Lesson Title: Looking Into the Earth: Seismic Surveys in Mineral Exploration.

Overview

The seismic reflection method of geophysical exploration is used widely to map geology below the surface. This activity is an introduction to how seismic data is collected and displayed, and how geophysicists and geologists interpret the data.

Source: This lesson was developed by S. Heenan for the Dancing Elephants and Floating Continents Teachers' Companion Material. It was adapted for Saskatchewan by the SMA.

Duration: One class

Materials:

- Tuning fork
- Stopwatches (one per group)
- 100m tape
- 4 markers (e.g. pylons, buckets, boxes)
- Copies of rock cards and student task cards
- Sidewalk chalk
- Recording sheet for class average

Notes to Teacher:

Do this activity after doing the activity Geophone: I "Heard" That!

This lesson plan is one of 15 developed to accompany the book ***Dancing Elephants and Floating continents. The Story of Canada Beneath Your Feet.*** By John Wilson.

Overview:

This simulation follows the steps used in seismic reflection surveying. First, the time for a wave to travel a known distance is measured. From this the average speed is calculated. Then the time for the wave to travel an unknown distance is measured. The unknown distance is calculated using the time taken and the average speed of the wave.

Students will **s**imulate a seismic wave travelling from the surface to a rock layer in the earth being reflected back up and recorded at the surface. Students measure the average velocity of a "wave", and then they calculate the distance to each layer using this average velocity.

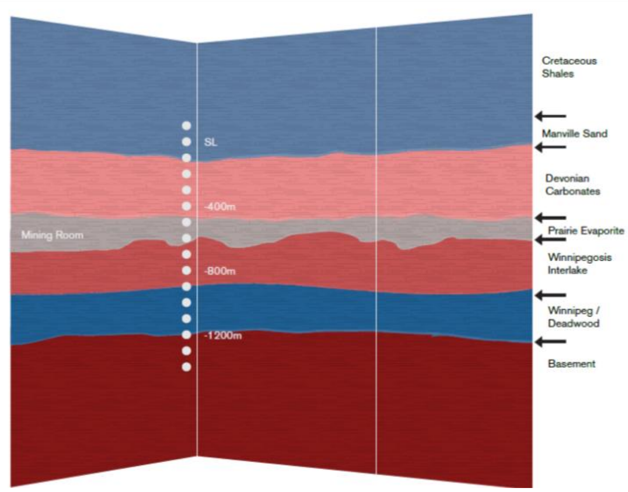
Prior Knowledge:

Before attempting this activity students should have some understanding of the following:

- Seismic waves in earthquakes
- Movement of sound waves

Instructional Methods:

- Discussion
- Small group work
- Inquiry



A typical interpreted seismic image, showing the cross-section of a potash mine. The numbers show the depth in metres below sea-level (SL). A mining room is labeled. Image courtesy of PotashCorp. (Source: Ore magazine, Spring –Summer 2013)

Learning Outcomes and Indicators

7ECR7.2 Identify locations and processes used to extract Earth's geological resources and examine the impacts of those locations and processes on society and the environment.

f. Provide examples of technologies used to further scientific research related to extracting geological resources (e.g., satellite imaging, magnetometer, and core sample drilling).

h. Provide examples of Canadian contributions to the scientific understanding and technological developments related to surface and sub-surface geology and mining, and identify societal and economic factors that drive such exploration and research. (Indirect)

7ECR7.1 Analyze societal and environmental impacts of historical and current catastrophic geological events, and scientific understanding of movements and forces within Earth's crust.

c. Construct a visual representation of the composition of Earth, including the crust, upper and lower mantle, core, and inner core. (Indirect)

h. Explain the operation of tools scientists use to measure and describe the effects of catastrophic geological events, including earthquakes and volcanoes (e.g., seismograph, Mercalli intensity scale, and Richter magnitude scale).(Indirect)

Earth Science 30: Lithosphere

ES30-LS3 Investigate the processes and technologies used to locate and extract mineral resources and fossil fuels locally, provincially and globally.

d. Contrast the operation and utility of different imaging methods (e.g., gravity, magnetics, electromagnetics and seismic) for locating hard rock and soft rock resource deposits.

Source: **Saskatchewan Evergreen Curriculum**

Other:

The students will:

• Understand how seismic data is collected and displayed.

Big Picture Questions

1. **How can geoscientists determine what occurs beneath our feet in a relatively non-destructive way.**

Background Information

In mining exploration, we ask one principal question: "What's under there?" The answer determines not only where to mine, but also how to mine – the risks and the rewards. The answer, in large measure, comes from geophysics. "Geophysics is used to map the earth's subsurface through the application of remote sensing survey techniques," "Changes in geology at depth, or of the same geological feature at depth, result in variations in the physical properties of the rocks. Exploration

geophysics is about mapping these changes from the air, on the earth's surface, or from within boreholes.

The properties of the rocks that we can measure include density, porosity, magnetic susceptibility, conductivity, **sonic velocities**, sulfide content and radioactivity."
The geophysicist is responsible not only for collecting this data, but also interpreting it. (ORE, spring-summer 2013).

Much of southern Saskatchewan is underlain by potash beds. Exploration of the potash deposits is mainly by surface seismic surveys which measure differences in seismic velocities among rock layers.

Seismic geophysics was pioneered in the oil and gas industry and is also now used extensively by the mineral industry. The main purpose for seismic surveys is to identify anomalies –changes or peculiarities – and mine around them (ORE, spring-summer 2013).

A typical seismic survey can cost millions of dollars, but its well worth it. The 3D images produced by the echoes identify anomalies such as "collapse zones" and other problematic areas that could endanger workers, lower the ore grade or destroy a mine. Seismic surveys in southern Saskatchewan produce some of the best seismic images you'll find anywhere in the world. "It's all about the sonic frequency you can get into the earth and the frequency you get back," explains Craig Funk Chief Geophysicist with PotashCorp. "The higher the frequency you get back, the better the image resolution you have." (ORE, spring-summer 2013).

The seismic reflection method of geophysical exploration is used widely to map geology below the surface. Potash and uranium exploration requires detailed knowledge of the geology, particularly to accurately locate disruptive features such as faults and collapse structures.

Other practical applications of seismic reflection imaging are in mapping folds, ore deposits, groundwater, underground contamination, and site investigation for construction.

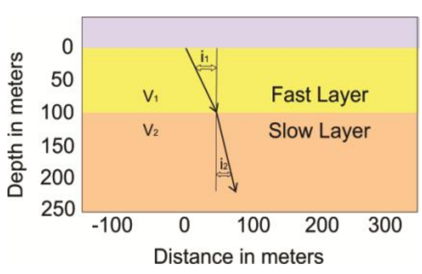
The seismic reflection method (Figure 1) requires a source of sound energy on or near Earth's surface. To create this energy, explosives or a large thumping device (e.g., Vibroseis truck "Dancing Elephant") are used. The sound (seismic) waves travel through the Earth and reflect back due to changes in the physical properties of rocks, in particular density. Sound waves also travel at different speeds through different types of rock. Faults and collapse structures can be recognized where rock layers distinguished by seismic characteristics are offset against each other.

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 reflected energy to arrive at a detector makes it possible to estimate the depth of the boundary.

The reflected sound waves are heard by microphones (geophones) that are placed at defined distances along the surface of the ground. The geophones transmit the sound waves to computers in a truck. The particular rates at which the sound waves are reflected back create a picture of the underground geology

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 and direction of the wave will change.

Seismic waves travelling through the Earth follow the same laws of refraction and reflection as any other wave at interfaces. When they encounter boundaries between different rock types, the wave will bend according to Snell's Law, and the angle of refraction across the boundary will depend on the sonic velocity of the second rock type relative to the first. The angle of reflection will be equal to the angle of incidence.



Snell's Law describes the relationship of energy passing across a boundary between faster and slower media (rocks).

Velocity of P-waves for some rocks

Material	VP (m/s)	Material	VP (m/s)
Granite	4,500 -6,500	Marble	5,000 – 6,000
Diorite	4,500 – 6,700	Sandstone	1,500 – 4,600
Gabbro	4,500 – 7,000	Limestone	3,500 – 6,500
Basalt	5,000 – 7,000	Anhydrite*	4,000 – 5,500
Gneiss	5,000 – 7,500	Evaporites (Potash, Salt)	4,000 – 4,400
Shale	2,000 – 4,600		

Source: (Properties of Rock Materials); *Stanford, PotashCorp

Vocabulary (hyperlink)

reflection	seismic
wave	geophysicist
refraction	Snell's Law

LESSON PLAN

The Activity: Looking Into the Earth

Teacher Preparation

1. Make copies of the student task cards. Use a different colour for each group of 6.
2. Make copies of the rock cards for the markers.
3. Using chalk, mark out a start line, a parallel line at 25 metres from the start and a third parallel line approximately 100 m from the start. Each line needs to be long enough for the class to stand along it.
4. Randomly place the 4 markers at any point along the 100 m distance and fix the rock cards to them. To add an "exploration flavour", don't put the rock cards in sequential number order. The aim is to discover which is the closest rock from the time it takes for the wave to reach it.

A comfortable, natural speed of walking for many people is 6 km per hour, or 100 metres in 1 minute. The distances have been chosen based on this speed to give suitable times for students to measure. See figure 1 for the layout of the activity and how each wave will travel in Part 2. (Wikipedia gives 5kph as an average speed of walking).

Review (X minutes)

1. Review what was learned in the activity Geophones: I "Heard" That.

   Explain: Tell the students that sound waves are one way that seismologists map the rocks and structures beneath the surface.

   Sound waves travel at different speeds through different types of rock. Seismologists use special equipment to determine the underlying rock units.

The Vibroseis trucks, also called Thumper trucks or "Dancing Elephants", are 25 ton trucks that pound the ground with huge hammers making it shake as an elephant would when stomping it's foot. Another way to create sound waves is by detonating explosives either on the earth's surface or in shallow pits underground.

The sound waves travel through the rock for up to tens of kilometers. The waves will bounce off a rock layer and travel back to the surface. The Seismologists measure the amount of time it takes for the shock wave to travel from the initial pounding/explosion back up to the surface to determine how far below the earth's surface the rock units are. The sound waves are heard by microphones (geophones) that are placed at defined distances along the surface of the ground. The microphones are connected to computers in trucks equipped with high-tech equipment that read the speeds at which sound travels through various types of rocks and interpret the sounds as a picture. Using this information and information from drill holes at the site, the Geophyscists identify rock formations and interpret the seismic information. Show the students the picture of a 2D seismic section (Figure 2.)

Activity: Looking Into the Earth. (Simulation) (20 minutes)

Part 1 Calculating the Average Walking Speed (10 min.)

1. Distribute the student pages. Students calculate the average walking speed for the class. Working in pairs, students time each other walking between the two lines that are 25 m apart (See Fig. 1). Prompt the students to try to walk at the same speed throughout both parts of the activity. It's not a race and they will get better results by keeping their speed constant.
2. Using the ***Recording Sheet for Class Average,*** collect the results from everyone in the class. Calculate the average time to walk 50 m for each person (add the three times and divide by three) and then calculate the class average walking speed over this distance.

The chart could be copied onto a large piece of paper and prominently displayed to help collect data from the whole group and demonstrate how the average is calculated.

Part 2 Seismic Reflection Survey Simulation (30 min.)

Students simulate a seismic reflection exploration survey.

1. Distribute student task cards to each group. Students take on the roles presented on the cards: the Vibroseis truck ("Dancing Elephant"), the travelling sound waves, and the recording computer. Within their group, students record the time for each "wave" to travel to a corresponding rock marker and return to the start. This is called the "two-way travel time". They then use the average speed of each "wave" (student) measured in part 1 to calculate the distance to each rock marker.

Modification: the whole class could be signaled to start simultaneously by a single strike of a bell, two pieces of wood slapped together, a drum beat, or a large object dropped on the ground. The latter would be a more authentic replication of the Dancing Elephant seismic method, which uses an impact to create the sound waves.

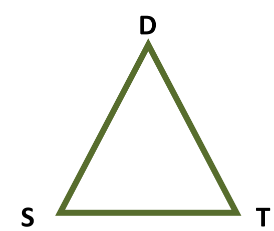
Repeat the activity if time is available, redistributing cards to switch roles.

The trick to this simulation is using elapsed time to determine distance. It is assumed that the waves travel at the average speed calculated in Part 1. If the time for the wave to travel an unknown distance is measured, the distance can be calculated from the relationship that

Speed = Distance / Time

Time = Distance / Speed

Distance = Speed x Time



Allow time for students to complete the analysis questions on the student page.

Discussion:

1. Discuss the analysis questions.
2. Display the ***Schematic of Lithoprobe's Exploration Technique*** *(Figure 3.).* Read through the numbers in order to explain the seismic reflection technique.
3. Explain how the activity that the students have completed is a direct analogy to how seismic reflection surveying methods operate, where depths to features in the crust are not measured directly, but inferred from the travel time of reflected seismic waves. Scientists determine the average speed of waves in different rocks and can calculate distance from the measured time and known speed.
4. Show the students Figure 4. The cross section of Saskatchewan showing the results of the seismic survey by Lithobrobe.

5. Have students complete the sequencing activity to answer the opening question: How do geoscientists find out what's beneath our feet?

Assessment Method and Evidence

Part 1:

✓ Calculation Sheet

- Students will work together to determine the average time to walk 50 m and then calculate the class average walking speed over this distance.

Part 2:

✓ Calculation Sheet/Discussion questions:

- Students will be able to explain how the use of seismic surveys further the geophysicists and mining companies knowledge of the Earths stratigraphy , how deep the resource occurs and how it could be used to determine where to mine.
- Students will be able to provide the example of the Canadian Lithoprobe seismic survey as a contribution to the scientific understanding the sub-surface geology to the depth of the MOHO, across northern Saskatchewan and Manitoba.
- Students will be able to determine the depth to the MOHO in Saskatchewan's north by interpreting the Lithoprobe seismic section.
- Students will construct a visual representation (core section) of Saskatchewan's geology in the area of potash resources.
- Students will be able to explain how geophysicists use small explosions or pounding to create seismic (sound) waves to measure the distance to geological boundaries in the earth's crust.
- Students will be able to explain that the wiggly lines recorded on a seismograph are the seismic waves after they have been reflected, refracted along geological boundaries and have returned to the surface where they are recorded by the geophones.

Resources

Heenan, Stella. (2004). Dancing ***Elephants and Floating continents. Teachers' Companion Material***. Lithoprobe Report number 87.
Available at:
http://www.docstoc.com/docs/42101467/Teachers-Companion-Material-Dan

Wilson, J., (2003). ***Dancing Elephants and Floating Continents The Story Beneath Your Feet***. Key Porter Books Limited, Toronto, Ontario. 47p.

IRIS Incorporated Research Institutions for Seismology. **Why do seismic waves travel a curving path through the Earth?** Available at:
http://www.iris.edu/hq/programs/education_and_outreach/animations/13

Sanford Rock Physics Laboratory: **Conceptual Overview of Rock and Fluid Factors that Impact Seismic Velocity and Impedance**. Available at:
https://pangea.stanford.edu/courses/gp262/Notes/8.SeismicVelocity.pdf

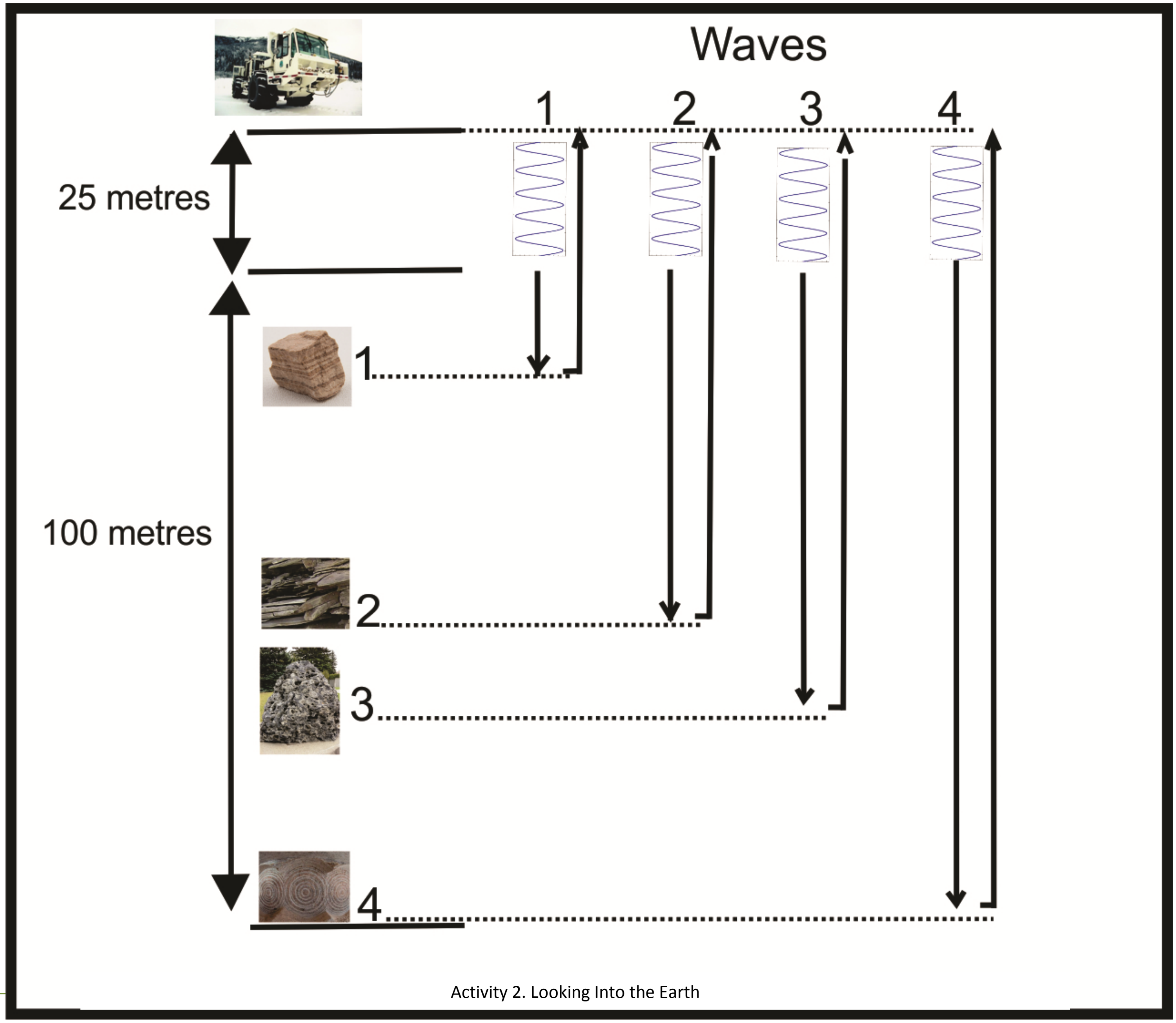
Hubenthal, M. and Taber, J. **How Shallow Earth Structure Is Determined: A Classroom Exercise Demonstrating Seismic Refraction Use in the Real World**. Available at:
www.iris.edu/hq/files/programs/education_and_outreach/lessons_and_resources/docs/shallowearthstructure/RefractionLabv2_0.pdf

Chapter 4: Properties of Rock Materials: Available at:
www.epfl.ch/en/ensei/Rock_Mechanics/ENS_080312_EN_JZ_Notes_Chapter_4.pdf

Student Task Cards

Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Truck	**Truck**	**Truck**	**Truck**	**Truck**
Computer	**Computer**	**Computer**	**Computer**	**Computer**
Wave 1	**Wave 1**	**Wave 1**	**Wave 1**	**Wave 1**
Wave 2	**Wave 2**	**Wave 2**	**Wave 2**	**Wave 2**
Wave 3	**Wave 3**	**Wave 3**	**Wave 3**	**Wave 3**
Wave 4	**Wave 4**	**Wave 4**	**Wave 4**	**Wave 4**

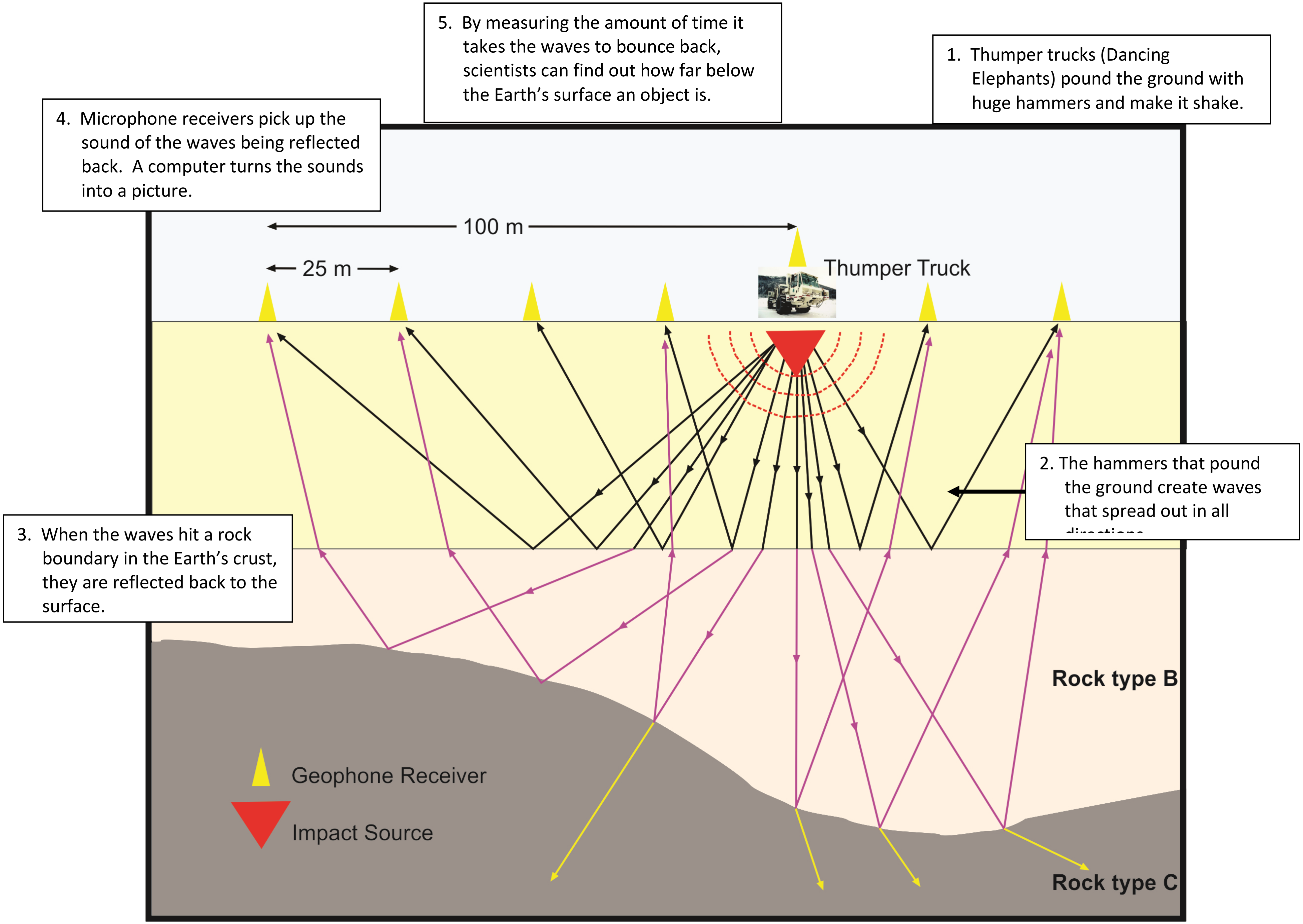
Figure 1. Layout



Part 1: Recording Sheet for Class Average

Name	Time to walk 50 m (=2 x 25 m) (seconds)			Average time to walk 50 m = (T1 + T2 + T3)/3 (seconds)
	T1	T2	T3	

Number of People		**Sum of all average times**	s
		Average time to walk 50 m for class **= sum / number of people (seconds)**	s
		Average speed of each person in class **= 50 / average time (metres per second)**	m/s



- **Figure 3. Seismic Reflection Method** (Schematic of Lithoprobe's Exploration Technique)

Name: ________________________________

Student Sheet – Looking into the Earth

Key Question: How do geoscientists find out what's beneath our feet?

Materials: Stopwatch, Student Task Cards

Keywords: Reflection, seismic, wave, speed, average

Instructions:

Part 1

Work with a partner. Use the stopwatch to time how long it takes for your partner to walk from the start to the line at 25 metres and return. Walk naturally, trying to keep at the same speed.

Switch roles and have your partner time you.

Repeat both measurements 3 times, record each time on the chart below.

Time to walk 2 x 25 m (seconds)	Person 1	Person 2
Time 1		
Time 2		
Time 3		

Add your times to the **Recording Sheet** for the **Class Average**. When the whole class has finished, calculate the average walking speed for the class.

Part 2

Join into a group of 6 people. Each person in the group takes a role card (**TRUCK, WAVES** (4) AND **COMPUTER**) and stands at the start line.

The **TRUCK** tells the 4 **WAVES** to start walking and starts the stopwatch.

The **WAVES** walk straight down along the course towards the rock markers. When a **WAVE** reaches a rock marker with the same number as their card, they turn around and walk back to the start line. For example **WAVE 1** walks to Rock 1 and back.

As each WAVE arrives back at the start line, the TRUCK announces the time on the stopwatch, and the COMPUTER records it on the chart below. **DO NOT STOP THE WATCH; KEEP IT RUNNING TO TIME THE OTHER WAVES.**

Repeat the task and record a second time for each **WAVE.**

	Time 1 (seconds)	Time 2 (seconds)	Average time = (Time 1 + Time 2) / 2
Example	**27**	**25**	**27 + 25 = 52** **52 / 2 = 26 seconds**
WAVE 1			
WAVE 2			
WAVE 3			
WAVE 4			

You only measured the time for each **WAVE** to reach the rocks, but using the calculated average walking speed from Part 1, you can find out the distance that each **WAVE** travelled.

Calculate: Distance = time x average speed

Rock	1	2	3	4
Distance from start	m	m	m	m

Analysis

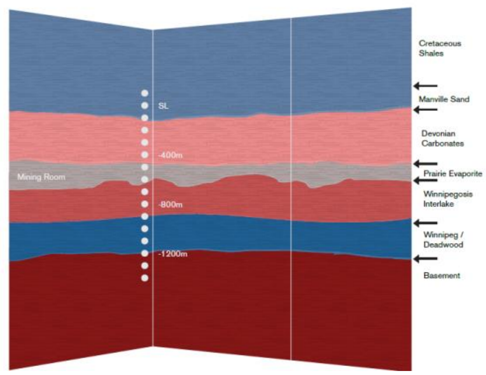
1. In Part 1, why did each student have to walk the 50 metres three times?

2. In Part 2 you found out how far the rock markers were from the start line. Are these distances exact measurements or estimates? Explain why.

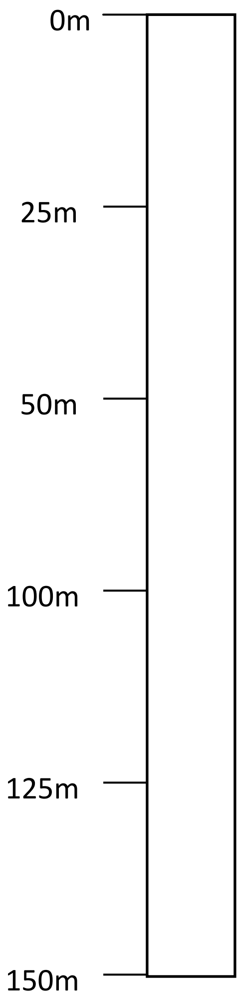
3. How do scientists find out what's beneath our feet? Number the steps in the correct sequence from 1 to 7 for how Lithoprobe's Dancing Elephants discover what's in the Earth's crust beneath us.

Scientists measure the amount of time it takes the waves to arrive back at the surface.	
Dancing Elephants pound the ground with huge hammers and make it shake.	
When the waves hit something in the Earth's crust, they bounce back to the surface.	
Microphone receivers pick up the sound of the waves being reflected back.	
They find out how far below the Earth's surface an object is using the speed of the wave.	
A computer turns the sounds into a picture.	
The hammers that pound the ground create waves that spread out in all directions.	

4. Look at the cross-section determined by seismic surveys conducted by PotashCorp. The top of the Prairie evaporite occurs approximately 480 m below sea level. Considering the altitude at Regina is 577 m above sea level (Saskatoon 481m). Using the speed you determined, how long would it take you to walk the distance to reach the potash unit?



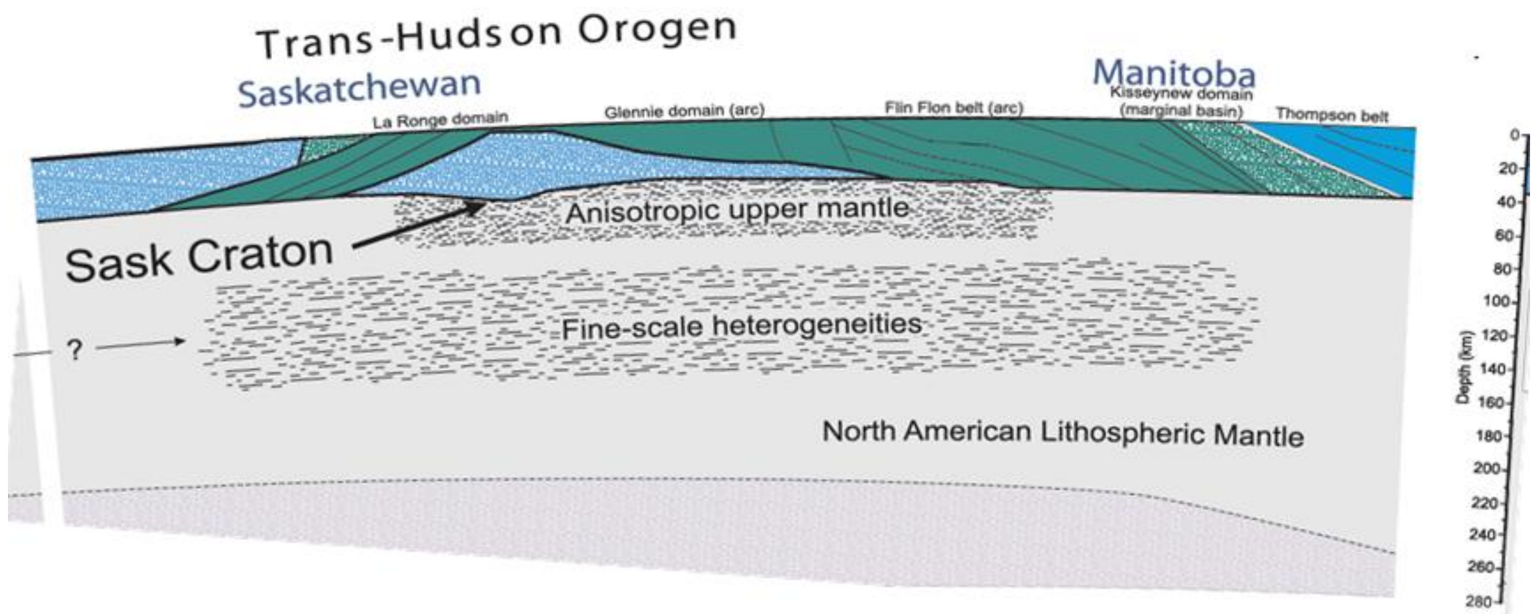
5. Draw your geological cross section using the depths from surface. Indicate the shale carbonate, potash and sandstone units using different colours.

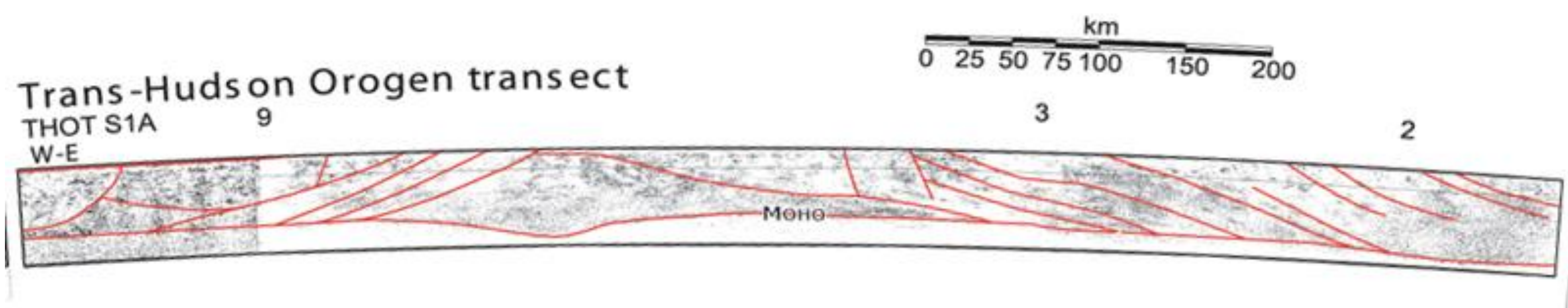


Student Activity 2. Sheet: Looking Into the Earth Seismic Surveys

6. The figures below show the Lithoprobe seismic survey conducted across Saskatchewan. Looking at the sections locate the Mohorovicic discontinuity (MOHO) the boundary between the Earth's crust and the mantel under northern Saskatchewan.

Depth to the MOHO ranges from _____________ to ______________ km deep.





Analysis – Sample Student Responses

1. In part 1, why did each student have to walk the 50 metres three times?

It is impossible to walk at exactly the same speed all the time. By taking 3 different measurements and calculating the average time, it better represents a fair number for the speed to use in Part 2.

2. In Part 2 you found out how far the rock markers were from the start line. Are these distances exact measurements of estimates? *Estimates because they are based on average travel speed (i.e., there is uncertainty about the absolute travel speed).*

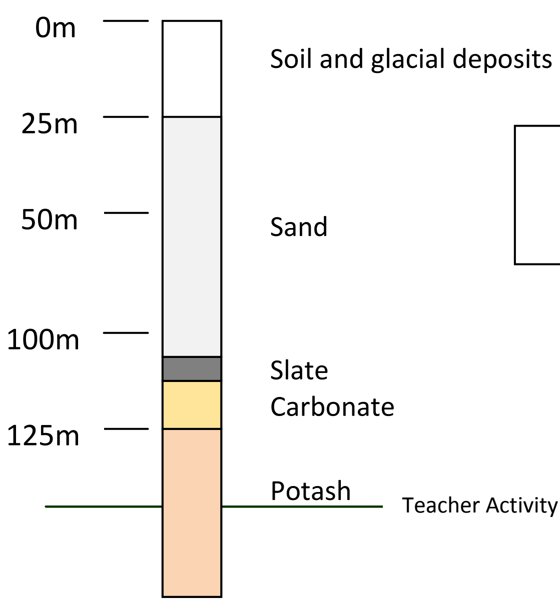
3. How do scientists find out what's beneath our feet? Number the steps in the correct sequence from 1 to 7 for how Lithoprobe's Dancing Elephants discover what's in the Earth's crust beneath us.

Scientists measure the amount of time it takes the waves to arrive back at the surface.	6
Dancing Elephants pound the ground with huge hammers and make it shake.	1
When the waves hit something in the Earth's crust, they bounce back to the surface.	3
Microphone receivers pick up the sound of the waves being reflected back.	4
They find out how far below the Earth's surface an object is using the speed of the wave.	7
A computer turns the sounds into a picture.	5
The hammers that pound the ground create waves that spread out in all directions.	2

4. Look at the cross-section determined by seismic surveys conducted by PotashCorp. The top of the Prairie evaporite occurs approximately 480 m below sea level. Considering the altitude at Regina is 577 m above sea level (Saskatoon 481m). Using the speed you determined, how long would it take you to walk the distance to reach the potash unit?

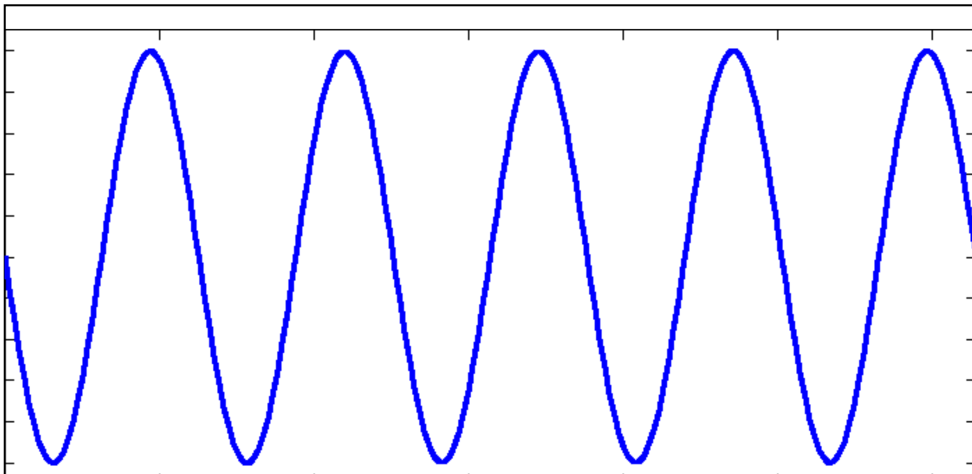
577 + 480 = 1057 m   T = D/T   T = 1057m/6km/hour   =1057/100m/min   10.57 minutes

5. Draw your geological cross section using the depths from surface. Consider the top 25 m are glacial deposits and soils. Indicate the shale carbonate, potash and sandstone units using different colours.



Answers may vary. Students should plot the top of each unit as that is the unit boundary the waves are being reflected off of.

Student Task Cards (one set of 6 for each group of students)



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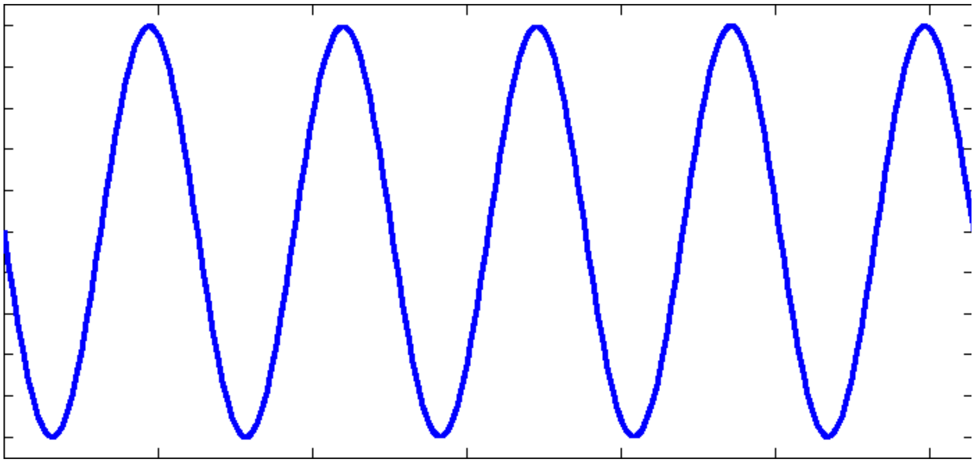

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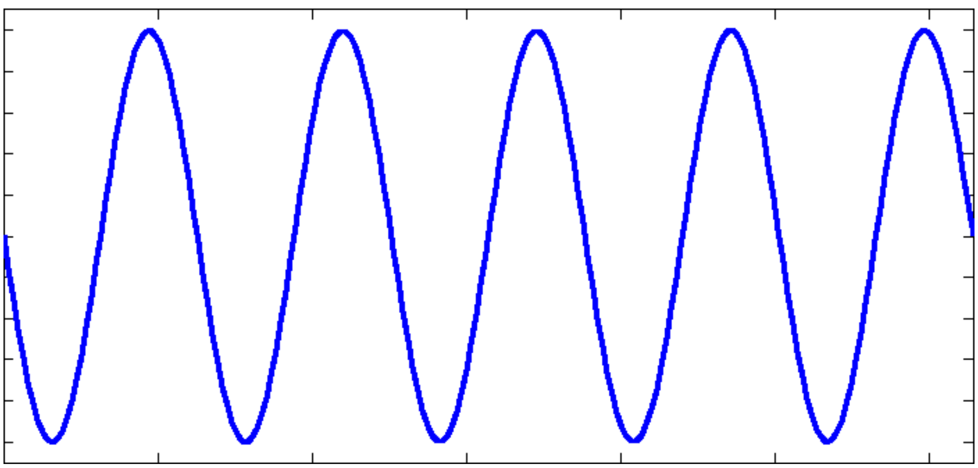

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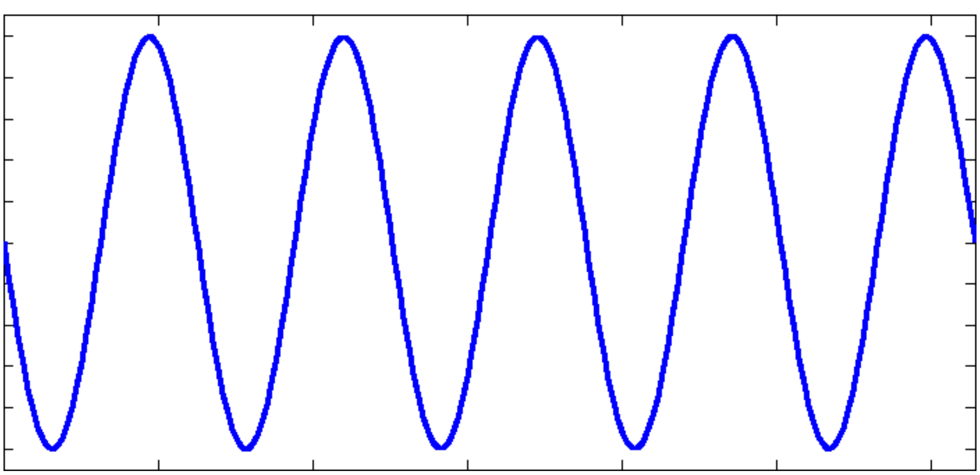

4

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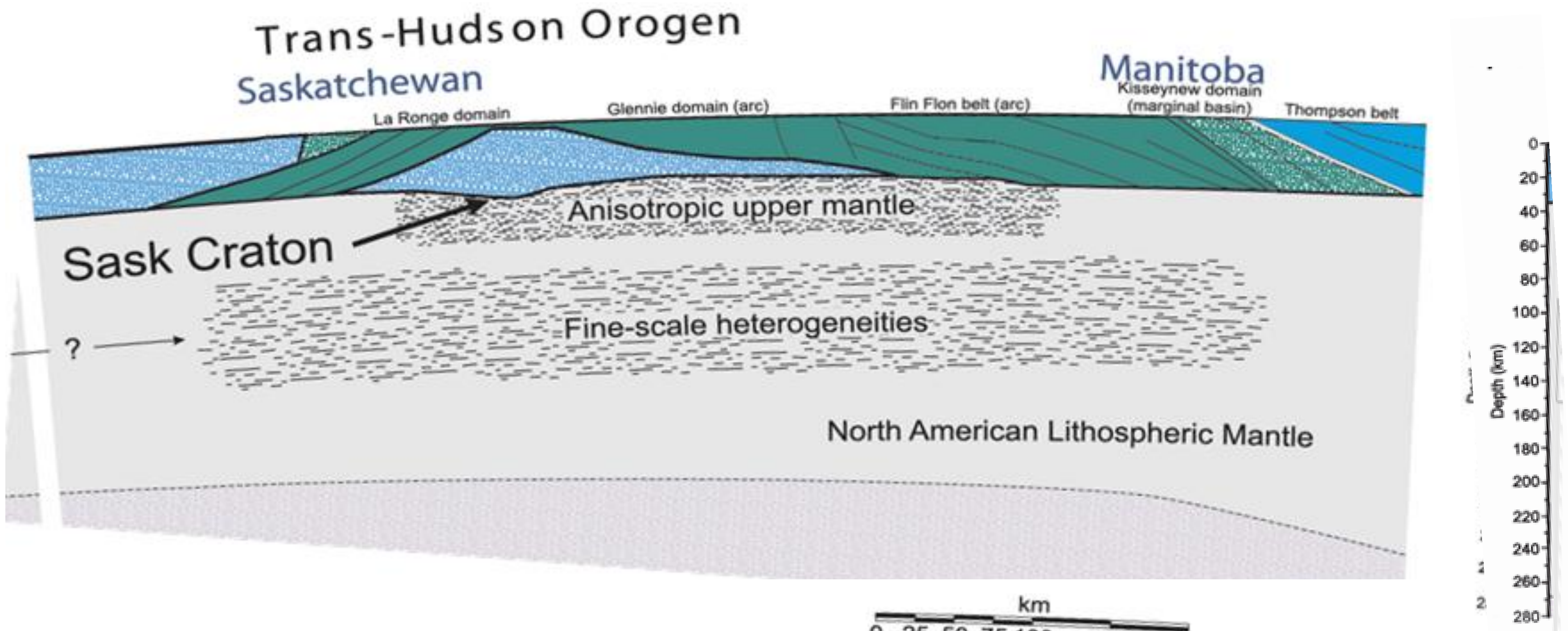

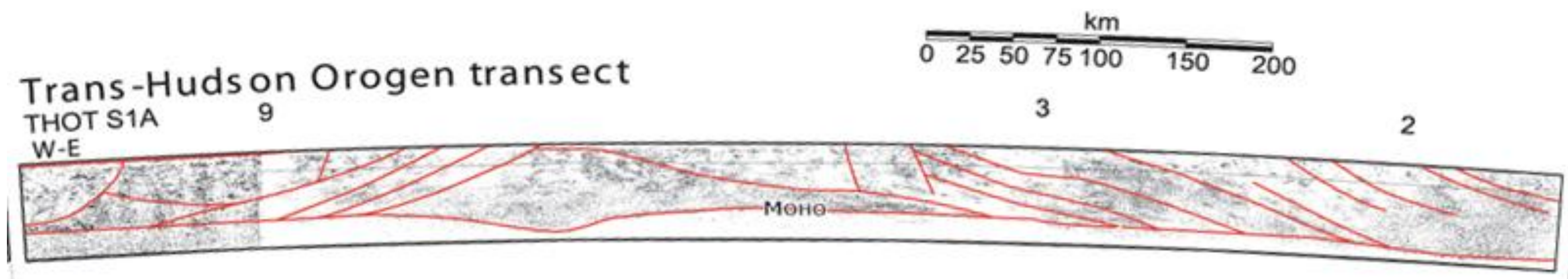

Over 900 scientists from universities, private companies and provincial and federal governments contributed to the Lithoprobe Project, a series of deep seismic surveys taken across Canada to determine what is beneath our feet. The bottom diagram shows a simplified seismic section compiled from many sites. The red lines interpret the boundaries between rock units identifying ancient continents. The upper diagram puts a name to the various continents or domains that stretch across Saskatchewan from east to west. If you look carefully you can see that the seismic survey identified the MOHO – or the Mohorovičić **discontinuity**, the boundary between the Earth's crust and the mantle under Saskatchewan.

Source: Wilson, J. (2003); Canada's National Litoprobe Geoscience Project (http://www.eps.mcgill.ca/~litho/method.html)

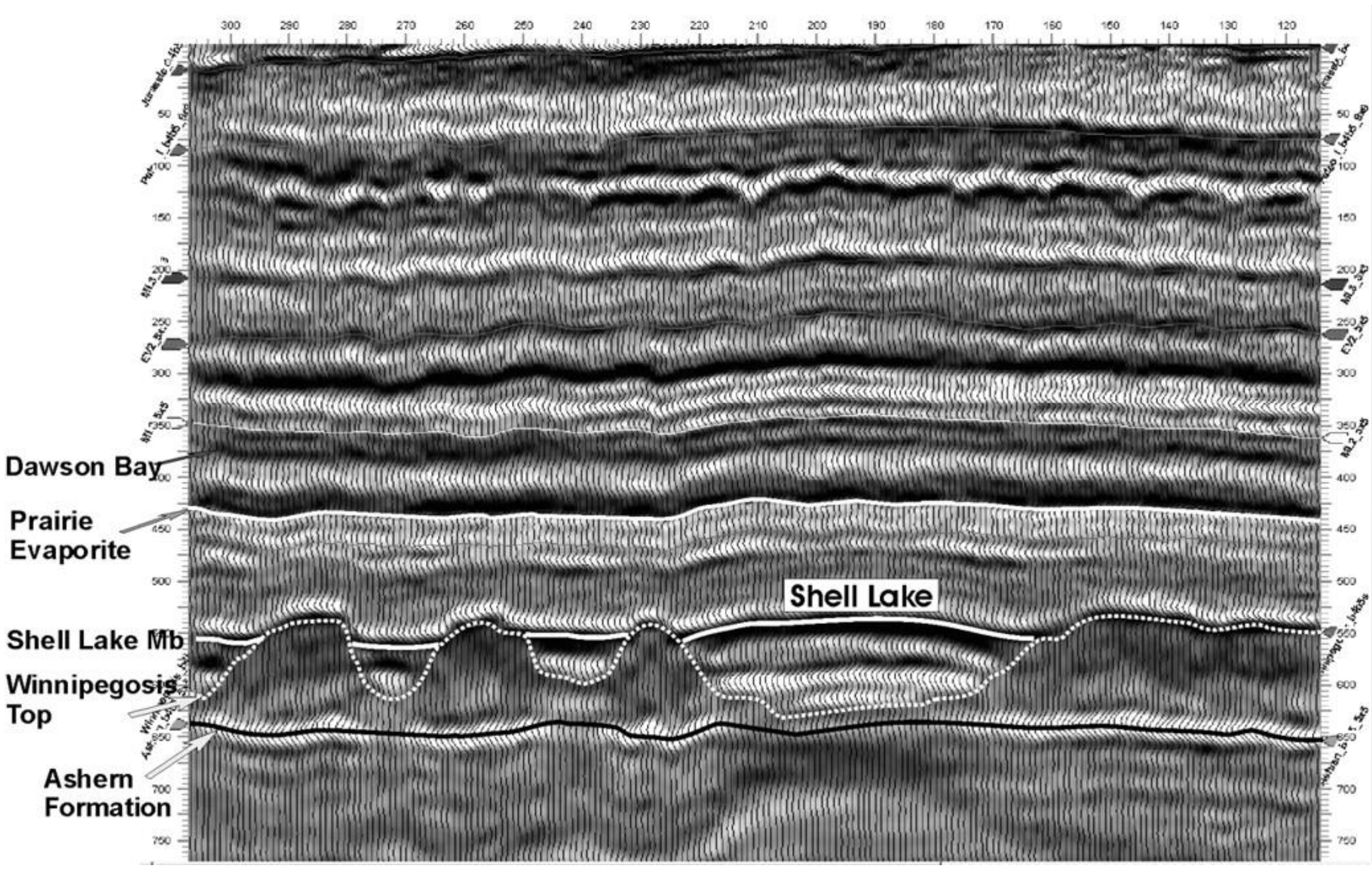

Figure 2. 2D (2 dimensional) seismic “picture of the rocks of southern Alberta and Saskatchewan (Source: Bulletin of Canadian Petroleum Geology)

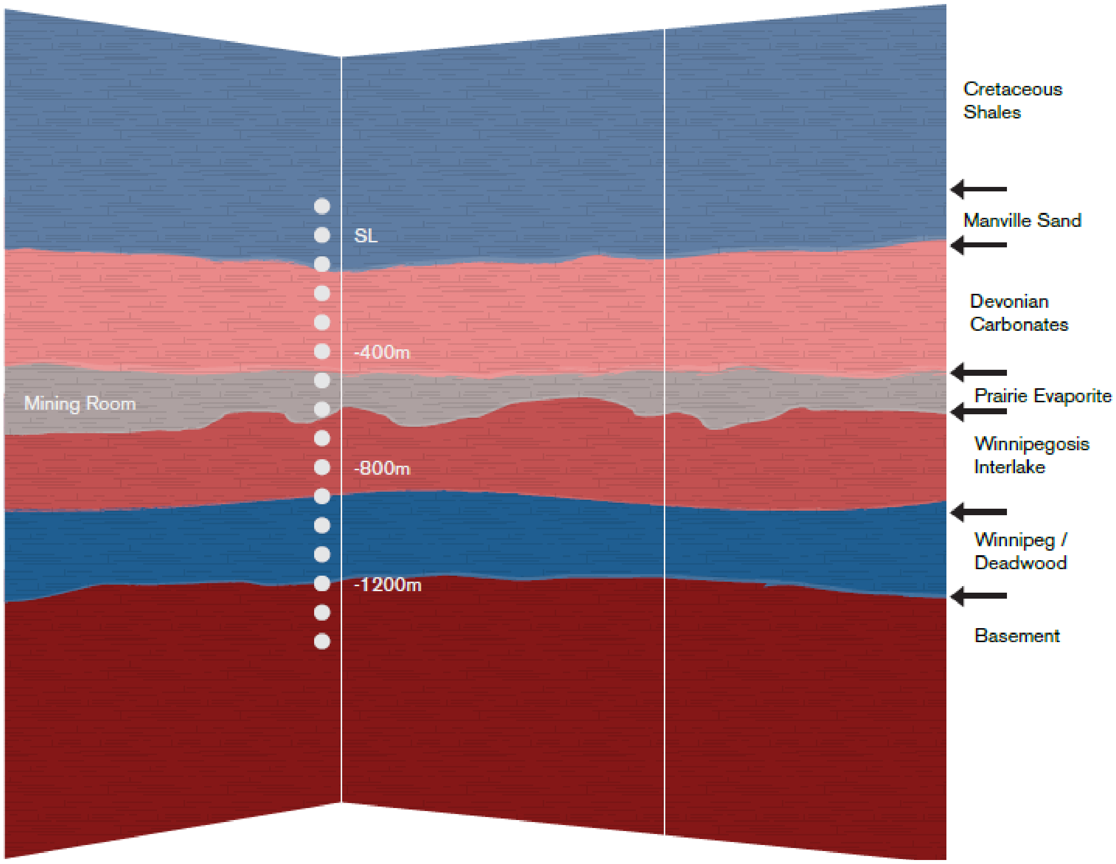

Fig. X . A typical interpreted seismic image, showing the cross-section of a potash mine. The numbers show the depth in metres below sea-level (SL). A "mining room" is labeled. Image courtesy of PotashCorp. (Source: Ore magazine, Spring –Summer 2013)