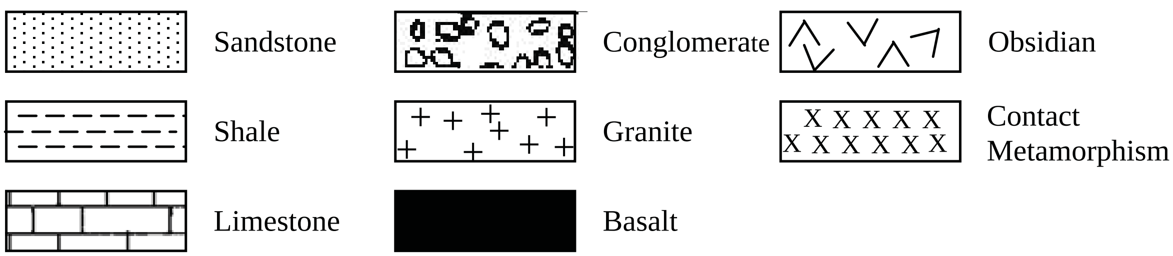


Figure 7

Core Lab 2 - Estimating Dinosaur Size and Speed from Trackways

Introduction

Dinosaur remains have been discovered on every continent. In North America, dinosaurs have been discovered in such places as Alabama, Alaska, Alberta, Colorado, Montana, New Jersey, Utah and Wyoming. Some of the most common dinosaur fossils are footprints and trackways. An individual foot impression is a footprint and a continuous line of these footprints forms a trackway. Footprints and trackways, and track morphology give scientists some of the only evidence of dinosaur behaviors. Using these fossils, inferences can be made about dinosaur size, gait (i.e. how they walked), activity, and speed of movement.

Purpose and Outcomes

The students will

- gain insight into the work of paleontologists
- be introduced to dinosaur footprints and trackways
- use developed skills to determine the speed of various dinosaurs from sketches
- work cooperatively with team members to develop and carry out a plan, and troubleshoot problems as they arise.

In this laboratory you will play detective and reconstruct the past history of the dinosaurs. Your only clues are their footprints found in rocks that lithified 100 million years ago. In the first part of the laboratory, you will be introduced to idealized dinosaur trackways using idealized footprints and trackways in the first part of the lab and will then use the skills developed to determine the speed of various dinosaurs from sketches and photos of actual footprints and trackways. Using just a set of footprints, you will determine the leg length, the body length, and the speed at which the dinosaur was traveling, and if the dinosaur was a carnivore or a herbivore.

Estimating Dinosaur Size from a Footprint

Foot length is the distance from the back of the heel to the front of the longest toe (usually the centre toe). A basic fact of physiology is that larger animals have larger feet. Thus, foot length can be used to estimate leg length. Most dinosaurs have leg lengths about 4 times the length of their foot. Leg length, which is also called hip height, is the distance from the toe to the hip of the dinosaur. Body length is the distance from the tip of the tail to the tip of the nose of the dinosaur.

Figure 2 is an illustration of an actual dinosaur footprint. Follow the steps below to estimate the size of the dinosaur.

- Using a ruler, measure the length of the footprint from the back of the heel to the longest toe in centimetres and record this length in Table 1.
- Calculate and record leg length by multiplying the footprint length by 4.0.
- Calculate and record body length by multiplying the leg length by 3.50. Measurements can be converted from centimetres to metres by dividing by 100. For example, 27.5 cm is equal to 0.275 m.
- According to Figure 1, is the dinosaur a carnivore or a herbivore?

Table 1: Information extrapolated from the footprint of a carnivorous dinosaur	
Footprint Length (cm)	
Leg Length (cm)	
Body Length (cm)	
Body Length (m)	
Carnivore /Herbivore	

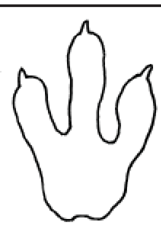
	**Herbivore (plant-eater)** Poorly defined toes with little or no claw impressions and large pad marks
	**Carnivore (meat-eater)** Well defined toes with good claw impressions and small or no pad marks

Figure 1: Classification of herbivorous and carnivorous dinosaur footprints

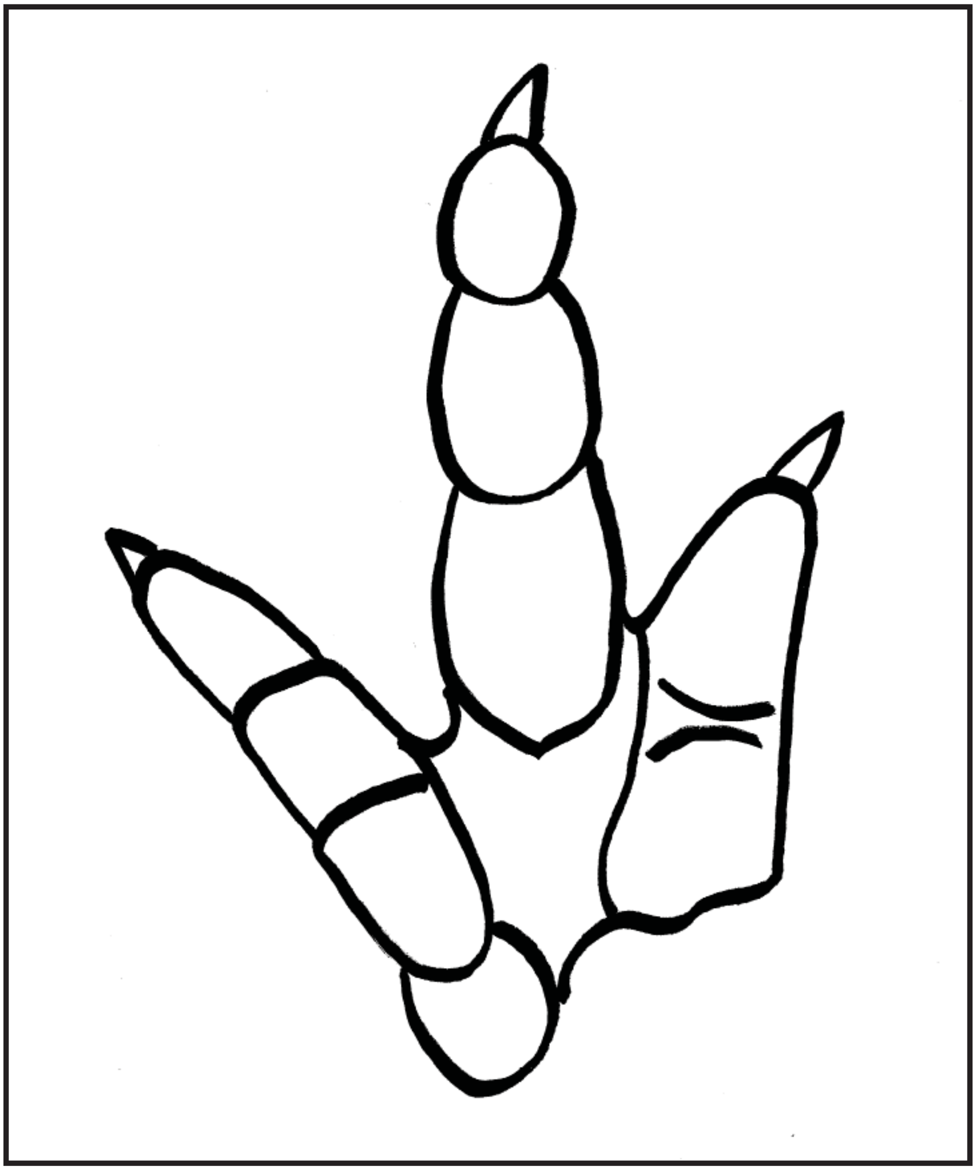


Figure 2: Illustration of the right footprint of a dinosaur. Scale: 1.0 cm = 1.0 cm

Estimating Dinosaur Size and Speed from Trackways

A single footprint yields a lot of information about the size of a dinosaur, but is it possible to calculate the speed at which a dinosaur moved? If you can find a trackway, a successive set of footprints, the answer is yes. Stride length is the distance from the heel of one footprint to the heel of the next footprint of the same foot. By measuring stride length, and relating it to the measured stride length and speed of a variety of present day animals, it is possible to determine the speed of movement from a trackway. Follow the steps of the sample calculation to learn how scientists estimate dinosaur speed from a trackways.

Sample Calculation for Estimating Dinosaur Size and Speed

Figure 4 is a photograph of an actual dinosaur trackway. Measurements from the trackway indicate that dinosaur foot length was 75 cm and stride length was 422 cm. Using these measurements, scientists estimate that the dinosaur was moving at a speed of 9.89 km/h. Follow the steps below to learn how this estimate was reached.

Table 2: Sample measurements and calculations for trackway depicted in Figure 4									
Foot Length		Stride Length		Leg Length		Relative Stride Length	Dimensionless Speed	Speed	
cm	m	cm	m	cm	m			m/s	km/h
75	0.75	422	4.22	300	3.0	1.41	0.5	2.7	9.89

Step 1 - Measure foot length. [75 cm]

Step 2 - Measure stride length along trackway. [422 cm]

Step 3 - Calculate leg length by multiplying foot length by 4. [3.00 m]

Step 4 - Calculate relative stride length by dividing stride length by leg length. [4.22 m/3.00 m = 1.41]

Step 5 - Dimensionless speed is a calculated value that relates actual speed to the leg and stride length of an organism. Data collected on present day animals was used to create the graph in Figure 3. From the graph, interpolate dimensionless speed of the dinosaur using the relative stride length calculated in step 4. If the relative stride length is less than 0.9, use 0.1 as the value for dimensionless speed. [dimensionless speed is 0.5 since the relative stride length is 1.41]

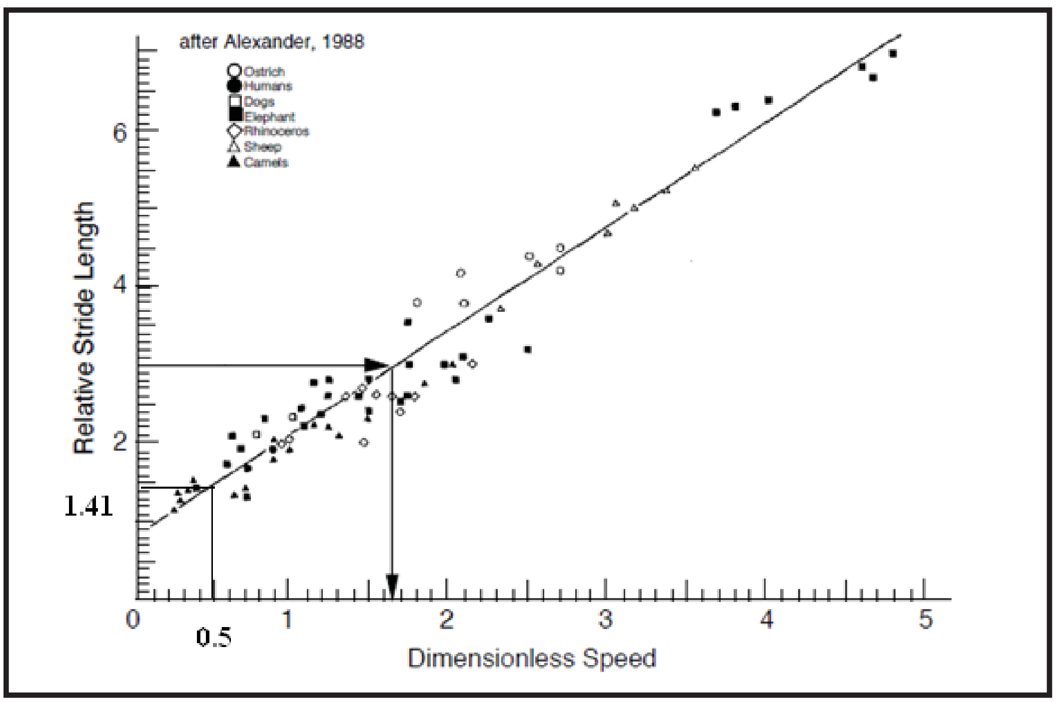


Figure 3: Graph illustrating the relationship between relative stride length and dimensionless speed among present day animals. (Alexander, 1989, Dynamics of Dinosaurs and Other Extinct Giants.)

Step 6 - Calculate dinosaur speed using the equation below. Note: gravitational acceleration is 10 m/s^2 and calculated dinosaur speed will be in metres per second.

$$\text{Speed} = (\text{dimensionless speed}) \times \sqrt{(\text{leg length}) \times (\text{gravitational acceleration})}$$

$$\text{Speed} = 0.5 \times \sqrt{3.00\text{m} \times 10\text{m/s}^2} = 0.5 \times 5.48 = 2.7\text{m/s}$$

[2.7 m/s]

Step 7 - Convert speed from m/s to km/h. Multiply the answer in step 6 by 3.6. [2.7 m/s x 3.6 = 9.89 km/h]

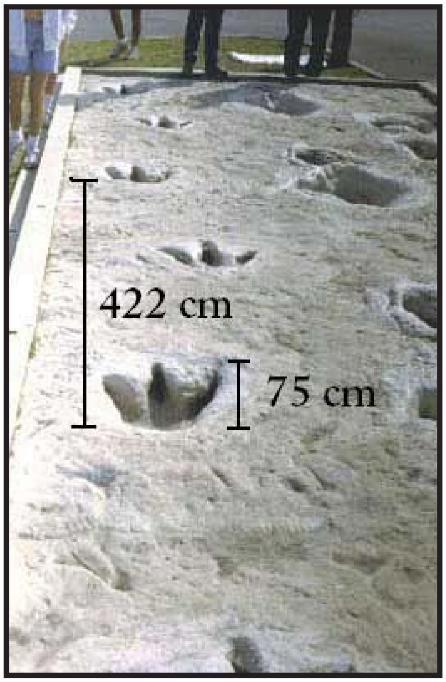


Figure 4: A dinosaur trackway. Modified from Pyle, 1996, Fossil Formation.

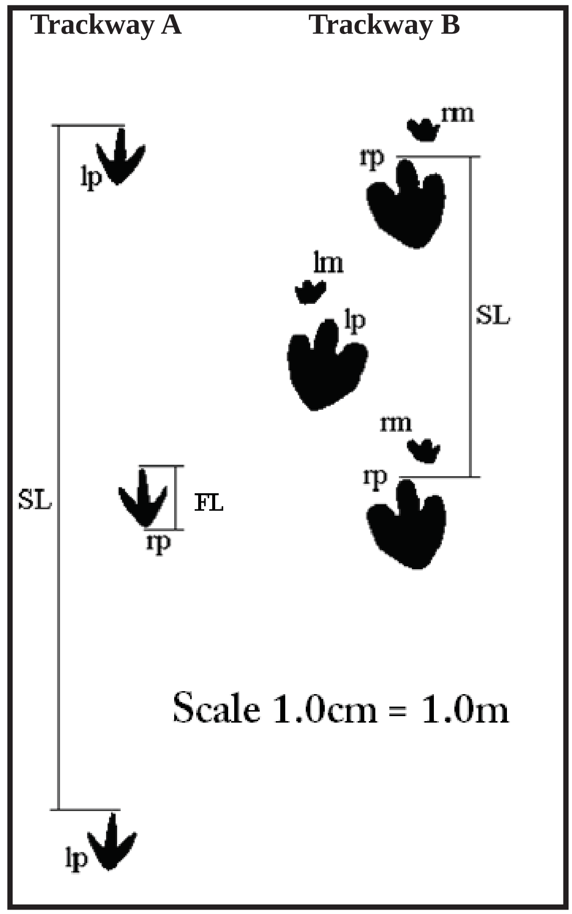


Figure 5: Measurement of foot length (FL) and stride length (SL) for a carnivorous dinosaur (A) and a herbivorous dinosaur (B). Footprints are labelled right (r) or left (l), and front (m) or hind foot (p). Modified with permission. Courtesy: Jeff Over

Practice Calculation for Estimating Dinosaur Size and Speed

Figure 5 shows two dinosaur trackways. Trackway A is from a carnivorous dinosaur and trackway B from a herbivorous dinosaur. Carefully follow the steps for the sample calculation to estimate the size and speed of the dinosaurs that created trackways A and B. Record your measurements and calculations in Table 3. Note: the scale of Figure 5 is 1.0 cm = 1.0 m.

Table 3: Measurements and calculations for trackways depicted in Figure 5										
Trackway	Foot Length		Stride Length		Leg Length		Relative Stride Length	Dimensionless Speed	Actual Speed	
	cm	m	cm	m	cm	m			m/s	km/h
A										
B										

Following the steps provided, it is possible to estimate dinosaur speed from a trackway; but was that dinosaur walking, trotting or running? This question can be answered by simply comparing the calculated relative stride lengths recorded in Table 3 to the information provided in Table 4. Were the dinosaurs that created Trackway A and B walking, trotting, or running? Record your findings in Table 5.

Table 4: Comparison of stride length to movement type	
Relative Stride Length	Movement Type
less than 2.0	walking
between 2.0 and 2.9	trotting
greater than 2.9	running

Table 5: Movement type for trackways depicted in Figure 5		
Trackway	Relative Stride Length	Movement Type
Example	4.2	running
A		
B		

Estimating Dinosaur Speed from Actual Trackways

Having completed the sample and practice calculation, we can now play detective and apply this method to actual dinosaur trackways to reconstruct something about their behaviour. Figures 6 and 7 show four different dinosaur trackways made by dinosaurs during the Mesozoic era. For each trackway, measure the foot length and stride length. Use these measurements to complete Tables 6 and 7. Note: measure accurately as each trackway has a different scale.

Table 6: Measurements and calculations for trackways depicted in Figures 6 and 7

Trackway Number Dinosaur Age and Name	Foot Length (m)	Stride Length (m)	Leg Length (m)	Relative Stride Length	Dimensionless Speed	Actual Speed	
						m/s	km/h
Trackway 1 Cretaceous Ornithopod							
Trackway 2 Jurassic Sauropod							
Trackway 3 Triassic Theropod							
Trackway 4 Triassic Prosauropod							

Table 7: Movement type for trackways depicted in Figures 6 and 7

Trackway Number Dinosaur Age and Name	Relative Stride Length	Movement Type
Trackway 1 Cretaceous Ornithopod		
Trackway 2 Jurassic Sauropod		
Trackway 3 Triassic Theropod		
Trackway 4 Triassic Prosauropod		

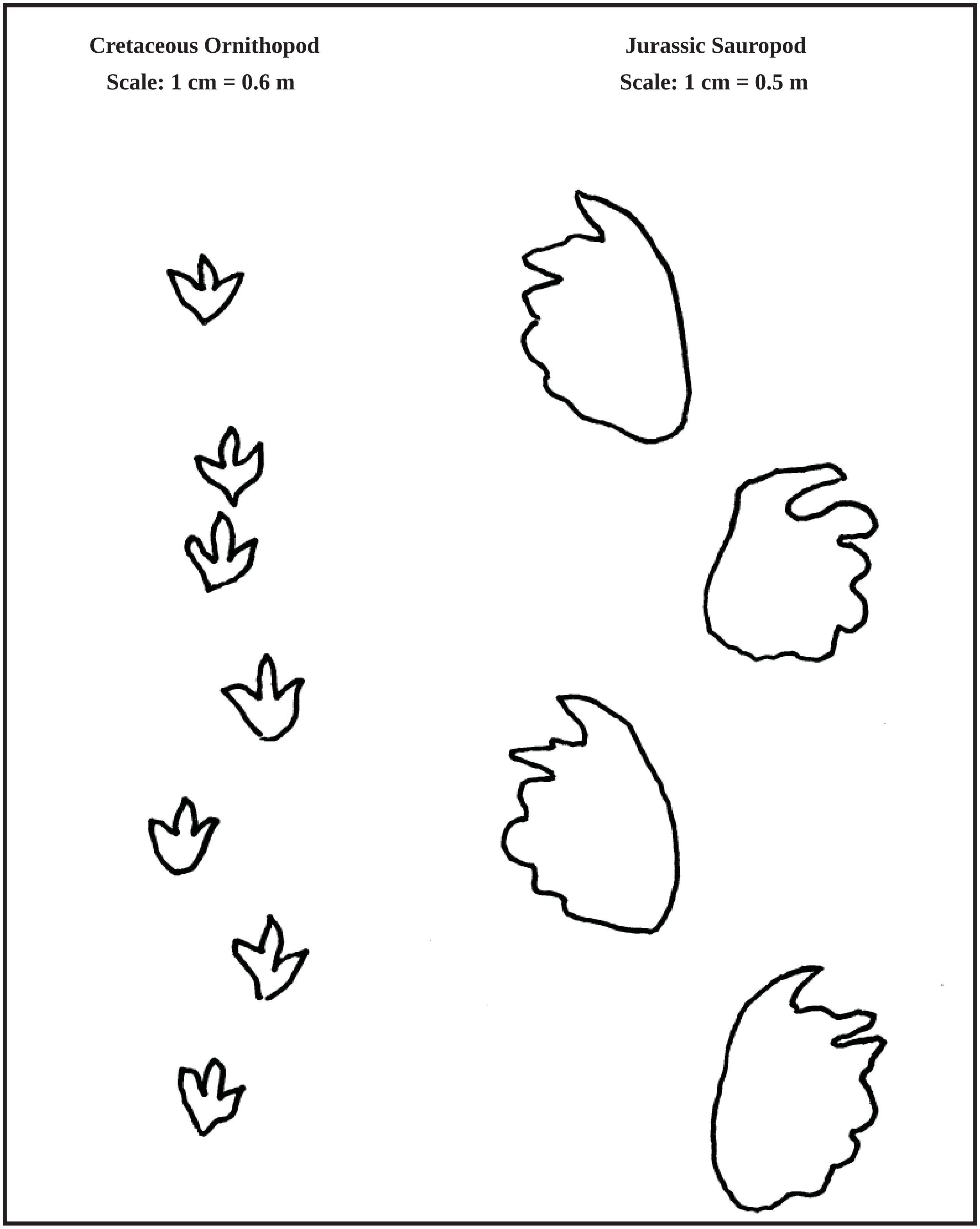


Figure 6: Trackways of dinosaurs. Modified from Lockley and Hunt, 1995, Dinosaur Tracks and Other Fossil Footprints of the Western United States

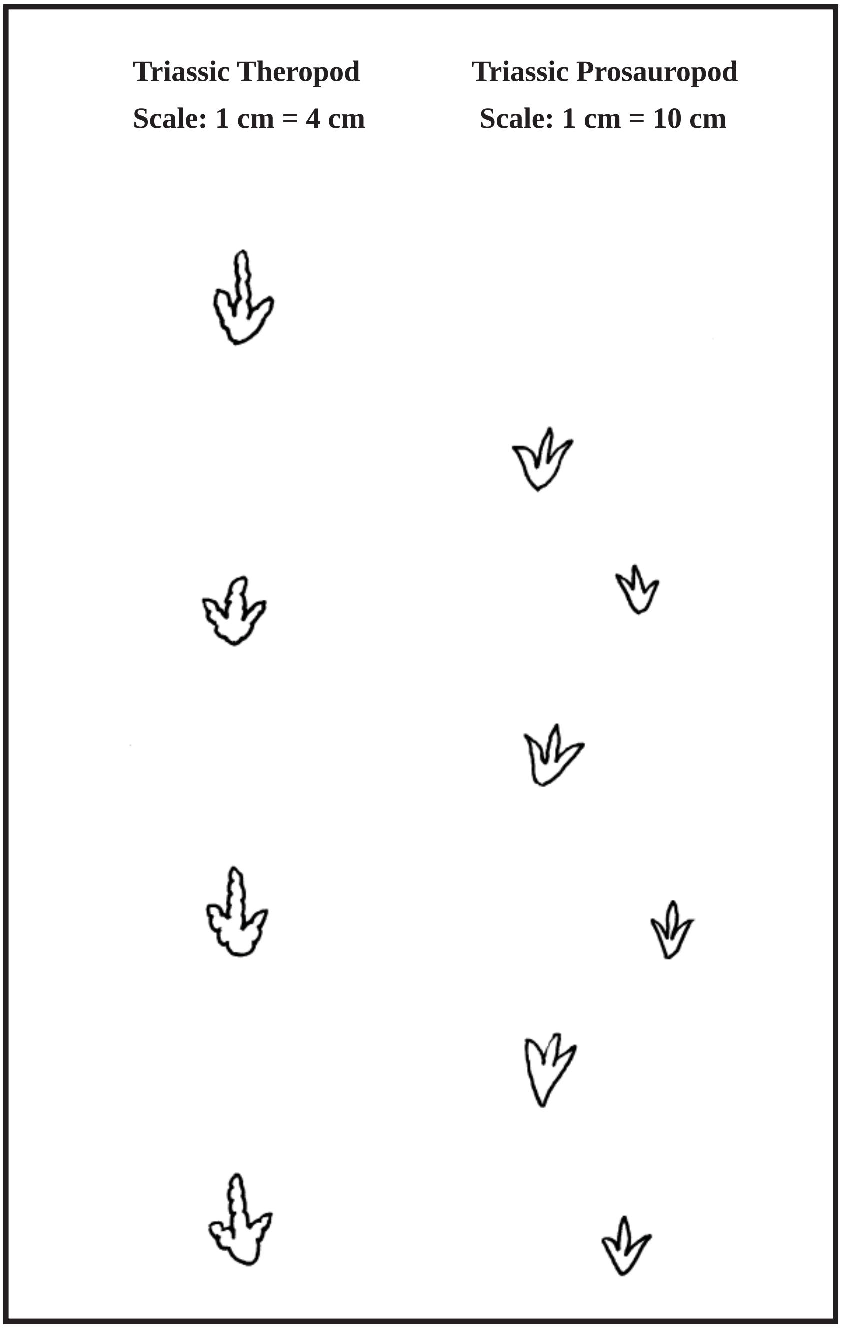


Figure 7: Trackways of dinosaurs. Modified from Lockley and Hunt, 1995, Dinosaur Tracks and Other Fossil Footprints of the Western United States

Extension Activity:

Could You Outrun a Dinosaur?

Use a metric ruler to determine your own foot length. Estimate your leg length by multiplying your foot length by 4. Confirm the accuracy of this measurement by measuring your actual leg length, while standing, from the floor to your hip bone. How accurate was the estimate? For the remainder of the activity use your actual measured leg length.

Stride length is best measured from heel to heel for the same foot while moving across some distance or course. First cross the course at walking speed, then at an easy trotting speed, and finally running speed. Each time measure your stride length. Then, using the method practiced in the laboratory activity, calculate your relative stride length, dimensionless speed and actual speed for each trial. Record your data in Table 8.

Assume you are being chased by a large dinosaur and are running as fast as you can. Transfer your running data to the appropriate row in Table 9. Use the additional information in Table 9 to calculate the speed of the various dinosaurs. Which of them could you outrun? Research which of these dinosaurs were carnivores and which were herbivores.

Table 8: Measurements and calculations for human trackways

Human Movement	Foot Length (m)	Stride Length (m)	Leg Length (m)	Relative Stride Length	Dimensionless Speed	Actual Speed	
						m/s	km/h
Walking							
Trotting							
Running							

Table 9: Measurements and calculations for human trackways

Organism	Foot Length (m)	Stride Length (m)	Leg Length (m)	Relative Stride Length	Dimensionless Speed	Actual Speed	
						m/s	km/h
Human							
Hadrosaur	0.3	1.4					
Struthiomimus	0.23	1.34					
Velociraptor	0.25	3.05					
Euoplocephalus	0.40	1.87					
Tyrannosaurus rex	1.0	5.76					

Post-Script

Did you know that a well-trained human athlete is capable of running approximately 5.5 m/s or 20 km/h? This speed is less than some dinosaurs. Also, consider that we cannot be sure that these dinosaurs were running at their top speed. Perhaps they could run even faster! After all, animals rarely travel at their fastest speed when traversing through difficult terrain (i.e. soft, sticky riverbank mud). For example, could you run at your top speed on a beach?

We can see there is a difference in performance between humans and dinosaurs. It is easy to understand why dinosaurs dominated terrestrial ecosystems during the Mesozoic era and why life would have been hard for small, defenceless mammals. It is somewhat comforting to know that dinosaurs and humans never met, as dinosaurs became extinct more than 60 million years before the earliest human (Homo ergaster) first appeared in central Africa.

Core Lab 3 - Part I: Mineral Identification

Purpose and Outcomes

The students will

- recognize and describe the physical properties of minerals.
- identify several minerals by sight.
- list the uses of several minerals.
- select appropriate instruments for collecting evidence, and appropriate processes for problem solving, inquiring, and decision making.
- use instruments effectively and accurately for collecting data.
- compile and organize data using appropriate formats and data treatments that facilitate interpretation of the data.
- use a mineral identification key to name minerals.

Materials

- hand lens
- mineral samples
- streak plate
- magnet
- stereoscopic microscope
- dilute hydrochloric acid
- quartz crystals (various sizes)
- contact goniometer
- crystal growth solution(s)

Common Minerals

1. List the uses for the following minerals:
   a) Chalcopyrite
   b) Feldspar
   c) Fluorite
   d) Galena
   e) Graphite
   f) Gypsum
   g) Halite
   h) Hematite
   i) Magnetite
   j) Pyrite
   k) Quartz
   l) Sphalerite
   m) Talc
   n) Olivine
   o) Hornblende
   p) Pyroxene

Physical Properties of Minerals

2. Primary properties include: optical properties (in particular lustre and the ability to transmit light), hardness, colour, streak, crystal form, cleavage and specific gravity. Briefly define these terms.

   The Mohs scale of hardness (Table 1), widely used today by geologists and engineers, uses ten index minerals as a reference set to determine the hardness of other minerals.

Table 1: Mohs scale of hardness with the harness of some common objects

Mineral	Scale	Common Objects
Diamond	10	• Steel file (6.5) • Glass (5.5) • Knife blade (5.1) • Wire Nail (4.5) • Penny (3.5) • Fingernail (2.5)
Corundum	9	
Topaz	8	
Quartz	7	
Orthoclase	6	
Apatite	5	
Fluorite	4	
Calcite	3	
Gypsum	2	
Talc	1	

Table 2: Hardness guide

Hardness	Description
Less than 2.5	A mineral that can be scratched by your fingernail
2.5 - 5.5	A mineral that cannot be scratched by your fingernail and cannot scratch glass
Greater than 5.5	A mineral that scratches glass

3. Test the hardness of several of the mineral specimens provided by your teacher by rubbing any two together to determine which are hard (the minerals that do the scratching) and which are soft (the minerals that are scratched). Doing this will give you an indication of what is meant by the term “relative hardness” of minerals.
4. Use the hardness guide in Table 3 to find an example of a mineral supplied by your teacher that falls in each of the three categories.
5. Colour, although an obvious feature of minerals, may also be misleading. Explain why this is so.
6. Observe two varieties of the same mineral, quartz. What is the reason for the variety of colours that quartz exhibits?
7. Examine your mineral specimens and identify any that appear to be the same mineral but with variable colours.
8. Why is streak a more reliable indicator than colour?

9. Select three of the mineral specimens provided. Do they exhibit a streak? If so, is the streak the same colour as the mineral specimen? List your observations for each specimen.
10. Most of the time, minerals must compete for space and the result is a dense inter-grown mass in which crystals do not exhibit their crystal form, especially to the unaided eye. Nonetheless, crystal form can often be used to identify mineral samples. At the discretion of your teacher, you may be asked to grow crystals by evaporating prepared concentrated solutions. Following the specific directions of your teacher, and after you have completed your experiment(s), write a brief paragraph summarizing your observations.
11. The mineral, quartz has a well-developed crystal form with six faces that intersect at about 120^0 and come to a point. Why do muscovite and biotite, two varieties of the same mineral, not exhibit crystal form?
12. Select one of the mineral specimens, other than quartz, that exhibits its crystal form and describe its shape.
13. Observe the various size crystals of the mineral quartz. Use the contact goniometer to measure the angle between similar, adjacent crystal faces on several crystals. Then, write a statement relating the angle between adjacent crystal faces to the size of the crystal.
14. Distinguish between crystal form and cleavage.
15. Distinguish between cleavage and fracture.

Minerals may have 1, 2, 3, 4, or 6 directions of cleavage. Table 3 describes some common directions.

Table 3: Common cleavage directions of minerals

Cleavage Direction	Shape
0	Irregular mass
1	Flat sheets
2 at 90°	Elongated form with rectablge cross section (prism)
2 not at 90°	Elongated form with parallelogram cross section (prism)
3 at 90°	Cube
3 not at 90°	Rhombohedron
4	Octahedron
6	Dodecahedron

16. The minerals, muscovite and biotite, have one direction of cleavage. Describe the appearance of a mineral that exhibits this type of cleavage.
17. Observe the calcite specimen. Several smooth, flat planes result when the mineral is broken.
    a) How many planes of cleavage are present?
    b) How many directions of cleavage are present?
    c) The cleavage directions meet at what angle? (90^0 angles or angles other than 90^0)
18. Select one mineral specimen that exhibits cleavage. Describe its cleavage by completing the following statement:______ directions of cleavage at _____ degrees.

Secondary Properties of Minerals

19. Secondary or special properties include feel and taste. These properties are of use in identifying certain minerals. List at least 3 more special properties.
20. Examine the mineral specimens provided by your teacher and answer the following questions.
    a) How many of your specimens can be grouped into each of the following lustre types?
    Metallic ______, Nonmetallic or glassy ______.
    b) How many of your specimens are transparent and how many are opaque?
    Transparent ______, Opaque ______.
21. Give at least one example, for each property, of a mineral that can be identified using it.
    a) Taste
    b) Feel
    c) Striations
    d) Magnetism
    e) Reaction to dilute hydrochloric acid

(CAUTION: Hydrochloric acid can discolour, decompose, and disintegrate mineral and rock samples. Use the acid only after you have received specific instructions on its use from your teacher. Never taste minerals that have had acid placed on them.)

22. Following the directions given by your teacher, examine the mineral specimens to determine if any exhibit one or more of the special properties listed above.

Identification of Minerals

To identify a mineral, you must first determine, using available tools, as many of its physical properties as you can. Next, knowing the properties of the mineral, you use a mineral identification key to narrow down the choices and arrive at a specific name. *As you complete the exercise, remember that the goal is to learn the procedure for identifying minerals through observation and not simply to put a name on them.*

23. Arrange your mineral specimens by placing them on a numbered sheet of paper. Locate the mineral identification chart, Table 4, and write the numbers of your mineral specimens, in order, under the column labelled “Specimen Number”.

Table 5 is a mineral identification key that uses the property of lustre as the primary division of minerals into two groups, those with metallic lustres and those with nonmetallic lustres. Colour (either dark or light) is used as a secondary division for the nonmetallic minerals. Examine the mineral identification key closely to see how it is arranged.

24. Use the mineral identification key. What would be the name of the mineral with these properties: nonmetallic lustre, light coloured, softer than a fingernail, produces small, thin plates or sheets when scratched by a fingernail, white colour, and a "soapy" feel?
25. Complete the mineral identification chart, Table 4, by listing the properties of each of the mineral specimens supplied by your teacher. Use the mineral identification key, Table 5, to determine the name of each of the minerals.
26. In question 1 you researched the use of some economic minerals. List their use in the column to the right of their name on the mineral identification chart, Table 4.

Table 4: Mineral Identification Chart

Specimen Number	Lustre	Hardness	Colour	Streak	Fracture	Cleavage (# of directions and angle)	Other Properties	Name	Economic Use or Rock-forming

Table 5: Mineral Identification Key			
Group I - Metallic Lustre			
Hardness	**Streak**	**Other Diagnostic Properties**	**Name (Chemical Composition)**
Harder than glass	Black	Black; magnetic; hardness = 6; specific gravity = 5.2; often granular	Magnetite (Fe_3O_4)
	Greenish-black	Brass yellow; hardness = 6; specific gravity = 5.2; generally an aggregate of cubic crystals	Pyrite (FeS_2) Fool's gold
	Red-brown	Grey or reddish brown; hardness = 5-6; specific gravity = 5, platy appearance	Hematite (Fe_2O_3)
Softer than glass	Greenish-black	Golden yellow; hardness = 4; specific gravity = 4.2; massive	Chalcopyrite ($CuFeS_2$)
	Grey-black	Silvery grey; hardness = 2.5; specific gravity = 7.6 (very heavy); good cubic cleavage	Galena (PbS)
	Yellow-brown	Yellow brown to dark brown; hardness variable (1-6); specific gravity = 3.5-4; often found in rounded masses; earthy appearance	Limonite ($Fe_2O_3 \cdot H_2O$)
	Grey-black	Black to bronze; tarnishes to purples and greens; hardness = 3; specific gravity = 5; massive	Bornite (Cu_5FeS_4)
Softer than your finger-nail	Dark grey	Silvery grey; hardness =1 (very soft); specific gravity = 2.2; massive to platy; writes on paper (pencil lead); feels greasy	Graphite (C)

Table 5: Mineral Identification Key (continued)

Group II - Non-Metallic Lustre (dark coloured)

Hardness	Cleavage	Other Diagnostic Properties	Name (Chemical Composition)
Harder than glass	Cleavage present	Black to greenish-black; hardness = 5-6; specific gravity = 3.4; fair cleavage, two directions at nearly 90°	Augite (Ca, Mg, Fe, Al silicate)
		Black to greenish-black; hardness = 5-6; specific gravity = 3.2; fair cleavage, two directions at nearly 60° and 120°	Hornblende (Ca, Na, Fe, OH, Al silicate)
		Red to reddish-brown; hardness = 6.5-7.5; conchoridal fracture; glass lustre	Garnet (Fe, Mg, Ca, Al silicate)
	Cleavage not prominent	Grey to brown; hardness = 9; specific gravity = 4; hexagonal crystals common	Corundum (Al_2O_3)
		Dark-brown to black; hardness = 7; conchoidal fracture; glass lustre	Smoky quartz (SiO_2)
		Olive green; hardness = 6.5-7; small glassy grains	Olivine $(Mg, Fe)_2 SiO_2$
Softer than glass	Cleavage present	Yellow-brown to black; hardness = 4; good cleavage in six directions; light yellow streak that has sulphurous odour	Sphalerite (ZnS)
		Dark-brown to black; hardness = 2.5-3; excellent cleavage in one direction; elastic in thin sheets; black mica	Biotite (K, Mg, Fe, OH, Al silicate)
	Cleavage absent	Generally tarnished to brown or green; hardness = 2.5; specific gravity = 9; massive	Native Copper (Cu)
Softer than your fingernail	Cleavage not prominent	Reddish-brown; hardness = 1.5; specific gravity = 4-5; red streak; earthy appearance	Hematite (Fe_2O_3)
		Yellow-brown; hardness = 1-3; specific gravity = 3.5; earthy appearance; powders easily	Limonite ($Fe_2O_3 \cdot H_20$)

Table 5: Mineral Identification Key (continued)			
Group III Non-Metallic Lustre (light coloured)			
Hardness	**Cleavage**	**Other Diagnostic Properties**	**Name (Chemical Composition)**
Harder than glass	Cleavage present	Pink or white to grey; hardness = 6; specific gravity = 2.6; two directions of cleavage at nearly right angles	Potassium feldspar ($KAlSi_3O_8$) (pink)
			Plagioclase feldspar ($NaAlSi_3O_8$) (white to grey)
	Cleavage absent	Any colour; hardness = 7; specific gravity = 2.65; conchoidal fracture; glassy appearance; varieties: milky, rose, smoky, amethyst (violet)	Quartz (SiO_2)
Softer than glass	Cleavage present	White, yellowish to colourless; hardness = 3; three directions of cleavage at 75° (rhombohe-dral); effervesces in HCl; often transparent	Calcite ($CaCO_3$)
		White to colourless; hardness = 2.5; three directions of cleavage at 90° (cubic); salty taste	Halite (NaCl)
		Yellow, purple, green to colourless; hardness = 4; white streak; translucent to transparent; four directions of cleavage	Fluorite (CaF_2)
Softer than your fingernail	Cleavage present	Colourless; hardness = 2-2.5; transparent and elastic in thin sheets; excellent cleavage in one direction; light mica	Muscovite (K, OH, Al silicate)
		White to transparent; hardness = 2; when in sheets, is flexible but not elastic; varieties: selenite (transparent, three direc-tions of cleavage); satin spar (fibrous, silky lustre);alabaster (aggregate of small crystals)	Gypsum ($CaSO_4 \cdot 2H_2O$)
	Cleavage not prominent	White, pink, green; hardness = 1-2; forms in thin plates; soapy feel; pearly lustre	Talc (Mg silicate)
		Yellow; hardness = 1-2.5	Sulphur (S)
		White; hardness = 2; smooth feel; earthy odour; when moistened, has typical clay texture	Kaolinite (Hydrous Al silicate)
		Green; hardness = 2.5; fibrous; variety of serpentine	Asbestos (Mg, Al silicate)
		Pale to dark reddish-brown; hardness = 1-3; dull lustre; earthy; often contains spheroidal-shaped particles; not a true mineral	Bauxite (Hydrous Al oxide)

Core Lab 3 - Part II: Specific Gravity

Density and Specific Gravity

Two important properties of a material are its density and specific gravity. Density is the mass of a substance per unit volume, usually expressed in grams per cubic centimetre (g/cm^3) in the metric system. The specific gravity of a solid is the ratio of the mass of a given volume of the substance to the mass of an equal volume of some other substance taken as a standard (usually water at 4^oC). Because specific gravity is a ratio, it is expressed as a pure number and has no units. For example, a specific gravity of 6 means that the substance has six times more mass than an equal volume of water. Because the density of pure water at 4^oC is 1 g/cm^3, the specific gravity of a substance will be numerically equal to its density.

Purpose and Outcomes

The students will

- find the specific gravity of selected minerals.
- identify minerals using specific gravity.
- compare theoretical and empirical values and account for differences.

Materials

- metric balance
- graduated cylinder (large)
- water
- mineral samples (magnetite, hematite, galena, sphalerite, quartz, calcite)

Method

The approximate density and specific gravity of a rock, or other solid, can be arrived at using the following steps:

1. Determine the mass of a small sample using a metric balance.
2. Fill a graduated cylinder that has its divisions marked in millilitres approximately two-thirds full with water. Note the level of the water in the cylinder in millilitres.
3. Tie a thread to the rock and immerse the rock into the water in the graduated cylinder. Note the new level of the water in the cylinder.
4. Determine the difference between the beginning level and the after-immersion level of the water in the cylinder.
5. Calculate the density and specific gravity using the following information and appropriate equations.

A millilitre of water has a volume approximately equal to a cubic centimetre (cm^3). Therefore, the difference between the beginning water level and the after-immersion level in the cylinder equals the volume of the rock in cubic centimetres. Furthermore, a cubic centimetre (one millilitre) of water has a mass of approximately one gram. (Note: Utilising the equipment already present in the lab, you may want to devise a simple experiment to confirm this fact.) Therefore, the difference between the beginning water level and the after-immersion level in the cylinder is the mass of a volume of water equal to the volume of the rock.

1. Determine the density and specific gravity of hematite, sphalerite, quartz, pyrite, galena and calcite finding the information listed below. Record your results in the table provided.
   a) Mass of mineral sample (g)
   b) After-immersion level of water in cylinder (mL)
      Beginning level of water in cylinder (mL)
      Difference (mL)
   c) Volume of mineral sample (cm^3)
   d) Mass of a volume of water equal to the volume of the mineral sample (g)
   e) Density of mineral (g/cm^3)

$$\text{Density} = \frac{\text{mass of mineral sample (g)}}{\text{volume of mineral sample (cm}^3\text{)}} =$$

   f) Specific gravity of mineral sample

$$\text{Specific Gravity} = \frac{\text{mass of mineral sample (g)}}{\text{mass of equal volume of water (g)}} =$$

2. Using the same procedure and the specific gravity data in Table 1, identify three unknown minerals by their specific gravity. Record your results in the table provided

Table 1: Specific Gravity of Some Common Minerals

Mineral	Specific Gravity	Mineral	Specific Gravity
Native Copper	9	Augite	3.4
Galena	7.6	Hornblende	3.2
Magnetite	5.2	Biotite	2.8-3.2
Pyrite	5.2	Calcite	2.7
Hematite	4-5	Feldspar	2.6
Chalcopyrite	4.2	Quartz	2.6
Sphalerite	4	Graphite	2.2
Limonite	3.5-4		

Data and Analysis

1. Record your data for in the table below.

Table 2: ____________________

Mineral	Mineral Mass (g)	Volume After (mL)	Volume Before (mL)	Volume Difference (mL)	Mineral Volume (cm^3)	Mass of Water (g)	Density (g/cm^3)	Specific Gravity
Hematite								
Sphalerite								
Quartz								
Pyrite								
Galena								
Calcite								

1. e) Calculate the density of each mineral and transfer it to the table above. Show your workings.

Hematite	Sphalerite	Quartz
Pyrite	Galena	Calcite

1. f) Calculate the specific gravity of each mineral and transfer it to the table above. Show your workings.

Hematite	Sphalerite	Quartz
Pyrite	Galena	Calcite

2. Record your data in the table below.

Table 3: ______________________________

Mineral	Mineral Mass (g)	Volume After (mL)	Volume Before (mL)	Volume Difference (mL)	Mineral Volume (cm^3)	Mass of Water (g)	Density (g/cm^3)	Specific Gravity
Unknown Mineral #1								
Unknown Mineral #2								
Unknown Mineral #3								

3. Calculate the percent error for each mineral in Table 2 using the data. and the formula given below. The actual specific gravity data can be found in Table 1 above.

$$\%\ \text{error} = \frac{\text{Actual Value - Calulated Value}}{\text{Actual Value}} \times 100\%$$

Hematite	Sphalerite	Quartz
Pyrite	Galena	Calcite

4. Suggest sources of error that may explain any discrepancy between the calculated specific gravity values and actual specific gravity values.

Core Lab 4 - Igneous, Sedimentary and Metamorphic Rocks

Part I: Igneous Rocks

Introduction

Two bases of distinction that you can apply to igneous rocks are:

1. Colour: light coloured, medium coloured or dark-coloured.
2. Texture: coarse grained (crystals are large enough to see with the unaided eye), fine grained (crystals cannot be seen with the unaided eye), and glassy.

Purpose and Outcomes

The students will:

- identify some igneous rocks and classify them according to the above criteria.
- see how the densities of light-coloured rocks tend to differ from that of dark-coloured rocks.

Materials Required

- igneous rock specimens, including andesite, basalt, diorite, gabbro, granite, obsidian, peridotite, pumice, rhyolite and scoria
- graduated cylinder and protective ring, 100 mL.
- laboratory balance
- magnifying glass

Method

1. First sort the rock samples into 2 groups by colour. Use your judgement on the medium coloured rocks!
2. Within each "colour-group," sort the rocks by texture.
3. Look at the Table 2 for common igneous rocks. Copy the table below on your own paper, but larger. Place the correct rock specimen in the correct location. Note that you will not use the medium coloured category.

	Light	**Dark**
Coarse		
Fine		
Glassy		

4. Recall that density, D, is given by $D = \dfrac{m}{V}$.

   Recall also that in Core lab 3, you calculated the density of a rock sample. Use a similar procedure to determine the density of the granite sample. Record your data in a table and use the same procedure to find the density of the gabbro sample. What differences do you notice?

5. Use your answer to part D to help predict how the density of rhyolite compares with the density of basalt.

6. Recall that the percent of error is given by the following expression.

$$\% \text{ error} = \frac{\text{Actual Value - Calulated Value}}{\text{Actual Value}} \times 100\%$$

   The average density of granite is about 2.6 g/mL. Calculate the percent error for your density.

7. Recall that the samples are composed of one or more distinct minerals. What minerals would you find in each sample? What do you notice about the mineral composition of granite/rhyolite and gabbro/basalt?

   (1) granite (use a hand lens)

   (2) rhyolite (give an explanation.)

   (3) gabbro

   (4) basalt (give an explanation.)

Table 1: ______________________________

Rock Name	Minerals Present
granite	
rhyolite	
gabbro	
basalt	

8. Examine your sample of obsidian. Explain how it can fit in two places on your chart based on colour and texture. Use the information in the summary table to locate the correct position.

9. Contrast the physical appearance of scoria and pumice. How are they different? Use the properties of the lava from which each was formed to explain this difference.

<table>
<tr><th colspan="6">Table 2: Common Igneous Rocks</th></tr>
<tr><th>Texture and Origin</th><th colspan="2">Felsic or
Light-Coloured Rocks</th><th>Medium-Coloured
Rocks</th><th colspan="2">Mafic or
Dark-Coloured Rocks</th></tr>
<tr><td></td><td colspan="2">Colours: white, tan, grey, pink, red
Minerals: feldspar (mostly orthoclase), quartz, also some mica and hornblende</td><td>Colours: grey, green
Minerals: feldspar (mostly plagioclase), hornblende, augite, biotite</td><td colspan="2">Colours: dark green, dark grey, black
Minerals: plagioclase feldspar, augite, also olivine, hornblende, biotite</td></tr>
<tr><td rowspan="2">Glassy: cooled quickly at surface of Earth</td><td>With quartz</td><td>Almost No Quartz</td><td colspan="3">Without Quartz</td></tr>
<tr><td>Obsidian
Pumice</td><td></td><td>Obsidian</td><td colspan="2">Basalt glass
Scoria</td></tr>
<tr><td rowspan="2">Fine-grained: cooled slowly at or near surface</td><td>Rhyolite</td><td>Trachyte</td><td rowspan="2">Andesite</td><td colspan="2" rowspan="2">Basalt
Diabase</td></tr>
<tr><td colspan="2">Felsite</td></tr>
<tr><td rowspan="2">Course-grained: cooled very slowly, usually at great depths</td><td rowspan="2">Granite
Pegmatite</td><td>Syentie</td><td>Diorite</td><td rowspan="2">Gabbro</td><td>No Feldspar</td></tr>
<tr><td colspan="2">Granodiorite</td><td>Periodite
Pyrozenite
Dunite</td></tr>
</table>

Part II: Sedimentary Rocks

Introduction

There are three major types of sedimentary rocks:

1. Clastic (sometimes called detrital): formed from pieces of other rocks.
2. Chemical: formed by chemical activity such as precipitation-generally in the sea.
3. Organic: formed from the remains of living creatures. Coal is a good example.

Purpose and Outcomes

The students will:

- identify some sedimentary rocks and classify them according to the above criteria.

Materials Required

- sedimentary rock specimens, including conglomerate, sandstone, shale, limestone (shell and compact), coal, rock salt
- sandpaper (coarse)
- magnifying glass

Method

1. Copy the chart below and make it larger. Use the Table 5 which follows to write the correct name in the proper location.
2. Place your rock specimens at the correct location on the chart.

Table 3: ____

	Description	Rock Name
Clastic (detrital)	larger grains struck together	
	smaller grains struck together	
	muddy look, easily broken	
Chemical	grains too small to see, light brown or grey, high specific gravity	
	salty taste	
Organic	made from the remains of plants	
	made from the remains of animals (shells and bones)	

3. Contrast:
   (1) conglomerate with sandstone and shale,
   (2) shale with conglomerate and sandstone.

   Table 4: ____

Conglomerate	**Sandstone**	
	Shale	
Shale	**Conglomerate**	
	Sandstone	

4. Identify the mineral in the largest grains of the conglomerate.
5. Suggest reasons why you rarely find fossils in conglomerate.
6. Use the hand lens. Identify the material from which the sandstone is formed. Explain why the sandstone feels like the sandpaper.
7. Describe the chemical test that can be used to identify limestone.
8. Examine the shell limestone. Can you identify any of its component parts? Explain how the appearance of the shell limestone differs from that of the compact limestone.

9. Describe the appearance of the coal sample. Can you identify any fossils in the sample?
10. Explain whether halite differs from rock salt.

Table 5: Common Sedimentary Rocks			
Name	**Colour**	**Distinguishing Features**	**Origin**
breccia	variable	contains angular fragments surrounded by finer grains	clastic
coal	shiny to dull black	found in beds located between other sedimentary rocks	organic
conglomerate	variable	contains rounded pebbles held together by cement	clastic
rock salt	colourless to white	cubic crystals	chemical
gypsum	white, grey, brown, red or green	grains range in size from very fine to very large, can have a very crumbly texture	chemical
limestone	variable - white, grey, yellow, red, brown	found in thick layers on cliffs, may contain fossils	organic
sandstone	white, grey, yellow, red	fine or coarse grains held together by cement	clastic
shale	yellow, red, grey, green, black	dense but soft, breaks easily	clastic

Part III: Metamorphic Rocks

Introduction

There are two major classes of distinction for the appearance of metamorphic rocks:

1. Foliated: rocks have bands which give a layered appearance.
2. Nonfoiliated: rocks have no apparent bands or layers.

Purpose and Outcomes

The students will:

- identify some metamorphic rocks and classify them according to the above criteria.

Materials Required

- metamorphic rock specimens, including gneiss, schist, slate, quartzite and marble
- magnifying glass

Method

1. Examine the rocks and separate them into two groups-foliated and nonfoliated.
2. Copy the chart below, but larger. Write the name of each metamorphic rock in the correct location and place the appropriate specimen next to the name.

Table 6: ______________________________

	Description	Rock Name
Foliated	light and dark bands, coarse-grained	
	wavy surfaces, thin, parallel banks	
	flat layers, fine grained, may be green, grey, purple or red	
Nonfoliated	fused quartz grains, dense, hard, crystalline	
	white or grey, crystals of calcite, crystalline	

3. Examine the gneiss with the magnifying glass. Note the coloured bands. Identify the minerals.

4. Explain why it is reasonable to assume that gneiss can be formed from granite.

5. Explain how the appearance of granite differs from that of gneiss.

6. Contrast schist with gneiss. Explain how the mineral bands differ in appearance.

7. Explain why it is reasonable to assume that slate may have been formed from shale.

8. Contrast the texture of marble with that of quartzite.

9. Explain how you can distinguish quartzite from marble using the following tests:

   (1) hardness test,

   (2) acid test.

Core Lab 5 - Locating an Earthquake Epicentre

Introduction

Earthquakes occur when blocks of the earth's crust suddenly slip along a fault break and release the strain energy built up over time by the pressure of oppositely moving pieces. The point where the earthquake occurs is its focus and earthquake waves of several types spread out in all directions from there.

P-waves and S-waves travel through the earth and are detected by seismograph stations at many locations around the world. The arrival times of the P-waves and S-waves from a minimum of three seismic stations can be used to determine the location of the epicentre of the earthquake, i.e., the point on the earth's surface directly above the focus of the earthquake.

Purpose and Outcomes

The students will

- locate the epicentre of an earthquake given approximate seismographic data.
- identify patterns in data.

In this activity you will first plot a travel-time graph for P- and S- waves from the data given in Part 1. Then, in Part 2, you will use seismic records from three stations to calculate the distance of each station from the epicentre. In Part 3, you will use these distances on a scale map to actually pinpoint the epicentre's location.

EARTHQUAKE!

At 7:30 a.m. on November 18, 1929, the town of Burin, Newfoundland, was hit by a "tidal wave" (tsunami) created by an earthquake and the town was flooded by a 15 m surge which rose up over the town, destroying wharves, boats, stages and houses. Nine people died from this disaster and many homes and properties were destroyed, creating considerable hardship. What was the location of the cause of this tsunami?

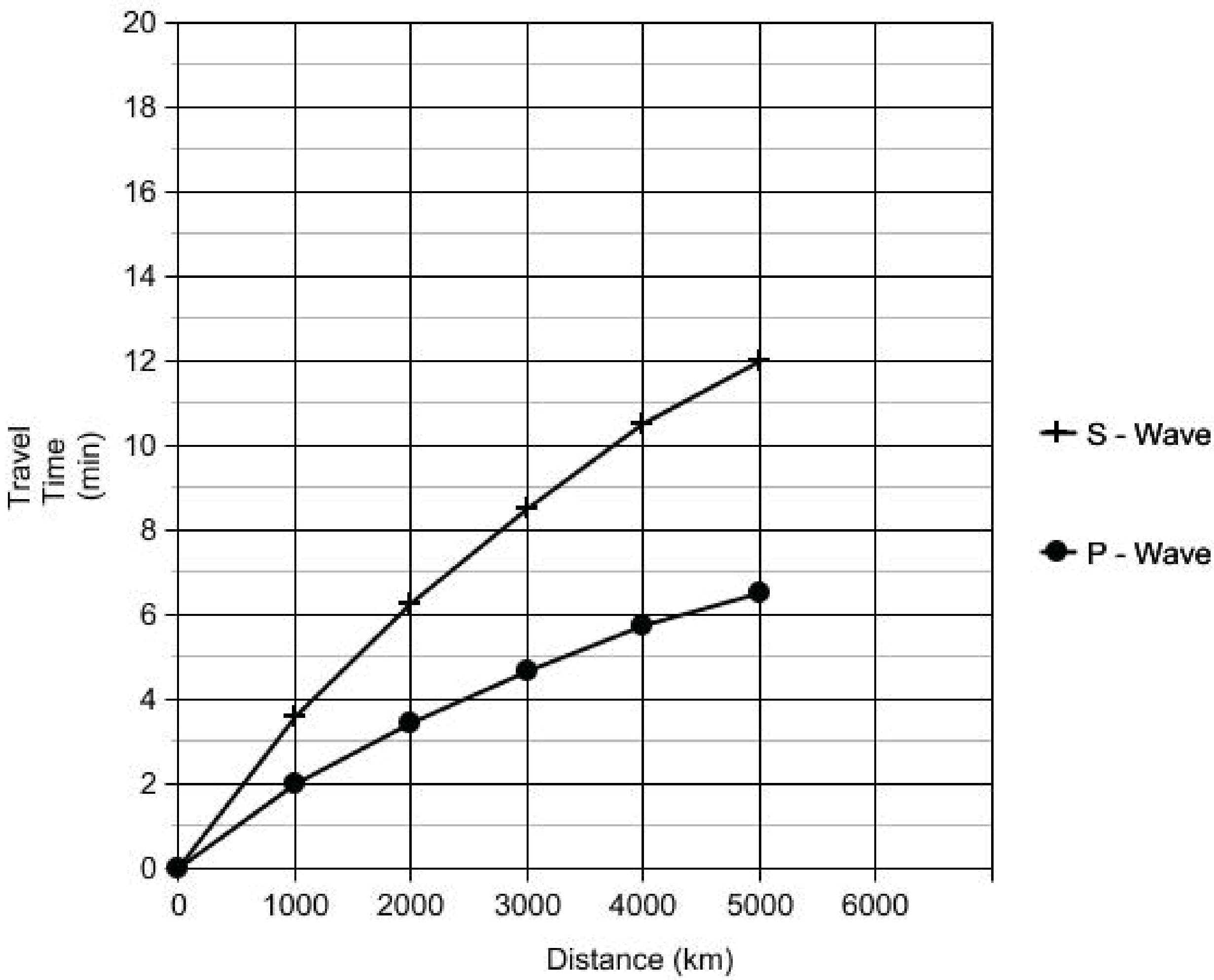
Part 1

Use the data below to plot a travel-time graph for seismic waves. Put travel time in minutes on the y-axis and distance in kilometers on the x-axis. Draw one line for the P-wave and another for the S-wave on the same graph. This data is for an earthquake assumed to have occurred at 7:00:00 am (h:min:s).

Table 1: ____

Location	Distance (km)	Arrival Time P-Wave	Arrival Time S-Wave	Difference S - P
A	1000	07:02:00	07:03:34	
B	2000	07:03:25	07:06:16	
C	3000	07:04:40	07:08:30	
D	4000	07:05:45	07:10:30	
E	5000	07:06:30	07:12:00	

Figure 1: ____



Use the graph to answer the following questions:

1. Which travels faster, P or S waves? ___________

2. From the graph, interpolate the arrival times for the P and S-waves at a station 2500 km from the source P _____________ S _______________

3. Extrapolate the graph to predict the arrival time for a P-wave at a station 6000 km away.

4. Find the difference between the S- and P- wave arrival times in each case and record it in Table 1. State the relationship between this and the distance from the source.

Part 2

Since surface waves travel more slowly than P- or S-waves, and tsunamis, being large sea waves, travel more slowly again, we will assume the earthquake that triggered the Burin tsunami to have occurred four hours earlier, at 3:30:00 a.m. on November 18, 1929.

Figure 2 shows sketches of three seismograph records such as might have been generated at the stations shown. Note the time scale markings on each and use them to determine the arrival times for the P- and S-waves at each location and the difference between these. Record the data in Table 2.

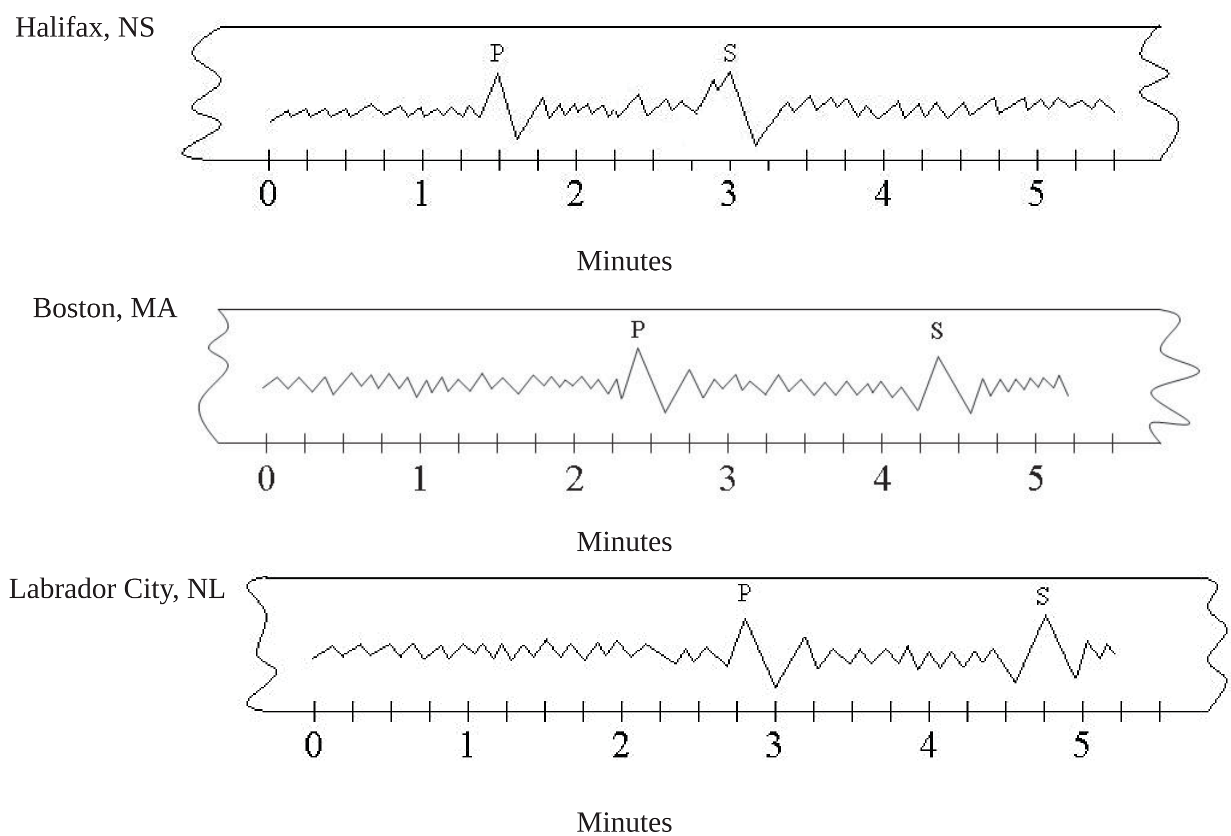


Figure 2: Seismic records for Halifax, NS, Boston, MA, and Labrador City, NL on November 18, 1929.

For each location, use the travel-time graph to determine the distance of each from the epicentre and record the distance in Table 2. (Hint: See Figure 3 for a visual representation of how to find this distance. Place a piece of paper by the time scale of the travel-time graph and put two marks on the edge at the appropriate time difference. Then bring this piece of paper onto the graph so that the P- and S- graphs just match these marks on the edge of the paper and read off the distance from the scale below as shown.) The time difference between the P- and S- waves will indicate the distance from the source.

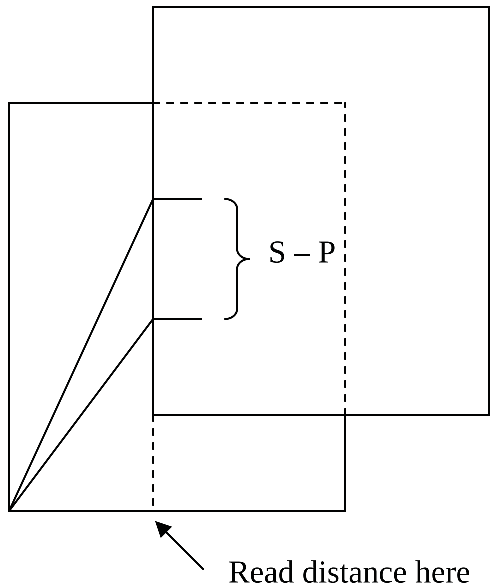


Figure 3: Finding the distance from the earthquake epicenter

Table 2: ____

Location	P-Wave	S-Wave	Difference	Distance (km)
Halifax				
Boston				
Labrador City				

Part 3

On the map below (Figure 4), make arcs from each station at the appropriate distance using the map scale where **1 cm equals 100 km**. Use a compass for this. The point where all three intersect is the epicentre of the earthquake.

5. Why are the arcs from two stations alone (e.g. Halifax and Boston) not sufficient to be sure of the location of the epicentre?
6. Does plotting the data on a flat map introduce some error? Explain.

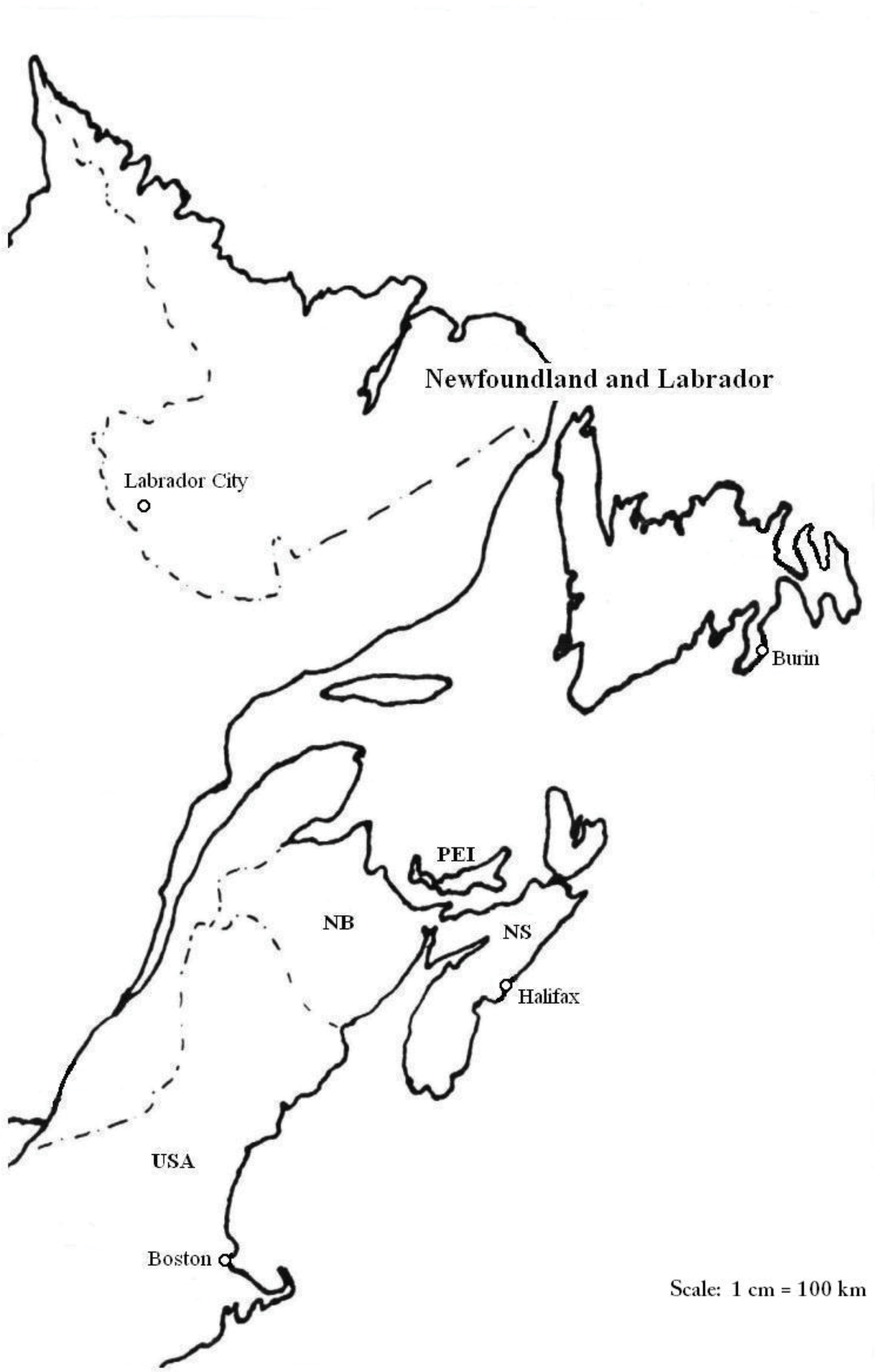


Figure 4: Map of Newfoundland and Labrador, the maritimes and eastern United States.

Core Lab 6 - Geologic Mapping and Cross-Sections

Note: it is best to print the map so that 1 cm measured on the printed map is equivalent to the scale bar having 1 cm = 10 m. If you print the map at this specific scale, it makes the exercise much easier to plot the cross-section. Moreover, it is highly advisable that students do the cross-section exercise on metric graph paper where 1 mm = 1 metre. This means students can plot distances on their cross-sections quite easily without having to deal with the mathematics of frustrating scale conversions that slow everything down.

Purpose and Outcomes

The purpose of this lab is to:

- introduce geologic map patterns in context of topography. Topography controls map patterns and often leads to maps that, at first glance, appear very confusing even when the underlying geology is quite straightforward
- provide methods (i.e. cross-sections) for interpreting geologic map data
- develop 3-D visualization skills which are fundamental to understanding geology in the subsurface
- introduce a commodity (gold) resource exercise that, thematically, is part of the job description of many professional geoscientists

Method

Part I: Legend

1. Look at the geology map and map legend in Figures 1 and 2. The legend reveals that the map portrays a stratigraphic sequence of volcanic and sedimentary rock units, including basalt, sandstone, siltstone, shale and limestone. Basalt is the oldest map unit present and limestone the youngest (i.e. a stratigraphic succession). The map has topographic elevation contours (in metres), as well as a line of section A-B and four vertical drill holes numbered 1 to 4. The drill holes were drilled because there was evidence found at surface in the area that significant gold mineralization existed in the area. Drill holes aim to define the 3-D orientation and extent of gold mineralization in order to evaluate whether there is enough gold to be recovered economically (i.e. a gold mine). See Figure 3 for the drill logs for the four holes drilled.

   If there were no topography (i.e. the world was perfectly flat), the map pattern of the geologic units appears much simpler (see Figure 4). This emphasizes the role of topography in maps.

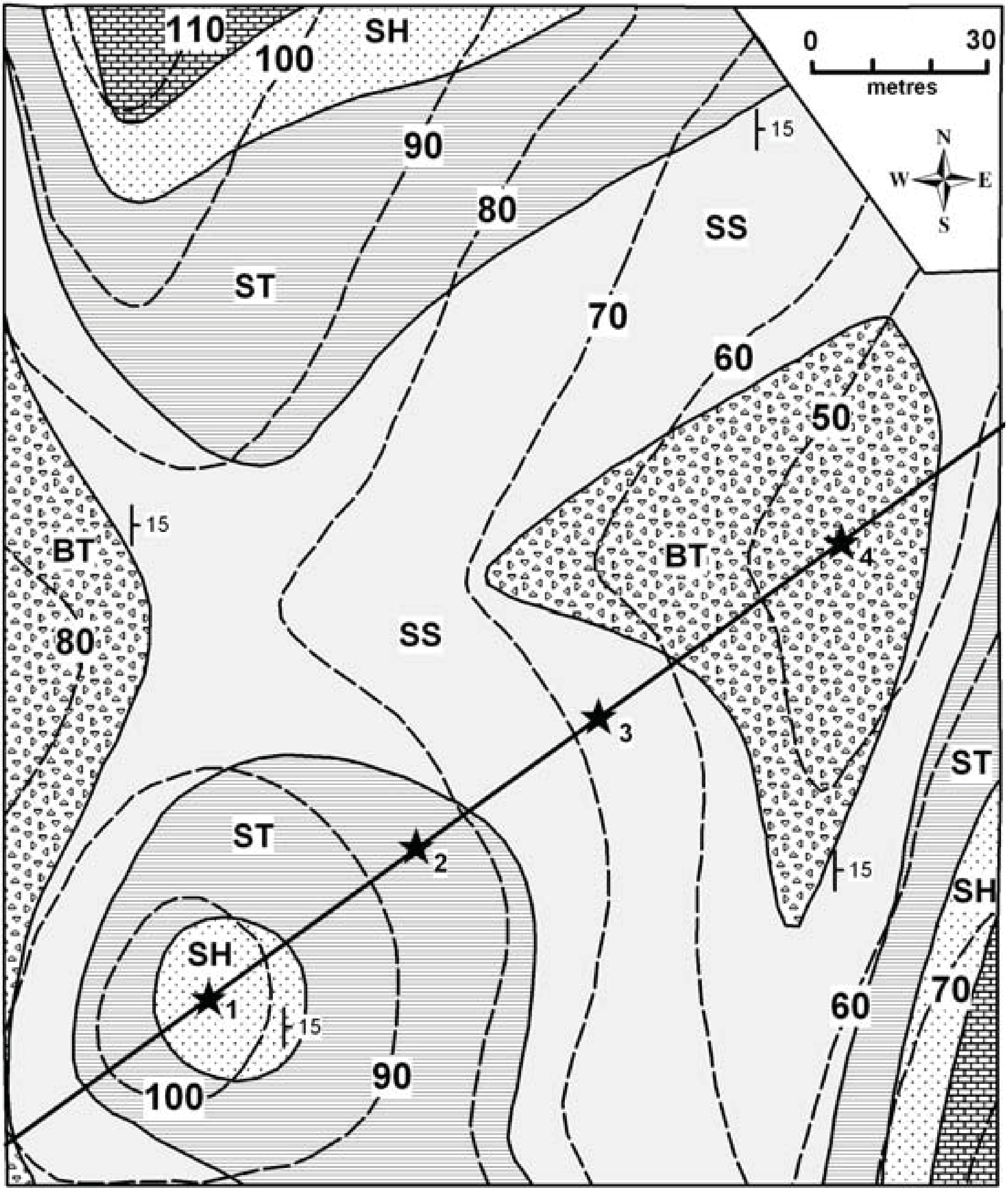


Figure 1: Geologic Map

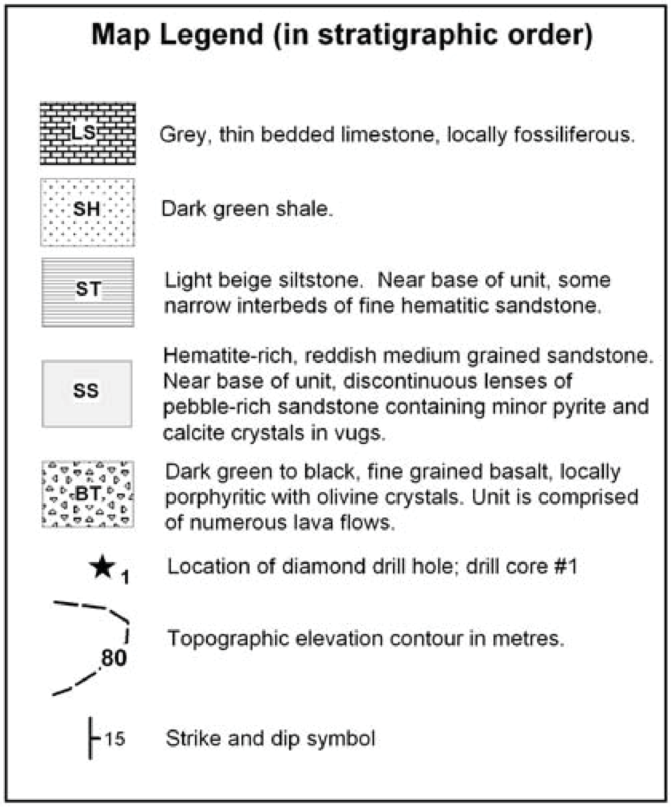


Figure 2: Legend for Geologic Map.

	Drill Collar Elevation (m)	Depth in core		Interval thickness (m)	Core Description
		From (m)	To (m)		
Drill Hole #1	105.0	0.0	3.5	3.5	Very fine grained, dark green shale (SH)
		3.5	13.0	9.5	Beige coloured, fine grained siltstone (ST)
		13.0	24.0	11.0	Medium-grained, reddish sandstone (SS), commonly hematitic. From 20.0 to 24.0 m, bottom of unit has narrow lenses of greenish, pebble-rich sandstone with 2-3% pyrite and 5% calcite interstitial to the pebbles. Core assays from 20.0 to 22.5 m has 2 g/ton Au (low grade mineralization); assays from 22.5 to 24.0 m has 10 g/ton Au (medium grade mineralization).
		24.0	70.0	46.0	Dark greenish black basalt (BT). Flow thickness vary between 2 and 15 m. Upper contact with sandstone is sharp; appears stratigraphic conformable. No visible pyrite in basalt near contact; assay from 24.0 to 26.0 m has no gold
		70.0			End of drill hole

Figure 3: Drill logs for the geologic cross section

Drill Hole #2	Drill Collar Elevation (m)	Depth in core		Interval thickness (m)	Core Description
		From (m)	To (m)		
	85.0	0.0	3.0	3.0	Beige coloured, fine grained siltstone (ST).
		3.0	14.0	11.0	Medium-grained, reddish sandstone (SS). From 8.0 to 14.0 m, bottom unit has numerous, narrow lenses of greenish, pebble-rich sandstone with up to 10% pyrite and 10% calcite interstitial to the pebbles. Core assays from 8.0 to 14.0 m have 20 g/ton Au (high-grade mineralization).
		14.0	60.0	46.0	Dark greenish black basalt (BT). Flow thicknesses vary between 3 and 15 m. Upper contact with sandstone is sharp; appears stratigraphic conformable. No visible pyrite in basalt near contact; assay from 14.0 to 16.0 m has no gold.
		60.0			End of drill hole

Drill Hole #3	Drill Collar Elevation (m)	Depth in core		Interval thickness (m)	Core Description
		From (m)	To (m)		
	68.0	0.0	5.5	5.5	Medium-grained, reddish sandstone (SS). From 2.0 to 5.5 m, bottom of unit has numerous, narrow lenses of greenish, pebble-rich sandstone with up to 10% pyrite and 10% calcite interstitial to the pebbles. Core assays from 2.0 to 5.5 m have 25 g/ton Au (very high-grade mineralization).
		5.5	48.0	42.5	Dark greenish black basalt (BT). Flow thickness vary between 3 and 15 m. Upper contact with sandstone is sharp; appears stratigraphic conformable. No visible pyrite in basalt near contact; assay from 5.5 to 8.0 m has no gold.
		48.0			End of drill hole

Drill Hole #4	Drill Collar Elevation (m)	Depth in core		Interval thickness (m)	Core Description
		From (m)	To (m)		
	45.0	0.0	40.0	40.0	Dark greenish black basalt (BT). Flow thickness vary between 3 and 15 m. No visible pyrite or calcite in basalt. Assay from 0 to 2.0 m has no gold.
		40.0			End of drill hole

Figure 3 (continued): Drill logs for the geologic cross section

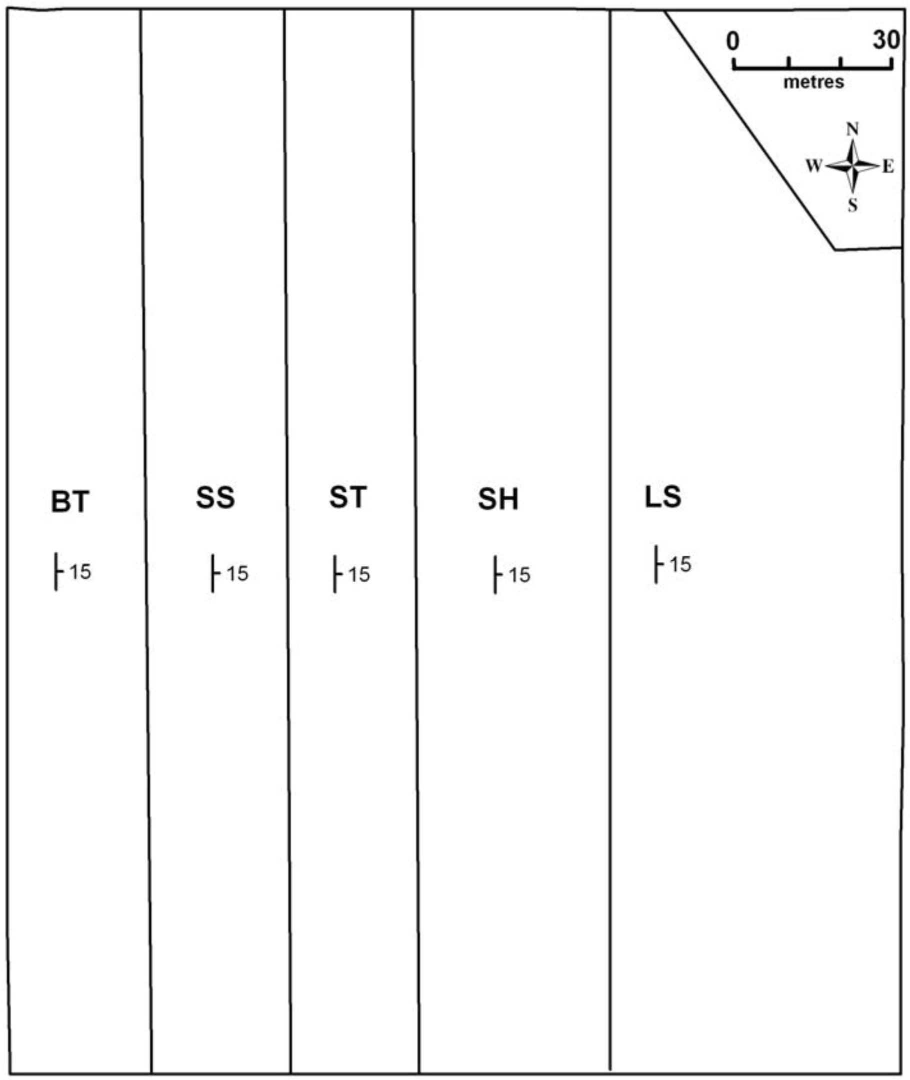


Figure 4: A map pattern of geologic units for a flat piece of land.

Part II: How to Construct a Cross-Section

In order to more clearly understand the 3-D orientation of the geologic stratigraphy in the map area, it is best to construct a cross-section that reveals clearly the topographic land surface and the subsurface geology. (You must work carefully and precisely or else plotting errors make the final section more difficult to interpret).

1. First, note the scale on the map (1 cm = 10 m or 1 mm = 1 m) and the location of the line of section A-B. Using the same scale as the map, draw and label a vertical axis from 0 to 120 metres on a piece of metric graph paper and label the axis “elevation”. Measure the length of the line of section A-B (21.6 cm) and draw a horizontal axis on the graph paper from 0 to 216 metres (1 cm = 10 m) that corresponds to the length of the line of section A-B shown on the map.

2. Lay a strip of paper along the line of section on the map and carefully mark the location of the end points (A and B). Next, mark the precise locations where topographic elevation contours cut across line A-B (these intersections are called “pick points”). It helps to label the pick points with the elevation they represent. Also, mark the precise locations of pick points where the geologic contacts cut across the line A-B, and label each side of the pick points with the unit abbreviation (e.g. SS) present on the map. Lastly, mark the locations where the drill holes are located along line A-B. Remember that each drill hole has a collar elevation given in the drill log that indicates the precise elevation of the land surface where the hole was drilled. This gives you additional topographic control points for your cross-section.
3. Carefully transfer each of the topographic pick points from your strip of paper onto the graph paper (your cross-section), and also transfer the collar elevations of each of the drill holes. By then joining these topographic control points together, you can draw a representation of the topographic land surface along your line of section. In order to draw the line representing the land surface, you’ll need to interpolate the elevation of the topographic surface between your control points. This can best be done by inspecting the map carefully and estimating how the elevation changes between your control points.
4. Carefully transfer the locations (pick points) of each of the geologic contacts from your strip of paper onto the graph paper (your cross-section). You can choose to now construct the cross-section using only these control points by joining together the control points that share the same map units on both sides. Alternatively, a more precise cross-section is possible if you first plot the geologic contacts recorded in the drill logs for the four vertical drill holes. Plotting the drill logs gives you many additional control points on your cross-section that allow you to more accurately construct the geologic contacts between the various map units. After drawing all of the contacts between the map units on your cross-section, label the different geologic units (or “layers”) on the cross-section. Note: it is accepted convention to draw contact lines in the subsurface using a solid line; and to use dashed lines to represent the contact lines when they project above the topographic land surface (i.e. in space).
5. There are four drill logs that report assay information for gold. Use a coloured pencil to carefully colour (highlight) the depth interval in drill core that is known to be mineralized. Record the gold assay values next to the intervals.

Part III: Geologic Interpretation

1. What is the dip of your rock units measured on your cross-section?

2. What can you infer about the geologic history or geologic development of the area? Start with the oldest rock unit and remember that the stratigraphic succession of map units is presently dipping. Recall that lava flows and sedimentary rock strata are originally deposited in near-horizontal layers.

Part IV: Assessing the Gold Mineralization

The dollar value of a gold deposit depends on the size of the deposit (i.e. tonnes of ore) and the grade (or amount) of gold present in the rocks. The higher the grade of gold, the richer is the deposit. Gold today is valued around $1400 U.S. per ounce which translates to about $41 / gram. By comparison, a gram of copper is valued today at around 1 cent (gold is indeed very valuable).

In typical gold deposits, gold grades of 1 to 5 grams/tonne are “low grade”, 6-15 grams/tonne are “medium-grade”, and anything above 20 grams/tonne is normally considered “high-grade” gold ore. A grade of 5 grams/tonne means that one has to mine a tonne of rock in order to extract 5 grams of gold (i.e. the vast majority of what is mined is waste rock of no value). In order to determine how much gold is present in a rock sample, a sample the size of your fist is submitted to a commercial laboratory for analysis (called an assay). The lab has chemical methods to extract the gold and to determine the precise concentration in the sample.

In addition to the assay grade, one must also know how many tonnes of mineralized rock are present in an area before a gold occurrence can become economic as a mine. So, when gold is first discovered at surface in the field, it is common to drill the surrounding area to test whether gold also occurs in the subsurface. The goal is to estimate the total volume of rock (i.e. tonnage) that is mineralized, and to estimate the average grade of gold present in the rocks. Maps and cross-sections are needed to determine the 3-D volume of mineralized rock that is to become a potential gold deposit.

Lastly, gold is so valuable that a very tiny amount of it in a rock can lead to an economic gold deposit. This also means that gold in rocks is commonly “invisible” to the naked eye, though flakes of native gold do occur in some cases. Fortunately, the occurrence of gold in rocks is commonly associated with other minerals that are present, such as pyrite and calcite, and these are easily identified. Therefore, people who prospect or explore for gold often use pyrite and calcite (or sometimes quartz veins) to guide them in their exploration. Samples that have the “right minerals” present are sent to the laboratory for assay which is the only way to conclusively establish whether gold is present.

Where does gold and minerals like pyrite come from? There is a lot of water circulating in fractures deep in the Earth. The water can percolate downwards from the surface; it can be released deep in the Earth’s crust from magmatic intrusions, or it can be released during burial and metamorphism of hydrous minerals like clays or micas. Regardless of the source of the water, these fluids are typically hot and as they percolate through rocks they dissolve metals such as copper or gold. Once soluble, these gold-bearing fluids can rise closer to the Earth’s surface along faults or in fractures, where the gold is precipitated in veins or pore spaces in rocks. As the hot fluids pass through rocks, they alter the minerals present and precipitate other minerals such as pyrite or calcite along with the gold.

Questions

1. (i) Which geologic map unit hosts the gold mineralization?

(ii) Is the host consistent among all of the drill holes?

(iii) Is there anything particular about where in the host unit the gold occurs, and is the gold associated with any diagnostic minerals that would help to find gold elsewhere?

2. (i) Why does drill hole #4 not contain gold?

(ii) Based on your cross-section, did you expect it to?

3. Try to imagine the gold as being part of a 3-D volume of mineralized rock, and attempt to extend this mineralization to the surface in all 3 directions. Examine your cross-section, where else might you look (outside of the drill holes) to see if gold occurs at surface elsewhere, beyond just the drill holes?

4. Now that the cross-section has given you an understanding of where the gold is likely to occur at surface, look at your geology map and try to imagine where else you might look (outside of the line of section) to see if the gold extends more widely. Where on the map would you want to prospect or explore more closely for gold?

5. Now that the cross-section and the map have given you an understanding of where the gold might occur, can you suggest other areas on the map that might be profitably drilled to test for gold? Where would you NOT want to drill?

Core Lab 7 - Seismic Reflection Imaging

Introduction

The seismic reflection method of geophysical exploration is used widely to map geology below the surface. Oil and gas exploration requires detailed knowledge of geology, particularly in relation to accurately placing wells. It is important to remember that wells are very expensive to drill. Drilling offshore is much more expensive than on land. Since most of Newfoundland and Labrador's oil and gas fields occur offshore, seismic reflection imaging is extremely important to planning a drilling program. Oil and gas companies do not want to lose money! Other practical applications where the knowledge gained from seismic reflection imaging is very useful is in mapping faults, folds, ore deposits, groundwater, underground contamination, and site investigation for construction.

Purpose and Outcomes

The students will:

- understand how seismic data is collected and displayed
- understand how some geologic features are identified in the sub-surface using the seismic reflection imaging method
- identify patterns in data that are captured in seismic reflection images.

This exercise is an introduction to how seismic data is collected and displayed, and how geologists and geophysicists interpret the data. Two exercises aimed at identifying specific types of geologic features are provided first and then a profile off the coast of Newfoundland is provided for experience at interpreting a more complex example.

How Seismic Data is Collected

The seismic reflection method (Figure 1) begins with a source of seismic energy (e.g. explosives) on or near Earth's surface. The seismic waves travel through the Earth and reflect back from changes in physical properties of rocks. The changes in properties, which the seismic reflection method is sensitive to, relate to a combination of speed of wave travel and density of the material that the waves are passing through. Changes in the Earth's physical properties are often significant in sedimentary sequences such as interlayered shale and limestone (Figure 2a), faulted areas where different rock types are offset against each other (Figure 2b) and boundaries such as where sediments are first deposited on bedrock (Figure 2c). When a seismic wave encounters a boundary between two different materials, some of the wave's energy gets reflected and the rest of the energy travels further into the Earth. The time it takes for this energy to arrive at a detector makes it possible to estimate the depth of the feature. Initially, waves travel outward from the source at a constant speed. As the waves encounter changes in geology (e.g. density of material) however, the speed of the wave will change as well as its direction.

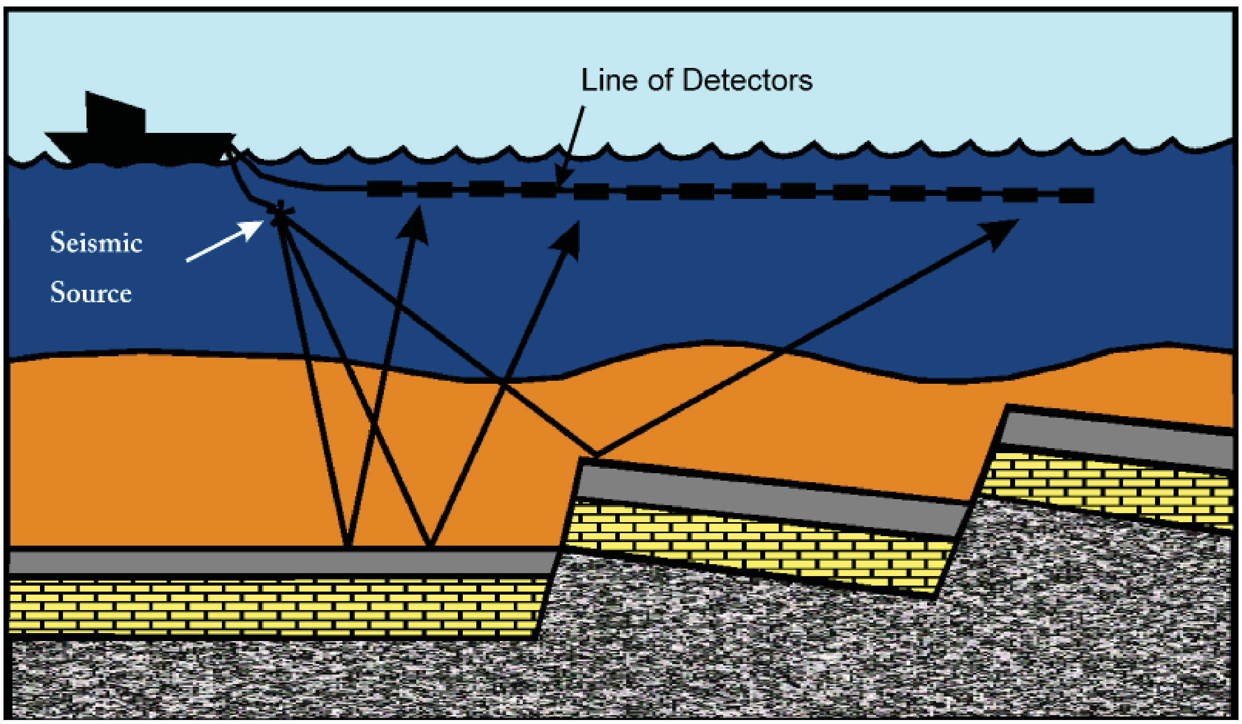
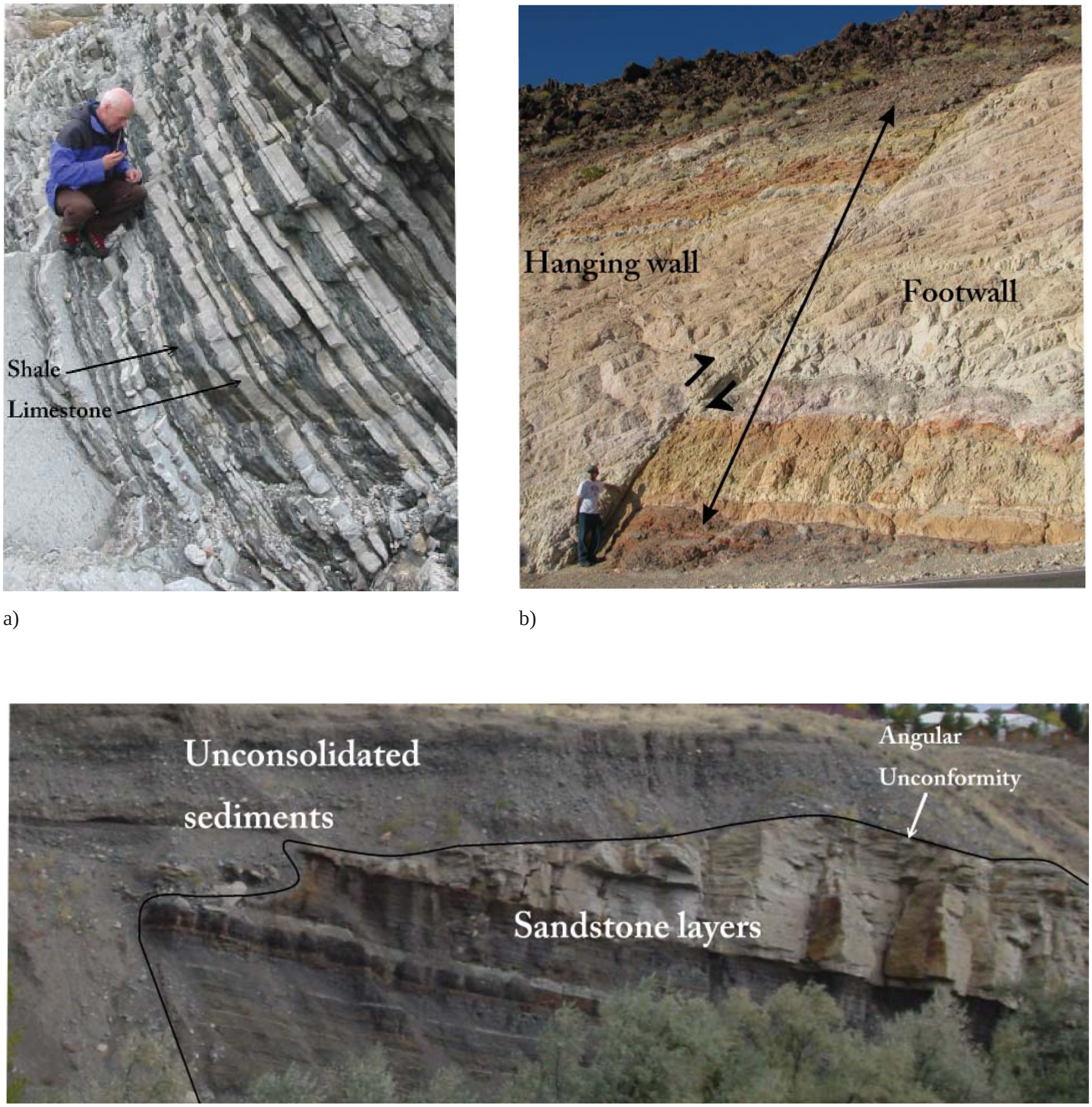


Figure 1. The elements of a seismic survey include a seismic source (explosive) and a group of detectors. In this marine survey, the detectors are towed by a cable behind a ship. The explosive source initiates a wave of energy that travels through the Earth. At each significant change in Earth's physical properties some of the energy is reflected towards the Earth's surface where detectors are located. This is a kind of echo-sounding.

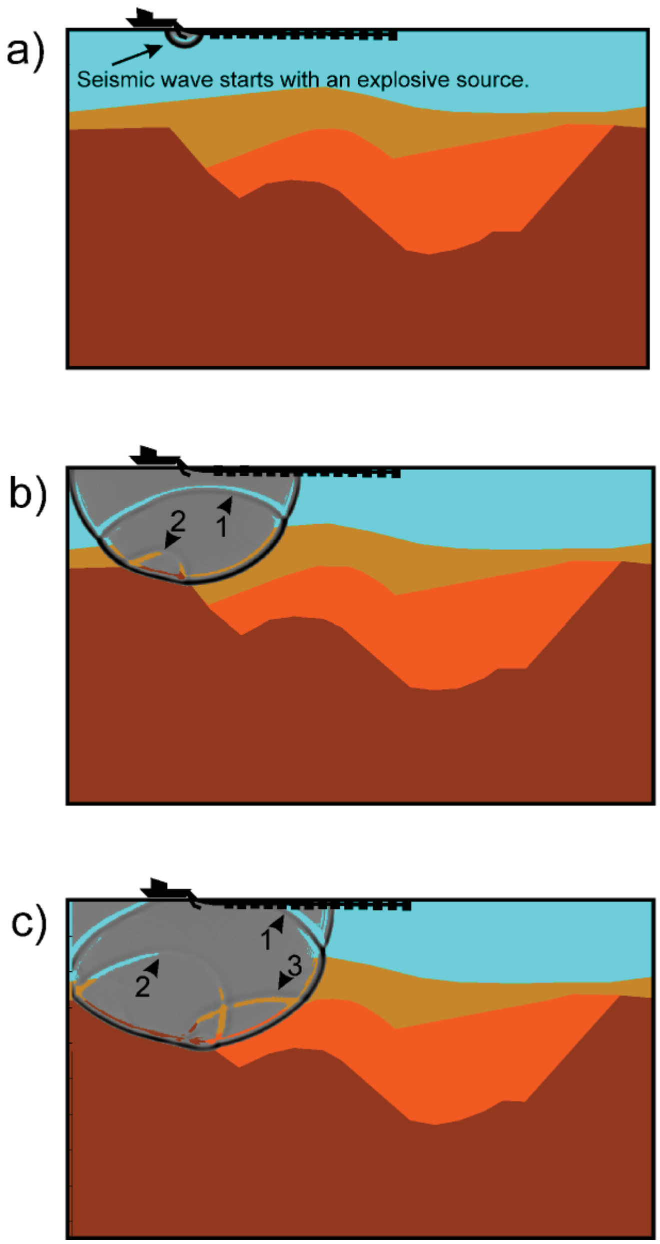


a) b)

c)

Figure 2. a) Interlayered limestones and shales at Cow Head, Newfoundland (Courtesy Dr. M. Wilson). b) Layered sediments from California offset by a reverse fault (i.e. hanging wall is pushed relative to the footwall). The dark layer indicated by the arrow above and below the fault was once continuous (courtesy R. Hicks). c) Unconsolidated sediments deposited on older sandstones in Cody, Wyoming (courtesy Dr. C. Hurich). The boundary is also an angular unconformity because the younger sediments are deposited in horizontal layers and the sandstones below the erosional surface are now dipping.

How Seismic Waves Travel



In order to show how the seismic reflection imaging method works, a model (Figure 3) was created approximating the shape of the main structure of the Jeanne d’Arc Basin on the Grand Banks where the Hibernia oilfield is located. The Jeanne d’Arc Basin has a deep sequence of sediments accumulated above normal faulted (the hanging wall moves down relative to the footwall) crystalline basement. Using a mathematical technique, the travel path of seismic energy moving through the model was calculated to show how the energy of a single shot travels through our model sedimentary basin.
At first, the wave travels symmetrically in all directions in the water (Figure 3a) until it reaches the first change in physical properties, which is the seabed. Some energy is reflected back to the surface (wave #1, Figure 3b) while the rest continues further into the Earth. Energy is next reflected from the boundary representing sediments in contact with crystalline basement (reflected wave #2, Figure 3b). Reflections from three parts of the model are visible in Figure 3c. The seabed reflection (wave #1) has already arrived at the surface where detectors record the arriving energy. Reflected waves are also returning from the sediment-basement boundary (wave #2) as well as a boundary within the sediments (wave #3). Meanwhile, the original wave continues to travel deeper into the Earth.

Figure 3. Illustration of how seismic energy travels through the Earth. The model is a simple representation of the Jeanne d’Arc structure with sediments (light and intermediate grey) accumulated over normal faulted crystalline crust (dark grey). a) The energy starts as a spherical wave travelling the same speed in every direction from its source point at the water’s surface. b) As the wave continues to travel, it reaches the seabed and part of the energy is reflected back (wave #1) through the water towards the surface and the rest continues to travel through the sediments below the seabed. The wave begins to change shape because the energy travels faster in the sediments than it does in the water due to increasing density. Another reflection is generated (wave #2) when the wave reaches the next major change in Earth’s properties where sediments lie on bedrock. c) Wave #1 has now reached the water’s surface and been recorded on the detectors nearest the ship. Wave #2 has progressed further towards the surface and wave #3 is now on the way to the surface. The original wave is continuing to travel deeper into the Earth.

Interpreting Seismic Reflection Data

1. Imaging Sediments and an Angular Unconformity

After processing, seismic reflection data are plotted as a cross-sectional view of the Earth's subsurface in terms of rock and sediment units that have reflecting surfaces. The data below (Figure 4) were recorded in the Eastern Mediterranean Sea by Earth Science researchers at Memorial University. Sedimentary rocks often have very well imaged reflectors. Note that a 'reflector' is a boundary where seismic energy is reflected because they are continuous over a large distance. In Figure 4, the seabed is a shallow, very strong reflector and below that are individual sedimentary units that are parallel to the seabed. These units also reflect well. Another sequence of sediments (older) is also visible and identifiable because there is an angular unconformity between the two sequences. Note that an angular unconformity is an erosional surface where the sedimentary layers below have a different angle than the layers above. Basement (i.e. crystalline rock that is often metamorphosed) underlies the sediments and is typically less reflective. The boundary between sedimentary rocks and basement is not a clear reflector in this area. In Figure 4, identify the following: 1) seabed; 2) other reflecting boundaries beneath the seabed; and 3) the angular unconformity between the two stratigraphic sequences.

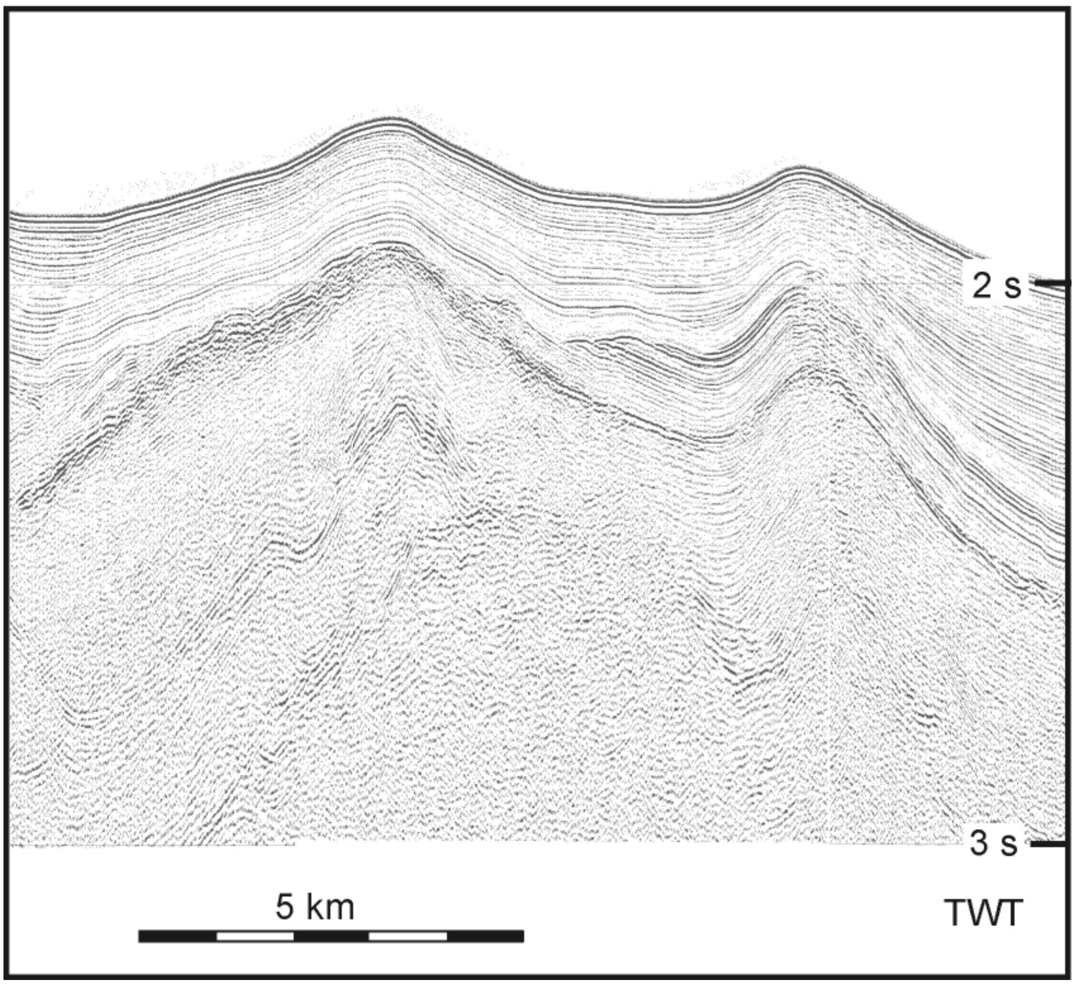


Figure 4. Seismic profile (cross sectional view) collected by Memorial University in the Mediterranean Sea.

2. Imaging Faulted Sediments

The next example of data from the Eastern Mediterranean (Figure 5) shows a set of very steep and closely spaced normal faults in a thick sequence of sediments. Remember that a normal fault is caused by tensional forces and is represented by the hanging wall moving down relative to the foot wall. Note that in this case the faults do not show up with reflections of their own. The steep orientation makes it nearly impossible to record reflected energy from them so what we interpret are the ‘breaks’ in the sediment reflections. In figure 5: 1) identify and mark as many normal faults as you can using a red coloured lead pencil; 2) indicate with arrows what the direction of motion (i.e. relative motion) is on each side of the fault; and 3) trace distinctive sediment boundaries across the faults from one side of the section to the other using a different colouring lead pencil for each of the sediment boundaries.

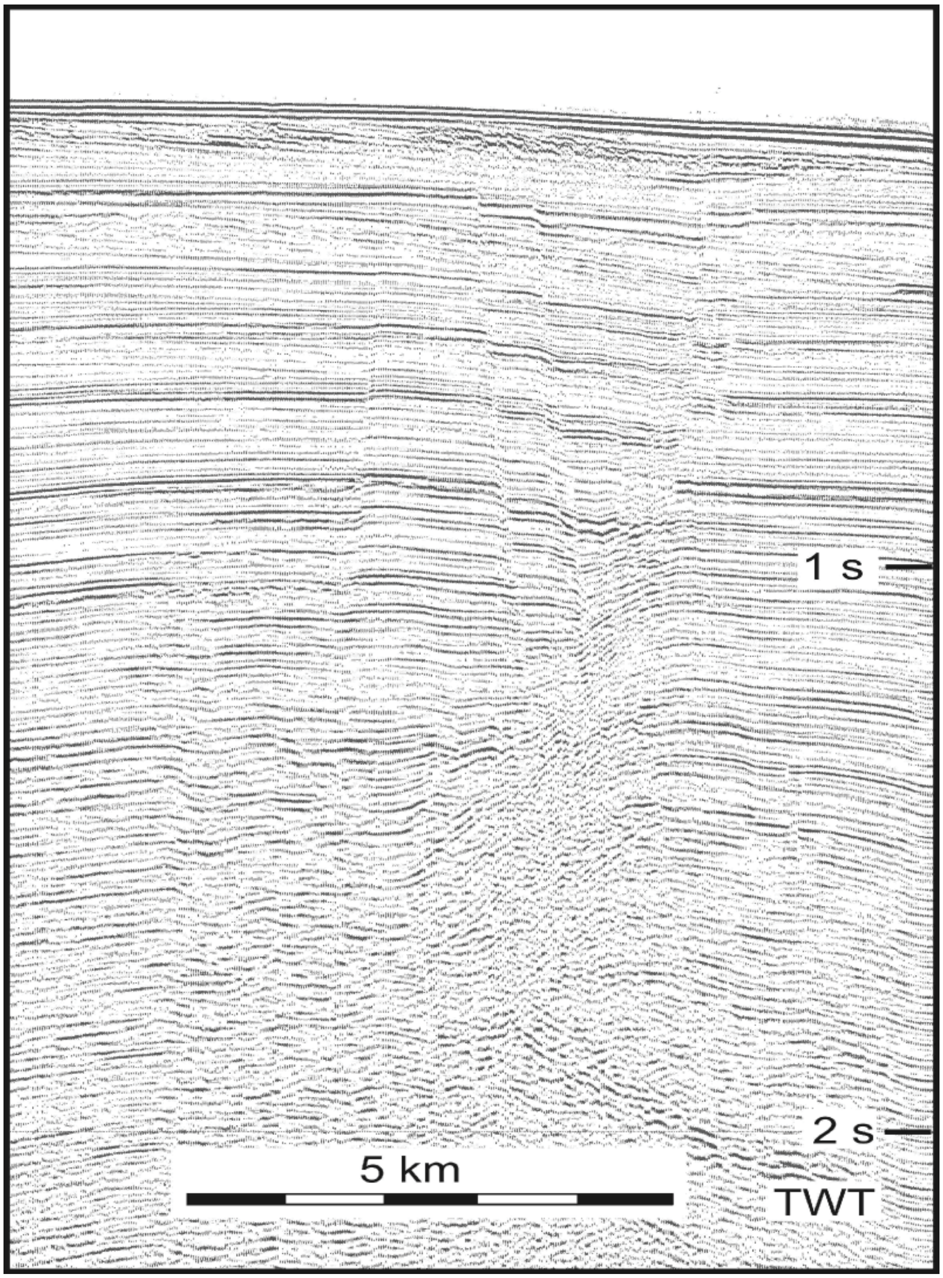


Figure 5. Seismic profile (cross-sectional view) collected by Memorial University in the Mediterranean Sea.

3. Putting It Together: An Example from Newfoundland

You are given a seismic reflection profile (Figure 6) from the continental shelf southeast of Newfoundland, provided by the Geological Survey of Canada from their Frontier Geoscience Program. The profile (cross-sectional view) is about 50 km long. The vertical scale is in reflection time (i.e. the time for elastic waves to go down to reflecting layers and to come back up again). Because elastic waves travel at different speeds in different rock types, we can only estimate that the cross-section extends down to about 12-15 km.

Seismic data has been used to correlate to a nearby borehole where rocks are sampled, observed, and dated. On this profile, the following identifications can be made: T = Tertiary period, UC = Upper Cretaceous period, LC = Lower Cretaceous period and J = Jurassic period. The boundaries between rocks of these ages are marked along the borehole. B is an easily-recognized layer within the Lower Cretaceous sequence due to it's strong reflection.

1. Trace the geological layer ‘B’ and the boundaries between the differently-aged layers as far as you can across the profile. Be careful to account for offsets in layers across faults.
2. Mark the faults and show how the layers are offset across them. Indicate with arrows the sense or direction of offset (i.e. relative motion) across the faults. The source rock for the oil discovered in this area is an organic-rich black shale, which is found just below the top of the Jurassic rocks. So it lies immediately below the deepest boundary you have drawn across the profile. However, oil is not always found today in the layers where it originally formed. In this example, it would have migrated (moved) along and up permeable layers (usually sandstones) until trapped where permeability becomes very low. This occurs when an impermeable layer lies above a permeable layer as part of an anticline fold, a permeable layer has been faulted (offset) and is resting against an impermeable layer, or a permeable layer is resting against an impermeable layer due to the existence of an unconformity.
3. Indicate with a star where there may be possible traps of oil from the Jurassic source rock.

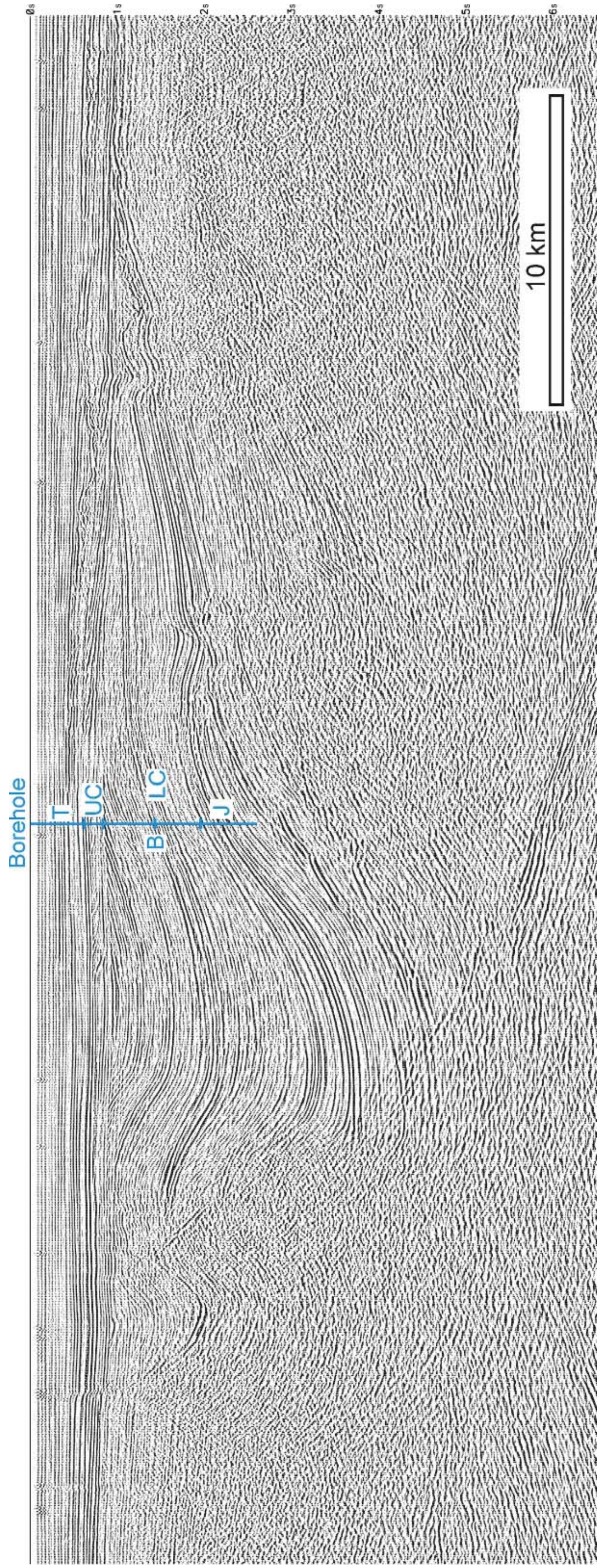


Figure 6. Seismic reflection data (cross-sectional view) acquired over the Jeanne d’Arc Basin on the Grand Banks, which is located southeast of the island of Newfoundland.

Interpreting Seismic Reflection Data - Answer Key

1. Imaging Sediments and an Angular Unconformity

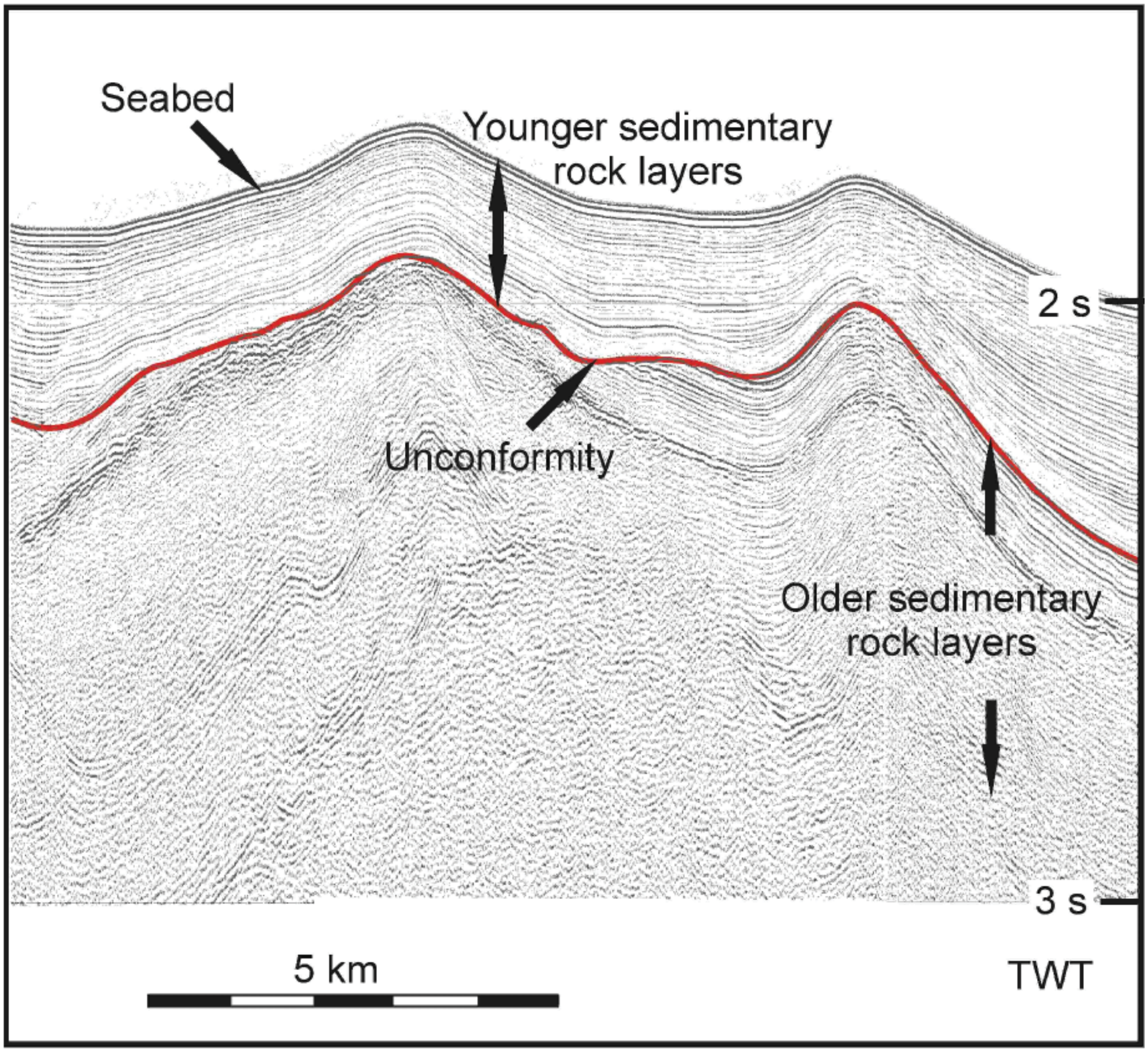


Figure 4. Seismic profile (cross-sectional view) collected by Memorial University in the Mediterranean Sea.

2. Imaging Faulted Sediments

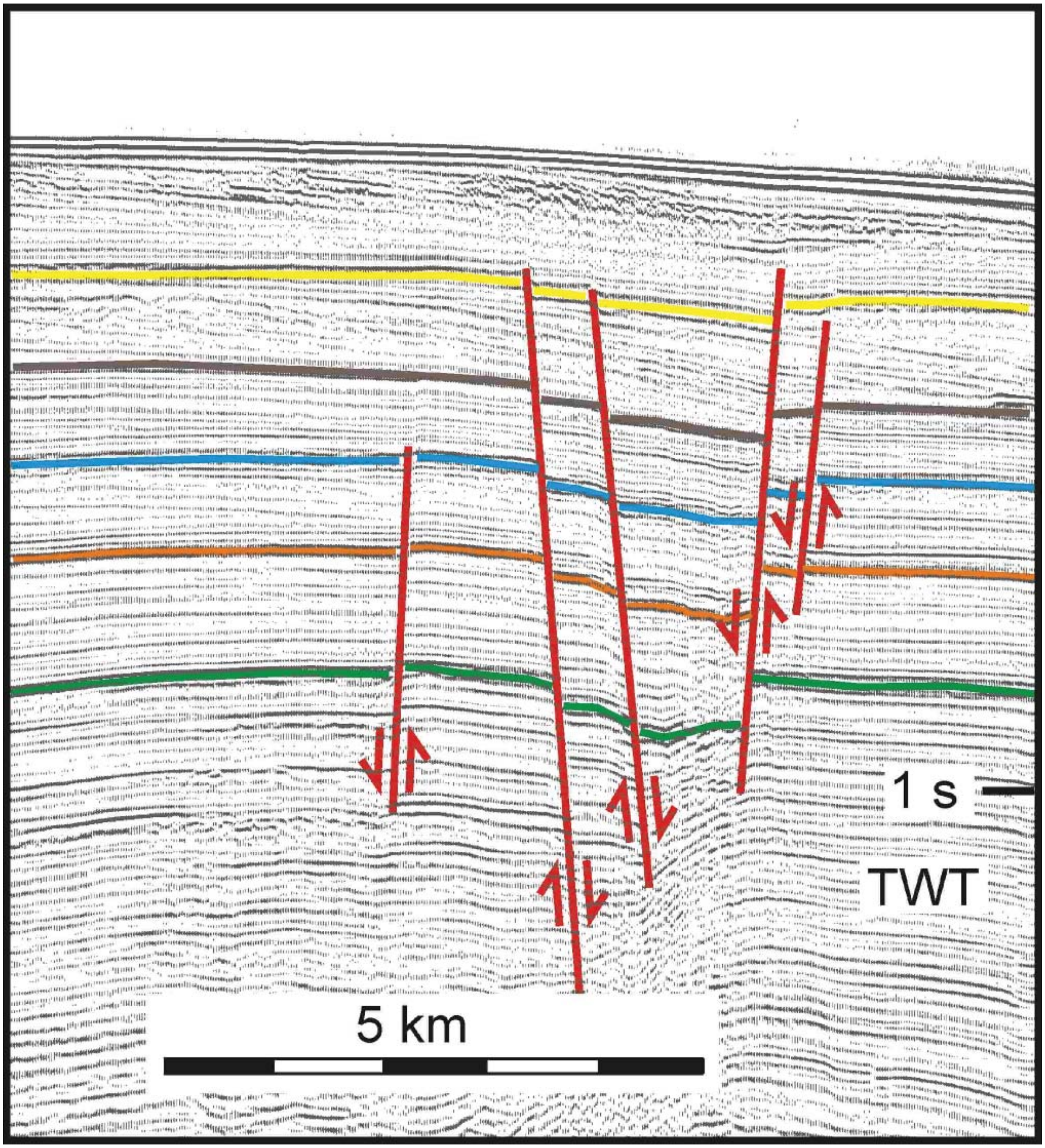


Figure 5. Seismic profile (cross-sectional view) collected by Memorial University in the Mediterranean Sea.

3. Putting It Together: An Example from Newfoundland

On the solution profile, the various geological layers and boundaries have been drawn across the section. Some small faults offset the sediments and a big fault, the Murre Fault, forms the western edge of the large basin known as the Jeanne d'Arc Basin. All the faults are normal faults, caused by the extension that formed the basin. Note that the extension (tensional forces) was occurring simultaneously with the rifting event that was creating the Atlantic Ocean approximately 200 million years ago. We can tell that they are normal faults because they dip down towards the side on which rocks are offset downwards. Oil sourced from the layers that are Jurassic ("J") in age would have migrated upwards to collect in possible traps. Traps that have been marked with stars include:

(i) below the upfold 3 km to the right of the borehole;

(ii) below the upfold 12 km to the left of the borehole and just above the Murre Fault;

(iii) against the Murre Fault and other faults (only if they are not leaky);

(iv) below the unconformity at the base of the Upper Cretaceous.

In each case, there would have to be a seal to prevent the oil escaping farther ("leaky"). Simply think back to the importance of cap rocks!

This profile intersects the structure which contains the Hibernia oil field, as indicated on the solution profile. Here oil collects in a number of traps in the upfold which is faulted in even more complex ways than shown in the solution profile. The actual profile does not actually intersect the oil field itself since it is farther north and somewhat deeper. Remember that this is only a profile giving a single cross-sectional view. Because the oil occurs in several traps, directional drilling is used to access the different pools from the one platform (i.e. Hibernia Gravity Base Structure).

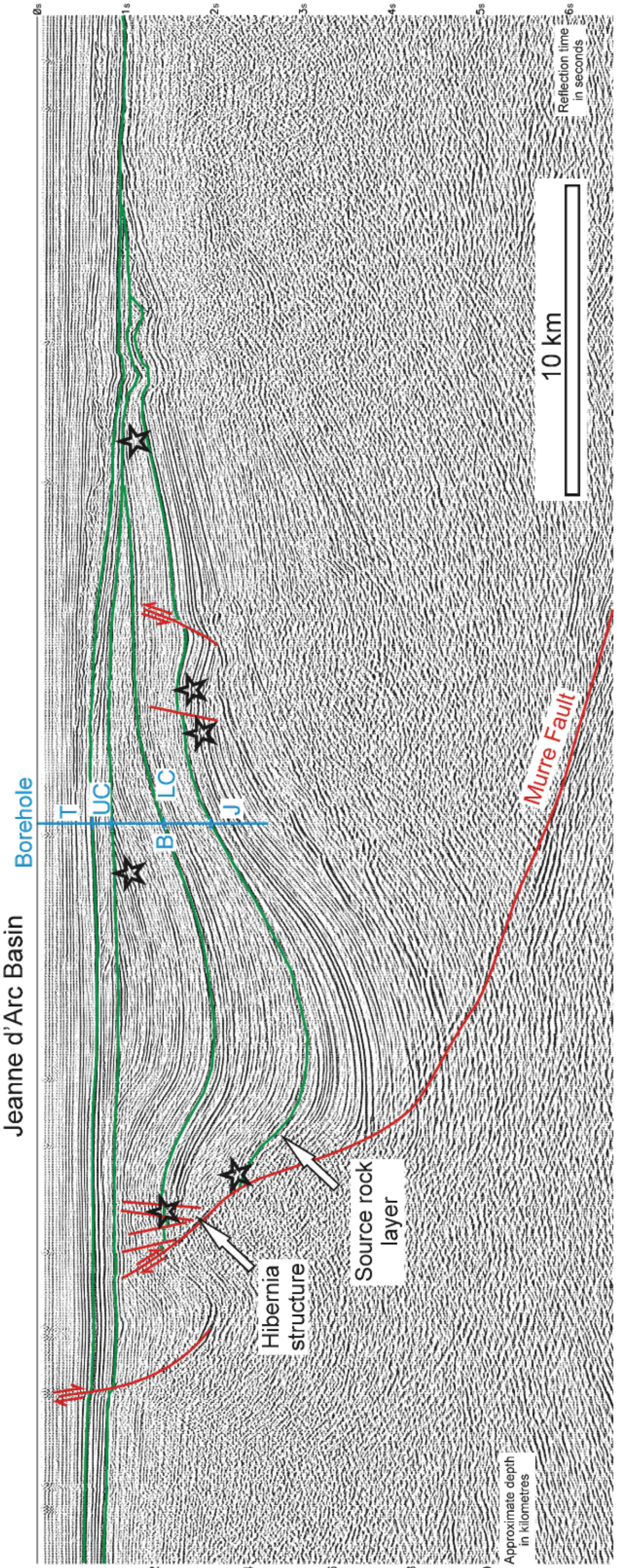


Figure 6. Seismic reflection data (cross-sectional view) acquired over the Jeanne d'Arc Basin on the Grand Banks which is located southeast of the island of Newfoundland.