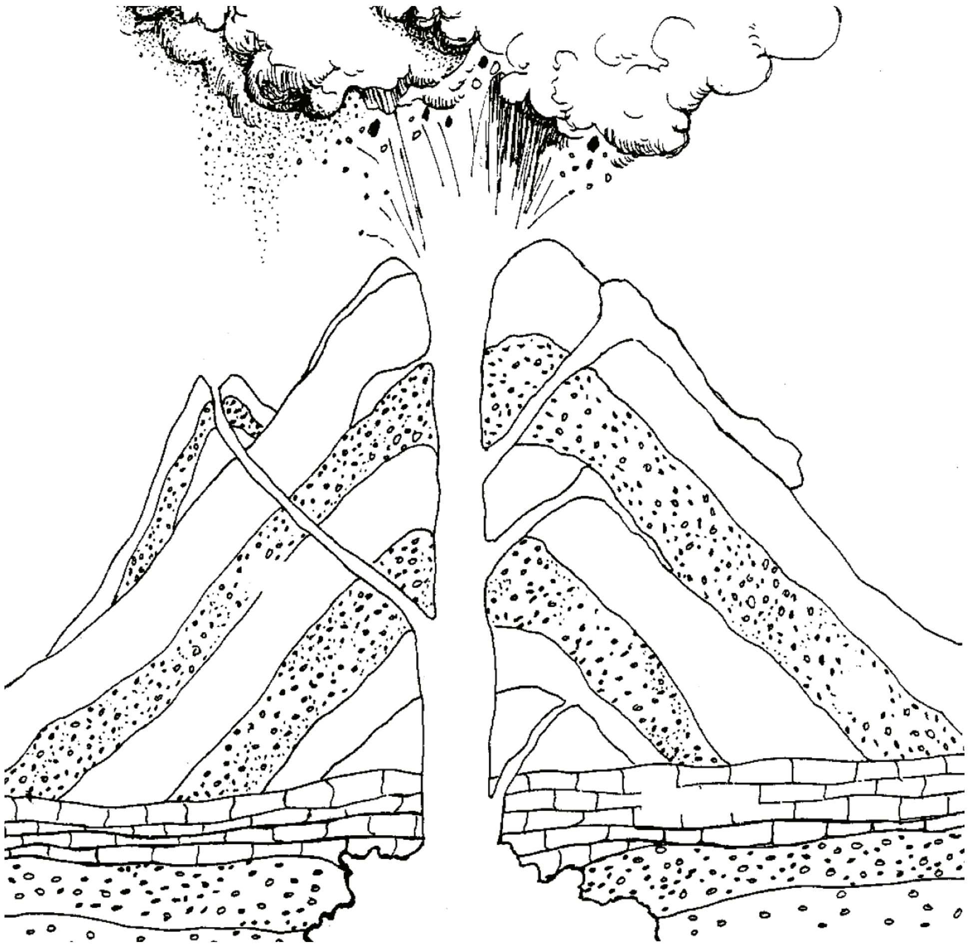
Earth Sciences 11 / Geology 12 Resource Unit



mineralsed
Mineral Resources Education Program of BC

Credits

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EARTH SCIENCE 11

ASTRONOMY	Student Activity	Contributing Teacher
A-1 to A-3	Impact Crater Simulation	Bleaney/Bourget
B-1 to B-5	Hertzsprung Russell Diagram	Kellas
C-1 to C-3	Hubble Relation	Kellas
D-1 to D-4	Diameter of the Sun	Kellas
E-1 to E-2	Parallax	Kellas
F-1 to F-3	Mars' Path	Kellas
G-1 to G-4	Kepler's Laws of Planetary Motion	Kellas
H-1 to H-2	Solar System Model	Kellas
I-1 to I-5	Constellations	Milross
J-1 to J-4	Sun's Apparent Path	Bleaney/Bourget
K-1 to K-13	Planet Quest	Bondi

ROCKS & MINERALS

L-1 to L-6	Mineral Project	Kellas
M-1 to M-5	Mineral Properties	Atal
N-1 to N-11	Rock Project	Kellas
O-1 to O-2	Metamorphic Rock Pancakes	Yee

EARTHQUAKES & VOLCANOES

P-1 to P-7	Volcano and Earthquake Distribution	Kellas
Q-1 to Q-10	Volcanoes	Milross
R-1 to R-7	Epicentre Location (1)	Kellas
S-1 to S-6	Epicentre Location (2)	Bleaney/Bourget
T-1 to T-2	Earthquake-Proof Building Competition	Yee

PLATE TECTONICS

U-1 to U-4	Depth of Focus	Kellas
V-1 to V-2	Ridges, Trenches & Rate of Plate Movement	Kellas
V-3 to V-5	Mid Atlantic Seafloor Profile	Kellas
W-1 to W-4	Rate of Seafloor Spreading	Kellas
X-1 to X-2	Tonga Trench	Kellas

MISCELLANEOUS

Y-1 to Y-2	Stereoscopic Vision	Nociar
Z-1 to Z-3	(Oceanography) Turbidity Currents	Bleaney/Bourget
AA-1 to AA-5	Drainage Basins	Nociar
BB-1 to BB-6	Barometric Pressure	Nociar

GEOLOGY 12

TIME AND THE FOSSIL RECORD

A-1 to A-29	Fossil Phyla	Kellas/Healing/Scott
B-1	Relative Age Dating (1)	Atal
C-1 to C-8	Relative Age Dating (2)	Kellas
D-1 to D-8	Relative Age Dating with Fossils	Kellas
E-1 to E-4	Faunal Succession/Sedimentary Structures	Bleaney/Bourget
F-1 to F-2	Radiometric Dating	Kellas
G-1 to G-2	Radiometric Dating Quiz	Kellas
H-1 to H-3	Geologic Time Scale	Bleaney/Bourget

INTERNAL STRUCTURES AND PROCESSES

I-1 to I-3	Earthquakes – Interpretation of Seismic Data	Atal
J-1 to J-4	Volcanoes- Damage Analysis and Control	Bleaney/Bourget
K-1 to K-3	Earthquake Safety at Your School	Milross
L-1 to L-5	Rate of Sea Floor Spreading	Kellas
M-1 to M-3	Clay Folds	Kellas
N-1	Structural Models	Kellas
N-2	Strike and Dip	Kellas
O-1 to O-3	Structural Block Diagrams	Kellas
P-1 to P-2	Structural Geology Cross section	Anuik
Q-1 to Q-18	Name the Structure	Della
R-1 to R-6	Tectonic Analysis of Planet X143B-M	Yee

SURFACE PROCESSES

S-1 to S-3	Surface Processes Assignment	Scott
T-1	Landslides and Road Construction	Anuik
U-1 to U-2	Glacial Charades	Milross

UNIT REVIEWS

V-1 to V-2	Geologic Time	Della
W-1 to W-7	Internal Structures and Processes	Della
X-1 to X-2	Surface Processes	Della
Y-1 to Y-2	Geology of BC	Della
Z-1	Minerals	Della
AA-1 to AA-2	Rocks	Della
BB-1 to BB-2	Mineral Resources	Della

MISCELLANEOUS

CC-1 to CC-2	Headband Review Technique	Milross
DD-1 to DD-5	Crossword Puzzles	Della
EE-1 to EE-5	Team Games Tournament	Della
FF-1 to FF-13	Jeopardy	Della
GG-1 to GG-10	Overheads	Kellas
HH-1 to HH-6	Internal Structures and Processess	Milross

RESOURCES

RES A-1 to RES A-2	Video References
RES B-1 to RES B-4	Geoscience Contacts

SLIDES & SLIDE TEXT

Slide Text 1-12

INSERVICE AND RESOURCE EVALUATION FORMS

Project Rationale

This resource package was created to provide Earth Science 11and Geology 12 teachers access to resources they may not otherwise know exist. Under the auspices of the Mining Association of British Columbia, we endeavored to design a package that would be useful to the novice Earth Science teacher, but would also provide the veteran teacher with some new ideas about curriculum content. The Mining Association has an educational component which is funded by mining companies, government agencies and interest groups. It was our intent that the format of the project be such that the ideas and lesson plans provided could either be immediately executable, or would at least provide inspiration for innovation. The resource section is provided so that the practicing teacher can access various resources ranging from rock samples, to videos, to exam questions.

It is imperative the users of this package realize it has been **designed by teachers for teachers**, the participation of whom will only add to the resource kit's relevance and viability. Every effort has been made to solicit input from our colleagues around the province. It is our hope that the project will continue to evolve as new ideas are added on an ongoing basis. The key is the participation of the resource packages' benefactors – namely the teachers using the kits. We hope to eventually develop a system where regular updates are provided to users of this package around the province - this will ensure the continued validity of the project.

It should be noted that a sincere debt of gratitude goes to Maureen Lipkewich and Bernard Dewonck of the Mining Association of BC, without whose ceaseless efforts, unfathomable resourcefulness and irrepressible spirits, this project would not have come to fruition.

Thank you for participating.

Steve Kellas
Jim Milross
(1995)

Impact Crater Simulation

This activity illustrates the effect of projectiles impacting the surface of the Earth. The topic encompasses several concepts including: weathering and erosion (Why aren't there more impact craters visible on Earth's surface?), comets and meteors (What are their effects on Earth after impact?), and evolution (What role, if any, did projectile impacts have in evolution on our planet?).

Set-up time and material required are minimal: aluminium foil baking pans, some flour, a ruler (or metre stick), and marbles or ball bearings of various sizes.

Safety Warning! Clear instructions and expectations must be given to the students to avoid any unnecessary impacting!

Student Exercise

Impact Crater Simulation

Purpose: To determine the effect on the surface of the Earth when a projectile impacts the surface.

Materials: Small aluminium cake or pie pan, flour, marbles of various sizes, ruler.

Procedures:

1. Place flour in a pan to a thickness of about 2 cm. Smooth out the surface to make it as even and level as possible.

2. Measure the diameter of a small marble and record the measurement in the table below.

3. Drop (DO NOT THROW) the small marble into the pan from a height of 50 cm. Measure the crater diameter produced from rim to rim. Record the measurement below.

4. Smooth out the flour and repeat Procedure 3 from a drop height of
   a) 100 cm
   b) 150 cm

5. Repeat Procedures 2, 3 and 4 for a large marble.

6. Observe the results when a marble lands in the flour at an angle. Drop a marble into a tilted pan. (Place your textbook under one edge of the pan to tilt it.) Observe the results of this oblique impact.

		Diameter of Crater (cm)
1.	**small marble size (mm)**	
	crater, drop height = 50 cm	______________________
	crater, drop height = 100 cm	______________________
	crater, drop height = 150 cm	______________________
2.	**large marble size (mm)**	
	crater, drop height = 50 cm	______________________
	crater, drop height = 100 cm	______________________
	crater, drop height = 150 cm	______________________

Student Exercise

Questions: Refer to your results as well as to pp 356-357 of your text.

1. How are craters formed?

____

____

2. Many of the craters discovered on Earth are vast in size. Based on your observations, could a crater 1 km in diameter be produced by a meteorite that is 1 km in diameter? Explain your answer.

____

____

3. Based on your observations, describe a relationship between
a) the speed at which a meteorite hits an object and the size of its crater.

____

____

b) the size of a meteorite and the size of its crater.

____

____

4. a) Name two major objects in our Solar System that have numerous impact craters.

____

b) The Earth has been hit by at least as many meteorites as these two objects, but comparatively few impact craters are found on Earth. Give at least two reasons why so few are seen.

____

____

____

5. Based on your observations, try to explain why the rim of a crater is usually higher than the surrounding terrain.

____

____

Teacher Information

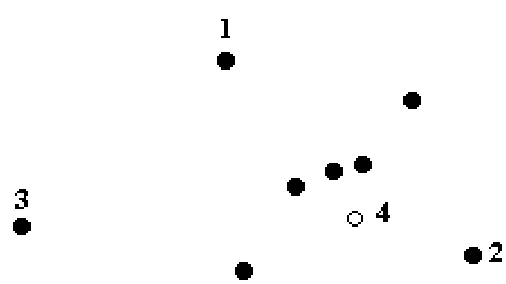
Hertzsprung-Russell Diagram

The H-R Diagram is a fundamental discovery that led to modern astronomy. Most students can understand it. All benefit from the valuable math experiences in it.

The H-R diagram compares the star's temperature to its luminosity. It is important because it shows that only a small number of star types exist, and not all possible combinations of temperature and luminosity as was previously thought. Students will be able to see from their plots that the star types cluster in separate areas on the grid. They will then be able to tell you the temperature and luminosity of each group; you can lead them to determine the size of the stars. The names are logical: Main Sequence (most stars), White Dwarfs (very hot, low luminosity), Red Giants and Super Giants (cool, very bright).

The axes on the H-R diagram are a useful math review. Ask the class what is wrong with the x-axis. (The numbers decrease to the right *backwards* and are not evenly spaced. This is because the original plot used spectral classes of stars, which is based on colour. When the colours were converted to temperature °K the result was this odd direction and numbering.) Next, ask what is odd about the y-axis? (It is logarithmic. Most students will be unfamiliar with it and will need help to plot on it.) Point out that its major divisions go up by powers of 10 – which is necessary in plotting very small to very large luminosities. You can easily help them by plotting 30, 300 and 3000 on an enlarged axis on the board.

It is important to encourage your students to turn to the sky and try to identify examples of the different star types. A good reference for you and the students is *Night Watch, An Equinox Guide to Viewing the Universe*, by Terence Dickinson published by Camden House (~$25.00). It has star charts, how to observe the night sky, planet watches and more. The star charts give a wealth of data about individual stars including distance, magnitude and type. A good place for them to start looking is at the constellation Orion (below).



1. **BETELGEUSE** (the armpit of the giant) Red Super Giant, 520 light years away
2. **RIGEL** Blue White Super Giant, 900 light years away
3. **SIRIUS** (about 2 hand spans from the belt stars) Blue White Giant, the brightest star we can see, 8.7 light years away
4. **ORION** Nebula, hazy patch to the naked eye

So why don't we see any White Dwarfs? Two reasons: none are near and they are too dim.

Student Exercise

Hertzsprung-Russell Diagram

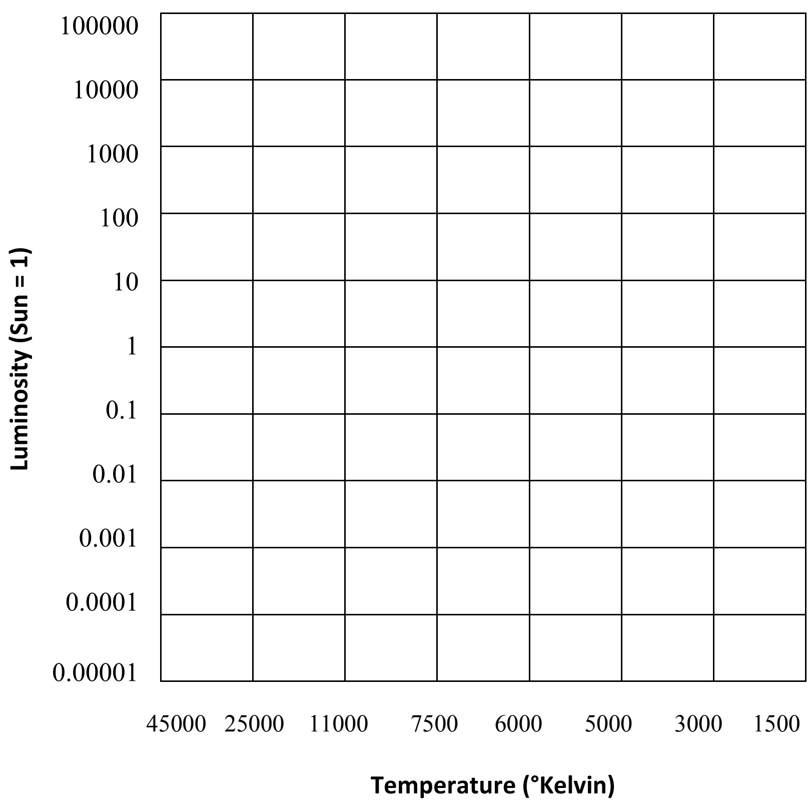
Purpose:

To study a method by which the types of stars can be determined.

In 1912, two astronomers, Hertzsprung (in Holland) and Russell (in USA), independently studied the relationship between the temperature and luminosity for a large group of stars. These properties were plotted on a graph which led to the discovery that stars exist as only a few types and not as a range of all possible combinations of temperature and luminosity. This graph became known as the H – R Diagram and a great deal of modern astronomy is based on it.

Procedures:

On the grid provided, plot the temperature and luminosity of the stars listed. Do not join the points with a line.



Student Exercise

Questions:

1. Examine the axes of the graph. How are they numbered? Is this the normal method of numbering? Why is this method used here?

2. Where is the Sun located on the graph?

3. The plotted points seem to be broken into three distinct groups. Describe each.

4. Where do most of the points fit on the graph?

5. Where is the smallest group of stars located on the graph?

6. What is the significance of the H-R Diagram to modern astronomy?

Student Exercise

Table 1

Star	Visual Magnitude	Distance (light years)	Temperature (° Kelvin)	Luminosity
Brightest Stars				
Canopus	-0.72	100.0	7,400	1500.0
Alpha Centauri A	-0.01	4.3	5,800	1.5
Arcturus	-0.06	36	4,500	110.0
Vega	+0.04	26.0	10,700	55.0
Rigel	+0.14	800.0	11,800	40,000.0
Procyon A	+0.38	11.3	6,500	7.3
Betelgeuse	+0.41	500.0	3,200	17,000.0
Achernar	+0.51	65.0	14,000	200.0
Beta Centauri	+0.63	300.0	21,000	5,000.0
Altair	+0.77	16.5	8,000	11.0
Aldebaran	+0.86	53.0	4,200	100.0
Spica	+0.91	260.0	21,000	2800.0
Antares	+0.92	400.0	3,400	5,000.0
Deneb	+1.26	1,400.0	9,900	60,000.0
Nearest Stars				
Sun	-26.7	0.00002	5,800	1.0
Alpha Centauri A	-0.01	4.3	5,800	1.5
Alpha Centauri B	+1.4	4.3	4,200	.33
Alpha Centauri C	+11.0	4.3	2,800	0.0001
Wolf 359	+13.66	7.7	2,700	0.00003
Lalande 21185	+7.47	8.1	3,200	0.0055
Sirius A	-1.43	8.7	10,400	23.0
Luyten 726-8 A	+12.5	8.7	2,700	0.00006
Ross 154	+10.6	9.6	2,800	0.00041
Epsilon Eridani	+3.73	10.8	4,500	0.30
Ross 128	+11.13	11.0	2,800	0.00054
Luyten 789-6	+12.58	11.0	2,700	0.00009
61 Cygni A	+5.19	11.1	4,200	0.084
61 Cygni B	+6.02	11.1	3,900	0.039
Procyon A	+0.38	11.3	6,500	7.3
Procyon B	+10.7	11.3	7,400	0.00055
Epsilon Indi	+4.73	11.4	4,200	0.14

Star	Visual Magnitude	Distance (light years)	Temperature (° Kelvin)	Luminosity
Other Stars				
Delta Aquarii	+3.28	84	9,400	24.0
Beta Cassiopeiae	+2.26	45	6,700	8.2
02 Eridani B	+9.5	16	11,000	0.0028
L879-14	+14.10	63?	6,300	0.00068
70 Ophiuchi A	+4.3	17	5,100	0.6
Delta Persei	+3.03	590	17,000	1,300.0
Zeta Persei A	+2.83	465	24,000	16,000.0
Tau Scorpii	+2.82	233	25,000	2,500.0
Van Maanen's Star	+12.36	14	7,500	0.00016

Teacher Information

Hubble Relation

The H-R diagram and the Hubble Relation seem like very complex concepts for Earth Science 11 and they are if you try to get the students to understand all of the ramifications of the ideas. However, they illustrate the kinds of things that can be measured from Earth and inferred from those measurements. Furthermore, they lead to the formation of modern astronomy and the theory of the formation of the Universe. Star sizes, means of energy production and possible life cycles all come from the Hubble Relation. This is a great way to get the students to think about the size of the Universe and to realize how fast the science of astronomy is changing.

Begin classroom discussion of this topic by getting the students to tell you about wavelengths and colour. Introduce the Doppler Effect by playing an audio tape of a car sounding its horn while travelling 50 km/hr towards and past the listener. The students can tell you how the wavelengths of sound change as the horn approaches and recedes (compress and stretch). Explain that Doppler used this phenomenon to calculate the speed of the source. (Radar speed traps use the Doppler Effect to compare the wavelength out and the returning wavelength to determine the speed of a car.)

Edwin Hubble saw that light from galaxies appeared redder than it should be, a phenomenon called the red shift. The students should now be able to tell you how the galaxies are moving relative to the Earth. The essential part of Hubble Relation is that all galaxies are receding and the farther ones are moving faster. This interpretation of the Hubble Relation leads to the theory of the Creation of the Universe, the Big Bang and Expansion and Contraction. (Recent studies have shown that the Hubble constant (the slope) may be incorrect and the Universe is smaller than previously thought.)

Student Exercise

Hubble Relation

Purpose:

To investigate the Hubble Relation.

In 1930, an astronomer named Edwin Hubble noticed that the spectral lines obtained from distant galaxies were shifted towards the red end of the visible spectrum. Hubble concluded that the *red shift* was caused by the galaxies receding (moving away) from the Earth at great speed. The distance to several of these *red shifted* galaxies had been found by other means. When Hubble plotted a graph of the Distances to the Galaxy compared to the amount of *red shift* (Speed of Recession), he found a simple relationship between the two quantities. (The speed of recession can be found by observing the amount of *red shift* – greater shift means higher speed.) Once the Hubble Relation of Red Shift and Speed of Recession was established, it became an easy job to find the distance to any galaxy.

Procedures:

1. Plot the following data with the Speed of Recession on the x-axis and with the Distance (from Earth) on the y-axis. Join the points with the best straight line. (The line does not have to go through each point.)

2. When you have the graph plotted use it to find the distance to the following galaxies for which only the speed of recession is known. Record the distance (ly = light-year) in the space provided.

   a. NGC 7619 - speed of recession = 3600 km/s Distance ________ ly

   b. Galaxy X - speed of recession = 54 000 km/s Distance ________ ly

Student Exercise

Data:

Galaxy	Red Shift	Speed Of Recession	Distance
Bootes Cluster	0.13%	39 000 km/s	2,600,000,000 ly*
Virgo Cluster	0.004%	1 200 km/s	30,000,000 ly
Hydra Cluster	0.20%	60 000 km/s	4,000,000,000 ly
Ursa Major	0.05%	15 000 km/s	1,000,000,000 ly
Corona Borealis	0.07%	21 000 km/s	1,400,000,000 ly

*ly = light year

Questions:

1. What causes the *red shift*?

2. What does the straight-line plot indicate about the speed of recession and the distance of a galaxy from Earth?

3. How does the speed of recession for galaxies near the Earth compare with the speed of galaxies further from the Earth?

4. What does the accuracy of the distances you found for galaxies NGC 7619 and Galaxy X depend upon?

5. Could you plot this graph if the distances to some of the galaxies were not known?

6. These galaxies are found in all directions from the Earth. All show a *red shift*. What does this mean about the Universe?

7. Describe how an astronomer could find the distance from Earth to a newly discovered galaxy.

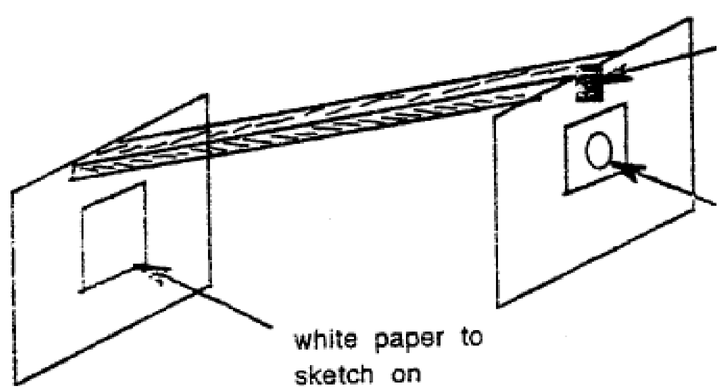
Teacher Information

Diameter of the Sun

This activity takes you and your students outside and involves them in taking some surprisingly accurate measurements with a very simple apparatus (below). Each apparatus requires:

- 1 metre stick
- 2 squares of manila tag board (file folders work) 20 cm X 20 cm, one with a 1 cm hole in the centre
- 1 rectangle of white paper about 6 cm X 8 cm
- 1 piece of aluminium foil 3 cm X 3 cm
- 15 cm of masking tape

Tape the manila tag squares to the end of the metre stick such that they hang down over both ends. Cover the hole in the tag board with the foil and poke a pin hole through the foil. (This way you can use the tag over and over again). Tape the white paper to the solid tag on the side facing the pin hole. (This prevents drawing on the tag and allows reuse.) Remove all tape when they are finished and before you store the materials for the next year's class.

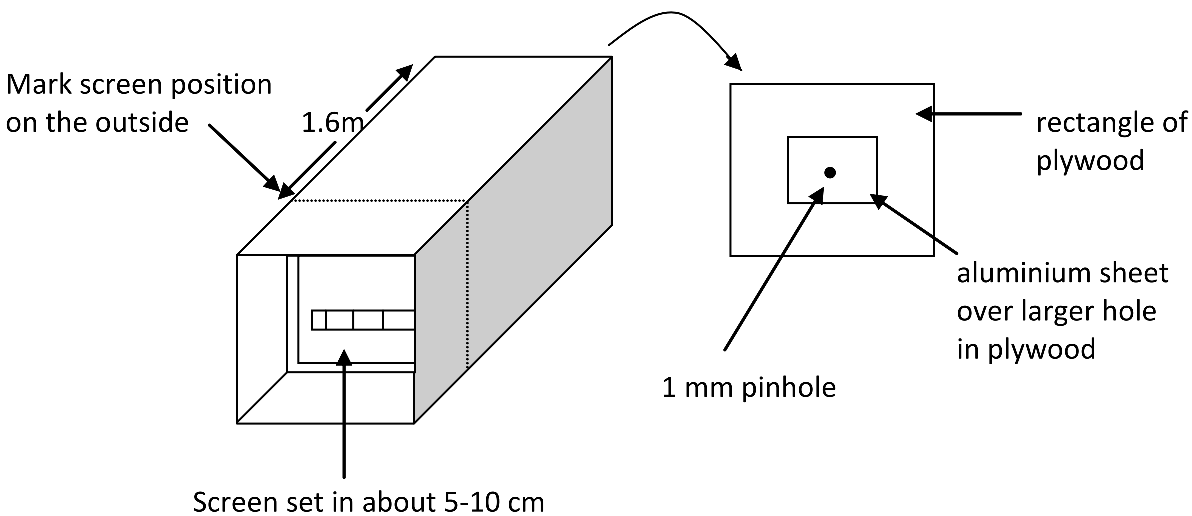


A bright sunny day is not critical. If you can see the disk of the sun in the sky, you will get an image on the paper. Dull days may require enlarging the pin hole with the tip of a pencil. Marking the image is difficult. One student should support the stick with the screen on his/her stomach. The other student can then mark the edges of the image quickly. It works best if the support doesn't breathe and the marker doesn't put his/her head in the way.

The long box (next page) can be made from any shipping container that is over 1.5 m long and has a small cross-section. (e.g. overhead projector screen boxes, 1.8 m long by 12 cm by 10 cm.) Remove one end and replace it with a square of plywood that has a 0.5 cm hole in the centre. Cover the hole with an aluminium sheet (not foil) that has a 1 mm hole in its centre. Remove the opposite end of the box and replace it with a frame of plywood covered with overhead acetate. Rub the acetate with sandpaper to frost it.

Teacher Information

Tape a section of plastic ruler to this acetate screen so the image size can be measured. Set this screen in the box at a distance of 1.6m from the pin hole. Mark the location of the screen on the outside of the box. The students are not to be told the length of the box. They must measure this length and use it in their calculation.



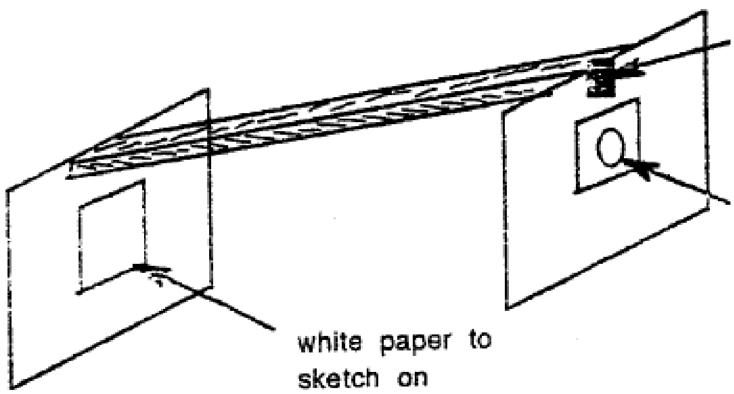
Student Exercise

Diameter of the Sun

Purpose: To measure the diameter of the Sun.

Procedures:

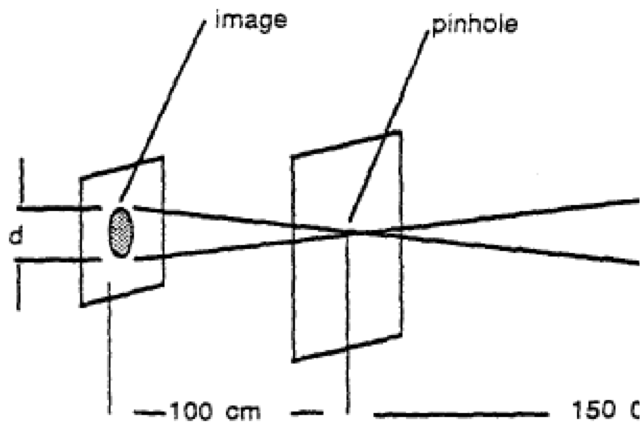
1. Assemble the metre stick apparatus as shown below. Poke a hole in the foil with a pin. (You may have to enlarge the hole with a pencil point on dull days.)



2. Carefully align the apparatus with the Sun such that the pinhole screen is nearer to the Sun. DO NOT LOOK through the hole at the Sun. Mark the diameter of at least three images on the small sheet of white paper taped to the solid screen. Calculate the average diameter of these images.

Student Exercise

3. Use the average image diameter (**d**) to calculate the diameter of the Sun (**D**) using the ratio below.



RATIO: $$\frac{d}{100\ \text{cm}} = \frac{D}{150\ 000\ 000\ \text{km}}$$ (d

4. Calculate your percentage error. $$\%\ \text{error} = \frac{\text{accepted value} - \text{calculated value}}{\text{accepted value}} \times \frac{100\ \%}{1}$$

5. Use the long box apparatus to measure the diameter of the image produced by its pinhole. Calculate the diameter of the Sun from this information. Is this method more or less accurate than the previous method?

Questions:

1. What are the sources of error in this method?

2. How could the apparatus be improved? Sketch your suggestions.

3. Could you make a permanent image of the Sun using this type of apparatus? Explain.

Teacher Information

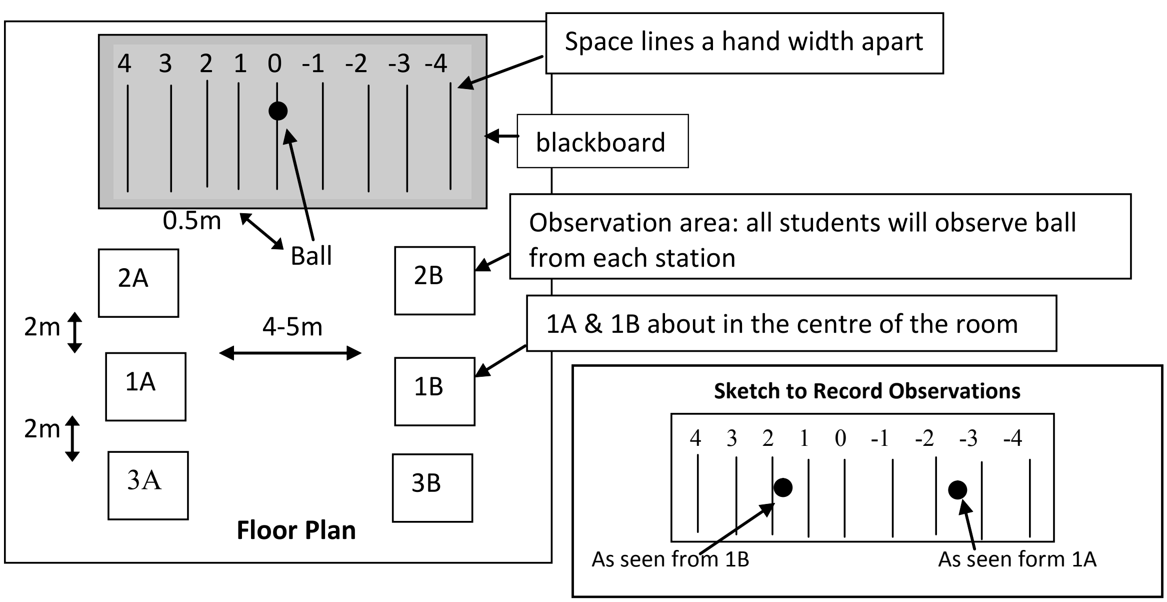
Parallax

It is important for the students to get a feeling for what parallax is and how it is used to measure (estimate) distance. The first important point is the apparent shift of the object; the second is that the observer moves to cause the shift. This exercise has evolved via experience over many years; its origin is lost from memory.

Begin the activity by asking the students to stretch one arm out in front with the thumb sticking up. Have them look at the thumb with one eye and study the background scene beyond it. Then, have them blink to the other eye several times. Ask what happens. Eventually the students will realize that the observer (their eye) is moving and this causes the apparent movement of the thumb.

The activity introduces distance as a factor affecting parallax. Classroom set-up is shown below. Position a styrofoam ball (6 cm diameter) about 0.5m from the blackboard. Mark a series of vertical lines behind the ball on the board and number them to give reference points. The students will observe and record the position of the ball, relative to the reference lines, as they stand in each of the position (1A, 1B, 2A, 2B etc.). (Label the observation areas and demonstrate how to observe to help the students get started.) Ask the students to report their results with a sketch (see below) showing the positions the ball appears to be in.

The idea the students should be able to report is that close objects show little shift and distant objects show a greater shift. In the universe, the amount of parallax (shift) displayed by a celestial object, as seen by an observer on Earth as it moves in its orbit, can be used to calculate the distance to the object.



Student Exercise

Parallax

Purpose: To study one method of measuring distances to distant objects.

Procedures:

1) a) Begin at Position 1A in the classroom. Sight at the ball using one eye only. Make a **sketch** of its apparent position relative to the marked wall behind it.

   b) Move to Position 2B. Repeat the procedures above. What changed from one side of the room to the other? Record your observations on the same **sketch**.

2) Move 2 metres closer to the ball (2A, 2B) and repeat Procedure l a and b. Make sketches each time. What changes have occurred from Procedure 1?

3) Move 2 metres back from the original position (3A, 3B) and repeat Procedure l a and b. What is the difference this time?

4) The ball will be moved closer to the wall. Stand as far back from the ball as you can and repeat Procedures l a and b.

   Summarize your observations in one or two sentences as to what appears to happen to the ball as you, the observer, are closer or farther from the ball.

Questions:

1. In which position of observation of the ball - 1, 2, 3, or 4 was the apparent shift in position the greatest? the least?

2. Define parallax.

3. Would parallax be most useful to measure distances to objects that are near or far away? Explain your answer.

4. Draw another sketch, as though you were looking down on the room, to show why the apparent shift is noticed in Procedure 1.

5. How could distances to stars be measured using parallax? Hint: Think about how the Earth moves around the sun.

Mars' Path

The Earth-centered versus Sun-centered debate on the configuration of the Solar System is long settled. Students are able to draw the Solar System; some will be able to name the planets in order. This exercise gives the students a feeling for the puzzling movements of the planets and the problems of trying to understand their motion while inside the system. This is excellent preparation for the next activity on Kepler's laws. The history of the ideas and the personalities who contributed them are important and interesting to cover.

300 BC - Aristarchus	- stated the Earth moved
140 BC - Ptolemy	- stated that the system is Earth centered - thought the Earth too large to move - was believed for 1400 years
1543 AD - Copernicus	- stated the Sun does not move - did not publish his ideas to avoid persecution
1580 AD - Brahe	- took and recorded volumes of measurements of sky motions - did not analyze measurements - had a silver nose, lost nose in a duel over math - died in 1601 of burst bladder; did not like to miss drinking parties
1633 AD - Galileo	- developed telescope (previously invented by someone else) - observed phases of Venus and set out to explain them - stated the system was Sun-centered and all planets orbited the Sun
1610 AD - Kepler	- student of Brahe - used Brahe's record s to show the shape of the orbits - formulated the three Laws of Planetary Motion - did not enter the Sun-centered debate but was in contact with others
1700 AD - Newton	- formulated the Law of Universal Gravitation - explained Kepler's Laws

The Mars' Path exercise is straightforward, but introduces new astronomical measurements. Carefully explain the co-ordinates (RA,D) on the grid. Ask the students what is unusual about the numbering of the axis. Be prepared for difficulty sketching the Earth-centered Solar System.

Student Exercise

Mars' Path

Purpose:

To investigate the path followed by Mars across the night sky and explain that path using two possible models for the Solar System.

Procedures:

1. Plot the data given on the grid provided. You do not need to label the points. The first position is plotted for you. **Declination** measures the angle north or south of the celestial equator. **Right ascension** measures the angle east from the Vernal Equinox. Join the points as you progress. You do not need to label the points.

Questions:

1. Is the graph a straight line? Describe it.

2. Are the points on the line always the same distance apart? Explain.

3. How much time is represented by the data? How much would you expect to see the position of Mars change from one night to the next?

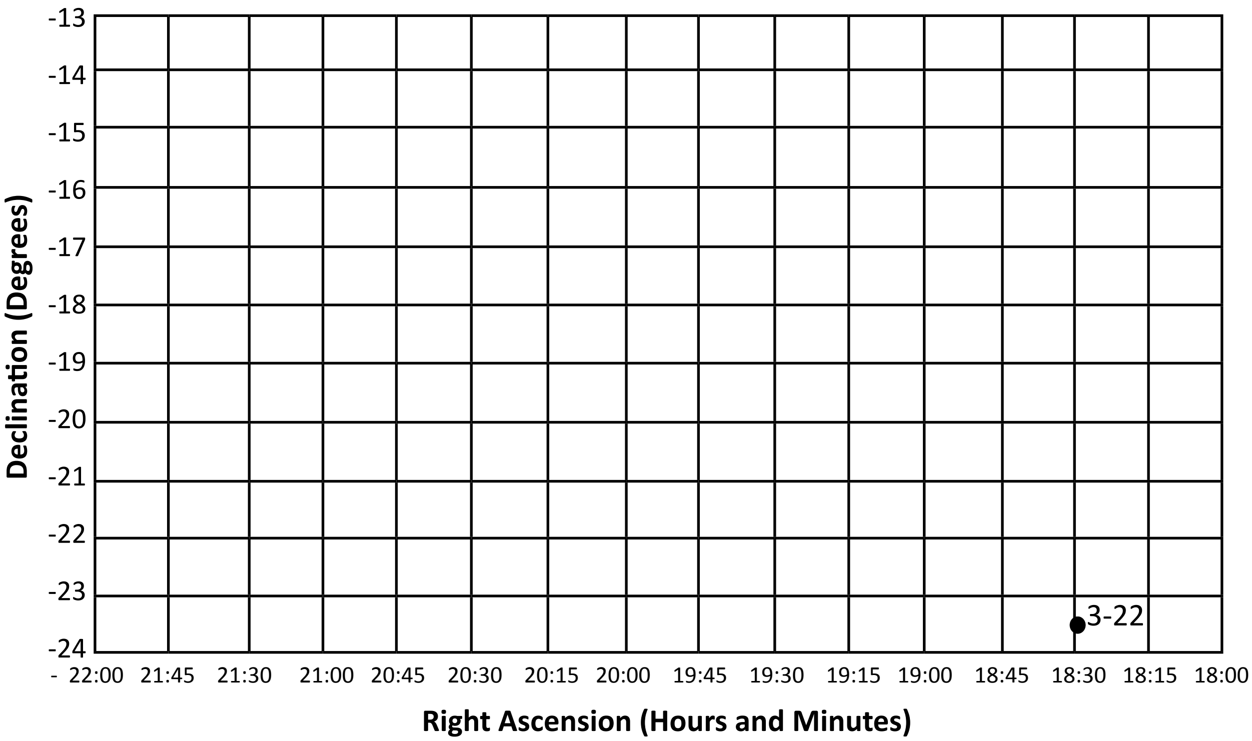
4. Draw a diagram to show what type of orbit Mars would have to travel to produce the path plotted on the graph if the Earth were the center of the Solar System and the Sun and Mars travelled around it.

5. Draw a diagram to show the true relation between the Sun, Earth and Mars as they orbit in the Solar System. What causes the loop seen in Mars' orbit?

6. The apparent motion shown by Mars is called *retrograde motion*. What does this term mean?

Student Exercise

Mars' Positions in the Sky (March-October, 1971)



Mars' Celestial Position Data (March-October, 1971)

Date	Right ascension		Declination		Date	Right ascension		Declination	
	Hours	Minutes	Degrees	Minutes		Hours	Minutes	Degrees	Minutes
Mar.22	18	25	- 23	34	July 21	21	43	- 20	11
Apr.1	18	51	- 23	24	July 31	21	37	- 21	13
Apr.11	19	16	- 23	02	Aug.12	21	25	- 22	28
Apr.21	19	40	- 22	30	Aug.21	21	16	- 22	57
May 1	20	04	- 21	50	Aug.31	21	08	- 23	05
May 11	20	26	- 21	06	Sept.5	21	05	- 22	56
May 22	20	48	- 20	16	Sept.25	21	09	- 21	13
June 1	21	06	-19	36	Oct.6	21	20	- 19	34
June 11	21	21	- 19	06	Oct.11	21	26	- 18	49
June 21	21	33	- 18	50	Oct.21	21	41	- 16	58
July 1	21	41	- 18	54	Oct.31	21	59	- 14	52
July 11	21	45	- 19	22					

Kepler's Laws of Planetary Motion

These exercises introduce the students to Kepler's Laws and give them necessary background for later study of seasons. The first exercise deals with Kepler's first and second laws; the second exercise examines Kepler's third law.

Kepler's First Law (Part A) is demonstrated by drawing ellipses to determine what controls their shape. You must acquire:

1. a class-size set square tack board or ceiling tiles (~30 cm X 30 cm) into which pins can be easily pushed
2. inexpensive sewing thread.

You must explain to them the foci and where the Sun is in the resulting sketches. They should be able to tell you what makes the ellipse more or less elliptical.

The Second Law, Part B of this activity, is a demonstration that requires some set up time and practice (by the teacher) before class begins. Suspend a 3 cm diameter steel ball from the ceiling. (Borrow or steal the ball from the Physics Department.) Clamp one end of a strong bar magnet to a ring stand. Position the ball level with the top of the magnet. Move the ring stand so that the magnet is about 10 cm out of line with plumb. It works best if the magnet is not centered. Swing the ball away from the magnet and direct it in an orbit around the magnet. As the orbit decays, you will see the ball speed up as it nears the magnet and change its direction sharply. It takes several minutes for the orbit to decay to the point where the ball is captured by the magnet.

Part C involves calculating data to complete a table and plotting a graph that proves Kepler's Third Law. Explain squaring and cubing as required and remind them to consistently use years (not days) for plotting the period. The graph will remind them of The H-R diagram, as they will have to use logarithmic scales on both axes. Those students taking Math 11 should be able to recognize *direct variation* between the data.

Teaching the formal language of Kepler's Laws is fun. Explain to them that Kepler wrote as he did because the math was not yet available to express the Laws more clearly (especially the Second Law).

Bonus mark question: What was Kepler's first name? Super bonus mark question: What was Kepler's Fourth Law? (It is actually Mrs. Kepler's Law: wash your hands before eating!)

Student Exercise

Kepler's Laws of Planetary Motion

Part A. The First Law

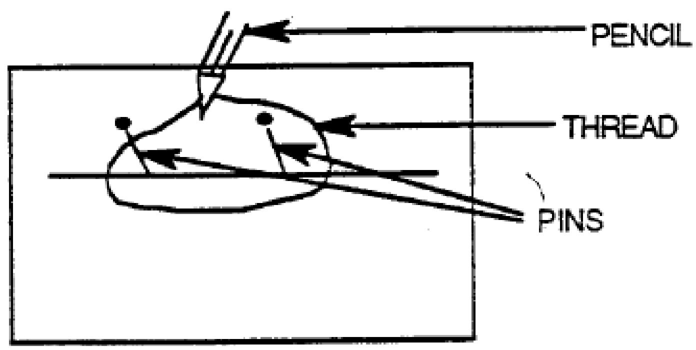
Purpose: To investigate the properties of ellipses.

Procedures:

1. Knot the ends of a length of thread to make a loop about this long.

2. Draw a line down the center of a piece of plain paper from top to bottom.

3. Stick two pins on the line (approx. 5 cm apart) and through the paper into a tile. Loop the thread over pins. Use a pencil to pull the thread out to one side to form a triangle.



4. Pull the pencil outwards to keep the thread tight and move the pencil around the pins drawing a line. You will have produced an ellipse.

5. What happens to the shape of the ellipse if:
   (a) you move the pins farther apart?
   (b) you move the pins closer together?
   (c) both pins are in the same place?

Student Exercise

Questions:

1. What part of the ellipse do the pins represent?

2. What controls the shape of the ellipse?

3. If the ellipses you have drawn represent the orbits of planets, where is the Sun and what could represent the planet?

Part B. The Second Law

Purpose: To investigate the speed of an object orbiting another in an elliptical path.

Procedures: Observe the apparatus as demonstrated by the teacher.

Questions:

1. Is the speed constant around the orbit? If not, describe how it changes.

2. When would the speed of a planet orbiting the Sun be the greatest? When would the speed be the least?

3. Explain why a planet's speed changes as it orbits the Sun.

4. Think of our seasons here. Which one lasts the longest? Based on this information, when is Earth closest to the Sun?

Student Exercise

Part C. The Third Law

Purpose: To verify Kepler's Third Law of Planetary Motion.

Procedures: Kepler's Third Law can be stated as: $\mathbf{p^2 = d^3}$
where **p** is the period of revolution of the planet about the Sun measured in Earth years, and **d** is the average distance from the Sun to the planet measured in Astronomical Units, A.U.
(1 A.U. = the average distance from the Sun to the Earth = 150,000,000 km.)

1. Use the following data to complete the table

Planet	Distance (in A.U.)	Period	d^3	p^2
Mercury	0.4	88 days		
Venus	0.7	225 days		
Earth	1.0	1 year		
Mars	1.5	1.88 years		
Jupiter	5.2	12 years		
Saturn	9.5	29.5 years		
Uranus	19.2	84 years		
Neptune	30.1	164 years		
Pluto	39.5	247 years		

2. Plot a graph with d^3 on the x-axis and p^2 on the y-axis. Look carefully at the size of the numbers you must plot **before** you number the axes. Is their range such that you can use the normal method of numbering? Use whatever system of numbering that you think is appropriate.

Questions:

1. What shape is the graph? What does this shape indicate?

2. What happens to the length of a planet's year the farther it is from the Sun?

3. Is the Earth always the same distance from the Sun? Why must this distance always be changing?

4. According to Kepler's Second Law, what must happen to the Earth's orbital speed as it travels around the Sun?

Solar System Model

Here is another chance to get out of the classroom, outdoors maybe, or at least in a long hallway. The model is based on 1 A.U. = 10 feet and planet sizes of

Sun	1" brass ball
Mercury, Mars, Pluto	knot in sewing thread
Earth, Venus	knot in string
Neptune, Uranus	knot in heavy string
Jupiter, Saturn	ball of plasticine (1 cm)

If you punch holes in recipe cards, tie the strings to them and label the cards, you will have a set to save from year to year. Start with the Sun at one end of the hall (parking lot, sidewalk, freeway centre line or whatever you can use). The model takes about 400 ft if you want to get to where Pluto is most of the time. The nearest star is 500 miles away. Have one student hold the end of a 100 foot tape (available from your Physics or PE department) and ask another student to reel the tape out to full length. You and the class can then move down the tape, placing cards in the appropriate spots and commenting on the planet. When you get to the end of the tape have the tape person pull it out another length and away you go again.

One variation would be to have groups of students research each planet and find the distance in A.U.s, the diameter, number of moons, etc., and present them to the class as you move down the model. This approach will make the learning theirs.

The model on adding machine tape is done by each student as an exercise in math, measurement and scales. Each student requires 2 metres of tape. Have them convert the distance in kilometres to A.U.s as math practice. Show those students who have not seen it yet, the memory function of the calculator. These paper models are easy to mark. You will quickly find which planet arrives at your nose after one arm length pull! Just make sure they put their names on the **outside** of the roll for ease of recording.

Student Exercise

Solar System Model

Purpose: To make a scale model of the Solar System.

Procedures:

1. Use the table on Page 489 of "Focus on Earth Science" (or suitable reference table that does not give the distance in A.U.) to calculate the mean distance to each planet from the Sun in A.U.s. (Divide the distance from the planet to the Sun in kms by the distance from Earth to the Sun in kms.) Round off to 2 decimal places.

   Display your data in a table of your own design.

2. Using a scale of 5 cm = 1 A.U., mark the Sun at one end of the 2m strip of adding machine tape. Plot the radii (distance from the Sun to the planet) of the planets' orbits. Label each orbit and note the periods of rotation and revolution of each near the orbit.

   Could you draw circles to represent the planets using the same scale?

3. Write your name on the **outside end** of the strip of tape when you hand it in.

Questions:

1. Are the planets evenly spread through the Solar System? What two groups can they be divided into?

2. The distances used are called **mean** distances. What does the word **mean** mean in this use? Explain why the planets have a mean distance to the Sun.

3. Pluto is sometimes closer to the Sun than Neptune. What does this mean about Pluto's orbit?

4. How long, in Earth years, is Pluto's year? What fraction of its year has Pluto gone through in your lifetime?

5. Which planet has the shortest day, that is, the fastest rotation? How many of its days would it have in its year?

6. Which planet has the longest day, that is, the slowest rotation?

Teacher Information

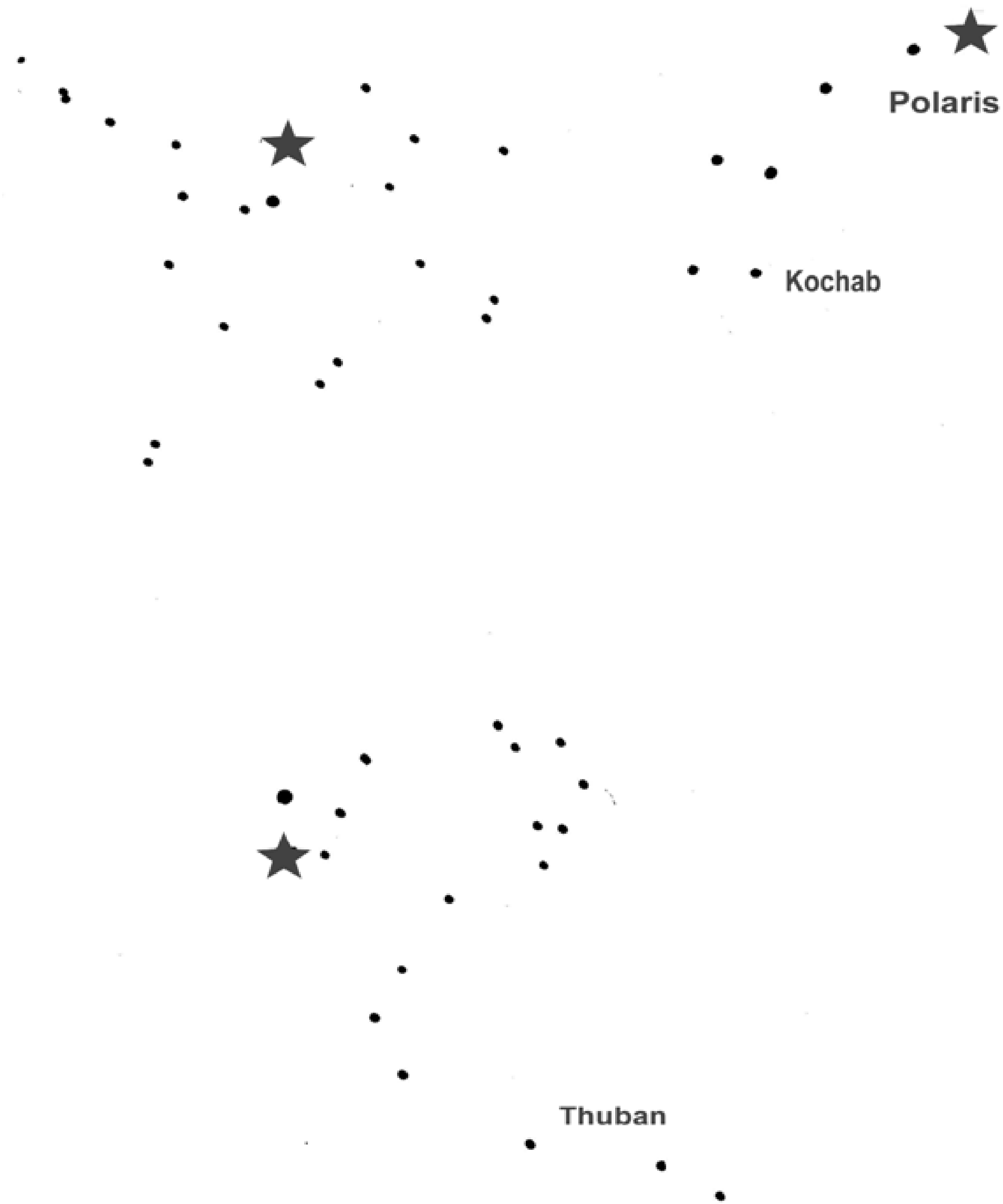
Constellations

This activity involves the students in creating their own constellations and associated mythology from a simple ink splatter pattern. It nicely follows the discussion of stars and galaxies in Chapter 21 of *Earth Science*. Just as important is the opportunity for students to exercise the right side of the brain to be creative and have fun!

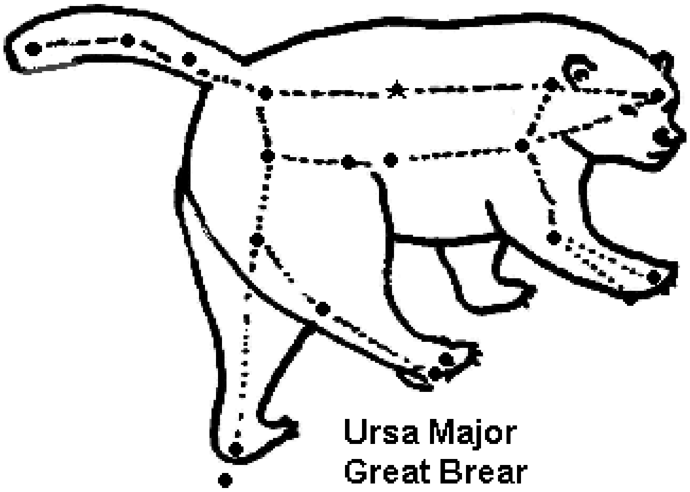
Introduce the activity by showing your students an overhead of a familiar star pattern and ask them to figure out the constellation or make some interpretation of the dots (I-2). When the guessing ends, place an overlay over the stars to show the ancients' interpretation of the star pattern (I-3). A reference from which a passage may be read aloud is Roy A. Gallant's book "The Constellations - How They Came to Be" (Four Winds Press). It is an excellent source for the legends behind many of the familiar constellations and also includes some amazing sky interpretations of the North American Indians, Mayans and Polynesians - many of which parallel their Greek and Roman counterparts! Some of the most amusing and interesting myths are those for Ursa Minor/Major, Cassiopeia, Cepheus, Draco and Cetus.

Provide each student with a photocopy of a simple splatter pattern of Indian Ink on an 8 ½ by 11" paper. An example is shown on I-5. The assignment maybe started in class, but works very well as a take home assignment. This will allow the students to access other resources and give them time to create their myths. Submissions must be appropriate; bonus marks are offered for effort and creativity.

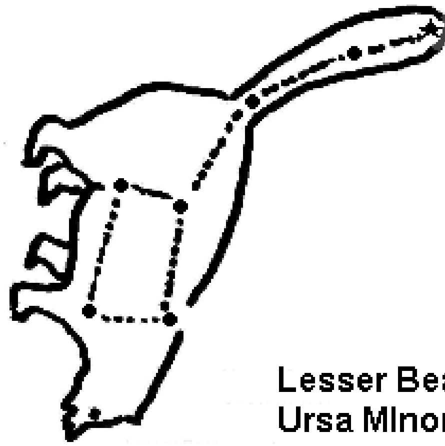
Constellations



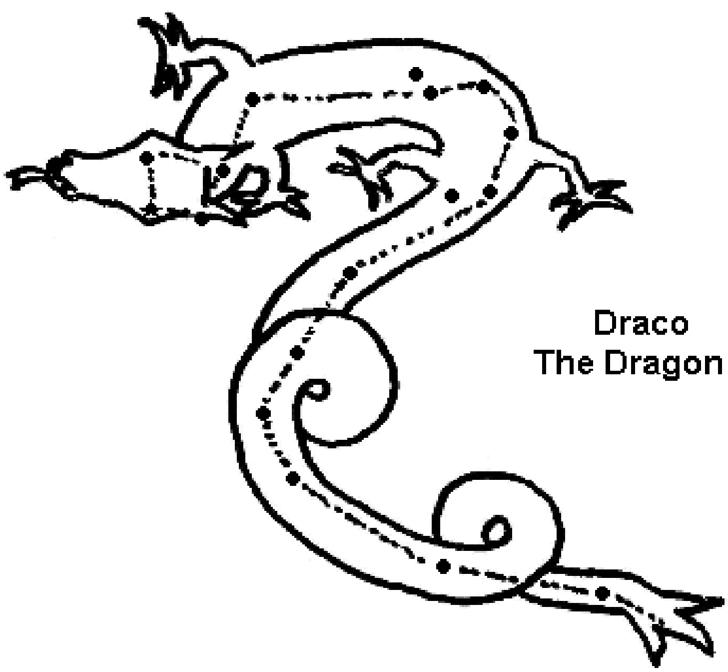
Constellations



Ursa Major
Great Brear



Lesser Bear
Ursa MInor



Draco
The Dragon

mineralsed
Mineral Resources Education Program of BC

Student Exercise

Name: ______________________________________Block: ___________Due Date:__________

Constellations

Rules

1. This sheet must be handed in with the assignment.

2. Use the sheet handed out to you, to design your own constellation. You may connect the dots, but you must also draw a picture of your constellation. Be creative! Effort and imagination will be rewarded with bonus marks.

3. Submit a one hundred to two hundred word story describing the origin of each constellation you create.

4. Name and describe 8 stars, 4 planets and a galaxy.

5. The assignment is worth 30 marks. 10% per day will be deducted for any late submissions.

Have fun --- be creative!

Constellations

Teacher Information

Sun's Apparent Path

This activity demonstrates how the motion of the Earth causes the apparent path of the Sun to vary throughout the year at different latitudes. It ties in naturally to a variety of related topics (e.g. latitude and longitude, seasons, the nature of weather, and differences in biospheric heating) and helps develop the students' plotting and graphing skills.

The activity requires approximately one hour to introduce, complete questions and wrap up. You should provide your students with graph paper.

Student Exercise

Sun's Apparent Path

Purpose: To determine how the motion of the Earth about the Sun causes the apparent path of the Sun to vary throughout the year at different latitudes.

Procedure:

1. Examine the data in Table 1 (below) which shows solar altitude data for three locations in the northern hemisphere over a one year period.
2. Plot a graph of **Maximum Daily Solar Altitude** (y-axis) vs. **Date** (x-axis) for the Equatorial (0° Latitude) location. The y-axis scale should extend from 0º to 90º. Connect these points freehand using a **blue** marker.
3. Repeat Procedure 2 for the Houston (30° Latitude) and Vancouver (49 º Latitude) data. Draw the Houston line in **red** and the Vancouver line in **black**.

Table 1: Maximum Daily Noontime Solar Altitude (in degrees above the horizon)

Date	**0° Latitude** (Equator)	**30o Latitude** (Houston, TX)	**49o Latitude** (Vancouver, BC)
Jan. 1	66.3	36.3	17.3
Jan. 20	69.2	39.2	20.2
Feb. 10	74.9	44.9	25.9
Mar. 1	82.0	52.0	33.0
Mar. 20	90.0	60.0	41.0
Apr. 10	82.0	67.1	48.1
Apr. 30	76.0	74.0	55.1
May 20	70.7	79.3	60.3
June 10	67.5	82.5	63.5
June 30	67.3	82.7	63.7
July 20	68.7	80.3	61.3
Aug. 10	74.7	75.3	56.3
Aug. 30	81.2	68.8	49.8
Sept. 20	89.0	61.0	42.0
Oct. 10	83.2	53.2	34.2
Oct. 30	76.0	46.0	27.0
Nov. 20	70.0	40.0	21.0
Dec. 10	66.7	36.7	17.7
Dec. 30	66.3	36.3	17.3

Student Exercise

Questions:

Refer to the blue Equatorial Latitude line on your graph for questions 1 and 2.

1. a) During what date(s) is the Sun highest in the sky?

____

b) For the date(s) you have listed, what is the Sun's position in the sky?

____

2. During which date(s) is the Sun lowest in the noon sky? Hint: Refer to Figure 25.5, p. 385 of the text.

____

3. What happens to the noontime (maximum) altitude of the Sun at Houston and Vancouver, as the year progresses from January through December?

____

4. a) What are the dates of maximum and minimum noontime altitude for both Houston and Vancouver?

____

b) Does the Sun ever pass directly overhead for these two latitudes (Houston, Vancouver)? Explain your answer.

____

Table 2: Path Length (in degrees of arc) **and Duration of Daylight** (in hours)

Date	**0° Latitude** (Equator)		**30° Latitude** (Houston, TX)		**49° Latitude** (Vancouver)	
	Path	**Duration**	**Path**	**Duration**	**Path**	**Duration**
Mar 21	180	12.0	180	12.0	180	12.0
Jun 21	180	12.0	205	13.7	245	16.3
Sep 21	180	12.0	180	12.0	180	12.0
Dec 21	180	12.0	155	10.3	115	17.7

Refer to Table 2 for questions 5-8

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Student Exercise

5. On which date(s) is the duration of daylight period 12 hours for
   a) the equator?____
   b) Houston? ____
   c) Vancouver? ____

6. During which months of the year is the duration of daylight greater than 12 hours for
   a) the equator?____
   b) Houston?____
   c) Vancouver? ____

7. During which months of the year is the duration of daylight less than 12 hours for
   a) the equator? ____
   b) Houston? ____
   c) Vancouver? ____

8. Which one of three locations sees the most sunlight on
   a) March 21? ____________________ b) June 21? __________________________
   c) September 21? _________________ d) December 21? _____________________

9. a) What is the longest day of the year in the northern hemisphere? (See p. 385, Fig. 25.5.)

   ____

   b) On this date, where on the Earth is the Sun directly overhead at noon?

   ____

10. Refer back to the March 20 data in Table 1. Examine the data carefully and predict the noontime altitude of the Sun at latitude

    a) 60° ______________________ b) 90° (North Pole) ______________________

Teacher Information

Sun's Apparent Path

Few topics in Earth Science capture the imagination of the students, as does Astronomy. Its combination of mystery and technology is alluring to most. The following activities compliment the information provided in the text. They may be used as an introductory exercise or for review of previously learned material.

"Planet Quest" is a two part activity designed to get your students out of their seats and learn about relative sizes and distances in our Solar System. The first part involves the students (either working in pairs or small groups) locating and identifying their mystery object from data that you provide them in an envelope. Situated on a playing field near school, the students must determine which celestial body they are, and where they are located with respect to other Solar System bodies. Part two of the assignment requires each pair of students to prepare a mission report describing the details of their planet, asteroid, comet or other celestial body.

Before starting the activity the teacher must:

1) divide the students into groups.
2) place 11 mission specifications in manila envelopes.
3) construct a box with (scale) models of planets, comets, asteroids, etc.
4) obtain additional paper for the scale drawings of the Solar System.

Student Exercise

Planet Quest

In this exercise you will form one of the “pieces of the puzzle" in a quest for the planets and other bodies in the Solar System.

You will not be told who you are but will be provided with characteristics of a component of our Solar System.

Your Mission:

To correctly identify yourself as member of the Solar System and to determine your role and position in relation to other members.

Mission Specifications:

You will be working with a partner throughout this exercise. Together it is your job to follow the procedure and clues to eventually identify and find the position of the planet or body in question.

Select a partner before opening the envelope.

Student Exercise

Planet Quest

Mission Specifications

You have selected a partner and are prepared to embark on a mission to seek the identity and location of one member of our Solar System. Follow the teacher's instructions carefully and consider the facts provided in the table below.

A scale model of our Solar System will be constructed from your astronomical data on the athletic field near school. The Sun will be located at one end of the field. Each class team has received an envelope with different data and will work independently. When you have identified your celestial body and its relative position, go to the box containing models of each Solar System member and place the model on the athletic field in the appropriate position (refer to **Distance from Sun** in the Table below).

On the blank sheet of paper provided, draw a model of the Solar System labelling all members and their distances.

Distance from Sun	**5m**
Number fitting across Sun's equator	**100**
Mass (Earth = 1)	**1**
Density	**5.43g/cm3**
Atmosphere	**nitrogen/oxygen**
Average surface temperature	**-85o to 65oC**
Average day (Earth = 1)	**23h 56min 4sec**
Time for revolution around Sun	**365.26 days**
Interesting feature	**71% water; supports life**

Who Are You?

What Is Your Position?

Student Exercise

Planet Quest

Mission Specifications

You have selected a partner and are prepared to embark on a mission to seek the identity and location of one member of our Solar System. Follow the teacher's instructions carefully and consider the facts provided in the table below.

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On the blank sheet of paper provided, draw a model of the Solar System labelling all members and their distances.

Distance from Sun	**1.85m**
Number fitting across Sun's equator	**380**
Mass (Earth = 1)	**0.055**
Density	**5.43g/cm3**
Atmosphere	**None**
Average surface temperature	**-180o to 426oC**
Average day (Earth = 1)	**59 days**
Time for revolution around Sun	**88 days**
Interesting feature	**Sun rises once every 2 months!**

Who Are You?

What Is Your Position?

Student Exercise

Planet Quest

Mission Specifications

You have selected a partner and are prepared to embark on a mission to seek the identity and location of one member of our Solar System. Follow the teacher's instructions carefully and consider the facts provided in the table below.

A scale model of our Solar System will be constructed from your astronomical data on the athletic field near school. The Sun will be located at one end of the field. Each class team has received an envelope with different data and will work independently. When you have identified your celestial body and its relative position, go to the box containing models of each Solar System member and place the model on the athletic field in the appropriate position (refer to **Distance from Sun** in the Table below).

On the blank sheet of paper provided, draw a model of the Solar System labelling all members and their distances.

Distance from Sun	**3.55m**
Number fitting across Sun's equator	**110**
Mass (Earth = 1)	**0.82**
Density	**5.24g/cm3**
Atmosphere	**Carbon dioxide (CO2)**
Average surface temperature	**470oC**
Average day (Earth = 1)	**243 days**
Time for revolution around Sun	**224.7 days**
Interesting feature	**Runaway greenhouse effect**

Who Are You?

What Is Your Position?

Student Exercise

Planet Quest

Mission Specifications

You have selected a partner and are prepared to embark on a mission to seek the identity and location of one member of our Solar System. Follow the teacher's instructions carefully and consider the facts provided in the table below.

A scale model of our Solar System will be constructed from your astronomical data on the athletic field near school. The Sun will be located at one end of the field. Each class team has received an envelope with different data and will work independently. When you have identified your celestial body and its relative position, go to the box containing models of each Solar System member and place the model on the athletic field in the appropriate position (refer to **Distance from Sun** in the Table below).

On the blank sheet of paper provided, draw a model of the Solar System labelling all members and their distances.

Distance from Sun	**7.5m**
Number fitting across Sun's equator	**190**
Mass (Earth = 1)	**0.11**
Density	**3.94g/cm3**
Atmosphere	**CO2 / argon / nitrogen**
Average surface temperature	**-120 to 30oC**
Average day (Earth = 1)	**24h 37min 23sec**
Time for revolution around Sun	**687 days**
Interesting feature	**Frozen ice caps; once thought to have life**

Who Are You?

What Is Your Position?

Student Exercise

Planet Quest

Mission Specifications

You have selected a partner and are prepared to embark on a mission to seek the identity and location of one member of our Solar System. Follow the teacher's instructions carefully and consider the facts provided in the table below.

A scale model of our Solar System will be constructed from your astronomical data on the athletic field near school. The Sun will be located at one end of the field. Each class team has received an envelope with different data and will work independently. When you have identified your celestial body and its relative position, go to the box containing models of each Solar System member and place the model on the athletic field in the appropriate position (refer to **Distance from Sun** in the Table below).

On the blank sheet of paper provided, draw a model of the Solar System labelling all members and their distances.

Distance from Sun	**25.9m**
Number fitting across Sun's equator	**9**
Mass (Earth = 1)	**317.8**
Density	**1.33g/cm3**
Atmosphere	**hydrogen / helium**
Average surface temperature	**-140oC**
Average day (Earth = 1)	**9h 50min 30sec**
Time for revolution around Sun	**11.86 Earth years**
Interesting feature	**Releases more energy than receives from Sun; large magnetic storms, largest is red**

Who Are You?

What Is Your Position?

Student Exercise

Planet Quest

Mission Specifications

You have selected a partner and are prepared to embark on a mission to seek the identity and location of one member of our Solar System. Follow the teacher's instructions carefully and consider the facts provided in the table below.

A scale model of our Solar System will be constructed from your astronomical data on the athletic field near school. The Sun will be located at one end of the field. Each class team has received an envelope with different data and will work independently. When you have identified your celestial body and its relative position, go to the box containing models of each Solar System member and place the model on the athletic field in the appropriate position (refer to **Distance from Sun** in the Table below).

On the blank sheet of paper provided, draw a model of the Solar System labelling all members and their distances.

Distance from Sun	**47.35m**
Number fitting across Sun's equator	**11**
Mass (Earth = 1)	**95.2**
Density	**0.70g/cm3**
Atmosphere	**hydrogen / helium / methane**
Average surface temperature	**-170oC**
Average day (Earth = 1)	**10h 14min 0sec**
Time for revolution around Sun	**29.46 Earth years**
Interesting feature	**Ring feature surrounding equator; large moon with nitrogen atmosphere**

Who Are You?

What Is Your Position?

Student Exercise

Planet Quest

Mission Specifications

You have selected a partner and are prepared to embark on a mission to seek the identity and location of one member of our Solar System. Follow the teacher's instructions carefully and consider the facts provided in the table below.

A scale model of our Solar System will be constructed from your astronomical data on the athletic field near school. The Sun will be located at one end of the field. Each class team has received an envelope with different data and will work independently. When you have identified your celestial body and its relative position, go to the box containing models of each Solar System member and place the model on the athletic field in the appropriate position (refer to **Distance from Sun** in the Table below).

On the blank sheet of paper provided, draw a model of the Solar System labelling all members and their distances.

Distance from Sun	**95.05m**
Number fitting across Sun's equator	**37**
Mass (Earth = 1)	**14.5**
Density	**1.30g/cm3**
Atmosphere	**hydrogen / helium / methane**
Average surface temperature	**-210oC**
Average day (Earth = 1)	**17h 0min 0sec**
Time for revolution around Sun	**84.01 Earth years**
Interesting feature	**Rotates on its side**

Who Are You?

What Is Your Position?

Student Exercise

Planet Quest

Mission Specifications

You have selected a partner and are prepared to embark on a mission to seek the identity and location of one member of our Solar System. Follow the teacher's instructions carefully and consider the facts provided in the table below.

A scale model of our Solar System will be constructed from your astronomical data on the athletic field near school. The Sun will be located at one end of the field. Each class team has received an envelope with different data and will work independently. When you have identified your celestial body and its relative position, go to the box containing models of each Solar System member and place the model on the athletic field in the appropriate position (refer to **Distance from Sun** in the Table below).

On the blank sheet of paper provided, draw a model of the Solar System labelling all members and their distances.

Distance from Sun	**197.15m**
Number fitting across Sun's equator	**500**
Mass (Earth = 1)	**0.003**
Density	**1.1 ?g/cm3**
Atmosphere	**None**
Average surface temperature	**-230oC**
Average day (Earth = 1)	**6 days 9 hours**
Time for revolution around Sun	**247.7 Earth years**
Interesting feature	**Believed to be an escaped moon of Neptune; has one accompanying moon**

Who Are You?

What Is Your Position?

Student Exercise

Planet Quest

Mission Specifications

You have selected a partner and are prepared to embark on a mission to seek the identity and location of one member of our Solar System. Follow the teacher's instructions carefully and consider the facts provided in the table below.

A scale model of our Solar System will be constructed from your astronomical data on the athletic field near school. The Sun will be located at one end of the field. Each class team has received an envelope with different data and will work independently. When you have identified your celestial body and its relative position, go to the box containing models of each Solar System member and place the model on the athletic field in the appropriate position (refer to **Distance from Sun** in the Table below).

On the blank sheet of paper provided, draw a model of the Solar System labelling all members and their distances.

Distance from Sun	**7.5 to 25.9m**
Number fitting across Sun's equator	**Variable sizes**
Mass (Earth = 1)	**Largest about 400 km in diameter**
Density	**Mostly rocky material**
Atmosphere	**None**
Average surface temperature	**-250°C**
Average day (Earth = 1)	**----**
Time for revolution around Sun	**Approx. 5 Earth years**
Interesting feature	**Believed to be fragments of a planet ripped apart by Jupiter's gravity or fragments that never formed a planet**

Who Are You?

What Is Your Position?

Student Exercise

Planet Quest

Mission Specifications

You have selected a partner and are prepared to embark on a mission to seek the identity and location of one member of our Solar System. Follow the teacher's instructions carefully and consider the facts provided in the table below.

A scale model of our Solar System will be constructed from your astronomical data on the athletic field near school. The Sun will be located at one end of the field. Each class team has received an envelope with different data and will work independently. When you have identified your celestial body and its relative position, go to the box containing models of each Solar System member and place the model on the athletic field in the appropriate position (refer to **Distance from Sun** in the Table below).

On the blank sheet of paper provided, draw a model of the Solar System labelling all members and their distances.

Distance from Sun	**Large, elliptical orbit**
Number fitting across Sun's equator	**Nucleus a few km across**
Mass (Earth = 1)	**Mass unknown**
Density	**Dry ice / dust / rocks**
Atmosphere	**Long dusty tail**
Average surface temperature	**NA**
Average day (Earth = 1)	**NA**
Time for revolution around Sun	**Each has a unique period**
Interesting feature	**Most famous spectacle orbits the Sun every 76 years; formed beyond the last planet in region called the Oort Cloud**

Who Are You?

What Is Your Position?

Student Exercise

Planet Quest

Mission Report

Research

You have completed a successful mission and have returned to Earth unharmed. Your task now is to report your findings to the public. In order to do this, your mission commanders (Mr/Ms________________) have provided some preparation time:

One period in the library to gather and organize as much data as possible on your mission.

Written Report

Your post-mission report is to include the following information:

1. Name and location of your Solar System member
2. Object distance from Sun
3. Object size
4. Object classification: gas giant / terrestrial / comet / asteroid, etc.
5. Object characteristics (5 or 6 important ones; check with Mission Commander)
6. Characteristics of moons (if any)
7. Pictures, photographs, slides, overheads (ask Mr./Ms.________________________)

Oral Report

Briefly summarize your Mission Report in a 5 minute (max) presentation to your class.

Mineral Project

This activity gives students a chance to learn how to identify minerals on their own. Assignments are based on Geological Survey of Canada Mineral Chip sets, but will also work with B. C. Mining Museum mineral sets, or the 2-3cm specimens in the Boreal 10-pack mineral sets. The goal is for students to learn the properties and to be able to identify some of the more common minerals.

The project is designed for students to work at their own pace. Provide class sets of magnifiers, streak plates, pennies, glass and magnets. Have enough sets of minerals on hand so that everyone has a mineral to work on and no one waits idly for a sample. Mineral sets stay complete and useful if they are not taken out of the room. Well-worn sets, if saved over the years, can be used as take-home sets for students to study for the practical test.

The practical test and two practice tests consist of small hand samples in soup cans. Questions on the samples are written on numbered cards corresponding to the numbered cans. Students are allowed 1 minute and 20 seconds to examine the unknown at each stop, then move from station to station in numerical order until everyone has examined every unknown. Try to write questions that guarantee at least partial success, such as asking the lustre and the name of a hard to identify mineral. They should all answer the lustre correctly. Also include a list of mineral names on the test sheet to eliminate spelling anxiety and give them instant confidence. Well-chosen samples and questions, and careful storage, give you a test that will last for years. Practice tests are necessary, as most students will not have experienced this type of test before. You want them to do well on the real test, and the better prepared they are, the better they will do.

The Geological Survey of Canada Mineral Set includes:

1	Arsenopyrite	13	Ilmenite	25	Siderite
2	Skutterudite	14	Magnetite*	26	Limonite*
3	Molybdenite	15	Talc* <u>h</u>	27	Feldspar Microcline* <u>h</u>
4	Graphite* **c**	16	Gypsum* **c** <u>h</u>	28	Garnet*
5	Stibnite	17	Mica, Muscovite*	29	Asbestos*
6	Galena* **c**	18	Calcite* **c** <u>h</u>	30	Fluorite* <u>h</u>
7	Chalcopyrite* **c**	19	Barite*	31	Apatite* <u>h</u>
8	Pyrrhotite	20	Anhydrite	32	Pyroxene*
9	Pyrite*	21	Feldspar, Albite* <u>h</u>	33	Mica, Biotite*
10	Hematite* **c**	22	Quartz, massive* **c** <u>h</u>	34	Sphalerite* **c**
11	Manganese Ore	23	Quartz, crystal* **c** <u>h</u>	35	Hornblende*
12	Chromite	24	Mica, Phlogopite	36	Tourmaline*

* = must be able to identify; **c** = must know the chemical formula; <u>h</u> = must know the hardness

Student Exercise

Mineral Project

Minerals are the chemical compounds that make up the rocks of the Earth's crust. They are defined as solid, crystalline substances, each with its own specific chemical composition and arrangement of atoms. The unique chemical makeup and atomic structure of a mineral determine all its physical and optical properties. Therefore, physical properties can be used to identify an unknown mineral.

Properties useful in mineral identification include:

- colour
- lustre
- hardness
- streak
- cleavage/fracture
- density/specific gravity
- crystal habit
- special properties:
  a. magnetism
  b. fluorescence
  c. radioactivity

The main purpose of this project is to learn about mineral properties and how to use them to identify some of the common minerals. It is important that you learn the proper terms associated with the various properties, as they are in common usage worldwide. You are not expected to become a mineralogist, but it is expected that you will be able to use the properties to identify common rock-forming minerals. The list of the minerals in the set is included in this project handout. The minerals you are expected to know the names of and those you are expected to know the chemical formula for are marked.

The set of minerals you will use is prepared by the Geological Survey of Canada and contains 36 common minerals. Each mineral is numbered; the corresponding name can be found on the list. Note that the samples used on the test will not be numbered; it does no good to memorize the list. Each time you pick up a set to work with, and before you return it, please check that it is complete.

As you work through the project, you will be examining one property at a time. Take careful note of what that property is and how it is used. Pay close attention to the properties of the minerals you are required to learn.

You will have **four** classroom periods to work on this project. At the end of that time there will be a practical test. You will have a chance to practice on **two** practice tests before the real exam, and to take home a set of minerals the night before the test.

Student Exercise

Properties of Minerals

Colour: This refers to the colour of a fresh (not weathered) mineral surface. It is important to observe, but is not diagnostic because many minerals may be the same colour and many minerals come in several colours.

Examine your set. What is the most common colour? What minerals have a unique colour?

Lustre: This is the way a mineral reflects light, or shines. It is independent of colour. There are two main categories: **metallic**: shines like a metal; **non-metallic**: does not shine like a metal.

The lustre of **non-metallic** minerals can be further described as vitreous (like glass), dull, pearly, brilliant (like a diamond), waxy, or silky. Vitreous and dull are the most common. You must be able to tell metallic from non-metallic minerals and to apply the terms (metallic, vitreous or dull) to the minerals you have been asked to learn to recognize.

Examine your mineral set. What are the lustres of the minerals numbered: 3, 4, 6, 7, 8, 9, 10, 14, 15, 16, 17, 18, 19, 21, 22, 23, 26, 27, 28, 30, 31, 34, 35? Note that the hand sample in your set may consist of more than one mineral. Some minerals occur as small crystals only. If you are not sure which part of the sample you are to observe, ask for help.

Hardness: The hardness of a mineral is a measure of how resistant it is to scratching. This hardness is related to the chemical bonds between the atoms of the mineral. The hardness of a sample is found by comparing its resistance to scratching to that of a set of common minerals arranged in a scale from softest (most easily scratched) to hardest. The scale is called **Mohs Scale of Mineral Hardness**, named after Frederik Mohs, the man who devised it.

Mohs Scale

Hardness	Example Mineral	Description
1	**Talc**	very soft, everything will scratch it
2	**Gypsum**	fingernail will scratch it
3	**Calcite**	scratches gypsum, penny scratches it
4	**Fluorite**	scratches penny
5	**Apatite**	steel knife will scratch it
6	**Feldspar**	may scratch steel knife
7	**Quartz**	scratches steel and glass easily
8	**Topaz**	scratches quartz (sample at front)
9	**Corundum**	very hard, you can't scratch it
10	**Diamond**	the hardest, not in your set for obvious reasons

Student Exercise

Note that the hardness numbers are relative. They tell an order of increasing hardness, but not how many times harder one mineral is than another. For example, diamond is 1000X harder than talc, not 10X harder, as the scale implies.

To find the hardness of an unknown mineral you must try to scratch it with samples from the hardness scale or with other common materials of known Mohs hardness that constitute the Prospector's Scale (below).

Prospector's Scale

Hardness	Test Item
2.5	Fingernail
3.0	Penny
5.5	Knife (razor blade)
5.5	Glass
6.5	Steel file

Example: A mineral that scratches gypsum (hardness 2) but is scratched by calcite (hardness 3) would have a hardness of 2.5. A mineral that cannot be scratched with your fingernail (hardness 2.5) and scratches a penny (hardness 3.0), but can be scratched by a knife (hardness 5.5) has a hardness >3 and <5.5. Hardness is not an exact measure, but is an important diagnostic property.

A Mohs Hardness set of minerals is on the front counter. Look at it, but **do not** scratch the samples. Use your fingernail, the penny, nail and glass plate provided to determine the hardness of the minerals in your set.

Try to find the hardness of the following minerals: 6, 7, 9, 10, 15, 16, 21, 22, 23, 28, 30. You must know the hardness of talc, gypsum, calcite, feldspar (both of them) and quartz and be able to determine the hardness of others.

Streak: This is the colour of the powdered mineral. It is found by scratching the mineral across a streak plate (unglazed porcelain tile). The colour of the resulting **streak** is the property to note.

The streak of a mineral is commonly different from its colour. Orthoclase feldspar, for example, is orange, but its streak is white. And although the colour of a mineral may vary, its streak never changes. Hematite, for example, may be rusty red, orange, or black in colour, but its streak is always reddish brown!

Student Exercise

Please note that if the mineral you are testing is harder than the streak plate (6), no streak forms; describe it as *colourless.*

Find the streak of the following samples: 3, 4, 6, 7, 9, 10, 14, 26, 28.

Cleavage/ Fracture: Cleavage and fracture are words used to describe how a mineral breaks. This property is determined by the crystal structure and the strength of the bonds between atoms in the crystals. A mineral exhibits **cleavage** when it breaks apart along one or more planar surfaces. Cleavage surfaces can be seen in hand sample as flat faces that reflect light. (Notice this as you tilt the sample back and forth under bright light!) A mineral is said to exhibit **fracture** if it breaks on irregular surfaces.

You must be able to recognize fracture versus cleavage in mineral specimens, and determine the number of cleavage directions.

Find the cleavage of the following: 4, 6, 17, 18, 21, 23, 27, 30, 32, 33, 35.
DO NOT BREAK THE SAMPLES IN YOUR MINERAL SET!

Cleavage / Fracture Demonstration:
On the front counter there are samples of halite, calcite and mica. Take the samples, a razor blade, and a steel rod to your desk and try to cleave the samples. Line the blade up with one flat edge of the sample and **carefully** tap the blade with the rod. How many directions do they split? How does the cleavage of halite (salt) differ from that of calcite?

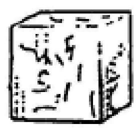
Density/ Specific Gravity: A mineral's density is its mass per volume (g/ml.) A mineral with a high density is very heavy for the size of the sample; a mineral with a low density is light for | the sample size. To estimate density, heft the mineral sample in one hand and compare its weight to a *similar sized* piece of massive quartz in the other hand. You will conclude that the mineral has *high* density if it feels heavier than the quartz, *medium* if it is about the same, and *low* if it feels lighter than quartz. (Specific gravity is a dimensionless value that is calculated by dividing the measured density of the sample by the density of water. Both density and specific gravity are measures of how heavy a mineral is relative to its size.)

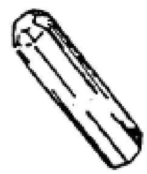
Estimate the density of the following minerals: 6, 7, 9, 10, 14, 16, 18, 19, 28, 30, 32, 35. How do the minerals with a metallic lustre compare in density to the non-metallic minerals? What is unusual about barite? (Look at its colour, density and lustre.)

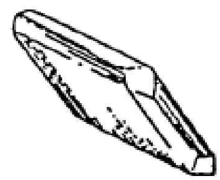
Student Exercise

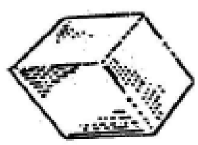
Crystal Habit: This refers to the shape of the crystal of the mineral. It is determined by the arrangement of atoms in the crystalline structure. Every mineral has one predominant and identifiable crystal habit; some have more than one form. Some of the most common crystal habits are shown on the following page. You will only be asked to identify the most obvious types.

Try to identify the crystal habits for minerals: 6, 9, 17, 18, 23, 28, 29, 30, 36. Also, look at the special samples on the front counter.


Cubic
example: gelena
pyrite


Columnar
example: tourmaline


Tabular
example: barite


Rhombic
example: calcite


Flaky
example: mica

Special Properties: Many minerals have unique properties that help to identify them. Check the following properties on minerals in your set.

Magnetism: Some minerals are magnetic. Test samples your set with the magnets provided. Name and site the chemical formula of those that are magnetic. Can you explain why other minerals with similar formulae are not attracted to the magnet?

Fluorescence: Some minerals fluoresce (glow different colours) in ultraviolet light. Examine the classroom set of fluorescent minerals under the UV lamp, then check the fluorescence of samples in your set. **Keep the light source pointed at the table. Do not look at the light. It will harm your eyes.**

Radioactivity: This refers to the release of subatomic particles and energy during the spontaneous breakdown of unstable atoms in a mineral. Radioactive elements usually have high atomic masses and break down into lighter elements. The simplest way to detect radioactivity is to use a Geiger Counter. The tube part of this device measures changes in an electric field as subatomic particles released by decay pass through it. Use the Geiger Counter provided to test the radioactive samples and your mineral set.

Teacher Information

Mineral Properties (Another Approach)

Identification of minerals in hand samples is a straightforward exercise, the required time for which depends on the available mineral collection. Ideally, your collection should include enough identical suites of samples so that no student is left idle. (If there are 30 students there should be >30 hand samples, three suites of 10, five suites of 6, etc…) Along with each suite provide two magnets, one small bottle of 10% HCl, a few streak plates, and a hardness kit (pennies, nails, glass plate).

Introduce the entire class to all of the physical properties; refer to the student worksheet to be completed. It may be difficult for novices to discern cleavage and to determine hardness very accurately. Demonstrate cleavage with a single mineral (e.g. calcite) and keep disposable mica on hand for students to handle. Do not allow students to destroy minerals in the teaching suites. You may demonstrate the method for determining hardness with one soft (e.g. talc) and one hard (e.g. quartz) specimen. It may be valuable to have each student simultaneously determine the Mohs hardness of one unknown in his or her suite.

The following student information pages are summary guides to refer to when working on mineral identification. The blank worksheet provided may be used as is or modified to suit your purpose. This activity is much more challenging when students are required to record all their observations, then allowed to use a key to identify their unknowns. A key tailored to their samples may be easier to use than one from a text that includes a much larger list of specimens.

Student Information

Mineral Properties

The following notes will assist you in studying the minerals provided.

1. **Colour**: This refers to the colour of a fresh surface. It is an important, but generally not a unique physical property. Sometimes it is not practical to break a mineral sample to see its fresh surface and other clues have to be found.

2. **Lustre**: This describes the way a mineral reflects light. All minerals can be generally characterized as having a **metallic** lustre or a **non-metallic** lustre. Non-metallic minerals can be specifically described as:

Adamantine (sparkling brilliant)	example:	diamond
Vitreous (or glassy)	example:	glass, quartz
Pearly	example:	pearl, mica
Silky	example:	asbestos fibres
Greasy (feels slippery like soapstone)	example:	talc
Resinous (looks like wax)	example:	hardened pitch
Dull or earthy (no shine at all)	example:	clay

3. **Hardness**: This refers to a mineral's resistance to scratching. A numerical value between 1 and 10 representing relative hardness can be determined for each mineral by trying to scratch it with minerals of known hardness. The latter make up Mohs Scale of Hardness (below). All minerals fit somewhere in that range. Hardness determination of minerals in hand sample is generally made by comparing with common materials of known hardness.

Hardness	Mineral	Common Material
1	**Talc**	
2	**Gypsum**	Fingernail 2.5
3	**Calcite**	Copper 3 Copper penny 3.5
4	**Fluorite**	
5	**Apatite**	Iron nail 5 Pocket knife 5.5
6	**Feldspar**	Glass 6 Steel file 6.5
7	**Quartz**	
8	**Topaz**	
9	**Corundum**	
10	**Diamond**	

Student Information

4. **Streak**: This is the colour of the powder of a mineral. Mineral powder is obtained by scratching the sample across a ceramic tile. Note that the tiles (streak plates) commonly used have a hardness { 6, so minerals of greater hardness will not streak.

   In your chart, write down 1) the colour of the streak, 2) uncertain or 2) no streak.

5. **Cleavage / Fracture**: Cleavage and fracture refer to how a mineral breaks. A mineral exhibits fracture when it does not preferentially break along planes. A mineral exhibits cleavage when it breaks along one or more planes.

   A mineral with one direction of cleavage, like *mica*, splits into flakes.

   A mineral with two directions of cleavage, like *feldspar*, breaks in a stairstep fashion. The angle between the two planes may be 90°, more, or less.

   A mineral with three mutually perpendicular intersecting directions of cleavage, like *galena*, breaks along planes to form cubes. A mineral with planes intersecting at angles > 90° or < 90°, as in calcite, breaks into rhombic pieces.

   You may not break the mineral samples, so examine the samples carefully to determine the number and orientation of the cleavage planes. It is difficult at first to discern. Ask your teacher for help.

6. **Specific Gravity**: Specific gravity (SG) is a measure of a mineral's weight compared to an equal amount of water. The value depends on the mineral's chemistry. Examples that demonstrate the range of this property include:

Mineral	**SG**	**Mineral**	**SG**
Quartz	2.7	Halite	2.1
Gypsum	2.3	Galena	7.5
Mica	~3	Barite	4.8

To make a qualitative measure of specific gravity simply heft the sample in one hand to feel if it is noticeably light or heavy for its size.

Estimate a value using this scale:

Light: 1 to 3
Normal: 4 to 6
Heavy: 7 or more

7. **Other Characteristics**:
This encompasses any other noteworthy characteristics that are not already reported such as taste, smell, feel, solubility, magnetism, and reaction to dilute HCl (hydrochloric acid).

8. **Name and Chemical Composition**:
Name is given in the key provided to you. Most minerals have complex chemical compositions often represented by long formulas. Write down simplified chemical composition such as Na-Al Silicate or Cu-Fe Sulphide etc.

Make sure that your tables are complete and accurate. These are going to form the basis of your review before the test during which you will be required to identify mineral samples by examining them and identifying their characteristics.

Student Exercise

Mineral Name / Chemical Formula	Colour	Streak	Lustre	Hardness	Cleavage/ Fracture	Other Characteristics

Teacher Information

Rock Project

Activities in this project allow the students to learn to identify the three main rock types. There are eight assignments, which fit nicely into five 75 minute periods. A practical exam can be conducted during a sixth period.

Emphasis is on recognizing the basic characteristics of the rock types, **not** on learning all the rock names, such as granodiorite and garnet-mica schist. Igneous rocks are subdivided into plutonic and volcanic. Sedimentary rocks are categorize as high, medium or low energy, based on fragment size and amount of energy required to move them. Only clastic types of sedimentary rocks are considered, as carbonates and other chemical deposits are too difficult for beginners to identify. Metamorphic rocks are also divided into high, medium and low energy in this case, based on the amount of energy applied to the original rock.

The first three assignments focus on rock identification and require rock samples. Six specimens for each rock category is adequate. You may purchase samples from various places, including rock shops and masonry stores, or you can gather them in the field from road cuts, quarries, and railway cuts. The larger your class collection, the more examples you will have for comparisons and for your lab practicals. Fist size samples and larger, with some freshly broken surfaces, are easiest for beginners to work with. Use samples that clearly exhibit diagnostic features, e.g. large crystals (plutonic), vesicles (volcanic), layers (sedimentary), etc. Do include water worn boulders and some puzzling oddities. Your students will inevitably cross paths with them in nature! The card in the sample tray asks students to describe colour, texture (crystals or fragments), pattern (layers or no layers), presence of fossils, unusual features, and what makes these samples different from the other two sets. Label the samples I_1, S_3, M_4, etc, so they do not get mixed up.

Assignments 4, 5, and 6 are experimental models of the rock formation processes. The igneous model involves making a crystalline solid and takes two periods to complete - one to set up the tubes and one to analyze the results. Required equipment (N-5) maybe obtained from your Chemistry department. However, since the tubes are destroyed, a separate purchase of disposable culture tubes is recommended. Use 18 X 150 mm test tubes. Place a 3-4 mm length of wax crayon (three different colours) in each tube and then fill each about half way with paradichlorobenzene crystals. (Dispensing of this chemical should be done by the teacher. A fume hood is useful, but the activity can be done in a room with an open window and a fan. The paradichlorobenzene is a hazard, but the students will not be exposed to it for long.) The crayon colours the samples so they can be readily identified after the tubes have been broken. Make sure that the students have written down which colour is in which tube. Help your students see the different crystal sizes by pointing out appropriate examples from their samples. You need a container for broken glass and used paradichlorobenzene. Do **not** put them in the garbage can in the classroom.

Teacher Information

The sedimentary rock model simulates cementation and lithification of clastic sediments. It requires 20 minutes during one period to set up, and then three to four days to completely harden. Coarse aquarium gravel works well as the sediment in this experiment. Ensure that the sample of real sandstone that you will test with 10% HCl does have carbonate cement and fizzes! (Put it and the chalk in petri dishes to eliminate dripping.) The simulated sandstone with silica cement will not react with acid and should **not** be tested. Use bathroom size paper cups or smaller *portion cups* (available through Northwest Scientific Supply Co.) designed for pill dispensing. The smaller the cup, the faster the sediment hardens. Use the sodium silicate with care. It is caustic to skin and harmful if it gets into your eyes! Sodium silicate can be purchased at drug stores, but is available in larger quantities from science supply houses. Dilute it 1:1 with water and just put out a small bottle at a time to reduce risk of spills. Drip enough onto the gravel (about 10 ml) to wet it all and have a little drip out the bottom.

The metamorphism model requires only part of one period to complete. Use either clay from your school's Art Department or play dough; a fist size clump per working group is sufficient. This experiment simulates how pressure influences mineral crystal orientation. Upon completion, ask your students to remove the pennies from the clay, then store the clay in a plastic container for reuse.

All of the models have a set of small samples with them to make the students explain the formation of real rocks based on information from the model. The samples in the igneous model are a volcanic, a granite and a pegmatite. The sedimentary ones are a shale, a sandstone and a conglomerate. The metamorphic ones are a slate, a schist and a gneiss. The samples for the models should be numbered 1_M, 2_M, 3_M, etc., so they are not confused with samples in parts 1, 2, and 3.

Assignment 7, on the Rock Cycle, is a simple one and can be done at home.

Assignment 8 involves making a personal rock collection. The samples the students collect will depend on your area and may be all of the same type. Commonly their samples will not look like examples they have seen in class, so they will have to make educated guesses to help identify them. Cutting them is not difficult. A rock saw with a diamond blade is required to cut their samples. If your school does not own one, check into the possibility of using or borrowing one from a local Lapidary Club. Some club members may voluntarily come in to your class to help your students do this activity.

Teacher Information

Familiarize your students with the practical exam before hand. Set up a practice test in your classroom for the students to try. Use spare samples they have seen and ask them the rock type and sub classification, e.g. igneous - plutonic. As was true with the mineral properties practical, the students need practice answering the kinds of questions you will ask on the real test. Post the correct answers and let them score themselves, one mark for each type and sub classification.

Choose samples for the real exam carefully. Label them and place each with a question card beside it at stations around the room. Allow the students 1 minute and 20 seconds at each station and have them move sequentially from one station to the other in order.

Note: Rock and mineral samples can be labelled using Porcelain Repair Fluid that is used to repair chipped sinks and is available at hardware stores. Write on the dried fluid label with India Ink using a nib-style pen.

Student Exercise

The Rock Project

In the next five periods you will work on a series of eight assignments designed to teach you the fundamentals of the three rock types which make up the Earth's crust. You may work in pairs or alone. Work at your own pace, but all assignments must be completed in the time allotted. At the end of the time period, the project will be collected and marked. Bind all written parts of the assignments together with a title page and a cover. Each person must hand in a report.

Assignments:

1. Observe the properties of Igneous Rocks.
2. Observe the properties of Sedimentary Rocks.
3. Observe the properties of Metamorphic Rocks.
4. Create a model for the formation of Igneous Rocks.
5. Create a model for the formation of Sedimentary Rocks.
6. Create a model for the formation of Metamorphic Rocks.
7. Describe the Rock Cycle.
8. Make a Local Rock Collection.

NOTE: Some of these assignments take more than one period. Plan your time accordingly.

When you have completed the Rock Project you will be able to identify a rock as to its basic type and its subcategory. A practical exam follows this project.

Student Exercise

Assignment 1, 2, 3: The Basic Characteristics of Igneous, Sedimentary and Metamorphic Rocks.

Equipment required:

- hand lens
- box of samples

Procedures:

1. Obtain a plastic tray labelled igneous, sedimentary or metamorphic. Check that all samples in the tray have the same prefix (I_1, I_2.. for Igneous, S_1, S_2.. for Sedimentary, M_1, M_2.. for metamorphic).
2. Follow the instructions on the card in the tray.
3. Compare the properties among the three types of rocks and among samples of the same type.

Student Exercise

Assignment 4: **Crystallization of Igneous Rocks - A Model for the Formation of Different Crystal Sizes**

Equipment required:

- 3 test tubes
- paradichlorobenzene (obtain from teacher)
- paper towels
- 3 small pieces of wax crayon (3 different colours)
- safety goggles

Procedures (Work in pairs):

1. Label the test tubes with your names and the numbers 1, 2, or 3. Put a piece of a different coloured crayon in each tube. Record on a separate sheet of paper the colour of each numbered tube.

2. Get the paradichlorobenzene from the teacher.

3. Heat the three tubes in a **hot water bath** until the mixture is molten.

4. Quickly place tubes 1 and 2 in the following locations:

   Tube 1: Place in a beaker of **cold** water.
   Tube 2: Place in beaker of dry sand. The level of the liquid in tube must be well below the surface of the sand.

5. Leave **Tube 3** in the hot water bath to cool over night.

6. Allow all of the tubes to cool and the substances contained to solidify. Wrap each in paper towel and break the glass away carefully using a hammer. CAUTION: You must wear the safety goggles! Do not powder the contents! Just break the glass.

7. Observe the crystal shape and size of the solids in each tube. Sketch the crystals in each; include a bar scale to indicate size. Dispose the broken glass and crystalline substance in the designated container when you have completed your observations.

Student Exercise

Questions:

1. Give the general name for the chemicals that make up rocks.

2. What does the molten mixture of paradichlorobenzene and crayon represent in this model?

3. Why is this crystallization experiment called a *model*?

4. Which tube cooled the fastest? Why? Which tube cooled the slowest? Why?

5. Which tube contained the largest crystals? Which tube contained the smallest crystals?

6. Relate the crystal size formed to the rate of cooling.

7. Observe the three igneous rock samples in the tray.
   They are: obsidian (1_I), granite (2_I), labradorite (3_I)
   What were their relative cooling rates? Where, on or in the Earth, would these cooling rates occur?

Student Exercise

Assignment 5: Sedimentary Rocks - A Model of Cementation

Equipment required:

- 2 small paper cups
- water glass solution (sodium silicate)
- dilute hydrochloric acid (HCl)
- aquarium gravel

CAUTION: Both water glass and hydrochloric acid are dangerous. Use them cautiously. Do not get them on your skin and do not touch your face until you have washed your hands.

Procedures:

1. Punch several small holes in the bottom of one paper cup with a pen or pencil. Fill the cup about 1/2 full with aquarium gravel. Tap it gently so that the "sediment" is as packed in the cup as possible.
2. Flood the gravel with water glass solution until the solution starts to drip out the holes. Catch the drips in the second cup. Allow the cup to drip for several minutes to remove the excess water glass solution. Place the cup containing the gravel on a petri dish with your name on it and store it until dry. This will take about three days. Carefully rinse out the second cup and throw it in the garbage.
3. When your sediment is dry and hardened, carefully peel the paper off. Observe this "sedimentary" rock. Be careful, as there may still be wet patches.
4. Investigate the **cement** in a real sedimentary rock. Put one drop of HCl on the sandstone in the tray and a drop on a piece of blackboard chalk. (Do **not** put HCl on your model.) Chalk contains calcium carbonate (CaCO3), which fizzes in HCl. Describe the reaction of the sandstone with the acid.

Questions:

1. What formed the cement in the real sandstone?

2. What formed the cement in your model sandstone?

3. Describe the natural processes by which loose sediments are turned into sedimentary rock.

4. Observe the three sedimentary rocks in the tray: They are:

   shale - 1_s sandstone - 2_s conglomerate - 3_s

   Describe the environment and energy conditions in which each might have formed.

Student Exercise

Assignment 6: Metamorphic Rock - A Model of Foliation Formation

Equipment required:

- lump of clay
- 15 pennies
- newspaper
- table knife

Procedures:

1. Cover your desktop with newspaper.

2. Mould the clay into a sphere and push the pennies into it in random directions. Sketch the orientation of the pennies.

3. Put the clay on the newspaper and flatten the lump as much as possible.

4. Cut through the flattened lump to find some of the pennies. Sketch the pennies' orientation in that cross-section.

5. Remove all pennies and store the clay in the designated container.

Questions:

1. What happens to the orientation of the pennies as pressure is applied to the clay?

2. Do you think this change in orientation is possible in a real rock? How would you recognize that pressure had been applied to a rock in nature?

3. Observe the metamorphic samples in the tray. They are:

   slate 1_M
   schist 2_M
   gneiss 3_M

   Describe how each must have formed.

Student Exercise

Assignment 7: The Rock Cycle.

Procedures:

1. Define each of the terms on the Rock Cycle diagram (N-11). Refer to your textbook and the model on display in the classroom.

2. Complete the Rock Cycle diagram. Add arrows to show <u>all</u> of the other directions in which rocks could be changed.

3. Write a summary of all changes possible to each of the three main rock types in the Rock Cycle. For example: " Igneous rocks can be weathered and eroded to form sedimentary rocks which ….".

Assignment 8: Local Rock Collection.

Procedures:

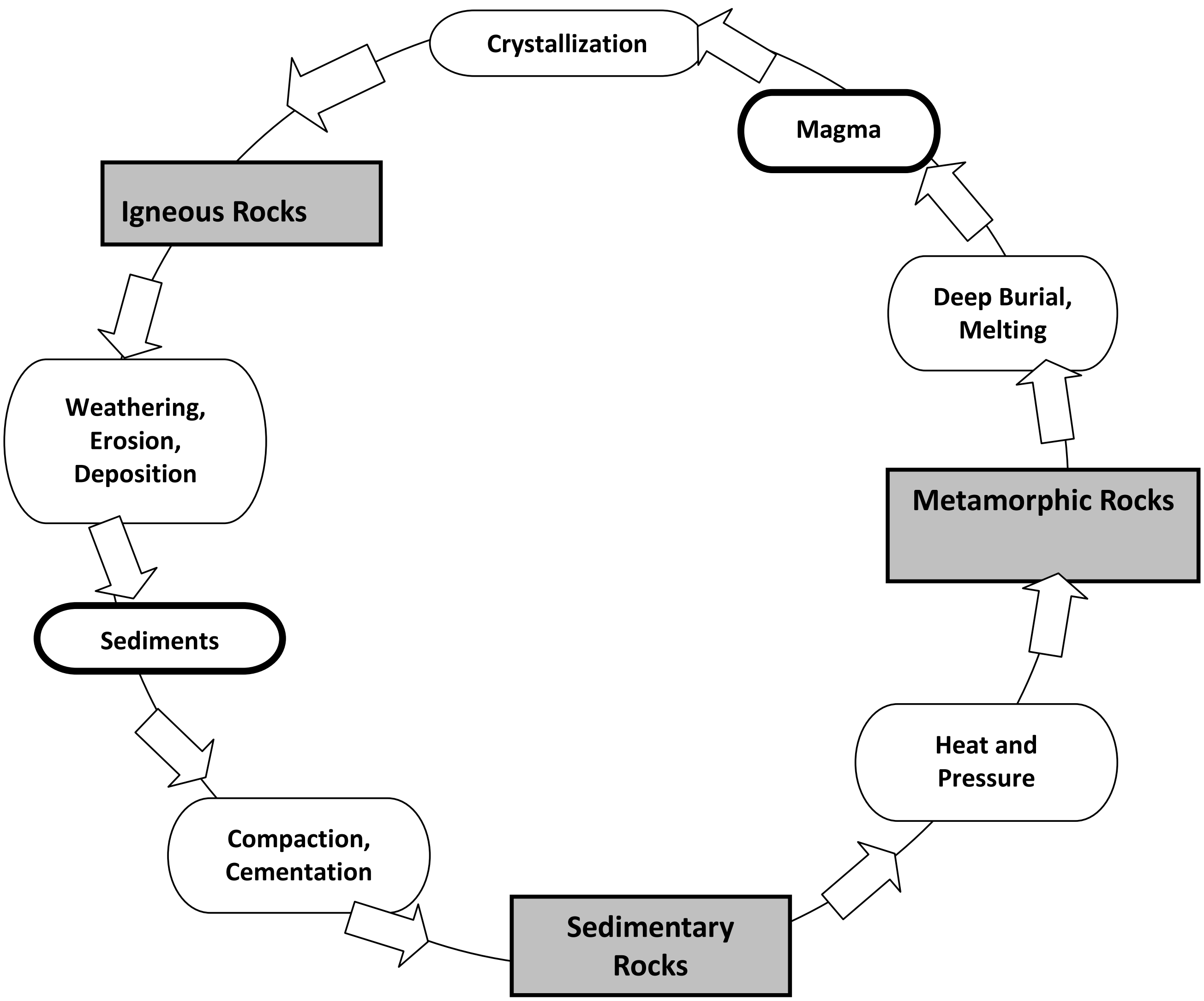
1. Collect at least five rock samples locally. The samples should be slightly smaller than fist size. Label each sample. Put a dot of white-out on the sample. Let it dry and then write your label with waterproof ink. Your samples must be placed in a box to be handed in. (They will not be marked if they are loose or in a bag.) Include both halves of cut samples.

2. Identify the basic rock type and subcategory of each sample. Include an identification key to your labelled rocks in the written portion of your project.

3. Cut at least two of your samples using the diamond saw.

Student Exercise

The Rock Cycle



Student Exercise

Names: ___________________________

Metamorphic Rock Pancakes

We are going to make metamorphic rock pancakes. This activity will help you understand some of the processes involved in metamorphic rock formation.

First, divide into groups of four. Each group will turn in one assignment.

Next, preheat the griddle to about 400°F (200°C) or until a drop of water dances on the surface. Now, make the pancake batter. Mix together all of the following ingredients in a bowl.

1 cup (250 ml) pancake flour
1 egg*
½ cup (125 ml) milk*
(*For waffles use ¾ cup milk, ½ egg, and add 1 tablespoon oil)

Once you've mixed the ingredients into a smooth batter, you are ready to begin the metamorphic rock process.

Throughout your cooking, you will be adding ingredients to your pancakes. They are:

sunflower seeds
raisins
chocolate candy sprinkles
multi-coloured candy sprinkles
chocolate drops
m&ms
chocolate cookie crumbs
chocolate mint wafers
blueberries

You will be observing how these ingredients react with heat (from the griddle) and pressure (from the flipper).

Write down your observations and answer the questions on the following page while you are doing this activity.

For each pancake, drop a 5-10cm diameter blob of batter onto the griddle. You can add several different ingredients to each cake, but **do not** exceed five. Point form will be fine, but be clear about which ingredients you are describing.

Student Exercise

1. Place chocolate or candy sprinkles onto your pancake.
   a) How are the sprinkles initially spaced? ____
   b) After the pancake is almost ready, how do the sprinkles appear? __________________
   ____
   c) Use the turner and apply some pressure on the pancake. How do the sprinkles appear oriented now? ____

2. Place some m&ms onto your pancake.
   a) What happens to the m&ms after a few minutes? ________________________________
   b) Apply some pressure with the turner. What happens to the m&ms now? ____________
   ____

3. Place some blueberries onto your pancake.
   a) How do the blueberries change through the cooking of the pancake? _______________
   ____
   b) Apply slight pressure to the pancake, how do the blueberries change? ______________
   ____

4. Add some chocolate drops and some chocolate mint wafers. The wafers can represent sedimentary rock.
   a) Do you have foliation with the chocolate drops? _________________________________
   b) What happens to the layering of the wafers while they are cooking? ________________
   ____

5. Add some chocolate cookie crumbs, sunflower seeds or raisins to your pancake.
   a) Do any of the above ingredients change with heat and pressure? Why or why not?
   ____
   ____

6. Of all the ingredients you added throughout this activity:
   a) Which one changed the most with heat? ______________________________________
   b) Which one changed the least with heat? ______________________________________
   c) Which one changed the most with heat and pressure? ____________________________
   d) Which one changed the least with heat and pressure? ____________________________
   e) What major properties and factors do you think account for the differences in metamorphism rates between the different ingredients? Explain. _________________
   ____
   ____
   ____

Teacher Information

Volcano and Earthquake Distribution

Volcanism and seismicity are evidence for a dynamic Earth and support plate tectonic theory. The world-wide distribution of active volcanoes and earthquake epicentres are interpreted to define lithospheric plate boundaries.

The following two exercises are variations on a theme that involves plotting volcano and earthquake data on a world map. Both exercises require the use of atlases. (A set of old discarded atlases from your library or Social Studies department is a valuable resource for your classroom.) If precise locations of volcanoes are not provided in your atlases, a dot plotted in the centre of the country is adequate.

These activities are good practice using atlases and reading maps, and are great lessons in geography. They can be introduced to your class together and completed as one activity or done sequentially to allow the students to discover the plate boundaries with the volcanoes and mountain chains before adding the earthquake data. (Allow for both in-class and out of class time to plot the data, answer the questions and discuss the importance of these data in contributing to the plate tectonic theory.

Student Exercise

Volcano Distribution

Purpose: To study the distribution of the world's volcanoes and mountains.

Procedures:

The volcanoes listed in Table 1 are a representative sample of the many volcanoes on Earth. They reveal the world-wide pattern of volcano distribution. Plot their locations by their given numbers on a Pacific-centered Map of the World.

When you have plotted this data, shade in the major mountain areas of the Earth.

Questions:

1. Is there any pattern to the distribution of volcanoes on the Earth's crust? If so, describe it.

2. Is there any pattern to the distribution of mountains on the Earth's crust? If so, describe it.

3. How do the locations of mountain chains and the locations of volcanoes compare?

4. Land around the Pacific Ocean basin is commonly referred to as the "Ring of Fire". Why is this an appropriate name?

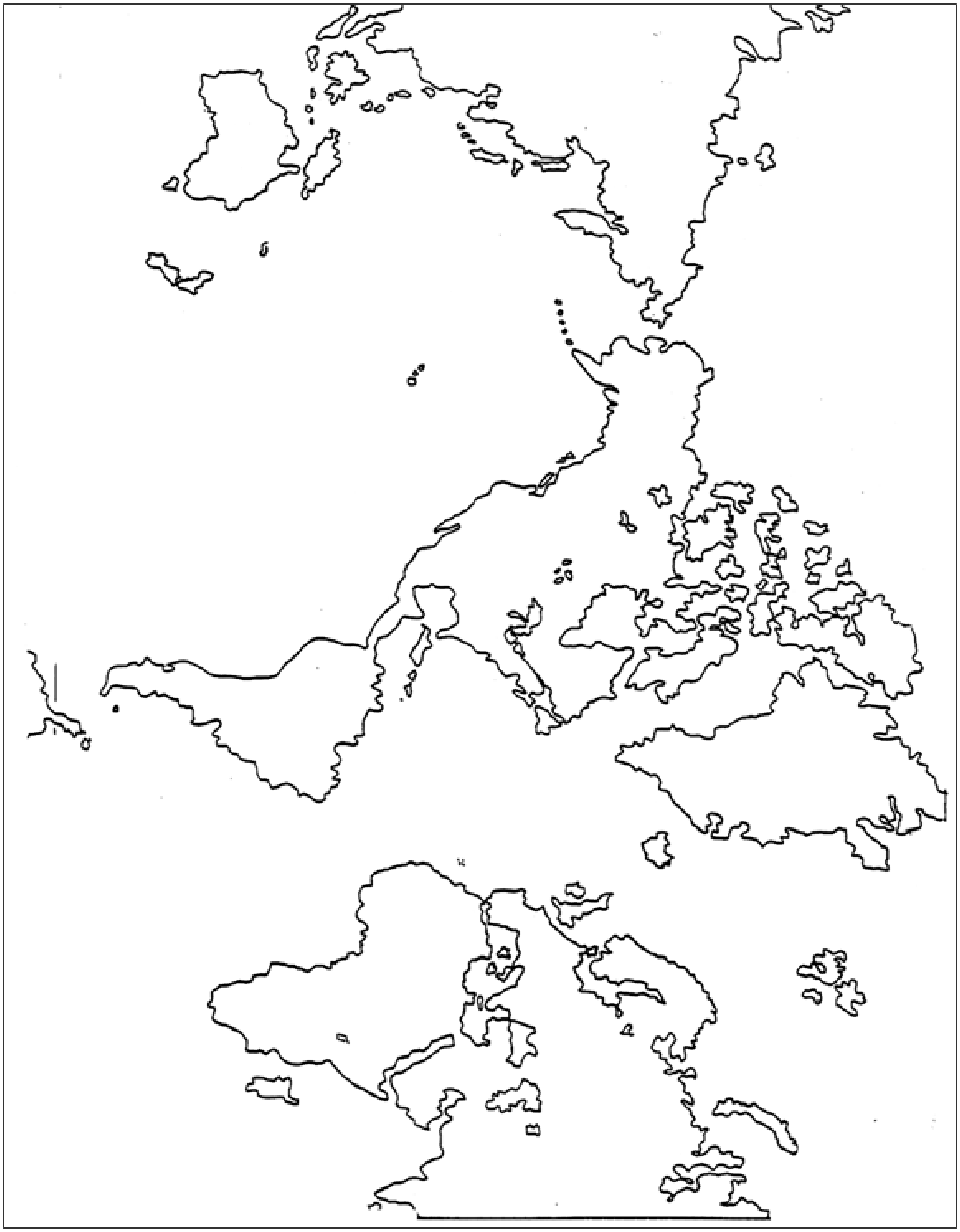
5. What volcano is nearest to us? (It may not be one you plotted.)

Student Exercise

Table 1: Volcanoes Around the World

	NAME	LOCATION
1.	Kilimanjaro	Tanzania (East Africa)
2.	Cameroon Mt.	Cameroon (West Africa)
3.	Fugo	Cape Verde Islands
4.	Tristan de Cunha	South Atlantic Ocean
5.	Deception Island	Antarctica
6.	Mt. Erubus	Antarctica
7.	Fayal	Azores
8.	Hekla	Iceland
9.	Mt. Etna	Sicily
10.	Mt. Vesuvius	Italy
11.	Mt. Stromboli	Italy
12.	Santorini	Thera, Greece
13.	Mt. Fuji	Japan
14.	Yaka Dake	Japan
15.	Konyakskaya	Kamchatka Pen., USSR
16.	Taal	Mindanao, Philippines
17.	Bulusan	Leyte, Philippines
18.	Krakatoa	Sumatra
19.	Tambora	Flores
20.	Tongoriro	North Island, New Zealand
21.	Lasear	Chile
22.	Orsono	Chile
23.	Miski	Peru
24.	Cotopaxi	Ecuador
25.	Nevado del Ruiz	Colombia
26.	Tajumulco	Guatemala
27.	Poas	Costa Rica
28.	El Chichón	N. Mexico
29.	Popocatepetl	C. Mexico
30.	Mt. Lassen	N. California, USA
31.	Mt. Shasta	N. California, USA
32.	Mt. Hood	Oregon, USA
33.	Mt. Rainier	Washington, USA
34.	Mt. Baker	Washington, USA
35.	Mt. Garibaldi	S. British Columbia, Canada
36.	Mt. Edziza	N. British Columbia, Canada
37.	Mt. Redoubt	Alaska, USA
38.	Great Sitka	Aleutian Islands, Alaska, USA
39.	Pelée	Martinique
40.	Kilauea	Hawaii, USA

Student Exercise



Student Exercise

Earthquake Distribution

Purpose: To study the distribution of earthquake epicentres on the Earth and to compare it to the distribution of volcanoes.

Procedures: Plot the following earthquake epicentres in Table 1 on the Pacific-centered Map of the World. Use the letter given to mark the location.

Table 1: Earthquake Epicentres

	Epicentre	Magnitude	Year	Deaths
A.	Syria		526	250,000
B.	China, Chihli		1057	25,000
C.	Japan, Kamakura		1293	30,000
D.	Portugal, Lisbon		1531	30,000
E.	Italy, Catania		1693	60,000
F.	Japan, Hokkaido		1730	137,000
G.	India, Calcutta		1737	300,000
H.	Northern Persia		1755	40,000
I.	Portugal, Lisbon	8.75	1755	30-60,000
J.	Italy, Calabria		1783	50,000
K	Ecuador, Quito		1797	41,000
L.	USA, New Madrid, MO		1811	0
M.	Venezuela & Colombia		1876	16,000
N	USA, San Francisco, CA	8.3	1906	503
O.	Chile, Valparaiso	8.6	1906	1,500
P.	Italy, Messina	7.5	1908	160,000
Q.	China, Kansu	8.6	1920	180,000
R.	China, Nan-Shan	8.3	1927	200,000
S.	Pakistan, Quetta	7.5	1935	60,000
T.	Turkey, Erzincan	7.9	1939	40,000
U.	Canada, Courtney, BC	7.3	1946	0
V.	Afghanistan, Kabul	7.7	1956	2,000
W.	Morocco, Agadir	5.8	1960	12,000
X-	Southern Chile	8.3	1960	5,700
Y.	Northwest Iran	7.1	1962	12,230
Z.	USA, Anchorage, AK	8.5	1964	114
AA.	USA, Seattle, WA	6.5	1965	7
BB.	Northern Peru	7.7	1970	20,000

Student Exercise

Table 1: Earthquake Epicentres (continued)

	Epicentre	Magnitude	Year	Deaths
CC.	USA, San Fernando, CA	6.5	1971	65
DD.	Nicaragua	6.2	1972	10,000
EE.	Guatemala	7.5	1976	23,000
FF.	New Guinea, Irian Jaya	7.9	1976	9,000
GG.	China, Tangshan	8.2	1976	700,000
HH.	Philippines, Mindanao	7.8	1976	8,000
II.	Canada, Pender Island, BC	6.0	1976	0
JJ.	Romania, Bucharest	7.5	1977	15,000
KK.	Ecuador, Columbia	7.9	1979	800
LL.	Northwest Algeria	7.3	1980	4,500
MM.	Southern Italy	7.2	1980	4,800
NN.	North Yemen	6.0	1982	2,800
OO.	East Turkey	7.1	1983	1,300
PP.	Mexico, Mexico City	8.1	1985	9,500
QQ.	Northeast Ecuador	7.3	1987	4,000
RR.	Armenia	7.0	1989	25,000
SS.	USA, San Francisco, CA	7.1	1989	63
TT.	Northern Iran	7.3	1990	40,000
UU.	USA, North Ridge, CA	6.7	1994	57
VV.	Kobe, Japan	6.9	1995	5,100
WW.	Afghanistan	6.1	1998	>1,500
XX.	Northwest Turkey	7.4	1999	17,000
YY.	Athens, Greece	5.9	1999	80
ZZ.	Venezuela	6.9	1999	47

Questions:

1. Describe the pattern of earthquake epicentres on the Earth's surface.

2. How does the distribution of epicentres compare to the distribution of volcanoes on the Earth's surface?

3. Give an explanation for the patterns noted in questions 1 and 2. What could cause this pattern?

Student Exercise

4. How long ago was the first recorded earthquake on the list?

5. No Richter scale magnitude is given for the first 13 earthquakes. (Lisbon, 1755 is an estimate.) Why is it not possible to give the magnitude for these? How could the magnitude for Lisbon be estimated?

6. Is there a pattern to the number of deaths in an earthquake? Explain.

7. Which would be the most hazardous place and time for an earthquake to occur?
   (a) Urban area (city) or rural area (country)?
   (b) Daylight hours or night hours?

8. The number of deaths in so-called “underdeveloped countries” is usually very large. Give some possible causes of the large toll.

Teacher Information

Volcanoes

Volcanoes always capture the interest of the students. The textbook covers the main concepts well and there are many videos that compliment lecture material. (See Video References in the Resources Section.)

This section contains teacher information sheets and two student activities. The former can be used as supplements at the discretion of the teacher - as overhead masters, or modified with white-out for quizzes. The information includes topics covered in the text and adds specific information on Cascade volcanism in our region.

“Ring of Fire” (Q-2) and “The Cascade Mountains” (Q-3) reinforce material presented on plate tectonics. The "Ring of Fire" is an abbreviated version of Volcano Distribution (P-2) and may also require atlases or maps for reference.

“A Look Inside a Volcano” (Q-4) provides relevant vocabulary with a schematic cross-section of a volcano. “What's the Difference?” (Q-5) and “Types of Volcanoes” (Q-6) provide comparable information on different volcano morphologies. They lead into a discussion of differences between mafic and felsic magmas. (The phrase “Mafic Magmas Move” may help students remember which type easily flows and generates a shield.) Subsequent discussion of magma on the surface may be illustrated with “Ropes, Pillows and Clinkers” (Q-7) which describes pahoehoe, aa and pillow lava. “Mountain on the Rise” (Q-8) and “East of the Cascades” (Q-9) illustrate the explosive eruption of Mt. St. Helens and the fissure eruption of the Columbia River Plateau basalts, respectively, in Washington State.

“Anatomy of a Volcano” (Q-10) is a student activity that serves to review volcano form and function and allows students to be creative in drawings and storytelling. You may be delighted with the wide variety of interpretations of this assignment.

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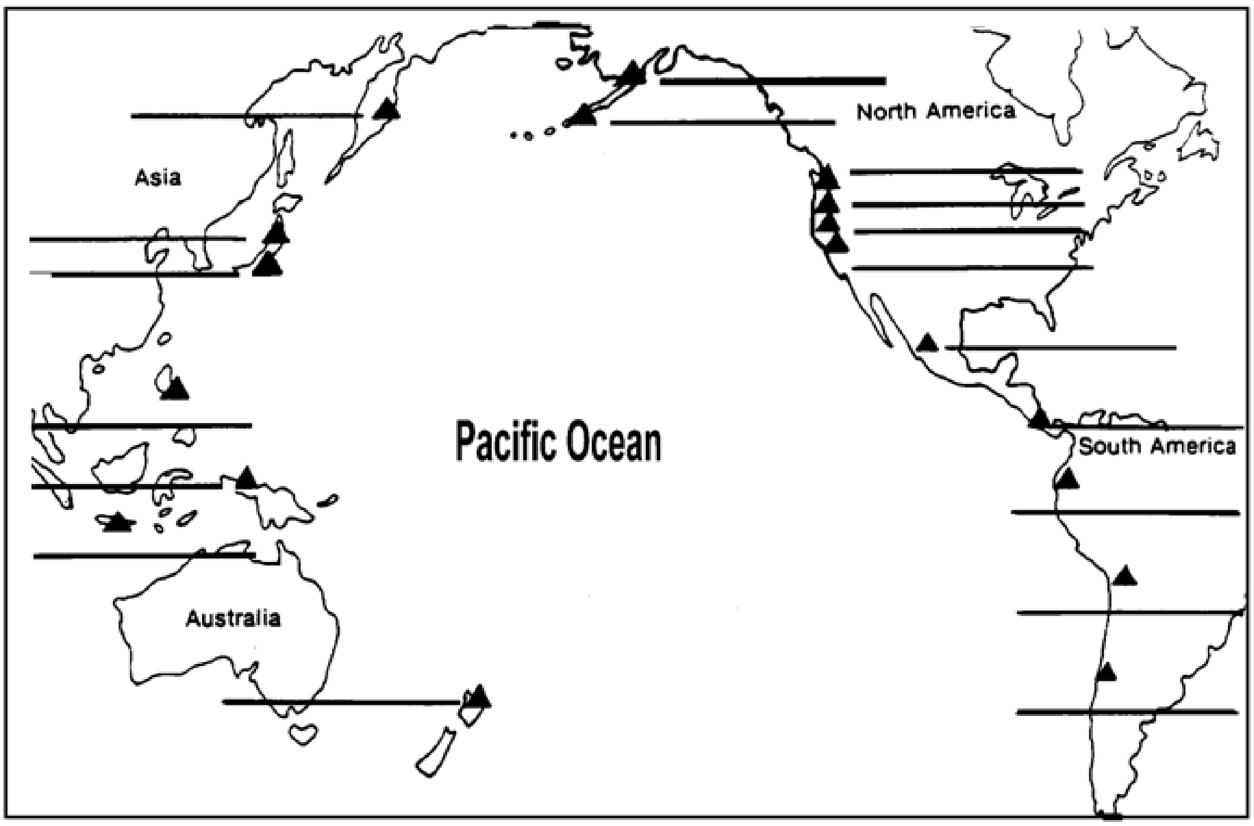
Student Exercise

Ring of Fire

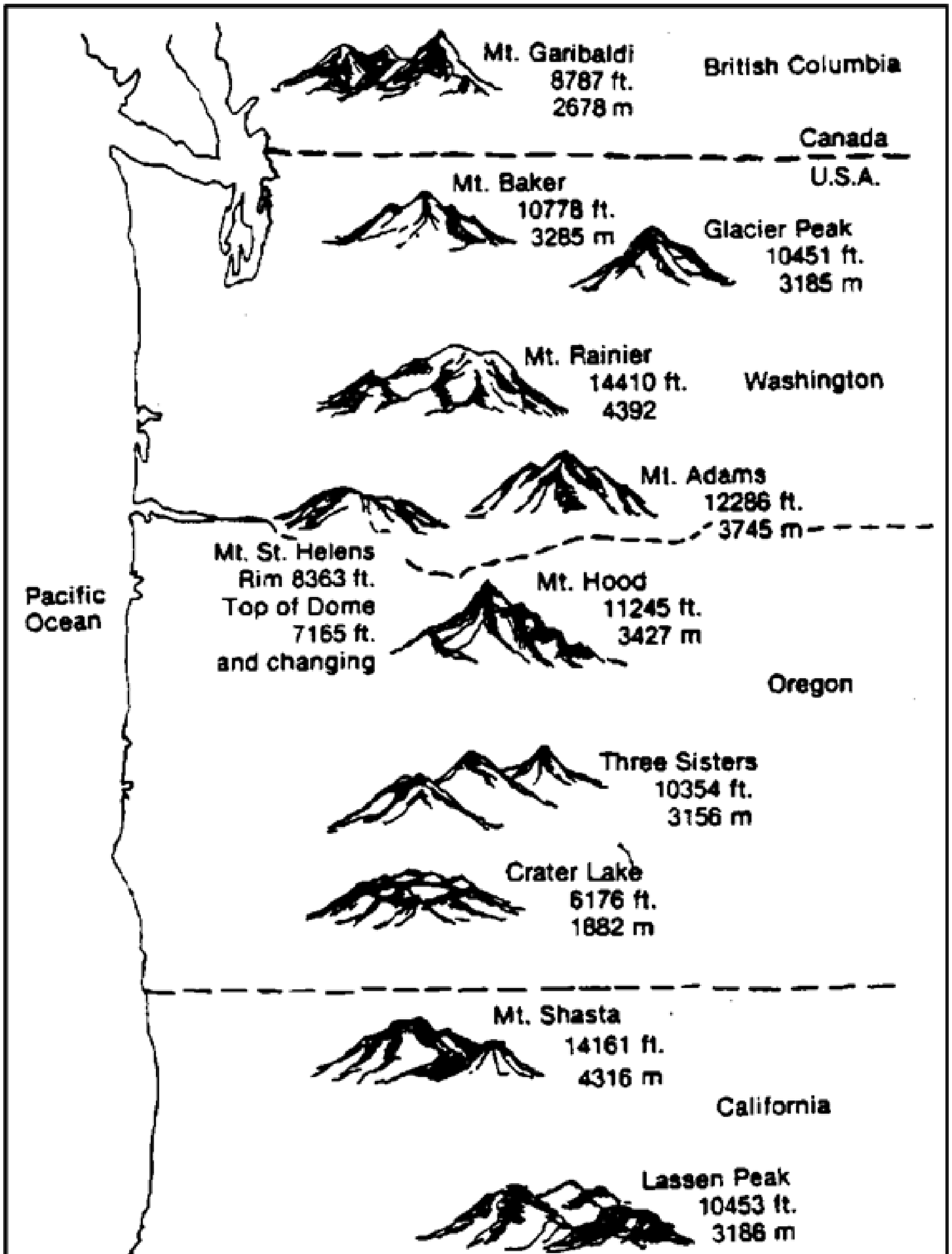
A circle of volcanic mountains called the "Ring of Fire" occurs on the edges of land surrounding the Pacific Ocean, marking collisions between oceanic and continental plates. Some of these are considered **active**, erupting fairly regularly. Others that have been inactive for centuries, but could erupt again, are considered **dormant**.



Write the name of each volcano in the list below in its proper location on the map.

1. Mt. St. Helens - USA (Washington)
2. Mt. Katmai – USA (Alaska)
3. Mt. Fuji – Southern Japan
4. Mt. Shasta – USA (California)
5. Krakatoa – Indonesia
6. Mt. Rainier – USA (Washington)
7. Mt. Paricutin – Mexico
8. Mt. Mayon – Philippines
9. Akutan – USA (Alaska/Aleutian Islands)
10. Irazu – Costa Rica
11. Mt. Hood – USA (Oregon)
12. Karymsky – Russia (Kamchatka)
13. White Island – New Zealand
14. Villarica - Chile
15. Reventador - Ecuador
16. Ubinas - Peru
17. Mt. Lamington – New Guinea
18. Bandai – Northern Japan

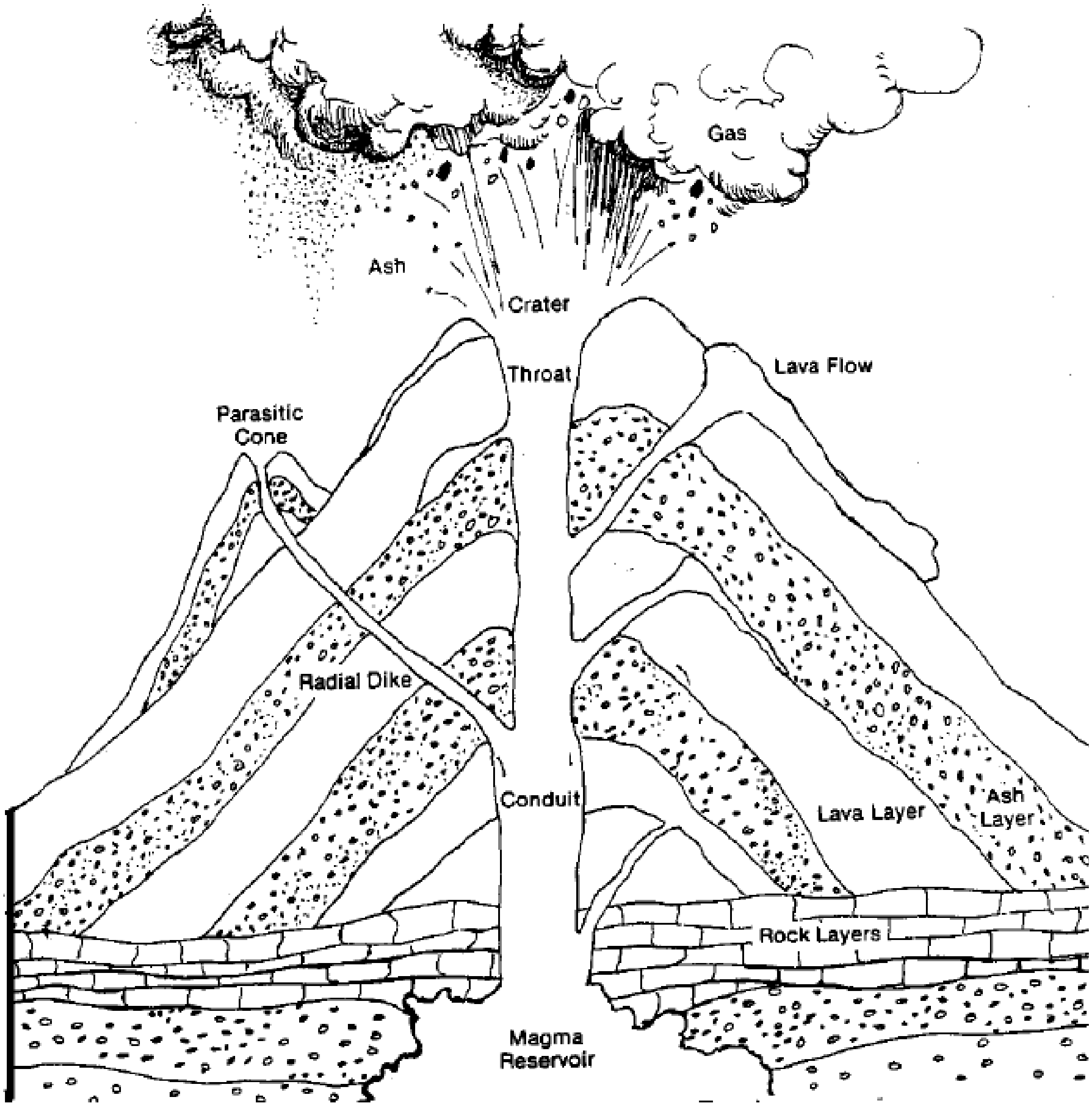
The Cascade Mountains



The Ring of Fire contains many mountain ranges. One is the Cascade Mountain Range. The Cascades extend from British Columbia, Canada to California. Not all the mountains are volcanoes. The volcanoes stand much taller than their surrounding mountains.

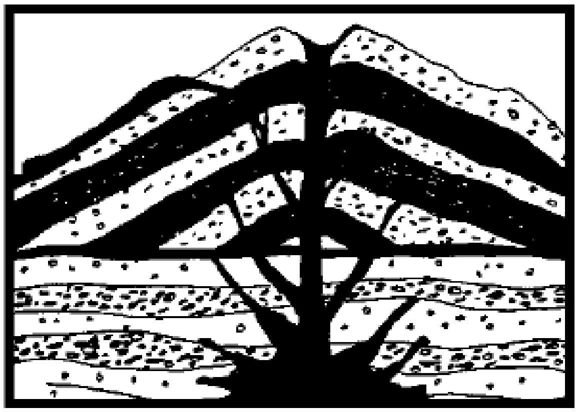
Student Information

A Look Inside a Volcano



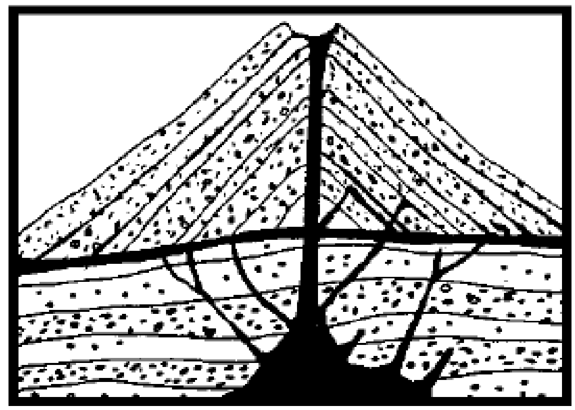
Look inside this volcano. Magma flows out of the volcano and becomes lava. When a volcano erupts more violently, tiny particles called ash are blown out. The lava and ash build up over the years forming this mountain, called a volcano.

What's the Difference?



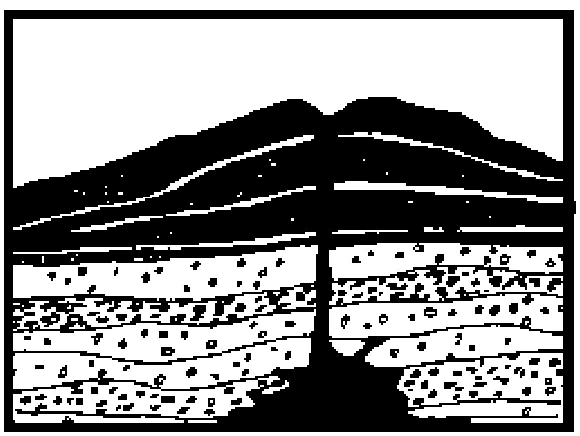
Composite or Stratovolcano

A stratovolcano is made up of alternating layers of ash and lava. Mt St. Helens, Mt. Rainier, Mt. Shasta, Mt. Hood and Mt. Adams are of this type.



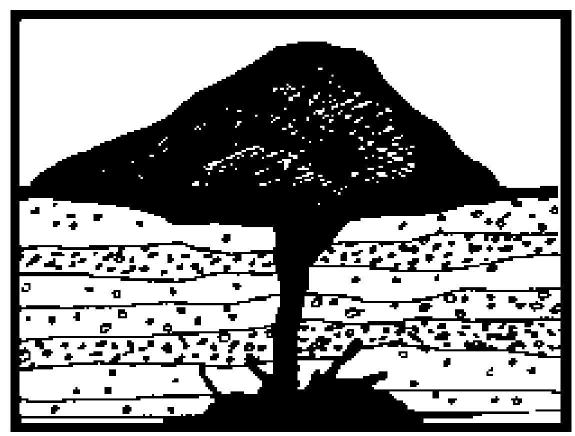
Cinder Cone

A cinder cone is made of many layers of broken rocks and ash. Wizard Island found in Crater Lake and Lava Butte in Oregon are examples.



Shield Volcano

A shield volcano is made of many layers of lava. This lava was very fluid when it flowed out of the volcano. Flow after flow piled up and formed a mountain with gentle slopes. The Hawaiian volcanoes are this type.



Lava Dome

A lava dome is made up of only a thick mass of lava that came through an opening. Lava just piled up and formed a dome, spreading out of the ground like toothpaste spreads out of a squeezed tube. Lassen Peak in California, is an example.

Student Information

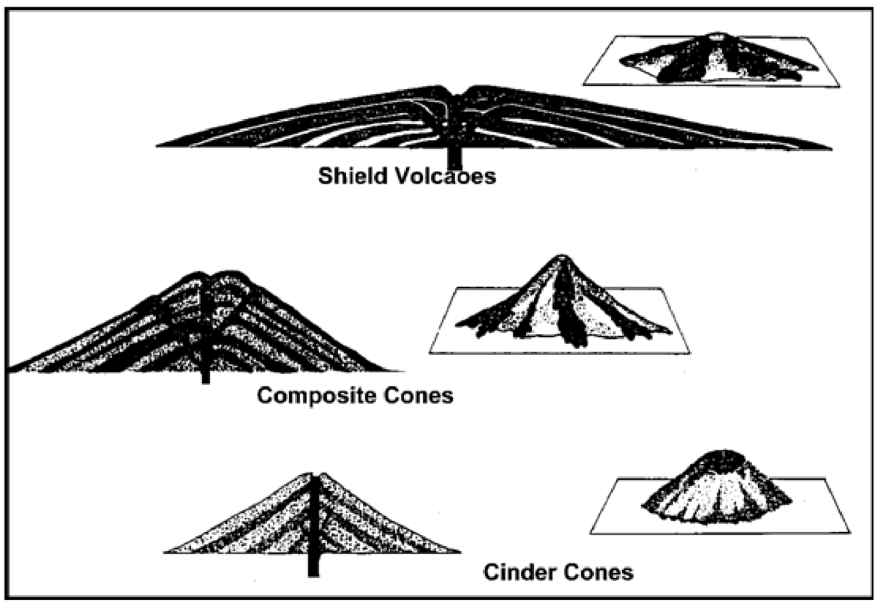
Types of Volcanoes

By Dr. Robert Christman and Robert Scott

Shield Volcanoes

Shield volcanoes have gentle slopes, like a shield, because they are composed of many gently dipping layers of basalt. This kind of molten rock flows easily to form thin layers sloping away from the crater. Some of the lava flows may originate along the flanks of the volcano. Shield volcanoes may be very large. The volcanoes that make up the Hawaiian Islands are good examples of this type.

Composite Cones



Composite cones consist of layers of both lava and cinder. The cinder causes the volcano to have steep slopes. The layers of lava cause the volcano to be more resistant to erosion. This kind of volcano may be very large. Most of the world's famous volcanoes, including Mount St. Helens, have composite cones. Many of these are composed of andesite which is an igneous rock having a slightly different composition than basalt. Andesite lava is more "sticky" than basalt and volcanoes composed of andesite are more explosive. Some are composed of dacite, which is even more "sticky" and explosive. The rocks of the May 1980 eruption of Mount St. Helens are composed of dacite. Volcanoes with composite cones are sometimes called stratovolcanoes.

Cinder Cones

Cinder cones are composed of fragments of volcanic rock that have blown out of the crater. When these land, the solid pieces of angular rock pile up around the vent to form a steep cone. Cinder cones tend to be smaller in size than the other two kinds of volcanoes. They are easily eroded away. The composition of the rock may vary. Some are composed of basalt, some are composed of andesite which, in a liquid state, does not flow as easily as basalt.

Student Information

Ropes, Pillows and Clinkers

Motion pictures make lava seem very scary. As lava emerges from the Earth, it appears red-orange, like fire. People do not need to fear the lava itself. Most lava moves very slowly. People can run or even walk away from the fastest lava flows.

Two common types of lava are given Hawaiian names:

Aa
(Pronounced ah-ah)

Aa is a rough, jagged lava with tiny spines. These jagged pieces of lava are also known as clinkers. The rough surface is very hard on the feet. If you slip and fall, you could cut your hands or tear your clothes.

Pahoehoe
(Pronounced pa-hoy-hoy)

Pahoehoe lava often looks like coils of thick rope. After it has cooled, the surface is smooth and easy to walk across.

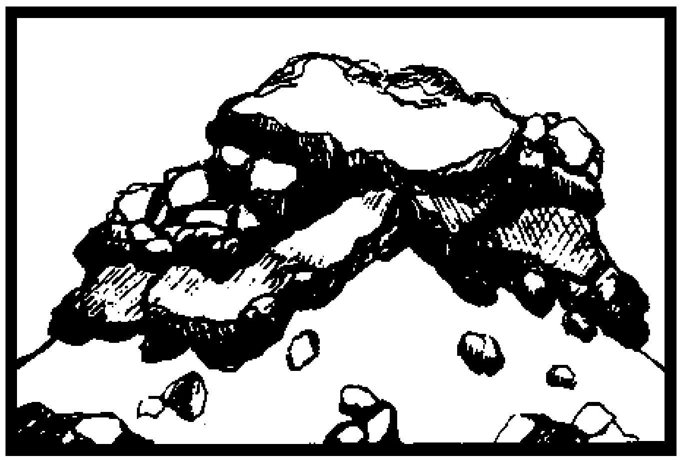
When the pahoehoe lava cools under water, it may look like pillows.

Student Information

Mountain on the Rise

Mount St. Helens lost its top in the big eruption, leaving a horseshoe-shaped crater nearly two miles across. Several smaller blasts followed.

Soon after the eruption a dome begins to grow in the crater.



The dome grows by internal swelling and by the formation of stubby lava flows or lobes.

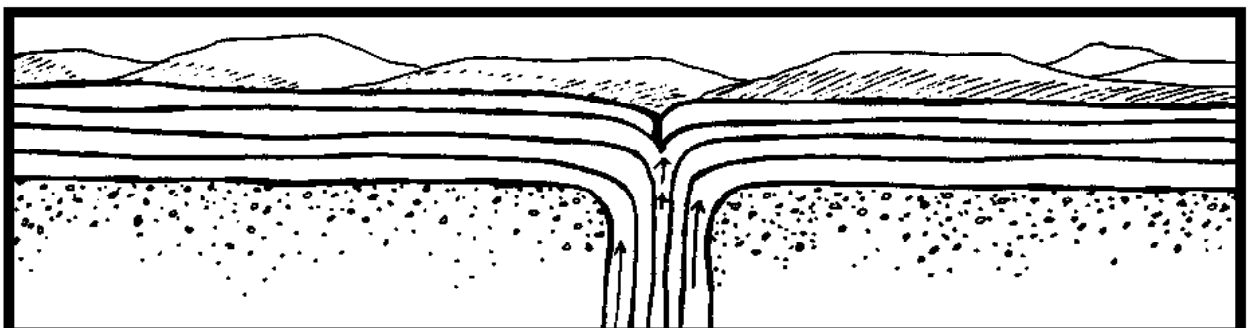
Since the fall of 1980, Mount St. Helens has had a series of **dome building** eruptions within the crater. Most of these have been nonexplosive with little or no ash. With each new eruption, magma is squeezed into the existing dome causing it to grow. Eventually the surface of the dome cracks and crumbles, allowing new volcanic material to flow onto the surface of the dome, forming stubby lava flows called **lobes**.

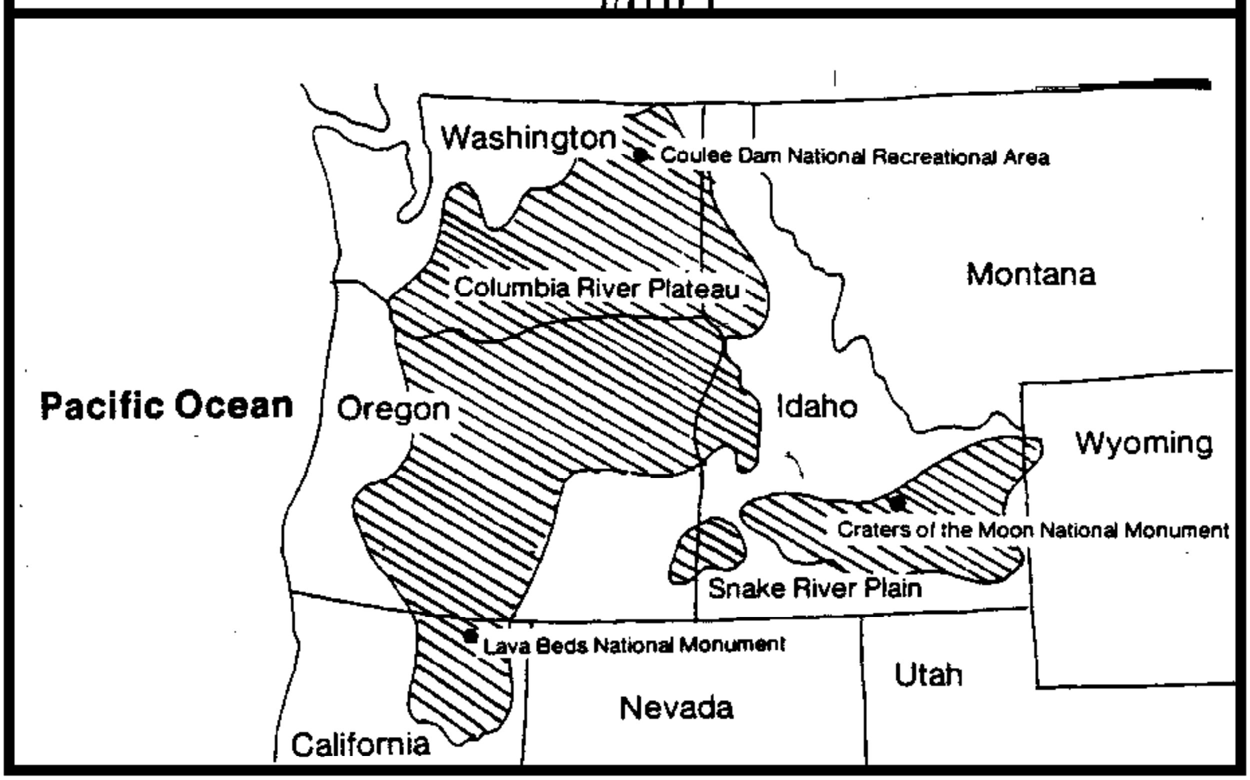
On August 26, 1982, the President of the United States signed a bill creating **Mount St. Helens National Volcanic Monument.**

Years later the dome is still growing.

East of the Cascades

East of the Cascades, lava has flowed from large cracks in the Earth, far from any volcano. Where the Earth's crust is weak, lava may pour out and spread over hundreds of square miles. This process is called a **fissure eruption** or **lava flood**. When the lava cools, it leaves flat areas called plateaus. Fissure eruptions occurred in the Pacific Northwest starting 30 million years ago, forming plateaus east of the Cascades. Almost 10,000 square miles were covered as deep as 5,000 feet.





Student Exercise

Volcano Building

The object of this exercise is for you to be constructive and creative. The assignment has two parts: a picture and text.

Part One: (20 Marks)

On a separate piece of paper (8 1/2" by 11"), you will draw a volcano. You must use the entire sheet of paper for your drawing (no postage stamps), and you must include the various features listed below. When you finish the drawing, name the volcano "Mount (your name)."

You may use any reference available to you, keeping in mind that the textbook may not be enough. You must label all relevant parts of your drawing, and colour it using felts, pencil crayons, or coloured pens. Be creative!

The following is a list of structures that must be included in your drawing. Where each is located and how each is oriented is up to you. All must be clearly visible and labelled!

Structures	
Gas cloud	Laccolith
Inactive Vent	Dike
Crater	Sill
Active Vent	Ancient Volcanic Neck
Lava Flow	
Magma Storage Chamber (located at base of vent in crust)	
Source of Magma (connected to magma storage chamber located in mantle)	

To start your drawing, draw a 20 centimetre line along the bottom of the page roughly 5 centimetres from the bottom. This line will be the Moho - the crust/mantle boundary. Make sure you clearly label the lithosphere and the continental crust.

Part Two: (10 Marks)

On a separate piece of paper, write an imaginary description of your volcano. In particular, describe:

a) The events leading up to the eruption (i.e. What were some of the warnings the volcano gave the day before the eruption?).

b) The nature of your volcano's eruption (i.e. What did your volcano look like when it erupted?)

c) What the area looked like following the eruption of your volcano. One sentence answers are not acceptable. Be creative! Staple the two pages with this assignment sheet on the top.

Epicentre Location (1)

This exercise compliments a lecture and discussion on seismic waves. Students first plot a Time-Distance graph from earthquake data provided, then use the graph to locate earthquake epicentres just as a real seismologist would do (or would have done prior to advances in technology).

Introduce the activity by showing your class an example (textbook or real) of a seismogram, the appearance of the different waves on it, and how arrival time is read. Plotting the graph for Part A is straightforward, but have an overhead showing the expected appearance on hand in case plots go awry. Math calculations required in Part B pose problems if students try to subtract time as hours, minutes and seconds on a calculator. Remind them that calculators operate in base ten and clocks do not! Provide each student with three maps. Please note that some photocopiers reduce the copy to 98% of the original and this changes the scale indicated. Compasses are required to draw the circles. (Buy a good set of compasses and keep them to yourself.) Ask your students to assemble the exercise in order before handing it in.

As an alternative to using this data, one could generate other epicentres by picking points on a map and finding the distances from three cities. Use those distances to find corresponding time difference in P-wave and S-wave arrivals from the Time-Distance graph and create clock times of those stations. (This is simply the reverse of the student activity.)

Student Exercise

Epicentre Location

Purpose: To study the relation between travel times for types of earthquake waves and to use that relation to locate earthquake epicentres.

Materials: Graph paper, compass, maps of North America

Procedures: This exercise is in two parts. In the first part, you will plot a "Time-Distance" graph of earthquake wave travel times. In the second part, you will use that graph to locate the epicentres of three earthquakes.

Part A:
A seismologist receives earthquake information with a device called a **seismograph**. This instrument records when earthquake waves arrive at the seismograph station. It cannot tell where or when an earthquake actually occurred. The first step in locating an earthquake epicentre is to prepare a "Time-Distance" graph.

The data in the table below is from a real earthquake. Create a Time-Distance graph by plotting this data on graph paper provided. Designate the x-axis **Distance From The Epicentre**, and label the y-axis **Arrival Times**. Number the axes to cover the maximum distance and time. Label the lines for the type of wave they represent. Plot and connect P-wave data to form one line. Plot and connect S-wave data to form a second line. Label both.

Arrival Time of Earthquake Waves

Recording Station		Distance from Epicentre	P-Wave Arrival Time	S-Wave Arrival Time
1.	Buenos Aires, Argentina	11 150 km	13m 55s	25m 32s
2.	Halifax, Nova Scotia	4 400 km	07m 38s	13m 45s
3.	Reykjavik, Iceland	5 660 km	09m 10s	16m 29s
4.	Marseille, France	8 510 km	11m 58s	21m 49s
5.	Edmonton, Alberta	820 km	01m 59s	03m 18s
6.	Los Angeles, California	1 740 km	03m 45s	06m 40s
7.	Ottawa, Ontario	3 520 km	06m 30s	11m 42s
8.	Azores	7 360 km	10m 56s	19m 48s
9.	Athens, Greece	9 710 km	12m 55s	23m 39s
10.	Anchorage, Alaska	2 060 km	04m 20s	07m 38s

Student Exercise

Questions: Part A

1. Describe the relative speed of the three types of earthquake waves (P, S, and Surface).

2. Describe the direction in which crustal materials move compared to the direction the wave energy travels for each of the three types.

3. Use the Time-Distance graph you have plotted to find the following:
   a. distance that P-waves would travel in 5 minutes.
   b. distance that S-waves would travel in 5 minutes.
   c. time it would take P-waves to travel 2 000km.
   d. time it would take S-waves to travel 2 000km.
   e. distance that the waves have travelled if they arrive 4 minutes apart.
   f. distance that the waves have travelled if they arrive 7 minutes apart.

4. What would be the time difference in arrival times at the epicentre?

Student Exercise

Part B:

A "Time-Distance" graph (T-D graph) enables a seismologist to easily locate an earthquake epicentre. The graph constructed in Part A is identical to one developed and refined by seismologists over many years and is applicable to all areas of the Earth's surface.

Earthquakes occur every day somewhere in the Earth. People do not notice most of them. All, however, are detected by **seismographs** around the world that are very sensitive to ground motion, and are recorded in continuous printouts called **seismograms**.

P-wave and S-wave arrival times can be read directly off a seismogram. The time difference between them can then be calculated and used to determine the distance to the epicentre from the T-D graph. The value read from the graph tells only the distance from the recording station, not the direction. All possible epicentre locations can be represented on a map by drawing a circle centred on the seismograph station with a radius equal to the distance from epicentre read from the T-D graph.

The exact epicentre location requires seismic data from three recording stations. Arrival time differences must be calculated and corresponding distances to the epicentre must be obtained from the T-D graph for each station. Circles with radii equal to those distances must be drawn on a map. The intersection of all three circles identifies the earthquake epicentre.

Use this method and your T-D graph to locate epicentres of three earthquakes. Draw the circles and mark the location of the epicentre for each on separate Equal Area Projection Map of North America.

Earthquake 1
Distances to the epicentre from three seismograph stations are known. Plot the great circles corresponding to these distances to find the epicentre.

Station	**Distance**
Edmonton	820km
Anchorage	2060km
Los Angeles	1740km

Student Exercise

Earthquake 2
Arrival times are given for this earthquake. Calculate the time differences and complete the table. Use them to find the distance from the epicentre on your T-D graph. Draw circles equal to the distances on the North America map. The times provided in the table are Universal Co-ordinated Time (UTC). What does this mean?

Station	Arrival Time		Time Difference	Distance to Epicentre
	P-wave	**S-wave**		
Edmonton	12:05:00	12:08:36		
Anchorage	12:01:24	12:02:24		
Los Angeles	12:06:30	12:11:35		

Earthquake 3
Arrival times are provided for this earthquake. Calculate the time differences and complete the Table. Be careful when subtracting these values and drawing the circles.

Station	Arrival Time		Time Difference	Distance to Epicentre
	P-wave	**S-wave**		
Edmonton	07:37:25	07:40:13		
Anchorage	07:39:25	07:44:01		
Los Angeles	07:40:25	07:45:49		

Student Exercise

Questions: Part B

1. How does the time difference change as the distance from the epicentre to the seismograph station increases? Why does this change occur?

2. What do all the points on the circle around the seismograph station represent?

3. Would it be possible to locate the epicentre with data from only one station? Explain.

4. How could the location be determined using just two stations?

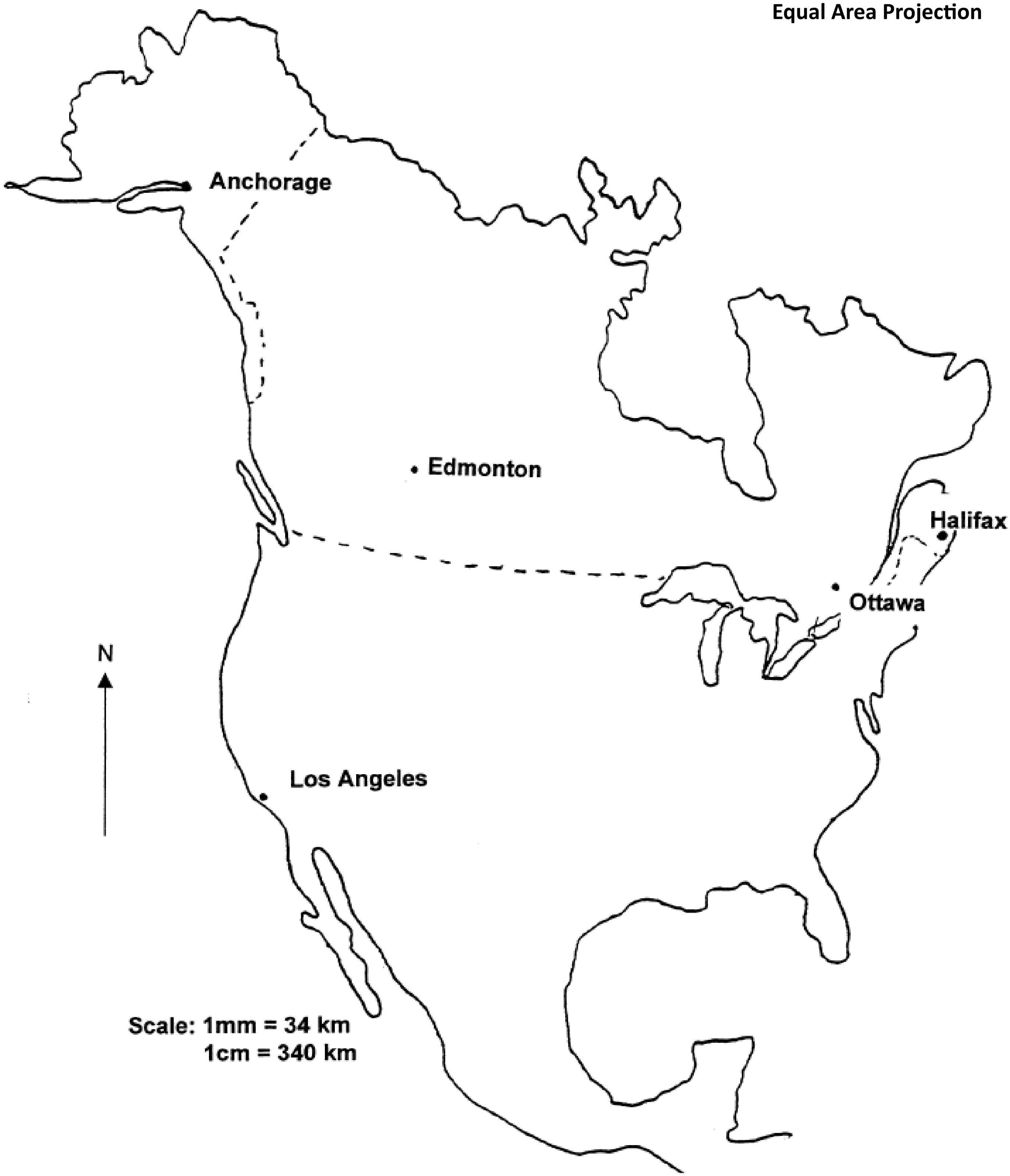
5. Why must three seismograph stations be used to locate the epicentre?

6. What are some reasons for determining the location of an epicentre?

7. How could the seismologist find the actual time an earthquake occurred?

8. What could happen if an earthquake occurred in the crust under the sea? Use the correct word!

Equal Area Projection



Teacher Information

Epicentre Location (2)

Including Magnitude and Intensity

Few subjects in Earth Science 11 and Geology 12 are as topical as earthquakes. For those teaching and living in the Lower Mainland, there is a sense of immediacy whenever discussion on this topic is initiated.

This exercise tackles the traditional activity of locating an earthquake epicentre (section R) and incorporates earthquake magnitude and intensity measurements. A table correlating Richter magnitude with Mercalli intensity on S-6 is useful as an overhead while discussing these concepts in class.

Students should have prior knowledge of P, S and L waves, and their differing velocities, as well as how and why S - P travel time differences occur, and the procedures necessary for plotting earthquake epicentre location. (See section R for the procedure.) In addition, the students should be familiar with contouring procedures. Although designated an Earth Science 11 activity, this exercise is equally appropriate for Geology 12 students.

Student Exercise

Epicentre Location (2)

Purpose: To locate an earthquake epicentre using magnitude and intensity data.

Background: Assume that you have woken up in the middle of the night to what sounds like thunder along with massive and violent shaking. It is an earthquake. You and your family scramble for cover as the shaking continues for about 45 seconds, knocking over lamps, books and shelving, shattering windows, and causing pictures to drop from their mounts as the drywall cracks.

Over the next few hours, information pours in from all over. The quake registered 7.3 on the Richter scale. All other information, including intensity readings and data based on seismic wave measurements, is included in this activity.

Materials:

- maps of Southwest BC showing the following locations:
  1. New Westminster, 2. Victoria, 3. Bellingham, 4. Hope, 5. Nanaimo
  and seismograph stations:
  A. UBC Geophysics, Vancouver, B. Pacific Geoscience Centre, Saanich,
  C. University of Washington, Bellingham
- compass

Procedures:

1. Examine Map 1. It shows the modified Mercalli earthquake intensity of one earthquake at several locations in Southwest BC and Washington State. Draw contour lines of intensity on this map, using an interval of two (even numbering, i.e. II, IV, VI, etc.) for each line. Note: contour lines never cross or touch each other.
2. Examine Map 2. It shows the location of three seismograph stations that recorded the earthquake. Using differences in P and S wave arrival times, the following distances from the earthquake to each location was determined:

Station A: 84 km	(U.B.C.)
Station B: 140 km	(Pacific Geoscience Centre)
Station C: 103 km	(University of Washington – Bellingham)

   a) Use a compass to draw the distance of the earthquake away from Station A on the map. Use the scale at the bottom of the map.
   b) Repeat 2(a) for each of the other two stations.
   c) Locate the earthquake epicentre at the circles' intersection and mark it with a red X.

Student Exercise

Questions:

1. a) At which locations was the intensity of the earthquake the greatest? ____________
____
b) Why do you think these locations showed the greatest intensity? _______________
____
____

2. Can you accurately determine the location of an epicentre using intensity data alone? Explain your answer. ____
____
____

3 a) Can you accurately locate the epicentre of an earthquake using one seismograph station alone? Explain your answer. ____
____
____

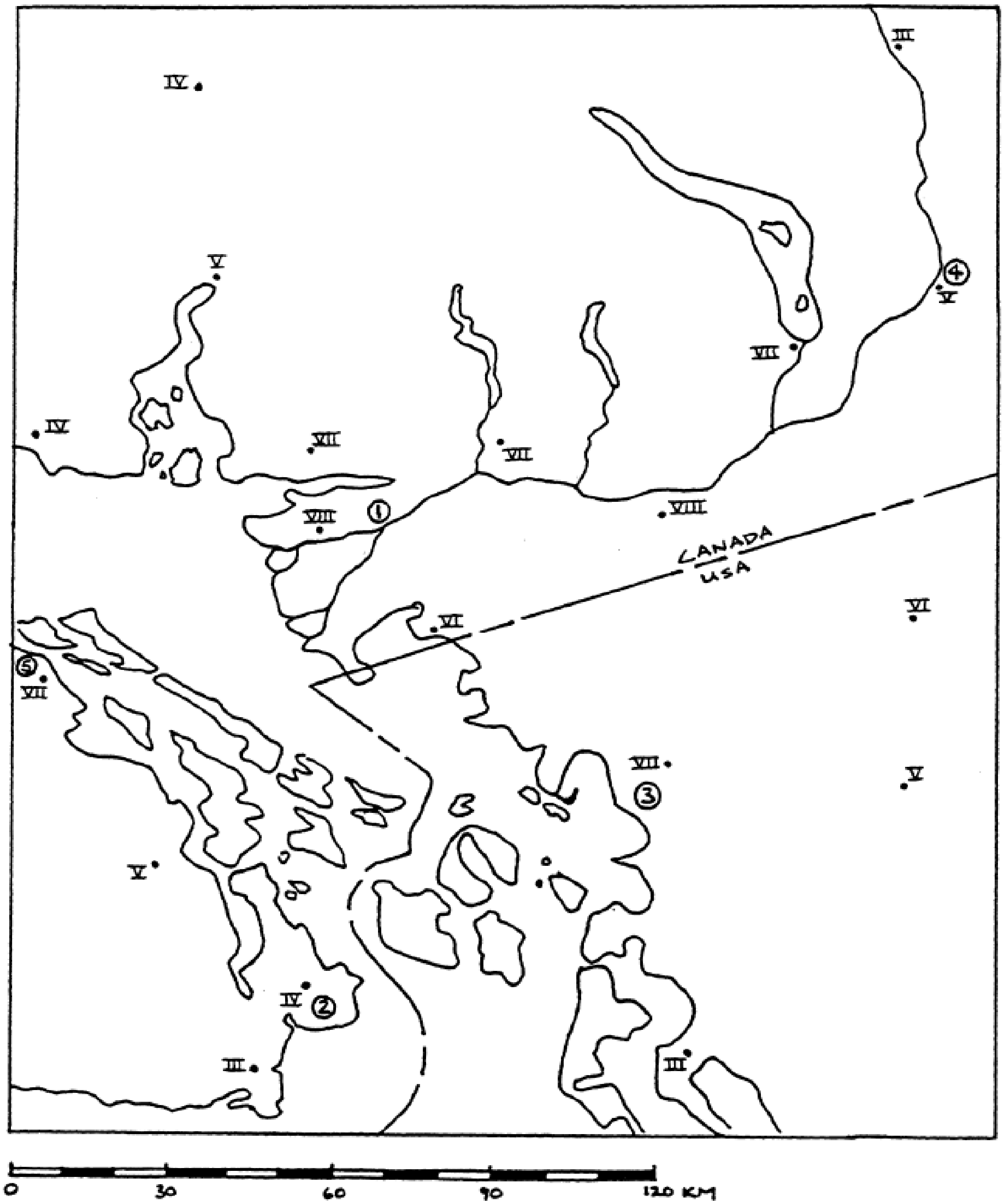
b) How many seismograph stations are needed to locate an epicentre? ____________

c) Describe a situation where more stations would be needed than you answered in (b).
____

4. As your distance away from the earthquake epicentre increases, describe what happens to:
a) intensity.
____
b) magnitude.
____

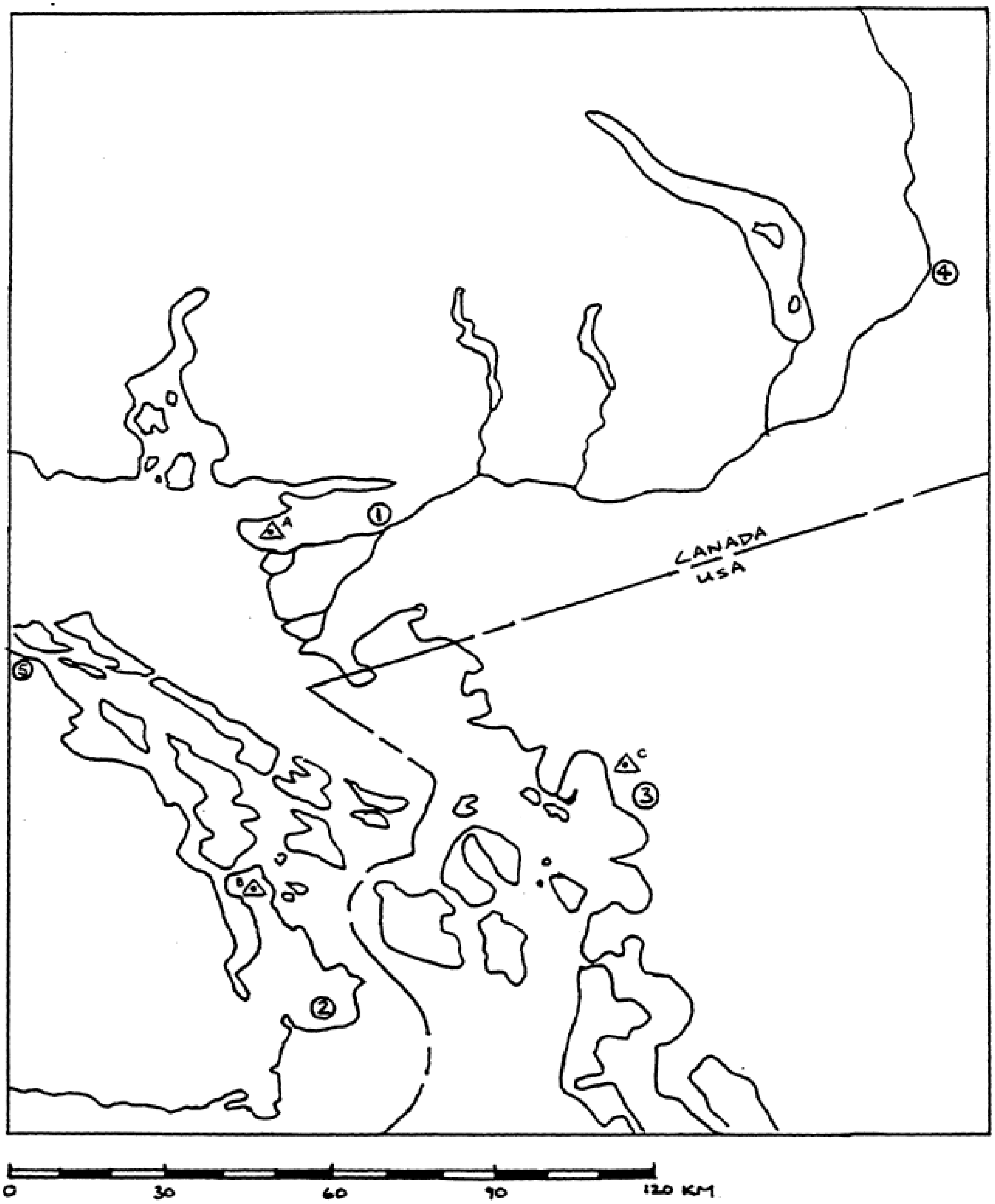
Student Exercise

Map 1: SW British Columbia & NW Washington with Earthquake Intensity Data



Student Exercise

Map 2: SW British Columbia & NW Washington Seismograph Locations



Student Exercise

Comparison of the Richter and Mercalli Scales

Richter Scale	Mercalli Intensity	Annual Occurrence	Approximate Energy	Ground motion at 100 km	Distance felt (km)
0	0	Many	Small car falling from a bridge	0.000000003 m	-
1	1	Many	Small dynamite charge	0.00000003 m	3
2	1.5	300,000+	1 t dropped from 2 km	0.0000003 m	7
3	2	49,000+	20 t TNT	0.000003 m	15
4	4	6,200	1 t dropped from 2000 km	0.00003 m	30
5	6	850	Hiroshima bomb	0.0003 m	70
6	7	120	Small hydrogen bomb	0.003 m	125
7	9	18	20 megaton hydrogen bomb	0.03 m	250
8	11	1	600 megaton bomb	0.3 m	450
9	12	0	1 million t dropped 2000 km	3 m	1000km +
10		None ever recorded	1 billion t from 2000 km – all rock would disintegrate	30 m	World-wide

Teacher Information

Earthquake-Proof Building Competition

The topic of earthquakes is always of great interest to students. Discussion of tectonic setting generally extends into discussion of structural damage to buildings. This is a serious concern, especially in urban areas where housing, infrastructure and public utility damage could be extensive. The influence of earthquake magnitude is one major factor, but the nature of the building substrate and construction materials is also extremely important.

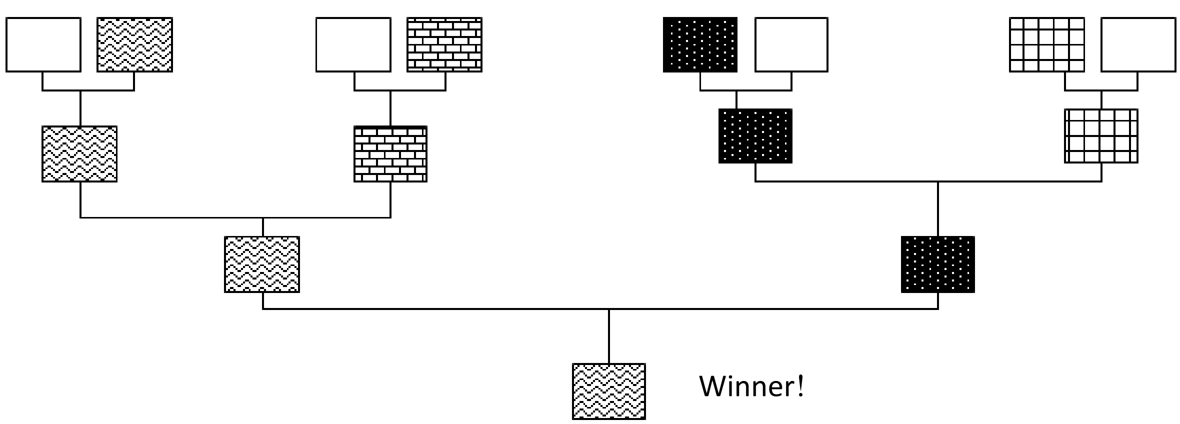
The following activity is designed to demonstrate 1) liquefaction of unconsolidated sediments during an earthquake and 2) how design and construction determine the extent of earthquake damage. It is particularly relevant to Lower Mainland students who must consider earthquake risk to buildings on solid bedrock, on unconsolidated glacial deposits, or on Recent river and delta sediments.

The teacher must construct the model of land as follows:

1. Fill a shoe box size or larger plastic container with fine to coarse sand.
2. Slowly add water to the sand until it is saturated (but not pooling on top).
3. Place the model on a giant orbital sander (sandpaper removed). This equipment is available in your school's workshop or metalshop. The sander will generate the seismic events for the building competition.

Students will work in pairs as they design and construct a model building using plasticine and a wooden skewer or toothpicks. Make sure they understand the constraints, and allow them one period to complete this stage.

In the following class period determine which building is most sound by pitting one team's building against another team's in the earthquake simulator and observing which building collapses first. Do a first order competition to create a second level of competition, then a third order competition, and so on until there is a winner!



Student Exercise

Names: _______________________

____

Earthquake-Proof Building Competition

Purpose: To construct a plasticine building which will survive the longest during an earthquake.

Materials: Bar of plastic modelling clay (Prang or Crayola)
Wooden skewer or toothpicks

Procedure:

1. Divide into groups of two.

2. Design and construct a plasticine building that will survive the longest during an earthquake. The foundation material for which you must design and construct the building is unconsolidated sand (e.g. Ladner, Boundary Bay or Beach Grove). The sand will be moistened, so liquefaction is imminent. Your group is allowed to use only 1 bar of plasticine and 1 wooden skewer. No other materials can be used.

3. Design the building on the back of this sheet first, then construct your building. Label special features you have included and write a brief description of their purpose. **This is to be handed in and marked at the end of class today.**

4. Your group will have 45 minutes to design and construct the building. Your building may be imbedded in the ground, but may not touch the bottom of the basin. At least **50% of your building** must be above ground, but its height cannot be less than 1 cm above the ground surface.

**DO NOT THROW ANY MODELING CLAY IN THE CLASSROOM
OR WE WILL STOP THIS ACTIVITY IMMEDIATELY.**

Question:

Describe the construction of the building that survived the longest during the simulated earthquake. Consider things like the type of design and features that helped it survive.

____

____

____

____

Teacher Information

Depth of Focus

The analysis and interpretation of earthquake foci distribution was essential in constructing plate tectonic theory in the 1960s and 70s. Similarly, in this activity students plot earthquake foci depth data from the western Pacific and see for themselves the evidence for subduction in the third dimension. Comparison of their plotted data with data from western South America, another convergent boundary, further demonstrates differences in subduction angle as determined by rate of subduction, age and temperature of the subducted lithosphere and composition of the overriding plate. These graphic representations of the earthquake data really make the students think about and visualize convergent boundaries in three dimensions. Together with the Volcano and Earthquake Distribution exercises (ESCI section P) this activity furthers the students' understanding of plate tectonics.

This exercise was adapted from "Spaceship Earth" (Houghton Mifflin, 1973). It was originally part of the Teacher Resource Package provided by the Ministry. There may still be a copy in your school. This exercise can be completed in one class period. Review it along with earthquake and volcano section, and follow with a quiz on all materials.

Student Exercise

Depth of Focus

Purpose: To study the distribution of earthquake foci at depth in the lithosphere.

Procedures: The data in the table below represent the locations of 20 earthquake foci under Japan as measured in depth and distance east from Asia. Place a dot on the graph provided (U-3) to indicate the location of each focus. Can the dots be joined in one line or do they cluster?

Earthquake Foci Under Japan

Depth (km)	Distance East (km)	Depth (km)	Distance East (km)
55	600	125	650
300	490	280	520
375	425	410	400
405	350	75	625
240	625	60	675
500	60	300	300
305	375	100	700
150	625	40	650
305	400	410	425
75	625	50	825

Questions:

1. Describe the pattern of the foci.

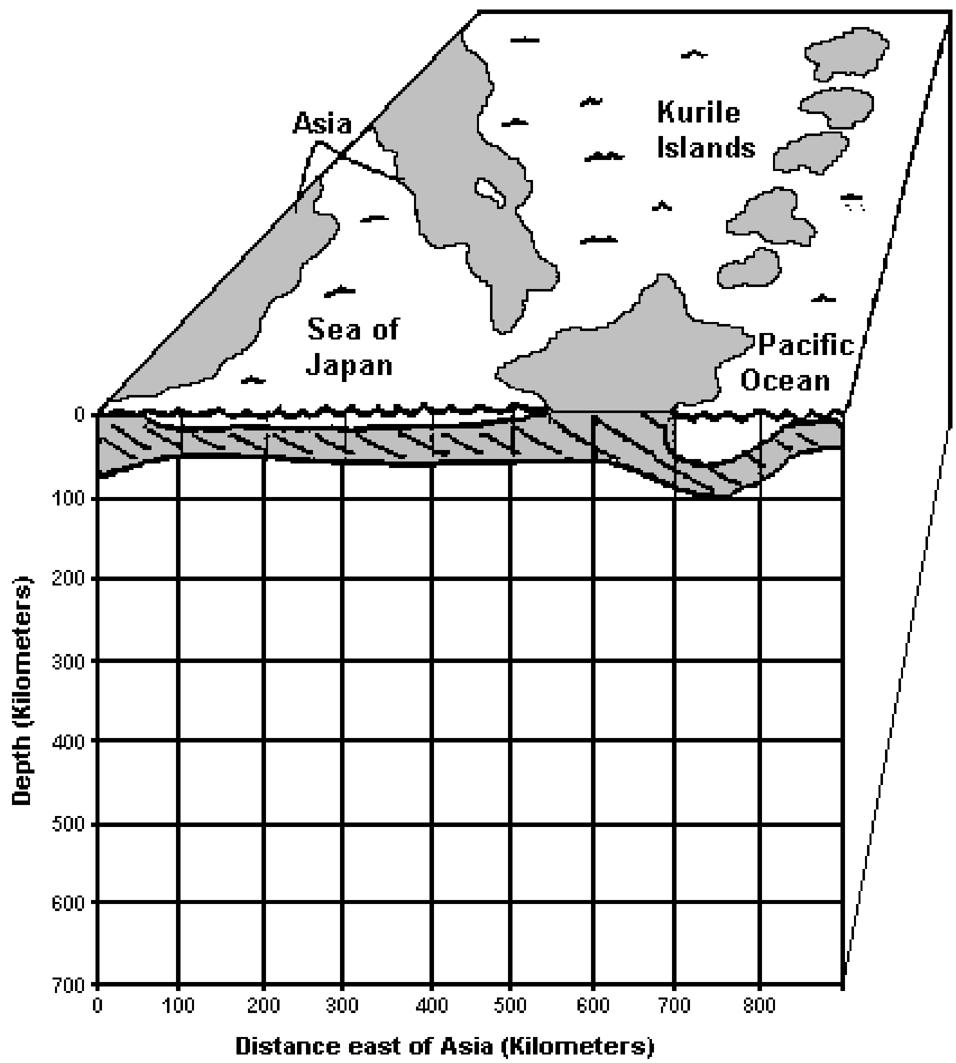
2. Which foci are most likely to cause damage to cities? Explain your answer.

3. Suggest a reason for the pattern of foci. What must be happening in this region of the Earth?

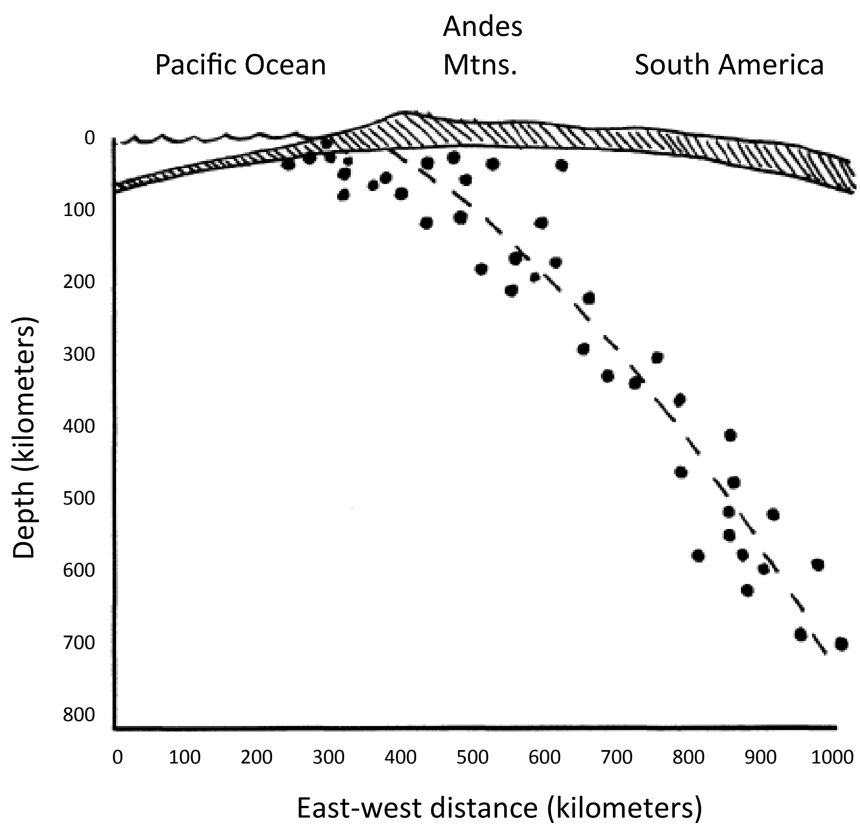
4. Are all of the foci in the lithosphere? What questions does this raise about the interior of the Earth?

5. The diagram on U-4 shows earthquake foci under South America. Compare this pattern to the one you just plotted. Compare in terms of direction, angle, curvature, and land forms.

Student Exercise



Student Exercise



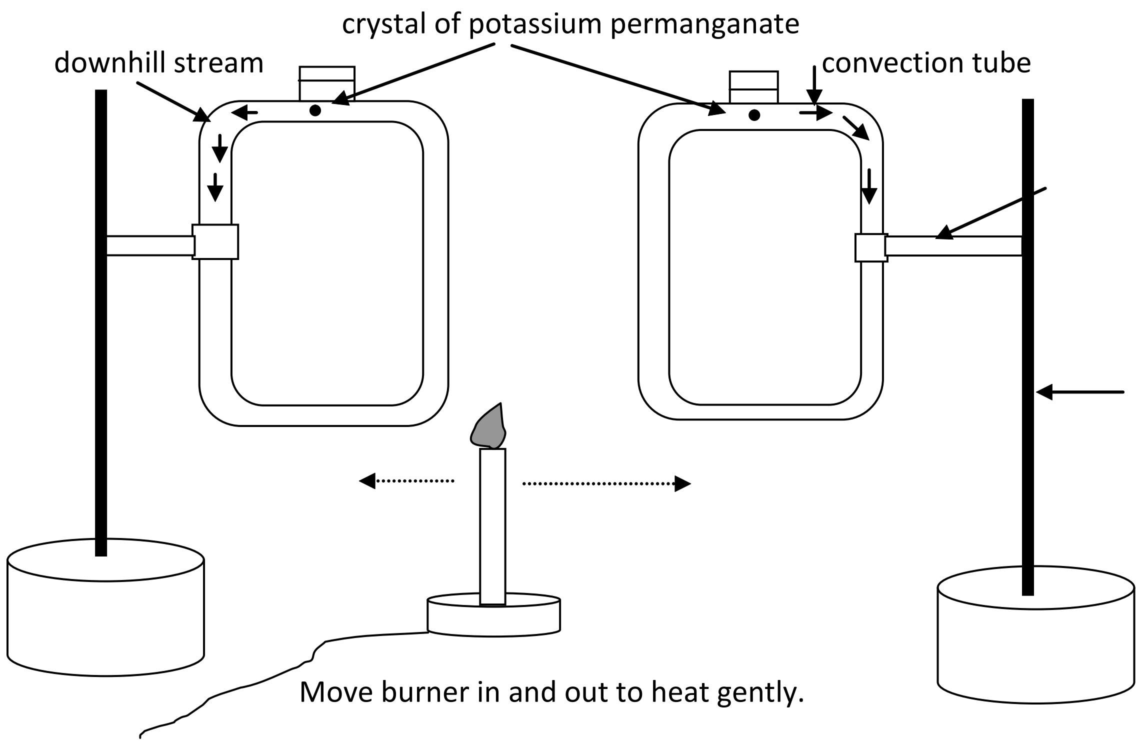
The foci of the earthquakes under South America seem to trace out a line.

Teacher Information

Ridges, Trenches & Rate of Plate Movement

Three activities included here accompany lectures on plate tectonics. They are designed to demonstrate where active plate boundaries are located, how rapidly plates move and what happens to excess material.

An introduction to Earth dynamics can begin with theories that the Earth is expanding or contracting. Students should be able to explain what they would see if Earth were expanding or contracting and reject the two possibilities. Explain the more likely convection cell mechanism. It can be simply demonstrate by placing a small jar with a small opening containing very hot, dyed water in a bowl of icy cold water. Movement of the coloured hot water simulates a convection cell. It can also be demonstrated with two convection tubes available from a science supply company. Support them side by side and heat the bottom gently. Convection will be more visible if a crystal of potassium permanganate is dropped in at the top. **Do not stir**. Caution: wash the tubes after use to prevent the dye from staining the glass.



The "Mid-Atlantic Seafloor Profile" (V-3) involves plotting the profile of the seafloor to define the Mid-Atlantic Ridge. Rolls of graph paper can be purchased from drafting supply companies, but they are not essential. Metric paper ruled 10 lines per centimetre works as well. By trimming the top margin off 4 of 5 sheets, the students can tape them together) top to bottom) to make one long sheet. This exercise, including the demo, takes about one and a half periods.

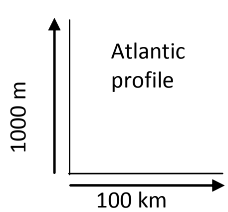
Teacher Information

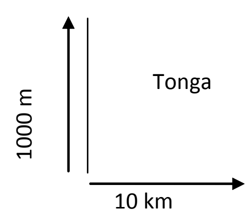
It is valuable to expand the discussion of mid-ocean ridges by asking where they are located. Ask the students to find the ridge named after a company. Find one named after a person. Is there one near BC? Ocean Floor Maps from the National Geographic Society are great sources for this information. (Ask your librarian for the catalogue.) These maps are inexpensive, colourful and are available for individual oceans, as well as for the world. National Geographic Society also has posters on mountain building and plate tectonics. All of these make great wall coverings that you can encourage your students to examine by asking bonus questions based on them.

“Rate of Seafloor Spreading” (W-1) is a plot of magnetometer and age data from mid-Atlantic transits. Demonstrate how magnetic reversals are recorded in oceanic rocks by pulling two sheets of paper up between two desks. As you pull the paper (representing the oceanic plates) off to each side, colour newly created crust on both sides of the crack (ridge) with felt pen to define normal polarity. Indicate reversed polarity in younger “crust” by colouring with another coloured marker. Ask your students where the magnetic signature is created and why there is a symmetrical pattern on each side of the ridge. Tell them if the age of the stripe and its distance from the ridge crest is known, then the rate of plate motion can be calculated. Rate = distance/ time.

This exercise is straightforward. The calculated average rate is approximately 1.2 cm/year on one side and 2.4 cm/year for the whole Atlantic. To illustrate the rate, have them hold their thumbs up and look at the nail. It also grows at about 2.5 cm/year, which is about equal to the length from the top of the thumb to the first knuckle.

Seeing the evidence that ocean basins grow should prompt some brilliant student to ask, "What is going on elsewhere? Where does the extra crust go?" You've got them! Many creative ideas may emerge. Introduce them to trenches via the “Tonga Trench” exercise (X-1). It is similar to the Mid-Ocean Ridge plot, so easier for the students to complete. Two great bonus questions for this activity are: What country does Tonga belong to? Answer: The Kingdom of Tonga. What infamous uprising of a ship’s crew took place near Tonga? Answer: Mutiny on the HMS Bounty. Both exercises, the Atlantic profile and the Tonga Trench, show vertical exaggeration. The y-axis is stretched compared to the x-axis.





The Atlantic profile is stretched 100X. That means you would need 100X the space on the y-axis to represent a similar space on the x-axis. With Tonga the exaggeration is only 10X. The profiles are exaggerated to show changes in shape more clearly. Atlantic profile uses exaggeration as a bonus question. In Tonga it is a hard question that must be answered. The teaching in between is up to you.

Student Exercise

Mid-Atlantic Seafloor Profile

Purpose: To plot the profile of the Atlantic Ocean floor and to relate this profile to plate tectonics.

Procedures:

1. Trim 5 sheets of metric graph paper (10 lines to the cm) so that they can be joined together lengthwise to form one long strip of graph paper.

2. Label the x-axis, the long direction, **Distance in kilometres**. Use a scale of two major divisions representing 100 km (i.e. 2 cm: 100 km). Number from 0 km on the left towards the right. The left edge of the profile is the western shore of the Atlantic Ocean.

3. Label the y-axis, the short direction, **Distance in metres**. Use a scale of two major divisions representing 1000 m (i.e. 2 cm: 1000 m).

4. Plot the data. This is actual data from a survey done by ship. Depths are plotted from sea level down. Watch out for point #51. Join the points with straight lines as you plot them.

5. Mark in sea level and name all of the landmarks.

Student Exercise

Atlantic Ocean Floor Profile Data

Data collected by depth sounder on a transit from Cape Cod, Mass., USA to Gibraltar on the south coast of Spain.

Depth is in metres; **Distance** is in kilometres. (Consider the depths given to be negative numbers, unless otherwise indicated, and measured from sea level down.)

Point	Distance	Depth	Point	Distance	Depth
1	0	0	36	3075	4000
2	120	200	37	3090	4000
3	200	2700	38	3100	2400
4	400	3700	39	3190	1800
5	440	4400	40	3200	2900
6	480	4400	41	3525	3500
7	490	3700	42	2540	2700
8	500	4400	43	3550	3500
9	560	4600	44	3625	3700
10	580	1600	45	3630	2400
11	600	4600	46	3640	3700
12	640	4600	47	4025	4000
13	660	1800	48	4035	900
14	680	1800	49	4050	2700
15	690	3700	50	4090	1800
16	700	2700	51	4100	+500
17	725	4600	52	4110	2200
18	1375	4800	53	4190	2700
19	1390	3700	54	4225	4100
20	1400	4800	55	4425	4400
21	1850	4900	56	4500	4600
22	1875	3700	57	4750	4800
23	1890	4600	58	4760	5100
24	2075	4400	59	4770	5100
25	2090	1800	60	4780	4600
26	2100	4400	61	4825	4400
27	2210	4400	62	5150	4220
28	2420	4000	63	5160	200
29	2440	3500	64	5170	4200

Student Exercise

Point	Distance	Depth	Point	Distance	Depth
30	2450	4000	65	5390	4400
31	2850	3500	66	5625	4600
32	2900	3100	67	5675	4000
33	2960	2700	68	5875	3700
34	2975	1800	69	6050	2700
35	3060	2200	70	6075	200
			71	6100	0

Questions:

1. Describe the most common shape of the sea floor. (Most of the irregularities on the sea floor are small in size across their base.)

2. Sketch the feature located between 2900 km and 3300 km from Cape Cod. Name this type of feature. (Remember that this is a two dimensional cross section and the feature stretches for many kilometres.)

3. How does this feature relate to plate tectonics?

4. What is point #51? Use a map or atlas to find its name. What probably formed this feature?

5. **Bonus**: Is point #51 the true shape of this feature? Explain your answer.

6. **Bonus**: What is the vertical exaggeration of this profile? Draw point #51 with no exaggeration.

Student Exercises

Rate of Seafloor Spreading

Purpose: To study the method by which the rate of seafloor spreading can be determined.

Iceland Exercise

Data in the table was obtained using a **magnetometer**. This device was towed behind a ship and measured the intensity and orientation of the magnetism locked in the rocks of the sea floor. Earth's magnetic field has reversed direction several times in the geologic past. (Magnetic north flips to the South Pole and back again.) The ages of magnetic reversals from the past several million years are known from magnetic and age data from lava flows on land. Correlating that age data with other seafloor information allows the rate of spreading to be calculated.

Procedures:

1. Plot the magnetism data in the table below for each station by latitude and longitude on the map provided. Use the symbol given for each station; denote the age when provided with a subscript: P for present, and 10 for 10 my (my = million years).
   Example: O_p, O_{10}, or X_p, X_{10}.
   Note: the second station has been plotted for you as an example.

Data:

Station	North Latitude	West Longitude	Magnetic Orientation	Symbol	Age
1	58.0	28.0	reversed	X	
2	58.0	29.0	normal	O	10my
3	58.5	29.5	reversed	X	
4	58.5	31.0	normal	O	present
5	59.0	31.5	reversed	X	
6	60.0	32.0	normal	O	10my
7	61.0	33.0	reversed	X	
8	60.5	31.0	normal	O	10my
9	60.0	30.0	reversed	X	
10	60.0	29.0	normal	O	present
11	59.5	28.5	reversed	X	
12	59.0	27.5	normal	O	10my
13	58.5	26.0	reversed	X	
14	59.0	26.0	reversed	X	
15	60.0	24.0	reversed	X	
16	61.0	24.5	normal	O	10my

Student Exercise

Station	North Latitude	West Longitude	Magnetic Orientation	Symbol	Age
17	61.0	25.5	reversed	X	
18	61.5	26.0	reversed	X	
19	61.5	26.5	normal	O	present
20	62.0	27.5	reversed	X	
21	62.0	28.5	reversed	X	
22	62.0	29.0	normal	O	10my
23	62.5	30.5	reversed	X	

2. a) When the data is plotted, draw a best straight line connecting the stations of "present age". (The best straight line averages out the variations in movement at the points.) Where are the 10my stations located relative to this line?

   b) Now connect the 10my stations with a **dotted** line. Again draw the best straight line. (**Do not cross** the "P" line.)

   c) Where is the Mid-Atlantic Ridge located on this map? Explain how you know this. To which compass direction does it point?

   d) If you move at right angles away from the Ridge, how does the age of the rocks on the sea floor change? Why?

   e) Which direction(s) is the sea floor moving away from the ridge? Put arrows on the map.

3. a) When was the 10my line situated at the Ridge?

   b) How many kilometres have the 10my lines moved from the Ridge?

   c) What is the average distance that the 10my lines have moved from the Present line? ((Distance East + Distance West) + 2)

   d) Use this average distance to calculate the rate of seafloor spreading in cm/year of one side of the Atlantic Ocean.

Student Exercise

Questions:

1. Draw a line equal to the length of the rate of sea floor spreading calculated in 3d.

2. The sea floor is spreading on both sides of the Mid-Atlantic Ridge at this rate. Draw another line twice as long as the line in 1. It represents total spreading of the Atlantic sea floor in one year. Mark its length in cm.

3. How is the direction of Earth's magnetic field preserved in the rocks of the sea floor? What kind of rocks must they be?

4. Where would the youngest rocks of the sea floor be found? Where would the oldest rocks of the sea floor be found?

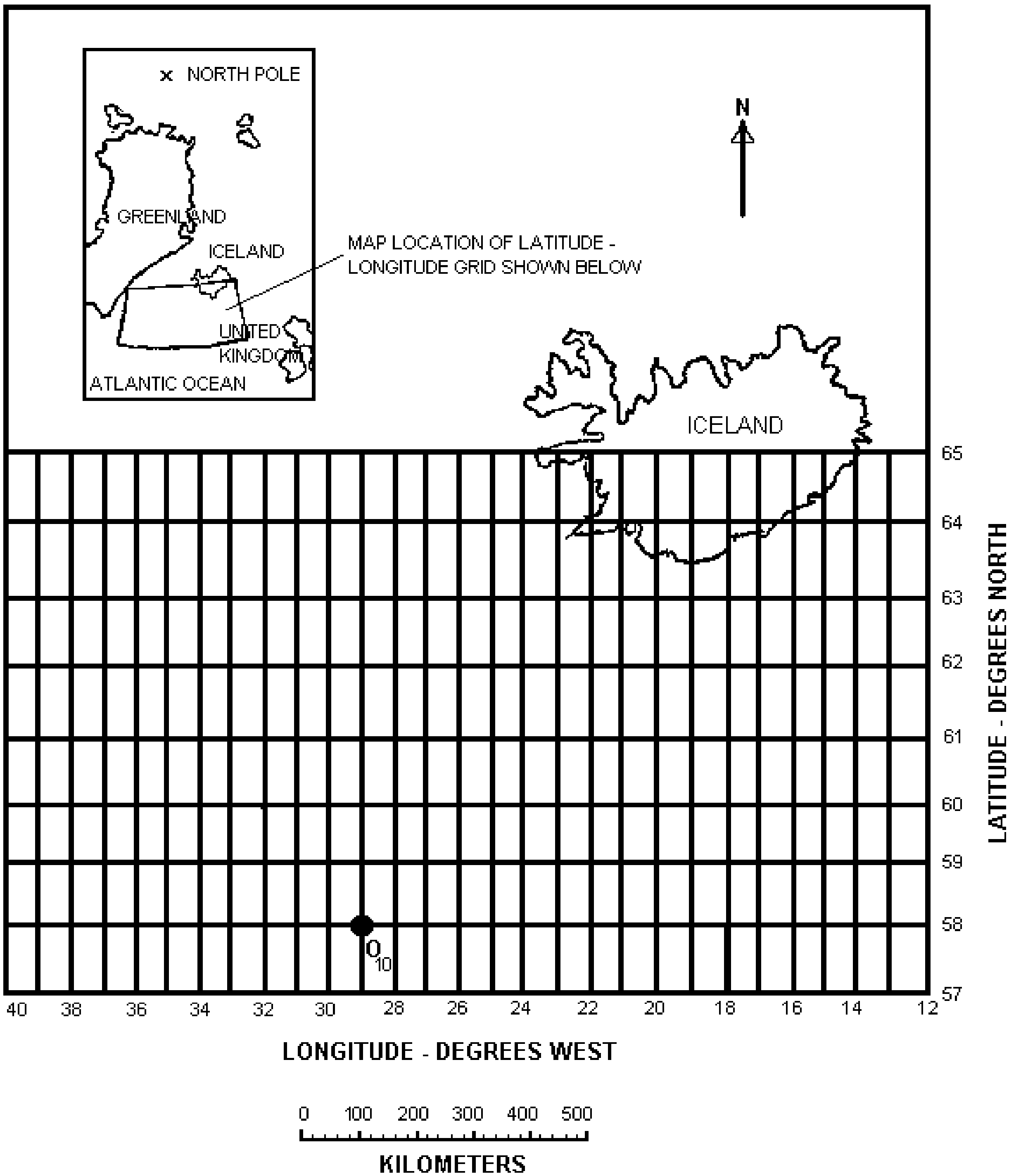
5. This type of spreading and ridge formation occurs more on the sea floor than on the continents. Why?

6. What is the driving force behind seafloor spreading?

7. Describe what must be occurring in the mantle.

8. **Bonus**: Draw a line equal in length to the amount of sea floor spreading in the Atlantic Ocean that has occurred in your lifetime.

Student Exercise



Student Exercise

Tonga Trench

Purpose: To plot a profile of the Pacific Ocean floor in the region of the Tonga Trench and to relate this seafloor topography to plate tectonics.

Procedures:

Data in the table below were taken by a **depth sounder** on a west to east traverse across the Tonga Trench in the South Pacific. The traverse crosses two islands, first Kao and then Lifuka. The Tonga Trench is located at 19ºS to 21ºS, 175ºW.

1. Trim 2 sheets of metric graph paper and join them to form one long sheet.
2. Label the x-axis (long direction), **Distance in kilometres**. Use the scale: 1 cm = 10 km. Start numbering from the left end.
3. Label the y-axis (short direction), **Depth in metres**. Use a scale: 1 cm = 1000 m. Start numbering at the top with +2000 m, and number downwards + 2000, +1000, 0, -1000, -2000, and so on.
4. Plot the data from the left end of the paper. This will be the **west** end of the profile.
5. Mark in sea level and label all **landmarks**.

Data:

(Consider the depths as negative numbers unless otherwise indicated)

Point	Distance (km)	Depth (m)	Point	Distance (km)	Depth (m)
1	0	2400	20	133	0
2	15	2350	21	140	400
3	20	2290	22	150	1425
4	25	2200	23	165	2400
5	32	2000	24	172	2800
6	45	1400	25	200	3800
7	50	1200	26	215	4400
8	55	0	27	225	4800
9	57	+1000	28	237	6200
10	62	0	29	250	8200
11	68	1100	30	257	9700
12	72	1440	31	260	9600
13	85	1445	32	270	7800
14	93	900	33	280	7000
15	100	50	34	290	6600
16	105	25	35	315	6000
17	110	10	36	330	5800
18	113	0	37	350	5800
19	125	+100			

Student Exercise

Questions:

1. How much deeper than the average depth of the ocean is the Tonga Trench? How does the depth of this trench compare to the height of Mt. Everest?

2. Compare the slope of the sea floor on the west side of the trench to the slope on the east side. Which side is steeper? Explain, in terms of plate tectonics, the cause of this difference.

3. Explain how Kao formed. Give a reason for your answer based on plate tectonics.

4. Where exactly is the Tonga Trench located? Sketch and label a map in the space below showing its location relative to its nearest major landmass.

5. What is the vertical exaggeration of this profile? On the far right end of your graph paper draw the 200 km to 300 km portion of the profile with no exaggeration (i.e. number both axes with the same scale).

6. Why are profiles like this drawn with a vertical exaggeration?

7. **Bonus**: The islands of Kao and Lifuka are part of Tonga. What country does Tonga belong to?

Teacher Information

Stereoscopic Vision

Learning how to read and use topographic maps is essential for geologists and useful for anyone who travels into the back country for recreation. Classroom introduction on this material is commonly omitted from ESCI 11 and is not required in Geology 12. It is worthwhile to expose your students to such maps and become comfortable using them.

The concept of topography can be brought into your class via an introduction to air photos and the stereoscope used to examine them. These tools are no longer used to construct topographic maps, but they are used together by exploration geologists (and other bush travellers) to locate themselves and map their courses of travel.

The following is a hands-on exercise that first introduces the nature of stereoscopic vision and three-dimensionality, and then involves examination of air photos. The book "Aerial Stereo Photographs" and stereoscopic glasses may be readily available from the Geography 12 teacher, but can be purchased from Northwest and other supply companies. Students at all levels enjoy examining the 3-dimensional photos. How rigorous their examinations should be is left to your discretion.

Demonstrations

1. Close one eye. Extend your arm out in front of you such that it is just above the level of the top of your head. Pointing your index finger down, try to touch the end of a partner's finger by moving your hand straight down to meet it.
2. Close one eye. Put your own hands in front of you. Can you tell by what you see which hand is closest? Open both eyes. See how your depth of vision appears.
   - Both eyes must view the same object at the same time.
   - The overlap in vision with two eyes provides depth to the picture.
3. Hold up your left hand and close your left eye. Move your hand to the left until it is out of sight. Hold that hand there. Now, close your right eye and move your right hand to the right until it is out of sight. Open both eyes. That is the area of overlapped vision.
   - Most predatory land animals tend to have stereoscopic vision with their eyes located on the front of their faces. Good examples are eagles, lions, and monkeys.
   - Animals that are preyed upon tend to have their eyes located on the sides of the head giving them a wider visual field. Good examples are rabbits, deer, and mice. (These animals tend to be first order consumers).

Teacher Information

Stereophotos

- They are used to give depth and steepness to a flat picture.
- They are two photos taken from the same altitude with about 60% overlap between the two exposures.
- Photo pairs are placed such that the same features are separated by about the same distance as the viewers eyes are separated. (The average is about 6.35 cm apart.)
- When they are viewed through a stereoscope, the image appears to be 3-dimensionsal.

Vertical Exaggeration Introduced by Stereophotos

- Objects in stereophotos appear taller than they really are. This affect results because viewers' eyes are 6.35 cm apart while most air photos are 203,200 cm apart.
- Horizontal scale of this photo is of 1/30,000.

Use of Stereoscopes

- Place the centre of each lens over the same feature on the two air photos.
- Rotate and move the glasses slowly until a sharp image appears in 3-D.

Stereophotos

See book: *Aerial Stereo Photographs*

Plate # 90 - Buildings (industrial complex)
Plate # 57 - Shiprock (volcanic plug)
Plate # 50 - Mt. Capulin (cinder cone)
Plate # 58 - Meteor Crater (meteor impact)
Plate # 18 - Longs Peak (glacier)

Oceanography (Turbidity Currents)

The following is an uncomplicated way to illustrate the motion and effects of a turbidity current. The procedure is straightforward and is a natural lead in to topics such as Ocean Processes and Mass Movement.

The demo fits the Oceanography Unit in the section on the origin of submarine canyons and continental rises. (This activity also fits with the PLOs on mass wasting.) It is advisable to prepare the students before the demo so that they are aware of seafloor features such as submarine canyons, continental shelves, etc. The student exercise that accompanies the demonstration has questions that refer to text readings. To complete the activity, students are required to make empirical observations, collect and analyze data and, from the analysis, make a logical interpretation.

Turbidity currents can operate in most aqueous sedimentary environments. Notably, they are the primary mechanism for transporting sediment off the continental shelves, down submarine canyons or across the continental rise, and onto abyssal plains. They operate on very gentle slopes and are capable of moving coarse material over tremendous distances. Turbidity current deposits, called turbidites, commonly have sole marks and graded bedding.

Student Exercise

Turbidity Currents

Purpose: To examine a model of a turbidity current.

Materials: 100 ml graduated cylinder; a small beaker containing a clay suspension; water.

Procedure:

1. Make a clay suspension by mixing a little cold water into a small amount of dry clay powder in a 50 – 100ml beaker. Use a stirring rod to mix it.

2. Fill up the graduated cylinder with warm water to near the top.

3. Tilt the graduated cylinder down so that it slopes at a 20°-30° angle.

4. Carefully pour the clay suspension into the graduated cylinder. Observe closely as it travels down along the side of the cylinder. Make a sketch of or describe in detail your observations in the space below. Use arrows to indicate the current direction.

5. Allow the suspension to settle. In the space below, sketch or describe the appearance of the sediment in the cylinder.

Student Exercise

Questions:

(Refer to Chap. 18 of the text, Earth Science, D. C. Heath & Co.)

1. In this model, what natural phenomenon did the water in the graduated cylinder represent?

   ____

2. What did the side of the graduated cylinder represent?

   ____

3. What is the name given to sedimentary deposits produced by turbidity currents?

   ____

4. What characteristic feature is found in these deposits? (Hint: Procedure 5 observations may be useful here.)

   ____

5. What features of the continental shelves are these currents thought to have formed?

   ____

6. Explain why this simulation works better when the water in the graduated cylinder is <u>warm</u>.

   ____

   ____

   ____

Drainage Basins

The following exercise was modified from one in "Earth Science - A Hands-on Science". Although intended for grades 7 to 10, the exercise is appropriate, useful and enjoyable, for both Earth Science 11 and Geology 12 students.

There are three main objectives:
i) to observe the random development of one or more drainage basins.
ii) to interpret the geological features of the landscape produced.
iii) to predict possible future changes in the basin.

The exercise is more meaningful to students who are already familiar with the concepts of streams, erosion and drainage patterns. As an excellent lesson on the changing nature of a river, it is a perfect launch into discussions on landscape engineering and planning, and on water use and water supply maintenance. The processes students will apply include observation, interpretation, inference, hypothesizing, graphing and prediction.

The activity can take up to one class period to complete. Go over the instructions clearly. Make sure they understand procedure 8 before they begin. They may finish everything the same day. However, students wishing to be more creative in their final presentation may need additional time.

The method for constructing the drainage here requires using a simple spinner. Alternatively, one could construct the drainage by throwing dice and drawing lines according to the following: “1” and “2” on the dice mean Right; “3” and “4” mean Straight; “5” and “6” mean Left.

Student Exercise

Drainage Basins - The Raging River

This activity demonstrates the potential erosional paths made by running water on the Earth's crust and the need for intelligent decisions regarding natural and man-made modifications to river channels.

Objectives:

- observe the random development of one or more drainage basins.
- interpret the geological features of the landscaped produced.
- make predictions regarding the likely future changes in the basin.

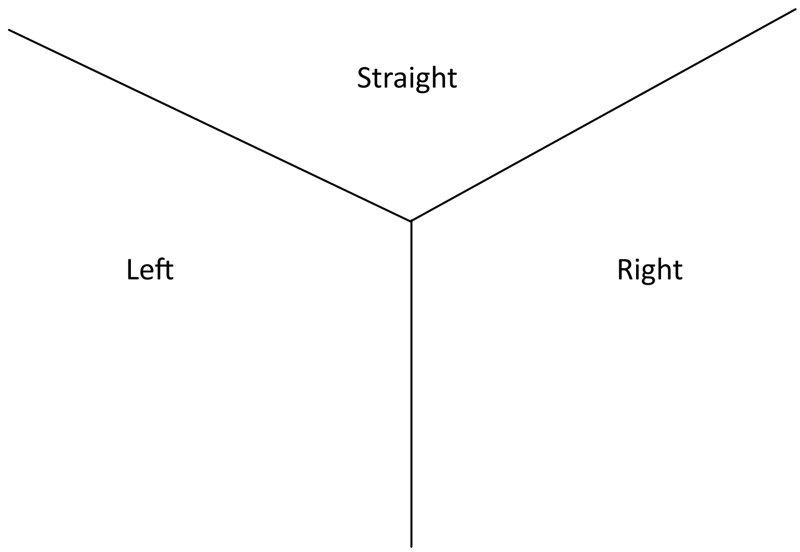
Required Materials:

- graph paper with a 1 cm grid (8.5” x 14” sheet)
- one paper clip per person
- pencils or pencil crayons

Procedures: (Read these completely before starting the activity!)

1. Tape 2 pieces of graph paper together (the long sides) to make 1 large graph.
2. Label the top of the paper "Highlands" and the bottom of the paper "Lowlands" or "Ocean".
3. Randomly place 20 pencil dots at any intersections of lines in the top 5 rows of the graph paper. Label the dots from “A” through “T” from the left to the right across the page. Each dot represents a source of running water like raindrops, spring water, or melting snow/ice.
4. Use a paper clip as a spinner to randomly determine your river flow. Hold the paper clip in place with a pen/pencil over the 3-line intersection (next page) on the figure. Flick the paper clip to see if the river is going to move to the LEFT, RIGHT, or STRAIGHT. If the spinner lands on the RIGHT, you will advance the river diagonally one square to the right. If the spinner lands on the LEFT, you will advance the river diagonally one square to the left. If it lands on STRAIGHT, you advance it one square down to the next intersection of lines.
5. Select dot “A”. Flick the spinner to determine which direction the river will flow.
6. After you have drawn a line for the first dot, go to Dot "B" and repeat Step 5 and continue until you have done up to Dot "T".

Student Exercise



7. After you have moved all of the dots once, go back to Dot "A" and continue spinning and extending the lines in the proper direction.
8. Whenever one stream merges with another, the streams combine and travel as a single but larger unit. If Stream “A” combined with Stream “B”, label the new stream “AB”. Now when you flick the spinner, you will move the line 2 squares. Each time streams combine, you add the letters and move the stream the same number as the number of letters.

   Example: Stream "FGJ" combines with stream "LNKM" to become Stream "FGJLNKM". If you spun to the Left on your next turn, you would move Stream "FGJLNKM" 7 squares diagonally to the left.
9. Continue working left to right until all streams come to the bottom (i.e. the Ocean). If a stream near the edge of the paper will extend off of the paper, just have it run to the edge and then turn back in.

Student Exercise

10. When the drawing is complete, do the following:
    a) Lightly shade in each drainage basin with a different coloured pencil and make up names for the principal rivers.
    b) Mark the "divides" between each basin in a red dashed line.
    c) Locate and name at least 3 towns or cities on your diagram. Think of good locations for a city.
    d) Identify any locations on your diagram where stream piracy might occur in the future as the result of spring runoff or other forms of erosion.

11. Using a scale of 1 cm = 1 km, determine the approximate **area** of each drainage basin.

12. Write a brief description of your river system and explain what kind of rock and terrain your river runs through. Explain why you located the cities where you did, and why you avoided other areas.

Student Exercise

Notes: Rivers and Drainage Basins

tributary:

- a stream that feeds or flows into a larger stream.

watershed / drainage basin:

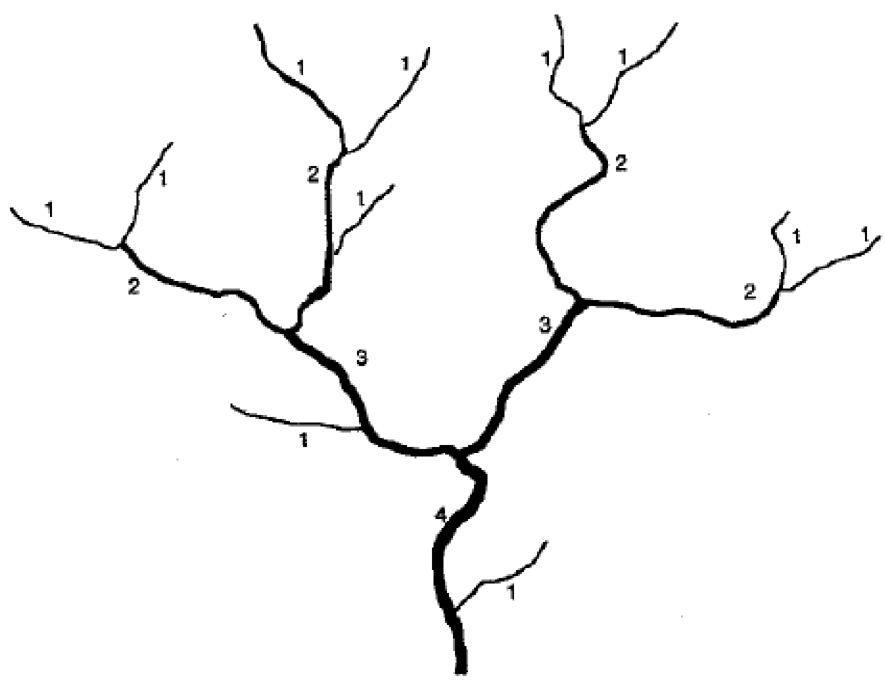
- the entire river system or area drained by a river and its tributaries.
- Watersheds are defined by a crest of a hill or by a continental divide.
- Precipitation that falls on opposite sides of a divide flows in opposite directions.

divide:

- an elevated boundary between areas that are drained by different river systems.
- The Rocky Mountains are a "continental divide", splitting the continent and sending water to either the Pacific Ocean or the Atlantic Ocean.

stream order:

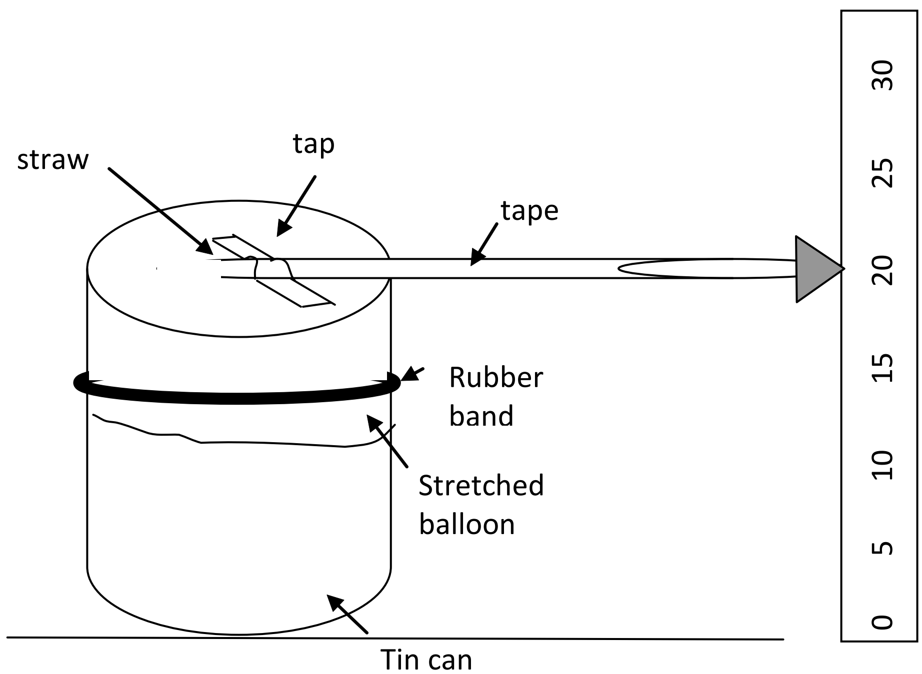
- a numerical classification of streams.
- The smallest streams that have no tributaries feeding into them are termed **first-order streams.**
- A **second-order stream** begins at the junction of **two** first-order streams. A **third-order stream** begins at the junction of two second-order streams, and so on.



Barometric Pressure

References to barometric pressure are familiar parts of our daily news. We acknowledge the correlation between pressure reading and weather systems. Most people, however, are not acutely sensitive to changes in atmospheric pressure, nor do they consider the physics involved.

The following lab is modified from one in "Invitations to Science Inquires" (published by T. L. Liem). Students first construct their own barometer (figure below). (Ask them to bring their own cans/ jars. Gather adequate supplies of other required materials before class.) Then they record barometric pressure changes over the course of a day and for an eight-day period. This activity effectively demonstrates to the students the weight of the air they breathe and provides the data necessary to recognize any patterns of pressure change (daily or long-term), and any correlation with temperature, humidity, precipitation and wind.



Student Exercise

Measuring Barometric Pressure

Atmospheric pressure is the force exerted on a unit area, such as a square centimetre, by the mass of the atmosphere as gravity pulls it down to Earth. An Italian mathematician working for Galileo invented the first barometer, an instrument used to measure atmospheric pressure. It became an important weather forecasting tool since changes in atmospheric pressure usually predict changes in the weather. There are two different kinds of barometers that meteorologists use to measure air pressure. A mercury barometer consists of a glass tube sealed at one end. The tube is filled with mercury and its open end is submerged in an open dish of mercury. The mercury falls to a level in the tube that is in balance with the weight of the atmosphere above the dish. The mercury column's height indicates the atmospheric pressure. The aneroid barometer is the barometer commonly found in homes. It has a sealed chamber with some of the air removed, which expands and contracts with changes in the atmospheric pressure. A pointer linked to the chamber, moves along a calibrated scale as the chamber changes in size.

We are going to be making a barometer and trying to predict the weather changes.

Materials:

- a tin can (500-850ml) with one end cut out or a wide-mouth jar
- a large balloon, 2 straws
- a ruler and masking tape
- poster board

Procedures:

Part A - Building the Barometer

1. Blow the balloon up to stretch it out, so that it is more sensitive to changes in pressure.
2. Cut a piece off the stretched balloon large enough to cover the open end of the can (or jar) and put an elastic around it to make it airtight.
3. Tape or glue two straws together. Cut a small poster board triangle and tape it to one end of the straws. Tape the other end to the centre of the balloon.
4. To measure changes in air pressure, hold the ruler upright next to the pointer. Write down the number on the ruler that the triangle points to.

Part B - Taking Measurements

Take two barometric readings each day for the next eight days and record them in the table provided. They should be taken at least 8 hours apart and as close to the same time each day. **All readings must be taken inside and at the same location**. When all data is collected, answer the questions on the following page.

Student Exercise

Questions:

1. What causes the straw to move up and down?

 ____

 ____

2. If the straw points upwards, what can you say about the air pressure?

 ____

 ____

3. If the straw points downward, what can you say about the air pressure?

 ____

 ____

4. Are there any regular changes (i.e. a pattern) between your morning readings and your afternoon readings?

 ____

 ____

5. Why did the readings have to be taken in the same place and inside?

 ____

 ____

 ____

6. What does increasing atmospheric pressure indicate for weather forecasting?

 ____

 ____

7. What does decreasing atmospheric pressure indicate for weather forecasting?

 ____

 ____

Student Exercise

8. List at least two sources of error that would affect your barometer readings.

____

____

____

9. What general conclusions about air pressures can you draw from this experiment?

____

____

____

____

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Student Exercise

Barometer Data Sheet

Location: ____

Date Readings Start: __________________ **Date Readings Completed:** __________________

Date	Time	Barometer Reading	Up or Down from Previous Reading	Present Weather Conditions	Approximate Outdoor Temp.
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					

Student Exercise

Date	Time	Barometer Reading	Up or Down from Previous Reading	Present Weather Conditions	Approximate Outdoor Temp.
9.					
10.					
11.					
12.					
13.					
14.					
15.					
16.					

Teacher Information

Fossil Phyla

The following materials are intended to simplify teaching Fossil Phyla to the students without replacing an entire biology class. Knowledge of certain phyla is required in the Learning Outcomes. Easily identified phyla are also subjects of questions on the Provincial Exam. The Geology 12 text does not address fossils. Information can be obtainable from a good Earth history book, including the lab manual "Interpreting Earth History". Line drawings and text on the following pages are distilled from voluminous information from several sources to a form you and your students can easily use.

The process of fossilization is well covered in "Interpreting Earth History". Guiding questions are easy to come up with to help the students recognize the fossilization methods. Let them pick out from Exercise 9 the three important requirements to become a fossil, the three main types of preservation and all of the ways organisms can be preserved. Real examples of each type are available from supply houses.

There are five information components in this section:

1. Pages A-2 through A-5 cover general information on fossilization processes and evolution.
2. Pages A-6 though A-9 summarize phylum characteristics and habitat.
3. Pages A-10 and A-11 are abbreviated glossaries of common palaeontology and sedimentology vocabulary.
4. Pages A-12 through A-14 offer simple drawings of fossils taken from “Interpreting Earth History”, 1982, Peterson, M. S. and Rigby, J. K. Photocopy them for your students and use them as overheads to give notes to the class on each phylum.
5. Pages A-15 through A-29 provide more detailed information on the fossil phyla, including any living relatives.

Include questions about fossils in your quizzes. Try to use the same format as is used on Provincial Exams. It will prepare your students for questions on fossil types, modes of living styles, methods of preservation, and other topics that commonly show up.
Note: The size of most organisms is not stated on the information sheets. Students will need a guide to possible sizes. The use of real fossils is ideal, but may be too expensive.

Teacher Information

Paleontology

Paleontology may be one of the most difficult topics for teachers to teach in the Geology 12 curriculum. Most reference material is more comprehensive than the intended learning outcomes require. Volumes of such detailed information naturally overwhelm most students.

The following pages (A-3 though A-5) are an informative and concise breakdown of the material necessary to cover the paleontology unit. An excellent companion graphic called "ME" is found in the BIOLOGY 12 text: *Biology*, by Creager, J. G., Jantzen, P. G., Mariner, J. L., 1985, MacMillan, NY. It has an exceptional graphic called "Major Radiations" that makes a quality overhead for this section. Do not forget, however, that such material is copyrighted.

Relative Dating with Fossils

William Smith's (1769-1839) principle of faunal succession states that fossil assemblages have changed over time and sedimentary rocks with the same assemblage of fossils are the same age. Fossils are used to determine the relative age of rocks. Fossils, therefore, allow geologists to **correlate** strata in widely separated localities.

Interpretation of the habitat and lifestyle of extinct fossils is based on the assumption that the same **natural** and **physical** laws have operated through all of geologic time. By observing present processes, the history and evolution of the Earth and its inhabitants can be understood. In geology circles, this is known as the principle of **uniformitarianism**, commonly summarized by the saying "The present is the key to the past".

Definition of a Fossil

A fossil is the remains of a living organism or any direct or indirect evidence of life preserved in the rock record. Most fossils are only partial remains of plants or animals, generally the hard parts like shells, skeletons, and teeth that are quickly buried and do not decay.

Fossils are only found in sedimentary rock. Why?

Processes of Fossilization

Living organisms mostly inhabit the relatively cool Earth's surface. They are not generally associated with igneous processes. (Exceptions now are found around hydrothermal vents associated with submarine volcanism.) High temperatures and pressures associated with metamorphism commonly destroy fossils.

Teacher Information

1. **Mold**:
   Over time, the hard parts of a buried organism may dissolve leaving a cavity in hardened sediment. The cavity is called a mold. Using a clam as an example, hardened sediment around the outside of the shell is identified as an **external mold**. Hardened sediment conforming to the shape of the inside of the shell is called an **internal mold**.

   Trapped insects are preserved as molds in amber.

2. **Cast**:
   This type of fossil forms when sediment or cement fills a mold and lithifies, which creates a solid duplicate. This is also the most common mode of preservation of many *trace fossils*, which are animal tracks or burrows in sedimentary rocks.

3. **Carbonization**:
   This involves removal of all elements in organic tissue except carbon, which is left behind as a film (e.g. leaf) or in bulk (e.g. peat).

4. **Permineralization**:
   The original hard parts have additional mineral materials deposited in pore spaces.

5. **Replacement**:
   Minerals in solution in pore waters replace original organic material as it dissolves or decays. Petrified wood, for example, is woody tissue replaced by silica.

Conditions Necessary for Preservation of "Soft" Parts

Soft organic tissues are subject to decay before lithification and to destruction during diagenesis. (Diagenesis encompasses all processes after sedimentation and during burial, at temperatures and pressures below metamorphism.) They are most commonly preserved as carbon films (carbonization) visible on split rock surfaces.

However, under unusual conditions, soft-bodied fossils may be well preserved. A world-class example is the Burgess Shale fauna preserved in outcrop near Field, BC, which was originally described in detail by Charles Walcott in 1909.

The shale was deposited approximately 520 million years ago during what is now designated the Cambrian Period. There was no life on land, and all the creatures were mostly small organisms that lived on the seafloor. Mudflows transported the Burgess fauna from their relatively shallow marine habitat, down an escarpment into deep water where they were rapidly buried by fine sediment. The water at depth must have been oxygen-poor, so there were no scavengers to feast on the transported animal bodies. As time went by, those sediments were buried by younger sediments, then compacted and lithified to form shale. Hundreds of millions of years later, the collision between western North America and a Pacific terrane caused the shale to be uplifted, forming part of an 8,000 foot peak in the Rocky Mountains. It is this unusual, detailed snapshot of life as it was 520 million years ago, soft tissue and all, that makes the Burgess Shale deposit so valuable. (Reference: Powell, W., 1997, A Geoscience Guide to The Burgess Shale: The Yoho – Burgess Shale Foundation, 37p.)

Therefore, the required conditions necessary for the preservation of soft tissue are:
1. **swift burial** of
2. **live organisms** in
3. deep, **low oxygenated water** followed by
4. **rapid burial and lithification** of sediment.

Another similarly rare fossil preservation is that of an Ice Age (Pleistocene) mammoth discovered frozen in ice with its flesh still intact.

Guide (Index) Fossils

A fossil that is widespread geographically but restricted in time, is useful in correlating rocks of the same age in different areas and is referred to as a **guide** or **index** fossil. The required characteristics of guide (index) fossils are:

1. They must be easy to identify and easy to distinguished from other similar fossils.
2. They must be found over a wide geographic area.
3. They must have a short time range so that they occur in only a few rock layers.

Recall that the **principle of faunal succession** is based on the principle that animal life forms change through time and that the same form is never exactly duplicated independently at two different times in history. Therefore, when exactly the same type of fossil organism is found preserved in rocks at different localities (regardless of rock composition), those rocks are the same age. Thus, age correlation between rocks exposed in different places is possible.

Why do life forms change through time? The fossil record preserves evidence of faunal succession as a result of the following (next page):

Teacher Information

Seven Principles of Evolution

1. **Divergence**:
   the separation of a single species into two or more groups exploring different habitats.

2. **Convergence**:
   two or more groups of different species become similar due to similar environmental demands.

3. **Adaptive Radiation**:
   the adjustment that a population makes to its environment over a period of time. When members of a single population undergo evolutionary divergence (successive generations become less and less alike), adaptive radiation is said to take place. (See Chart 15-7, in *Biology*, 1985, Creager, J. G., *et al*., MacMillan, NY.)

4. **Natural Selection**:
   survival of those organisms best suited to their environment.

5. **Extinction**:
   death of all the individuals of a species because of environmental changes. The extinction of intermediate species helps explain the wide separation between the major groups of animals.

6. **Punctuated Equilibrium**:
   a model of the mechanism of evolution that proposes that long periods of no change (status) are punctuated by periods of rapid formation of new species (speciation), followed by natural selection acting on the new species.

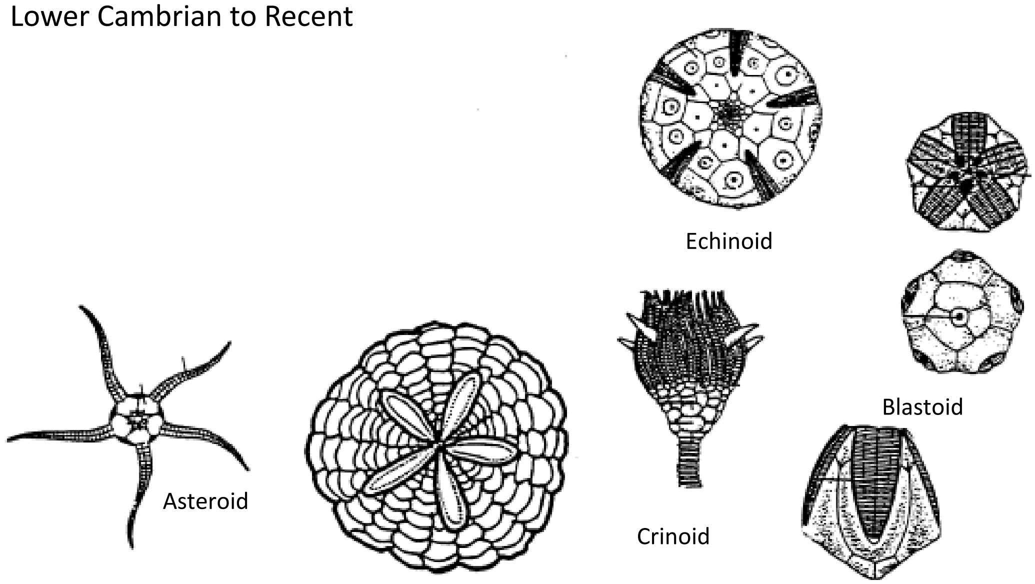
7. **Gradualism**:
   a model of the mechanism of evolution that proposes gradual changes in form in response to gradual changes in environment over a long period of time, give rise to new species.

Paleontology - Classifying Organisms

Kingdom, Phylum, Class, Order, Family, Genus, Specific Name

Students must be able to identify and classify fossils from the following phyla (or class):

1. **Echinodermata** (pronounced *ee kine o dermata*)
   - All are marine, most live on the sea bottom
   - Head and body form a single unit (not segmented)
   - Examples: sea cucumber, sea urchins, starfish
   - Three most important extinct classes, Cystoidea, Blastoidea and Edrioasteroidea
   - Lower Cambrian to Recent



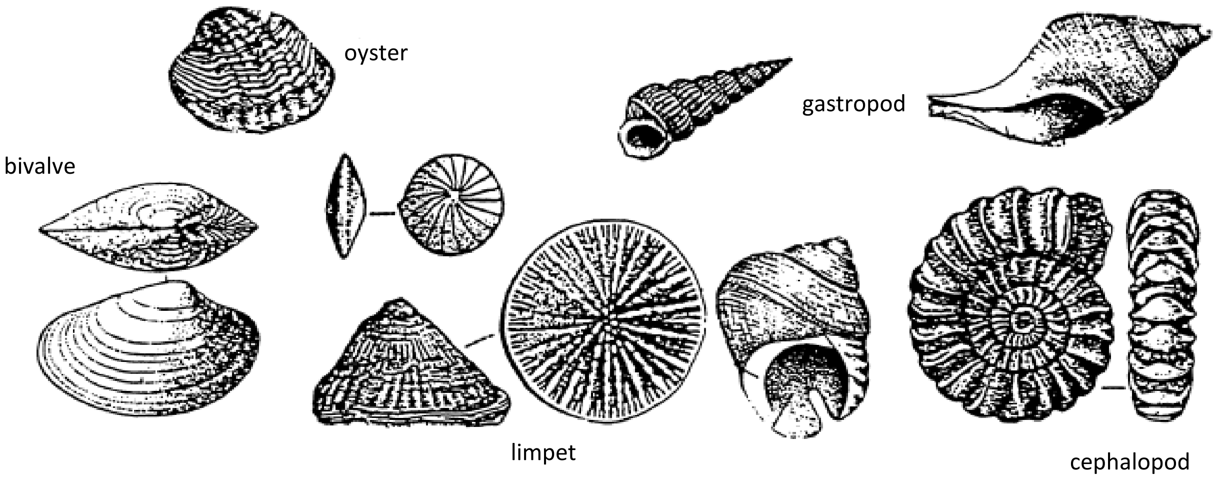
2. **Mollusca**
   - Most familiar of marine invertebrates
   - Almost all have shells that are readily fossilized
   - Most complete fossil record of any phylum
   - Dominate the marine fossil record in the Mesozoic and Cenozoic
   - One piece body

     e.g. **Gastropods** (snail): one shell, head (with eyes) and a muscular foot for locomotion.

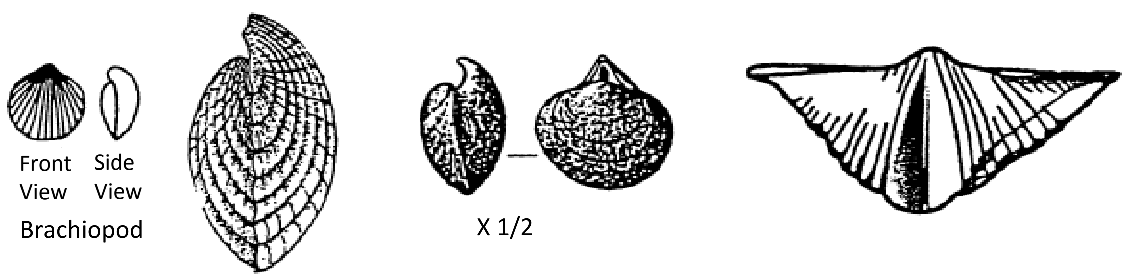
     Bivalves (oysters, clams, mussels): two shells, no head, muscular foot for locomotion; some are important as guide fossils.

     Ammonites (squids, octopus, Nautilus): one chambered shell or internal shell; well developed head with eyes and tentacles.
   - Lower Cambrian to Recent
   - Bivalves originated in the Cambrian, but did not diversify much until the Ordovician.

Teacher Information



3. **Brachiopoda** (Pronounced *brak ee o poda*)
   - Mostly marine; some brackish water
   - All have a shell with two valves; bilateral symmetry
   - Most have stalks to attach to firm objects
   - Good Palaeozoic guide fossils and useful indicators of paleogeography of ancient oceans
   - Relatively few (200) living species
   - Very diverse and abundant in the Paleozoic Era
   - Lower Cambrian to Recent



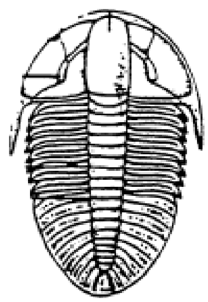
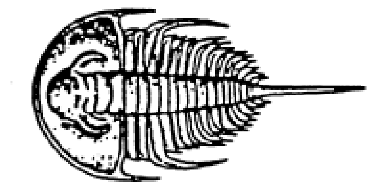
4. **Arthropoda** (means "jointed legs")
   - Diverse and abundant
   - External skeleton (exoskeleton) of chitin, segmented body, jointed appendages
   - Easily adapt to land and ocean environments
   - Cambrian to Recent

     e.g. **Aquatic**: crabs, shrimps, lobsters (crustaceans)

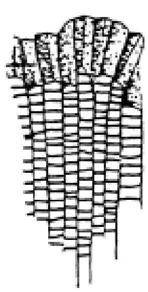
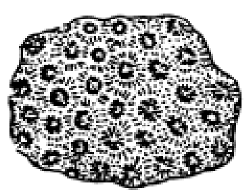
     e.g. **Terrestrial**: scorpions, spiders, millipedes, centipedes, insects

Teacher Information

5. **Subphylum Trilobita**
    - Diverse and abundant marine arthropods throughout the Paleozoic; good guide fossils
    - Global distribution patterns used to define **faunal provinces**. Strata with similar trilobite faunas are thought to have either been adjacent or in same climate belt or connected by ocean currents.
    - Only living relative is the horseshoe crab
    - Named for the three lobes along the length of their bodies
    - Most ancient visual system known
    - Cambrian to Permian


Trilobite


6. **Cnidaria** (Pronounced *nuh dair' ee a*) (formerly in **Coelenterata** (*suh len' terata*)
    - Simple, radially-symmetric, sack-like body with mouth usually ringed by tentacles (e.g. coral, jellyfish, hydroid, sea anemone)
    - Shallow, clear, warm, marine environment
    - Precambrian to Recent.
    - Calcareous coral skeleton well-preserved in the fossil record
    - Precambrian to Recent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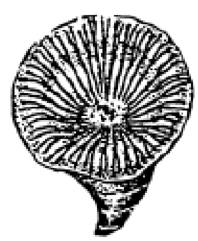
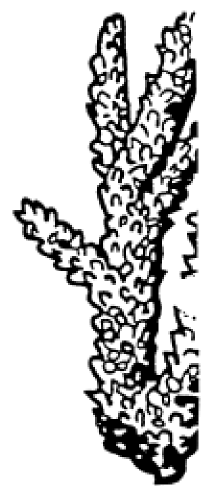
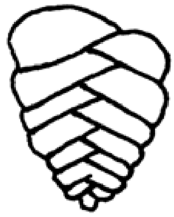
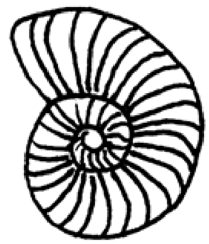



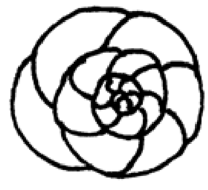
7. **Foraminifera** (Pronounced for *å men if' aira*)
    - Class in Phylum Protozoa (single-cell)
    - Marine organism with a shell (±chambered) of calcite or grains stuck together
    - Occur in great numbers in the ocean
    - Comprise chalk deposits that make up the White Cliffs of Dover (England)
    - Cambrian to Recent



Textularia

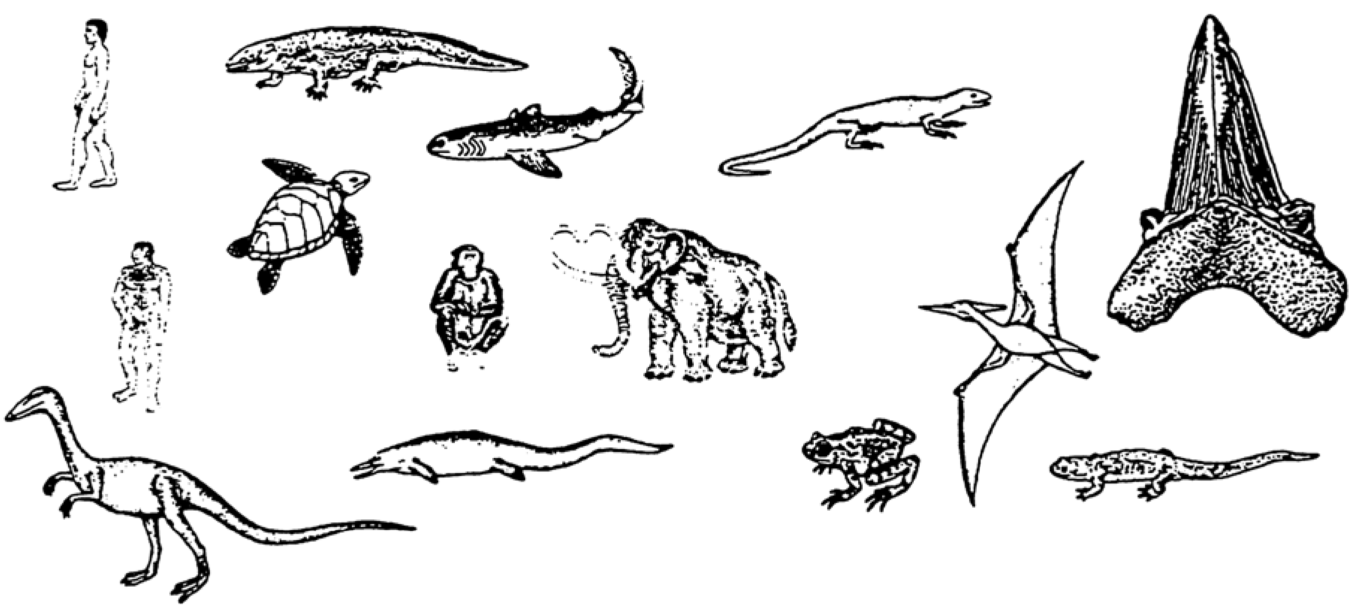


Operculina



Discorbis

7. **Vertebrates**
   - Organisms with backbones
   - Most familiar animals on Earth (e.g. fishes, lizards, frogs, snakes, birds and mammals)
   - First forms were fish, found in Lower Ordovician rocks
   - Much more rare than invertebrate fossils. Most vertebrate specimens are relatively large and small in number, so relatively rare. Bodies are scavenged before being entirely covered with sediment. Bones of terrestrial creatures become scattered.



Paleontology Vocabulary

Appendage: a jointed limb, like a leg

Bivalve: a shell composed of two parts (valves)

Calcareous: composed of calcium carbonate

Calcified: impregnated with calcium carbonate

Carbonaceous: composed mainly of the element carbon

Chitin: a durable organic substance that forms the arthropod exoskeleton

Fauna: animal life of a region, during a period of time, or in a particular geological unit

Flora: plant life of a region

Invertebrate: multi-cellular animal lacking a backbone

Marine: lives in seawater

Shell: the external skeleton of a mollusc or brachiopod

Skeleton: the hardened internal or external part of an animal providing support or protection

Steinkern: an internal mold of a shell, free from the surrounding matrix

Terrestrial: lives on land

Valve: one or two separate parts of a shell

Vertebrate: animals possessing a backbone composed of vertebrae

Whorl: one complete turn of a coiled shell

Teacher Information

Sedimentology Vocabulary

Aqueous: pertaining to water

Benthic: bottom dwelling

Brackish: salinity values between freshwater and normal marine

Carbonate: sediment made of calcite derived from fragments of calcareous plant or animal skeletons

Clastic: sediment made of fragments of pre-existing rocks or minerals

Deltaic: of, or pertaining to deltas

Eolian: formed by, or related to wind action

Fluvial: of, or pertaining to rivers

Hadal: ocean bottom at depths below 6500m

Littoral: shoreline region between high and low water (intertidal)

Lacustrine: pertaining to, or produced by a lake

Marine: of, pertaining to, or caused by the sea

Temperate: having a moderate climate

Tropical: a warm humid climate found 23^{o} either side of the equator

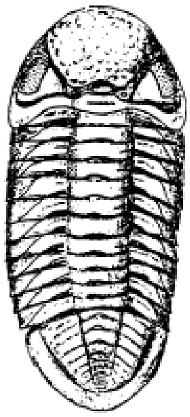
Other Terms Used:

Shallow sea – generally refers to depths at which normal waves affect the sea bottom and at which sunlight penetrates the water column. Some shallow marine features include ripple marks, cross-bedding, abundant burrows, skeletal limestone, and algae.

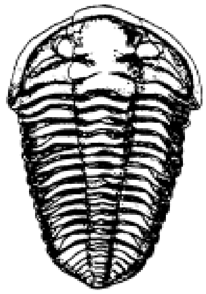
Deep sea – generally refers to depths below storm wave base where sediment either rains out of the water column or is transported in and deposited by turbidites.

Alluvial fan – a fan of clastic debris deposited by intermittent rivers and debris flows at the base of a relatively steep slope. Some alluvial fan indicators include poorly-sorted conglomerate, stratified sands and gravel, and terrestrial plant fossils.

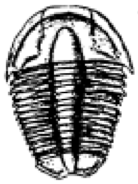
Delta - fine sediment deposited rapidly where a river meets a standing body of water. Indicators of a delta may include fluvial and marine features such as channelled sandstone, laminated shale and ripple cross-laminated very fine sandstone, terrestrial plant material and coal, and freshwater, brackish water and marine shells.



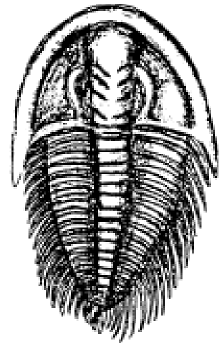
Phacops, Sil.—Dev.



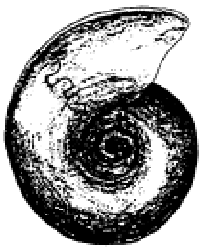
Calymene, Sil.—M. Dev.



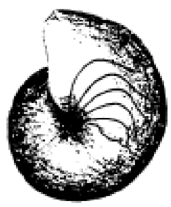
Elrathia, M. Camb.



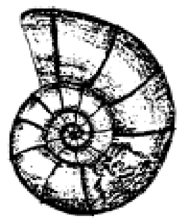
Wanneria, L. Camb.



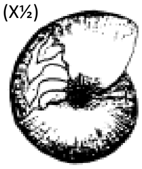
Ceratites, M. Trias. (X½)



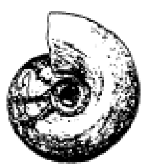
Imitoceras, U. Dev—M. Perm. (X½)



Lytoceras, Jur.—Cret.



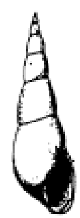
Goniatites, U. Miss.



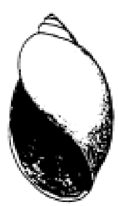
Eoasianites, Miss.—L. Perm.

Ophileta, L. Ord.

Worthenia,
Miss.—M. Trias.

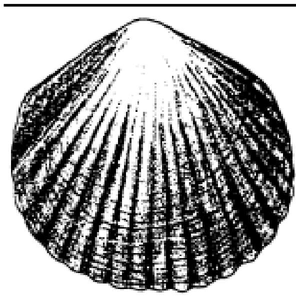


Loxonema,
M. Ord.—Miss.



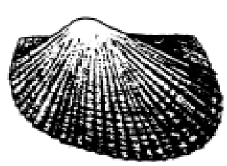
Physa, Jur.—Rec.

Goniobasis,
Cret.—Rec.



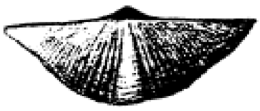
Glycimeris, Cret.—Rec.

Monotis, Trias.



Arca, Jur.—Rec.


Mucrospirifer, M. Dev.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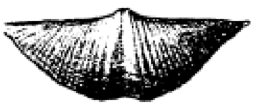
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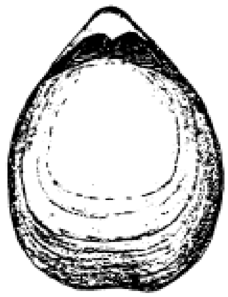
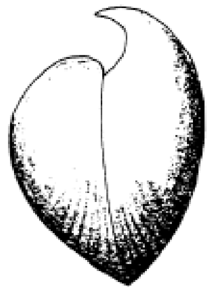
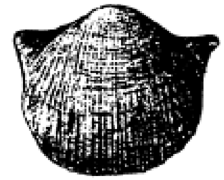
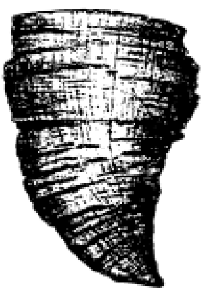

Stringocephalus, M. Dev.

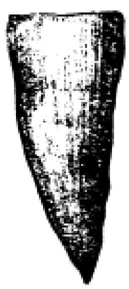

Stringocephalus, M. Dev.

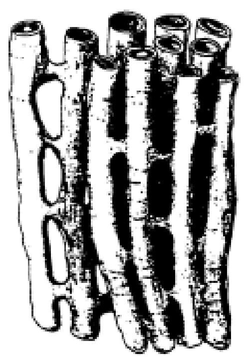

Mesolobus, M. Penn.—L. Perm.

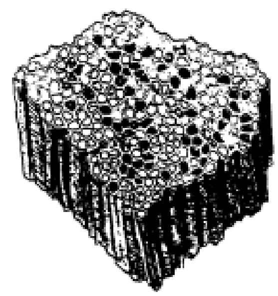

Chonetes, Sil.—Perm.


Penicularis, L. Perm.

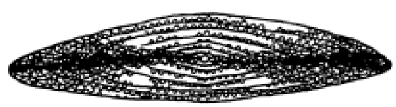

Heliophyllum, Dev.

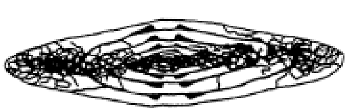

Streptelasma, M. Ord.—M. Sil.

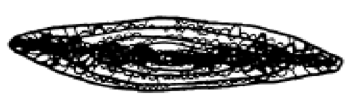

Syringopora, Sil.—Penn.

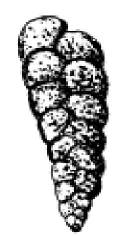

Favosites, Sil.—Carb.

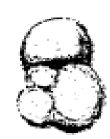

Triticites, U. Penn.—L. Perm. (X20)

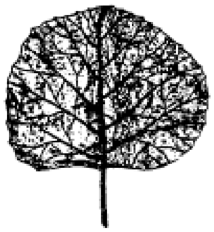

Polydiexodina, U. Perm. (X2)


Fusulinella, Penn. (X30)

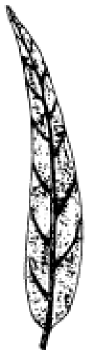

Parafusulina, Perm. (X2)


Textularia, Jur.—Rec.

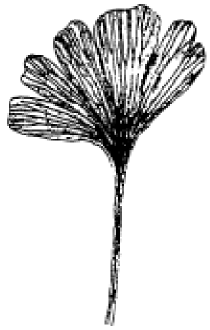

Globigerina, Paleoc.—Rec. (X50)



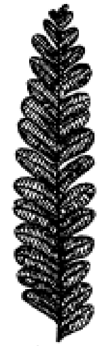
Populus (poplar), Cret.—Rec.



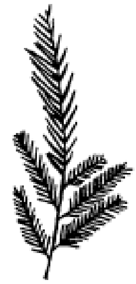
Salix (willow), Cret.—Rec.



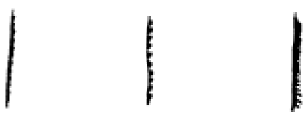
Gingko, Jur.—Rec.



Alethopteris, Penn.



Metasequoia, Cret.—Rec.



Monograptus (three species), Sil.—L. Dev.

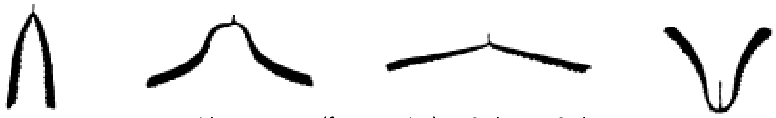
Diplograptus, M. Ord.—L. Sil.

Climacograptus, L. Ord.—L. Sil.

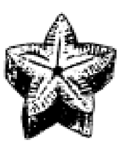
Monograptus, Sil.

Nemagraptus, M. Ord.

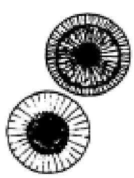
Tetragraptus (two species), L. Ord.



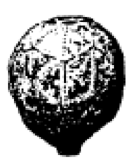
Didymograptus (four species), L. Ord.—M. Ord.



Pentacrinus, Tri.—Plio.

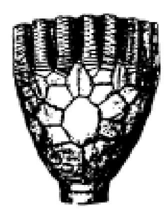


Crinoid columnals

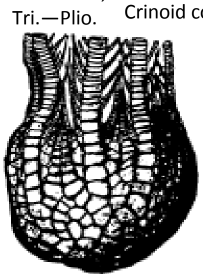


Caryocrinites, M. Ord.—M. Sil.

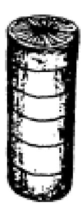
Pentremites, Miss.—Penn.



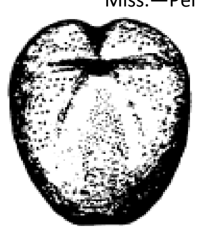
Eucalyptocrinus, Sil.—Dev.



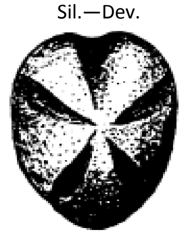
Uintacrinus, U. Cret.



Crinoid stem fragment



Micraster, Cret.—Mio. (X 3/4)

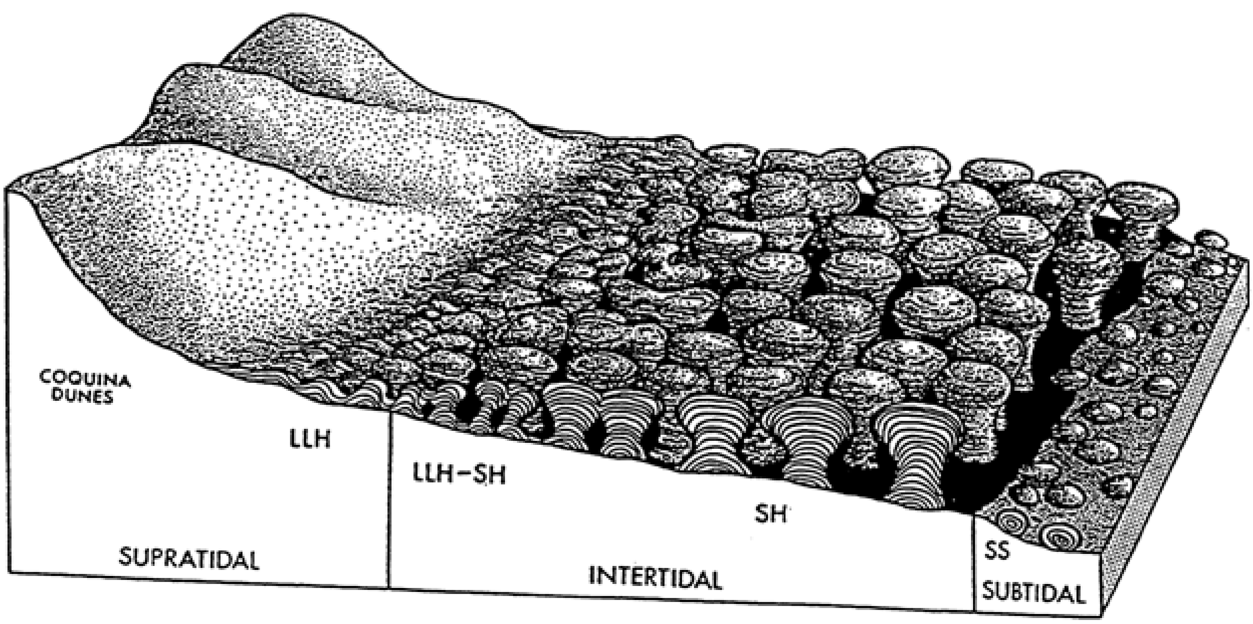


Micraster, Cret.—Mio. (X 3/4)

Student Information

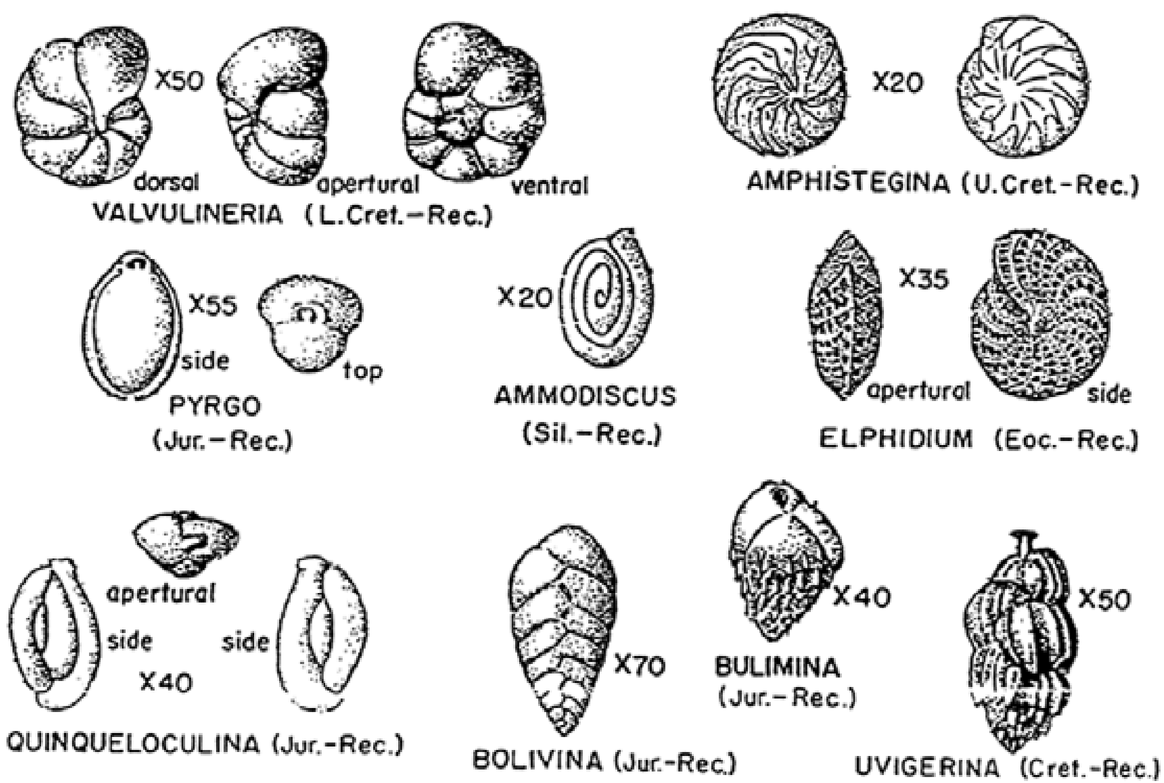
Fossil Description

Fossil name:	Algae (stromatolites)
Close living relatives:	Algae/ single celled plants
Kingdom:	Plant
Phylum:	N/A
Time range:	Precambrian to Recent
Guide fossil for:	
Sedimentary environment:	Marine shallow water, usually. Formed mats, capstan like reefs, mounds on sea bottom
How the creature moved:	N/A
Similar fossils:	None
Distinguished from above by:	N/A
Other details:	The first organism was algae. They were responsible for the production of oxygen in the Earth's atmosphere by the process of photosynthesis.



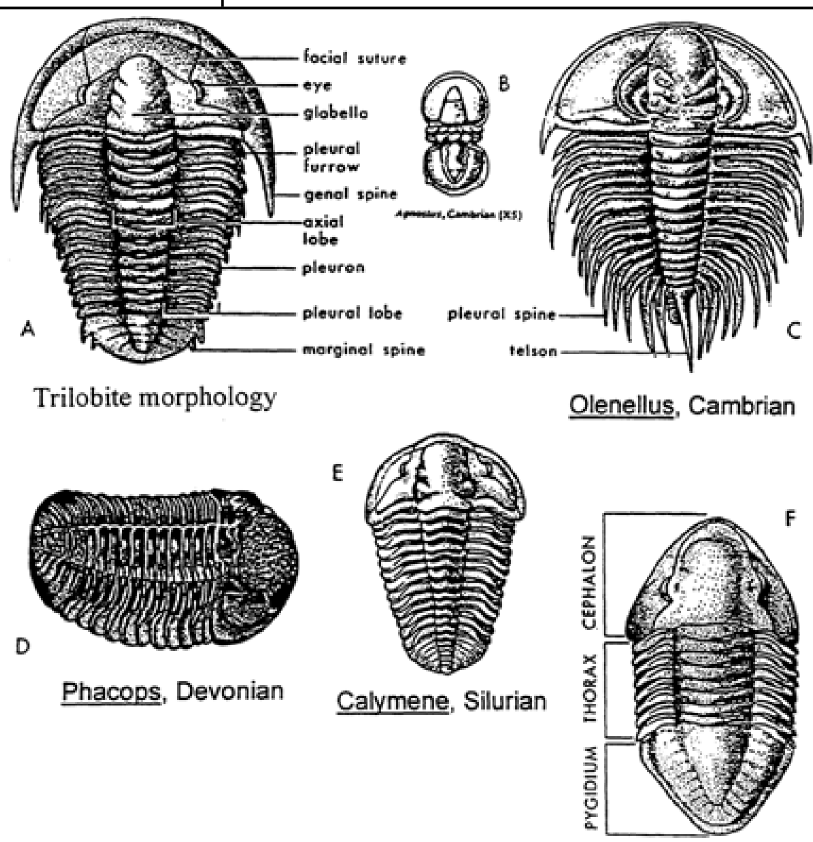
Distribution of modern stromatolites in the tidal area of a modern hypersaline lagoon (Shark Bay, Western Australia); highly generalized.

Fossil Description	
Fossil name:	Foraminifera
Close living relatives:	Foraminifera, Radiolaria, Amoeba
Kingdom:	Animal
Phylum:	Protozoa
Time range:	Ordovician to Recent
Guide fossil for:	Permian, Pennsylvanian, Cretaceous
Sedimentary environment:	Marine. Some foraminifera are bottom dwellers, but many dwell in the water column and when they die, their remains settle on to sediments in many marine environments.
How the creature moved:	Floated or Stationary
Similar fossils:	None
Distinguished from above by:	N/A
Other details:	Foraminifera are microscopic and so are especially useful for age dating because they can be recovered whole from drilling chips.



Student Information

Fossil Description	
Fossil name:	Trilobite
Close living relatives:	Crab
Kingdom:	Animal
Phylum:	Arthropoda
Time range:	Cambrian to Permian
Guide fossil for:	Cambrian
Sedimentary environment:	Marine, mainly shallow waters.
How the creature moved:	Crawling on its many legs, burrowing, jumping, swimming.
Similar fossils:	Crabs, shrimps, Eurypterids
Distinguished from above by:	N/A
Other details:	Rigid, jointed outer exoskeleton. Molted when exoskeleton became too small for the organism. Fed on organic matter in bottom muds.



Trilobite morphology

Olenellus, Cambrian

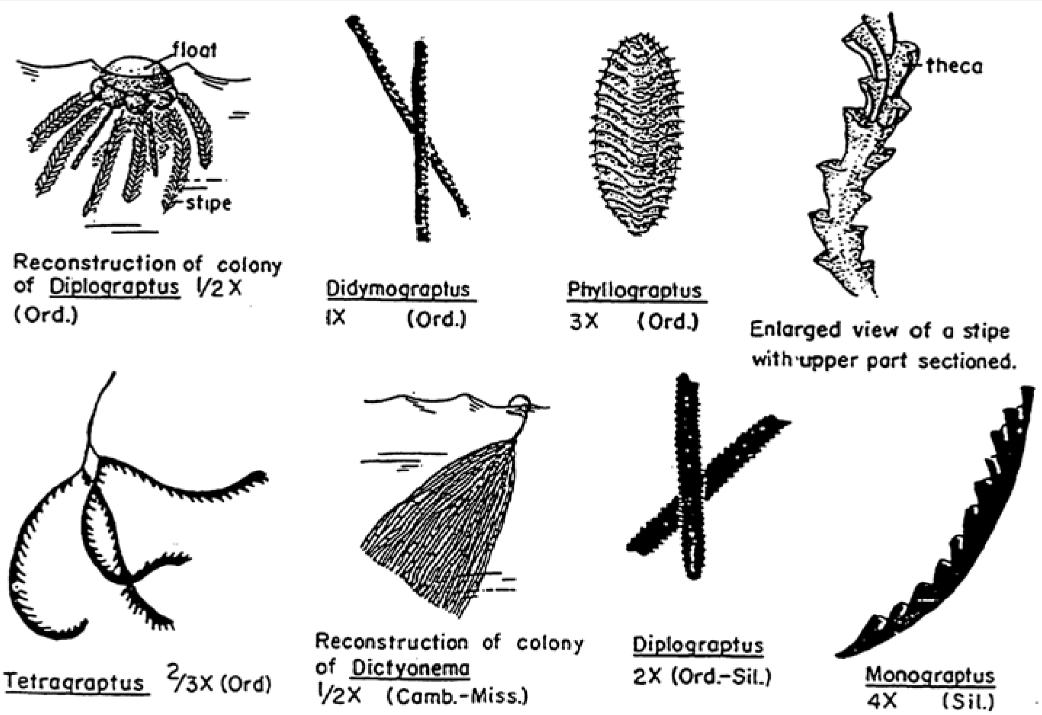
Phacops, Devonian

Calymene, Silurian

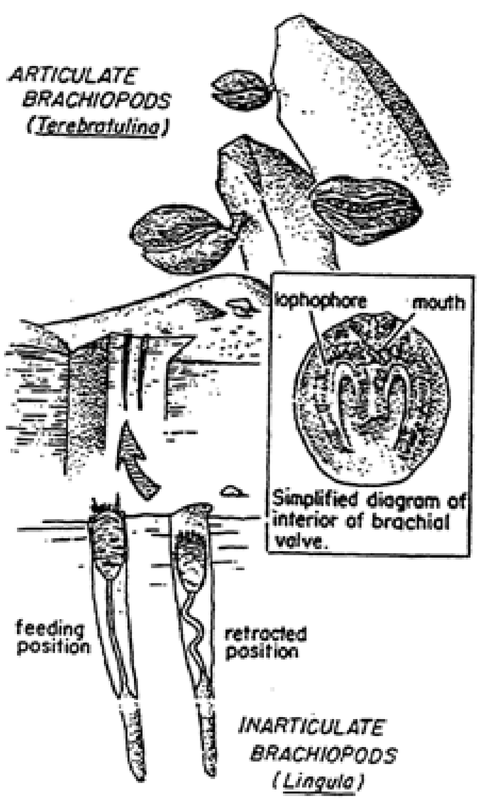
Student Information

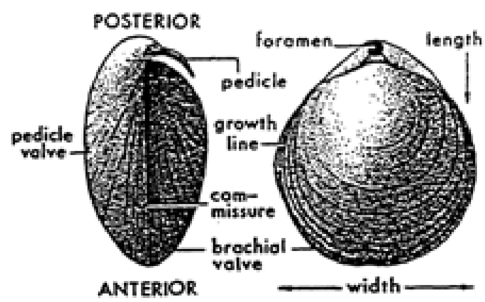
Fossil Description

Fossil name:	Graptolite
Close living relatives:	None
Kingdom:	Animal
Phylum:	Protochordata
Time range:	Cambrian to Carboniferous
Guide fossil for:	Ordovician and Silurian
Sedimentary environment:	Marine; free floaters in surface waters that upon death settled through the water column onto sediments of a variety of environments.
How the creature moved:	Free floating
Similar fossils:	None
Distinguished from above by:	N\A
Other details:	Colonial organism; individuals lived in each of the cups (theca) along the main skeleton (stipe). Commonly found in black shale deposited in a low energy, oxygen-free, deep-water environment where such delicate remains are more likely preserved.

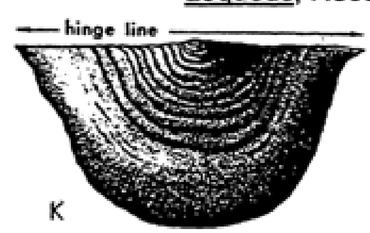


Fossil Description	
Fossil name:	Brachiopod
Close living relatives:	Brachiopod (lamp shell)
Kingdom:	Animal
Phylum:	Brachiopoda
Time range:	Cambrian to Recent
Guide fossil for:	Silurian, Devonian, Carboniferous
Sedimentary environment:	Marine, mainly shallow to moderately deep water.
How the creature moved:	Mostly stationary, commonly fixed to the sea floor by a stalk; could sway in moving water. Some types were burrowers.
Similar fossils:	Bivalves
Distinguished from above by:	Brachiopods have bilateral symmetry across the shells.
Other details:	There are 200 living species. All are bottom dwelling, filter feeders.

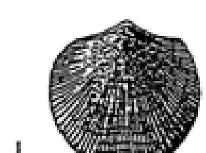




Lequeus, Recent



Leptaena, Silurian



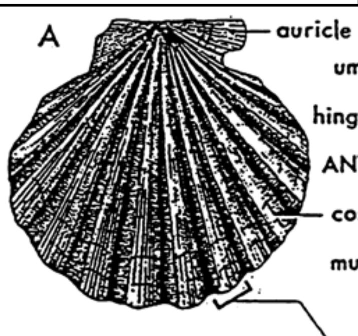
Atrypa, Devonian

Lepidocyclus, Ordovician

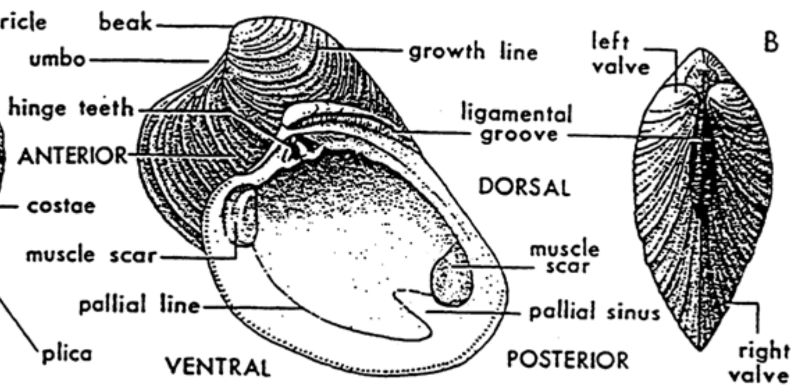
Student Information

Fossil Description	
Fossil name:	Bivalve
Close living relatives:	Clams, oysters
Kingdom:	Animal
Phylum:	Mollusca, Class Pelecypoda
Time range:	Ordovician to Recent
Guide fossil for:	Mesozoic, Tertiary
Sedimentary environment:	Mainly marine, some brackish and freshwater. Bottom dwelling, shallow water. Many burrow into the sediment.
How the creature moved:	Most are stationary. Some creep using the foot. Some swim by jerkily closing valves.
Similar fossils:	Brachiopods
Distinguished from above by:	Dorsal and ventral shells are symmetrical.
Other details:	Bivalves are also called pelecypods. There are over 7000 living species.

A

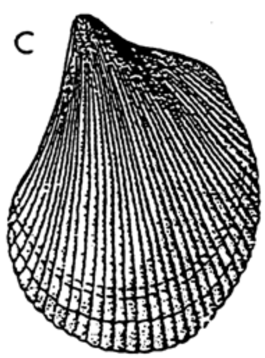


Pecten, Miocene



Venus, Pleistocene

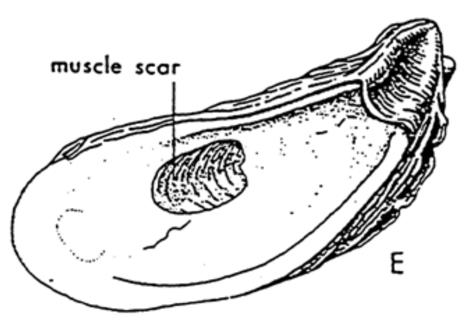
C



Byssonychia, Ordovician

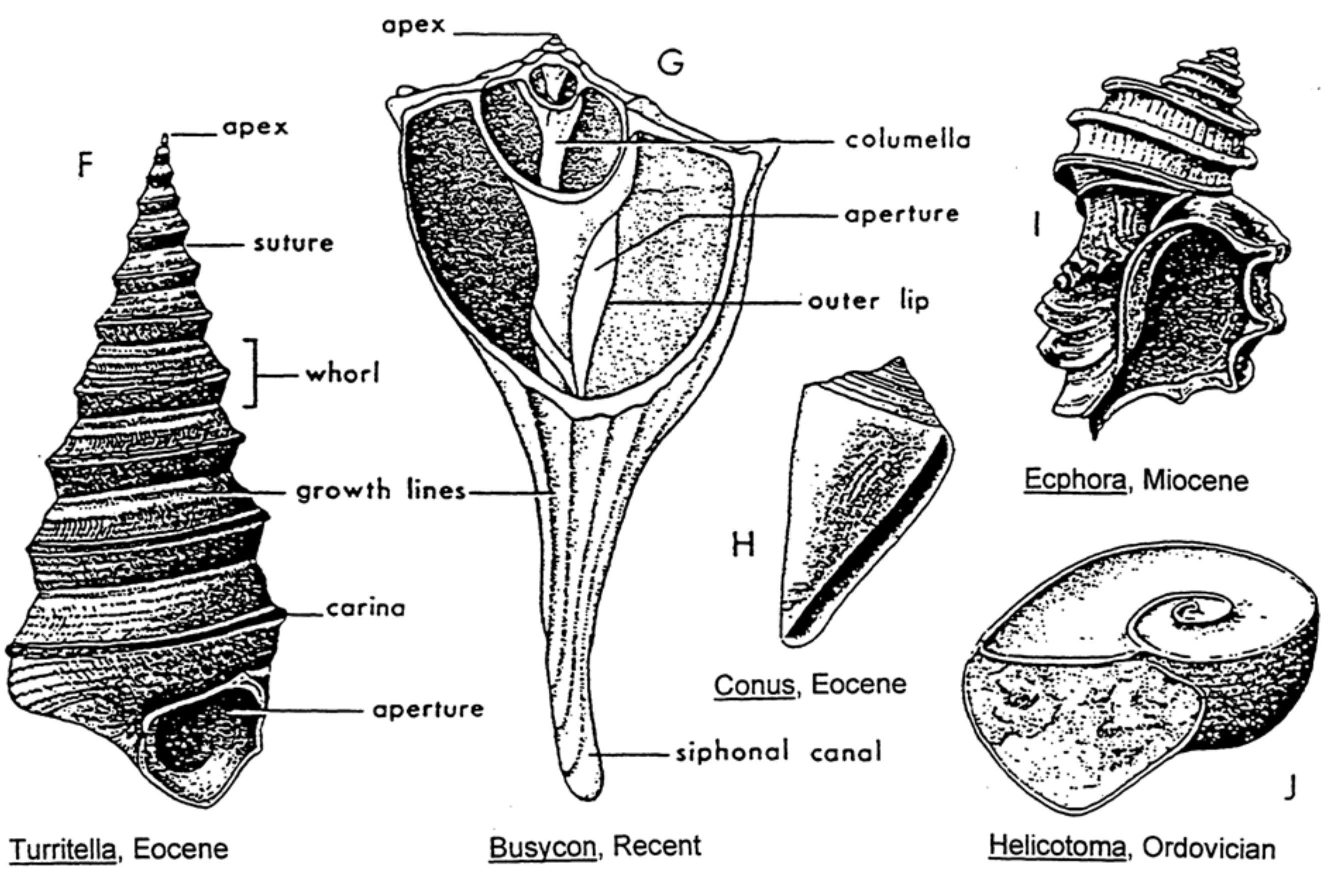
D

Gryphaea, Jurassic



Ostrea, Pliocene

Fossil Description	
Fossil name:	Gastropod (snail)
Close living relatives:	Snails, whelks, slugs
Kingdom:	Animal
Phylum:	Mollusca, Class Gastropoda
Time range:	Cambrian to Recent
Guide fossil for:	Tertiary
Sedimentary environment:	Marine, freshwater, brackish or terrestrial. Bottom dwelling.
How the creature moved:	Crawling using muscular foot.
Similar fossils:	Ammonites
Distinguished from above by:	Gastropods shells are not chambered.
Other details:	



Student Information

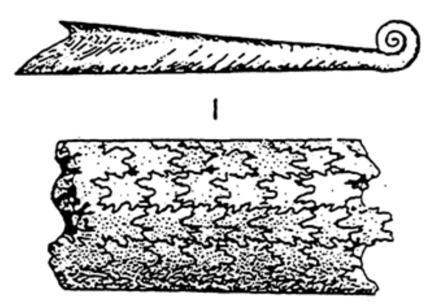
Fossil Description

Fossil name:	Ammonite
Close living relatives:	*Nautilus*, squid, octopus
Kingdom:	Animal
Phylum:	Mollusca, Class Cephalopoda
Time range:	Devonian to Cretaceous
Guide fossil for:	Triassic, Jurassic, Cretaceous
Sedimentary environment:	Marine. Ammonites were free swimming thus are found in deposits of many different marine environments.
How the creature moved:	"Jet-propelled" backward by forcing water through a muscular tube.
Similar fossils:	Nautiloids and gastropods
Distinguished from above by:	Nautilus shells are less ornate and have simple sutures. Distinguished from gastropods by their chambered shells.
Other details:	Ammonites are extinct. Spiralled shells predominate; some are straight. All have bilateral symmetry and complex sutures.

Psuedoparalegoceras,
a Pennsylvania goniatite

Ceratites,
a Triassic ceratite

Mortoniceras,
a Cretaceous ammonite

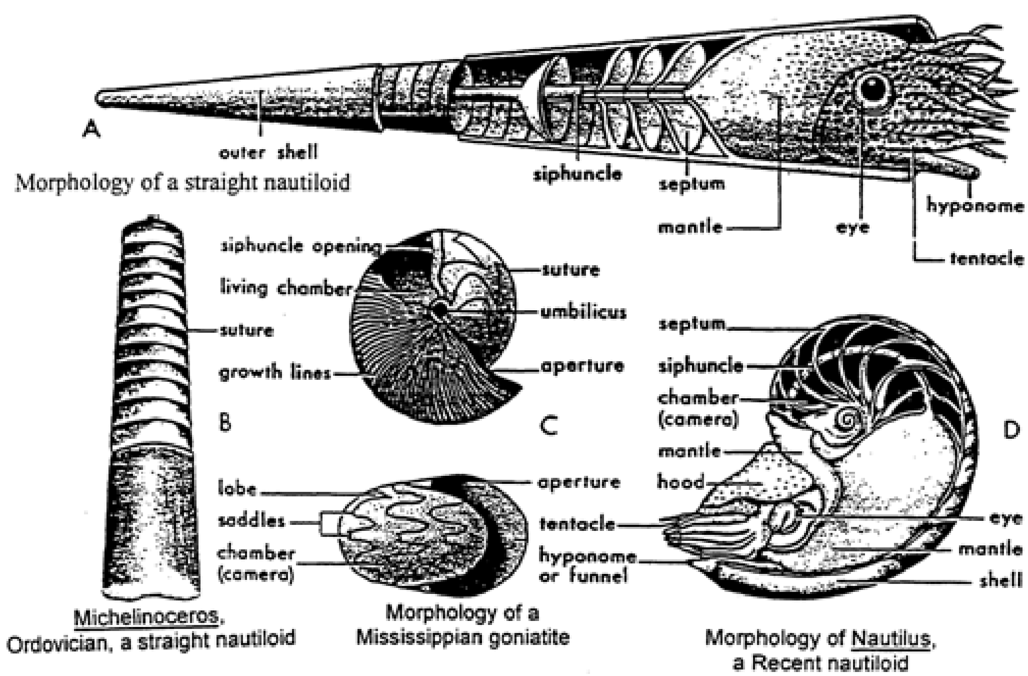


Baculites,
a Cretaceous ammonite (above X8)

Student Information

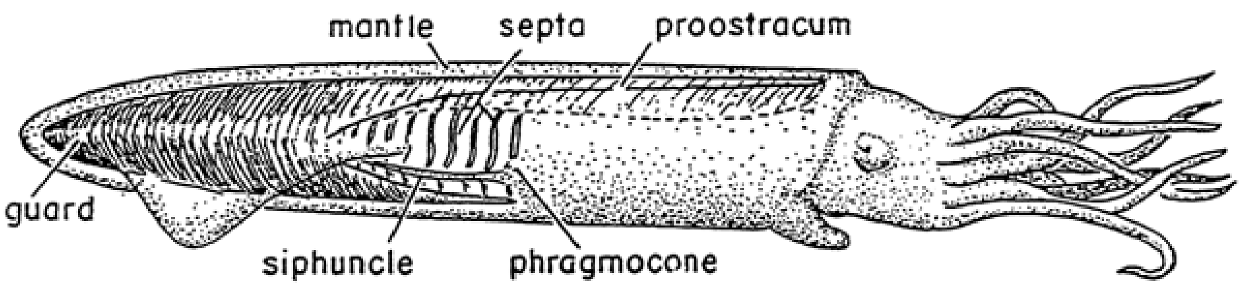
Fossil Description

Fossil name:	Nautiloid
Close living relatives:	*Nautilus*, octopus, squid
Kingdom:	Animal
Phylum:	Mollusca, Class Cephalopoda
Time range:	Ordovician to Recent
Guide fossil for:	Ordovician
Sedimentary environment:	Marine. Nautiloids were/are free swimming, so shells are found in deposits of many different sedimentary environments.
How the creature moved:	"Jet propelled" backwards by forcing water through a muscular tube.
Similar fossils:	Ammonites and gastropods
Distinguished from above by:	Ammonite shells are more ornate and have complex structures. Gastropods shells commonly have a conical spiral and are not chambered.
Other details:	The shell is bilaterally symmetric and chambered; it may be straight or coiled. Organism maintained buoyancy by changing pressure in chambers.

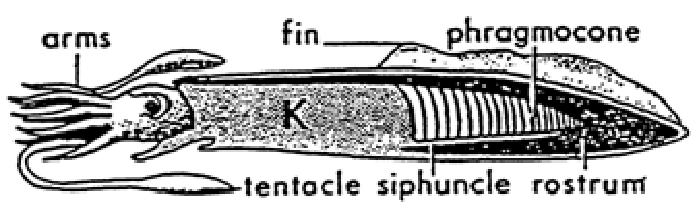


Student Information

Fossil Description	
Fossil name:	Belemnite
Close living relatives:	Squid and cuttlefish
Kingdom:	Animal
Phylum:	Mollusca, Class Cephalopoda
Time range:	Carboniferous to Cretaceous
Guide fossil for:	Jurassic and Cretaceous
Sedimentary environment:	Marine. Belemnites were free swimming, so are found in deposits of many different of marine environments.
How the creature moved:	"Jet propelled" backward by forcing water through a muscular tube.
Similar fossils:	None
Distinguished from above by:	N/A
Other details:	The belemnite fossil is the only hard part of the living organism. It was inside the body (like the pen of a squid) and played a role in buoyancy.



Restoration of a belemnite.



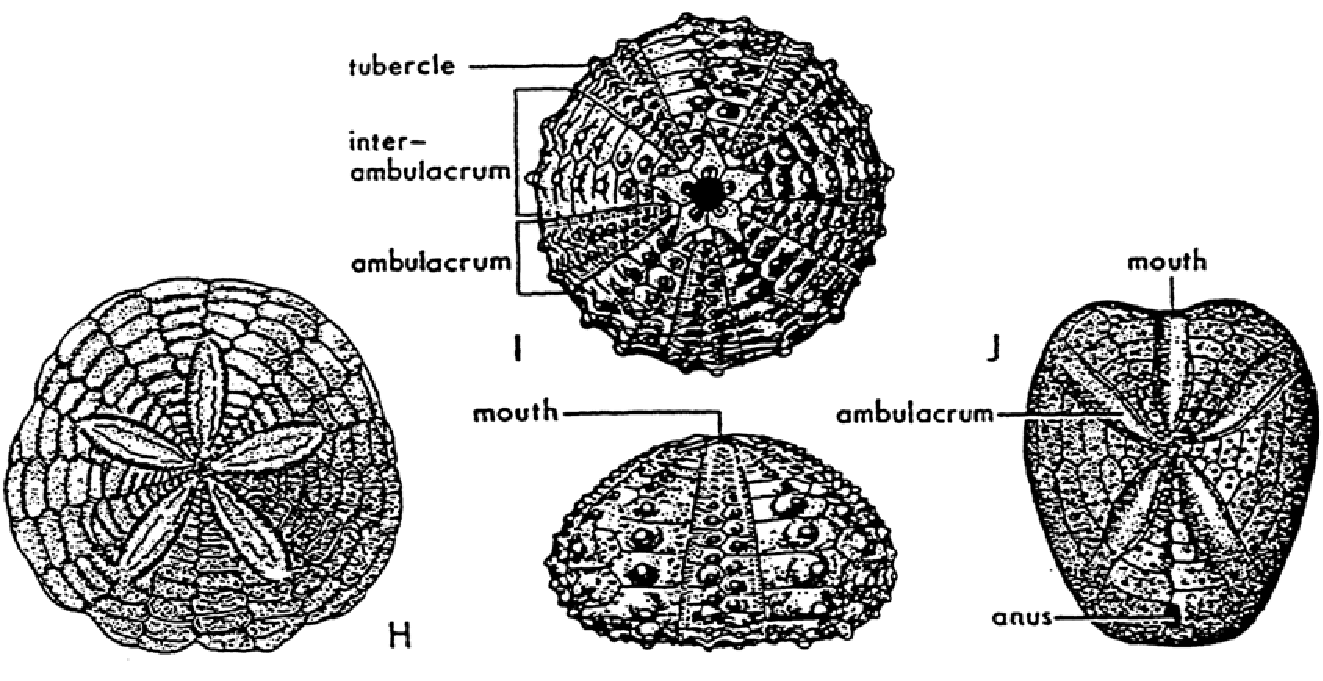
Restoration of a belemnite.

Belemnitella, a Cretaceous belemnite

Student Information

Fossil Description

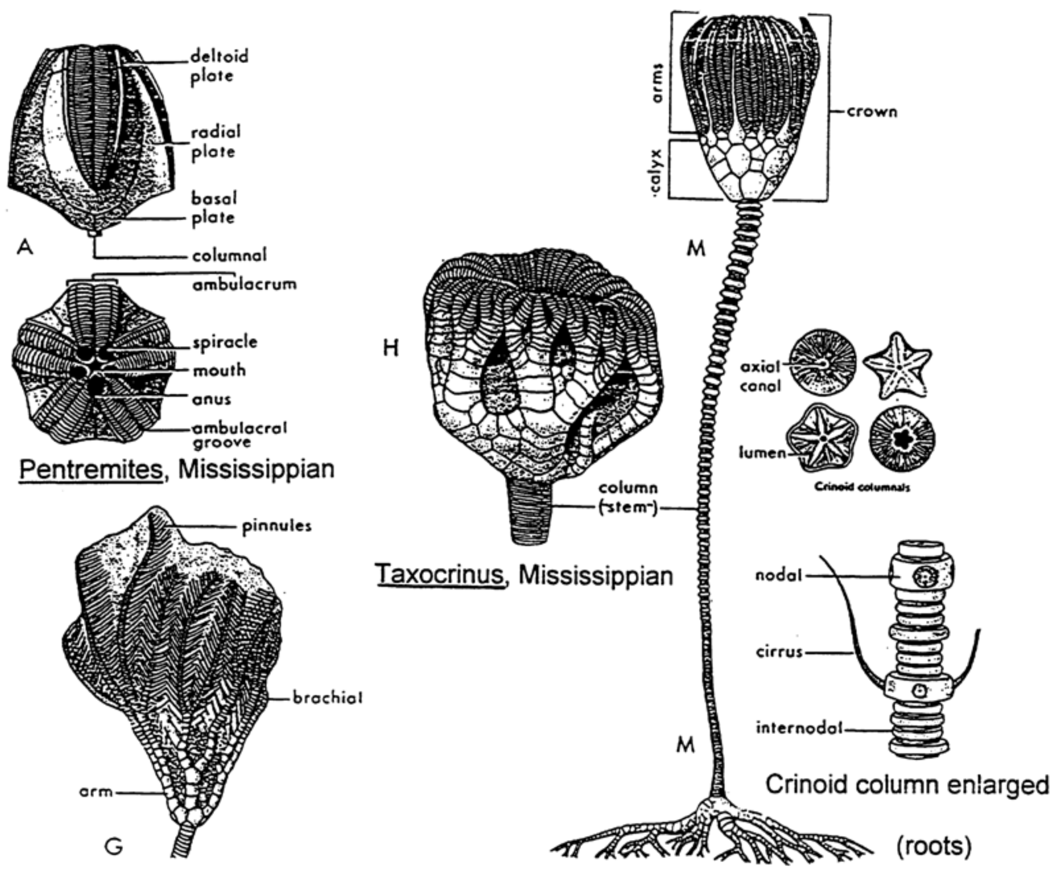
Fossil name:	Echinoid
Close living relatives:	Sea urchin, sand dollar, star fish
Kingdom:	Animal
Phylum:	Echinodermata, Class Echinoidea
Time range:	Ordovician to Recent
Guide fossil for:	Cretaceous
Sedimentary environment:	Mainly shallow marine. Generally bottom dwelling. Some burrow into the sediment.
How the creature moved:	Crawling by moving spines on underside. Burrowing common in some types.
Similar fossils:	None
Distinguished from above by:	N/A
Other details:	The outer shell (exoskeleton) is divided into five main plates. Echinoids may have bilateral or five-fold radial symmetry. The mouth is on the underside.



Scutella, Miocene   Goniopygus, Cretaceous   Epiaster, Cretaceous

Student Information

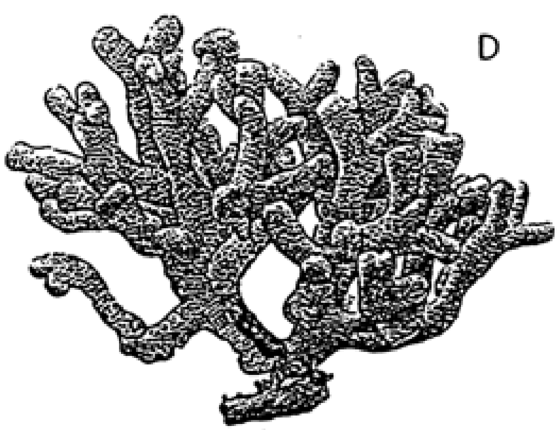
Fossil Description	
Fossil name:	Crinoid
Close living relatives:	Sea Lily, Feather Star
Kingdom:	Animal
Phylum:	Echinodermata, Class Crinoidea
Time range:	Ordovician to Recent
Guide fossil for:	Cretaceous
Sedimentary environment:	Mainly shallow marine, in moving, well-oxygenated water.
How the creature moved:	Stationary (fixed to the sea floor by a “stem”)
Similar fossils:	None
Distinguished from above by:	N/A
Other details:	Outer body is made up of plates. Hair-like cilia on the inside of the arms waft water and food particles down to the mouth in the top of head.



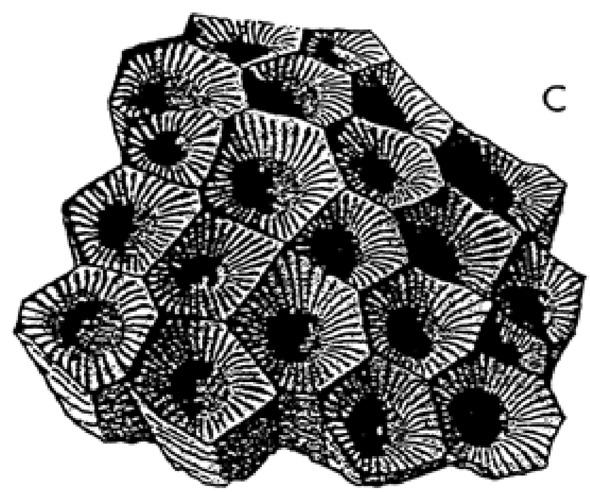
Student Information

Fossil Description

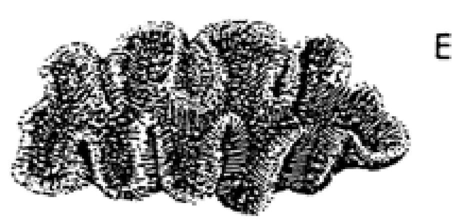
Fossil name:	Coral (colonial)
Close living relatives:	Coral, jellyfish, hydra, sea anemones
Kingdom:	Animal
Phylum:	Cnidaria (formerly in Coelenterata), Class Anthozoa
Time range:	Precambrian to Recent
Guide fossil for:	Devonian and Carboniferous
Sedimentary environment:	Shallow marine; clear, warm water in the photic zone.
How the creature moved:	Stationary. Builds up coral colonies consisting of thousands of organisms.
Similar fossils:	None
Distinguished from above by:	N/A
Other details:	Colonial organisms construct hard skeletons that can form major reefs. Most have microscopic plants in the soft tissues that assist in the formation of the skeleton.



Porites, a Recent colonial coral (scleractinian)



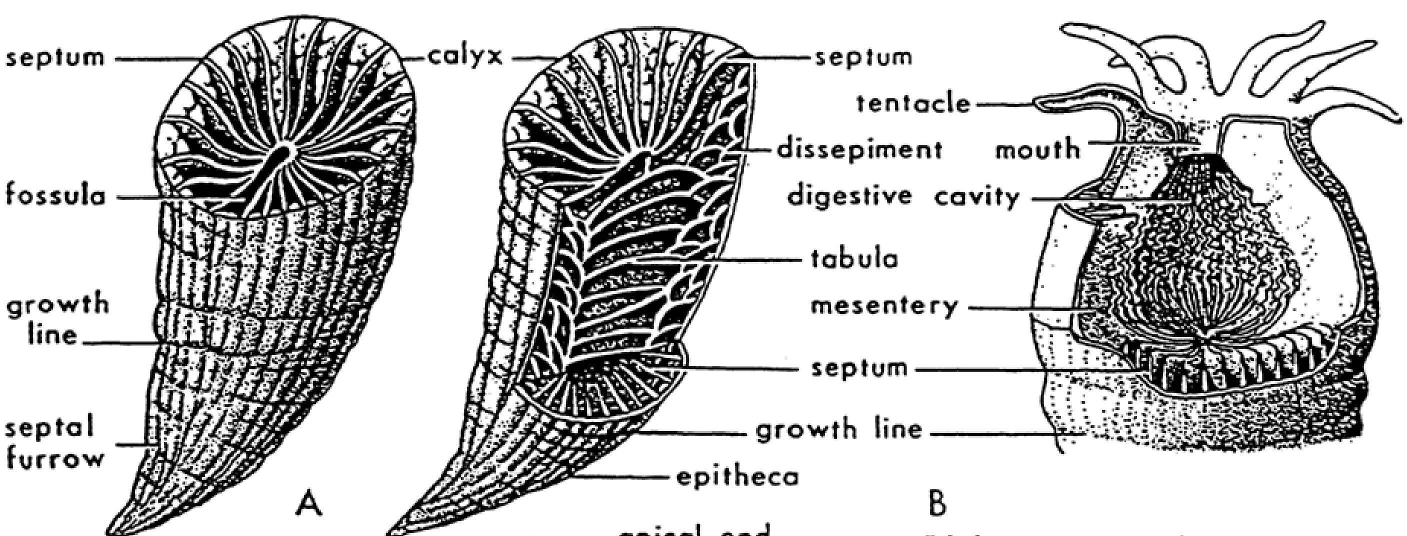
Hexagonoria, a Devonian colonial rugose coral



Monicina, a Recent "solitary" coral (scleractinian)

Student Information

Fossil Description	
Fossil name:	Rugose coral
Close living relatives:	Coral, jellyfish, hydra, sea anemones
Kingdom:	Animal
Phylum:	Cnidaria (formerly in Coelenterata, Class Anthozoa)
Time range:	Cambrian to Triassic
Guide fossil for:	Devonian
Sedimentary environment:	Marine; generally clear, warm water in the photic zone.
How the creature moved:	Stationary. The base of the horn-like coral was attached to the sea bottom.
Similar fossils:	None
Distinguished from above by:	N/A
Other details:	Calcium carbonate skeleton with a single, living polyp in the centre. Skeleton has radial symmetry.



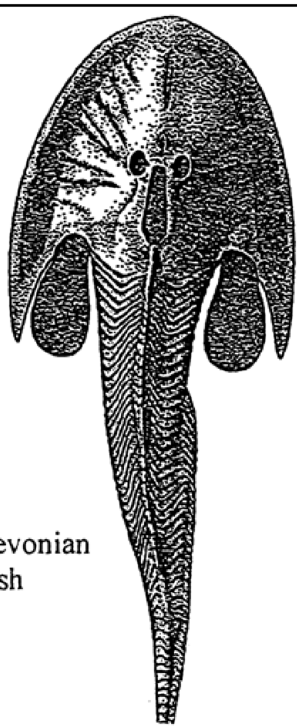
Rugose coral morphology

Living rugose coral, reconstructed

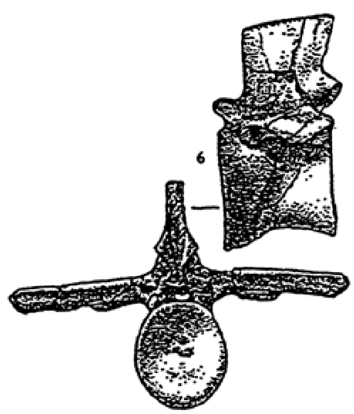
Student Information

Fossil Description

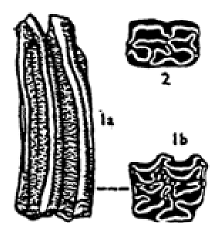
Fossil name:	Vertebrates
Close living relatives:	Fish, Amphibians, Reptiles, Fish, Mammals
Kingdom:	Animal
Phylum:	Vertebrata
Time range:	Ordovician (fish) to Recent
Guide fossil for:	N/A
Sedimentary environment:	Marine, freshwater, terrestrial.
How the creature moved:	Swimming, walking, flying etc.
Similar fossils:	N/A
Distinguished from above by:	N/A
Other details:	Vertebrates are animals with backbones. The evolutionary line is: fish, amphibians, reptiles, birds, mammals. Marine vertebrate fossils are quite common, but land vertebrate fossils (e.g. dinosaurs) are rare. The most commonly preserved hard parts are bones and teeth; hair is rarely found. Sharks have cartilage skeletons rather than bone. Thus, only their teeth are preserved.



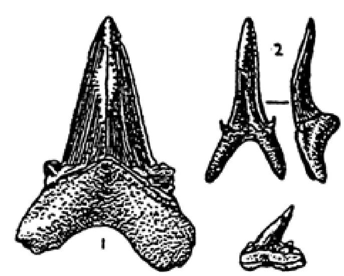
Devonian Fish



Vertebrate Jurassic-Crocodile



Teeth Pleistocene-Horse



Teeth Eocene-Shark

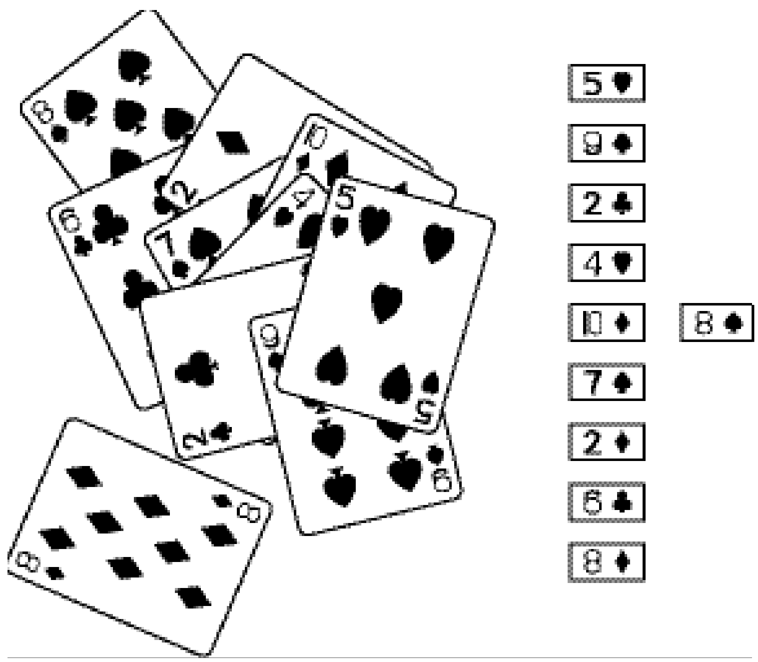
Teacher Information

Relative Age Dating (1)

Here is a quick "throw away" to get the students to think about the order of events and develop the idea of relative dating and the principle of superposition. The idea here is to look at the pile of cards and list them in the order they were dealt in. You could do this with actual cards, giving each pair of students 8 to 10 cards to toss in a stack. An alternative could be to make a photocopy of a stack similar to one below or just use the one below.

The students can list the order in column form with the oldest on the bottom or as a list from oldest to youngest. The card that does not touch any of the others is an important point. Can we say where it fits in the sequence? No, not by superposition alone. Could we find rock layers that show this type of "outsider"? Another challenge for the students!

A stack of playing cards illustrates the principle of superposition. The arrangement from bottom to top shows the order in which the cards were laid down. The boxes on the right give the order of superposition for all the cards except the one that does not touch the others. The "age" of this card cannot be determined by superposition alone.



Teacher Information

Relative Age Dating (2)

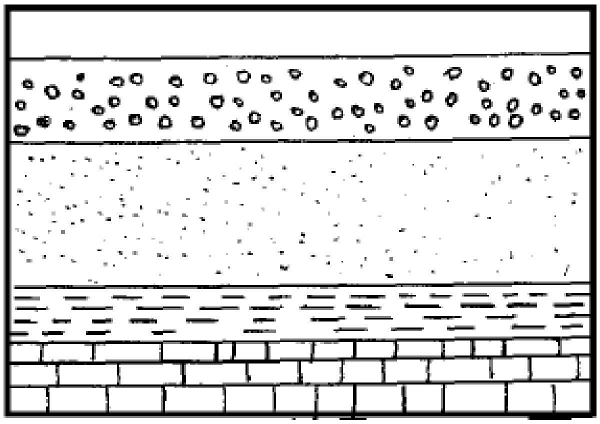
Relative age dating is new and interesting to most students. Once the basic principles are in their grasps they do enjoy working out the chronology of events in schematic cross-sections. To demonstrate the Law of Superposition use the top 20 cm from the newspaper recycling bin and ask the students to tell you about the ages of the papers in the pile. Which is the youngest? the oldest? Why? This is easy for them. Then point out that this simple statement (oldest is on the bottom) did not hit scientific minds until 1669 when Steno formulated the idea.

Two student activities are included to give them practice deciphering geologic sequences. In the first (C-2 to C-3), block diagrams are provided for the students to take notes on all of the age dating principles. Block "A" is for Principle of Superposition. Ask the students to list the events in order in the two conventional fashions: as a line from oldest to youngest and as a column with the oldest on the bottom and youngest on top. Block "B" is for demonstrating the Principle of Original Horizontality. Block "C" complicates the history by including folding. Blocks "D" and “E” demonstrate the Principle of Cross-cutting Relations. The empty block maybe used as you see fit.

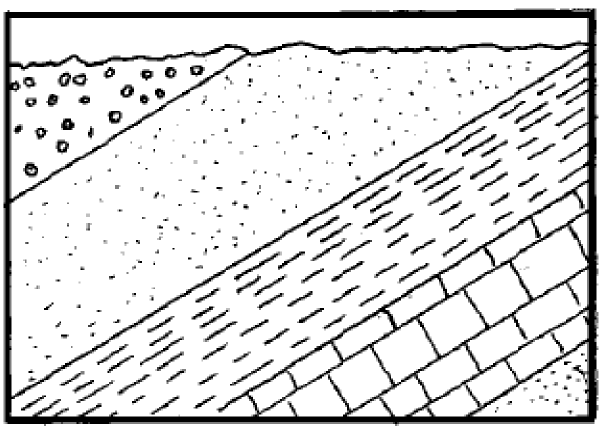
While going through the sequences make sure they understand what they are dating. Ages can be determined for a depositional event, erosion, deformation, intrusion or other processes. (Quiz questions can also make them think about these.) This is also a good time to point out the symbols conventionally used to indicate rock types (e.g. Sandstone – stippled pattern, SS) Lots to learn!

The second activity lets the students put the dating principles to practice. The nine cross-sections provided are of increasing complexity. You might also assign your students the exercises from the lab text "*Laboratory Manual in Physical Geology*" by AGI/NAGT. (It is Exercise 19 in the 1st edition and Exercise 13 in the 3rd edition.)

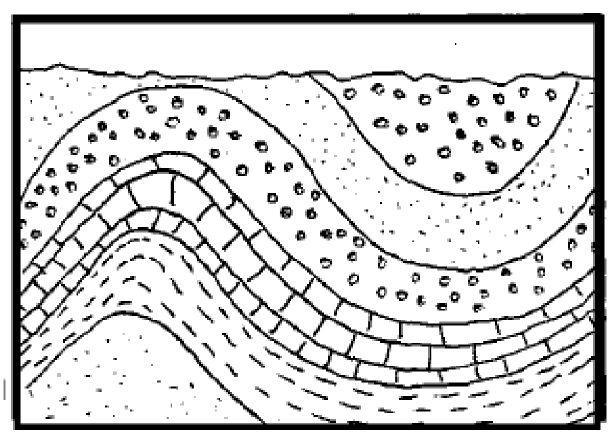
Student Notes



A

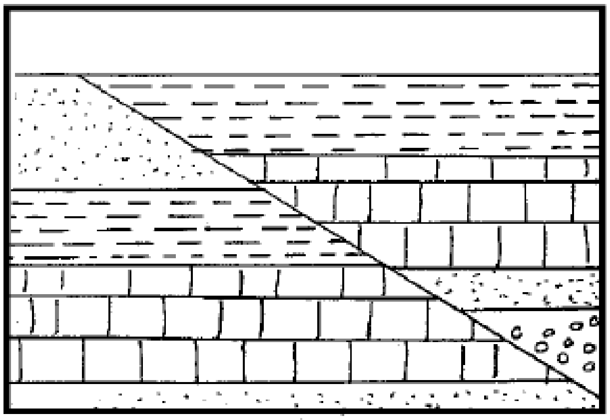


B

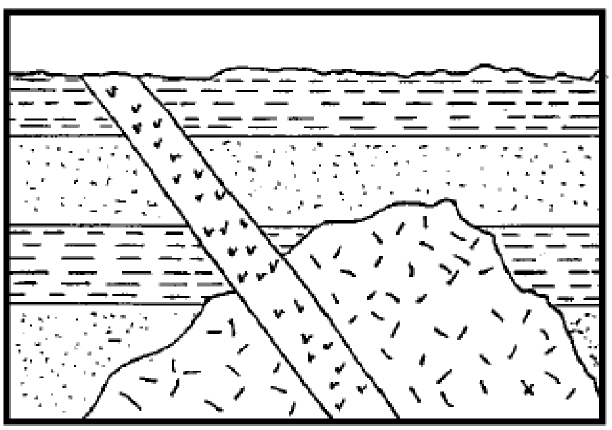


C

Student Notes



D ______________________________



E ______________________________

Student Exercise

Geologic Time - Relative Age Dating

The following nine cross-sections represent hypothetical strata of the Earth. Write your answers in the space beside each section.

Questions:

1. (a) State the Law of Superposition.
   (b) List the strata in order from oldest to youngest. (It is convention to always list from oldest to youngest or to display in a column with the youngest rock unit at the top.)

2. (a) Record the geologic events in column form.
   (b) Which event occurred first?
   (c) Which event occurred last?
   (d) State the Law of Original Horizontality.

3. (a) Record the geologic events in column form.
   (b) What occurred at P?
   (c) What is a feature like P called?

4. (a) What occurred first?
   (b) What occurred between the deposition of A and K?
   (c) What was the last event to have occurred?

5. (a) Record the geologic events in column form.
   (b) How do you know where to put A in the series?
   (c) What is A called?

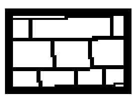
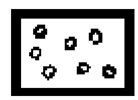
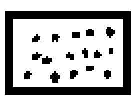
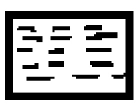
6. (a) Record the geologic events in column form.
   (b) What occurred at Y?
   (c) What could have occurred between B and C?
   (d) When did the tilting take place compared to dyke X? How do you know?

7. (a) Which is the oldest?
   (b) What is Z? What type? How do you know?
   (c) What happened between X and N?

8. (a) List in conventional order.
   (b) What type of feature is E?
   (c) What would you notice along the margins of A? Why?
   (d) **Bonus**: Name the type of rock you would probably find between C and A.

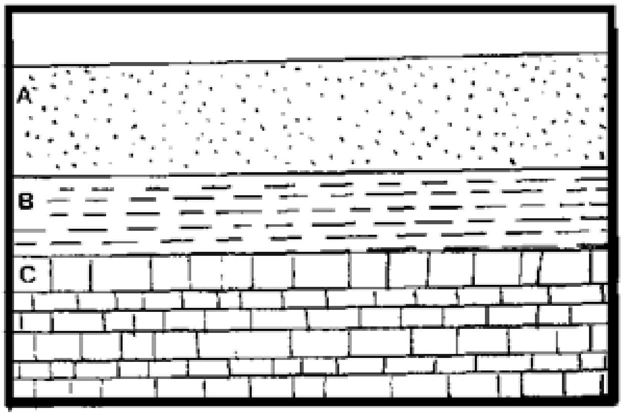
9. (a) List the igneous activity in order from oldest to youngest.
   (b) What are two pieces of evidence for the order of dykes C and D?

Legend for Rock Types:

Limestone -		Conglomerate -	
Sandstone -		Volcanic Rock -	
Shale -		Plutonic Rock -	

Student Exercise

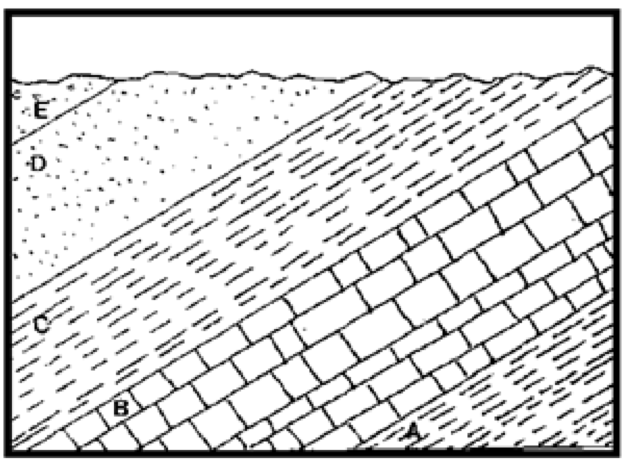
1



a) ____________________________________
____
____

b) __________ __________ __________

2



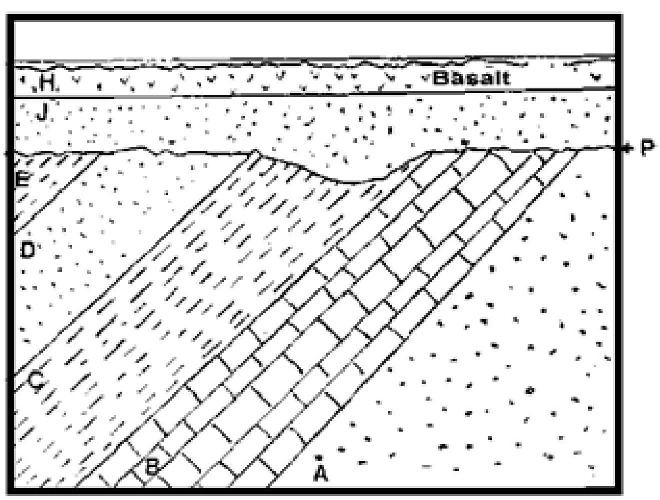
a) Youngest: ___________________________
____
____
Oldest: ___________________________

b) ____________________________________

c) ____________________________________

d) ____________________________________
____
____

3



a) Youngest: ___________________________
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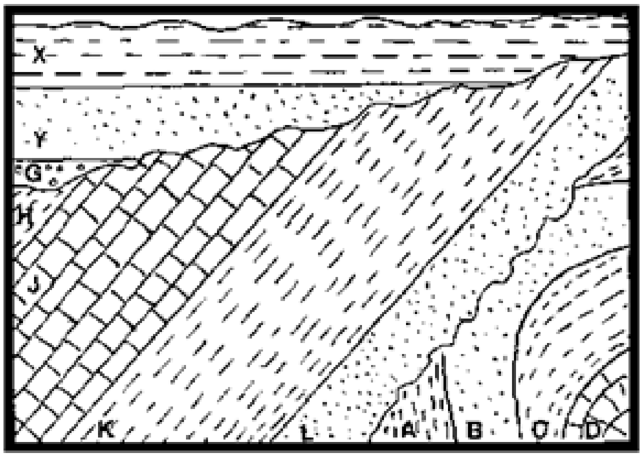
Oldest: ___________________________

b) ____________________________________
____

c) ____________________________________

Student Exercise

4



a) ______________________________

b) ______________________________

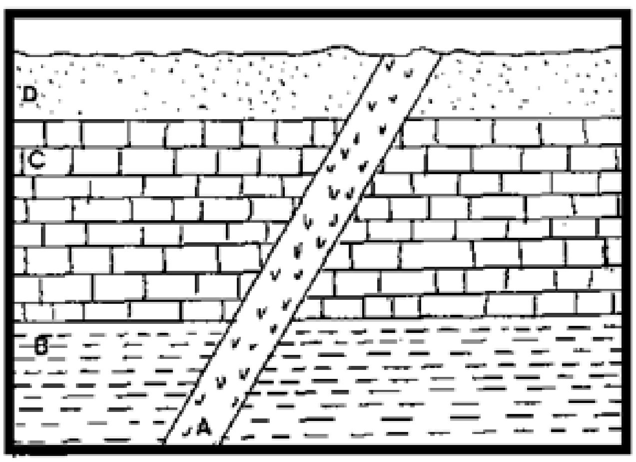
____

____

____

c) ______________________________

5



a) Youngest: ______________________________

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b) ______________________________

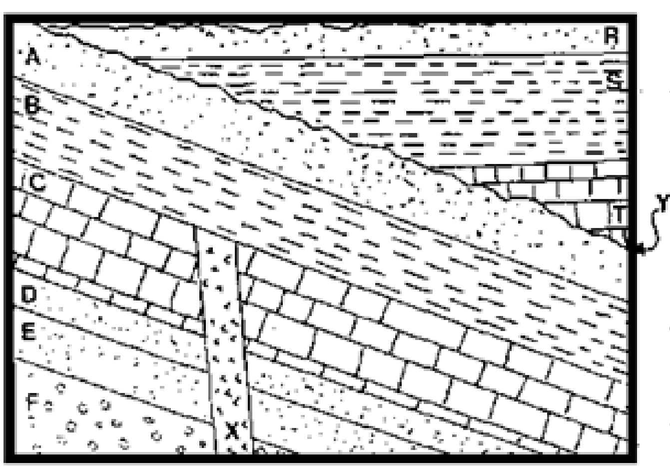
____

____

____

c) ______________________________

6



a) Youngest: ______________________________

____

____

Oldest: ______________________________

b) ______________________________

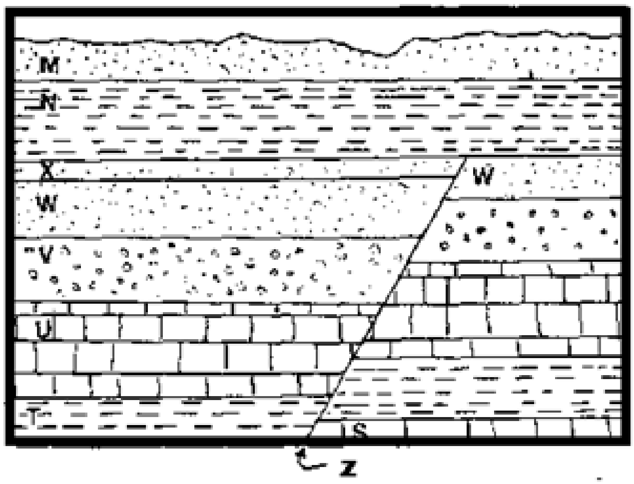
c) ______________________________

____

d) ______________________________

Student Exercise

7



a) ____________________

b) ____________________

____

____

c) ____________________

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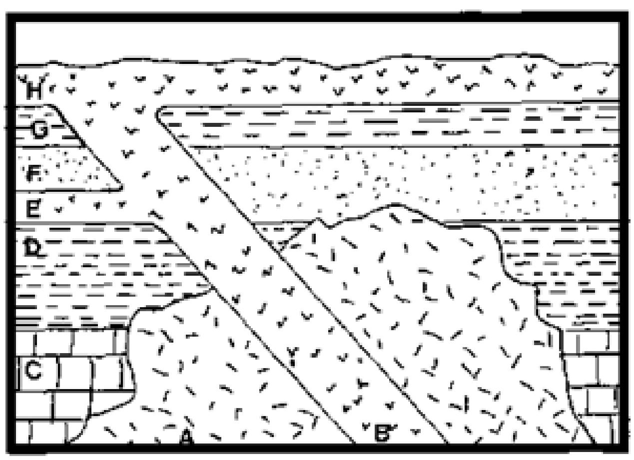
____

____

8



a) ____________________

b) ____________________

c) ____________________

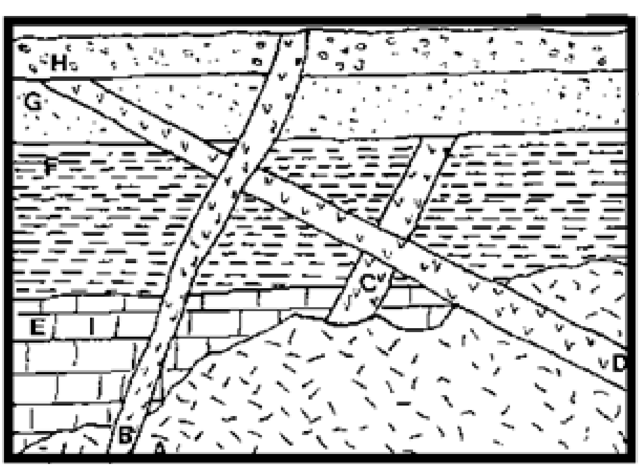
____

d) Bonus ____________________

____

____

9



a) ____________________

b) ____________________

____

____

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Teacher Information

Relative Age Dating with Fossils

In this exercise students employ the principles of relative age dating to unravel geologic sequences, but they are also provided fossil data to relate the histories to real geologic time. It is an opportunity to become more familiar with geologic period names and the time intervals they represent. Block diagrams (D-7 to D-8) further require the students to complete geologic structures in the 3rd dimension. This provides a nice introduction to interpreting structure from geologic maps!

The drawings of fossils come from *Spaceship Earth*, Houghton Mifflin, 1979. This text was at one time part of a reference package for Earth Science 11. It is a great source for ideas, sketches, exercises, tests and a host of other things. Your department may still have a copy.

Student Exercise

Relative Age Dating with Fossils

The sketches on D-5 through D-8 show hypothetical geologic cross-sections. The Rock Type Legend is on D-3 and the key to fossils is on the Geologic Time Scale (D-4). Write answers to the questions below in the blank space beside each cross-section.

Questions:

1. Give the ages of the layers. State as the Period from the Geologic Time Scale.
   Give the possible age of the fault.

2. Give the ages of the layers. State the Period and the possible span of years. When did the tilting occur?
   What is the age of the intrusion?
   Is **A** a dyke, sill, or a flow? How do you know?
   What is surface **B** called?

3. Give the ages of the layers as the Period.
   Give the time in years that the intrusion could have occurred.
   How could you find the age of the intrusion exactly?
   When did the tilting occur?
   How many layers are missing above the unconformity? Name them. Why are they missing?

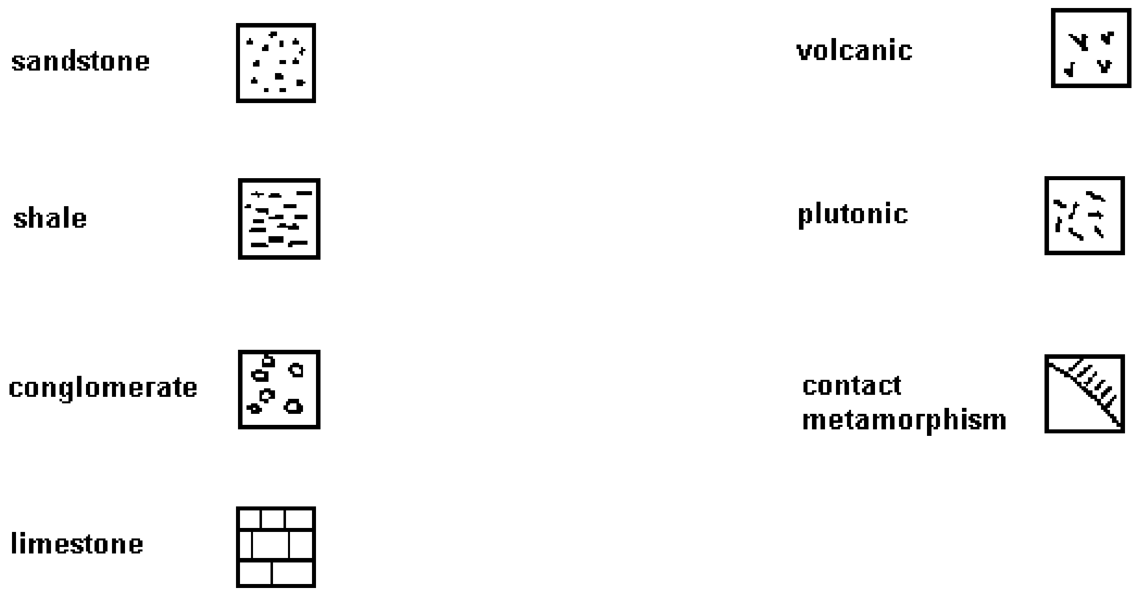
4. Give the ages of the layers as the Period.
   What happened at **A**?
   Is the radiometric date for the volcanic rock correct for the ages of the layers? Explain.

5. Give an age for A. What method would be used to find the date of the log? Give a possible age for B.
   What is missing at C? What are two possible reasons?
   What type of fault is it?

6. Explain what happened here.

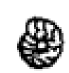
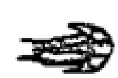
Student Exercise

Rock Types Legend:



Student Exercise

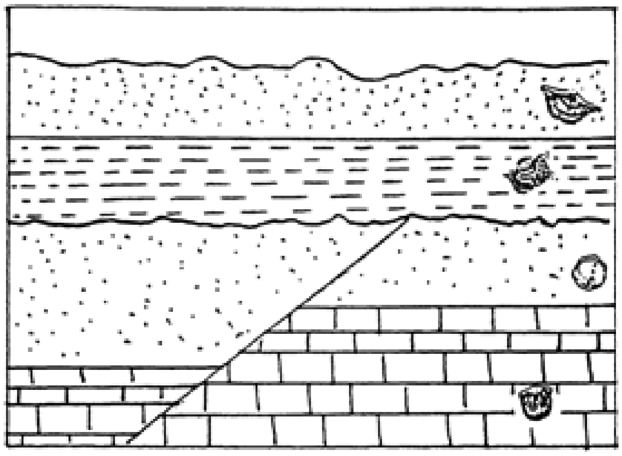
Geologic Time Scale

Geologic Period	Period Began (in millions of years ago)	Fossil Name	Fossil Appearance
Quaternary	2	Equus	
Tertiary	70	Turritella	
Cretaceous	135	Inoceramus	
Jurassic	180	Eoderoceras	
Triassic	225	Monotis	
Permian	270	Neospirifer	
Pennsylvanian	325	Dictyoclostus	
Mississippian	350	Muensteroceras	
Devonian	400	Phacops	
Silurian	440	Pentamerus	
Ordovician	500	Rafinesquina	
Cambrian	600	Paradoxides	

This geologic time scale includes names and drawings of fossil remains that can be used to date rocks in which they are found.

Student Exercise

1



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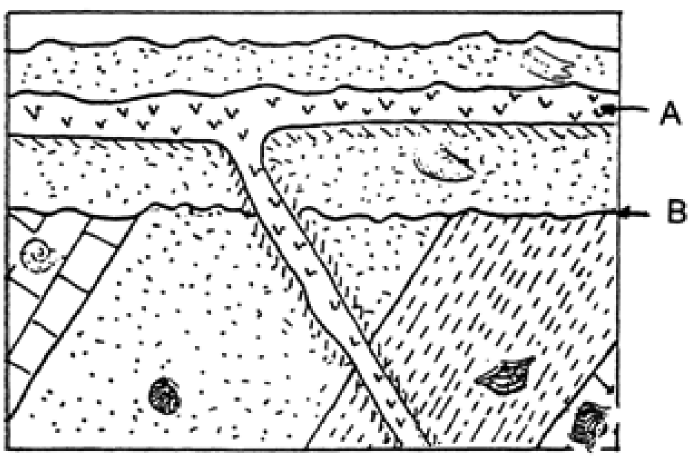

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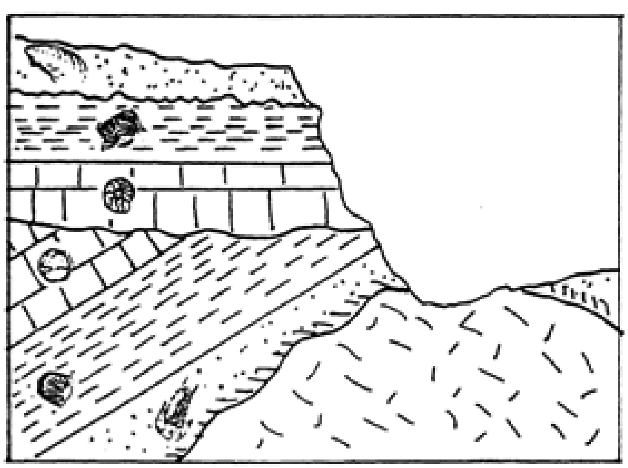
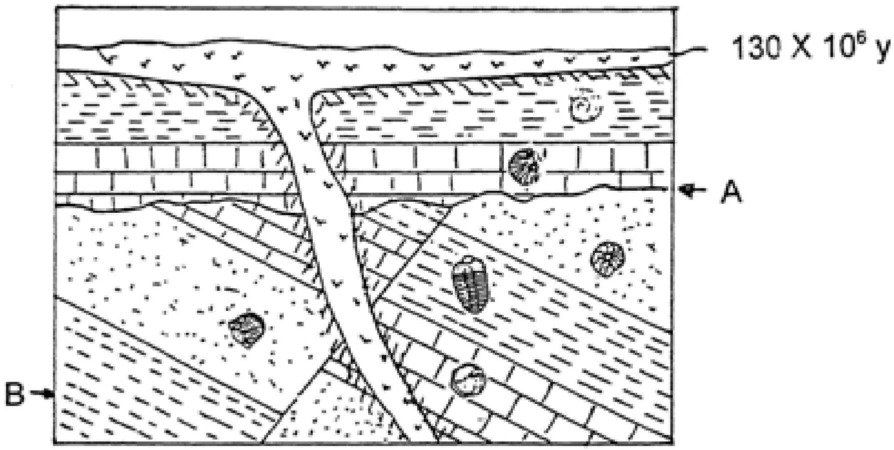
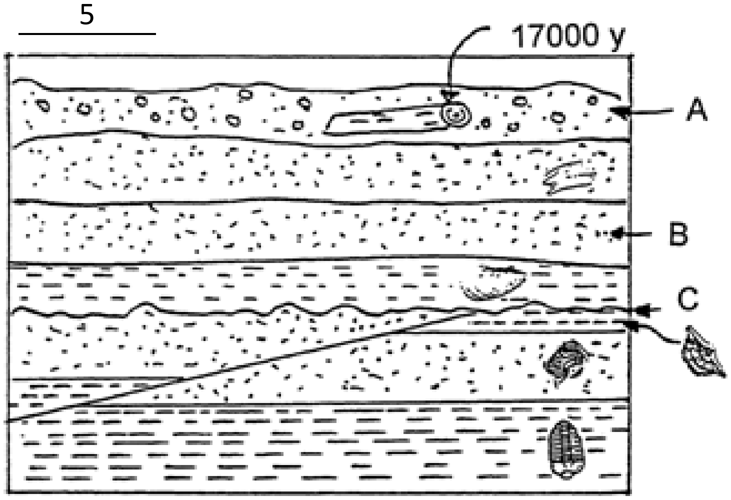


Student Exercise

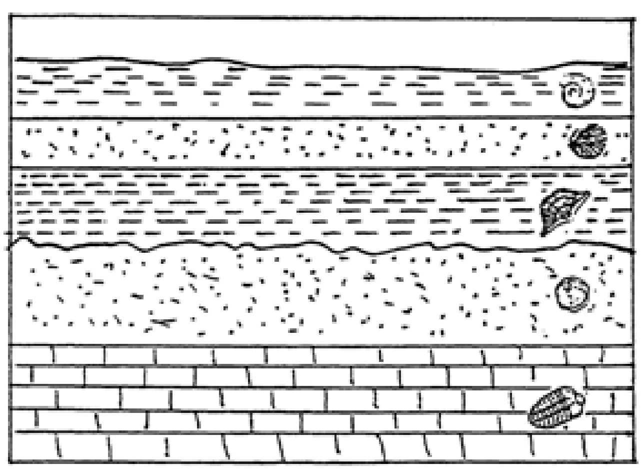
4 ______



5 ______



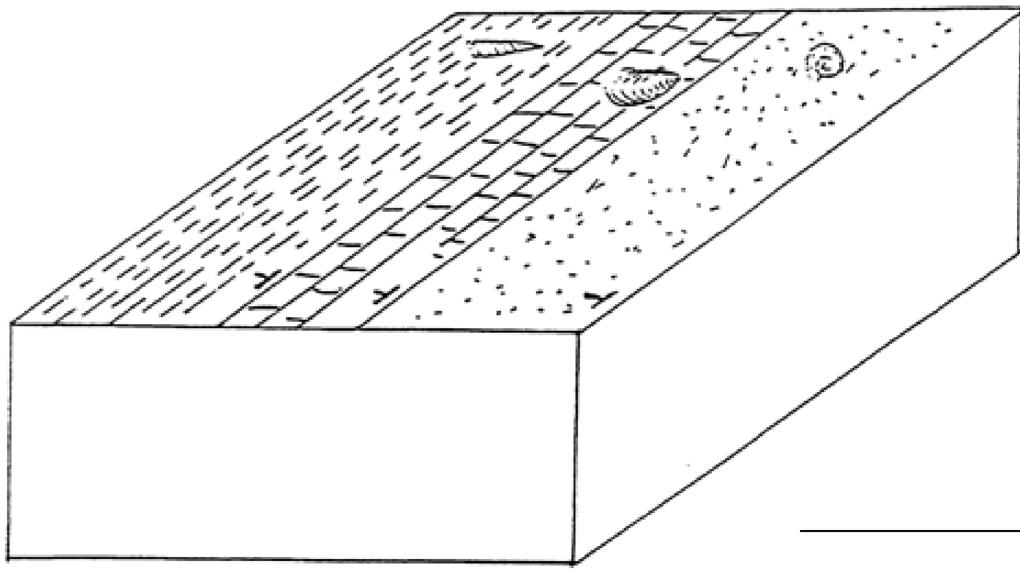
6 ______



Student Exercise

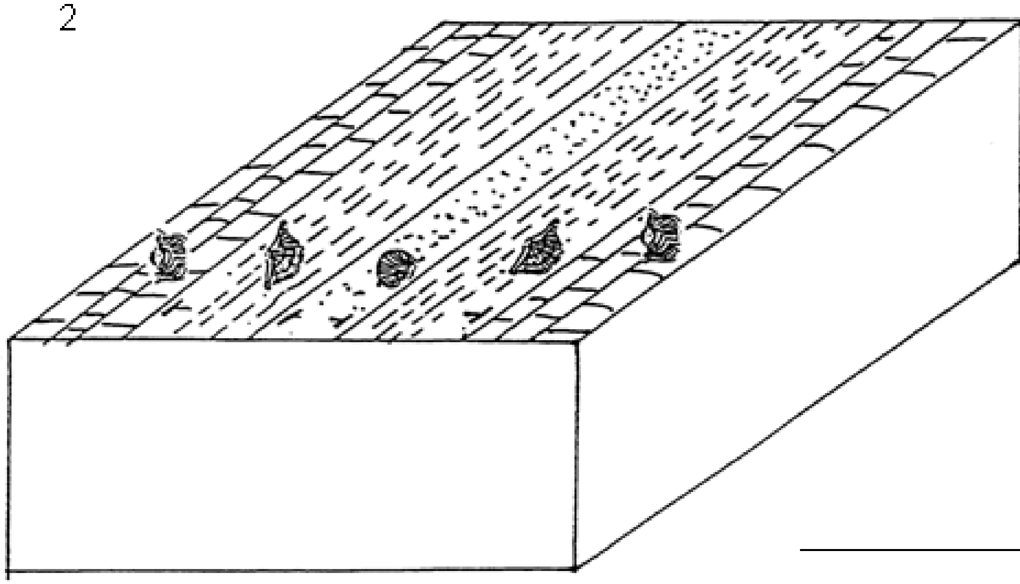
For block diagrams 1-4:
a) give the age; b) complete the end and side views; c) name the structure.

1



____

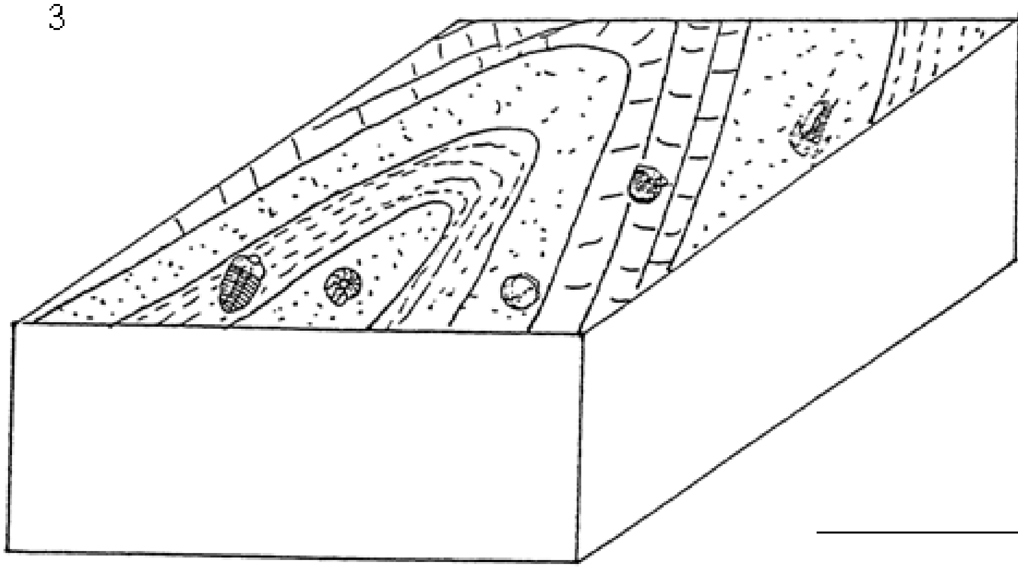
2



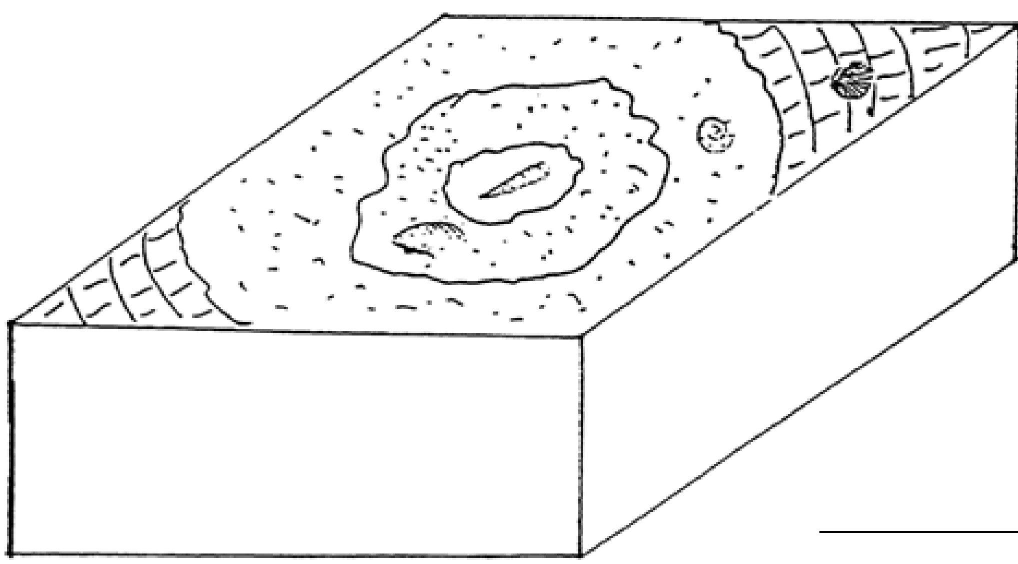
____

Student Exercise

3



4



Faunal Succession/Sedimentary Structures

Part 1

The first exercise in this section was designed as an accompaniment for the lab books from Peterson and AGI. The activity is a quick and easy illustration of the principles of superposition, faunal succession, and correlation. The students will need scissors and glue. It will take 20 minutes or less to complete.

Part 2

This part of the activity on Sedimentary Structures can stand alone as an exercise accompanying sedimentary rocks in lecture. It is included here for review, linking physical and biological indicators together, for the purpose of environmental interpretation. It derives from Exercise 5 in the AGI *Lab Manual in Physical Geology* 3rd Ed. and is (ideally) combined with a display of various structures in hand specimen. It is useful if students can interpret fossils and environments, so it could be used in either place.

Student Exercise

Part 1: Faunal Succession & Correlation

The Principle of Faunal Succession
Each successive time interval of Earth history has a unique assemblage of fossil types. As a result, rock units can be dated and correlated by analysis of their fossil content and comparison to standard reference sequences. The term **index fossil** refers to those fossils that are useful in age determinations. To be used for this purpose an index fossil must be easily identified and distinct, abundant, have a wide geographic range, and have a rapid evolutionary pattern, which results in a short geologic time range.

Fossils are almost exclusively found in sedimentary rocks. (Poorly preserved fossils maybe found in some low-grade metamorphic rocks.) Biostratigraphic correlation as a means of age dating, therefore, is of somewhat limited usefulness. Keep in mind as well, that there is no single place on the globe where strata of all ages are found in one intact sequence. Therefore, the complete record of fossil succession must be constructed from overlapping segments distributed worldwide, making correlation difficult.

Figure 1 (page E-3) shows vertical sequences of sedimentary rock at six different localities. At least one index fossil was found in each layer. The Key (Figure 2 on E-3) shows each index fossil symbol and states the geologic period during which it lived. Note that the fossils are not listed in chronological order.

Procedures:

1. Cut out the six columns in Figure 1.

2. Apply your knowledge of the Law of Superposition and arrange the columns side-by-side on a blank piece of paper (8 ½" x 11") such that strata with the fossils are relatively lined up (see Figure 1, lower right).

3. Draw lines to show biostratigraphic correlation from one locality to another. Note that some fossils disappear in some localities.

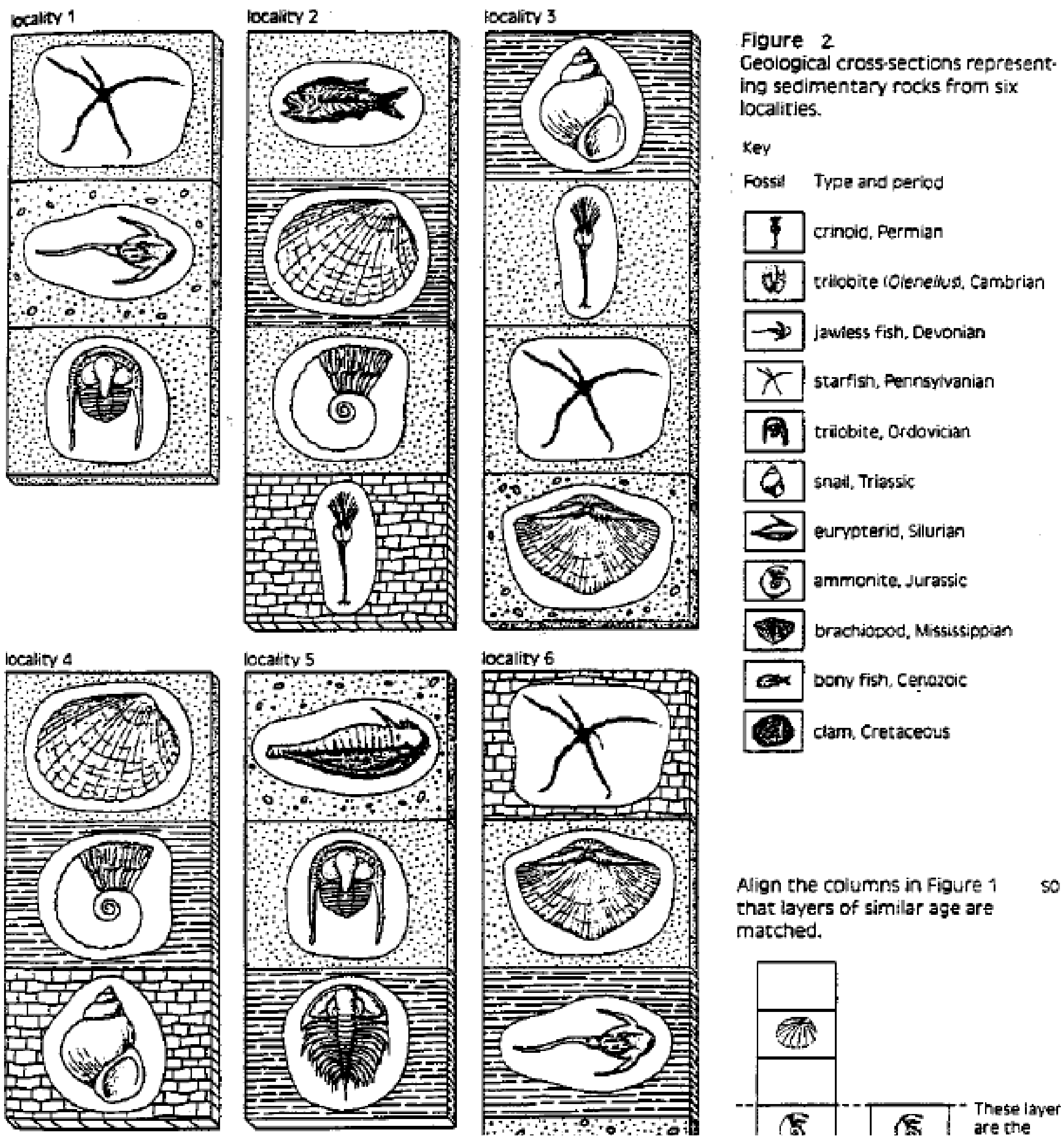
Questions:

1. Explain the absence of some fossils in some localities.

2. List all the fossils in the Key in chronological order, from oldest at the bottom to youngest at the top.

Student Exercise

Figure 1



Part 2: Sedimentary Structures

Procedure:
Read over the various sedimentary structures and their descriptions on pp 26-33 in the AGI lab text.

Questions:

1. Which of the structures discussed in this exercise might be useful in helping to distinguish the top from the bottom of a bed?

2. Which of these structures might be useful in determining the direction in which currents flowed?

3. Place an X in the table under each environment in which the sedimentary structure may form.

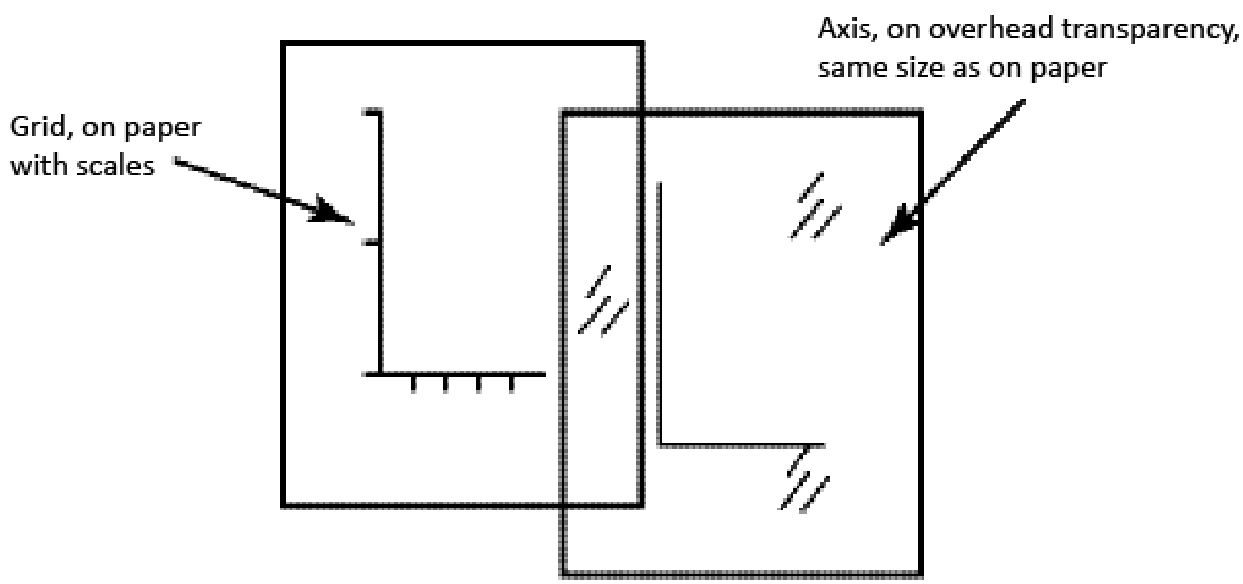
Sedimentary structure	River, stream	Shallow sea	Beach	Dry lake bottom	Sand dunes (wind)	Deep sea	Tidal flat
Asymmetrical ripple marks							
Symmetrical ripple marks							
Cross-bedding							
Mudcracks							
Raindrop imprints							
Lamination							
Graded bedding							
Flute marks							
Tool marks							
Tracks							
Trails							
Burrows							
Stromatolites							

Teacher Information

Radiometric Dating

Here is a perfect exercise to demonstrate the phenomenon of radioactive decay to your students so that they can fully understand the radiometric dating methods.

It comes from the original ESCP text project in the '70s. If the students plot their decay curves on a standard grid that you give them, they can then trace theirs onto an overhead sheet. If you stack the overhead tracings on the projector, the class can see how similar the curves are. You can then show the curve for one of the isotopes commonly used in real dating.



Student Exercise

Radiometric Dating

Purpose: To develop the concept of half-life.

Procedure:

The box your group is using contains 100 "radioactive" corn atoms. (Check that you have 100 before you begin. These atoms will decay as you shake the box. The corn has a triangular shape with the attachment point of the kernel at the narrowest vertex. The atoms, which have decayed, will be the ones that point, with the attachment end of the kernel, at the side of the box marked **X**. Remove these kernels and set them aside.

The passage of time will be represented by the shaking of the box to mix the kernels. Each "shake" will consist of 5 rattles of the box.

When all of the atoms in the box have decayed, plot a graph of the data with "Time" (number of shakes) on the X-axis and the Number of Atoms Remaining on the Y-axis.

Each person in the group will need a Data Table with columns labelled: "Shake" number, Number of Atoms Removed, and Number of Atoms Remaining.

Caution: **Do not eat** any of the corn. It is poisoned with a fungicide.

Questions:

1. What shape is the graph? What does this shape indicate?

2. Find the point on the graph where 50 atoms remain in the box. How many shakes occurred to get to this stage? The time at which one half of the original atoms remain, is called the *half-life*. What is the half-life of the corn, in shakes?

3. If each shake represents 1.0×10^6 years, what is the half-life of this corn? Do all the corn groups in the class have the same half-life?

4. In the textbook find the list of the most common radio active isotopes used in radiometric dating and list them from shortest half-life to longest half-life. Some are useful for specific rock types only. Which apply to metamorphic rocks only?

Teacher Information

Radiometric Dating Quiz

The following quiz is useful for determining if the students understand the radiometric dating method. If you set up the sets and store them in zip-lock bags, they can be used for years. To colour the macaroni, put some in a plastic bag and add a few drops of rubbing alcohol (isopropyl) and a few drops of food colouring and shake. Dry the coloured macaroni on paper towel. (You may use plastic beads as atoms instead of corn. Pony beads are a good size and they are more durable. Pick two nice colours, of course.). Use ratios (D:P) of: 1:1, 3:1, 7:1, 15:1 and 31:1. Count the coloured and natural out in those ratios as 5 colour to 5 natural for the 1:1 ratio, 18 coloured to 6 natural for 3:1 ratio and so on. Use whatever numbers of "atoms" you like. Number the sets to fit your class numbers. If you have 30 students, make 5 of each ratio and record the Set Numbers on a master list. This will make it easier to mark - just look up the set number and you know the age. You don't want to spend all your life marking! This quiz works very well as a SURPRISE in the last 20 minutes at the end of the section on Radiometric Dating.

Student Exercise

Radiometric Dating Quiz

Set # _________ **Radiometric Age** ________________________

Each bag contains a sample representing a parent isotope isotope its stable daughter.

Parent - ^{28}Ma macaronium 28 (natural colour)

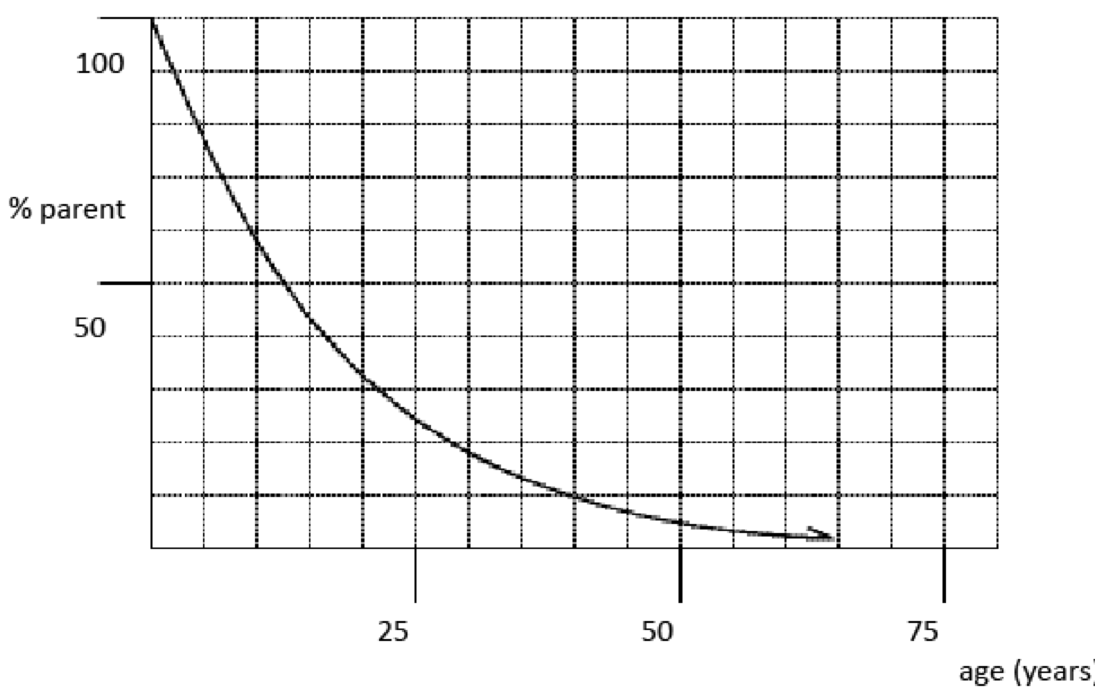
Daughter - ^{28}Pa pastanium 24 (green colour)

Caution: The atoms are fragile and **not** edible.

The decay curve for ^{28}Ma is given below.

Find the age, in years, of your sample. Neatly show all calculations used to find the age in this space.

Bonus: Sketch the curve for the stable daughter on graph, in pencil.



Teacher Information

Geologic Time Scale

One of the most difficult concepts for the average student to grasp (and for that matter, the average person) is the nature and vastness of geologic time. The enormity of our planet's history can prove to be a challenge for one to visualize. The following exercise is a straightforward activity that will give the student the opportunity to visualize time spatially, by plotting time and important events on a strip of paper. In addition, the student will become familiar with the different geologic eras, periods and epochs that geologists use to break up geologic time. (It will also prove teachers were born after the dinosaurs.)

With introduction and closure, the time required is roughly one sixty-minute period. The teacher must supply pieces of adding machine tape. It maybe obtained from the school store, the cafeteria or the Business Management teacher. Whether students work alone or in pairs may depend on your adding machine tape supply. The students should be prompted to bring their own coloured pencils/pens/felts and a calculator.

For a different twist, provide students with a 12 month Planning Calendar (all the days of a year on one page) and have them plot the time scale over the calendar year. The good students will calculate the number of years represented by one day.

Student Exercise

Geologic Time Scale

The easiest way to visualize the vast amount of time that the Earth and its past and present life forms have existed is by means of a time line. In this exercise, you will be constructing a time line showing some of the major events that have taken place on our planet. Adding machine tape will be used to plot such a line.

Procedure:

1. Obtain a 2.5 metre long piece of adding machine tape. Mark the far right-hand side: **PRESENT** in **red**.

2. Using a scale of 1 mm = 2 x 10^6 years (2 million), plot the following by measuring back in time to the left:
   a) the Phanerozoic portion of the time scale, along with all its divisions, on the TOP side of the tape. Eras should be marked in **red** with a 2 cm line, Periods in **blue** with a 1 cm line, and Epochs in **green** with a 1/2 cm line.
   b) all the events in the table below in **black** (or lead) with a line across the strip:

Event	Time (Years Ago)
Formation of the Earth	4.6 x 10^9
first invertebrates appear	570 x 10^6
first fish appear	500 x 10^6
first reptiles appear	300 x 10^6
first amphibians appear	400 x 10^6
first mammals appear	200 x 10^6
first man-like animal	2.5 x 10^6
Pleistocene glaciation (most recent)	1.0 X 10^6
Pacific Coast Orogeny (mountain building)	70 x 10^6
Appalachian Orogeny	350 x 10^6
first known plants appear	3.2 x 10^9
first known animals appear	1.2 x 10^9
oldest rocks on the planet	3.9 x 10^9
first dinosaurs appear	225 x 10^6
last dinosaurs disappear	70 x 10^6
age of Canada	1.32 x 10^2
your birth	

Student Exercise

Geologic Time Scale

ERA	PERIOD		EPOCH	TIME MY
CENOZOIC	QUATERNARY		Holocene	0.01
			Pleistocene	2
	TERTIARY		Pliocene	5
			Miocene	24
			Oligocene	37
			Eocene	58
			Paleocene	66
MESOZOIC	CRETAEOUS			144
	JURASSIC			208
	TRIASSIC			245
PALEOZOIC	PERMIAN			286
	CARBON-IFEROUS	PENSYL-VANIAN		320
		MISSISS-IPPIAN		360
	DEVONIAN			408
	SILURIAN			438
	ORDOVICIAN			505
	CAMBRIAN			570
PRECAMBRIAN				4000 [1]

Based on Hamblin, *The Earth's Dynamic Systems*, 1982, Dates from Montgomery, *Physical Geology*, 1987
It is recognized that there is some variation in the dates given in the literature

[1] Approximate age of the oldest rocks.

Teacher Information

Earthquakes - Interpretation of Seismic Data

This activity is a variation on the one in ESCI 11 Section R. It involves the students in plotting P- and S- wave arrival times, interpreting epicentre distances from those curves, and calculating the velocities of the two wave types. There is less guidance and more chance to think about and interpret the seismic data in this activity than in the ESCI 11 exercise.

Another way to get them to work with earthquake data is to use "The Bellingham Seismogram Package". It uses real seismic data from the Good Friday earthquake in Alaska in 1964. The package contains a class set of seismograms recorded at Western Washington University and a booklet of exercises to guide the student through the process. The seismograms contain two days records with all the time marks. The exercises included are too much for the time available in Geology 12, but are easily customized to suit the course. This package is available from scientific supply companies at a reasonable cost.

Student Exercise

Interpretation of Seismic Data

Arrival Times of Earthquake Waves

Seismograph Station	Distance from Epicentre	P-waves arrived at	S-waves arrived at
1. Buenos Aires (Argentina)	11150	10: 13: 55	10: 25: 32
2. Halifax, NS (Canada)	4400	07: 38	13: 45
3. Reykjavik (Iceland)	5660	09: 10	16: 29
4. Marseilles (France)	8510	11: 58	21: 49
5. Edmonton, AB (Canada)	820	01: 59	03: 18
6. Los Angeles, CA (USA)	1740	03: 45	06: 40
7. Ottawa, ON (Canada)	3520	06: 30	11: 42
8. Azores (Atlantic Ocean)	7360	10: 56	19: 48
9. Athens (Greece)	9710	12: 55	23: 39
10.Anchorage, AK (USA)	2060	04: 20	07: 38

Look carefully at the data above. Find each seismograph station listed above on a world map. Try to see what the given information means. Please note that arrival times are in Greenwich Mean Time (GMT), which is International time named after a village in England located on longitude of 0^{o}. For example, 10:00:00 GMT is same as 7:00:00 a.m. Pacific Standard Time.

On a single sheet of graph paper, plot a graph with **Distance from the Epicentre** on the x-axis (horizontal) and **Arrival Times** on the y-axis (vertical) for
(a) P-waves, and (b) S-waves.

Please **use a pencil and eraser in case of mistakes**. Your finished graph will have two lines on it, one for P-waves and one for S-waves.

Use the following scales:
Distance from the Epicentre is plotted on the short side of the paper such that 1 inch = 2000 km (i.e. the smallest division represents 200 km). This will allow you to plot even the largest distance (11 500 km) on the data table.

Arrival Times is plotted on the long side such that 3 inches = 10 minutes (i.e. the smallest division represents 20 seconds, or three smallest divisions represent 1 minute). This will allow you to plot the largest time interval of up to 30 minutes.
Identify every plotted point by the number of each seismograph station.
Label the graph with a title, and mark each axis properly, showing the scale on each. Label the axes with proper names, units of measurement and scales.

Student Exercise

Questions:

1. How far from the epicentre was a given seismograph station X if the first P-waves arrived there at
   - (a) 8 minutes after the quake started ___________________________________
   - (b) 13 minutes after the quake started ___________________________________
   - (c) 20 minutes after the quake started ___________________________________

2. How far from the epicentre was a given seismograph station Y if the first S-waves arrived there at
   - (a) 8 minutes after the quake started ___________________________________
   - (b) 12 minutes after the quake started ___________________________________
   - (c) 20 minutes after the quake started ___________________________________

3. Calculate the average speed of P-waves between the epicentre and Edmonton (the distance is 20 km) in km/sec and in km/hr. Use your calculator.

   ___________________________________ ___________________________________

4. Calculate the average speed of S-waves between the epicentre and Edmonton in km/sec and in km/hr. Once again use your calculator.

   ___________________________________ ___________________________________

5. Calculate the average speed of P-waves between the epicentre and Marseilles (the distance is 8,510 km) in km/sec and in km/hr. Use your calculator.

   ___________________________________ ___________________________________

6. Challenge question: A recording station is 2 000 km away from the epicentre of the earthquake. What is the difference between the arrival times of P- and S- waves at that station?

   ____

Volcanoes - Damage Analysis and Control

The following exercise is a cooperative learning assignment that needs to be completed in small groups. It is an excellent way to get the students thinking not only of the damage a volcanic eruption does in the immediate locality of the disaster, but also of the global effects a major eruption can have.

This is an activity that will really illustrate the students' understanding of the nature of a volcanic eruption, and all its related effects. The potential for worthwhile and provocative discussion and student interaction adds to the appeal of this exercise. It is essential, however, that the teacher's expectations for each participant's role are discussed prior to initiating the activity, and that there be a scientific (or possibly moral) rationale for any decisions put forth.

Student Exercise

Volcanoes - Damage Analysis and Control

Preliminary Information:

Your group is to take on the role of the Advisory Panel and make decisions regarding action to be taken in the event of a volcanic eruption emergency.

Procedures:

1. Read the Memo "Explosion of Volcano Aruba in Micronesia".

2. Have each person in your group select one of the five different problems described (J-3 and J-4). Each person will then list the possible effects on human life, based on the situation presented by his/her problem.

3. Have each person tell what should be done to help solve the specific problem. He/she must also list the positive and negative effects of his/her actions.

4. Acting as the Advisory Panel, your group must take corrective measures on the five problems within **a limited amount of time**. Get together and decide:

   a) the order of importance which you would place on each problem. Also indicate why you would choose this order.

   b) what action(s) should be taken on each of these problems.

   This assignment is a group project. Therefore, each group will hand in one paper, with all names signed to it, for marking.

   Note: The situation described is not science fiction. There is evidence that catastrophes of such proportions have occurred in the past. There is no reason to believe that they will not occur in the future.

Student Exercise

Memo

To: Advisory Panel
From: Joint Advisory Staff
Date: October 8, 2009
Subject: Explosion Of Volcano Aruba In Micronesia

We may be facing a disaster that will affect the entire world. We feel that all decisions must consider the worst possible consequences. We recommend that plans be drawn up immediately to deal with the problems listed under "Action To Be Taken." Failure to do so may result in the destruction of not only our society but perhaps, most other societies.

Background

As we all know, the giant volcano Aruba exploded on the evening of October 2. Clouds of smoke and ash could be seen for over 50 miles. Aruba continues to give off large amounts of smoke and ash. A cloud of particles that blots out the sun is becoming larger each day. Our experts estimate that more ash has been put into the atmosphere than from the explosion of the volcano Tambora in 1815. The dust and ash from Tambora, as you may recall, circulated all over the world and had severe effects on climate. Weather records show there were frosts every month of the year in Europe and North America. The skies were always gray, and low rainfalls caused drought. The average annual temperature in Europe dropped almost 2^{o}C. Thus, the growing season was severely shortened. The price of food doubled as a result of widespread food shortages. Weather conditions did not return to normal until 1818. In short, the explosion of Tambora was a disaster felt around the world.

The explosion of Aruba is already larger than that of Tambora. So its effects on world climate will be greater. And there are two other factors which you must consider. (1) The world population was less than one billion in 1815. The present world population is greater than six billion. (2) The atmosphere already has a pollution load that was not present in 1815.

Action To Be Taken

As you all know, decisions that affect all parts of our society must be made now. Whatever you decide, there will be those who consider your decisions unfair and even undemocratic. And since no changes have occurred yet, many people will question your judgement. But you alone must make important decisions now.

Student Exercise

Problem One: Water Shortages

Shortages of fresh water should be expected. Lower temperatures will reduce evaporation. This means that less rain and snow will fall. Water for drinking, washing, irrigation, and industrial use will have to be cut back. Any rain or snow that does fall may contain sulfur dioxide and other chemical compounds from the volcano. In high levels, these chemicals will be poisonous.

Problem Two: Fuel Shortages

Temperatures may drop on a worldwide scale. If so, we could have several severe winters in a row. This means that we will not have enough fuel for home heating, transportation, and normal levels of industrial production. Our domestic supplies of oil and natural gas are almost gone. Imported oil would certainly become too expensive to buy.

Problem Three: Food Shortages

We assume that the growing season will be shortened for the next few years. The reduced light, heat, and water and the increased air pollution may totally destroy the 2010 crops. If so, our food reserves will last only six months beyond the 2010 growing season.

Problem Four: Air Pollution and Respiratory Diseases

Gases and ash particles from the volcano are polluting the atmosphere and will cause frequent smog. This condition will be hazardous to health. Elderly people, heavy smokers, and people suffering from tuberculosis, emphysema, and asthma will be in danger. High increases in all types of respiratory diseases should be expected. Safety measures must also be taken against poisonous clouds from the volcano.

Problem Five: Mental Illness and Stress-Related Diseases

Our people will soon experience psychological shock. Life styles will have to change drastically. Rationing of food, water, and fuel, poison cloud alerts, high unemployment, and high prices will cause great stress. Death rates and crime rates may soar. Psychologists report that unless citizens respond to the challenge, we may face great increases in many kinds of mental illness.

Earthquake Safety at Your School

Purpose:

This activity is designed for students to apply knowledge of earthquakes gained in Earth Science 11. It requires them to analyze situations that they, for the most part, consider mundane and take for granted. It is fairly straightforward: find out the best and worst places to be in the school during an earthquake. However, each opinion must be rationalized by legitimate concerns or reasons.

Procedure: (For a 60 minute class period.)

1) Give the students the activity sheet (K-3) and instruct them to fill in their timetable, listing course name, room number, and potential hazards located in and about the room. (This may, in fact, include the room location itself.) The sheet provided was designed for a semester school (i.e. four courses per term), but can be used for a linear school. Just ask them to list their favourite classes instead. Have the students think of all the factors, not just the obvious ones, for example: age of the school, wing they are in, what floor are they on, what is the number of students in the class, type of construction (cinder block, lathe and plaster, etc.), are they near windows, overheads, or doorways, etc. (**10 min**.)

2) Divide the students into small discussion groups of three to five people. In their groups, they are to share and compare their information with the other group members, and try to come up with two examples (for the group) of the worst rooms to be in at school during an earthquake. The first should be one taken from one of their lists. The second should be one derived from mutual consensus from anywhere in the school. Again, it is important that the students be able to substantiate their choices by offering valid reasoning. ("Because Mr. Kurdunawitsk might spontaneously combust" is not valid.) (**5-10 min**)

   After this part of the process, the teacher will take submissions created by procedure 1 from each of the different groups and copy them on the board or overhead. The result: a compilation of various places in the school, and the potential earthquake problems associated with each. (**10 min**)

3) Now have the students describe what the best rooms in the school might be during an earthquake, and why they think so. Again, all group members will come up with two examples of what they consider to be the absolute best room to be in during an earthquake at school. (**5-10 min**)

   The teacher will again take submissions for the best rooms to be in, as well as a brief description why each was chosen, and record them in list form. (**10 min**)

4) In the last step, the teacher asks what is the ultimate worst place chosen by the greatest number of students, as well as the best place to be at school in an earthquake. (**5 min**)

5) For closure, the teacher can review common hazards in and around the school, earthquake procedures and expectations, and even lead into a discussion of problems and preparations at home. (**5 min**)

The papers may be collected and graded for participatory marks, or just as a matter of interest for the teacher.

Evaluation:

This exercise is particularly useful for several reasons:

1) It gets the students thinking about their surroundings and looking analytically at potential dangers in their day-to-day environment.

2) It allows the teacher to determine the nature, and make-up of the groups. This enables the teacher to mix up the class, and lets students work with a greater variety of other students.

3) It forces the students to use communication skills as they discuss and defend their choices.

Student Exercise

Name: ___________________

Earthquake Safety at Your School

Part One: Individual

List your classes below and identify all the potential hazards associated with each room. Keep in mind where you sit in the room and all the potential debris.

Course	Room No.	Hazards
_____________	_________	____
		____
		____
_____________	_________	____
		____
		____
_____________	_________	____
		____
		____
_____________	_________	____

Part Two: Group Work

A) 1. From the examples in your group, list two of the worst rooms to be in during an earthquake:

Room No.	Hazards
_________	____

2. What do you think is the absolute worst place to be in the school during an earthquake?

Room No.	Reason
_________	____

B) List two places in the school that your group considers the best (safest) in event of an earthquake.

Room No.	Reason
_________	____

Room No.	Reason
_________	____

Teacher Information

Rate of Seafloor Spreading

This is a beefed up version of the exercise in Earth Science 11 (Section W). The data is real, derived from airborne magnetometer surveys. Students are able to follow the exercise instructions alone, but to save time make an overhead of the data and show them how to number the peaks and estimate ages. The calculated overall average rate of spreading is 1.2 cm/year for one side and 2.4 cm/year for the whole Atlantic floor. It takes a long period (1hr 15min to 1hr 30min) for the students to complete this activity, but the rewards are great. There is lots of math in unusual ways. There is no accompanying map to locate the magnetometer traverses. It is helpful to show your students the location of Iceland on a world map, perhaps even mark on representative crossing lines.

The questions include some bonuses. You may not be comfortable with the one about the teacher's age. (You may find that not very many kids try it; few will have the courage to find your height.) The clock question puzzles them. Most do not know how many times the hour hand goes around in a day. For your information, for a typical classroom clock with a 10 cm long hour hand, the tip of the hour hand will travel 0.46 km/yr. That's much faster than the plates, but so slow when you are waiting for class to end!

mineralsed
Mineral Resources Education Program of BC

Teacher Information

Rate of Seafloor Spreading

As molten rock is extruded out onto the Earth's surface, the iron minerals act in it like tiny compass needles and line up with the lines of force of the Earth's magnetic field. As the rock solidifies and crystallizes, these iron minerals are locked in place, pointing to magnetic north and making a permanent record of the direction of the Earth's magnetic field at the time. The magnetic record of the rock can be identified by using a sensitive instrument called a **magnetometer**.

The graphs on the attached page were made from magnetometer readings taken on three passes across the Mid-Atlantic Ridge just south of Iceland. The peaks above the base line represent magnetism in the "normal" direction, that is, the same as today's polarity. The peaks below the base line represent magnetism in the "reverse" direction, that is, opposite to today's polarity. The distance below or above the base line represents the strength of the magnetism locked in the rock.

The observed pattern of normal and reverse direction of the magnetic north pole in rocks indicates that the Earth’s magnetic field has changed many times in the past. At times the North Magnetic Pole was where it is now and at other times it was located at the present day South Pole region of the Earth. The times at which the reversals occurred have been documented at other locations on the Earth's surface and the date of reversals has been found. From the data on the attached graphs it is possible to calculate the speed at which the sea floor has been spreading and find the rate at which the plates have been moving.

In this exercise you will calculate the rate of movement of the plate at the Mid-Atlantic ridge.

Procedures:

1. On each of the three magnetometer traverses (page L-5), number the peaks above the base line 1, 2, 3, 4, 5 and 6, both to the east and west of the central line. (The central line marks the axis of the Mid-Atlantic Ridge.) Note that on some of the traverses not all of the peaks are present. What could cause them to be missing?

2. Draw two lines parallel to the central dashed line that come as near as possible to the two peaks numbered 1, east and west of the center. The lines do not have to go exactly through each peak on the traverses, but as near to each as you can and still be parallel to the center. This process averages the distance the peak is from the center.

3. Measure the distance the lines are from the center using the scale at the bottom of the graph. (1mm: 2km) Record these distances in the data table.

4. Repeat the process for the other peaks.

5. Find the average distance the set of peaks is from the ridge for each peak number {(distance west + distance east) / 2} and enter this data in the table.

6. Using the time scale across the bottom of the page, convert the average distance of the peak to age of the rock at that distance. (10mm: 10 km and 12.5mm: l my)

7. Calculate the rate of movement of the rock for each peak in cm/y to complete the data table. Calculate the overall average rate for all of the data. Note: this rate is for one side of the Ridge only. It is doubled for the whole Atlantic Ocean.

Data Table:

Peak Number	**1**	**2**	**3**	**4**	**5**	**6**
Distance West (km)						
Distance East (km)						
Average distance from Ridge (km)						
Age (my)						
Rate of Movement (cm/y)						

Overall Average Rate (cm/y)

Student Exercise

Questions:

1. Where would you find the youngest rock on the Atlantic Ocean floor? Explain your answer.

2. Where would you find the oldest rock on the Atlantic Ocean floor? Explain your answer.

3. The magnetic peaks are symmetrical East and West of the ridge. Explain why.

4. Draw a line that is the length of the average rate of movement for one year on one side of the Atlantic Ocean sea floor. Draw a line that represents the amount of movement of both sides of the floor in one year.

5. How does this evidence for the age of the seafloor and rate of spreading support the plate tectonic model?

6. Draw a line that represents the amount that the Atlantic Ocean has widened in your lifetime. Show how you calculated this distance.

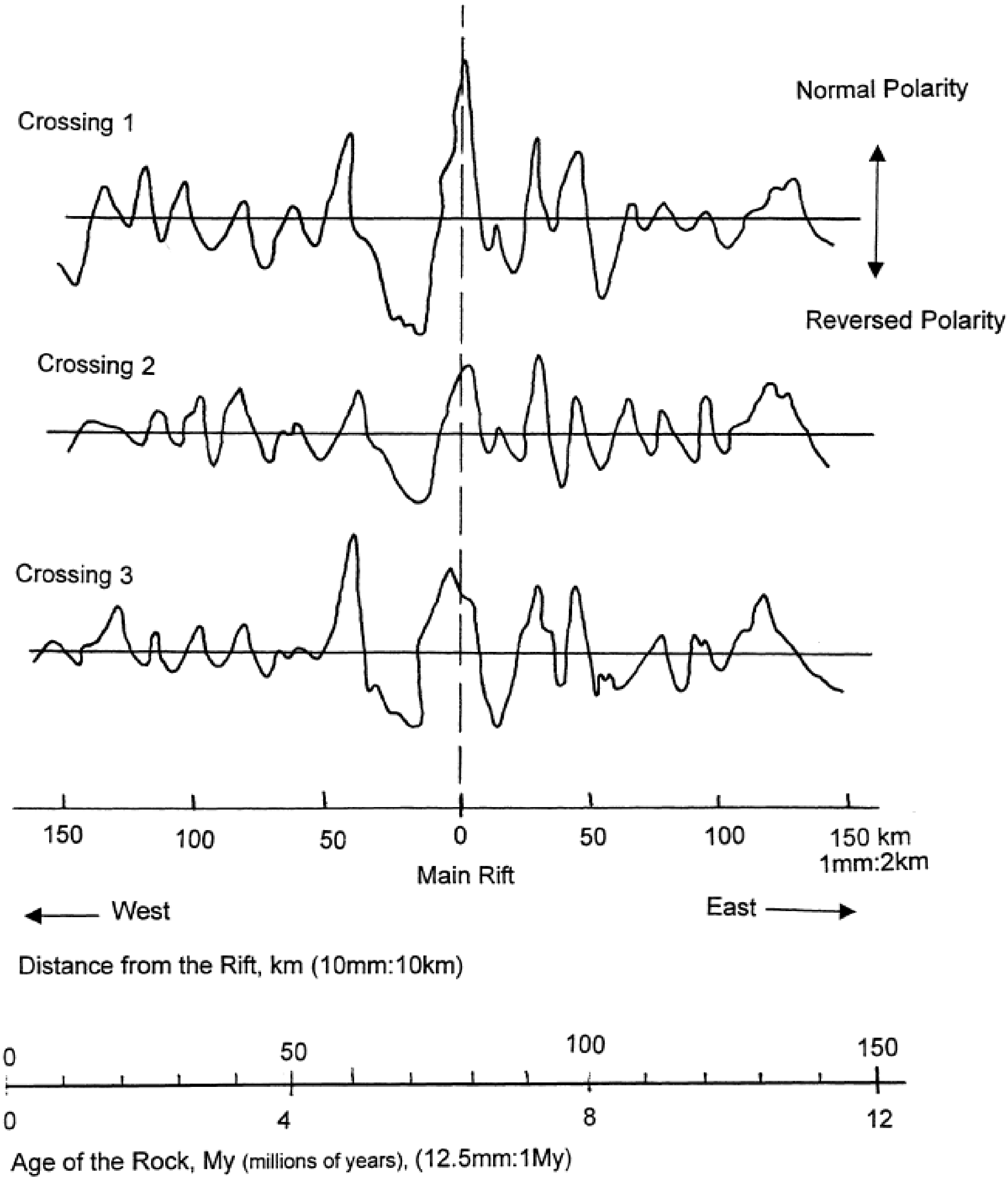
7. The distance from Africa to the Mid-Atlantic Ridge is 2400 km. How long ago was Africa at the Ridge according to your calculated rate of spreading? Is this consistent with the plate tectonic model and the break-up of Pangaea?

8. **Bonus**: How old is your favourite Geology teacher? The Atlantic Ocean has widened by _____% of his / her height in his lifetime. What is his / her age? Show your calculations.

9. **Bonus Bonus**: How far, in centimetres, does the tip of the hour hand of the classroom clock travel in one year? How does this compare to the seafloor spreading rate for the Mid-Atlantic? Show your calculations.

Student Exercise

Rock Polarity Across the Mid-Atlantic Ridge



Teacher Information

Clay Folds

The surface pattern created when tilted layers, folds and faults are eroded can be confusing to students. Here is a fun, yet messy way to help them understand. Show them some map patterns with dip and strike marked on them. Ask them to predict what the subsurface structure must be. Begin with simple tilted layers that are easily interpreted and progress to simple folds before introducing plunging or overturned structures. The purpose of this exercise is to have them make folds, predict what the surface pattern will be, then erode the surface to see if they are right.

Provide each student pair with two, 12 cm X 12 cm blocks of clay, each composed of three different coloured clay layers 0.5 cm thick. Clay used by your school's Art Department works best. It comes in 12 cm square blocks in three colours and can be carefully sliced by pulling a taut wire through it. (Plasticine can be used, but is much more expensive. You could also use play dough; there are simple recipes for making it at home.) If you cut slices before hand, stack them with moist paper towel between and store in a plastic bag. (If you do not have three colours of clay, you can use two.)

To make the fold pairs, cut one block in half to make two strips 12 cm by 6 cm. Carefully fold each strip into an anticline/syncline pair (see sketches). Use one block for non-plunging folds, the other for plunging folds. Have them draw a dotted line around the block to show the cut-line, as indicated in the sketch, and predict what the cut surface will look like before the cut. Let them use a taut, strong nylon fish line with large washers or wood blocks tied to the ends to cut through the structure. The second, plunging fold pair is harder for students to predict, but they will be better at recognizing the surface pattern later on maps after having done this activity. (The Art Department may be able to recycle the clay into something interesting.)

The remaining block is used to make a dome. Students can drape the clay over a fist or a clay ball made from the scraps from the folds. Ask them to cut carefully, not too deep, so they will see the characteristic bull's eye pattern. By replacing the cut piece on the model they can create a basin and erode it.

The block diagram exercise that follows (section O) will help reinforce the learning that has taken place here. To complement that exercise, give them photocopies of the blocks in the lab text. This will make them think!

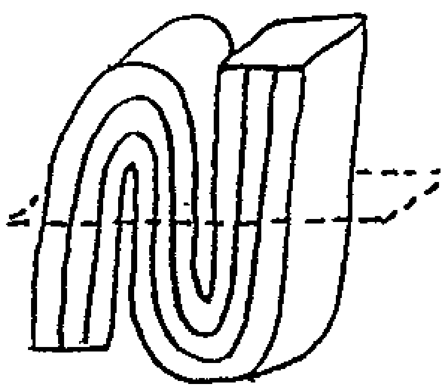
Student Exercise

Clay Folds

You will be working in groups of two. The slab of clay consists of three layers; consider the top layer to be the youngest. The object is to investigate the surface patterns created by the layers in folds when the folds are eroded. In each case, you are to predict the pattern you expect to see before you "erode" the surface by cutting in the direction indicated (dashed lines). After you have made the prediction, cut the fold and sketch the map view of the resulting pattern. Label the youngest and oldest layers each time they appear in the sketch.

1. Anticline – Syncline pair

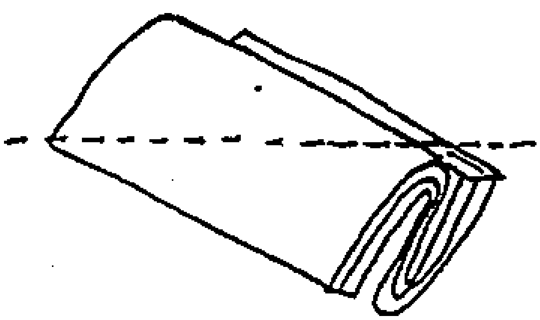
- cut parallel to the fold axis



Prediction | Sketch of Cut Surface

2. Plunging Anticline – Syncline Pair

- Cut at 45^{o} to the fold axis

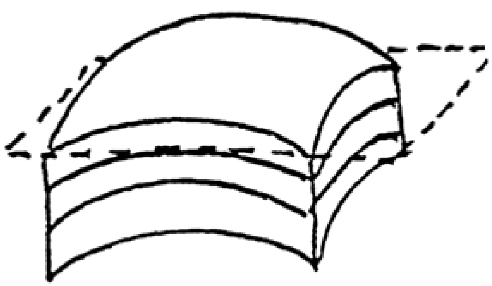


Prediction | Sketch of Cut Surface

Student Exercise

1. Dome

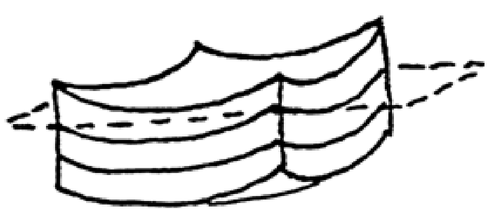
- form by draping clay over a clay ball, then cut off the top



Prediction | Sketch of Cut Surface

4. Basin

- Difficult to make but try to predict what it would look like



Prediction | Sketch of Cut Surface

Teacher Information

Structural Models (Strike & Dip, Folds & Faults)

Here is a collection of ideas, hints and exercises to help you get the ideas of Structural Geology across in class. This is a new topic to the students, so they will be keen and full of enthusiasm.

Strike and dip are easiest to explain and best understood at the outcrop. However, if you do not have a dipping sedimentary rock exposed on your schoolyard, make an acceptable model by setting a large slab of shale in a dishpan full of sand. (Borrow the sand from your track and field's jumping pit.) The slab should be at an angle to the surface of the sand (the dip) and not square across the pan. Ask your students how this layer could be described to someone else either using words or by drawing. They will figure out that they need to speak of the dip and the strike but, of course, won't use those words. If you do this as a group, with everyone standing around the pan, they can see the two directions and the need to describe them. You provide them with the proper terms. If the slab is big enough, you can mark the horizontal direction on it with chalk and roll a ball down it to show dip direction at right angles to the strike. Introduce how strike and dip are measured using a compass, and point out the map symbols for them. Also tell them about other structural features, like fault planes and cleavage surfaces, that can be defined by strike and dip.

After this nice compact lesson, give your students the strike and dip exercise (page N-2). Set up six pans with slabs set in sand for the students to sketch the contact and mark the strike-dip symbol in the appropriate box on the paper. (Borrow some dissecting pans from Biology. They are a good size. Rock slabs look best, but odd shaped pieces of cardboard work too.) Tell them not to move the pans or the material in them. Ask them to hand the sheet in at the end of the period.

Faults are also best explained by demonstrating with models. Make inexpensive fault blocks from 2-inch thick, rigid styrofoam insulation that can be obtained from a lumberyard. (Ask if there are any inexpensive or free scraps or broken sheets.) You do not need much material to make the blocks, but you do need two colours. Cut some strips, all the same width (about twice the thickness of the material) and laminate then together with white glue, alternating the colours. Cut the laminated block into **three** sections (about 25 cm long). These must be cut at appropriate angles to make a strike-slip block, a dip-slip block (does both normal and reverse faults) and a thrust fault. Presto! Cheap, indestructible and easy to store models.

Folds can be demonstrated using foam sheets. Obtain at least two colours of some thin foam sheets that are about 1.5 cm to 2 cm thick and 10 cm to 20 cm wide. Spread glue on the foam and stack the sheets together to form a three-layered strip. Bend the strip over a 4 litre paint can (or a big beaker) and tape it in place until dry. When dry you will have a permanent curve that serves as a syncline or an anticline. Cut a "T" out of black cardboard for a strike-dip symbol to use with this demonstration.

The possibilities for models like these are endless. Ask some students to build models that show the before and after stages of the structural blocks diagrams found in the lab manual or other geology texts or maps.

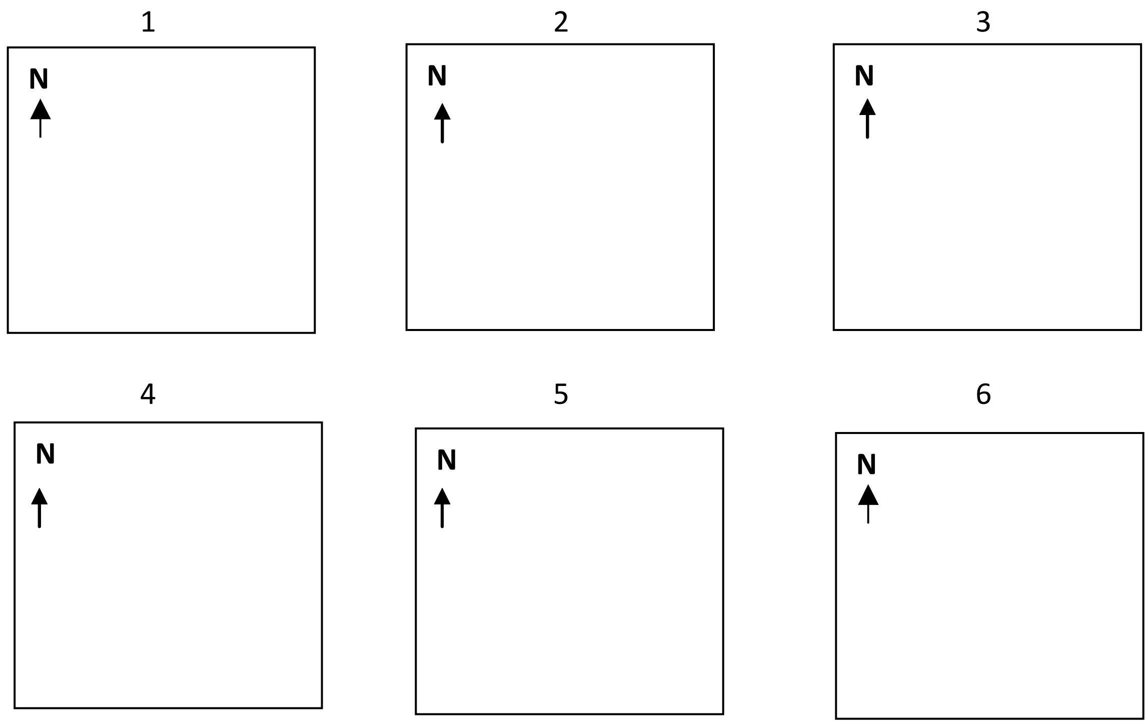
Student Exercise

Name: ____________________

Strike and Dip

You may answer directly on this sheet. You will hand this in as you leave the room.

1. Indicate with the correct strike-dip symbol, the approximate strike and dip of each of the six (6) samples set up around the room. Sketch the edge of the planar feature in the square provided. Mark the appropriate symbol, estimating the angle of dip. Don't move the examples!



2. Define: planar feature.

3. Sedimentary bedding is the easiest form of planar structure to describe. Explain why.

4. What types of plutons (igneous intrusions) could not have a strike and dip?

5. What is the strike-dip symbol for a horizontal structure?

6. What is the strike-dip symbol for a vertical structure?

Teacher Information

Structural Block Diagrams

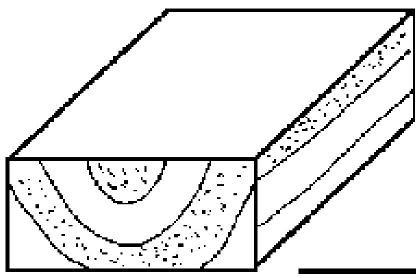
Once the students understand that the map pattern and strike and dip symbols indicate the structure hidden in the Earth, it is time for an exercise to reinforce these ideas. The following uses some simple block diagrams and more complex structures used in the lab text (*Lab Manual in Physical Geology*, AGI/NAGT). After the students have completed the blocks, have them do the lab text exercises (1^{st} Ed., Exercise 13; 3^{rd} Ed., Exercise 14). Photocopy the model pages (1-6) so students can cut and fold them. It takes a couple of periods but is helpful to their learning.

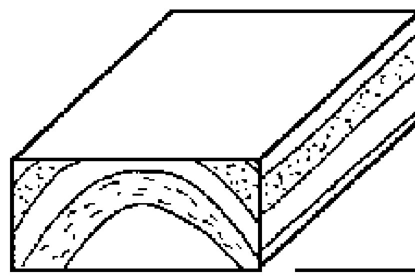
Student Exercise

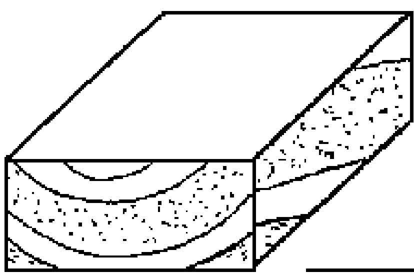
Structural Block Diagrams

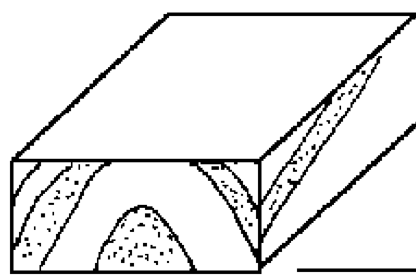
You may answer directly on this sheet. You will hand this in as you leave the room.

1. Complete the following by drawing the contact lines on the map surface, adding the appropriate strike-dip symbols, and stating the fold type.

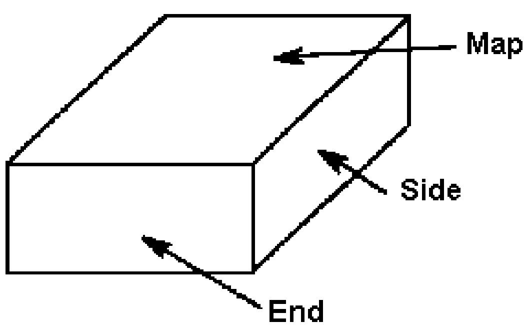
a


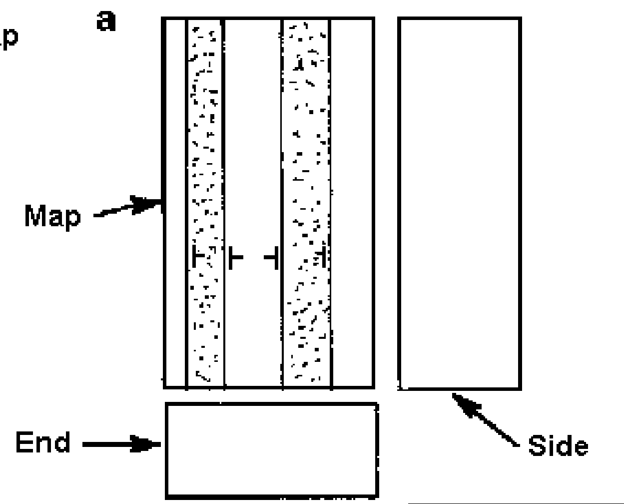
b


c


d


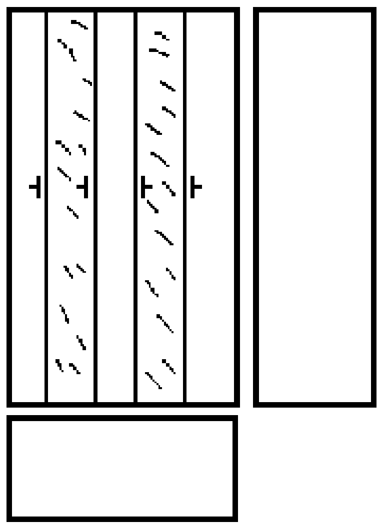
2. Complete the diagram based on the map or subsurface data provided.



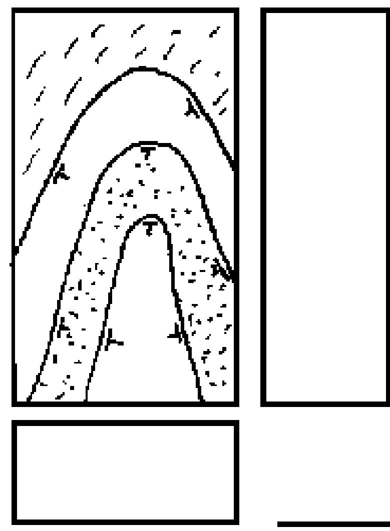
a


Student Exercise

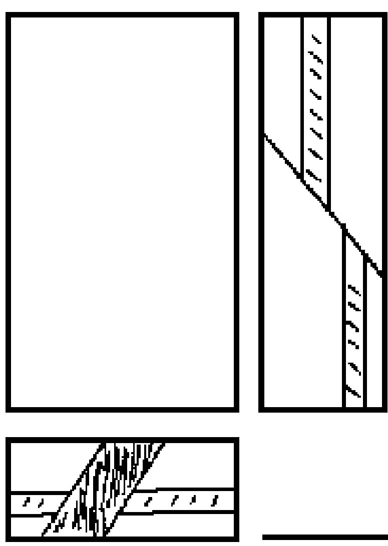
b.



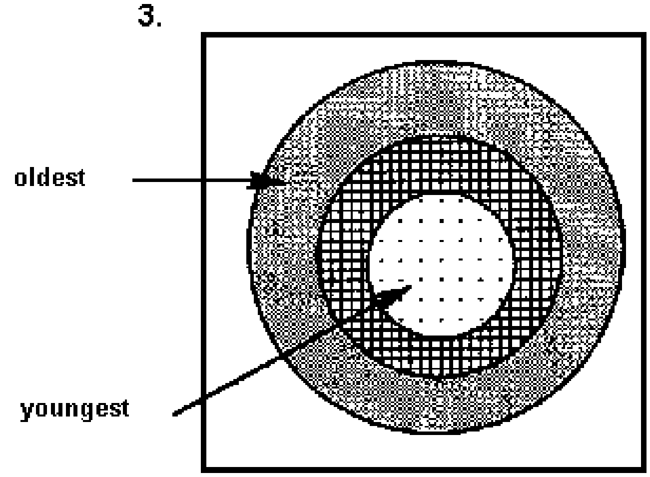
c.



d.



3.



What type of structure is this?

Teacher Information

Structural Geology Cross-Section

The following assignment requires students to use their knowledge of geologic structures and map view indicators of subsurface conditions. Using strike and dip information and a map view of the surface, the students construct and interpret a cross-section. This exercise requires a number of skills, so is best assigned near the end of the unit when the students are capable of data analysis and interpretation. It may be offered as a take-home lesson, as a topic review, or even as a quiz.

It is important that Geology 12 students develop an understanding of the deformation and distribution of rock bodies in 3-dimensions. Although structural geology accounts for only about 20 percent of the Internal Structures and Processes unit of the curriculum guide, structural geology questions that require understanding these concepts are common on the provincial exam.

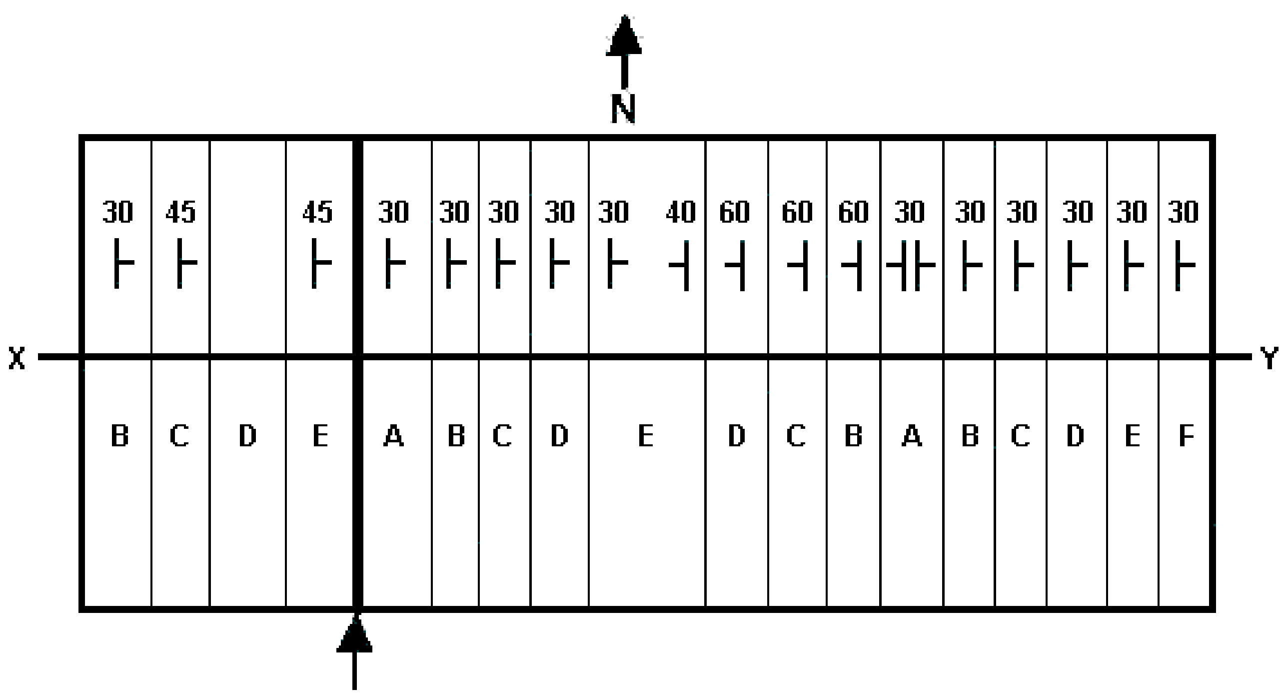
Student Exercise

Structural Geology Cross-Section

Name:_______________________
Date:________________________
Score:____**/15**

Assignment

1.	Draw a cross-section through X Y.	5 marks
2.	Label the fold axis (use the correct symbol) .	2 marks
3.	Name and indicate movement of the fault.	2 marks
4.	Which bed is the oldest?	2 marks
5.	Which bed is the youngest?	1 mark



NOTE: FAULT DIPS 60 DEGREES WEST

Teacher Information

Name the Structure

This is a structural mapping project your students can complete in the classroom. It nicely simulates mapping in the field. To set this up in your classroom you must:

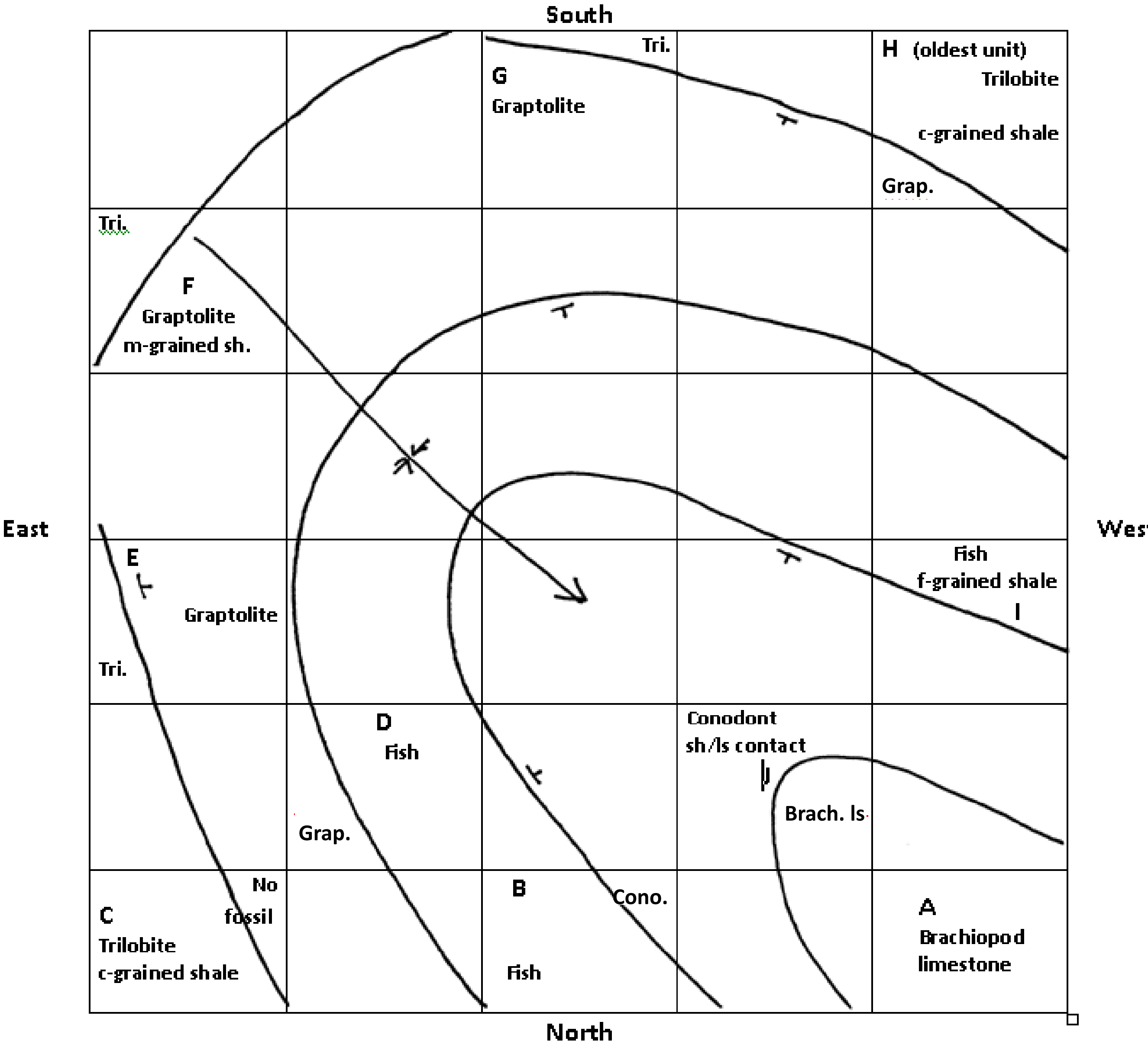
Put the ten "outcrops" on the desks as indicated on the answer key (Q-2). (Use tape to hold them in place.) Add the designated letter of each outcrop on the back of the sheet to make it easier to lay it out. If desks in your class are arranged differently than shown (5 rows of 6 desks), you will need to adjust for that fact. Put the fossil signs on the wall at the back of the classroom for the students to refer to.

Put the classroom activity overhead up for all to see. Help your students get started mapping by quickly drawing a blank grid of the desk layout on the blackboard. Most students will catch on to the fact that they will find mapping easier of they draw a similar grid to plot the outcrop data. When students bring an answer that is only partially correct, it is important to tell them so and to make them try to figure out what is wrong. Prizes offered for correct answers could be a homework pass, a pack of gum or a candy bar.

Teacher Information

Name the Structure - Answer Key

Map View: each square represents one desk in a 5 X 6 layout.



Answers: plunging syncline
transgression (sea level rising)
map should have: contact lines
plunging syncline symbol
some strike and dip symbols

plunge direction

Overhead

Name the Structure Classroom Activity

Work in partners or alone.
Please notice the fossil signs at the back of the room and the 10 outcrops on the desks around the room.

Instructions: Answer the following questions.

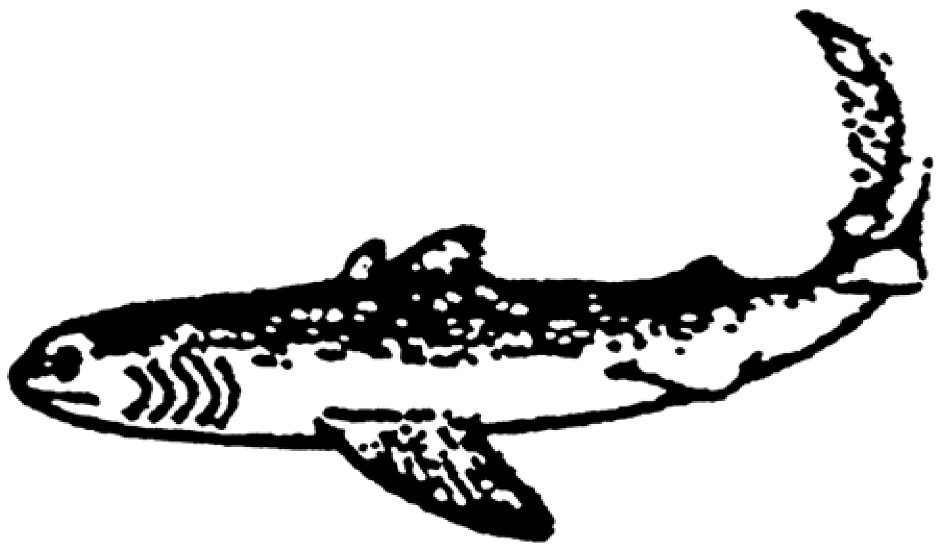
1. **Draw the structure (map view) with all the details (i.e. strikes, dips, structure symbol, contact lines, plunge direction, if any).**

2. **Name the structure.**

3. **Was the sedimentary sequence deposited during a transgression or regression?**

The first THREE totally correct answers I receive will earn a prize!

Fossil 1
Vertebrate Fish
Devonian

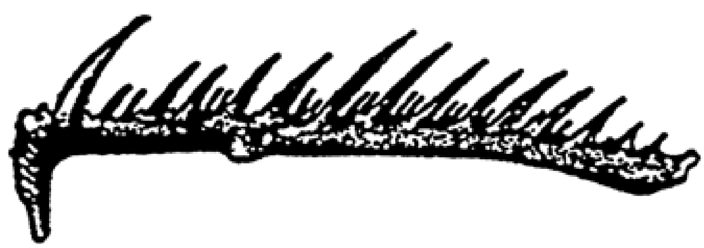


Rock type found here:
fine-grained shale

Fossil 2
Brachiopod
Permian

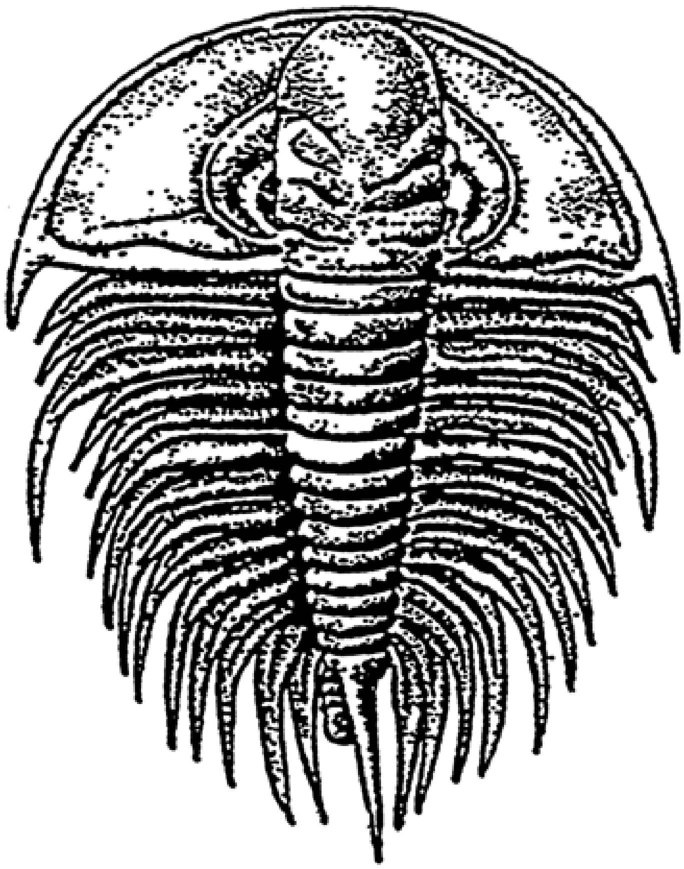
Rock type found here:
limestone

Fossil 3
Conodont
Mississippian



Rock type found here:
shale / limestone mix

Fossil 4
Trilobite
Cambrian



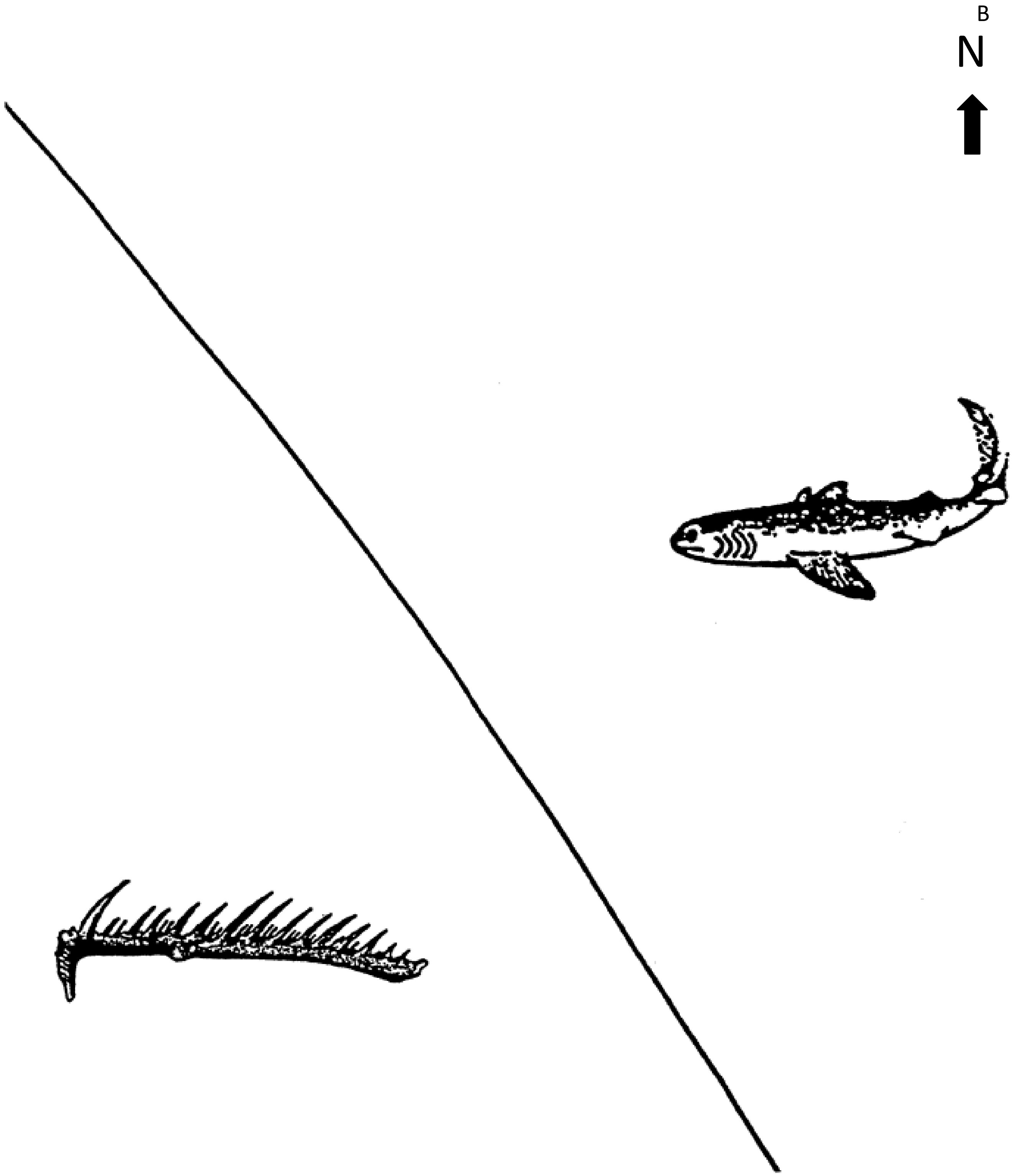
Rock type found here:
coarse-grained shale

Fossil 5
Graptolite
Ordovician

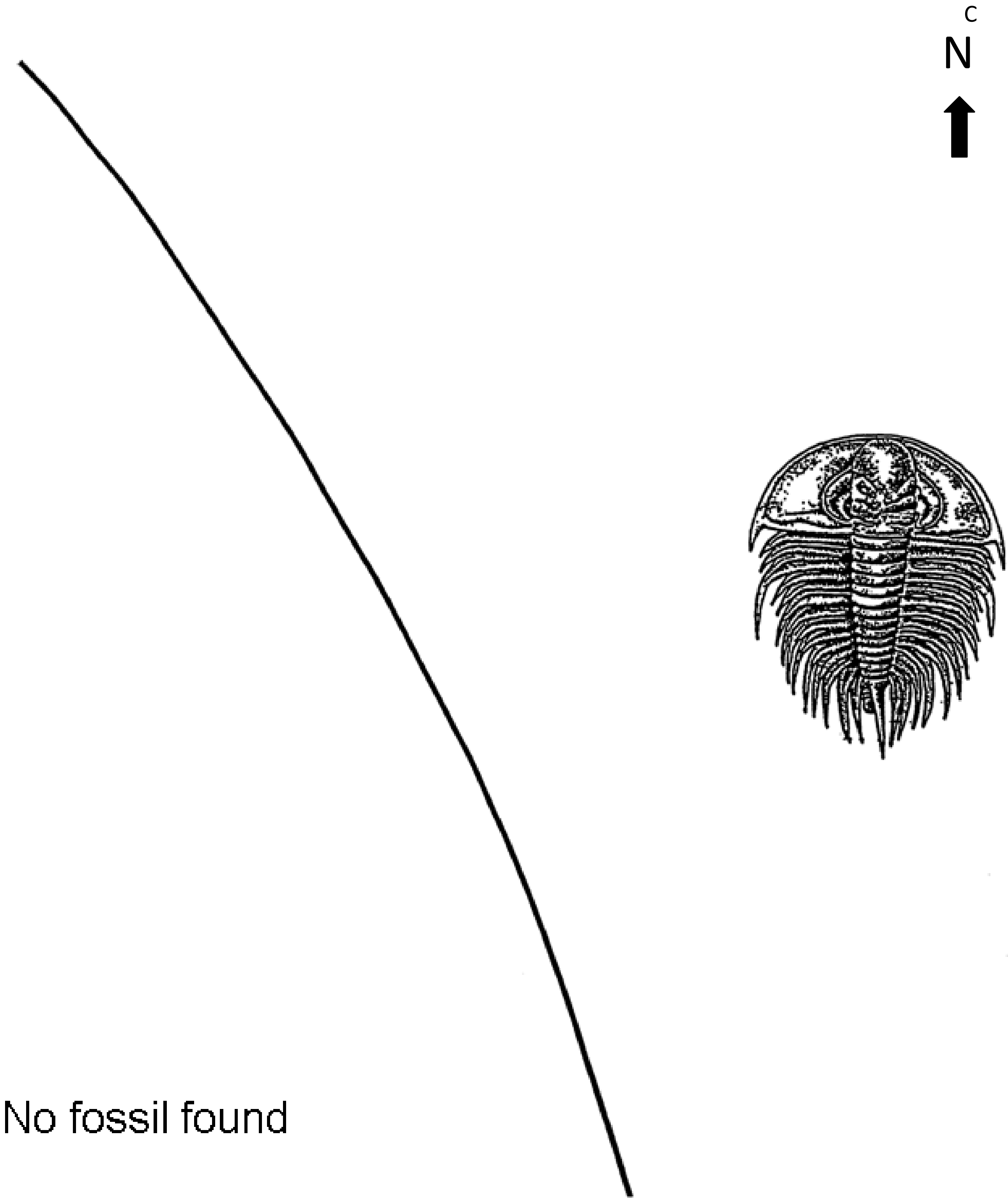
Rock type found here:
medium-grained shale

A

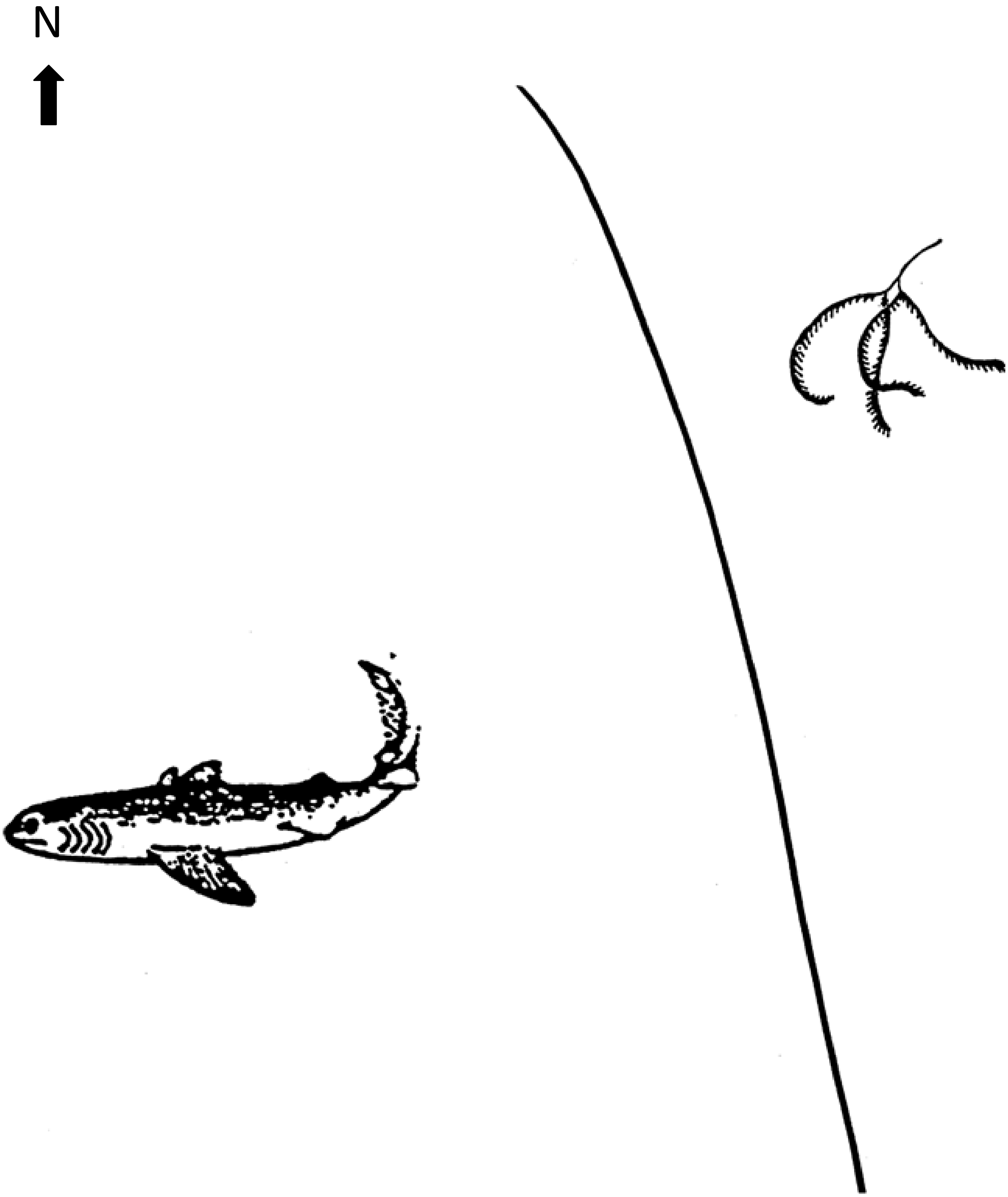
N

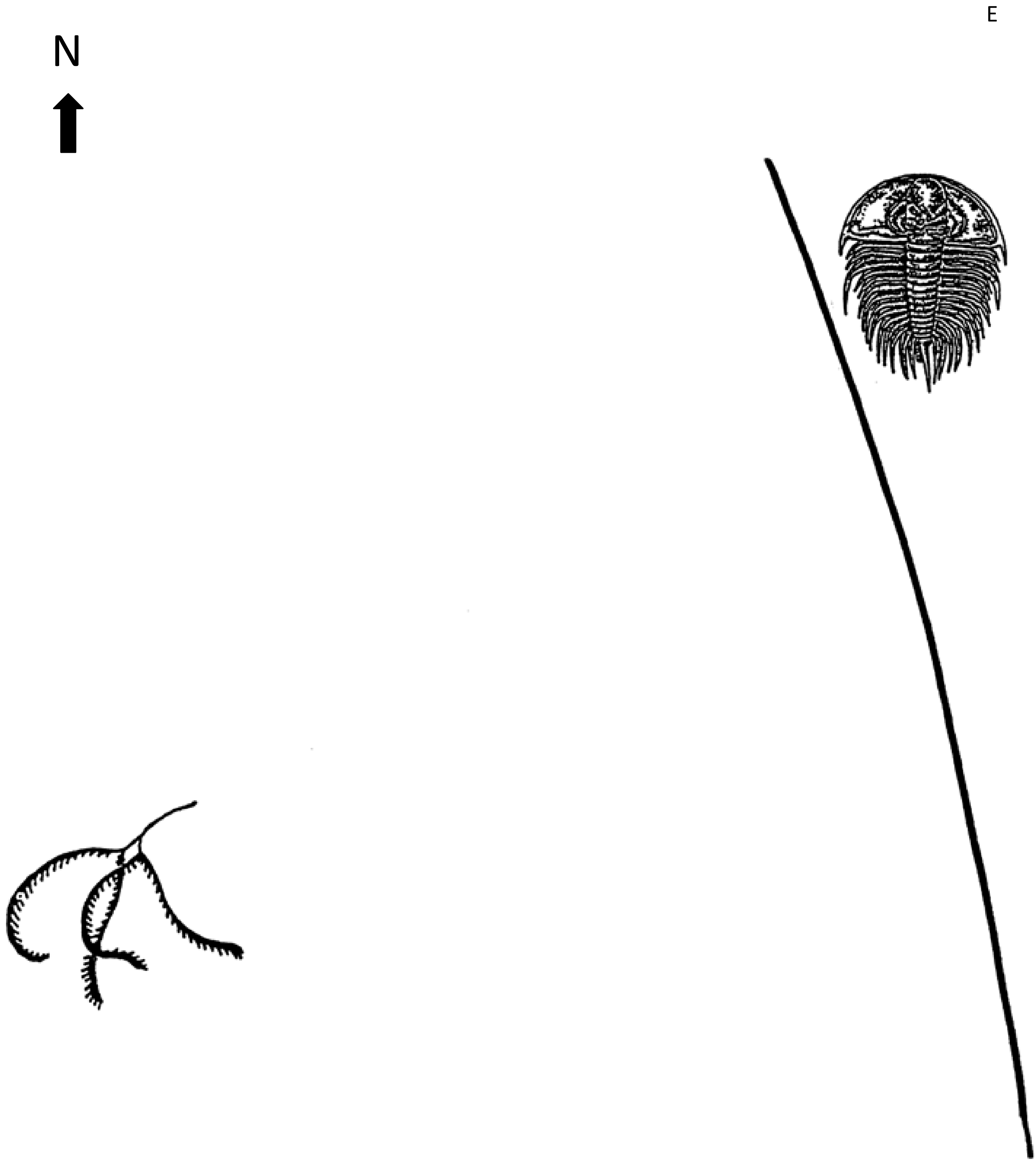


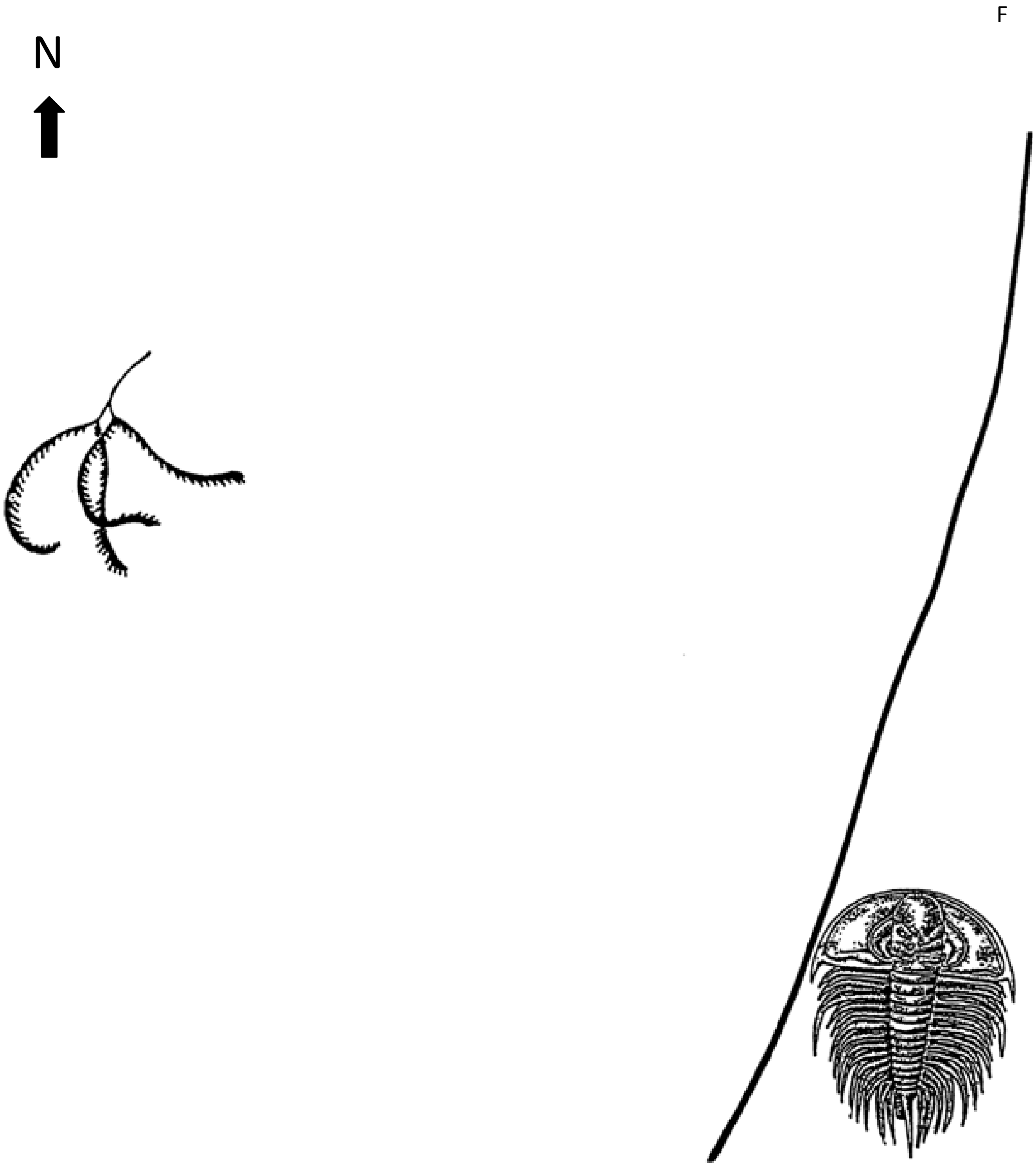
B
N

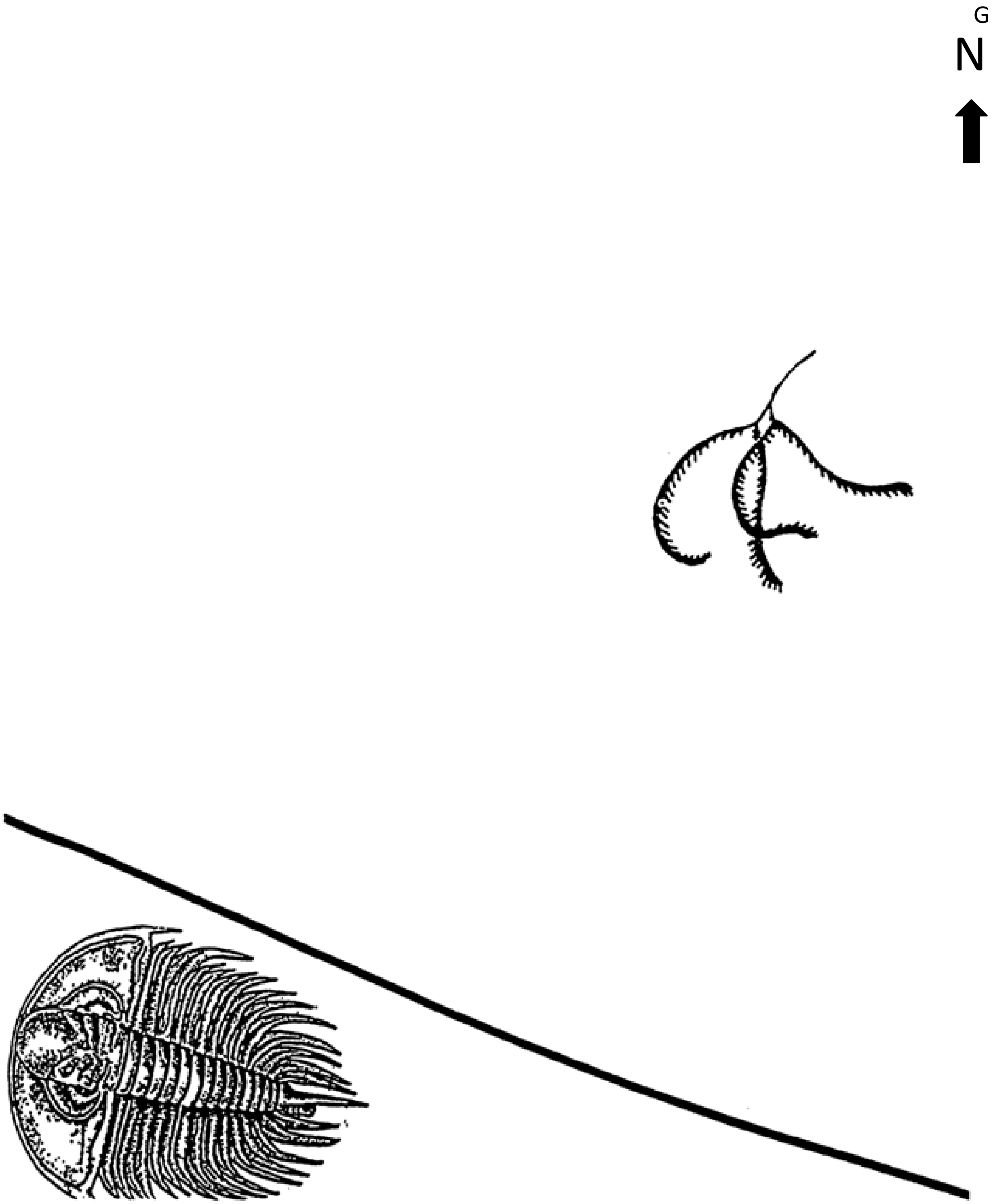

C
N
No fossil found

D



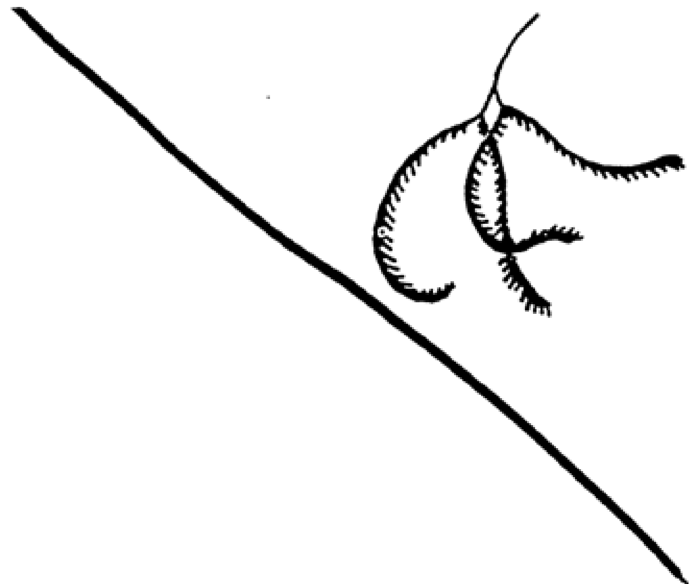

E
N

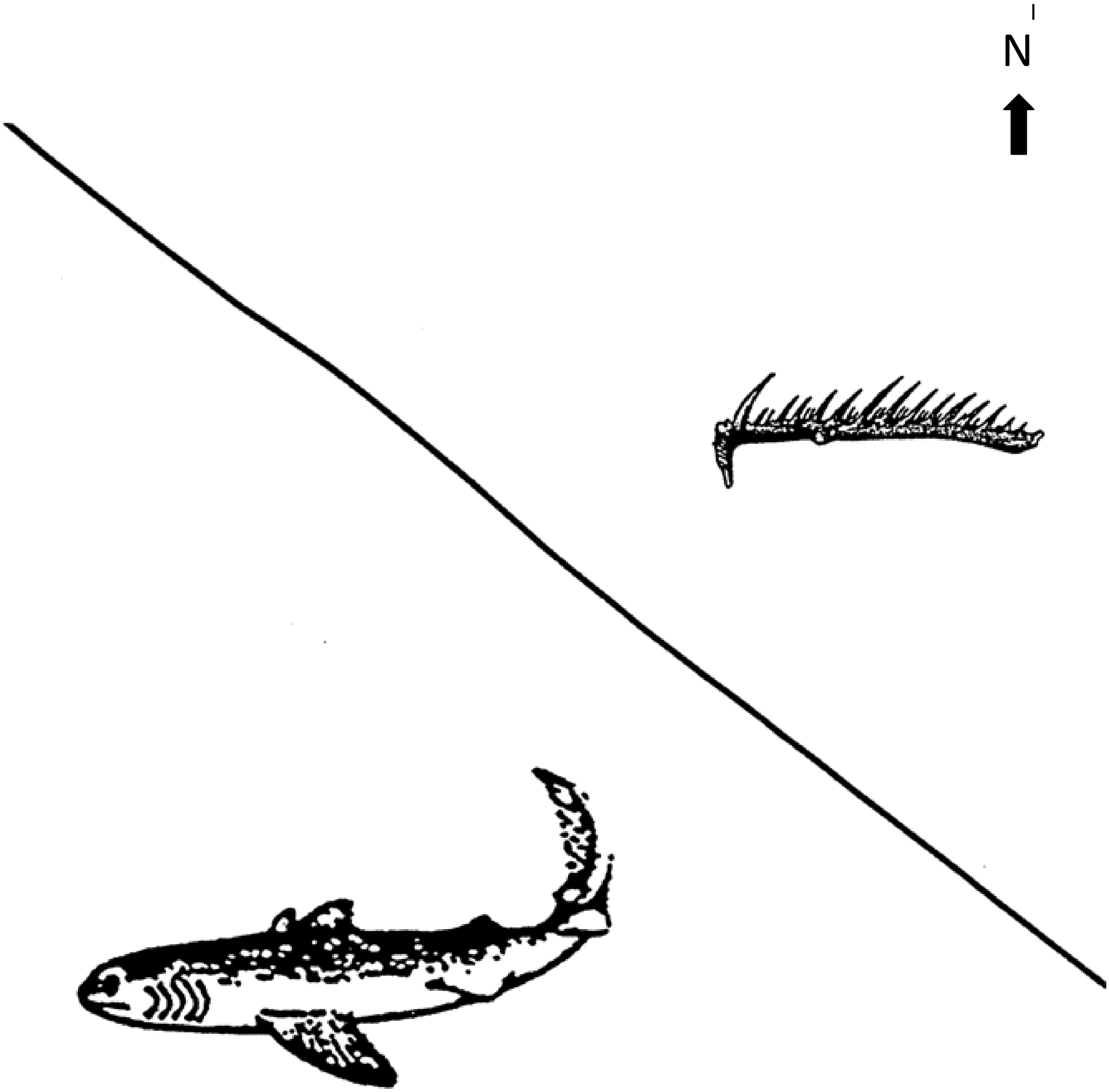

F
N

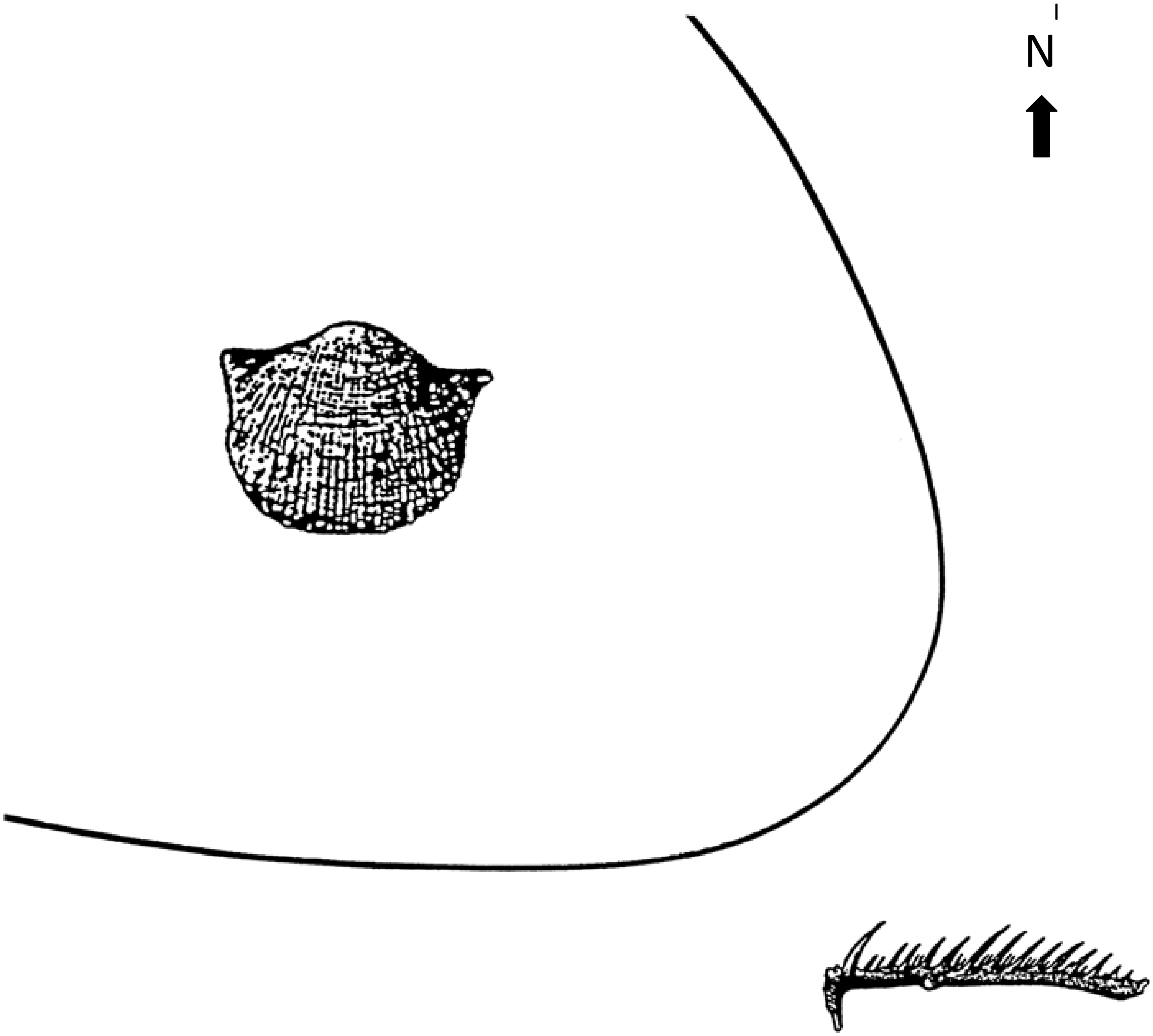

G
N

H

N




N


N

Teacher Information

Tectonic Analysis of Planet X143B-M

Increasing data from space research has helped construct a model of planet formation and evolution in our Solar System. Similarities among the rocky inner planets has naturally led to speculation on whether or not tectonism as we know it on Earth has shaped any of these other planets. Now that geologists and geophysicists know what evidence is required to support such activity, analysis of other celestial bodies is possible.

The following activity involves analyzing and interpreting baseline geologic information from a fictional planet to determine whether plate tectonics is operating. Students must integrate all their Earth-based knowledge of the plate tectonic model and submit a final report of their conclusions. It is a fun and creative project.

Student Exercise

Tectonic Analysis of Planet X143B-M

Introduction

It is the year 2199. Humans are now exploring the Milky Way galaxy looking for suitable planets to colonize. One possible candidate is Planet X143B-M. You are an extraterrestrial geologist and have been given the job of analyzing the preliminary geological data from this planet.

Planet X143B-M (please feel free to give it a better name) is very similar to Earth, but there are some important differences. Planet X143B-M has a magnetic field about the same as the Earth's magnetic field. Oceans cover approximately 55% of the planet and like the Earth, it has a nitrogen and oxygen – rich atmosphere.

The Data

1. Echo-sounding data are available for two transects: line A-B in the northern ocean, and line C-D in the southern ocean (see Figure 1). These data are given in Tables 1 and 2. Note: the 0-km depth is sea level. Positive depths are actually elevations above sea level (i.e. not covered by water) and negative depths are below sea level (i.e. underwater).
2. A number of seismometers have been placed on the planet to record earthquake activity. The epicentres of the earthquakes are shown in Figure 1.

Interpretation of the Data

1. Topographic Profiles (in the computer lab)
    a. Draw two topographic profiles along the lines A-B in the northern ocean and C-D in the southern ocean.
    b. Label and colour any prominent topographic features in each profile.
        i. continents (blue)
        ii. ocean floors (red)
        iii. trenches
        iv. ridges
    c. How do the continental margins at locations A and B differ from the continental margin at D? Explain why.
2. Looking Beyond the Raw Data
    a. Like planet Earth, Planet X143B-M is tectonically active. How do we know this? Give as much evidence as possible. You must link all concepts taught to you in class and show how they are related to each other.
    b. How many crustal plates can be seen? Separately shade each one with a different colour.
    c. Outline the plate boundaries on the map and label which ones are divergent, convergent and transform boundaries. Show the relative direction each plate is moving by drawing arrows on the map. (Hint: look at Figures 9.4 and 9.5 in your text.)

d. What other information might we collect on a future trip to the planet that would further support our conclusion?

The Final Report

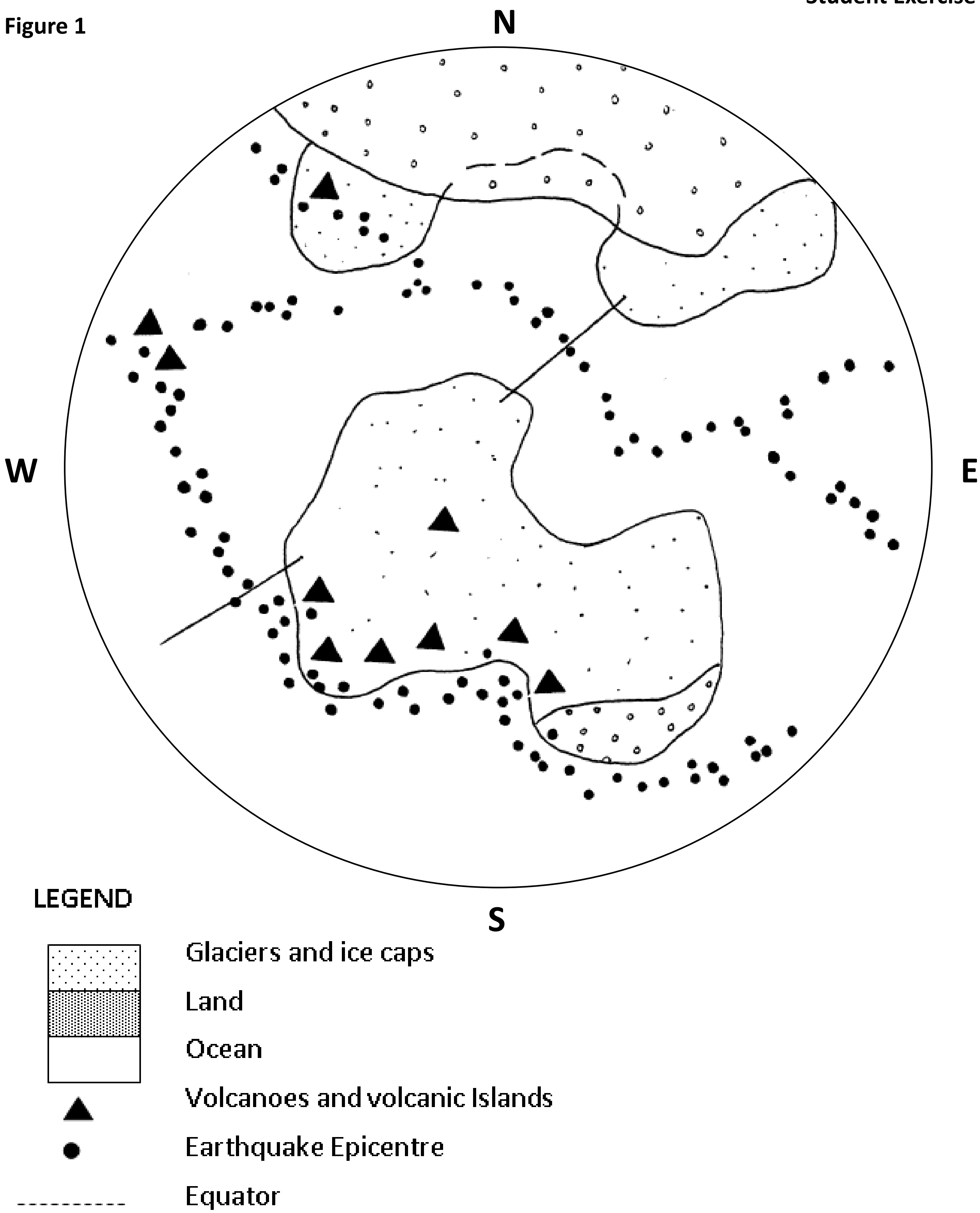
You are to work in groups of 2-3. You may discuss your findings with other groups but all group reports must be your own work. Any significant sign of copying and all groups involved will have their final marks adjusted accordingly.

The final report must be no longer that two pages, double-spaced, Calibri, 12 point font. You must also include your diagrams and figures. Your report will be marked on the following criteria:

1) Topographic Profiles	
a. A-B Profile	6 marks
i. colour (2)	
ii. labeling (2)	
iii. accuracy (2)	
b. C-D Profile	6 marks
i. colour (2)	
ii. labeling (2)	
iii. accuracy (2)	
2) Figure Diagram	
a. Plate Outline	7 marks
i. colour and outline boundaries (2)	
ii. directions of movement with arrows (5)	
3) Report	
a. Introduction	2 marks
i. hypothesis (1)	
ii. methods of analysis (1)	
b. Discussion Questions	6 marks
i. are all topics addressed (3)	
ii. is there sufficient evidence for support (3)	
c. Conclusion	3 marks
i. summarize all data (1)	
ii. state conclusions (1)	
iii. support with evidence (1)	
TOTAL	30 marks

Student Exercise

Figure 1



Student Exercise

Table 1: Data for Line A-B

Elevation or Depth (m)	Distance (km) from A
140	0
100	100
60	200
40	250
0	350
-160	360
-200	380
-400	400
-800	440
-1000	480
-1100	480
-1500	520
-2000	580
-2500	660
-3200	800
-3500	900
-3600	1000
-3700	1100
-3700	1200
-3700	1300
-3700	1400
-3500	1500
-3200	1540
-3000	1600
-2800	1640
-2600	1680
-2900	1750
-2600	1800
-2800	1840
-3000	1880

Table 2: Data for Line C-D

Elevation or Depth (m)	Distance (km) from C
-4200	0
-4200	250
-3800	500
-3500	750
-3800	1000
-4100	1250
-4200	1500
-4200	1750
-4200	2000
-4200	2250
-4200	2350
-4200	2500
-4200	2750
-4300	3000
-4400	3200
-4600	3400
-4800	3450
-5000	3500
-6000	3550
-7000	3600
-8000	3650
-9000	3700
-10000	3750
-8000	3800
-6000	3850
-2000	3900
-1000	3925
-500	3950
-250	3975
0	4000

More data for lines A-B and C-D on the next page

Student Exercise

Elevation or Depth (m)	Distance (km) from A	Elevation or Depth (m)	Distance (km) from C
-3200	1940	20	4020
-3500	2000	40	4040
-3700	2050	60	4060
-3700	2100	80	4080
-3700	2180	100	4090
-3700	2400	140	4100
-3600	2500		
-3500	2600		
-3400	2800		
-3200	2900		
-3000	3000		
-2750	3050		
-2250	3150		
-2000	3200		
-1500	3240		
-1000	3280		
-500	3380		
-200	3440		
0	3480		
40	3600		
60	3700		
80	3800		
100	3900		
120	4000		
140	4100		

Note: the 0 m depth is sea level. **Positive** depths are actually elevations **above** sea level and **negative** depths are depths **below** sea level.

Surface Processes Assignment

Surface Processes section of the curriculum, according to the Ministry guide, comprises approximately 15 per cent of the Geology 12 course. This assignment can serve as either the main body of the unit, or as an excellent means of reviewing concepts contained in the curriculum. It is set up with references to both the second and third editions of the text book, as well as second and third editions of the lab manual, and covers all the major concepts of each section in the Surface Processes unit.

Student Exercise

Surface Processes Assignment

Make complete notes from pages in *Physical Geology*, Montgomery, C. W., Wm. C. Brown Publishers and *Lab Manual for Physical Geology*, AGI.

> * indicates page references from Physical Geology 2nd Edition, 1987
> ( ) indicates page references from Physical Geology 3rd Edition, 1993

<u>Neatness</u> counts! (sketches help)

Due in 2 weeks:____________________(Date)

A. Running Water

*P269 (P298)

1. **Load** = **Bed load** + **suspended load** + **dissolved load**. (define each)
2. Relate steam velocity to sediment sorting.

*P262-268 (P294-298 and 302)

3. Streams as Agents of Erosion
   - What determines the load actually transported?
   - Define gradient and discharge. Explain: discharge = area X velocity).
   - How does channel shape and composition affect erosion?
   - Define downcutting, meander, oxbow and floodplain.

B. Glaciers (Refer to the Lab Manual: Alpine Glaciation and Continental Glaciation exercises).

*P220 (P250)

1. Explain, with the aid of diagrams, isostacy and isostatic rebound. Relate the concepts to glacial movement.

*P326-334 (P364-372)

2. Describe alpine glaciers and continental glaciers and indicate the ways they have sculpted the land. Distinguish between erosional and depositional glacial features using the following:
   a) Erosional features: U-shaped valley, hanging valley, cirque, tarn, horn, arête, and glacial striations.
   b) Depositional features: glacial erratic, ground, recessional, lateral, terminal and medial moraines, drumlin, kame, and esker.
3. Explain how erosional and depositional features can be used to reconstruct past glacial positions.

Student Exercise

*P334-337 (P375-377)

4. Propose possible explanations (hypotheses) for the origin of ice ages.
5. Define calving, ablation and accumulation.

C. Wind (Lab Manual: Work of the Wind)

*P346-350 (P388-393)

1. Dune Forms
   Describe surface forms of moving sands and relate them to specific sedimentary structures.
   - Include explanations and/or diagrams of eolian, dune, blowout (or deflation basin), barchan dune, parabolic dune, longitudinal dune, transverse dune and loess.

*P345-346 (P385-386)

2. Wind Erosion and Sediment Transport
   Compare wind blown sand and river sand in terms of microscopic grain appearance and variation of grain size. Contrast the bedding planes of the two.
   - Define abrasion, ventifact, deflation, desert pavement and saltation.

D. Weathering and Erosion

*P360-364 and 369

1. Distinguish between weathering and erosion.

(P86-93 and 97,98)

2. Define and describe the processes of:
   a) Physical (mechanical) weathering
      - Include frost wedging and exfoliation
   b) Chemical weathering
      - Relate Bowen's reaction series to susceptibility to chemical weathering.
      - Which minerals and rocks are most resistant to chemical weathering?
   c) Biological weathering

*P382-385 (P400-404) *P378-381 (P406-412)

3. Describe the causes and consequences of mass weathering, i.e. the downslope movement of soil and rock materials. Include the terms: rock fall, slump, slide, scarp, slide, landslide, flow, avalanche, debris avalanche, creep and solifluction.

Student Exercise

Name: ___________________

Date: _____________

Score: /15

Landslides and Road Construction

You are Joe and /or Jolle geologist, a landslide expert. The highways department has cut a road through a landslide area. You are to review the facts and propose a solution, or solutions to this natural hazard. Once you have made your analysis, you are asked to write a short report explaining your findings, and recommendations. You may use drawings to help explain your answers.

Problem 1 (5 Marks)

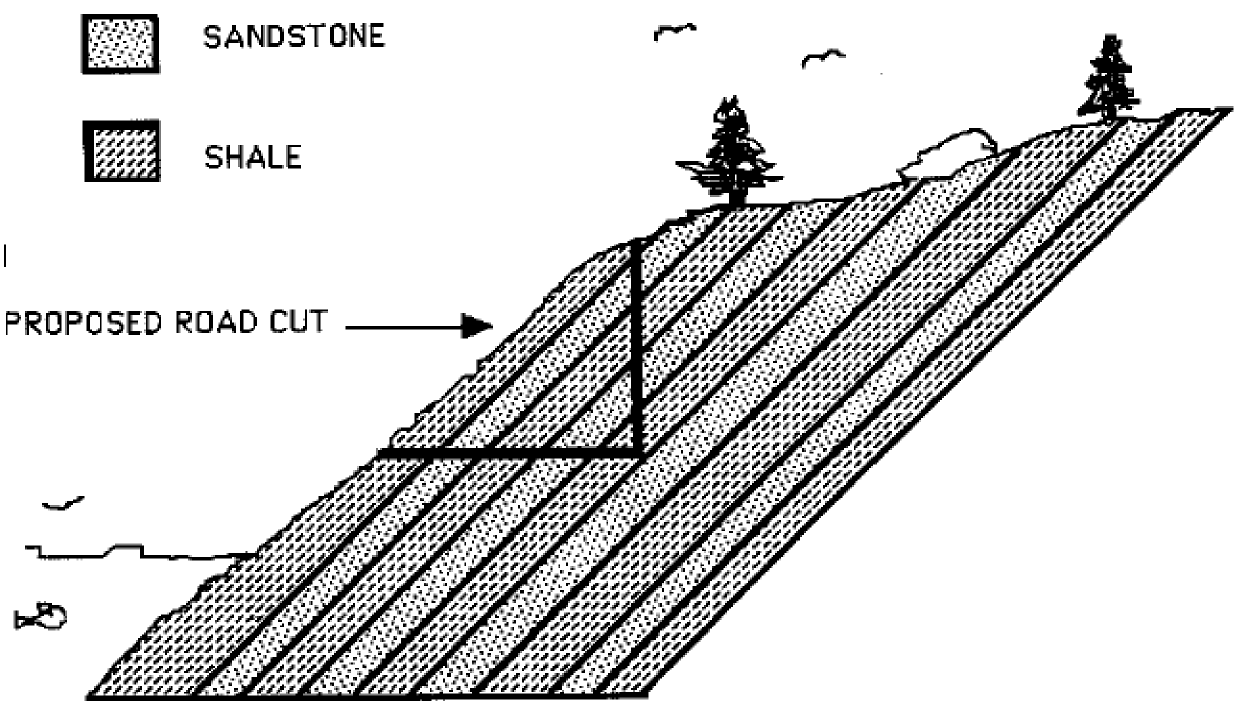
The rock unit is a steeply dipping shale with interbedded sandstone. The shale slides along the bedding planes and results in downward movement of the shale.

Problem 2 (5 Marks)

The sandstone beds act as an aquifer. The water in the beds acts as a lubricant and enhances downslope movement.

Problem 3 (5 Marks)

The shale weathers quickly and this results in unconsolidated soil which moves downslope.



Teacher Information

Glacial Charades

Purpose:
This exercise expands the concept of a unit review by offering students an opportunity to utilize their right brain skills, namely artistic expression and creativity. It addresses many of the multiple intelligences not typically exploited: visual-spatial (visualizing, imagining), kinesthetic (processing knowledge through bodily motions) and interpersonal (sharing, comparing, cooperating). You may experience some moans and groans when you propose the idea, but it doesn't take long for the students to buy into it. (They inevitably want to do it some more.)

Procedure:
Divide the class into small groups of 3 to 4 people. Make the groupings random so students talk to and work with different people in the class.

Take the standard vocabulary words associated with the glacier section of the textbook (below). Number them 1 to 27:

drift	valley glacier	ice sheet	snow line
ice cap	continental glacier	nunatak	firn
crevasse	ice front	calving	rock flour
glacial till	hanging valley	striations	roche moutonnée
arête	horn	cirque	outwash plains
drumlin	esker	kettle	tarn
	terminal moraine	lateral moraine	medial moraine

Have each group select a number from 1 to 27; each group must chose a different number. Secretly show each group the item they have selected, and tell each group to keep the discussion to themselves. Give the groups about 5 minutes to work out how they will present their concept to the rest of the class.

The rules are simple.
1) No noises are allowed, unless it is a "glacial sound".
2) The only props available are desks and chairs.
3) If a process is being demonstrated, it only has to be acted out twice (pay attention the first time).
4) The rest of the class tries to figure out what particular glacial concept is being acted out.

Teacher Information

Evaluation: This exercise is successful and valuable for the following reasons:

1) It allows the students to be creative in an unconventional forum. That requires both left brain and right brain activity.

2) The process forces the students to meet and work with others with whom they do not normally associate.

3) To properly execute the charade, the students must clearly understand the concept. If the concept is clear, they must then visualize the best way of conveying it. If the concept is not quite clear, the mere act of participating will be a concrete learning experience.

4) It is a no fuss, no mess activity that requires little preparation (save for sliding the desks or tables to the side of the room to allow floor space), can take as much time as the teacher will allow, is a valid learning instrument, and the students enjoy it.

5) The interpretations are sometimes ingenious, and more often than not, hilarious.

Geologic Time

Relative Age Dating – put geologic events in order by considering these principles:

Faunal succession – No life form is exactly duplicated at another point in time.
Uniformitarianism – "The present is the key to the past."
Original horizontality – Sediments are deposited in flat-laying layers.
Cross-cutting relations – A fault or dike that cuts across layers is younger than the layers.
Correlation – Two rocks containing the same fossil must be the same age.
Superposition – If undisturbed, the oldest layer is on the bottom, the youngest is at the top.
Included fragments – Pieces of rock (xenoliths or intraclasts) in a rock are older than the rock they are in.
Unconformity – a break in the rock record due to erosion or nondeposition. Angular unconformity: layers above and below are not parallel. **Disconformity**: layers above and below are parallel.

Absolute Age Dating – find a numerical age for a rock by radiometric dating techniques, counting tree rings or varves, or using index fossils.

Radiometric Dating

When an igneous rock forms, it contains an amount of parent isotope. That isotope instantaneously starts to spontaneously decay to form daughter isotopes. Scientists (geochronologists) can measure the amount of parent and daughter isotopes in a rock sample and determine how many half-lives have passed. The age of the sample is calculated:

Age = (# of half-lives) X (length of half-life)

Half-life – the length of time for half a radioactive parent sample to decay and become a stable daughter. It is unique for each radioactive isotope. It never changes.

Sources of Error in Radiometric Dating

- Daughter isotope may have been present when the rock formed, so the sample will appear older.
- Daughter isotopes may have escaped from the rock (e.g. argon gas), so the sample will yield a younger age.
- Some parent/daughter isotopes may have been added to the sample, so the sample will yield a younger or older age, respectively.

Scientists can correct for possible errors by using more than one radiometric isotope and comparing the ages obtained.

Student Information

Numerical age ranges for sedimentary rocks can be obtained by radiometric dating sills, dikes, or lava flows which underlie, overlie or intrude them.

Carbon 14 has a short half-life (5730 years) and is predominantly used to date organic material.

Geologic Time Scale: Review the events written on the geologic time scale.

Fossils: Review the fossil phyla. You must be able to recognize the phyla, know where and how they lived, approximately when they lived, and the living relatives, if any.

A **fossil** is a replica of an organism.

- Hard parts preserve most easily.
- Generally fossilized in water where most sediments accumulate.
- Rapid burial required to prevent scavenging and decay (i.e. seal from oxygen and bacteria).

Fossilization of **soft** parts (a replica, not the soft parts themselves) requires that the entire organism must be buried shortly after death in deep, low-oxygenated water.

Trace fossil - a sedimentary structure made by an organism such as a footprint, burrow, or feces

Index fossil – a plant or animal fossil especially useful in correlating strata; It must be short-lived, geographically widespread and abundant, and easily identified.

Methods of Fossilization

Original preservation – original skeletal material or soft tissues remain e.g. frozen wooly mammoth

Carbonization – a “picture” in carbon; common plant fossilization method

Replacement – a mineral (e.g. quartz) takes the place of the original structure

Permineralization – a mineral fills in the pore spaces of the original structure

Mold – sediments solidify around the shell, water flowing through dissolves the shell, and the hollow remaining shows the external features of the shell

Cast – sediments fill in the mold and show only the external features of the shell, no internal structure is present

Punctuated equilibrium – a model for evolution that predicts that life forms remain unchanged for long periods of time and then, suddenly, undergo a major change followed by a long period of stability.

Adaptive radiation – animals adapt to the environment they are in and, consequently, are different from their parents.

Natural selection – a principle of the theory of evolution: survival of the fittest.

Internal Processes and Structures

Evidence for Plate Motion

- Earthquakes
- Volcanoes
- Tropical fossils in northern climates, glacial features at the Equator, fossil seashells on mountain tops
- Polar wandering curve
- Magnetic stripes on the seafloor

Seafloor Spreading

- Plates separate as magma rises up from the mantle.
- Youngest rocks are along the ridge; oldest are furthest away.
- Magnetic stripes record polarity reversals.

Plate Boundaries and Associated Volcanics

Converging - two plates collide. Subduction occurs between oceanic plate and oceanic or continental plate. Composite volcanoes (explosive, andesitic, layers) form above the boundary. Mountains are uplifted at continent-continent collisions. Compressional forces generate folds and reverse and thrust faulting.
Diverging - two plates separate (e.g. Mid-Atlantic Ridge, Juan de Fuca Ridge). Characterized by tensional forces, normal faulting, newly created crust, smooth flowing flood basalts.
Transform - two plates move horizontally past each other (e.g. San Andreas Fault). Characterized by a shearing force, strike-slip faults, and no addition or reduction in crust.

Mountains Around the World

- Himalayans (N. India) and Alps (N. Italy) – formed by collision between two continents.
- Andes (South America) and Cascades (U. S.) – volcanic chains formed on continental crust above subduction zones.
- Appalachians and Cordilleran (North America) – formed by the collision of micro-continents and volcanic island arcs with the margins of the continent.
- Aleutians (Alaska) and Japan – volcanic islands formed above a subduction zone between oceanic plates.

Cause of Plate Motion

- Convection currents in the asthenosphere drag the plates along or/and **gravity** pulls on cool plates being subducted.

Student Information

Origin of Magma

- The temperature of the Earth gets hotter with depth (geothermal gradient) at a rate of 30^{o}C/km. It is hot enough in the upper mantle (50-250 km) to melt rock. Different minerals melt at different temperatures. More heat is required to melt rock under great pressure.

Isostatic Adjustment

- The crust adjusts up and down as it floats on the mantle. If a load is removed, as with a melting glacier, it moves up. If a load is added, as with formation of a volcano, it sub sides.

Volcanic Features

Hotspot - a stationary plume of magma that rises and breaks through a lithospheric plate. The plate moves and eventually the magma comes through at a different location on the plate. Shield volcanoes form (basaltic, smooth-flowing, low and wide outline).
Columnar joints – fractures that form as lava (generally basaltic or andesitic) cools and contracts into polygonal columns perpendicular to the cooling surfaces.
Volcanic dome – lava mound that forms when viscous magma (felsic) oozes out, like toothpaste, and piles up near the vent.
Lava plateau - upland formed by flood basalts on a continent.
Nuée ardente - a hot, fast, ash flow that burns everything in its path as it travels down the side of a volcano; commonly associated with andesitic volcanism.
Pillow lava - basaltic lava extruded under water where it forms bulbous pillows with glassy crusts and coarser crystals inside.
Aa lava - slightly cooled and so thicker, basaltic lava that breaks into sharp, blocky chunks as it flows; hard to walk on.
Pahoehoe lava - a basaltic lava flow that develops a wrinkled, ropy surface as the flow underneath continues to move.

Plutonic Features

Batholith – a large, complex intrusion of numerous plutons.
Stock – a small intrusion.
Sill – an intrusion between parallel layers of sediment (or pre-existing flows).
Dike – an intrusion that crosscuts pre-existing rock layers or rock body.
Xenolith – fragment of unmelted country rock in an intrusive rock body.

Student Information

Relationship of the Rock Cycle to Plate Tectonics

- Where magma is generated (diverging plates or subduction zones) igneous rocks form. Where plates collide, metamorphic rocks form. Where rock is exposed and weathered, or shelly creatures thrive, sediment is formed, transported and deposited on the Earth's surface. The composition of the sediment reflects the source terrane.

Earthquakes

Creep – plates slowly move past each other; no build up of pressure.
Elastic rebound – plates continue to move slowly and deform, but are frozen along the actual boundary. Pressure builds until the jam breaks and the plates move back into their original shapes in offset positions.
Magnitude – a measure of ground motion (up by factors of 10) and energy release (up by factors of 30). Measured with the Richter Scale, which has no maximum value.
Intensity – a measure of earthquake damage. Based on the Mercalli Scale in which total destruction is 12.

- **Epicentre location** can be determined by measuring the difference in arrival times of P (faster) and S waves at three seismograph stations, referring to a Time-Distance graph to determine how far away the earthquake occurred from each station, and drawing great circles with radii equal to each distance to see where they intersect.
- **Seismic Risks**

  Geographic location: e.g. if you live near an active plate boundary
  Topography: e.g. if you live next to a mountain face that will slide during an earthquake
  Ground strength: e.g. bedrock is more stable than sediments
  Proximity to faults: the further away, the better
  Construction design: difficult to do using scale models; specifications always change
- **Earthquake Prediction**

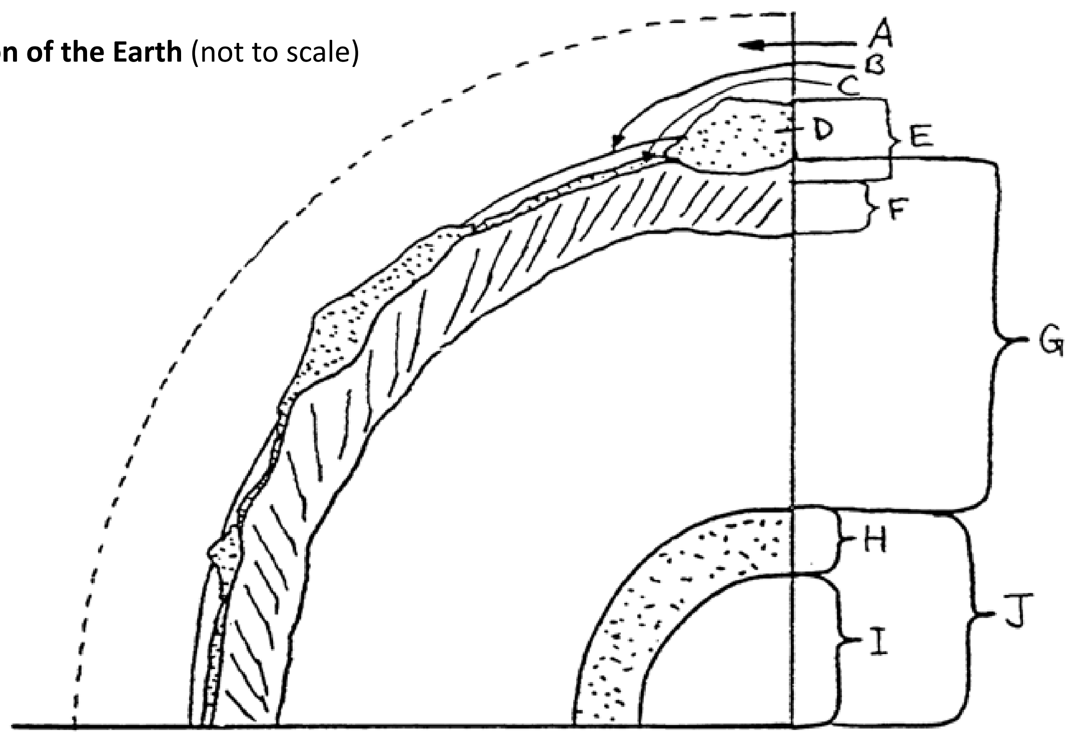
  Dilatancy data: the amount of water pore spaces, lubricates fault surfaces, affects water table levels.
  Seismic gaps: area along an active fault that has not moved in a long time.
  Animal behaviour: dogs and cats go astray.
  Land rising: caused by pressure buildup along a fault.

Student Information

Evidence of a Layered Earth

- Seismic waves speed up at the Moho (between the crust and mantle).
- S-waves disappear at the outer core (liquid).
- Seismic waves refract (bend) at boundaries.
- Some P-waves reflect at the inner core (denser).

Cross-section of the Earth (not to scale)



A - atmosphere, 80 km, 78% N, 21% O, 1% other
B - ocean, average depth 4 km, deepest 11 km (Marianas Trench), water
C - oceanic crust, average 10 km thick basalt
D - continental crust, average 50+km thick, granitic (average)
E - lithosphere, 50-100 km thick, solid
F - asthenosphere, to 500 km thick, solid, but plastic
G - mantle, base of crust to 2900 km, silica and ferromagnesians
H - outer core, 2900 to 5000 km, liquid
I - inner core, 5000 to 6370 km, solid
J - core, 2900 to 6370 km, iron and nickel
Moho seismic discontinuity - between D (continental crust) and G (mantle)

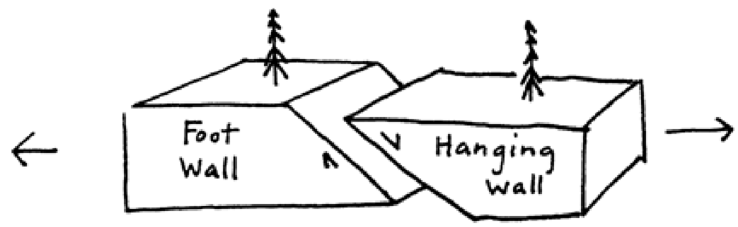
- Whether a rock behaves plastically (i.e. changes in shape permanently) or brittly (i.e. breaks) depends on temperature (high = more plastic), confining pressure (higher = more plastic) and the intrinsic characteristics of the rock.

Student Information

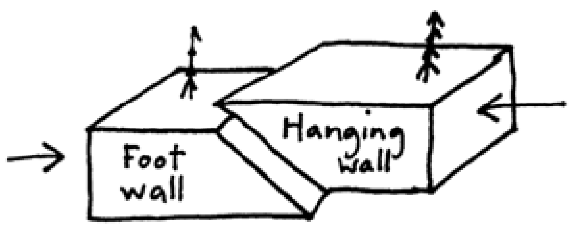
Structures
Fault - break in rock along which there is movement.
Joint - fracture in rock along which there is no movement.

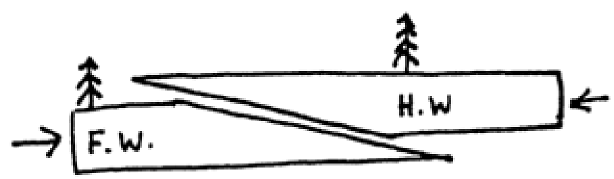
1. **Dip-Slip Faults** (vertical movement)

Normal - tensional forces (e.g. divergent plates)



Reverse - compressional forces (e.g. convergent plates) or **Thrust** (low-angle)

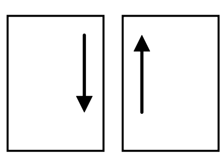




2. **Strike-Slip Faults** (horizontal motion; shear forces)

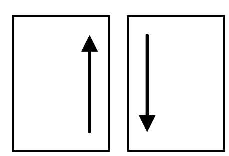
Left Lateral

map view



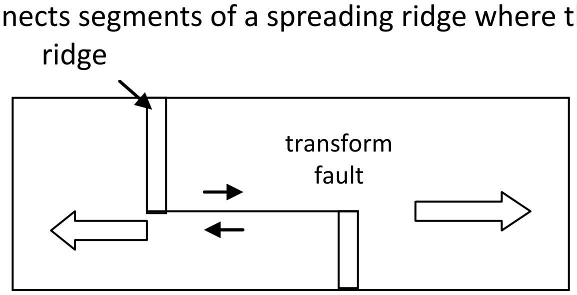
or

Right Lateral



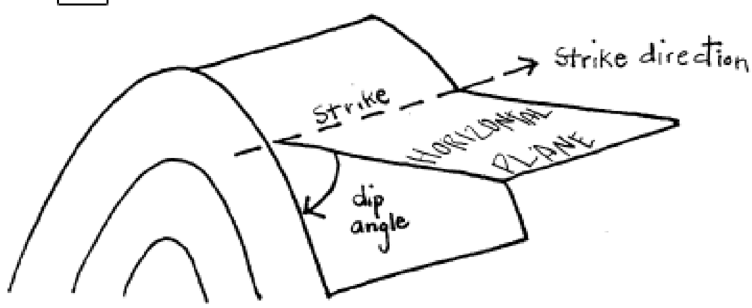
map view

Transform - connects segments of a spreading ridge where there is plate rotation

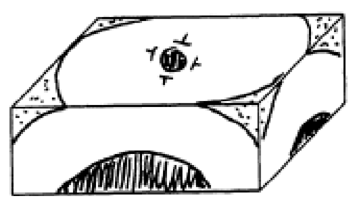


Student Information

Strike and Dip – orientation measurements used to describe geologic structures.
Strike - the compass orientation of the line of intersection of a horizontal plane with the structure.
Dip - the angle between the horizontal plane and the slope of the structure.
Strike and Dip Symbol - $\boxed{\perp}$ looks like a capital T and is only drawn on maps.

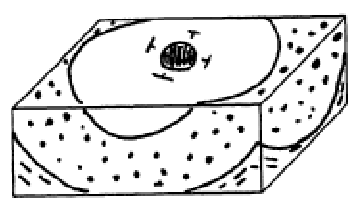


Dome
- oldest in the middle
- looks like an upside-down bowl

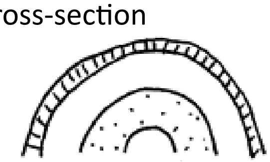


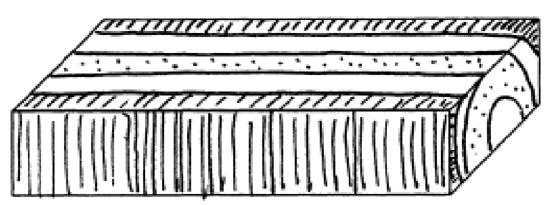
Strike is always parallel to the contact lines on the map.

Basin
- youngest in the middle
- looks like a bowl



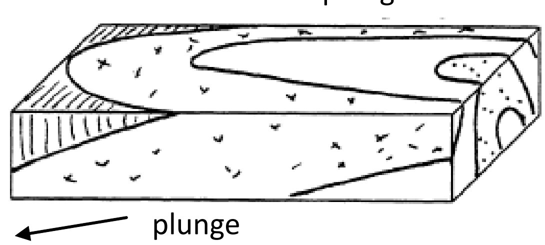
Anticline (anthill)
- oldest in the middle (in map view)
  cross-section





Plunging Anticline

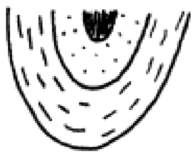
plunges toward the nose

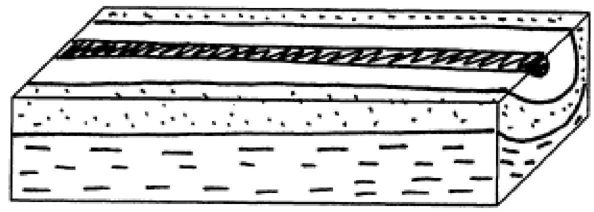


plunge

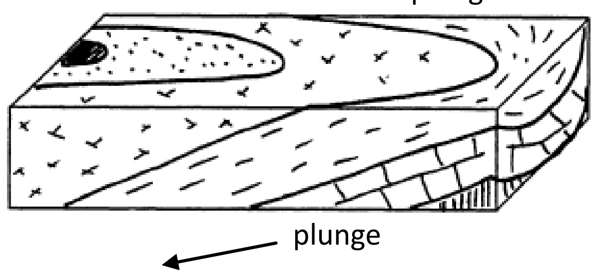
Student Information

Syncline (smile)
- youngest in the middle (in map view)
  cross-section

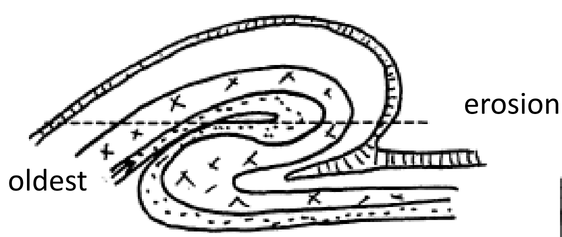


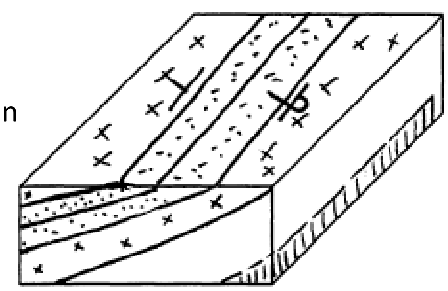


Plunging Syncline plunges toward the open end



Overturned Fold





Surface Processes

Weathering and Erosion

Weathering - the breakdown of rock in place.
Erosion - the transport of rock by wind, water, or ice.
Physical (mechanical) weathering - physical breakdown of rock without chemical change (e.g. ice wedging, exfoliation).
Chemical weathering - breakdown of rock caused by chemical reactions with the minerals (e.g. acid rain dissolution, iron oxidation to rust).

- Bowen's Reaction Series order of mineral crystallization is opposite the order of susceptibility to chemical weathering. Olivine breaks down most easily; quartz is most stable.

Biological weathering - breakdown caused by living organisms (both physical and chemical) (e.g. acids produced by organic decay, root wedging).
Mass wasting - downslope movement of rock material and soil due to gravity and triggered by heavy rainfall or earthquake activity, etc. It includes many types and speeds of travel.

- Mass wasting can be controlled by planting vegetation on slopes, dewatering slopes, building retaining walls and barriers, etc.

Running Water

Load - the material carried by a stream.
Bedload - the sediment rolled along the stream bottom.
Suspended Load - the sediment carried in suspension.
Solution Load - the sediment (e.g. elements and compounds) dissolved in the water.

- **Sorting** by sediment size occurs in a stream according to the speed of the water. e.g. If a stream slows down locally, some of the coarsest sediment transported as bedload will be deposited.
- **Erosion and deposition** are greater when the stream carries a greater load, moves faster (e.g. along a steeper gradient), discharges more water, and/or there are more erodible sediments in the channel.
- **Meanders** have erosion on the outside of the curve and deposition along the inside.
- **Water transported particles** are most likely to be: round and smooth (physically mature), chemically mature, fine to medium-grained, and well-sorted.
- **Wind transported particles** are likely to be: well-rounded, pit-marked, chemically immature, very fine-grained, and very well-sorted.

Student Information

Glaciers

Erosional Features

U-shaped valley - a valley generated by glacial erosion.
Hanging valley - a valley formed by a tributary valley glacier feeding into a larger valley glacier.
Cirque - a bowl-shaped excavation at the head of an alpine glacier.
Horn - a multi-sided mountain peak formed by three or more glaciers.
Arête - an erosional remnant ridge between two parallel valley glaciers or adjacent cirques.
Striations - scratch marks on bedrock made by rock debris carried in a glacier.

Depositional Features

Erratic - a large rock deposited by a glacier.
Moraine - till deposited by a glacier.
Ground Moraine - hummocky till layer deposited at the base of a receding glacier.
Terminal Moraine - till mound deposited at the front edge of a glacier at its farthest extent.
Recessional Moraine - till mound deposited at the front edge of a glacier during a standstill as it recedes.
Lateral Moraine - till mound deposited at the edge of a glacier.
Medial Moraine - till mound deposited at the boundary of two (valley) glaciers as they recede.
Kame Terrace - sediments deposited in meltwater lakes along the edge of a glacier.
Esker - stratified sands and gravels deposited by a stream on or in a glacier; identified on a glaciated landscape as a sinuous ridge.

Ground Water

- The **water table** is the top of the **Zone of Saturation** where all pore space is filled with water. Above it lies the **Zone of Aeration** where pores are partly filled with water and air.
- A **perched water table** lies above the regional water table in places where impermeable rock, such as a layer of shale, acts as a barrier trapping water above it.
- A **confined water table** is overlain and underlain by impermeable rocks. It is the source of artesian water wells.
- An **aquifer** is a body of rock capable of holding groundwater because of great porosity and permeability, such as sandstone.
- **Porosity** is a measure of the volume (abundance) of holes in a rock. The greater the porosity the more water a rock body can hold.
- **Permeability** is a measure of the interconnectedness of the pores. The greater the permeability, the more readily water can move through a rock.

Student Information

Geology of BC

History
At the beginning of the Mesozoic Era (225 my), the west coast of Canada in British Columbia was near Salmon Arm. The core of the continent was made of granitic batholiths and volcanics that formed as the Earth cooled 4.5 billion years ago. It was overlain by younger sedimentary rocks (Paleozoic) that formed as the core of the continent was weathered and eroded forming sediments that were redeposited in rivers, deserts, and inland seas. A great wedge of sediment accumulated on the west coast of North America as rivers moved material from the interior to the Pacific Ocean. The entire landmass, which was part of Pangaea, was situated further South; the climate was tropical. There were many swamps filled with vegetation that accumulated as it died and fell to the ground. An inland sea covered Alberta and northeastern BC. The many marine organisms it supported were buried with the sediment deposited by the sea. Dinosaurs inhabited the adjacent land areas.

Pangaea broke up about 200 million years ago. Then, approximately 170 million years ago several strings of volcanic islands (terranes) collided with the western edge of the North American continent. The collision occurred over many millions of years; the plates were moving only a few centimeters per year. The sedimentary layers that had been piling up along the coast were folded and faulted (thrust faults) by the compressional forces, forming the Rocky Mountains. (Had the crumpling and telescoping not occurred, BC would be 300 km wider.) Erosion wore the Rockies down at the same time and has continued to do so ever since then. (Had erosion not occurred, the mountains would be 10 km higher than they are today.)

The volcanic islands that collided with North America have been deeply eroded over time. Isostatic uplift has brought their deeply-formed, batholithic roots to the Earth's surface. The Coast Mountains north of Vancouver, which extend along the edge of the continent to Alaska, are the roots of such islands.

More recent volcanics have cross-cut the Coast Mountains forming, for example, Mt. Garibaldi near Squamish (Pleistocene) and Mt. Edziza north of Terrace (Recent).

A **hot spot** has formed the Anahim chain of volcanoes southeast of the Queen Charlotte Islands. The North American plate has been moving northwestward over the stationary hot spot forming a linear belt of volcanoes with the oldest at the west end and the youngest furthest east.

The Juan de Fuca plate is being subducted under the North American plate. Composite volcanoes in the Cascade Mountains, like Mount St. Helens, Mount Rainier and Mount Baker, have formed above this boundary. Motion along this plate boundary also threatens a big, 9.5 magnitude earthquake expected in this area.

Student Information

Rock Types

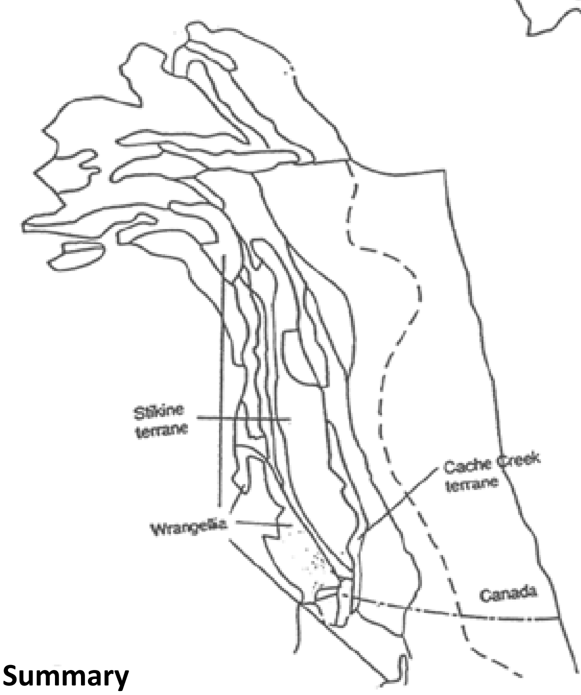
British Columbia has all three rock types:

- **Igneous** - where there were/are volcanoes, roots of volcanoes, cross-cutting dikes or sills.
- **Sedimentary** - in the Rocky Mountains and local areas across BC from erosion of uplifted areas during mountain building. (Sedimentary rocks make up 3/4 of the continent's exposed rock.)
- **Metamorphic** - in collision zones (from 170 million years ago or the current subduction zone) where significant T, P and water content changes alter rocks.

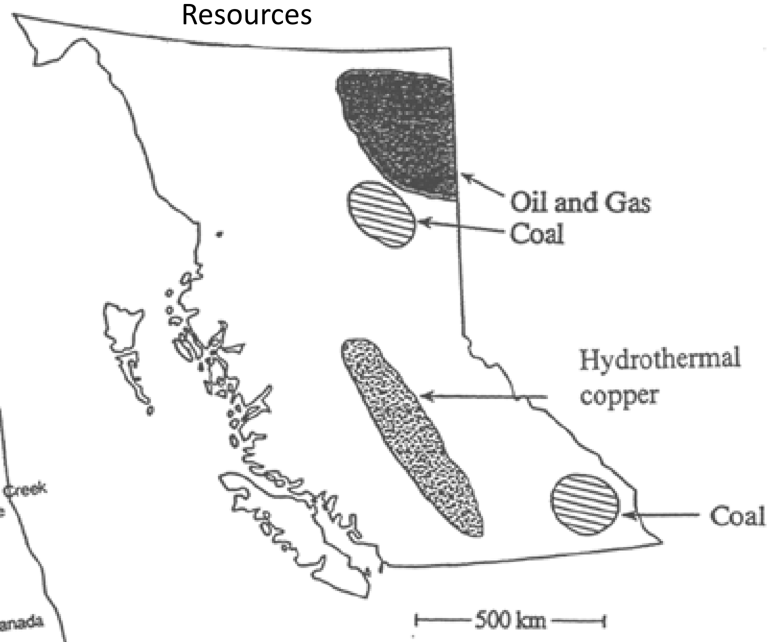
Resources

The sedimentary layers in the Rockies contain **coal** that formed from vegetation falling into the swamps before the collision. Northeastern BC and Alberta have **oil and gas** derived from the marine organisms that lived and died in the inland sea. **Metallic minerals**, such as copper sulphides, form by magmatic processes and, consequently, are found near the Coast Mountains (roots of ancient volcanoes), the Anahim chain (hot spot volcanoes), and the Cascade Mountains (subduction volcanoes).

Terranes



Resources



Summary

British Columbia formed by elongated segments of mini-continents (terranes) that drifted across the Pacific and docked onto ancient North America. These collisions pushed up the Rocky Mts. Erosion by glaciers, rivers, mass wasting, and wind has formed the landscape seen today.

Minerals

Silicates

Silicates are a class of minerals that make up most of the Earth's crust. (Oxygen makes up 46.6% and silicon makes up 27.7% of the crust.) They include all common rock-forming minerals, i.e. all those in Bowen's Reaction Series, and many, many more.

Definitions of Mineral Properties

Cleavage – breaks along one or more flat planes
Fracture – breaks along irregular surfaces (not along flat planes)
Hardness – resistance to scratching (not resistance to breaking; mineral may be brittle)
Specific gravity - similar to density, a measure of how heavy a mineral is relative to its size
Colour – as seen in regular daylight, it is a property that may vary for one mineral
Streak – colour of the mineral powder, a property that does not vary for a mineral
Lustre – the way a mineral reflects light, metallic (like a metal) or nonmetallic, which includes vitreous (glassy), earthy, pearly, dull, adamantine, etc. Metallic minerals generally have a dark streak; nonmetallic minerals generally have a light coloured streak.
Special Properties - magnetism, e.g. magnetite
reaction with acid e.g. calcite and other carbonates
double refraction, e.g. calcite
fluorescence, e.g. fluorite
salty taste, e.g. halite, sylvite
radioactivity, e.g. K-feldspar, uraninite

Select Minerals

Quartz	hexagonal prismatic crystals, fracture, hardest common mineral (H=7), many colours, vitreous, framework silicate
Mica	muscovite (light) and biotite (dark) are common, sheet silicate, common in metamorphic rocks (lines up under pressure creating foliation)
Garnet	hard (H=7), red (and other colours), vitreous, forms during metamorphosis in some shales, semi-precious gemstone
Asbestos	fibrous, forms during metamorphosis of ultramafics, good insulator, carcinogenic
Hematite	iron oxide, various colours, but always has a reddish-brown streak
Galena	lead sulphide, very dense, metallic, cubic crystal structure
Pyrite	Fool's Gold, metallic, commonly associated with gold, source of acid rock drainage
Chalcopyrite	Fool's Gold, metallic, mined for copper, less dense than real gold
Bornite	peacock ore, metallic, mined for copper
Graphite	carbon, metamorphic origin, high temperature lubricant, pencil lead
Gold	Native element, unattached to other elements, very high density
Fluorite	cubic crystals, cleaves octahedrally, purple and green common, vitreous

Student Information

Rocks

Rock Cycle

- One rock type can change into another type by natural, physical and chemical forces acting on it. Igneous rocks form by melting pre-existing rocks and solidification of that magma. Sedimentary rocks form from the weathering and erosion of pre-existing rocks, deposition and lithification. Metamorphic rocks form by the application of heat and/or pressure to, or by chemical reactions in pre-existing rocks.

Igneous

- If magma cools slowly (intrusive/plutonic), there is more time for large crystals to grow.
- If magma is thin (i.e. runny), it is easier for large crystals to form.
- If magma cools quickly (extrusive/volcanic), a glassy and/or frothy (vesicular) texture may result.
- Magma near the surface is under less pressure, so gas dissolved in it can "undissolve" to form bubbles in the magma.
- **Pyroclastic textures** result from explosive volcanic eruptions.
- A **porphyry** has two crystal sizes that record two cooling stages of the magma.
- **Felsic** magma is viscous (thick) and light-coloured, has a relatively low density, erupts explosively due to trapped gases, is extruded as rhyolite and intruded as granite, and forms **composite volcanoes**.
- **Intermediate magma** has properties similar to felsic magma, but is extruded as andesite and intruded as diorite.
- **Mafic** magma is thin (relatively runny) but dense, is very high temperature, erupts in relatively smooth flows to form gently-sloping **shield volcanoes**, and is extruded as basalt and intruded as gabbro.
- **Intrusive** features include: sill (parallel), dike (cross-cutting), **xenolith** (unmelted fragment of country rock).

  Obsidian: glassy (can be vesicular), has cooled very quickly, exhibits conchoidal fracture and is generally felsic in composition.
  Pumice: vesicular, cooled quickly from an explosively erupted, frothy magma, and floats on water.
  Pegmatite: very coarsely-crystalline intrusion that formed from a thin (runny), very slowly cooled magma.
  Tuff: volcanic ash glued together.
- **Bowen's Reaction Series** explains the order in which mineral crystals form from a melt as it cools. Olivine forms first; quartz forms last.
- Be able to use the Minerals in Igneous Rocks chart to identify unknown rock samples by the percentage of minerals present and to identify compositionally equivalent rocks.

Student Information

Sedimentary

Clastic -- made of broken rock or mineral grains glued together (lithified); e.g. conglomerate (coarsest), sandstone, shale (finest), breccia (angular)
Chemical -- precipitated from solution, crystals may be visible; e.g. limestone ($CaCO_3$), chert (SiO_4), evaporites (gypsum, halite)
Stratification – layering in a sediment or sedimentary rock
Cross-bedding -- inclined stratification deposited by big ripples moving in water or air
Ripple marks -- asymmetrical in flowing water (e.g. streams), symmetrical in waves (e.g. beach, lake)
Mud cracks – V-shape structures that form in fine-grained sediments that have dried up. They are widest at the top.
Graded bedding -- decrease in grain size up through a bed caused by rapid settling of sediment suspended in a turbulent flow (e.g. turbidite)
Varves -- annual layers of fine sediment deposited on a glacial lake bottom

- The further sediment has been transported, the more physically mature it will be.
- The longer sediment is in contact with water, the more chemically mature it will be.

Metamorphic

- Pre-existing rocks are changed by heat and/or pressure and/or chemical reactions into other types of rocks. For example:

Shale (sedimentary) → **Slate** (micas line up under P; cleavage) → **Phyllite** (more foliation) →
→ **Schist** (micas larger; imperfect foliation = schistosity) → **Gneiss** (under greater pressure, under certain conditions)

Granite (igneous) → **Gneiss** (compositional banding = gneissic banding)
Conglomerate (sedimentary) → **Meta-conglomerate** (stretched pebbles, break across pebble)
Limestone (sedimentary) → **Marble** (coarser crystals)
Sandstone (sedimentary) → **Quartzite** (recrystallized quartz grains)

Foliation -- planar structure in a metamorphic rock caused by parallel alignment of inear or planar minerals (as seen in slate, phyllite, schist, and gneiss)
Non-foliated – lacking metamorphic foliation and consisting predominantly of equidimensional grains (e.g. quartzite, marble)
Compositional banding – metamorphic foliation caused by recrystallization of minerals in the rock and segregation into bands of differing composition or texture
Contact metamorphism – changes in country rock caused by the heat of a nearby intrusion
Regional metamorphism – high T and P changes to bedrock over a large area due to deep burial or tectonic collision
Chill margin -- edge of an intrusion exhibiting relatively fine crystal size due to rapid cooling of the magma adjacent to the country rock

Mineral Resources

Economic Minerals:

- are profitable to mine
- must be adequately concentrated and in great enough volume
- mining depends on supply and demand and value (selling price)
- mining requires physical accessibility
- mining requires assurance of environmental protection

Magmatic Deposits

Kimberlite – isolated ultramafic pipes from mantle-derived magma, bearing diamonds locally.
Fractional crystallization – accumulations of mineral crystals that settle to the bottom of a magma chamber, e.g. chromite and magnetite.
Pegmatite – very coarsely crystalline rock commonly formed from residual magma with higher concentrations of rare elements – e.g. lithium, boron, and uranium.
Hydrothermal – minerals precipitated from hot, metalliferous fluids that have escaped from cooling magma (or groundwater heated by adjacent magma), commonly sulfide ore or Native elements, e.g. copper, lead, zinc, gold, silver, platinum, uranium.

- **Magmatic activity** commonly occurs along plate boundaries, so mineral deposits are commonly found along ancient boundaries.

Minerals and Metals of Value (see tables provided/created in class)

Formation of Natural Gas and Oil

Numerous marine organisms that live in the water column, and are rich in carbon and hydrogen, settle out on to the seafloor when they die. If they are rapidly buried by sediment, the organic tissues do not decay. Burial is accompanied by an increase in P and T, which slowly over time causes chemical reactions that break down the large complex organic molecules into simpler hydrocarbon molecules. As breakdown continues, large thick hydrocarbons become progressively smaller and thinner until, finally, very simple, light, gaseous molecules (natural gas) are formed. This process mostly occurs between 50-100^o C. At higher temperatures methane gas (CH_4) forms. Oil and gas formation takes time. No petroleum is found in rocks younger than 1 to 2 million years old.

Student Information

Porosity - the volume of pore space in a rock.
Permeability - the interconnectedness of pore space in a rock. A good oil reservoir has high porosity and high permeability.
Oil traps - porous and permeable reservoir rock with an impermeable cap rock that prevents the oil/gas from migrating to the surface.

Coal

Coal is the remains of land plants that have fallen into and accumulated in a tropical swamp.

Stages of Coal Formation

peat → **lignite** → **subbituminous** → **bituminous** → **anthracite**
low heat, low carbon → high heat, high carbon
softer → harder

- The higher the T and P, and longer the time, the harder and higher heat coal is produced.
- If the burial T is too high, the organic tissues metamorphose; graphite is formed. (Graphite does not burn.)

Methods of Exploration

- Gravitational survey, look for gravitational high
- Magnetic survey, look for magnetic high
- Soil sample geochemical analysis
- Mapping bedrock geology and interpreting history
- Drilling and coring
- Drilling and geophysical logging

Headband Review Technique

Purpose:
The purpose of this exercise is a simple one: to offer a forum for student review of concepts, but with a slight twist and a little bit of humour. Each student will ask questions to try to determine the earth science or geology term written on a card taped to his/her head. This activity is best used as a supplement to a unit or for a mid-term or a final review, as the choices will be more varied, and the students' questions will have to be more strategic.

Preparation:
The teacher will need to prepare a series of cardboard cards with various geoscience concepts written on them. (Paper will work, but is far less durable.) The nature of the card depends on the focus of the review. Typical examples for a final review for Esci 11 might include epicentre, supernova or cleavage. The minimum number of cards necessary is a class size set. However, a suite of 100 cards allows the teacher to list the key concepts of most of the topics covered in the course.

Once the cards have been marked clearly in felt pen, place them face down on a table, and attach a small piece of doubled over masking tape.

Procedure:
Divide the class into small groups of 3-4 students. Next ask each student to select a card, and without looking at its face, tape it to his/her forehead out of view.

One at a time, each student will ask others in his/her small group a **yes/no type question** in an effort to identify the concept on the card taped to his/her head. No clues are allowed. The object is to identify the topic with as few questions as possible. (Students will keep track of the number themselves.)

The question asking can be done one-at-a-time, or on a rotational basis, to minimize the downtime of the other group members. The teacher may decide to make this a timed event, or to just go with the flow.

Be alert! Students will try ingenious ways to find out what their cards say: looking at a watch dial of their watch, looking deep into a partner's eyes (or glasses) for a reflection, or even looking out the window.

Evaluation:

This exercise succeeds on a number of levels:

1) In order to be successful, the students must be able to use a logical sequence of questions in order to narrow down their concept. Their questions have to start on a broad and general scale and, by process of elimination, be fine-tuned in their focus.

2) The students must be able to clearly communicate their thoughts, in the form of strategic questions, to their peers.

3) The exercise can yield success in students of varying academic capabilities. The forum is more fun-centered and less stressful. Depending on the nature of the students, the teacher can make it a competitive game or not.

4) The duration of the game is entirely up to the teacher. It can be a short, one word exercise, or a period long exercise in which students attempt four or five words each.

5) The students enjoy this activity. It's silly, it's fun, and everyone looks equally ridiculous. It is a useful supplement to customary review techniques.

Teacher Information

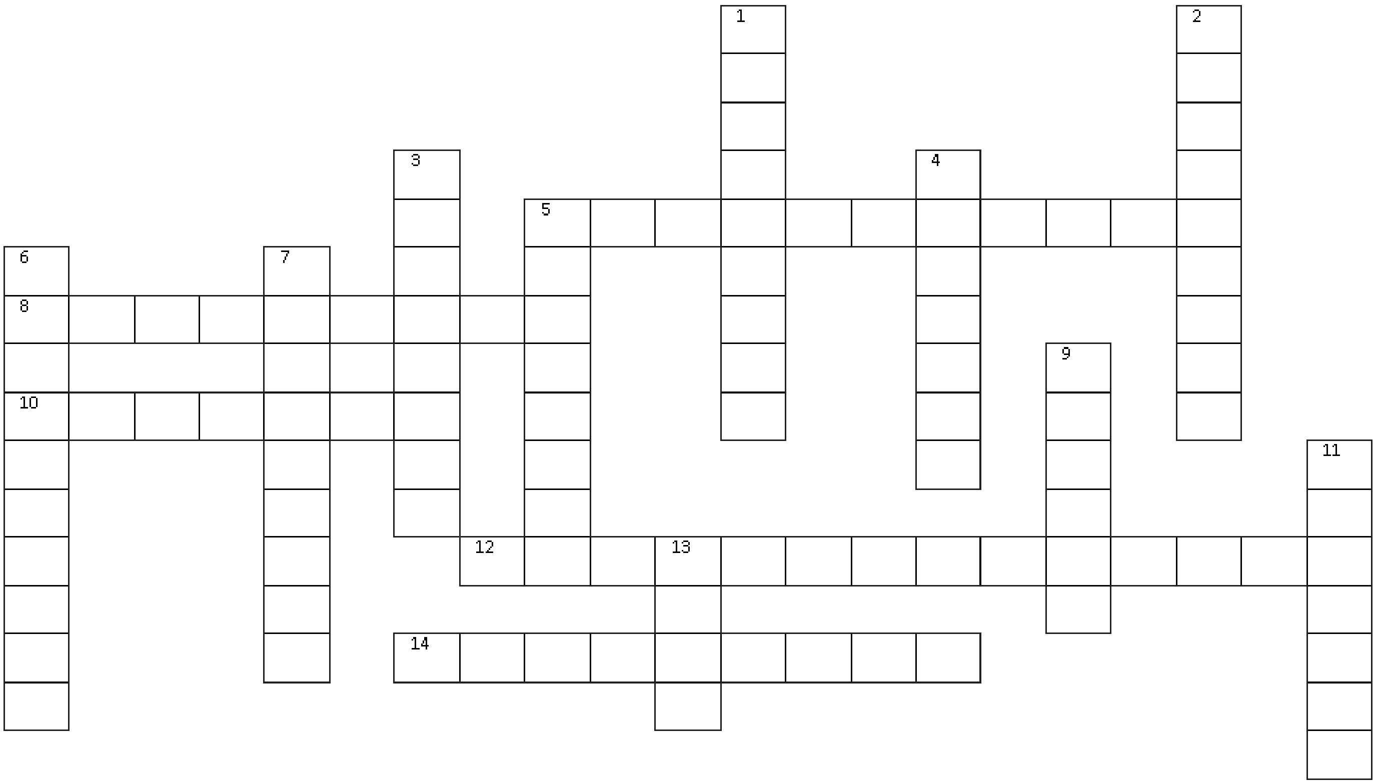
Crossword Puzzles

Crossword puzzles are fun and a terrific way to reinforce geologic vocabulary. Those included here cover minerals and the three main rock groups. For extra credit, you may ask your students to submit puzzles on other topics of their choice.

The following puzzles are built from vocabulary taken directly from the appropriate chapters in *Physical Geology*, 1987, Montgomery, Carla W., Wm. C. Brown Publishers.

Student Exercise

Mineralogy Crossword



Across

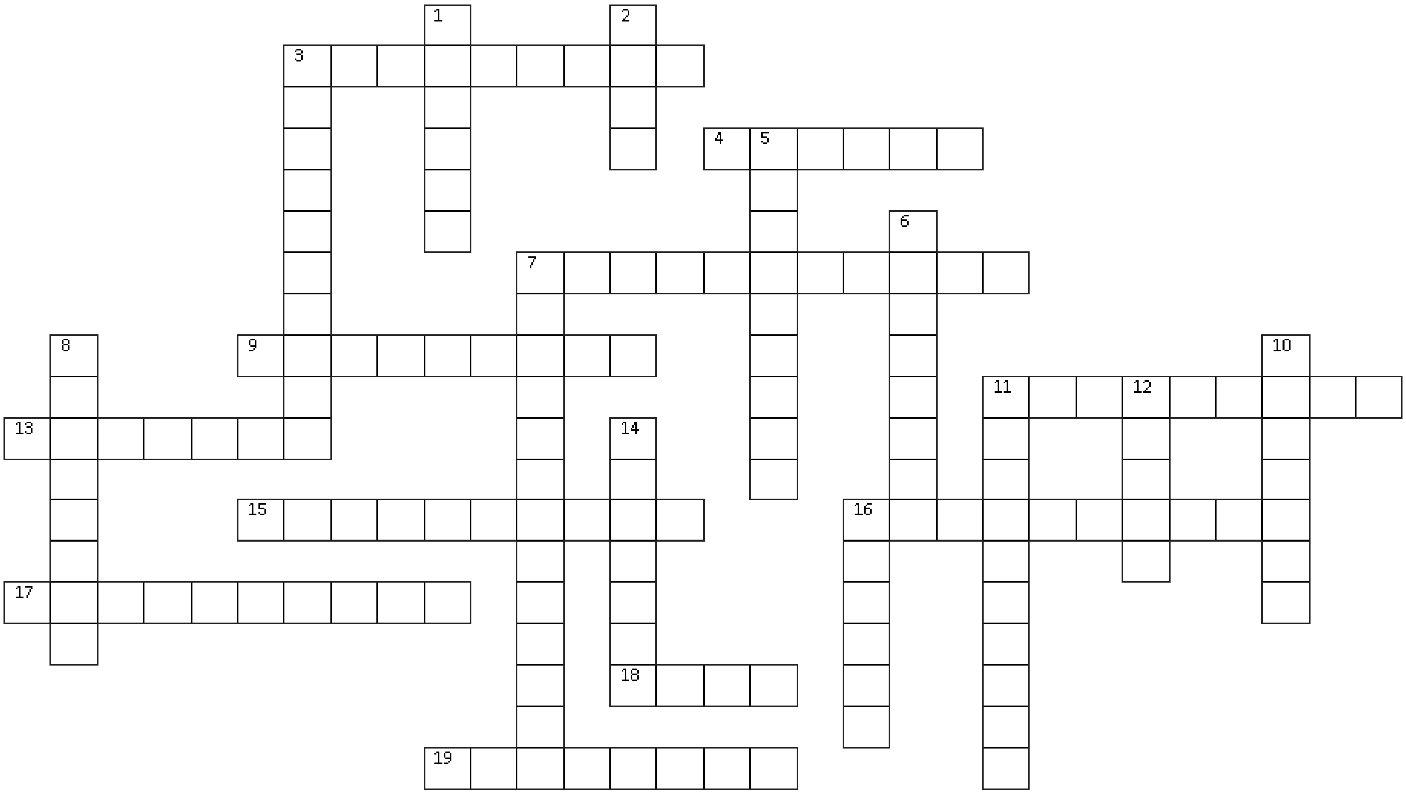
5. external shape of crystals
8. hydrous, ferromagnesian, double-chain silicates
10. dark mica, rich in iron and magnesium
12. silicate containing significant iron and/or magnesium
14. continuous path of transformation that gives rise to all rock types on Earth

Down

1. framework silicates that are the most abundant minerals in the crust
2. same chemical composition, different crystal structure
3. single chain silicates, mostly ferromagnesian
4. the simplest kind of chemical substance
5. tendency of a mineral to break along planes in the crystal structure
6. these fizz with acid
7. minerals containing silicon and oxygen
9. surface sheen exhibited by a mineral
11. a naturally occurring, inorganic, solid element or compound with a definite composition and a regular internal crystal structure
13. solid, cohesive aggregate of one or more minerals

Student Exercise

Igneous Rocks Crossword



Across

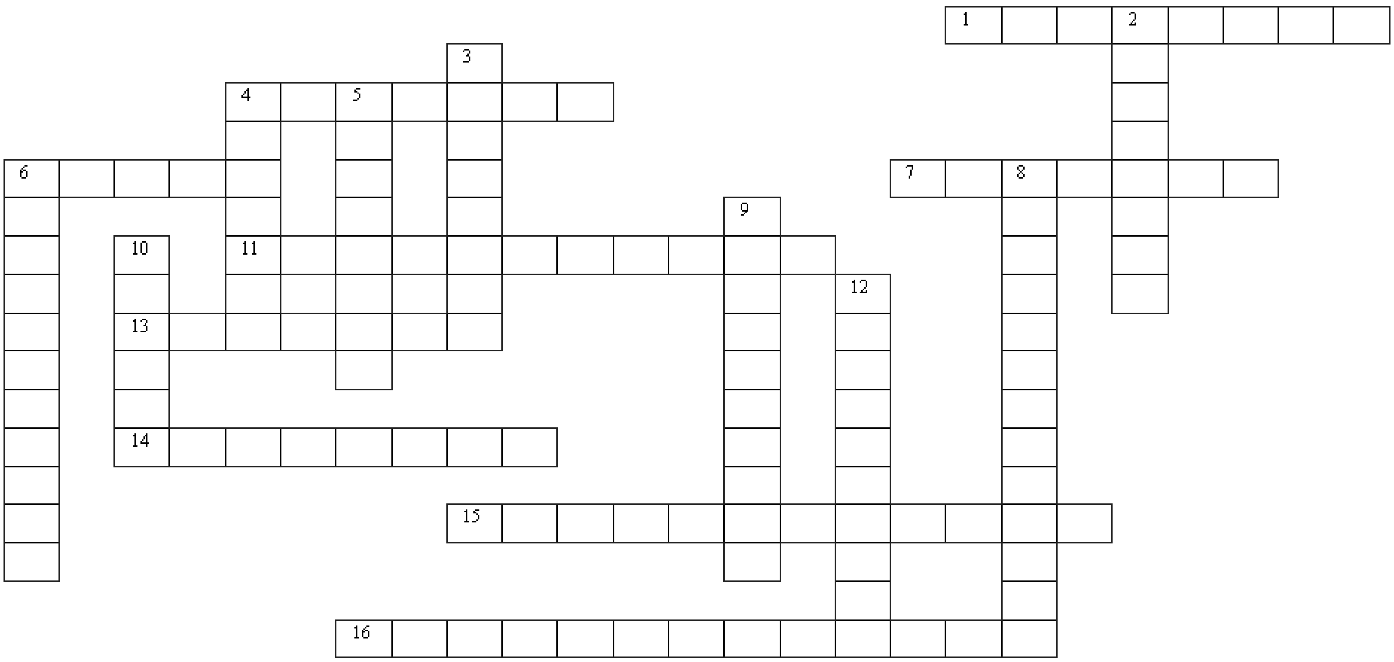
3. grains too fine to distinguish with the naked eye
4. rock rich in feldspar and silica
7. rock into which a pluton is intruded – wallrock
9. massive, discordant pluton, often produced by multiple intrusions
11. a very coarse-grained igneous rock (>1 cm)
13. a plutonic rock rich in quartz and K-spar
15. having contact parallel to the layers of adjacent rocks
16. grains coarse enough to distinguish with the naked eye (>1 mm-10mm)
17. the fine-grained matrix of a porphyritic rock
18. a tabular, concordant pluton
19. a rock caught up in magma as an inclusion

Down

1. mafic volcanic rock, equivalent of gabbro
2. a tabular, discordant pluton
3. magma incorporates and melts bits of country rock
5. classification of all igneous rocks erupted onto the Earth's surface
6. a concordant pluton with a sagging floor
7. a fine-grained rock at the edge of a pluton that shows the effect of rapid cooling
8. an igneous rock with coarse crystals in a fine-grained groundmass
10. rich in silica (SiO_2) (lower melting temperature)
11. a coarse crystal in a porphyritic rock
12. rich in iron and magnesium (high melting temperature)
14. rocks formed from or related to magma
16. a body of igneous rock that crystallized at depth

Student Exercise

Sedimentary Rocks Crossword



Across

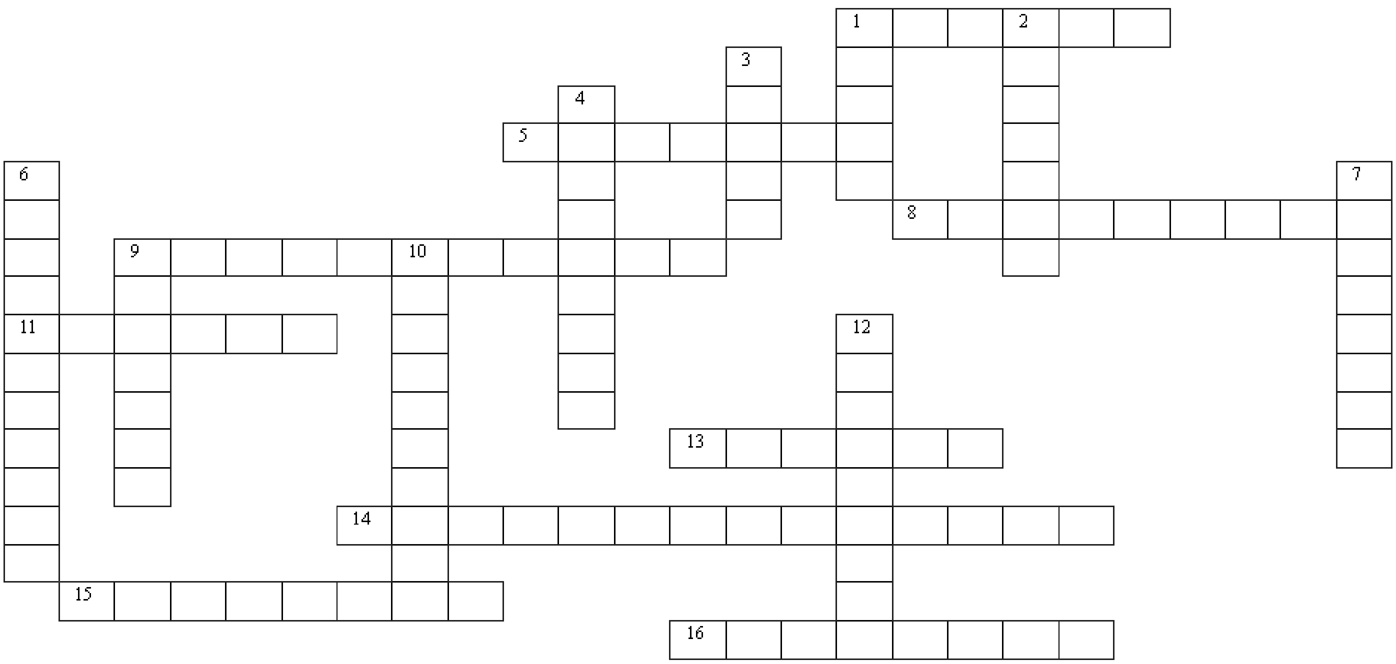
1. rock or sediment precipitated directly from solution
4. depositional layering
6. clastic sedimentary rock made of clay-sized particles; tends to break along parallel layers
7. spheroidal carbonate grains with concentric layers
11. sticking sediments together by precipitation of mineral material between grains
13. sediment made of fragments of pre-existing rocks and minerals
14. unconsolidated rock and mineral grains and organic matter that was transported by wind, water or ice
15. clastic sedimentary rock consisting of coarse-grained, rounded fragments in a finer-grained matrix
16. landward encroachment of the sea.

Down

2. very fine-grained clastic; siltstone or claystone
3. sediment produced by biological processes
4. clastic sedimentary rock consisting of angular fragments in a finer-grained matrix
5. a carbonate mineral ($CaMg(CO_3)_2$)
6. rock formed at or near the Earth's surface from sediment
6. conversion of sediment into sedimentary rock
9. compression and consolidation of sediment under compressive stress
10. set of environmental conditions that leads to the formation of a particular type of sediment or sedimentary rock
12. set of low temperature processes by which lithification is accomplished during burial

Student Exercise

Metamorphic Rocks Crossword



Across

1. medium to coarse-grained metamorphic rock displaying schistosity
5. metamorphism characteristic of wallrock surrounding a pluton
8. metamorphosed quartz-rich sandstone
9. metamorphic rock rich in amphibole
11. metamorphosed limestone
13. metamorphic rock with compositional banding
14. pressure that is not uniform in all directions
15. formed by progressive metamorphosis of slate; cleavage shiny due to mica
16. contact metamorphic rock, formed under low to medium T

Down

1. metamorphosed shale
2. line connecting points of equal metamorphic grade
3. measure of intensity of metamorphism
4. directionally uniform pressure that rocks at depth are subjected to
6. rock that has been "changed in form"
7. metamorphism on a large scale; increase in T and P
9. contact-metamorphic zone around a pluton
10. high-pressure metamorphic facies
12. parallel alignment of minerals or compositional banding

Teacher Information

Team Games Tournament

Reviewing geology topics at the end of the term or end of the year is more fun when it is done as a game. In this format, individuals compete against each other in small groups. First, divide your class into groups of four students of equal ability to ensure each person has a chance of winning. Do this quickly by printing the class list in order of grades and dividing accordingly.

Give each group 1) a question sheet, 2) an answer sheet and 3) a deck of cards numbered 1-20 (the number of questions). Photocopy the Question and Answer sheets onto different coloured paper and mark the back (blank) sides with giant **Q** and **A**. Create the number cards ahead of time using index cards; bundle each deck with an elastic.

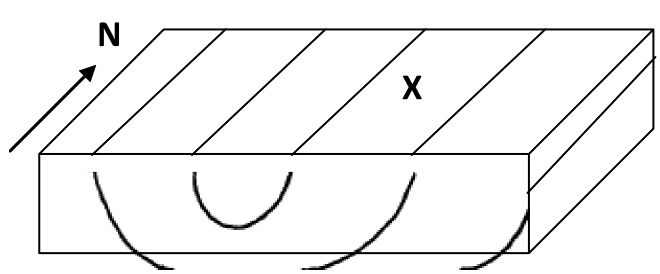
To decide who goes *first* in each group, each person draws a number card and the highest goes first. The *first person* draws a card to find out which Question he/she needs to answer. The person to his/her right reads the Question. NOBODY looks at the answers yet! The *first person* initially attempts to answer the question. If the person on his/her immediate left thinks he/she has a better answer, he/she can attempt it. The next person on the left gets a try next, and finally the person who read the question. **Then** the group can read the answer. Whoever got the correct answer **first** gets to keep the card. If nobody got the correct response, the card returns to the deck to be attempted later. (Whoever draws it should have an easy answer, since the group just read the answer!) The game proceeds in a clockwise direction after each question.

The student with the most cards at the end of the game wins. Ties must be broke, even if it is simply by flipping a coin. Each group winner receives a suitable prize (e.g. a homework pass, gum, candy bar).

Student Exercise
Question Set 1

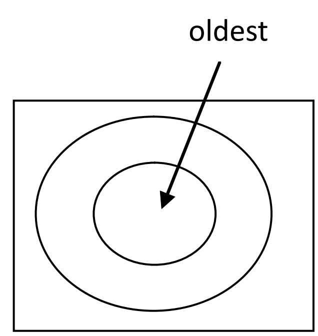
Team Games Tournament

1. Give three pieces of evidence of continental drift.
2. How is magnetism preserved on the sea floor?
3. Explain what happens at a continental-oceanic plate boundary.
4. What are two possible causes for the movement of the plates?
5. How does a seismograph work?
6. Compare and contrast P and S waves.
7. How does the ground movement change as the magnitude goes up on the Richter Scale?
8. Describe an earthquake safe place to build (include at least two criteria).
9. Describe a shield volcano (physical form, type of lava, type of eruption).
10. Describe a composite volcano (physical form, type of lava, type of eruption).
11. How do columnar joints form?
12. How does pillow lava form?
13. Distinguish between the crust/mantle and the lithosphere/asthenosphere boundaries.
14. As the material gradually gets denser, the seismic waves ____________.
15. List the compositional layers of the Earth from the centre to the surface.
16. List the physical state of layers of the Earth from the centre to the surface.
17. What is the difference between joints and faults?
18. Compressional forces cause ___________ or ___________ faulting and _____________.
19. Draw the map of an eroded dome. Label the oldest strata.
20. Describe how the strike and dip symbol would be oriented at **X** in the following diagram.



Student Exercise
Answer Set 1

Team Games Tournament

1. Measurably moving, fit together, fossils match, rocks match, paleoglacial features match, symmetric stripes on the sea floor, oldest rocks farthest from the ridge
2. When magma cools down to the Curie T, the iron-bearing (magnetic) minerals align with the Earth's magnetic field and stay aligned once the rock solidifies.
3. Oceanic plate is subducted and melts; magma rises through continental crust forming a volcano.
4. 1. Convection currents in the mantle 2. subducting plate dragged down by gravity
5. 1. A pen is attached to heavy mass with inertia, so stays still in an earthquake 2. A rotating drum with seismogram paper is attached to bedrock, so it moves during an earthquake.
6. P: primary, fastest (twice as fast as S-waves), compressional body wave
S: secondary, slower, shear body wave, transmitted through solids only
7. Goes up by factors of 10
8. Far from faults, on bedrock (not wet sediment), away from unstable slope
9. Shallow slope, basaltic composition, smooth flowing
10. Alternating layers of ash and lava, steep-sided, andesite/rhyolite composition, explosive
11. As basaltic magma cools **slowly** it contracts into polygonal shapes
12. Lava that extrudes under water cools quickly, so its surface is glassy and crystal size increases progressively toward the centre of the pillow.
13. Crust/mantle is a compositional boundary; lithosphere/asthenosphere is a physical state boundary
14. ….. Speed up
15. Core, mantle, crust
16. Inner core, outer core, mantle, asthenosphere, lithosphere
17. Joints – fractures along which there is no movement
faults – fractures along which there is displacement
18. …… reverse or thrust faulting and folding
19. 

20. Strike = N-S; dip = W

Student Exercise
Question Set 2

Team Games Tournament

1. Explain in detail how radiometric dating is used to find the age of an igneous rock.
2. Define half-life.
3. What is an unconformity? Explain the difference between disconformity and angular unconformity as well.
4. Explain how the solar system formed.
5. What is the "Principle of Included Fragments"?
6. What are the key characteristics of an index fossil (guide fossil)?
7. How did the atmosphere change from CO_2 - rich to O_2 – rich?
8. If, in a sample, there is 1/16th Uranium 235 and 15/16th Lead 207, and the half-life of U 235 is 704 million years, how old is the sample?
9. Explain how faunal succession is important to correlation.
10. What is the geological age of the Earth believed to be? How do we know this?
11. Explain permineralization.
12. Explain replacement.
13. Explain molds and casts.
14. What is a varve?
15. When did algae evolve?
16. What is the "age of invertebrates"?
17. When did fish first flourish?
18. When did "modernish man" appear?
19. What is one important issue in deciding between punctuated equilibrium and gradualism?
20. When and where did/do brachiopods live?

Student Exercise
Answer Set 2

Team Games Tournament

1. Compare the amount of radioactive parent material present with the amount of stable daughter material. Knowing that half the parent decays in each half-life, we can determine how many half-lives have passed to get this parent/daughter ratio. Multiply the number of half-lives by the length of the isotope's half-life to get the age.
2. The time it takes for half of a given radioactive isotope to decay to a stable end product.
3. A time gap in the rock record due to erosion or nondeposition. A disconformity is an unconformity between parallel rock layers. An angular unconformity is an erosional gap between layers that are not parallel.
4. A cloud of dust and gas contracted due to gravity. Fusion reactions started at the center forming the Sun. Dust rotating around the Sun contracted into clumps that evolved into the planets and asteroids.
5. If a fragment is a part of another layer, the fragment must have existed before the layer it is in.
6. Unique, easy to identify, widespread geographically, short-lived on Earth.
7. Photosynthesizing blue-green algae that constructed stromatolites utilized CO_2 from the atmosphere and gave off O_2. Marine invertebrates constructing calcareous shells also removed CO_2 from the atmosphere.
8. 2816 million years
9. Faunal succession says that a life form can only exist once during geologic time, so rocks that have the same fossil must be the same age (i.e. they correlate).
10. 4.55 billion years, based on radiometric dating of meteorites and moon rocks
11. Pores in an organic structure become filled with mineral carried in ground water.
12. Water dissolves original organic material and other mineral matter is precipitated in its place.
13. Mold – the imprint left when a fossil decays; Cast - the mold is filled with sediment
14. Layer(s) of sediment deposited during one year.
15. Precambrian
16. Paleozoic
17. Devonian
18. Pleistocene
19. Evolution also occurs in the soft parts of an organism, but soft parts are not easily fossilized.
20. Mostly in the Paleozoic (marine and brackish, shallow to deep); modern forms marine, cold deep water.

Jeopardy

Before class begins, divide the students into groups of equal ability. Do this quickly by printing the class list in order of grades and number the students at the top and bottom simultaneously: 1,2,3,4,5,6,7,7,6,5,4,3,2,1,1,2,3,4,5,6,7,7,6,5,4,3,2,1. (In this example there are four groups of seven.)

First, have the students form into the groups you have defined and ask them to spread out in the room. Next, go over the rules on the Overhead (next page). Make it clear that all groups answer all questions. (This is one difference from TV Jeopardy.) Have all groups set up a score paper as shown. Have them number the questions with the point value on the left side of the paper and leave blank space for the group who will score their paper on the right side.

Depending on the length of your class period, you may need to cut out some of the questions. That affects everyone the same, so it is OK. Note that the questions with the asterisks beside them indicate that there is an overhead needed for the question.

Have the students exchange papers (one per group) counter-clockwise with the next group for marking after each topic's questions. When the papers are returned to the original group for the next topic's questions, they will be checking that the addition was done correctly. Record the subtotals on the board so everyone knows how everyone is doing.

Two Final Jeopardy questions are included. You may wish to create some alternates, especially if you teach more than one section.

Classroom Jeopardy

- You will work together in teams.
- We will play both Single and Double Jeopardy
- I will read out all the questions for each topic, giving time between each question for your team to answer the question on a paper set out in the format shown below.
- I will read each question only ONCE, so you must be listening.
- Once all questions for a topic have been answered, we will exchange papers between teams in a rotational fashion for marking.
- Only TOTALLY CORRECT answers will earn points. No partial marks.
- Incorrect answers will result in a deduction of points from your score. (Yes, you could end up with a negative total.)
- I will keep a running total of the points each group has on the board.
- Once double Jeopardy is complete, we will have a Final Jeopardy where you may wager all your points, if desired.

Paper Set-up

Topic Name				Score
100	*Answer*	√		+100
200	*Answer*	x		-200
300	*Answer*	√		+300
400	*Answer*	√		+400
			subtotal	**+600**
Topic Name				Score
100	*Answer*	√		+100
200	*Answer*	√		+200
300	*Answer*	x		-300
400	*Answer*	x		-400
			subtotal	**-400**
etc.				

Note: only the subtotal for the current category here. (+600 from above is NOT included!)

Overhead

Single Jeopardy

Minerals	Time	Plate Tectonics et al.	Resources
100	100	100	100
200	200	200	200
300	300	300	300
400	400	400	400

Teacher Information

Single Jeopardy Questions

* = Overhead needed for the question

Minerals

100 It fizzes with acid.
200 For a large crystal to grow it requires what two conditions?
300 It can be brown, red and grey in colour, but its streak is always brown.
400 This reddish mineral sometimes forms when shale undergoes metamorphism.

Time

100 "The present is key to the past." is what principle?
200 If the daughter is present when the samples forms, what happens to the apparent age?
300* Use the graph on the overhead and the following information to determine the age: there are 1600 parents and 4800 daughters in a sample.
400* Label **all** the events oldest to youngest using the diagram on the overhead.

Plate Tectonics

100 Hot spots result in what type of volcano?
200 Explosive volcanoes have what composition of lava?
300 How were the Alps formed? (They are in Italy.)
400 Explain by a well-labeled diagram the functioning of a seismograph.

Resources

100 What is the ore mineral of zinc?
200 Vegetation falling into a swamp describes the beginning formation of what?
300 Weathering enrichment produces the ore of what element (or metal)?
400 Draw an anticlinal oil trap and descriptively label it in detail.

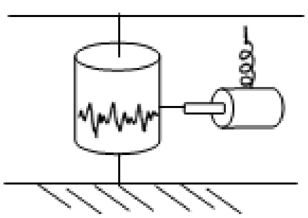
Teacher Information

Single Jeopardy Answers

Minerals
100 calcite
200 time and space (room)
300 hematite
400 garnet

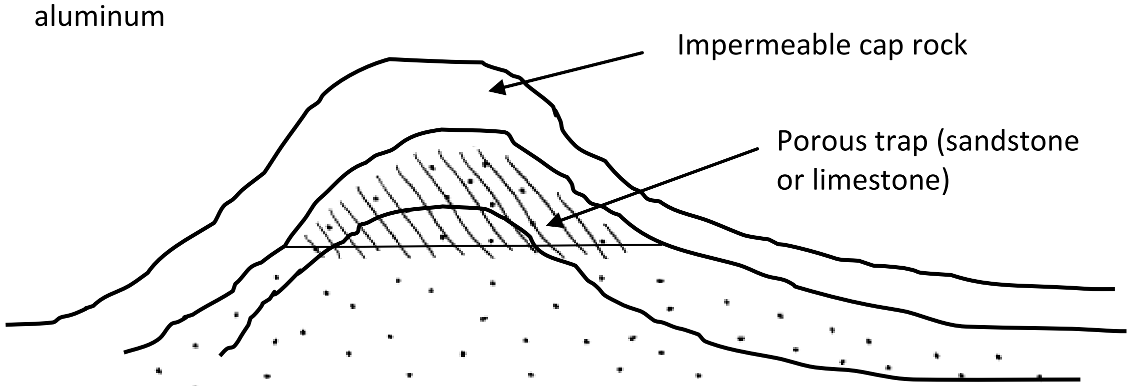
Time
100 uniformitarianism
200 appears older
300* 20 million years (units must be included to be correct)
400* 5, 6, 4, 3, 2, erosion (or unconformity), 1

Plate Tectonics
100 shield
200 andesite or rhyolite
300 continents colliding
400

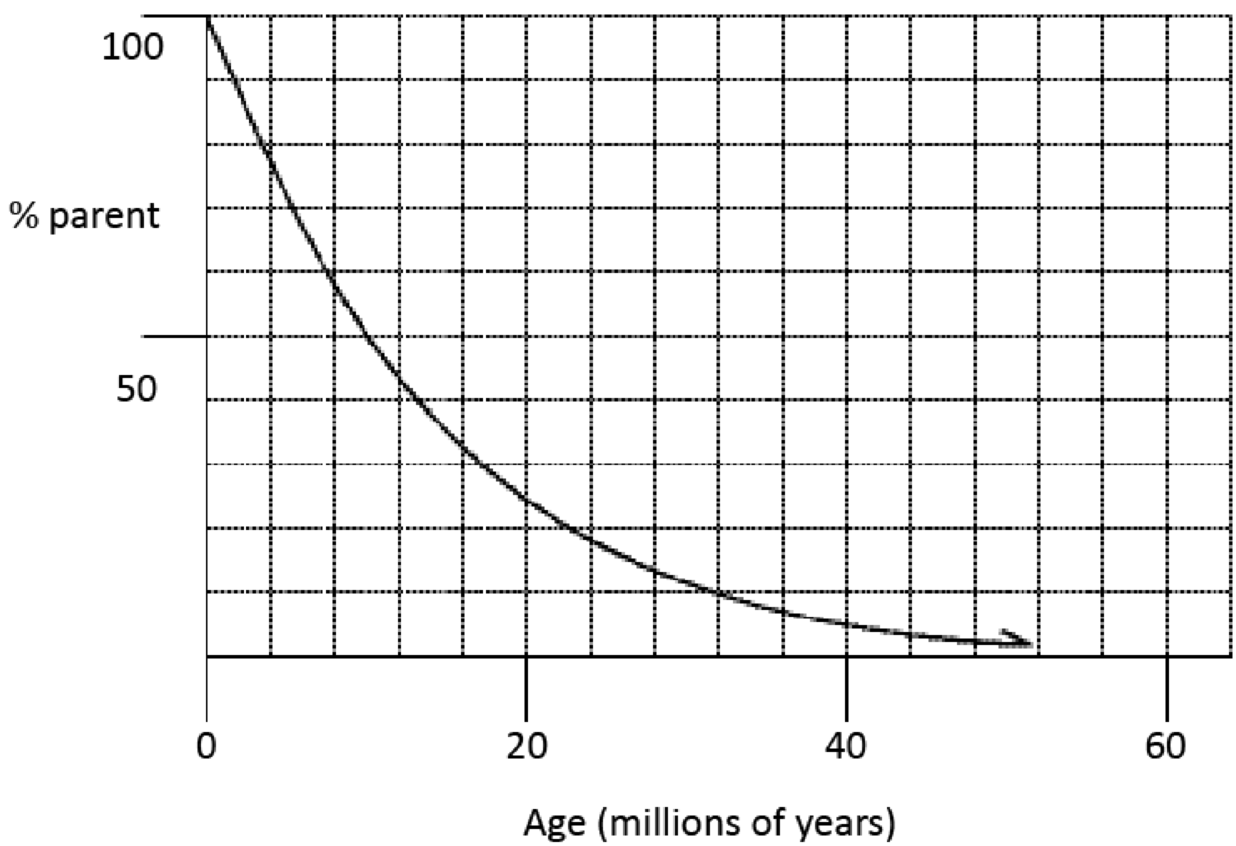


The pen is attached to a heavy mass that has inertia, so the pen will not move in an earthquake. The seismograph paper is on a drum which is attached to the bedrock which will move in an earthquake.

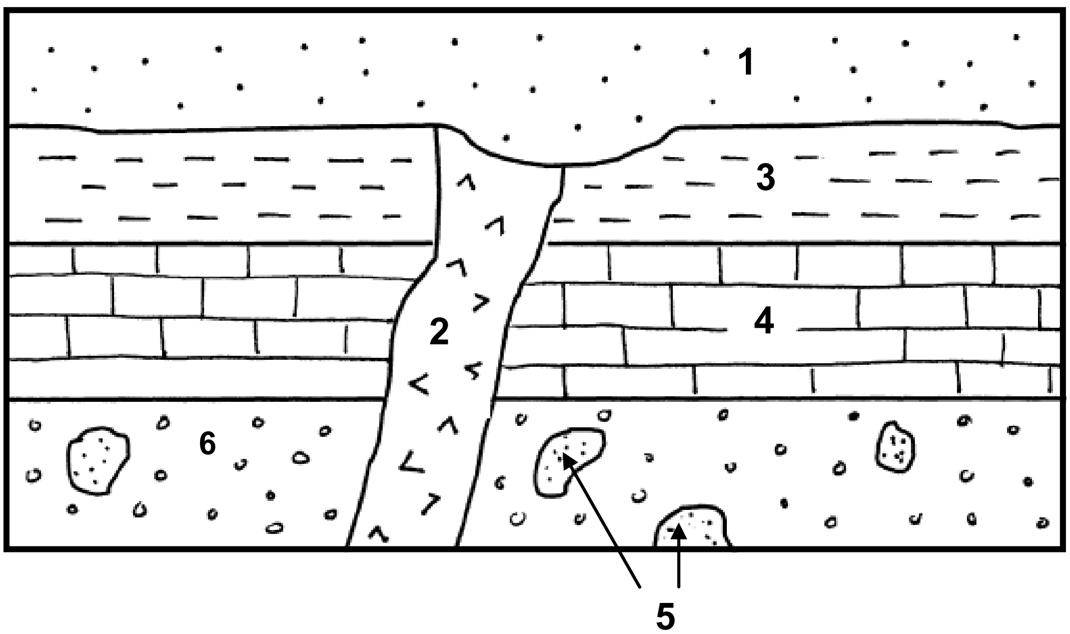
Resources
100 sphalerite
200 coal
300 aluminum
400



Single Jeopardy Overhead 1
Time 300



Single Jeopardy Overhead 2
Time 400



Overhead

Double Jeopardy

Rocks	Fossils	The Internal Earth	Glaciers, Mass Wasting & Planets
200	200	200	200
400	400	400	400
600	600	600	600
800	800	800	800

Double Jeopardy Questions

* = Overhead needed for the question

Rocks

200 It has conchoidal fracture.
400 Put these in order of crystallization: quartz, olivine, biotite, pyroxene, amphibole.
600 Name a sedimentary environment in which only asymmetrical ripple marks (as opposed to symmetrical) would form.
800 Match the rock with its metamorphic counterpart.
Limestone becomes __________.
Granite becomes _____________.
Sandstone becomes ___________.

Fossils

200 When did algae first appear? Name the Era.
400 When did fish dominate? Name the Period.
600* Identify the Phyla indicated by the three fossils shown on the overhead.
800 Explain how a tree becomes petrified.

Internal Earth

200 S-waves do not pass through the outer core. What does that indicate about the outer core?
400 Reverse faulting is a result of what type of plate motion?
600 Draw a labeled cross-section of the Earth showing the relative thicknesses of the various layers. (Do not worry about precise numbers.) Include the compositional layers and the physical state layers.
800 Draw a block diagram of a plunging syncline. Include one end, one side and a map view.

Glaciers, Mass Wasting and Planets

200 As a glacier retreats it temporarily stops, leaving what? Be specific.
400 As a glacier melts, the crust rises. What is this phenomenon called?
600 What is the general term for downslope movement where rocks move quickly and chaotically in contact with the ground?
800 Why does Mercury have such extreme temperatures? Give two reasons.

Teacher Information

Double Jeopardy Answers

Rocks

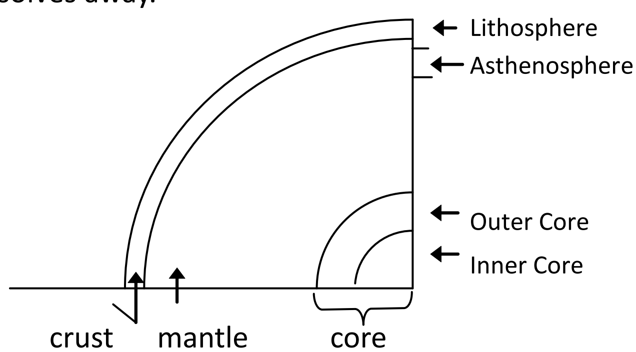
200 obsidian
400 olivine, pyroxene, amphibole, biotite, quartz
600 stream
800 Limestone becomes marble.
Granite becomes gneiss.
Sandstone becomes quartzite.

Fossils

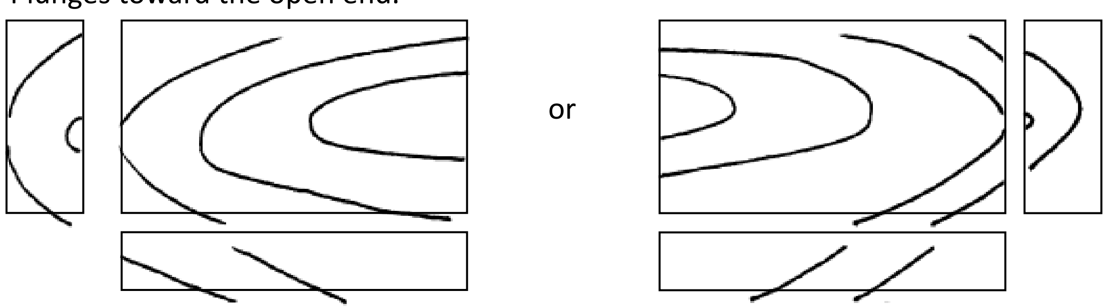
200 Precambrian
400 Devonian.
600* a) Arthropoda b) Brachiopoda c) Cnidaria (Coelenterata)
800 Silica replacement. Minerals in solution in pore water take the place of original material as it decays or dissolves away.

Internal Earth

200 It must be liquid.
400 Converging
600



800 Plunges toward the open end.

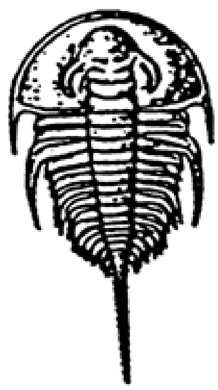


Glaciers, Mass Wasting and Planets

200 recessional moraine
400 isostatic rebound
600 flow
800 no atmosphere AND slow rotation on axis (the word revolution is NOT correct.)

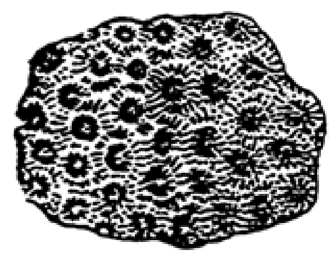
Double Jeopardy Overhead
Fossils 600

a.



b.

c.



Final Jeopardy

Topic: Geology

Make your secret wagers and hand them in to me.

QUESTION: The collision of which two plates resulted in the formation of the Himalayan Mountains?

ANSWER: The Indian-Australian Plate and the Eurasian Plate.

Final Jeopardy Overhead 2

Final Jeopardy

Topic: Geologic Time

Make your secret wagers and hand them in to me.

QUESTION: How old is the rock layer that overlays a layer which contains an early trilobite index fossil and is cross-cut by a dike dated at 450 million years old?

					66
MESOZOIC	CRETAEOUS				144
	JURASSIC				208
	TRIASSIC				245
PALEOZOIC	PERMIAN				286
	CARBON-IFEROUS	PENSYL-VANIAN			320
		MISSISS-IPPIAN			360
	DEVONIAN				408
	SILURIAN				438
	ORDOVICIAN				505
	CAMBRIAN				570
PRECAMBRIAN					4000 [1]

ANSWER: Between 450my and 570my old.

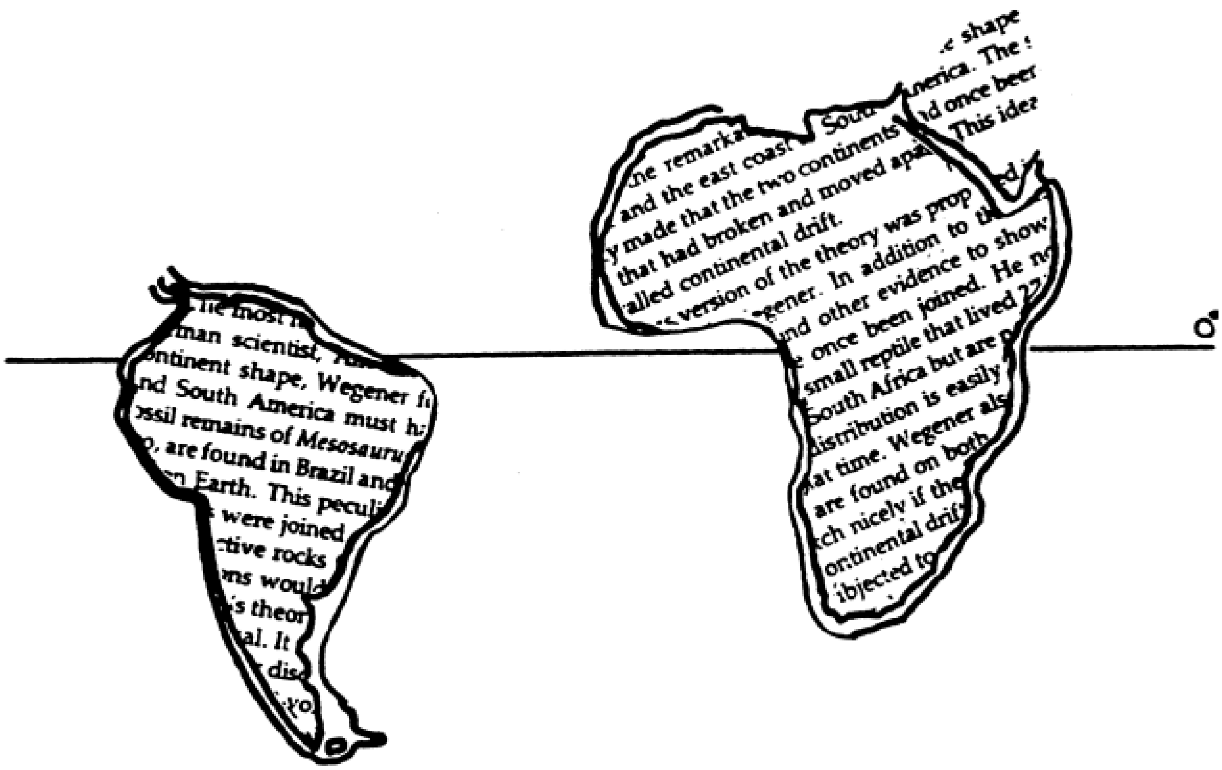
Teacher Information

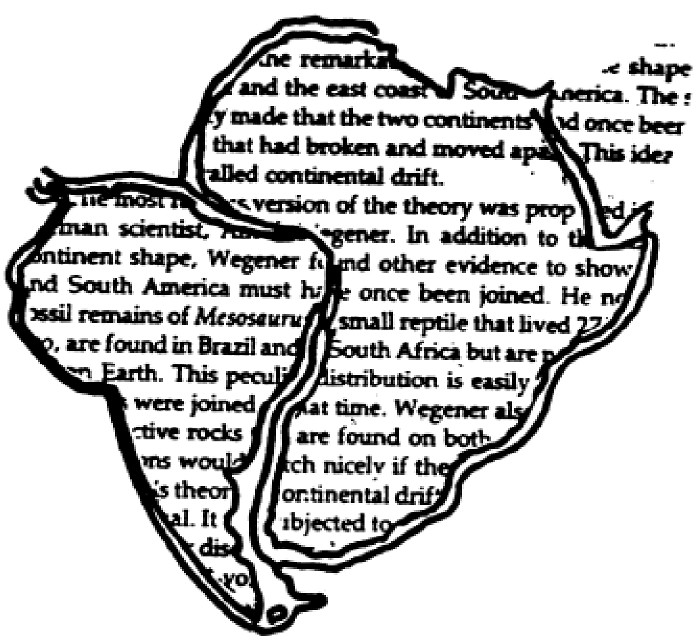
Overheads

The following information and diagrams may be useful as overheads or as handouts in class.

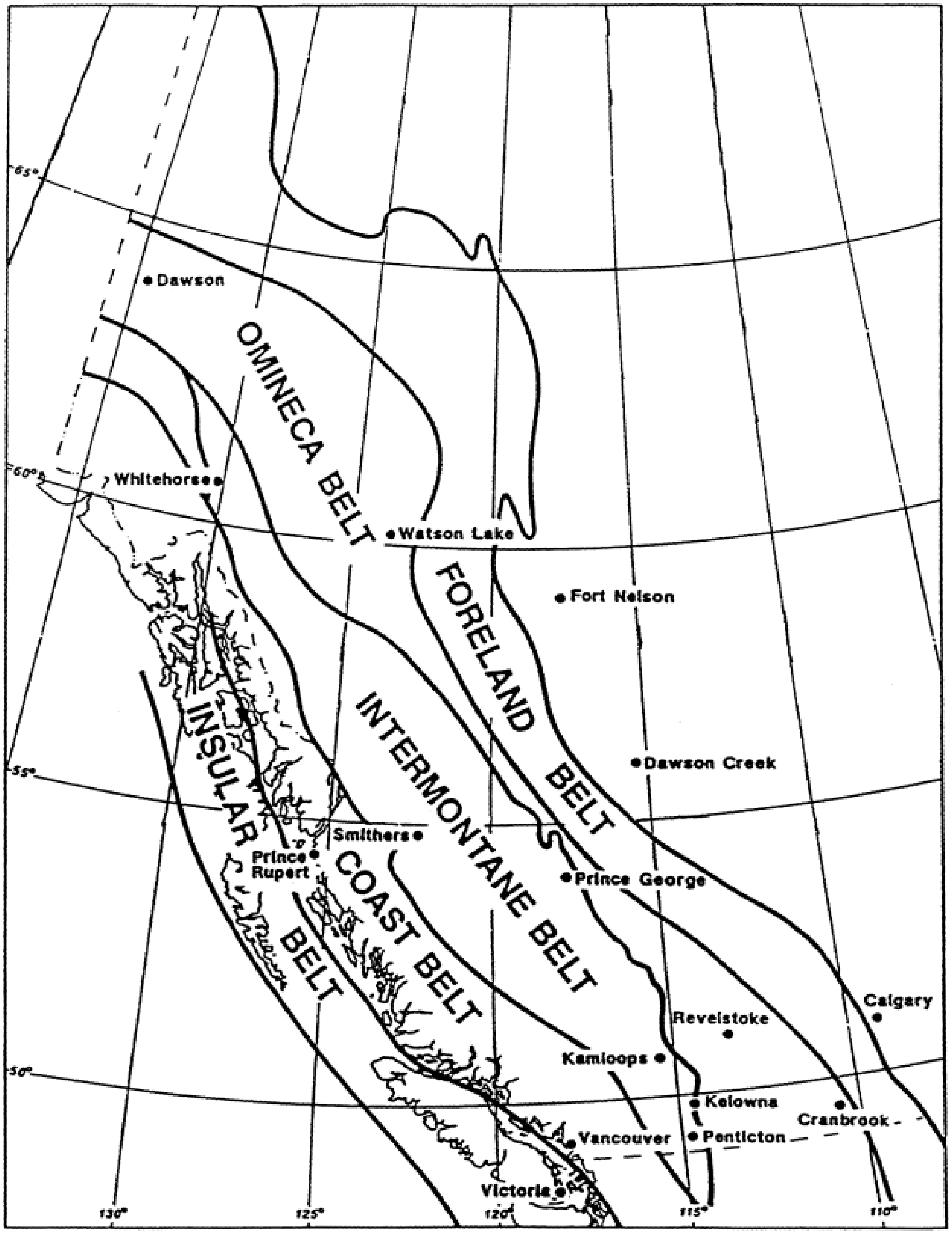
GG-2	Continental Drift
GG-3	Canadian Cordilleran Map
GG-4	Northwest North American Plate Tectonic Elements
GG-5	Juan de Fuca Subduction Zone
GG-6	Continent Amalgamation and Fragmentation (Precambrian – Recent)
GG-7	Earthquakes (1978-1984)
GG-8	Geologic Time Scale
GG-9	Ten Largest Earthquakes (1900-1994) Map
GG-10	Ten Largest Earthquakes (1900-1994) Data

Continental Drift

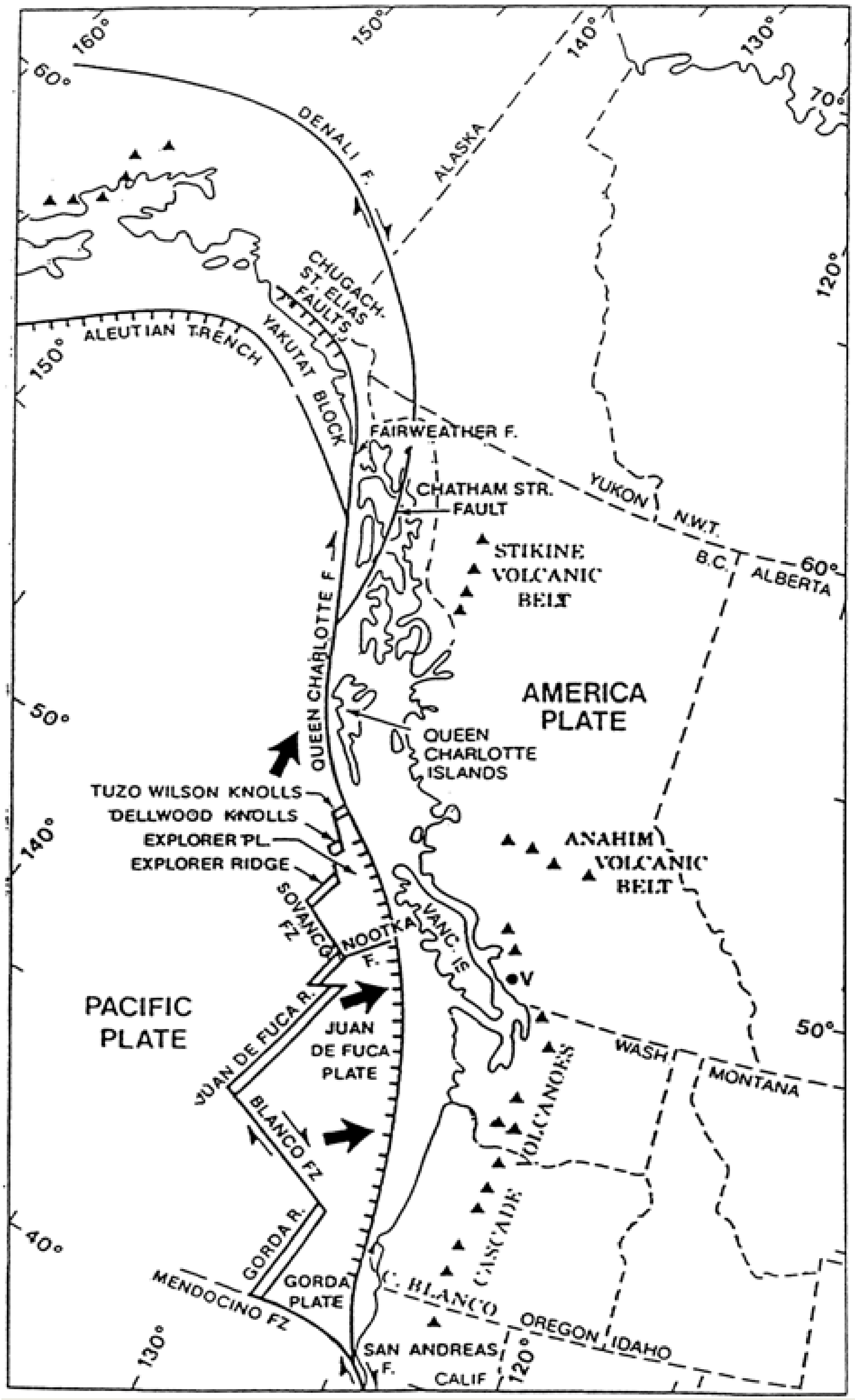




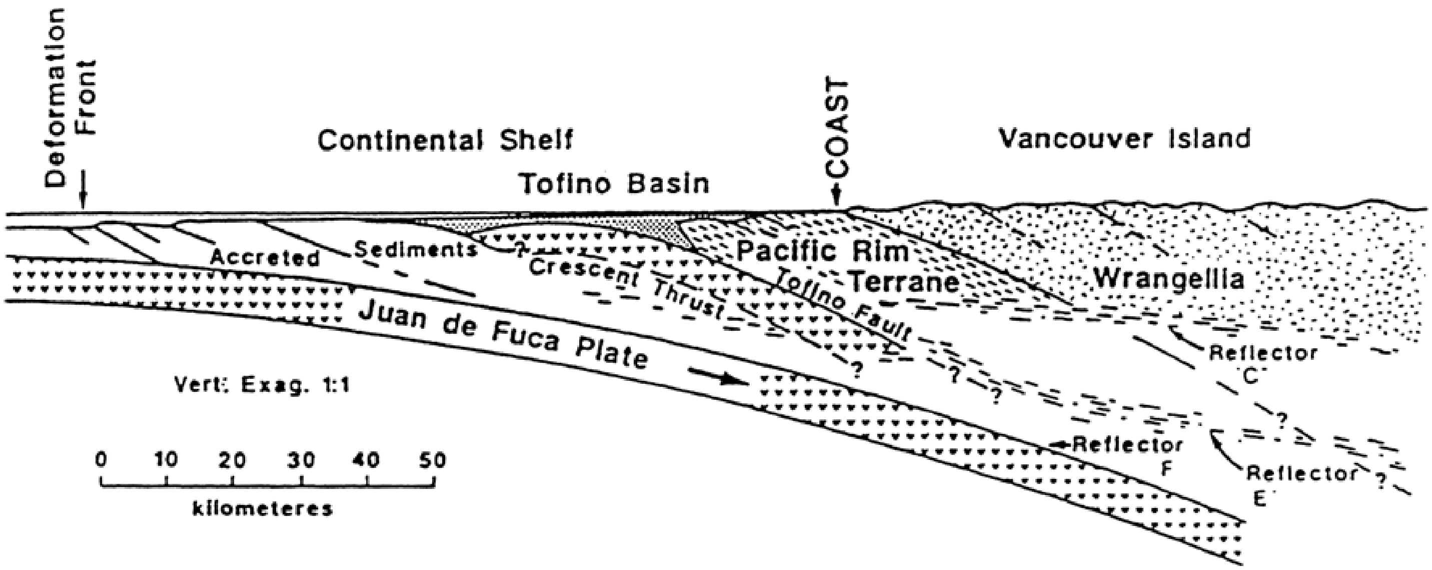
Canadian Cordilleran Map



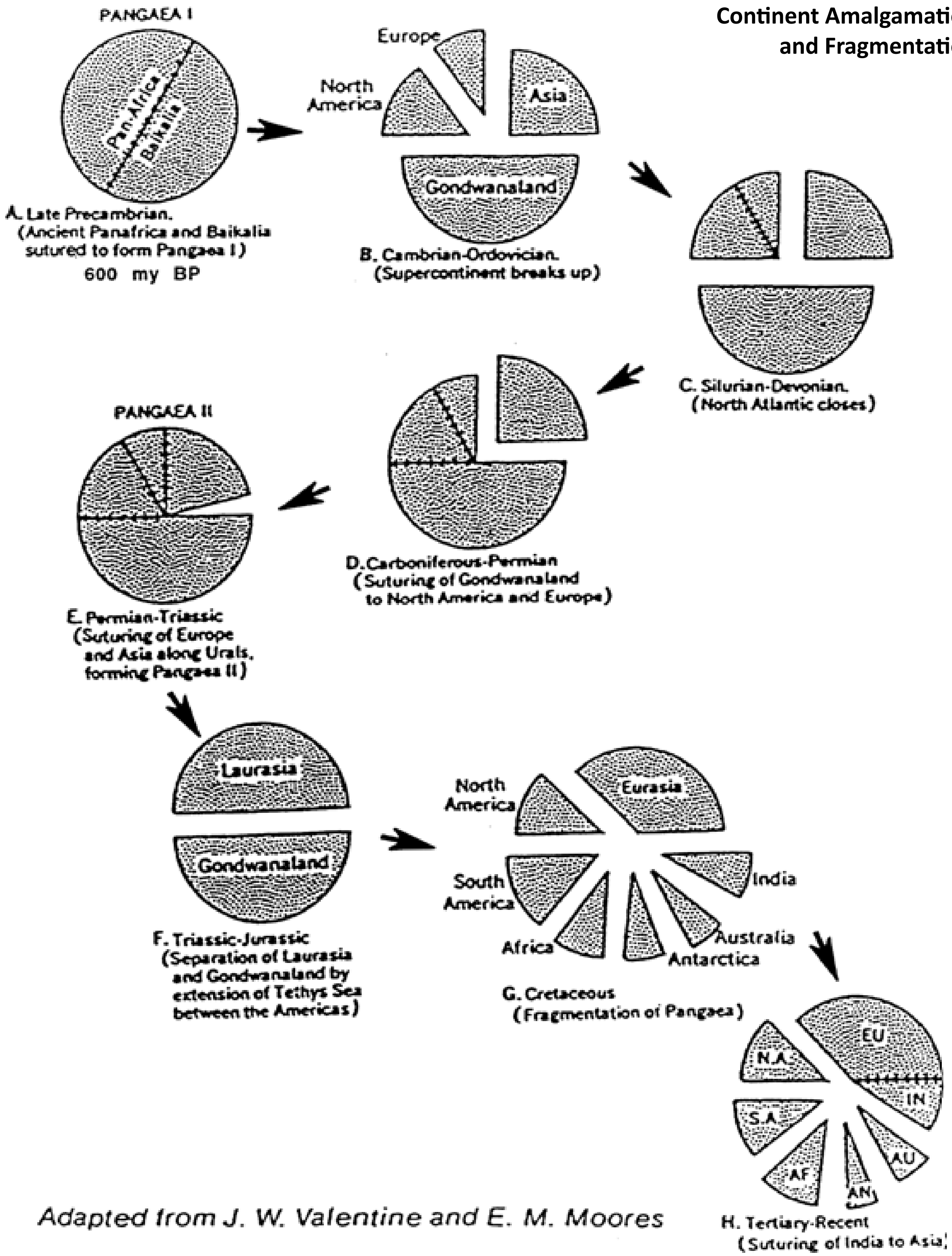
Northwest North American Plate Tectonic Elements



Juan de Fuca Subduction Zone

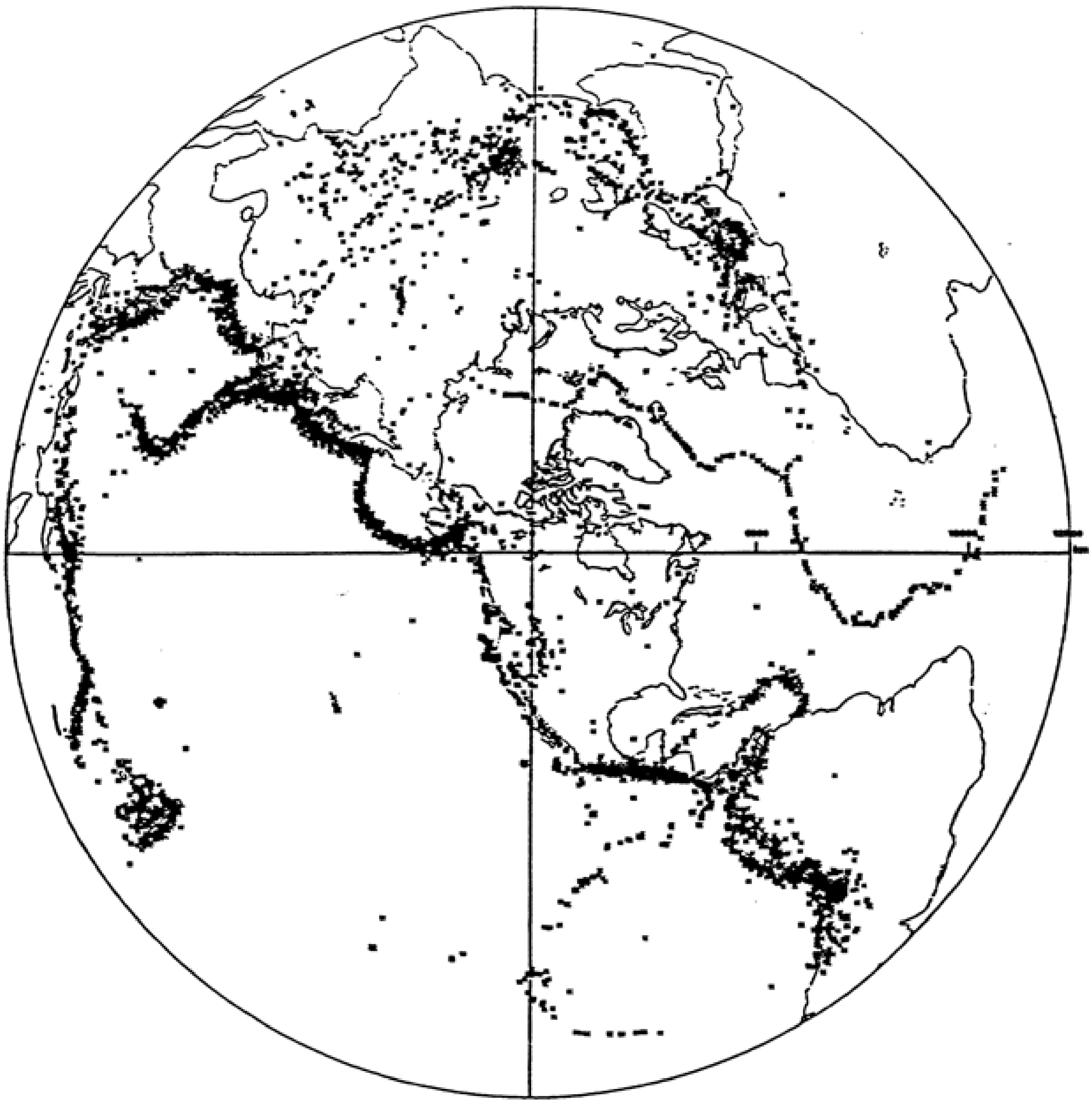


Continent Amalgamation and Fragmentation



Adapted from J. W. Valentine and E. M. Moores

Earthquakes
(1978-1984)



Sample of seven years of events detected by the Yellowknife seismological array (1978-84). The majority of these are earthquakes, but some are underground nuclear explosions at the test sites shown on the previous illustration.

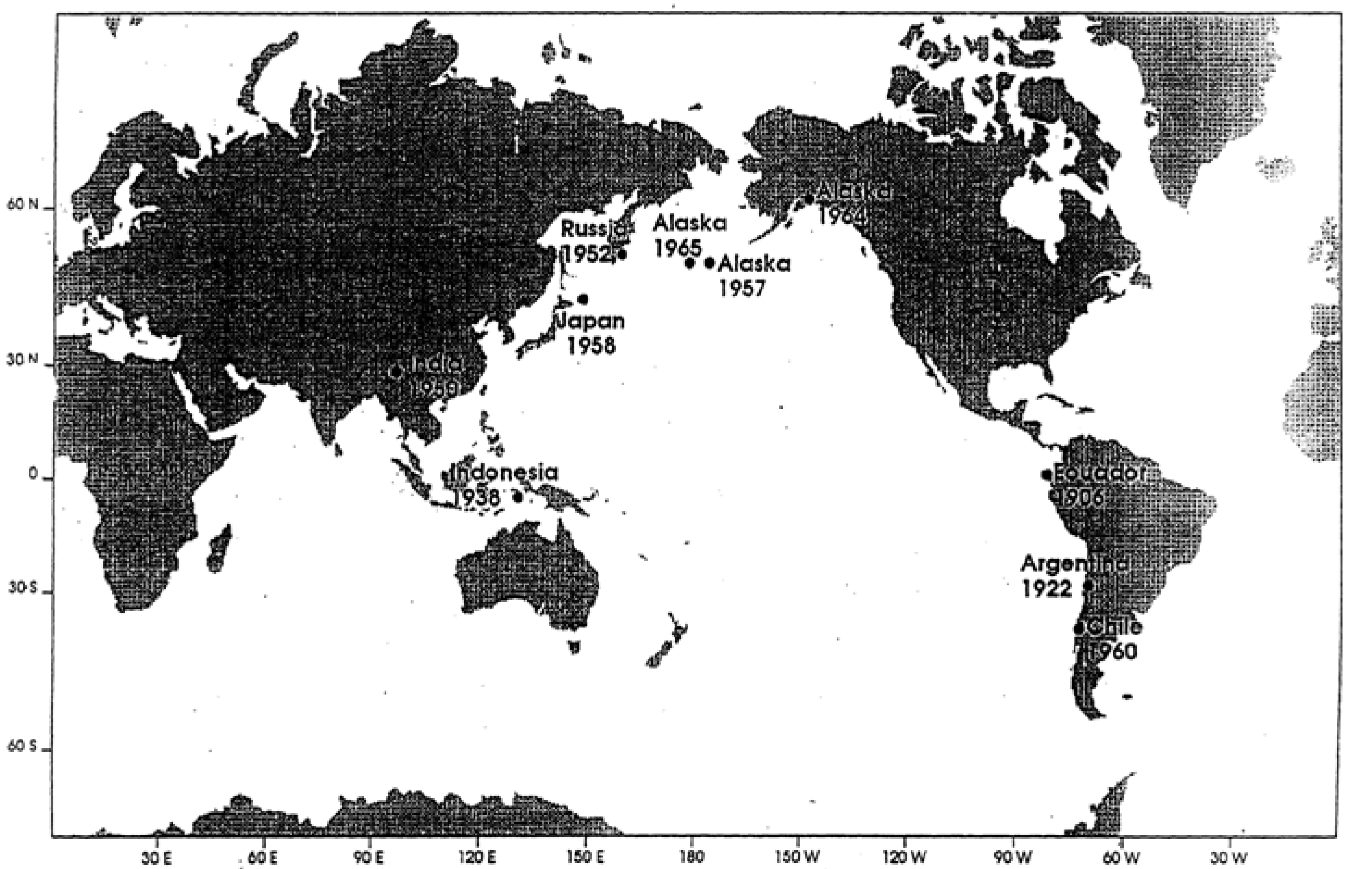
Geologic Time Scale

ERA	PERIOD	EPOCH	EVENTS IN THE HISTORY OF LIFE	OTHER IMPORTANT EVENTS
CENOZOIC	Quaternary	Recent (10,000)	Earliest man; Modern horse evolves in North America, then dies out	Ice Ages; Grand Canyon carved; Pacific Coast Ranges formed
		Pleistocene (1,000,000 to 2,000,000)		
	Tertiary	Pliocene (11,000,000)		
		Miocene (25,000,000)	Rapid spread and evolution of grazing mammals	
		Oligocene (40,000,000)	Earliest elephants	
		Eocene (60,000,000)	First primitive horses, rhinoceroses, and camels	
		Paleocene (70,000,000)	First primates	Uplift and folding of Western Geosyncline
MESOZOIC	Cretaceous (135,000,000)		Extinction of dinosaurs Great evolution and spread of flowering plants	Half of North America covered by seas; Uplift of Sierra Nevada
	Jurassic (180,000,000)		First birds and mammals Dinosaurs at their peak; Dinosaurs	
	Triassic (225,000,000)			Arid climates in much of western North America
PALEOZOIC	Permian (270,000,000)		Mammal-like reptiles	Ice Ages in Southern Hemisphere World climate much like today Deserts in western United States
	Pennsylvanian (305,000,000)		First reptiles; Large insects	Widespread swamps, coal source Tropical climate in United States; Uplift and folding of Appalachian Geosyncline
	Mississippian (350,000,000)		Sharks abundant	Widespread flooding of North America, limestone deposited
	Devonian (400,000,000)		First amphibians First forests; Trilobites	Filling of Appalachian Geosyncline and Western Geosyncline
	Silurian (440,000,000)		First air-breathing animals (scorpions) First land plants	Deserts in eastern and central U.S.
	Ordovician (500,000,000)		Trilobites at peak First vertebrates (fish)	Widespread flooding of North America by seas
	Cambrian (600,000,000)		Marine shelled invertebrates common First abundant animal fossils	
PRECAMBRIAN – PROTEROZOIC	(2,500,000,000)		Marine invertebrates probably common; few with shells, (1,200,000,000)	Glaciation–probably worldwide; Many geosynclines filled, uplifted, and eroded
PRECAMBRIAN – ARCHEOZOIC	(4,500,000,000)		Earliest plants (marine algae) (3,200,000,000)	

NUMBERS REFER TO TIME IN YEARS B.P. (BEFORE PRESENT) SINCE THE BEGINNING OF THE ERA, PERIOD, OR EPOCH

Ten Largest Earthquakes Map (1900-1994)

Ten Largest Earthquakes in the World
1900 to 1994



Prepared by the United States Geological Survey National Earthquake Information Center

Ten Largest Earthquakes Data (1900-1994)

Year	Month	Day	Time	Latitude	Longitude	Location	Magnitude
1906	01	31	15:36:00.00	1.0° N	81.5° W	Ecuador	8.8 MW
1922	11	11	04:32:36.00	28.5° S	70.0° W	Argentina	8.5 MW
1938	02	01	19:04:18.00	5.25° S	130.5° E	Indonesia	8.5 MW
1950	08	15	14:09:30.00	2 8.5° N	96.5° E	India	8.6 MW
1952	11	04	16:58:26.00	52.75° N	159.5° E	Russia	9.0 MW
1957	03	09	14:22:28.00	51.3° N	175.8° W	Alaska	9.1 MW
1958	11	06	22:58:06.00	44.4° N	148.6° E	Japan	8.7 MS
1960.	05	22	19:11:14.00	3 8.2° S	72.6° W	Chile	9.5 MW
1964	03	28	03:36:14.00	61.1° N	147.5° W	Alaska	9.2 MW
1965	02	04	05:01:22.00	51.3° N	178.6° E	Alaska	8.7 MW

Student Exercises

NAME ________________________

Mountain Building, Rift Movements, Faulting and Folding

When we look at the rocks and rock layers in the mountains of British Columbia we can see that they have been deformed by compression or by stretching. The rocks have developed fractures, faults and folds that tell a story about the geological history of the area, and the forces of deformation which must have existed in the past.

Large scale pressures acting within the lithosphere are caused by tectonic plate movements. Where plates are converging, the compressional stresses produce near horizontal thrust faults or folds. Where plates diverge, the tensional stresses produce steeper faults, called normal faults. Laboratory investigations on real rocks are difficult to carry out. Instead, the activity described below uses layers of flour and cocoa that behave like layers of rock.

Activity:

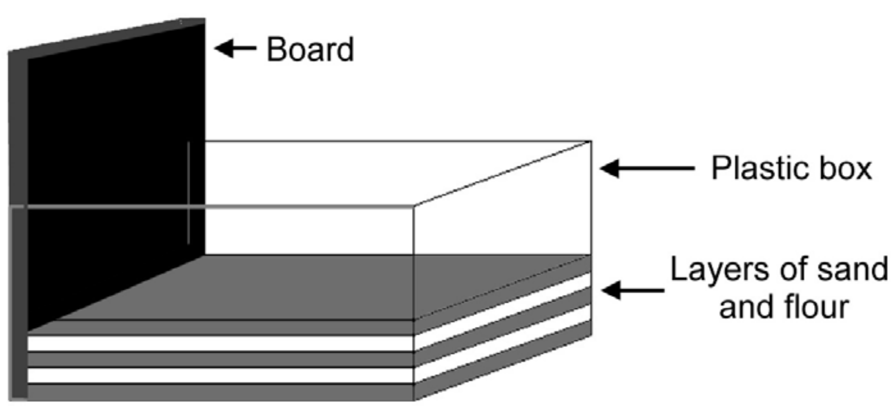
Make your own folds and faults.

Purpose:

To show how faulted or folded rocks in an outcrop can provide evidence of the size and direction of the forces that produced the fault.

Notes:

The apparatus and materials required are: a transparent plastic box (Ferrero Rocher chocolate boxes or small plastic storage boxes are excellent); spatula or dessert spoon; tray; a piece of board to fit snugly into the box; 500g of dry fine flour; 25g of cocoa. Only thin layers of cocoa are needed, sprinkled along the front of the box alone, in order to save cocoa.



How to set up the box for 'Push'

When pressures are applied to solid materials they may bend or break. When sands or sandstones bend, folds are produced; when they break, faults are formed. Find out what types of folds and faults are produced by compression by following these instructions.

Part 1 - Compressing the Crust - Mountain Building:

1. Place the board vertically inside one end of the box.

2. Build up several thin layers of flour and cocoa. Do not fill it more than half-full. Spread the cocoa along the front of the box only. The more carefully you do this step, the better your results will be!

3. Very carefully and **very slowly**, push the vertical board across the box, so that it begins to compress the layers. When you notice the layers beginning to fracture, stop pushing the board. Hold the board upright and draw a diagram of the result.

Experiment 1

4. Continue pushing the layers with the board until the layers are starting to fold and the flour and cocoa are about to overflow the box. Hold the board upright and draw a diagram of the result.

Experiment 2

5. Then add arrows to your diagrams to show the directions of the forces, which were acting whilst you compressed the layers with the board.

6. Are the layers still horizontal, or are they folded? ________________________________

7. Did one set of layers slide over the rest? ____

If you have been careful, you will have produced a fault in which layers of rock are pushed up and over other layers. These types of faults are often nearly horizontal:

Part 2 - Stretching the Crust - Rift Movements:

8. Place the board vertically about five centimetres from one end of the box.

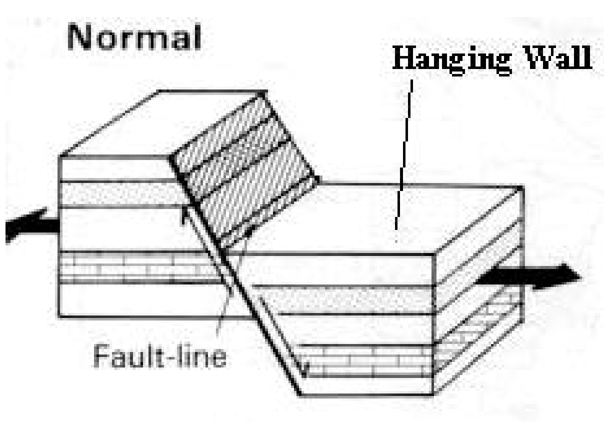
9. Fill the longer side with layers of flour and cocoa.

10. Very carefully and **very slowly** move the board away. If nothing happens, then press very gently on the top with the edge of a circular lid. With a bit of luck, you should have formed a steeply dipping fault.

11. Draw a diagram of the result and add arrows to your diagrams to show the directions of the forces, which were acting whilst you stretched the layers with the board.

Experiment 3

Types of Faults

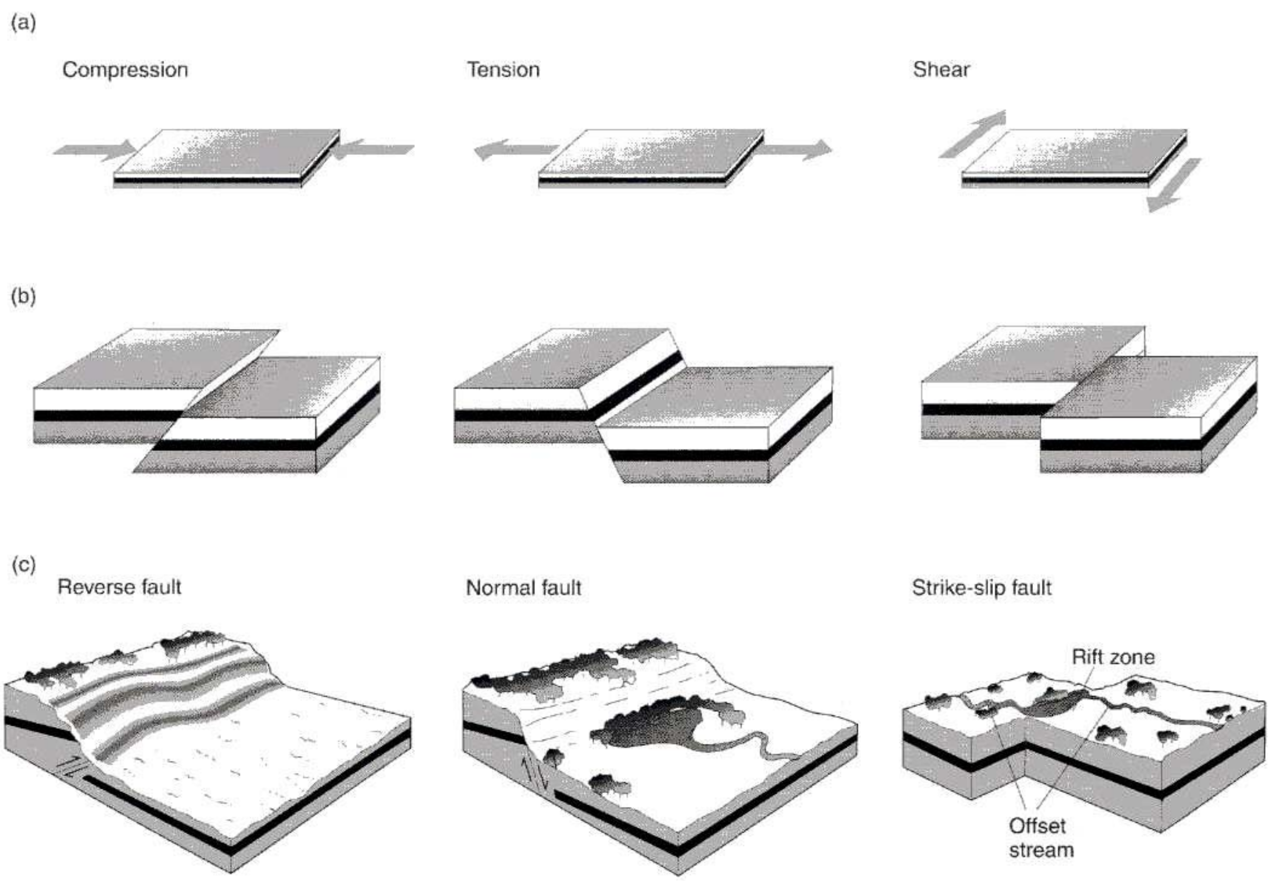


When we talk about faults, we need to learn a few names. The first name is “Hanging Wall”. It is the side of the fault that overhangs the fault. The right hand side of the fault, shown above, is the hanging wall.

If the hanging wall of a fault appears to have moved **down the fault**, then the fault is said to be a normal fault.

If the hanging wall of a fault appears to have moved **up the fault**, then the fault is said to be a reverse or thrust fault.

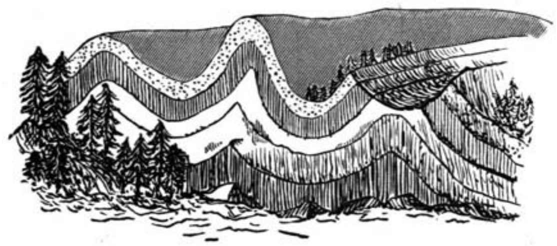
If the movement along the fault is only horizontal, then the fault is said to be strike slip.



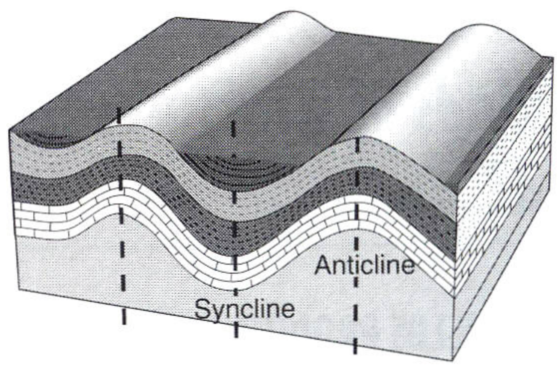
Exercise:

Examine experiment diagrams 1 and 3 and label the following:
i.. Fault Plane ii. Hanging wall iii. Normal Fault or Reverse Fault or Strike Slip Fault

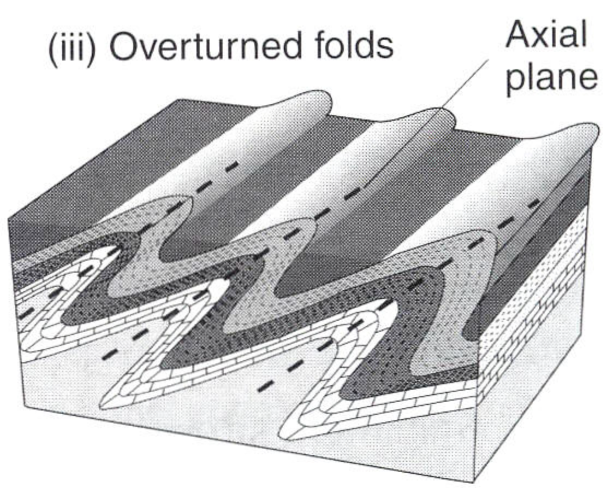
Types of Folds



Folds are usually created when rock layers are compressed. Geologists call the arch like folds ANTICLINES and the sink like folds SYNCLINES



If the folded rocks are compressed even more, they will start to fall over and are then called **OVERTURNED** folds. Examine the fold that should have been sketched in experiment diagram 2 and label the following:



i. Syncline fold OR Anticline fold OR Overturned fold

ii. Axial Plane of the fold iii Direction of pressure that made the fold.

Questions:

1. Examine the faults shown in the photo below and label: Hanging wall, type of fault, direction of pressure or stretching,

2. Examine the fold photos shown below and label fold types, axial planes and directions of pressure.

Teacher Information

Video References

Geological Survey of Canada

The Geological Survey of Canada has a variety of educational videos available on DVD. Teachers may request copies free of charge through the contact information below. For a listing of available titles, please visit http://gsc.nrcan.gc.ca/edumat_e.php. The following specific titles are recommended:

1. *Beyond the Ocean Frontier: the Juan de Fuca Ridge* (1986), 8 min
   - discusses the geology and tectonism of the Juan de Fuca Ridge area off the west coast of British Columbia

2. *The Earth Scientists* (1985), 18 min
   - describes the role and responsibilities of geoscientists in five distinct disciplines

3. *Earthquakes in Canada?* (1987), 15 min
   - describes earthquakes in Canada in terms of their geologic causes and consequences

4. *The Geological Survey of Canada --- Past to Present* (1987), 15 min
   - presents the history of the GSC and its current role

5. *Lithoprobe: Probing the Earth* (1986)
   - describes the Lithoprobe project and its focus on sub-surface mapping
   - data collected by the Lithoprobe project (1986-2005) is available free of charge for download: *www.nrcan.gc.ca/earth-sciences/products-services/geoscience-data-repository/11846*

Other resources: NRCAN Library (Vancouver Branch)
www.nrcan.gc.ca/library/6275
Phone: 604-666-1147
625 Robson St., 15th floor
Vancouver, BC V6B 5J3

6. *Surviving the Big One*
   - an exceptional video on earthquake preparedness produced by a Los Angeles fireman who describes how the average person should prepare for the magnitude 8.5 quake the southern California region is anticipating. All the information he provides is applicable to us in southwestern BC. Descriptions are provided in several scenarios: what to do if the earthquake hits while you are at work, at school, at home, in a mall, or even at an entertainment facility. The students will find the video interesting, entertaining and tremendously informative. It is an excellent tool for forcing all of us to reassess what we take for granted, and consider the impact a major natural disaster can have.

Contact: **BuyIndies.com**
PO Box 391620, Cambridge, MA 02139 USA
Phone: 1-877-889-7477
www.buyindies.com/listing/FCTS-13605

NOVA

The entire Nova library is available to educators and schools at a special reduced rate: $19.95 US per video. They can be ordered through WGBH (Boston):

Contact: **WGBH**
P.O. Box 200, Boston, MA 02134 USA
Phone: 1-888-255-9231
www.wgbh.org/shop

Recommended videos include:

7. *In The Path of a Killer Volcano*
   - deals with the problems of trying to forecast the eruption of Mount Pinatubo in the Philippines. It includes incredible footage of the scientists' last minute evacuation during the chaos of the eruptions.

8. *Earthquake!*
   - gives great historical accounts of major earthquakes, including ones in Alaska, San Francisco (1906), and Loma Prieta, CA (1989), as well as the current status of earthquake prediction.

9. *Killer Quake!*
   - provides all the details surrounding the Northridge, CA (near Los Angeles) earthquake in spring 1994.

Teacher Information

Geoscience Contacts

Bernica Enterprises Ltd. (Lloyd Twaites Minerals)
2954 West 34th Avenue
Vancouver, BC V6N 2J8
Email: lloydtwaites@telus.net
- Rock and mineral samples
- Order form available at www.bcminerals.ca/pdf/LTwaites_OrderForm.pdf

B.C. Geological Survey
Mining and Minerals Division
Ministry of Energy, Mines and Petroleum Resources,
PO Box 9333, Stn Prov Govt,
Victoria, BC V8W 9N3.
Ph.: 250-952-0454
Fax: 250-952-0381
Web: www.em.gov.bc.ca/mining/geolsurv
- Maps and BC geological publications

Britannia Mine Museum
P.O. Box 188
Britannia Beach, BC V0N IJ0
Ph.: 1-800-896-4044
Fax: 604-896-2260
Website: www.britanniaminemuseum.ca
- Rock and mineral samples; mining and geoscience activities; school tours

Association for Mineral Exploration BC
800-899 West Pender St.
Vancouver, BC V6C 3B2
Ph.: 604-689-5271
Fax: 604-681-2363
Web: www.amebc.ca
- Prospecting information and courses; exploration and mining information

Teacher Information

HR MacMillan Space Centre – Space Resource Centre
1100 Chestnut St.
Vancouver, BC V6J 3J9
Ph.: 604-738-7827
Fax: 604-736-5665
Web: www.hrmacmillanspacecentre.com

- To order a PSC catalogue of available classroom materials contact Claudette Martin (604-738-7827 ext. 223) or cmartin@hrmacmillanspacecentre.com

McAbee Fossil Beds
Cache Creek, BC
Ph.: 250-374-7164
Web: www.dll-fossils.com
Email: DaveL@sageserve.com (Dave Langevin)

- Students dig the fossil beds and are able to keep their find
- Digging season runs from May to October. There is an on-site guide daily from 9:00 - 4:00 during the high season in July/August

MineralsEd (Mineral Resources Education Program of BC)
900 – 808 West Hastings Street
Vancouver, BC V6C 2X4
Ph.: 604 682-5477
Fax: 604-681-5305
Web: www.mineralsed.ca

- Educational resources, workshops, field trips and other learning opportunities

Mining Association of British Columbia
900 – 808 West Hastings Street
Vancouver, BC V6C 2X4
Ph.: 604-681-4321
Fax: 604-681-5305
Web: www.mining.bc.ca

- Current information on operating mines in BC
- PricewaterhouseCoopers Report on Mining in BC

Teacher Information

Natural Resources Canada
Geological Survey of Canada: Pacific Division – Vancouver Subdivision
Suite 101-605 Robson Street
Vancouver, BC V6B 5J3
Ph.: 604-666-0271
Fax: 604-666-1337
Web: http://gsc.nrcan.gc.ca/org/vancouver/index_e.php

- Maps, geology publications (nationwide and local), rocks and mineral sets and posters

The Pacific Museum of the Earth
Earth and Ocean Sciences Building
University of British Columbia
6339 Stores Road
Vancouver, BC V6T 1Z4
Ph.: 604-822-6992
Web: http://www.eos.ubc.ca/resources/museum/index.html
Email: Mackenzie Parker, mparker@eos.ubc.ca pme@eos.ubc.ca

- Geology exhibit and mineral collection, school tours

SFU Earth Sciences Lab
Department of Earth Sciences
Simon Fraser University
8888 University Drive
Burnaby, BC V5A 1S6
Ph.: 604-291-4925

- Contact: Ms. Robbie Dunlop

The Exploration Place
333 Becott Place
Prince George, British Columbia
(Mailing address: P.O Box 1779, Prince George, B.C. V2L 4V7)
Ph.: 250-562-1612
Email: info@theexplorationplace.com
Web: www.theexplorationplace.com

- On-site and virtual exhibitions on a variety of topics including Earth Science
- Offers Science To Go! Resource packages for rental

Teacher Information

Select Geoscience Websites

1. http://earthquakescanada.nrcan.gc.ca/index_e.php
   - Natural Resources Canada; current information on earthquakes in BC and western Canada

2. www.cuug.ab.ca/johnstos/geosci.html
   - Calgary Unix Users Group; K-12 geoscience resources

3. http://infotrek.er.usgs.gov/pubs/
   - United States Geological Survey; geoscience information

4. http://www.bced.gov.bc.ca/exams/search/
   - Ministry of Education; Provincial exams for Geology 12

5. http://www.mcrel.org
   - Mid-Continent Research for Education and Learning; good resources

6. http://nesen.unl.edu
   - Nebraska Earth Science Education Network; good resources

7. http://quest.arc.nasa.gov/
   - NASA; an electronic field trip to study planets, stars and galaxies

8. http://www.cmec.ca
   - Pan-Canadian Science Project; Canada-wide science curriculum-writers' guide; K to 12 in Earth Science, Physical Science and Life Science.

9. http://www.nasa.gov/centers/kennedy/home/index.html
   - NASA; averaging 2 million hits per month

10. http://www.whatonearth.org/
    - University of Waterloo Department of Earth Science; geoscience education

11. http://volcano.und.nodak.edu/vwdocs/current_volcs/currentold.html
    - University of North Dakota; updates on current volcanic activity worldwide

12. www.ec.gc.ca
    - Environment Canada; meteorology information

Teacher Information

Earth Science 11 / Geology 12 Slide Set Descriptions and Questions

Slide # **GLACIERS**

1. Two alpine glaciers converging; lateral moraines on the left, medial moraines in the middle formed by converging lateral moraines.
   - note the surface of the ice
   Q1: Why is it not white? Where does the "dirty" material come from?
   Q2: What evidence does the ice surface show that it moves?
   Q3: Have the glaciers in the slide ever reached the tops of the peaks?

2. Alpine glacier, showing extent from headwall of cirque down to toe in main valley
   - note the number of moraines on the surface of the ice
   Q1: How do these moraines form in the centre of the ice?
   Q2: How many glaciers have joined to form this large glacier?
   Q3: Where is the zone of accumulation, zone of ablation? What can you say about the year round temperatures at the two ends of the glacier?

3. Alpine glaciers joining up to form a valley glacier (note extent of glacier's retreat on the valley walls)
   - make note of the non vegetated area between ice and treeline
   Q1: Why is there no vegetation in this area?
   Q2: Is the glacier getting larger or smaller?
   Q3: What is the source of water for the lake near the toe of the glacier?

4. Alpine glacier in a cirque
   Q1: What evidence do you see that would indicate the glacier was once larger?
   Q2: Give an example of an erosional feature and of a depositional feature shown in the slide.

5. Scud Glacier, Stikine River area (northwest BC)
   - use this slide on a test or a quiz, as it parallels two of the previous slides.

6. Arêtes and cirques
   Q1: How many cirques are evident in the slide?

7. Hanging valley
   Q1: Explain the formation of this feature.

8. Arêtes formed between parallel glacial valleys

9. Ice mounds covered in glacial sediment (mounds are solid ice covered in dark material)
Q1: What is the source of the material spread over the ice surface (in the foreground)?
Q2: Why is it angular?

10. Broad, U shaped valley with V shaped, stream cut valley beginning to develop in its floor. Streams cutting down in flanks of main valley also. They are offset. Is the main creek a fault trace?
Q1: If the main stream follows a fault trace, what type of fault would cause the offset of the tributaries on each side of the main stream?

11. Medial moraine in Robson Glacier (Rocky Mountains NE of Tete Jaune Cache, BC)
Q1: How did this material get to be in a line down the center of the ice?
Q2: Does this material extend through the entire thickness of the ice?

12. Glacial till: note wide range of particle size, from cobble to "flour"
Q1: Classify the larger particles as angular, sub angular or rounded.
Q2: Would this sediment be considered sorted or unsorted?
Q3: Speculate as to the cause of the rounded particles.

13. Outwash plain
Q1: What is the large boulder classified as?
Q2: How does this depositional environment differ from alluvial (river)?

14. Outwash fan, delta
Q1: What evidence shows the stream does not follow a single channel?
Q2: Why is there little vegetation on the gravel plain?

15. River delta, braided stream
Q1: What kind of stream is this? (braided)
Q2: What causes a stream to flow like this? (low grade too much sediment)

16. Esker
Q1: How does this ridge of gravel form?
Q2: Describe the nature of the sediments found in this pile.

17. Icicle, under glacier, bent due to ice flow

18. Rapidly drained glacial lake called a "jokulhlaup" (Summit Lake). The glacier to left of center has dammed the valley running from left to right. Water stored behind the ice

builds up pressure and forces its way under the ice causing a catastrophic draining of the lake. The fragments of ice on the valley floor are a result of this rapid draining.

MASS WASTING

19. Rock slides
Q1: Hypothesize as to the cause of this mass wastage.
Q2: Why did this occur in this specific location? (possible stream bed, extensive weathering)

20. Talus cone (Keremeos, BC)
Q1: What is this?
Q2: How does this feature form?

SEDIMENTARY FEATURES & EROSION

21. Young stream cutting through volcanics
Q1: Describe the maturity of this stream.
Q2: Describe the nature of the rock material it has cut through.

22. Entrenched meander (San Juan River, Utah)
Q1: Describe the nature of the rock the river has cut through.
Q2: Describe the processes involved in creating this feature. (uplift of area = downward erosion of stream)

23. Meandering stream   speculate on the stream pattern
Q1: Are all the streams active? (Are some abandoned? Are some older than the others?)
Q2: Where is there potential for future oxbow lakes?

24. Alluvial fan (Yehiniko Lake)
Q1: Why are the sediments deposited here?
Q2: Did the river do all the carving of the valley?

25. Meandering stream
Q1: Where is the present stream channel?
Q2: Speculate as to why some scars have water in them and others have vegetation in them.

26. Oxbow lake

27. Ripple marks (asymmetrical)
Q1: What causes this sedimentary structure?

28. Ripple marks (symmetrical)
Q1: What causes this sedimentary structure?
Q2: These patterns give clues to the depositional environment, what can they tell you?

29. Ripple marks
- use for test or quiz

30. Climbing ripple cross-lamination in sandstone
- note the coarse grained sediment at the bottom of the picture

31. Cross-bedding in quartz sandstone

32. Cross-bedding in a sandstone slab

33. Large-scale, eolian cross-bedding in (De Chelley Sandstone, Canyon de Chelley, AZ)

34. Flame structures. Form when a soupy, fine-grained deposit (mud) is rapidly overlain by a thick sand deposit. The weight of the sand forces the mud upward into these flame like structures.

35. Load and flame structures (Archean, Knife Lake Metasediments, MN)

36. Load casts on the base of a steeply-dipping bed (Big Bar Ferry road, BC)

37. Flutes. Water moved sediments dragging previous sediments cause these shapes.
Q1: What is the current direction?

38. Graded bedding (layer above camera case shows pebbles grading upward into finer particles)

39. Horizontal bedding
Q1: Why are some layers more distinct than others? (they are harder)

40. Hoodoos
Q1: Comment on the formation of these structures.
Q2: Describe the kind of climate necessary for the formation (and preservation) of these types of structures.

41. Interbedded argillite and silicified limestone

42. Raindrop prints (pock marks located on the slab that the card is resting on)

43. Rhythmically bedded siltstone
Q1: Comment on the pattern of this structure.

44. a. Block with graded bedding and crossbedding
Q1: Describe the different depositional environments.
Q2: What is the "up" direction of the slab?
b. Graded pebble conglomerate to sandstone (Silurian, Goldson Formation, Lewisport, Newfoundland)

FOSSILS

45. Fusulinid in thin section

46. Coral in dolostone (Pelly Mountains, Yukon)

47. Preserved tree stump

48. Trilobite scratch marks in shale (Mackenzie Mountains, Yukon) a trace fossil

49. Fossilized worm burrows in siltstone (Mackenzie Mountains, Yukon)

50. U shaped worm burrows in quartz sandstone (Diplocraterion)

51. Plant fossil (Jurassic, Ladner Group strata, Manning Park, BC)

52. Ammonite

53. Rugose coral (horn coral)

54. Fusulinids

55. Bedded crinoidal calcirudite (limestone or dolomite composed of coarse, broken fragments of calcitic skeletons or intraclasts)

56. Thin to medium bedded (up to left), shallow marine limestone with stratigraphic coral reef (Ordovician, Lourdes Limestone, Port au Port, Newfoundland)

57. Petrified tree

58. Planolites trace fossil on the base of a sandstone bed (Cambrian, Wisconsin)

STRUCTURE

59. Folded limestone

60. Asymmetric fold (ribbon limestone block in mélange, Black Point, Newfoundland)

61. Recumbent fold (on top of snow patch)
Q1: Is there a fault in this picture? If so, what kind?

62. Macro shot of folded layering in schist

63. Mesoscopic folds
Q1: What is the name of the structure?

64. Dipping coal seam in road cut
Q1: Describe the sequence of events leading to this formation.
Q2: What was the environment of formation of the coal seam?

65. Bedding (dipping to left) and slaty cleavage (right) in slate interbeds between sandstone (Ordovician, Stanley Shale, OK)
Q1: What do we call this type of structure?
Q2: Describe the sequence of events leading to this structure. (Include the depositional environments.)

66. Angular unconformity

67. Angular unconformity (Siccar Point, Scotland)

68. Unconformity

69. "Grand Unconformity", Grand Canyon, AZ, USA
Q1: What geologic processes must have taken place in order for the "Grand Unconformity" to occur?

70. Diabase dyke becoming sill, occupying reverse fault
Q1: List the geologic structures.

71. Jointed granite
Q1: What would cause this type of structure?
Q2: Is this type of structure related solely to climate?

72. Recumbent folds
Q1: How did the recumbent folds (to the left in the picture) form?

73. Slickensides on the fault plane (close up of slide 74)
Q1: How do slickensides form?

74. Fault plane - forms cliff face

75. Strike slip fault
Q1: From this angle, what classification (left/right lateral) of fault is this?

76. San Andreas Fault

ROCKS

77. Xenoliths of wallrock in granitic dyke (Archean, Hurley, WI)
Q1: Explain which material is the oldest.
Q2: How did this formation occur?

78. Feldspar breccia
Q1: What is the reason the large black material is angular?

79. Rhyolite, andesite, basalt: colour change of fine grained igneous rocks.

80. Intrusive rock of intermediate composition (granodiorite)
Q1: Which of the three principal rock types is this? (igneous) Can you give it an even more specific designation? (intrusive, granodiorite)

81. Close up of intrusive rock (granite)
Q1: What is the grey mineral?

82. Examples of porphyries
Q1: What texture is represented in all three specimens? (porphyritic)
Q2: What distinguishes the middle sample from the other two? (dark (mafic) phenocrysts in a light coloured groundmass)

83. Close up of feldspar porphyry
Q1: Describe how this sample was formed.

84. Flower gabbro porphyry
85. "Purple pyroclastic" breccia

86. Pebble conglomerate
Q1: Describe the sorting in this picture.
Q2: What does the angularity of the particles tell you about the transportation of the sediments?

87. Schist outcrop

88. a. Gneiss boulder (west coast of Newfoundland). B. Gneiss outcrop (Omineca Belt, southeast shoreline of Skaha Lake)

MISCELLANEOUS

89. Elevated shorelines resulting from isostatic rebound of Earth's surface after covering glacier has receded (Iceland). (glaciers)
Q1: What would cause this "tiering" of shorelines?
Q2: Why are the rings concentric?

90. Septarian concretion eroded from shale (on a New Zealand beach)

91. Abandoned underground mine headframe (mining)

92. Drillpad construction at high elevation in remote area of northwest BC (Iskut River area) (mining)

93. Major BC terranes

94. Jointing pattern in intrusive rocks: weathering and erosion of outcrops controlled by this pattern. (weathering)
Q1: Describe the formation of this outcrop.

95. Copper stain: azurite (weathering)

96. Polygon pattern typical of permafrost terrains (northern Yukon)
Q1: Describe the ways this pattern might form.
Q2: Is there a particular climate, or environment you would expect to see this type of pattern?

97. Gold in quartz (mining)
Q1: Explain how the gold might end up in this quartz sample.
WIND

98. Eolian sand dunes (sedimentary features)
Q1: Describe the formation of dunes such as these.
Q2: What kind of sand dunes are these?
Q3: Which way is the wind blowing? Why?

99. Great Sand Dunes National Monument (Colorado, USA)

EARTHQUAKES

100. Tsunami wave damage in Port Alberni, BC (1964 Alaska earthquake)
101. Earthquake damage (California freeway, 1971)

102. Earthquake scarp (Gorah Peak)
Q1: What do we call that little "cliff" formed by an earthquake?
Q2: What type of fault is displayed here? (normal)
Q3: Geologically speaking, did the earthquake that caused this scarp occur a short time, or a long time ago?

VOLCANOES & VOLCANIC ROCKS

103. Mount St. Helens (WA) before eruption

104. Mount St. Helens after eruption: "Civilization exists by geological consent subject to change without notice." (W. Durant)
Q1: What type of lava came from Mount St. Helens?

105. Mt. Edziza volcano cone N of Terrace, BC
Q1: Describe the nature of the volcanic material surrounding this cone.

106. Mt. Edziza - (distant shot)

107. Aerial view of cinder cone volcano

108. Cinder cone volcano

109. Active cinder cone volcano

110. Volcanic island (Surtsey) forming on the Mid-Atlantic Ridge off Iceland

111. Table Mountain, Garibaldi Provincial Park, BC
Q1: Name this igneous structure. (volcanic neck)
Q2: Describe its formation.

112. Black Tusk (Garibaldi Provincial Park, BC)
- a volcanic neck

113. Columnar basalt (Squamish, BC)
Q1: What is the name of this feature?
Q2: How does it form?

114. Columnar basalt (near Whitehorse, YK)

115. Columnar jointing in obsidian (Yellowstone, WY, USA)

116. Columnar jointing in inclined basalt flow

117. Gently inclined columnar jointing (Tertiary plug, Yukon Territory)

118. Pillow basalt (Sylvester Group, northern BC)
Q1: What is the name of this feature?
Q2: What does it tell you about the environment of its origin? (cooled under water)

119. Pillowed Triassic basalt with radial vesicles

120. Pillow lavas

121. Pahoehoe lava
Q1: What kind of lava is this?
Q2: Describe its composition.

122. Sinuous lava rivers with levees
Q1: What kind of lava (mafic/felsic) is this?
Q2: What were the clues to naming it?

123. Ropy lava

124. Ropy lava (large scale)

125. Wallrock clasts in volcanic formation dyke?
Q1: Which material is older, light or dark? Why?
Q2: Which one is the intruder?

126. Breccia

127. Dyke, showing chill margin effects
Q1: What is a chilled margin?
Q2: If the material being intruded was a limestone, what rock would result from contact metamorphism?

128. Sustut Conglomerate (BC) with white tuff marker
Q1: Explain the presence of the tuff margin.

129. Sustut Conglomerate cut by two basalt dykes
Q1: From evidence shown in the picture, describe the sequence of events resulting in these formations.

130. Volcanic hoodoo
Q1: Describe how this structure might form.

131. Lava tube (Yellowstone, WY, USA)
Q1: Explain how a lava tube might form.

132. Volcanic agglomerate (Tertiary, Keetley Tuff, UT)

133. Flow banding in rhyolite

134. Contact of basalt dyke with gabbro
Q1: Describe the nature of the material you would expect to find at the contact of the basalt dyke and the gabbro.

135. Exfoliation weathering of massive flow, with joints
Q1: What type of weathering is illustrated in this picture?
Q2: Describe the process of exfoliation.
Q3: Is this type of breakdown specific to one particular climate?

136. Xenolith
Q1: What is a xenolith?
Q2: How do xenoliths occur?

137. Zoned granodiorite dyke
Q1: What causes the zoning (banding) in this igneous intrusion (granodiorite dyke).

138. Felsic dyke and fracture fillings
Q1: Which of the two rock materials is the oldest?
Q2: Describe how this igneous intrusion could result in this pattern.
Q3: Explain which came first, the fractures or the dyke.

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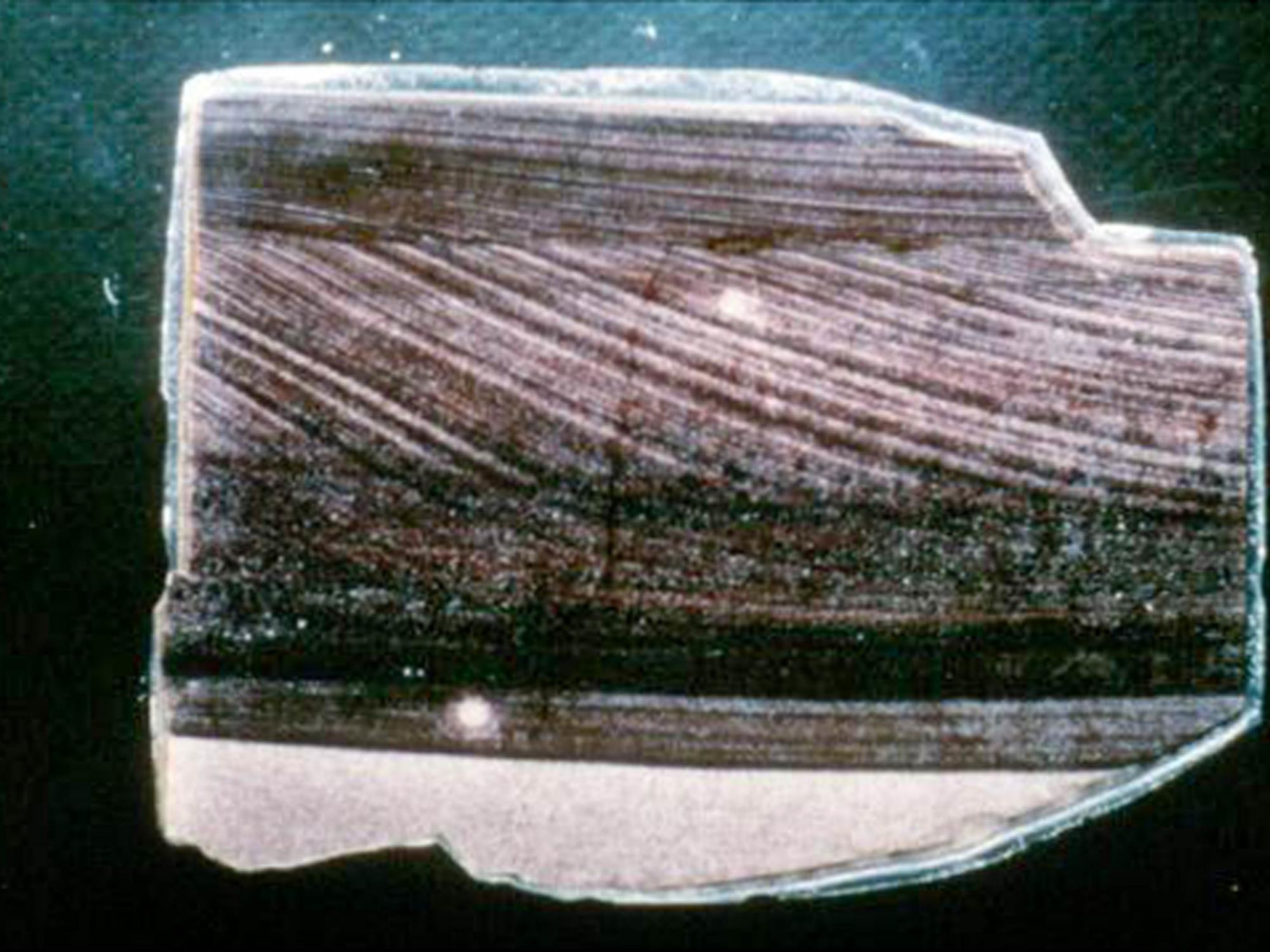
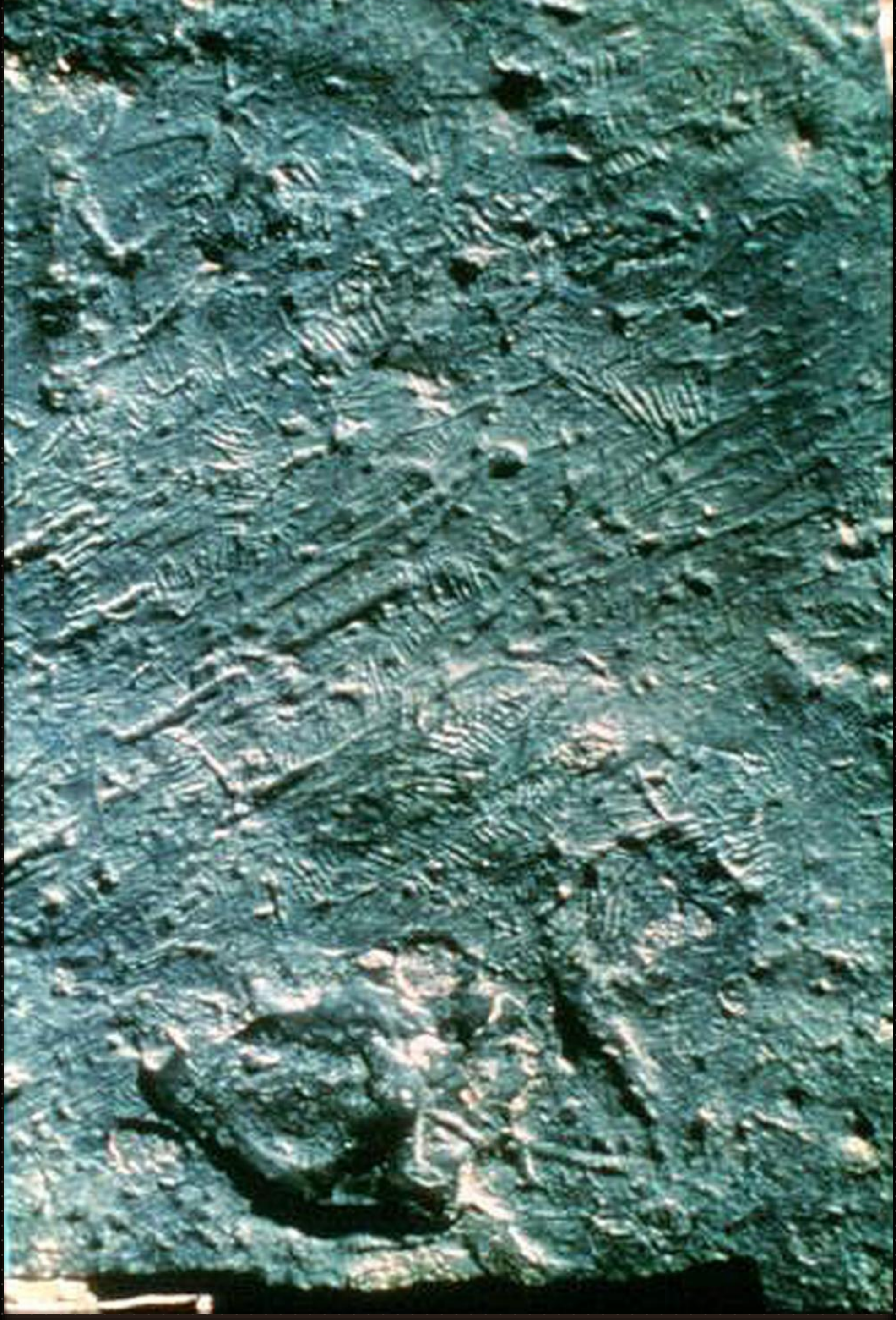
EARTH SCIENCE 11 / GEOLOGY 12 SLIDESHOW


ASAHI
PENTAX

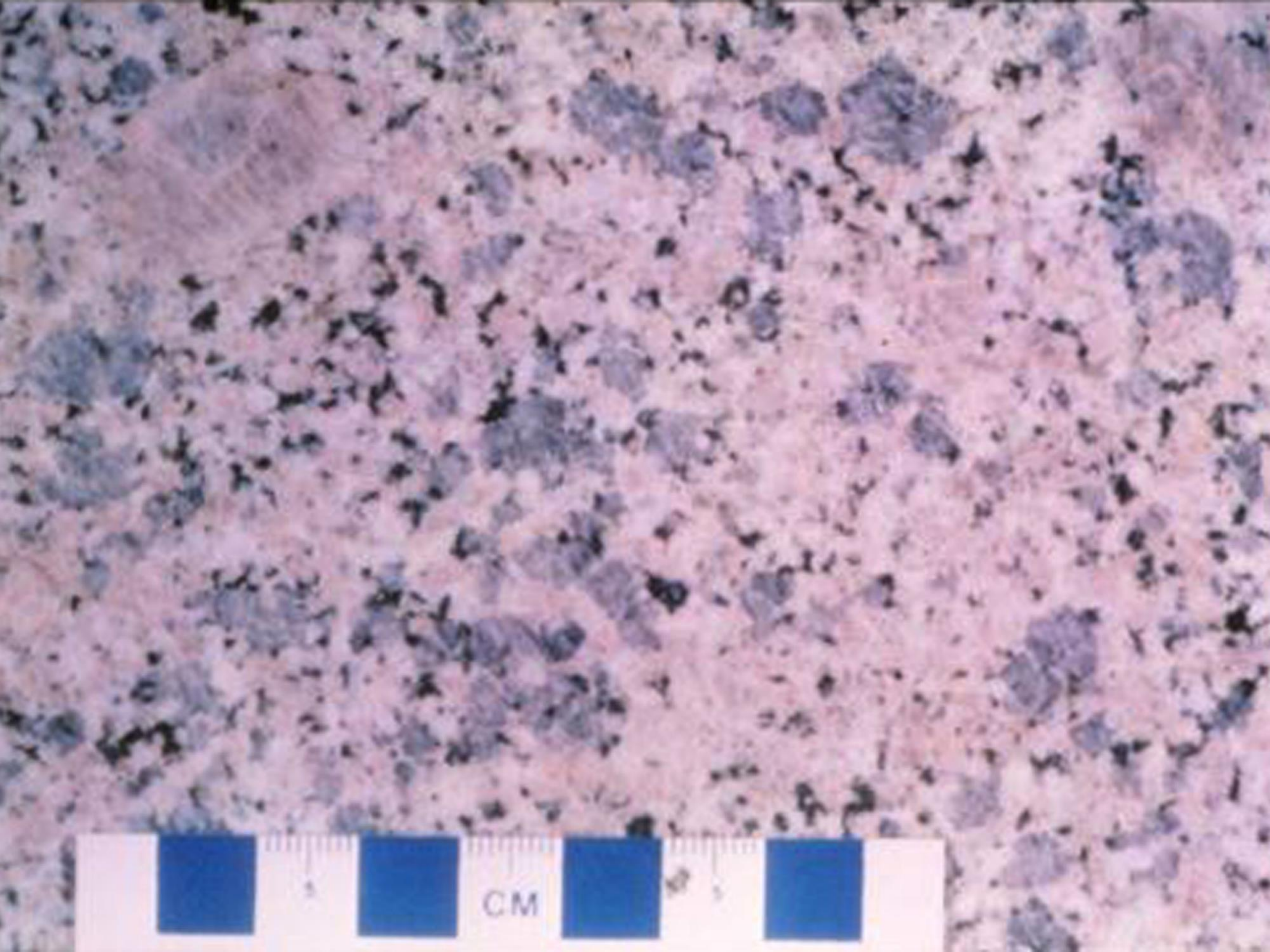





CARDIOCERAS
(L. OXFORDIAN)
cm


CENTIMETRES
INCHES


Canon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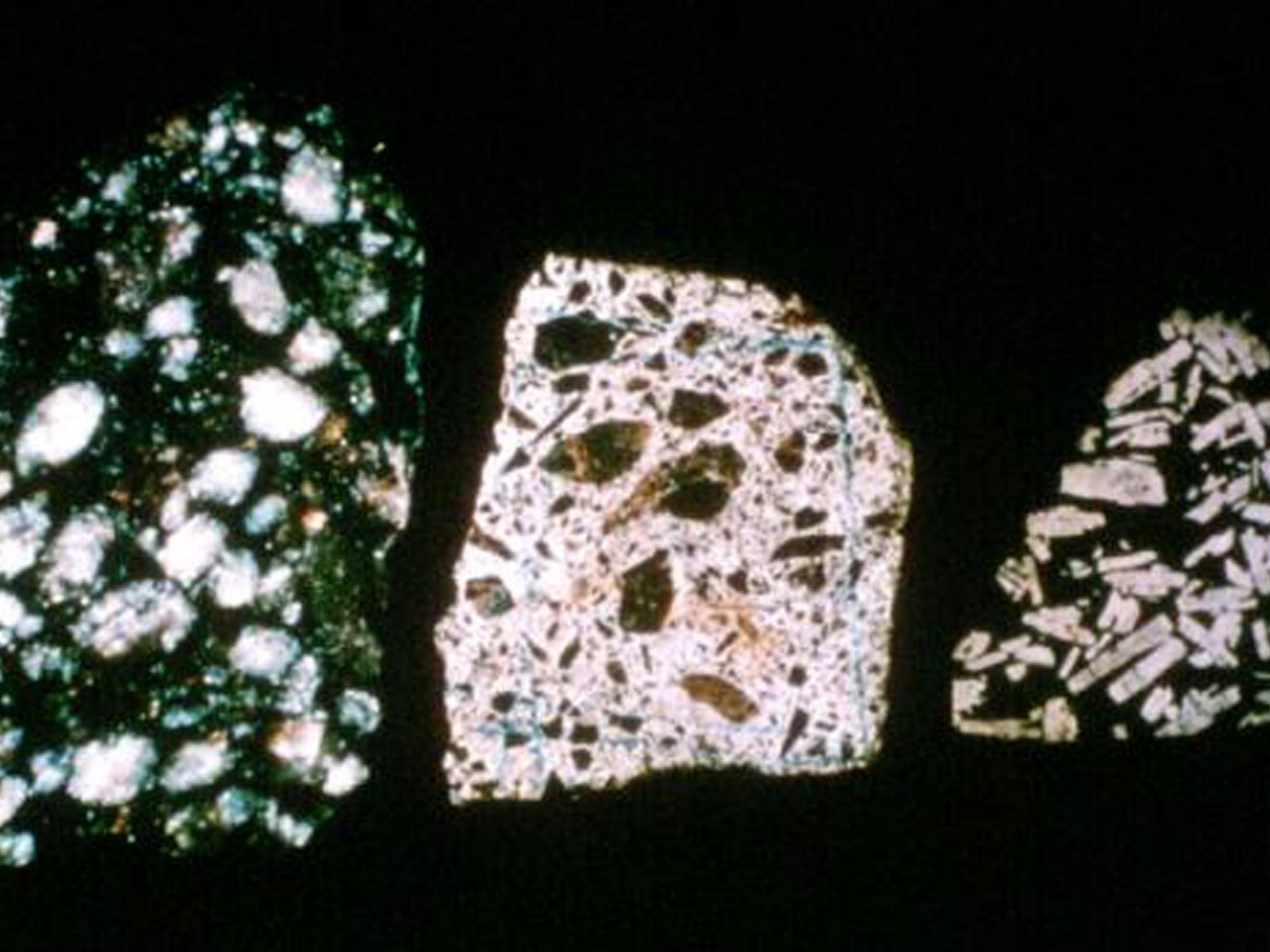


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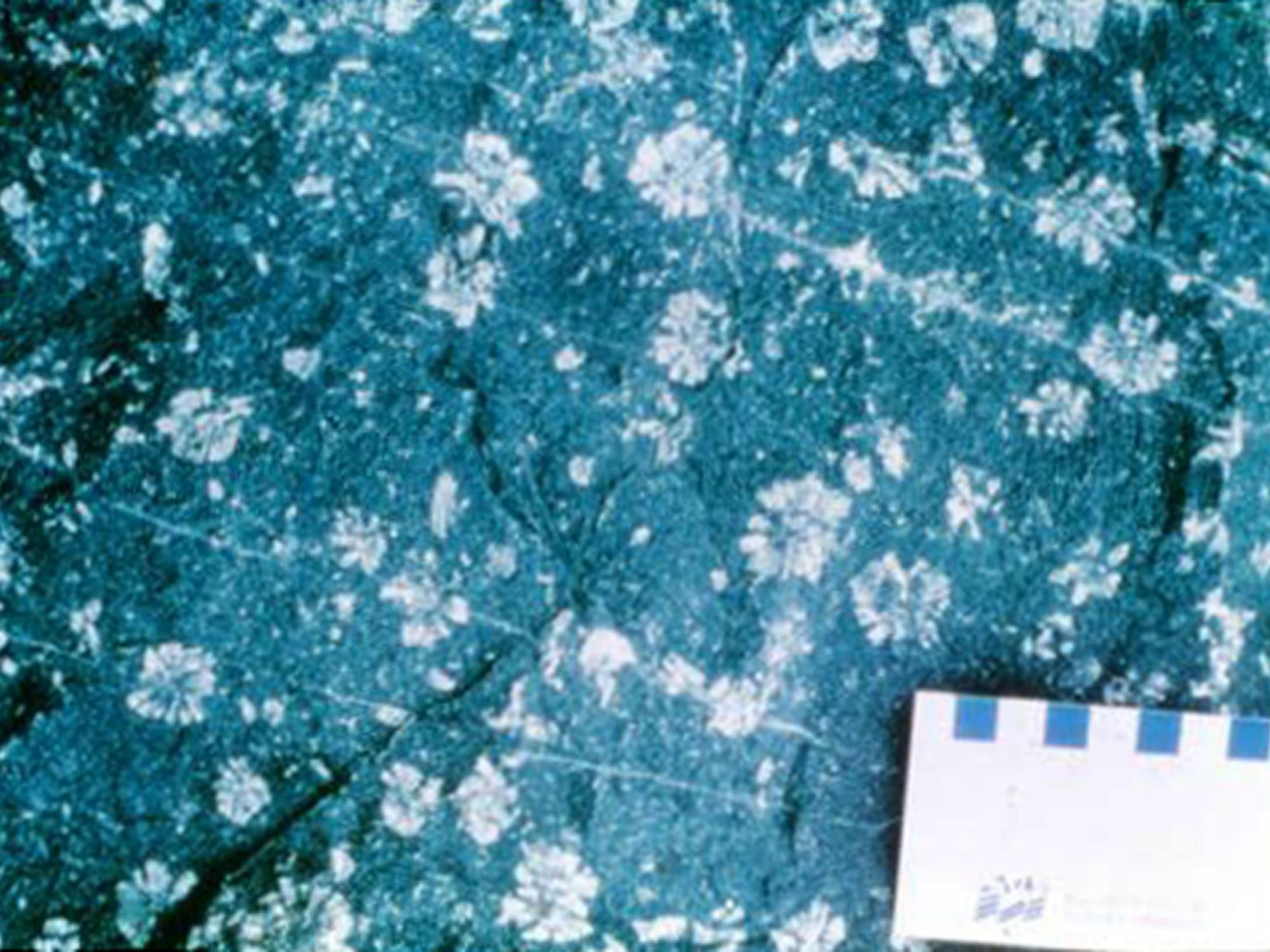
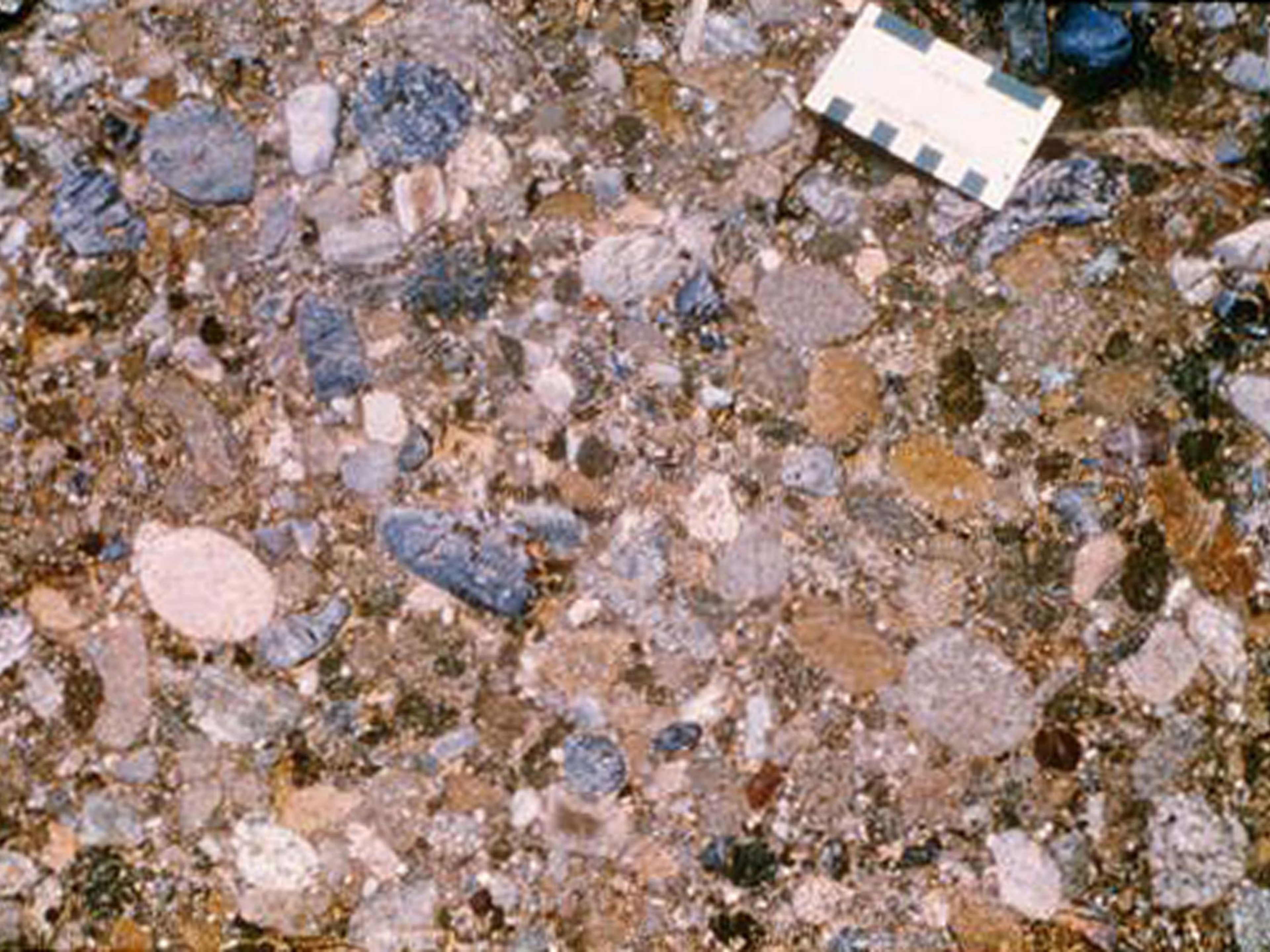
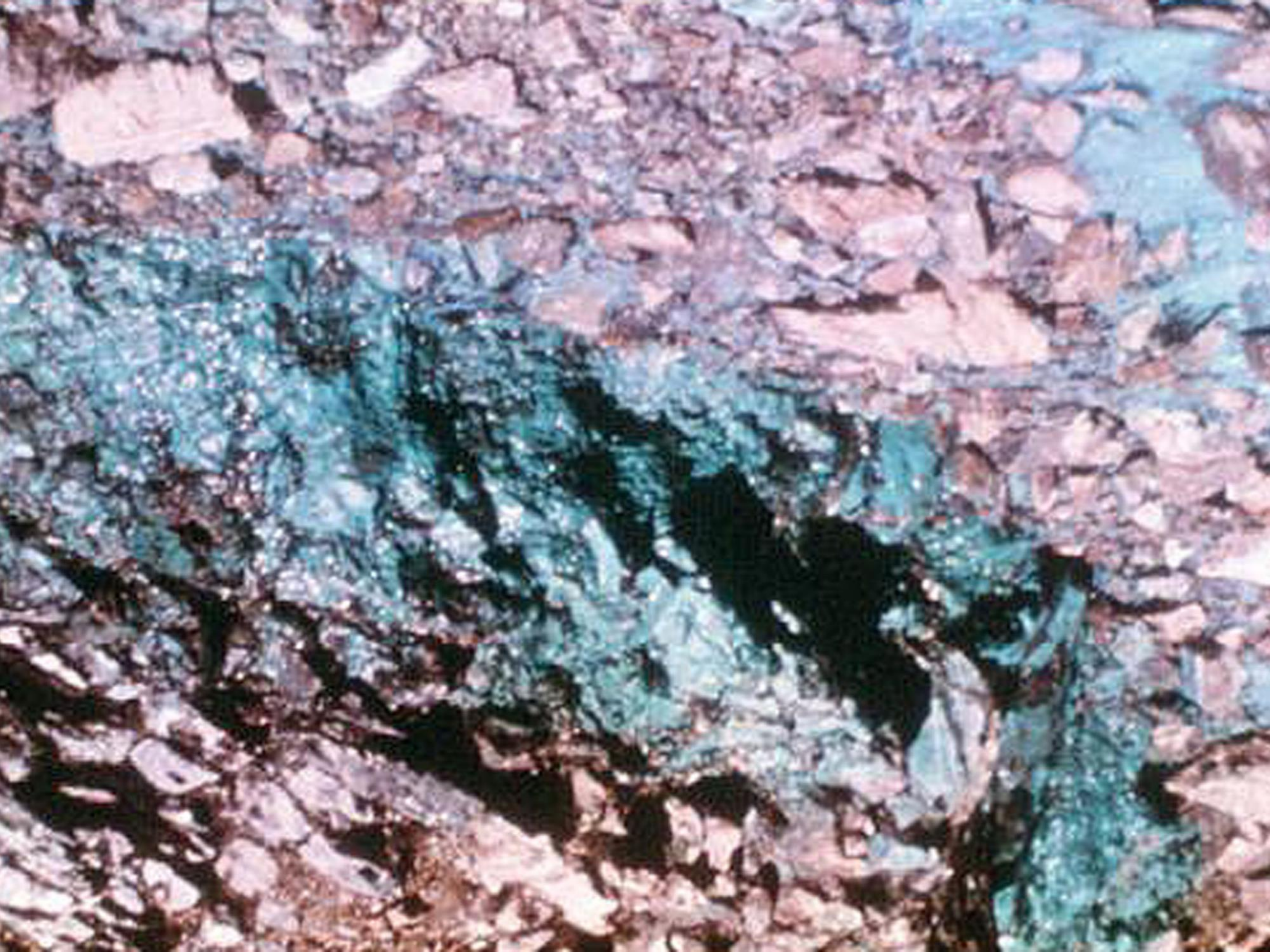
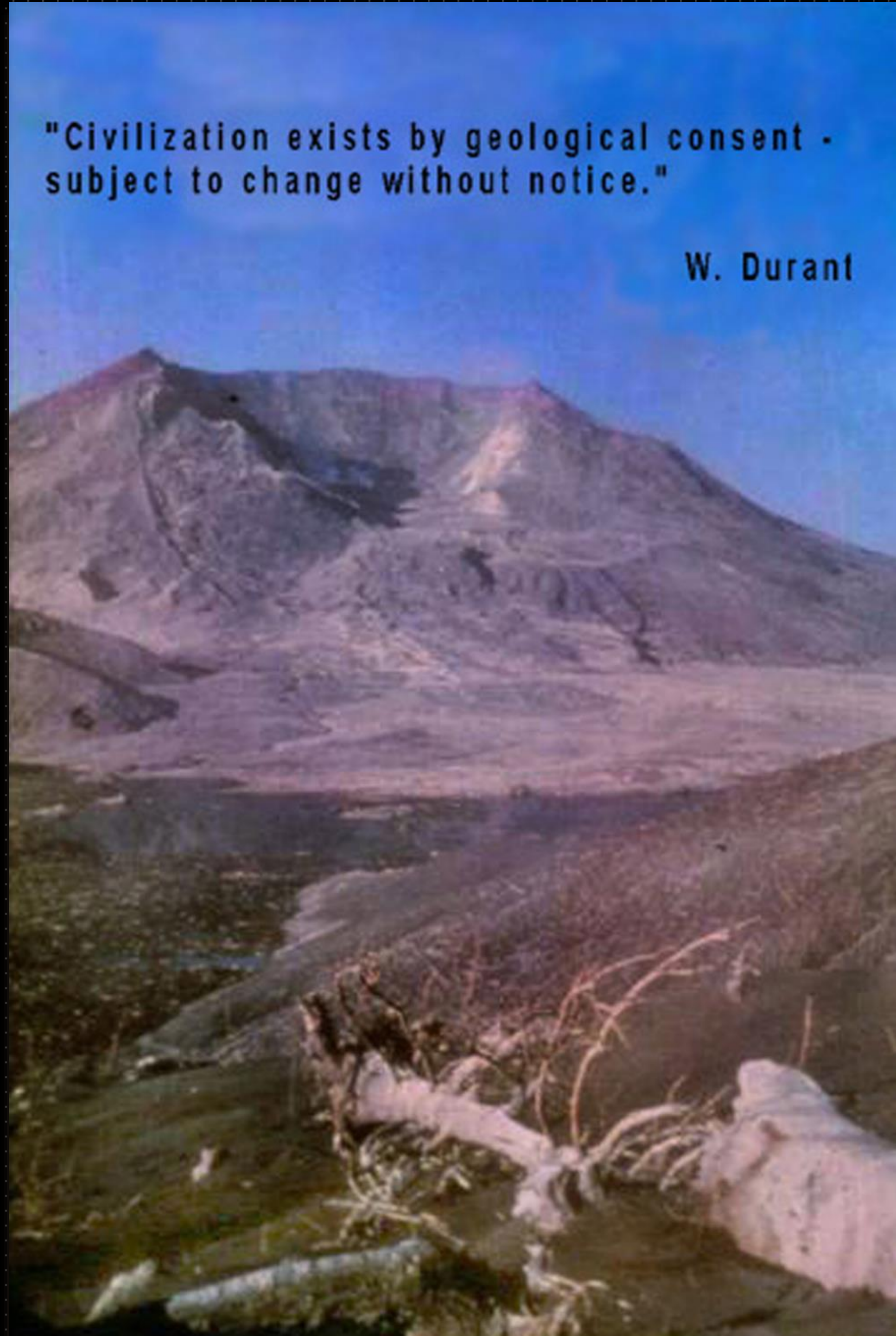





CRATON
EASTERN MARGINAL BELT
OMINECA BELT
INTERMONTANE BELT
COAST CRYSTALLINE BELT
INSULAR BELT

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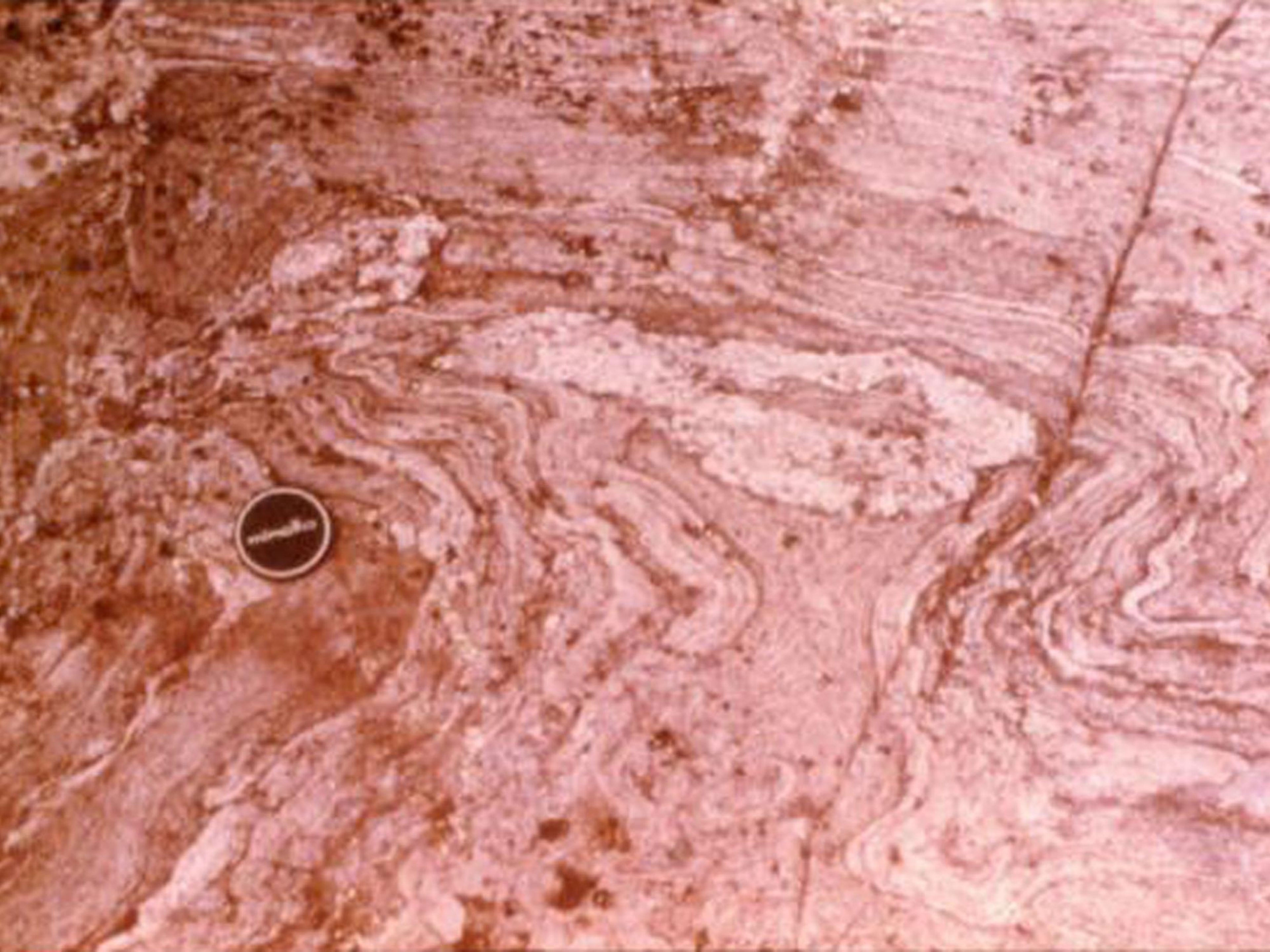


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CENTIMETRES