DOCUMENT RESUME

ED 166 006 SE 025 355

TITLE	Geology 12. Curriculum Guide.
INSTITUTION	British Columbia Dept. of Education, Victoria.
PUB DATE	77
NOTE	121p.; Photographs will not reproduce well; Pages 101-102 missing from document prior to its being shipped to EDRS for filming; Best copy available
AVAILABLE FROM	Publication Services Branch, Ministry of Education, Parliament Buildings, Victoria, British Columbia, V8V 2Z6 ($1.00)
EDRS PRICE	MF-$0.83 HC-$6.01 Plus Postage.
DESCRIPTORS	*Course Descriptions; Curriculum Development; Earth Science; Educational Resources; *Geology; *Instructional Materials; Learning Activities; Science Education; *Secondary Education; *Teaching Guides
IDENTIFIERS	*Canada

ABSTRACT

This publication, developed by the Ministry of Education, Province of British Columbia, Canada, is a teaching guide for the Geology 12 course. The course is intended to provide secondary school students with the background and desire to investigate their earth, its materials and its processes. The guide consists of the following four sections: (1) Physical geology; (2) Historical geology; (3) Earth resources; and (4) Planetology. Learning outcomes, suggested activities and investigations, a list of references, and instructional aids are also included in each section. A list of equipment and supplies, audiovisual materials, supplementary reference texts and prescribed textbooks are presented in the appendix. An introduction including the purpose of the course, terms, and definitions is also presented. (HM)

b. the mineralogy of the following non-silicates:

- — magnetite
- — pyrite
- — calcite and aragonite
- — halite
- — diamond and graphite

PROVINCE OF BRITISH COLUMBIA
MINISTRY OF EDUCATION
DIVISION OF EDUCATIONAL PROGRAMS — SCHOOLS
CURRICULUM DEVELOPMENT BRANCH

GEOLOGY 12

Victoria, B.C.
1977

ACKNOWLEDGEMENTS

The Ministry of Education gratefully acknowledges the professional advice and assistance of the following members of the Course Development Committee:

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Further acknowledgement is extended to the following for use of their photographic material.

Fred Chapman

Dr. Slaweson
Courtesy of Planetology Section
University of British Columbia

Curator
M.Y. Williams
Geological Museum
University of British Columbia

Anand Atal
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Geological Survey of Canada

NASA

Issued by the
Authority of the Minister
Ministry of Education
British Columbia
1977

Further copies available from:
Publication Services Branch
Ministry of Education
Parliament Buildings
Victoria, B.C.
V8V 2Z6

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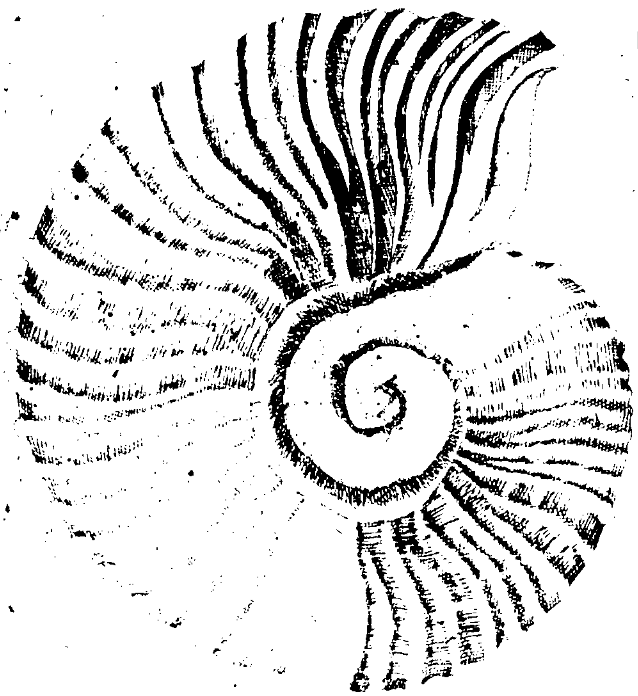

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INTRODUCTION

PART I —PURPOSE OF THE COURSE

Historians of science, notably T.S. Kuhn, have suggested that major scientific discoveries frequently occur as slow metamorphoses rather than unique events. Such a slow metamorphosis is presently responsible for an entirely new way of viewing our earth, its processes and its history.

Kuhn (1970) describes the maturation of a science as tangential groups of studies being united by a major theory which is consistent with a large body of observations. Copernican astronomy, Newtonian physics and Lavoisier's oxygen theory of combustion are some excellent examples of revolutionary theories that have emerged in response to a breakdown in the ability of previously held beliefs to explain a growing body of observations. It is the appearance of such new theories, termed paradigms by Kuhn, which allows the correlation, integration and explanation of observed puzzles and anomalous data, thus allowing science to progress to the point where a new paradigm becomes necessary.

Such a point was reached in the earth sciences in the late 1950's. Maps and oceanographic charts produced for nuclear submarines began to show that the seventy percent of the earth's surface which lay below the oceans was not the flat, uncomplicated place that it was once thought to be. Vast mountain ranges and deep trenches were among the most impressive structures of a topography quite unlike anything observed on the land surface of the earth. P.J. Coney (1970) states that perhaps the most startling discovery resulting from the explosion in oceanographic research has been the fact that the *OCEANIC RISE* is one of the major features of our planet. It is a system of adjoining rifts, which circles the globe like the seams on a baseball. Such major features of our earth demand an explanation and the emergence of the plate tectonic theory of continental drift has precipitated a major scientific revolution. Canadian geologist J. Tuzo Wilson (1971) states that:

> *... The acceptance of continental drift has transformed the earth sciences from a group of rather unimaginative studies based on pedestrian interpretations of natural phenomena into a unified science that is exciting and dynamic and that holds out the promise of great practical advances for the future ...*

Geology 12 and Earth Science 11 are intended to provide secondary school students with the background and the desire to investigate their earth, its materials and its processes.

References Cited:

1. Coney, Peter J., 1970. *The Geotectonic Cycle and the New Global Tectonics:* Geological Society of America Bulletin, Vol. 81. pp. 739-747.

2. Kuhn, T.S., 1970. *The Structure of Scientific Revolutions,* (Second Ed., enlarged), University of Chicago Press.

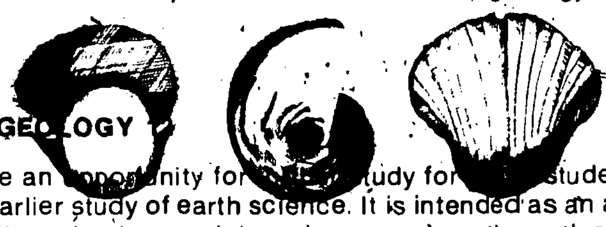
PART II — THE SCIENCE OF GEOLOGY

Geology, the science of the earth, is concerned with the systematic study of rocks and minerals, in which there is preserved the history of the planet earth. The geologic record shows that processes have long been at work on the surface of the earth and deep within it.

The sciences of geology and astronomy have made and continue to make contributions to our knowledge about the earth's origin and place in the solar system; in attempting to understand the earth's dynamic evolution, geology makes use of physics and chemistry; and in its inquiry into the origin and evolution of life, it embraces biology and contributes to the understanding of ancient geography. In short, geology (and science) must use every available tool in the difficult task of understanding the planet on which we live.

Investigations of the physical properties and internal processes are called **geophysics.** The study of the meaning and implications of the fossil record is termed **paleontology.** Aspects of geology that deal with chemical processes are referred to as **geochemistry.** But geology has powerful tools of its own, especially geologic mapping and its application to the exploration of mineral resources.

Geologic information is derived from the accurate and systematic study of rocks and minerals, soils and fossils which provide all the ingredients for observation, measurement and analysis. Further, the study of diverse forms of the land surface and the sea floors, and of the various processes that produce and change them is a vital part of the sciences of geology, physical geography and oceanography.



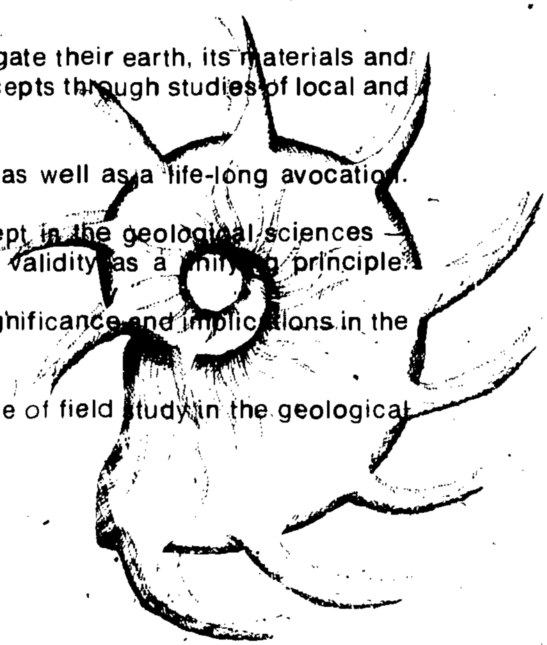
PART III — FOCUS OF GEOLOGY

Geology 12 should provide an opportunity for [illegible] study for [illegible] students whose ability and interest was stimulated by earlier study of earth science. It is intended as an academic science course requiring as a prerequisite a background in science and mathematics. Earth Science 11 is a desirable prerequisite to Geology 12.

The following guide outlines a core program. Local geology is intended as a major course theme in addition to and integrated with this core outline. It is estimated that a study of local geology will comprise approximately 25% of the course. Broader themes should stress the geology of British Columbia, Canada, and North America. Plate tectonic/continental drift theory will be utilized as a general unifying theory. As well, consideration will be given to the earth as a planetary body in relation to the geology of members of the inner solar system. It is desirable that reference be made to the Earth Science 11 curriculum guide, Section B (Geologic Science) and Section D (Resource Sciences).

PART IV — MAJOR GOALS

1. To provide students with the desire and foundation to investigate their earth, its materials and processes as well as to illustrate fundamental geological concepts through studies of local and regional geology.
2. To encourage the study of geology as an aesthetic science as well as a life-long avocation.
3. To focus the students attention on the most important concept in the geological sciences — plate tectonic and continental drift theory, and to study its validity as a unifying principle.
4. To understand the methods of measuring geologic time, its significance and implications in the reconstruction of earth history.
5. To provide a basic understanding of the methods and practice of field study in the geological sciences.



6. To discuss critically the geological evolution of Western Canada.

7. To examine the important relationship between economic, environmental and geological considerations of non-renewable mineral and fossil fuel resources.

8. To understand the hazards associated with living in a land prone to landslides, earthquakes, floods, etc.

9. To enable the student to discuss the origin of the planet Earth in terms of its place in the solar system.

PART V — TERMS AND DEFINITIONS

Textbooks:

A subject with a scope as broad as physical and historical geology cannot be adequately covered in a single textbook, so teachers have been presented with a choice of text and reference material. It is recommended that teachers select texts from the lists provided in such a manner as to best supplement each of the major areas of study. (See list of Textbooks in the Appendix of this Guide.)

Equipment and Supplies:

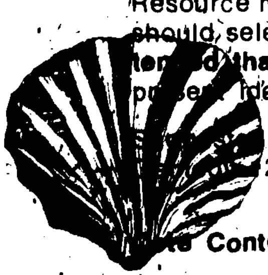
A comprehensive list of equipment and supplies has been provided in order to allow for variations from school to school. The list contains all the materials necessary for completion of the investigations in each phase of the course; however many supply items such as beakers or certain chemicals may already be present in a school in sufficient quantity.

Other Aids:

There are many excellent films, film strips, slide sets and transparencies available and as many as possible have been listed. Because of the specialized nature of this course, teachers are encouraged to develop their own sets of slides of local geological features.

Resource Material:

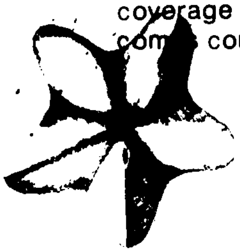
Resource material is included in this Guide for each section of the course. Teachers and students should select the Activities and Investigations considered most suitable for the class. **It is not intended that all Activities and Investigations be tried.** The resource material is provided to help present ideas which may be useful to teachers and students.



Activities and Investigations are indicated following most learning outcomes in the Geology 12 course.

Core Content:

It is intended that approximately 70 to 75% of the time for Geology 12 be devoted to adequate coverage of the core topics. (See suggested time allotments per section below.) All learning outcomes considered essential to the understanding of Geology 12 are indicated with an asterisk (★).



Scholarship Exam:

It will be possible for students to write a scholarship examination in Geology 12. All scholarship candidates should have studied the complete program as outlined, with particular emphasis on the core material.

Suggested Time Allotments:

	Core	Total
Section A	40%	50%
Section B	20%	40%
Section C	5%	5%
Section D	5%	5%
	70%	100%

TOPICAL OUTLINE

Page

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PHYSICAL GEOLOGY

LEARNING OUTCOMES AND SUGGESTED ACTIVITIES

Earth Materials
Earth Processes — Surface
Earth Processes — Subsurface
Structural Geology

Teacher Resource Material is indicated by number in the parentheses following most Learning Outcomes. Details regarding references, activities and investigations follow the respective sections of the Geology 12 course. (These are suggested activities only and may be used at the discretion of the teacher.)

PHYSICAL GEOLOGY

EARTH MATERIALS

The study of earth materials includes consideration of important rocks and minerals. As such, it forms as integral part of the study of local geology and related industries. This study provides a brief introduction to such disciplines within the geological sciences as MINERALOGY, PETROLOGY, and CRYSTAL CHEMISTRY.

LEARNING OUTCOMES

Part I — Introduction to Rocks and Minerals

The student should be able to:

★ 1. *Recognize the importance and abundance of various elements in the earth's crust.*

(Reference #1, 2)

★ 2. *Differentiate between rocks and minerals.*

(Activity #1, 2)

★ 3. *Describe the formation of igneous, sedimentary and metamorphic rocks; classify rocks as igneous, sedimentary or metamorphic.*

(Activity #1, 2)

★ 4. *Interpret a rock cycle diagram.*

(Activity #1)

★ 5. *Study crystal growth and:*

a. distinguish a single crystal from an aggregate.

b. recognize the law of constancy of interfacial angles.

c. explain the factors governing crystal growth and relate these factors to textures of igneous rocks.

(Activity #2)

References

1. AGI, *Geology and Earth Sciences Sourcebook,* 1970, pp. 1-4

2. Gilluly, et al., *Principles of Geology,* 1975, Chapter 3. (Materials of the Earth — minerals and matter.)

3. James, J. Robert, *Geology and the New Global Tectonics,* 1976. p. 18.

4. *Investigating the Earth,* 1973, Chapter 2 — Rocks and Minerals/Atoms and Molecules/The abundance of the Elements.

Activities and Investigations

1. Collect a variety of **local,** igneous, sedimentary and metamorphic rocks (with substitutions as necessary) and utilize as an introduction to the classification and relationships, of rocks and minerals.

2. Hamblin and Howard, **Exercise in Physical Geology,** Exercise #1, Introduction to Minerals: Crystal Growth.

3. **Investigating the Earth,** investigating rocks and minerals, p. 30.

Part II — Minerals

The student should be able to:

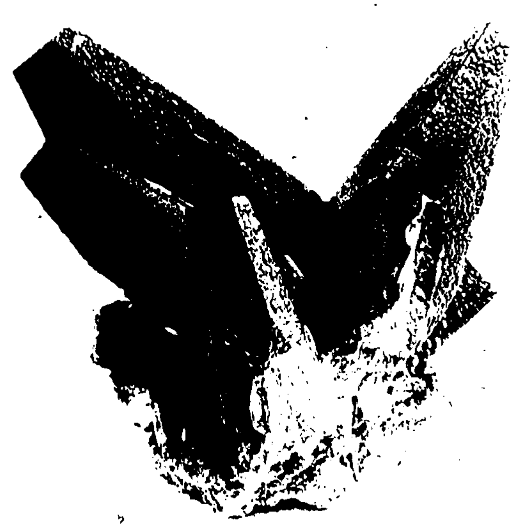
★ 1. *Utilize the following properties in identification of minerals:*

   a. crystal form (crystal faces)
   b. cleavage and fracture
   c. hardness
   d. specific gravity (heft)
   e. color
   f. streak
   g. luster
   h. special properties:
      — diaphaneity
      — reaction to dilute hydrochloric acid
      — double refraction
      — magnetism
      — taste

   (Activity #1, 2)

2. *Relate chemical bonding and crystal structure, in particular:*

   a. the mineralogy of the silicates and the aluminosilicates:
      — the silicate tetrahedron
      — paired tetrahedra
      — rings
      — single chains of tetrahedra
      — double chains of tetrahedra
      — layer lattice
      — framework silicates and aluminosilicates



b. the mineralogy of the following non-silicates:

- — magnetite
- — pyrite
- — calcite and aragonite
- — halite
- — diamond and graphite

(Reference #1, 2, 6)

★ 3. *With references, identify the following minerals:*

a. the following rock forming minerals and ore minerals in the **Prospector's Set of Mineral Chips** (Geological Survey of Canada):

- — arsenoypyrite
- — molybdenite
- — graphite
- — stibnite
- — galena
- — chalcopyrite
- — pyrrhotite
- — pyrite
- — hematite
- — ilmenite
- — magnetite
- — gypsum
- — mica, muscovite
- — calcite
- — feldspar, albite (Plagioclase Feldspars)
- — quartz, massive
- — quartz crystal
- — limonite
- — feldspar, microcline (Potassium Feldspars)
- — garnet
- — asbestos
- — fluorite
- — apatite
- — pyroxene (Pyroxene Group)
- — mica, biotite
- — hornblende (Amphibole Group)
- — tourmaline
- — barite

b. others:

- — malachite
- — bornite
- — cinnabar
- — chlorite
- — varieties of quartz and cryptocrystalline quartz
- — azurite
- — halite
- — olivine
- — selenite gypsum

(Activity #1, 2; Reference #4)

4. *Integrate the study of minerals with local geology and industry.*

References

1. AGI, *Geology and Earth Science Sourcebook,* 1970, pp. 5-27.
2. Janes, *Geology and the New Global Tectonics,* 1976, Chapter 4, Igneous Intrusion and its Products, pp. 99-113.
3. Gilluly, et al., *Principles of Geology,* 1975, Appendix II, Identification of Minerals.
4. Geological Survey of Canada, *New Materials of Canada's Mineral Industry.*
5. *Investigating the Earth,* 1973, pp. 31-42.
6. Long, L.E., *Geology,* 1974, Chapter 3, Plane Faces, pp. 51-75.

Activities and Investigations

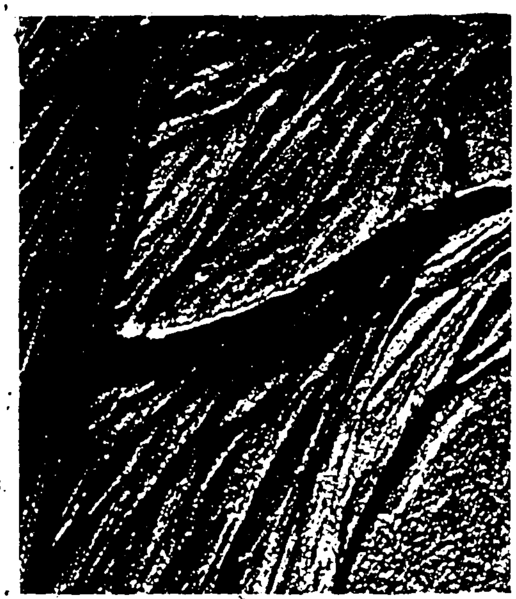
1. Hamblin and Howard, **Exercises in Physical Geology:** Exercise #2, Physical Properties and Mineral Identification.
2. AGI, **Geology and Earth Science Source Book,** pp. 18-27.

Part III — Igneous Rocks

The student should be able to:

★ 1. *Identify and classify igneous rocks according to their texture and composition.*

(Activity #1, 2)



★ 2. *Classify the texture of an igneous rock as one of:*

a. phaneritic
b. porphyritic — phaneritic
c. aphanitic
d. porphyritic — aphanitic
e. glassy
f. fragmental

★ 3. *Relate rate of crystallization to texture.*
i.e. extrusive (volcanic) and intrusive (plutonic) igneous rocks.

★ 4. *Classify an igneous rock as silicic, intermediate or mafic.*

★ 5. *Estimate the amount of quartz in an igneous rock.*

★ 6. *Use a table of classification of igneous rocks to determine a rock name.*

★ 7. *Interpret a table showing order of crystallization of the common rock forming minerals.*

★ 8. *Identify the following igneous rocks:*

a. Geological Survey of Canada: Prospector's Set of Rock Chips:

- — granite
- — diorite
- — peridotite
- — andesite
- — basalt, (amygdaloidal)
- — tuff
- — syenite
- — gabbro
- — rhyolite
- — basalt
- — breccia
- — porphyry, feldspar

b. others:

— obsidian, pumice, porphyritic igneous rocks in general.

(Reference #4)

References

1. AGI, *Geology and Earth Science Sourcebook,* 1970, pp. 28-57.

2. Janes, *Geology and the New Global Tectonics,* 1976, Chapter 3, (Volcanoes and Their Products) pp. 73-79, Chapter 4, (Igneous Intrusion and its Products) pp. 94-97 and 113-125.

3. Gilluly et al., *Principles of Geology,* 1975, Appendix III, Identification of Rocks, pp. 470-473.

4. Geological Survey of Canada, *Raw Materials of Canada's Mineral Industry.*

5. Long, L.E. *Geology,* 1974, Chapter 4 (Born of Fire) pp. 76-99.

6. *Investigating the Earth,* 1973, Chapter 12 (Rocks Within Mountains) pp. 260-264 and 271-275.

Activities and Investigations

1. Hamblin and Howard, **Exercises in Physical Geology,** Exercise #3, Igneous Rocks.
2. AGI, **Geology and Earth Science Sourcebook,** 1970, pp. 28-34, 51.

Part IV — Sedimentary Rocks

The student should be able to:

★ 1. *Briefly describe the origin and the processes of formation of sedimentary rocks.*

(Activity #1, 2)

★ 2. *Classify the texture of sedimentary rock as clastic or chemical (precipitate or biochemical).*

★ 3. *Recognize such sedimentary structure as:*

a. stratification or layering
- — horizontal layering
- — cross-bedding

b. ripple marks

c. mud cracks

d. rain imprints

★ 4. *Identify the following sedimentary rocks:*

a. from the Geological Survey of Canada — Prospector's Set of Rock Chips:

— conglomerate
— sandstone
— greywacke
— shale
— limestone
— dolomite

b. also:

— breccia
— arkose
— siltstone
— travertine
— fossiliferous limestone
— chert
— coal

(Reference #4)

References

1. AGI, *Geology and Earth Sciences Sourcebook,* 1970, pp. 28-57.
2. Janes, *Geology and the New Global Tectonics,* 1971, Chapter 5, (Sediments and the Sedimentary Rocks) pp. 127-160.
3. Gilluly, et al., *Principles of Geology,* 1975, Appendix III, pp. 465-470.
4. Geological Survey of Canada, *Raw Materials of Canada's Mineral Industry.*
5. Long, L.E., *Geology,* 1974, Chapter 5, (Recycled Rocks) pp. 101-117.

Activities and Investigations

1. Hamblin and Howard, **Exercises in Physical Geology,** Exercise #4 Sedimentary Rocks.
2. AGI, **Geology and Earth Science Sourcebook,** 1970, pp. 33-35, 52.

Part V — Metamorphic Rocks

The student should be able to:

★ 1. *Discuss the formation of metamorphic rocks — with reference to the types of metamorphism:*

a. contact metamorphism
b. regional metamorphism

(Activity #1, 2)

★ 2. *Classify metamorphic rocks as foliated or non-foliated.*

★ 3. *Identify metamorphic rocks on the basis of presence or lack of foliation and texture.*

★ 4. *Identify the following metamorphic rocks:*

a. from the Geological Survey of Canada — Prospector's Set of Rock Chips:

— quartzite
— slate
— schist
— gneiss

b. also:
- phyllite
- metaconglomerate
- marble

(Reference #4)

References

1. AGI, *Geology and Earth Science Sourcebook,* 1970, pp. 28-53.

2. Janes, *Geology and the New Global Tectonics,* 1976, Chapter 6, (Metamorphism and the Metamorphic Rocks), pp. 166-189.

3. Gilluly, et al., *Principles of Geology,* 1975, Appendix III, pp. 473-475.

4. Geological Survey of Canada, *Raw Materials of Canada's Mineral Industry.*

5. Long, L.E., *Geology,* 1974, Chapter 5, (Recycled Rocks) pp. 118-129.

6. *Investigating the Earth,* 1973, Chapter 12, (Rocks Within Mountains) pp. 265-270.

Activities and Investigations

1. Hamblin and Howard, **Exercises in Physical Geology,** Exercise #5, Metamorphic Rocks.
2. AGI, **Geology and Earth Science Sourcebook,** 1970, pp. 38-39, 53.

★ ★ NOTE: It is very important that a study of local samples be integrated into this section of Geology 12.

EARTH PROCESSES— SURFACE

Surface earth processes break down and redistribute earth materials in a variety of ways. A study of these processes enables a better understanding of how sedimentary rock formations occur. An analysis of these formations enables the reconstruction of the geologic past in a given area.

LEARNING OUTCOMES

Part I — Erosion by Running Water

The student should be able to:

★ 1. *Reconstruct and observe a model of running water processes, by means of a stream table.*

(Activity #1, 3)

★ 2. *Recognize sediments from stream loads as they are sorted by water, taking note of their locational deposition at various stages of delta formation.*

(Activity #1. 3, 4, 5; Reference #3)

★ 3. *Identify and relate the source material sediments with the type of sedimentary rocks produced through the water sorting process.*

(Activity #1, 2; Reference #1)

4. *Devise a method to measure the stream load carried by a local creek or freshet by way of:*

   a. **sediment**

   b. **solution**

   c. **corrosion materials (bed-load)**

(Reference #1, 3)

5. *Measure and graph longitudinal stream profiles for a number of our major rivers. Compare gradients as they affect landscape as deduced from topographical maps.*

(Activity #5; Reference #1, 2, 3)

References

1. Gilluly, James, et al., *Principles of Geology,* 1975, Chapter 12, The Hydrologic Cycle and the Work of Streams, pp. 247-263.

2. Long, Leon E., *Geology,* 1974, Rivers, The Pleistocene braided Mississippi, The modern meandering Mississippi, pp. 382-394.

3. Janes, J. Robert, *Geology and the New Global Tectonics,* 1976, Chapter 9, Erosion: Change at the Surface of the Land, pp. 246-264

Activities and Investigations

1. American Geological Institute, **Investigating the Earth,** 1973, pp. 200-201, a simplified version of a stream table involving stream volume, slope, and gravel sorting processes by means of a trough is presented.

2. American Geological Institute **Investigating the Earth,** 1973, pp. 308-309, investigating areas of erosion and deposition with emphasis on miniature landscape reproduction.

3. American Geological Institute,**Geology and Earth Sciences Sourcebook,** 1970, pp. 172-175, gives detailed instruction in how to construct a stream table and utilize the same in a variety of ways to demonstrate: delta bedding, stream meandering, undercutting, cutbanks, slip-off slopes, effect of resistant rock masses, lake filling and cutting, relationship of rate of flow to stream formation.

4. American-Geological-Institute, **Investigating the Earth,** Teacher's Guide, 1973, pp. 158-165. Topics include: the parts of a landscape, investigating areas of erosion and deposition, rates of change, landscapes and climate, how low can a landscape get, investigating regional landscapes.

5. Hamblin, Kenneth W., Howard James D., **Exercises in Physical Geology,** 1975, Exercise 9, pp. 72-79, Stream Erosion.

Part II — Ice Ages and Glaciers

The student should be able to:

★ 1. *Propose hypotheses listing assumptions regarding the origin of ice ages.*

(Reference #1, 2, 3)

★ 2. *Demonstrate methods of determining relative and absolute ages of glacial deposits.*

(Activity #1; Reference #1, 2, 3)

★ 3. *Reconstruct past glacial positions on a map of North America.*

(Activity #1, 4; Reference #1, 3)

★ 4. *Relate the effect of glacial load on the earth's crust to isostatic response.*

(Reference #1, 3)

★ 5. *Cite and demonstrate ways in which alpine and continental glaciers have sculptured the land.*

(Activity #1, 2, 3)

References

1. Gilluly, et al., *Principles of Geology*, 1975, Chapter 13, Glaciers and Glaciation, pp. 279-308.
2. Long, Leon. E., *Geology*, 1974. Glacial erosion and deposition, Ice and isotopes, Causes of the ice ages, pp. 432-457.
3. Janes, J. Robert, *Geology and the New Global Tectonics*, 1976, Chapter 10, The evidence of glaciation, Examining the Pleistocene record. Some special aspects of the Upper Wisconsin record, Plate tectonics and the causes of an ice age, pp. 289-324.

Activities and Investigations

1. American Geological Institute. **Investigating the Earth,** 1973, pp. 410-411.

   An ice-age puzzle is offered in which research data is plotted onto a map. From the information given students can determine time lapse and glacial features produced.

2. Hamblin and Howard, 1975, **Exercises in Physical Geology,** pp. 84-87.

   This exercise presents a topographic map from which students are required to identify continental features of glacial origin, to determine the direction of glacial movement in the area, and are asked to evaluate the drainage pattern created in a typical continentally glaciated area.

3. Hamblin, W. Kenneth, and Howard, James P., **Exercises in Physical Geology,** 1975, pp. 88-98.

   This exercise has as its objective the recognition of the types of landforms developed by alpine glaciers and the understanding of the processes responsible for their development.

4. Using reference texts, Gilluly, James, et al., **Principles of Geology,** 1975, pp. 298-300 and Janes, J. Robert, **Geology and the New Global Tectonics,** 1976 Edition, p. 316 as well as the **Geologic map of Wisconsin and Recent Ice in North America,** Geological Survey of Canada, Ottawa, past glacial positions of North American ice can be determined and placed on outline maps together with prominent glaciated features produced by the ice.

Part III — Eolian Process

The student should be able to:

1. *Identify the interrelationships between climate, soils and landslopes as they affect topographic features of eolian origin.*

   (Reference #1)

★ 2 *Identify and describe the erosional processes and features produced by sand blasting.*

   (Reference #1, 2)

3 *Deduce the relationships between grain size, amount of sand, speed of wind, and vegetation to the degree and size of desert slopes.*

   (Activity #3; Reference #1, 2)

★ 4 *Describe surface forms of moving sands investigating how these desert landforms develop.*

   (Activity #3, Reference #1, 2)

5 *Recognize the significance of sporadic rainfall in desert areas in the shaping of the landscape.*

   (Activity #2, Reference #1)

★ 6 *Differentiate between river sand and wind blown sand. (Take note of microscopic grain appearance and variation in grain size. Contrast the bedding planes of the two.)*

   (Activity #1, Reference #1, 2)

7 *Describe the physical characteristics, the origin and world distribution of loess deposits.*

   (Reference #1, 2)

References

1. Gilluly, James, et al., *Principles of Geology,* 1975, pp. 326-345.

2. Janes, J. Robert, *Geology and the New Global Tectonics,* 1976, pp. 264-269.

Activities and Investigations

1. Find local cross-bedding planes in local sandbanks to determine whether they are of eolian or fluvial origin. See illustrations in Gilluly, et al., **Principles of Geology,** 1975, p. 344 compared with p. 375.

   Determine also regularity of grain size, angular edges and opaque characteristic of sand blasting by means of a microscope.

2. Hamblin, W. Kenneth, Howard, James D., **Exercises in Physical Geology,** 1975, Chapter 10, Erosion in Arid Regions, pp. 80-83.

3. American Geological Institute, **Geology and Earth Sciences Sourcebook,** 1970, pp. 161-165.

   Streams of sand poured in front of a fan, when allowed to settle around obstructions, are used to simulate sand dunes formation.

Part IV — Ground Water

The student should be able to:

1. *Manipulate apparatus to investigate porosity, permeability and hydraulic conductivity.*

   (Activity #1, 2)

★ 2. *Describe the relationship of the water-table to marshes, lakes and streams.*

   (Reference #1, 2)

★ 3. *Discriminate between perched, confined and typical ground water tables.*

   (Reference #1, 2, 3, 4)

4. *Describe the hydraulic gradient and the movement of water according to Darcy's Law.*

   (Reference #1, 2)

5. *Discriminate between the effects of natural and artificial discharge of ground water.*

   (Reference #1)

6. *Describe ground water formations of solution and precipitation*

(Reference #1, 3)

7. *Map the major productive aquifers in Canada and U.S.A.*

(Activity #3; Reference #1, 2, 4)

References

1. Gilluly, James, et al., *Principles of Geology*, 1975, pp. 310-320.
2. Long, Leon E., *Geology*, 1974, Groundwater, pp. 463-475.
3. Janes, J. Robert, *Geology and the New Global Tectonics*, 1976, Groundwater: The movement and work of underground waters, pp. 230-239.
4. American Geological Institute, *Geology and Earth Sciences Sourcebook*, 1970, pp. 144-150.

Activities and Investigations

1. American Geological Institute, **Geology and Earth Sciences Sourcebook,** 1970, pp. 144-145, methods of measuring porosity, permeability and capillary action are shown.
2. American Geological Institute, **Investigating the Earth,** 1973, pp. 172-174.

   Investigating the movement of water in earth. Apparatus required illustrated.
3. Using references 1 and 4 together with hydrological maps for the local area from municipal sources, map some of the major areas in North America rich in ground water.

Part V — Physical Erosion, Chemical and Biotic Weathering

The student should be able to:

★ 1. *Discuss the hazards and effect of the downslope movement of soils and rock materials.*

(Reference #1, 2)

2. *Gather data and determine how individual minerals react chemically to hydration, hydrolysis, oxidation and carbonation*

(Activity #1, Reference #1, 2)

3. *Suggest ways in which physical and chemical weathering take place through biotic influences.*

(Activity #1, Reference #2)

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References

1. Gilluly, James, et al., *Principles of Geology,* 1975, pp. 215-245.

2. Janes, J. Robert, *Geology and the New Global Tectonics,* 1976, pp. 220-251.

Activities and Investigations

1. American Geological Institute, **Geology and Earth Science Sourcebook,** 1970, pp. 160-162.

   Exercises which demonstrate the effect of freezing water, of oxidation in steel wool, of hydration using plaster-of-paris, of carbon dioxide solution as an acid, and of plant roots producing acid are presented.

SUBSURFACE EARTH PROCESSES

Subsurface earth processes are not known from direct observations. The physical and chemical properties of magma are based on observations of volcanic products and synthetic magmas and on studies of geophysical properties of the earth.

LEARNING OUTCOMES

Part I — Volcanism

The students should be able to:

★ 1. **Volcanic Rocks**

Classify at sight, using a hand lens, volcanic rocks according to a classification chart for igneous rocks.

(Activity #1; Films #3 and 5; Videotape #1; Filmstrip #3)

★ 2. **Types of Volcanoes**

Distinguish between the following volcanic features:

a. shield volcanoes
b. cinder cones
c. composite volcanoes
d. lava plateaus
e. plug dome

(Investigation #2, Sheets 4, 5, 6, 7, and 12; Films #1, 2, 3 and 4; Videotapes #1 and 2; Filmstrips #1, 2 and 3; Field trip #1)

3. **Geothermal Eruptions**

Describe eruptions, including geysers, hot springs and phreatic explosions, according to:

a. activity (active, extinct, dormant)
b. continuity of eruption
c. type of eruption (central, areal, fissure, phreatic)
d. type of product (proportions of gas, liquid, solid)
e. violence of eruption

(Investigation #2, Sheets 10, 11, 16; Films #1, 2, 3, and 4; Videotapes #1, 2 and 3)

★ 4. **Types of Lava**

Distinguish between, and name, the various types of lava by their composition and behaviour while flowing; and identify, the rock formed when the lava cools.

a. flood flows

b. ash flows or nuee ardente

c. pillow lava

(Investigation #2, Sheets 1, 10, and 11; Films #2 and 3; Videotapes #2 and 3)

★ 5. **Weathering and Erosion of Lava Flows and Volcanic Cones**

a. recognize and describe results of the weathering of volcanic structures (e.g. plug domes, exposed dykes and sills, deposits of volcanic soil, guyots, lava plateaus and mesas.)

b. distinguish between the effects of various times, methods and amounts of weathering on each of these five: composite cones, cinder cones, shield volcanoes, lava plateaus and plug domes.

(Investigation #2, Sheets 9, 11, and 13; Activity #3)

6. **Hazards**

Given the characteristics of a volcanic area (frequency and length of time of eruption, nature of lava and other products, source of lava and other products, violence of eruption, prevailing winds, slopes), describe the nature and extent of the hazards to humans, structures and communities.

(Investigation #2, Sheet 20)

References

1. AGI, *Geology and Earth Sciences Sourcebook,* Chapter 2, Volcanoes.
2. Janes, *Geology and the New Global Tectonics,* Chapter 3, Volcanoes and Their Products.
3. *Atlas of Volcanic Phenomena.*
4. Gilluly, et al., *Principles of Geology.*

Activities and Investigations

1. Hamblin and Howard, **Exercises in Physical Geology,** Exercise #3, Textures, Aphanitic and Glassy; Families; Gabbro-Basalt and Peridotite.
2. **Atlas of Volcanic Phenomena,** Sheets 1, 4, 5, 6, 7, 8, 10, 11, 12, 15, 16 and 20.
3. Hamblin and Howard, **Exercises in Physical Geology,** Exercise 14, Volcanic land forms.

Films

1. Heartbeat of a volcano, EBF.
2. Volcanic Landscapes Part 1. MOY.
3. Volcanic Landscapes Part 2. MOY.
4. Volcanoes: Exploring the Restless Earth, EBF.
5. Rocks That Originate Underground, EBF.

Videotapes

1. The Fire Within, TV Ontario.
2. Volcanic Landscapes Part 1. MOY.
3. Volcanic Landscapes Part 2. MOY.

Filmstrips

1. Volcanoes, Parts 2 and 3. MEM.
2. Volcanicity, MEM.
3. Volcanic Rocks, EBF.

Field Trips

1. Bowers, **Garibaldi Geology,** Geological Survey of Canada.
2. **Vancouver Geology,** Geological Survey of Canada.
3. **Field Trips to Southwestern B.C.** Department of Geological Sciences, U.B.C.

Part II — Intrusive Formations

The student should be able to:

★ 1. **Plutonic Rocks**

a. classify at sight, using a hand lens, plutonic (igneous) rocks according to a classification chart of igneous rocks.

(Activity #1; Film #1; Filmstrips #1 and 2)

★ 2. **Bodies of Plutonic Rock**

a. describe the locations of local large bodies of granite rock (batholiths).
b. describe the locations of local sills and dykes.
c. compare and contrast the size and frequency of crystals in samples of igneous rock of various compositions. Deduce the origins of the rock from the evidence collected.

(Investigation #2, Sheet 2)

★ 3. **Magma**

Suggest, from looking at rocks, a hypothetical composition for the original magma:

a. a solution of molten rock.

b. A solution of molten rock containing fragments of unmelted rock, dissolved gases and crystals, in amounts determined by the temperature and pressure.

(Investigation #2; Sheet 2)

★ 4. **The Formation of Igneous Rock**

a. describe and explain the order of crystallization (the Bowen reaction series).

b. describe and demonstrate factors affecting cooling rate and crystal size.

c. describe the following processes, which occur as magma cools and the pressure on it diminishes:

— gases and vapours escape
— crystals of low density float
— crystals of high density settle
— one substance diffuses through another at the interface
— the rock in the wall of the magma chamber is assimilated into the magma.

d. with reference to the Bowen Reaction series suggest how and where in the batholith a given igneous rock was formed.

(Investigation #2, sheet2; Investigation #3, Unit 1, Earth Materials, Volcanism)

5. **Oceans and Atmospheres**

a. suggest a method by which oceans and atmospheres have reached their present composition.

b. describe the interaction of the oceans and the crust of the earth.

(Investigation #3)

References

1. AGI, *Geology and Earth Sciences Sourcebook,* Chapter 4. Mountain Building and Rock Deformations. Chapter 5. The Atmosphere.

2. Janes, *Geology and The New Global Tectonics.* Chapter 4. Igneous Intrusion and its Products.

3. Gilluly, et al., *Principles of Geology,* Chapter 9. Constructive Part of the Geologic Cycle-Igneous Activity and Metamorphism.

Activities and Investigations

1. Hamblin and Howard. **Exercises in Physical Geology,** Exercise #3.

2. **Atlas of Volcanic Phenomena,** Sheets 1 and 2.

3. AGI, **Geology and the Earth Sciences Sourcebook,** Chapter 5, The Atmosphere.

Films

1. Rocks that Originate underground. EBF.
2. Why Do We Still Have Mountains? EBF.

Filmstrips

1. Plutonic Rocks.
2. Rock Families.

STRUCTURAL GEOLOGY

Structural geology includes the study of the major geologic processes responsible for the evolution of not only the layers of the earth but also the development of the broad patterns and grain of the crust of the planet. As such it includes the study of plate tectonics, sea floor spreading, and mountain building.

LEARNING OUTCOMES

Part I — The Structure and Mechanics of the Earth

The student should be able to:

★ 1. *State the layers of the earth and be able to make a rough sketch of the interior of the earth, labelling all principle parts and showing approximate thickness of each layer in kilometres.*

(Activity #6, 7, 8, 9, 46)

★ 2. *Give evidence for the fact that the solid earth is layered.*

(Activity #6, 7, 8, 9, 46; See also Part III, Activity #1, 3)

★ 3. *Summarize the history of continental drift, stating names of people who proposed the theory and giving the names of the original continents they proposed.*

(Activity #26, 27, 28, 29, 30)

★ 4. *State what is meant by sea-floor spreading and list the evidence to support it.*

(Activity #4, 5, 10, 13, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 39, 41, 42, 43, 44, 45)

★ 5. *Discuss the mechanisms of plate tectonics including different types of plate boundaries.*

(Activity #4, 5, 7, 9, 15, 16, 17, 18, 23, 24, 25, 26, 27, 28, 29, 32, 33, 34, 35, 36, 37, 38, 40)

★ 6. *List the probable causes for the movements of the plates.*

(Activity #26, 27, 29, 41)

★ 7. *State where the new material comes from that reaches the crust in plate tectonics.*

(Activity #15, 16, 17, 18, 20, 26, 29, 32, 33, 34, 35, 36, 40)

★ 8. *State the geological activities that go on where the crustal material is being destroyed and give the evidence that supports it.*

(Activity #22, 23, 26, 27, 28, 32, 37, 38, 40)

9. *Predict the "future" of continued displacement on the San Andreas fault and the role it might play in the movement of the Pacific Plate.*

(Activity #17, 24)

References

1. Long, L.E., 1974, *Geology*, Chapter 11 — The Grand Synthesis: Introduction (pp. 322-353). Chapter 12 — The Grand Synthesis: Conclusion (pp. 354-377).

2. Gilluly, James, et al., 1975, *Principles of Geology*. Chapter 8 — Renewing the Geologic Cycle (pp. 127-157). Chapter 9 — Constructive Part of the Geologic Cycle — Igneous Activity and Metamorphism (pp. 158-203). Chapter 7 — Earthquakes and the Earth's Interior (pp. 89-126).

3. Stokes, W.L., 1973, *Essentials of Earth History*. Chapter 8 — Structure and Mechanics of the Earth (pp. 168-189).

4. Janes, J.R., 1976, *Geology and the New Global Tectonics*. Chapter 1 — Plate Tectonics and the Study of the Earth. Chapter 7 — Mountains and Geological Structures.

5. AGI, *Investigating the Earth*, 1973, Chapter 13 — The Driving Force of the Rock Cycle (pp. 279-298). Chapter 11 — Mountains from the Sea. Chapter 18 — Development of a Continent (pp. 395-415).

6. AGI, *Investigating the Earth, 1973, Teacher's Edition*. Chapter 11 — Mountains from the Sea (pp. 122-133). Chapter 13 — The Driving Force of the Rock Cycle (pp. 145-153). Chapter 18 — Development of a Continent (pp. 207-217).

7. The Open University (TOU), 1971, *Major Features of the Earth's Surface, Continental Movement, Sea-floor Spreading and Plate Tectonics* (Units 24 and 25).

8. The Open University (TOU), 1971, *Earth History I and II*. Unit 26.2.4.1 — Features of Young Fold Mountains at Continent/Ocean Boundaries (pp. 19-23).

9. Hamblin, W.K., and Howard, J.D., 1975, *Exercises in Physical Geology* (4th Ed.). Chapter 17 — Tectonics of North America (pp. 146-153). Chapter 18 — Topography of the Ocean Floor (pp. 154-163).

10. Brice, J.C., and Levin, H.L., 1969, *Laboratory Studies in Earth History*. Chapter 6 — Inferences from Geologic Maps (pp. 65-74). Chapter 13 — A study of Crustal Movement: San Francisco Bay (pp. 191-196).

11. *Continents Adrift* (Readings from Scientific American). Paper 4 — The Interior of the Earth (pp. 22-27). Paper 6 — Continental Drift (pp. 41-56). Paper 7 — The Confirmation of Continental Drift (pp. 57-67). Paper 11 — The Breakup of Pangaea (pp. 102-114). Paper 13 — Geosynclines, Mountains and Continent-building (pp. 124-132) and Paper 15 — The San Andreas Fault (pp. 143-157).

12. AGI, *Geology and Earth Sciences Sourcebook for Elementary and Secondary Schools*. Chapter 3 — Earthquakes and the Earth's Interior (pp. 79-98). Chapter 4 — Mountain Building and Rock Deformation (pp. 99-114).

13. ISCS, *Crusty Problems — Teacher's Edition*. Chapter 1 — A First Look at Earth (pp. 1-25). Chapter 2 — The Mountains (pp. 27-44). Chapter 17 — Wedge-shaped Mountains and Uplift by Faulting (pp. 79-82). Chapter 18 — Uplift of Mountains Due to Folding (pp. 83-85).

Activities and Investigations

Continents

1. Construct a sketch across a hypothetical continent and show the following features to scale: (a) an 8 000 m mountain range (b) a wide coastal plain extending up to the average height of land in continental platforms (840 m) (c) a wide continental shelf at a depth of 200 m (d) a narrow and steep continental slope extending down to a very wide abyssal plain at 6 000 m (e) and a deep ocean trench (but very narrow) extending down to a depth of 11 000 m. Note how a small rise or fall of sea level would considerably change the areas of land relative to sea. Study the cross-section in The Open University, 1971, **Major Features of the Earth's Surface** (Unit 24), p. 19, fig. 8.

2. Compare the present map of Europe to a map of Europe as it must have looked during the Pleistocene, when water was frozen in the enlarged ice caps and sea levels were about 200 m lower than today. See the map in The Open Univeristy, 1971, **Major Features of the Earth's Surface** (Unit 24), p. 19, fig. 7.

3. Study the present-day distribution of oceanic and continental crust by percentage area (the Earth's surface area is approximately 51×10^7 km^2). Study the percentage of land versus sea and make some assumptions about the kinds of sediments being deposited today as they relate to their environment of deposition. See table 2 in The Open University, 1971, **Major Features of the Earth's Surface** (Unit 24), p. 20.

Continental Structure

4. Define and compare orogenic belts and cratons. Study a map showing the distribution of major orogenic belts and note the concentric arrangement of orogenic belts around the cratons. Suggest a possible explanation of this process of nucleation and construct a series of plastic overlays that show how North America grew by the plastering of successively younger orogenic belts around a central craton. See p. 21, fig. 9 in The Open University, 1971, **Major Features of the Earth's Surface** (Unit 24).

5. Tensional movements create rift valleys such as the Rhine Rift Valley and the Great Rift Valley system of East Africa. Experiment with two boards through which a few nails have been driven so as to allow only their heads to protrude about 1 cm above each boards surface. Place the edges of the boards together and press a 2 cm thick layer of modelling clay firmly against the surface so that it is firmly molded around the nail heads. Then gently pull the boards apart and observe the kinds of surface features formed. By moving the boards parallel to the edges another kind of deformation can be observed in the clay. Try the experiment again but use plaster or a flour and water paste. By moving the boards at different times and using different consistencies of plaster a number of interesting structures can be created. Try the experiment again by placing the clay on the boards with the edges 3 cm apart and then slowly push them together or move them tangentially or parallel to the board edges. Those structural features created in the clay and/or plaster will resemble the kind that develop in orogenic belts under a state of compression. Compare the structures created to actual cross-sections of mountain ranges in North America such as the Appalachians and to those in Europe such as the Alps. See figs. 10 and 11, pp. 21-22 in The Open University, 1971, **Major Features of the Earth's Surface** (Unit 24).

Mountains

6. Provide students with the two figures of a plumb-bob — transit setup as shown in figures 12 and 13 of TOU (The Open Univeristy), **Major Features of the Earth's Surface** (Unit 24) on p. 23. Question: Will the plumb-bob at survey X station near a mountain range hang vertically? Review Newton's Law of gravitational attraction and give them in the basic equation

$$F = \frac{Gm_1m_2}{r^2}$$

Students should be able to discuss the probability of the four propositions posed on page 24 in TOU (Unit 24). Provide numerical estimates of the forces involved in a "typical" mountain range and calculate the effect on a plumb-bob. Let them measure the mass of a real plumb-bob. Simplify the assumptions such as regarding the mountain as a point mass and that the force exerted by the mountain is horizontal. See the procedure outlined on pp. 25-26 in TOU (Unit 24). The answer indicates that there are light-weight 'roots' under mountainous areas. Airy's assumption that the Earth's crust can be likened to a rigid shell floating on a liquid substratum of greater density provided the first meaningful data on the behaviour of the material in the mantle. One hundred years later this data had important implications in the theory of plate tectonics.

7. The depth to which columns (mountain masses) sink into the Earth depends on the density differences between the 'liquid' substratum and that of the 'floating crustal logs'. See p. 27 in TOU (Unit 24). Experiment with different types of material such as ice and wood floating in water and calculate the density of each material based on the amount of 'subcrustal' material displaced. Assume the ice and wood are crustal blocks and the water is subcrustal material. Calculate the density of each by measuring the amount of fluid displaced in a graduated cylinder. Experiment using other types of 'subcrustal material' such as mercury. In each case direct measurements of the amount of fluid displaced can be determined if the experiment is performed in a wide-mouth graduated cylinder. Introduce the concept of isostasy as it now explains the fact that surface features of the earth are in a state of balance. See pp. 28-30 in TOU (Unit 24).

8. Provide sufficient data to students to enable them to discuss gravity anomalies. The unit used to measure a gravity anomaly is a milligal (mgal) a thousandth of a gal. A gal is the average total **g** for the Earth and is named after Galileo. Explain the method by which an area of gravity anomaly can be mapped by surveying an area in detail and by joining up points of equal gravity (lines are isogals and are analogous to contours). Study the illustrations and gravity map of the Baltic in TOU (Unit 24) on pp. 31-34. Attempt the questions on pp. 32 and 33 of TOU (Unit 24).

9. One idea, long held, is that there are movements of material within the upper part of the Earth's mantle which compensate for mass movements at the surface. Consider a mountainous area and a nearby sea. With time, the tops of the mountains will be eroded and the rock debris transported to the sea. The load of the mountain will be less and a compensating movement occurs as the mountain is 'floated' to a higher level within the fluid substratum. Demonstrate this by floating a thick piece of wood in water. Place a pile of sand on the surface of the wood and mark the water level. Simulate erosion by removing some of the sand and mark the new water level. The 'mountains' rise to replace the debris removed. See pp. 34-36 in TOU (Unit 24) and answer questions on pp. 35-36.

Oceans

10. Study the sketch section across the North Atlantic from Florida to the English Channel. Is there any symmetry about the general distribution of topographic features of the Atlantic? See p. 38 in TOU (Unit 24).

11. The continental shelf, an inner flat zone along the edge of a continent, has an average inclination away from the continents of only 0° 07′. The water over the continental shelf is usually less than 200 metres deep. The area occupied by continental shelves occupies about 12 per cent of the Earth's surface. Bearing in mind that the continental shelf is geologically continent; can you think of any reason why this area should be so flat? See pp. 38-39 in TOU (Unit 24). Use a stream table to study the effect of wave action on a sandy beach. See Activity 4-2, pp. 158-159 in Crusty Problems (Teacher's Edition).

12. Contrast and compare the sediments of the continental margin and those of the deep ocean floor. Study recent and rock samples of continental margin marine sediments and turbidites. Create turbidity currents in a sedimentation tank. See Activity 13-4 (Investigating density currents.) in ESCP, Investigating the Earth — Teacher's Guide (part 2) on pp. 361-362.

13. Investigate a sea mount. The hills which project well above the general level of the ocean floor are generally termed sea mounts. These submarine volcanoes are illustrated in cross-section on p. 41 in TOU (Unit 24). Provide a topographic map of a hypothetical or real sea mount and construct a cross-section from the data. Account for the flat tops of sea mounts and explain their location and depth in various parts of the Pacific Ocean. Flat topped sea mounts are termed **guyots.**

14. Investigate the evolution of an atoll. Provide data given on p. 42 in TOU (Unit 24). Why not suggest that the sea floor has sunk beneath a volcano by isostatic readjustment as in fig. 25 of TOU (Unit 24) p. 42. Construct a model volcano of clay and place it in a plastic tray or aquarium. By adding water the volcano is gradually submerged and becomes an island. Add a ring of pink clay as a doughnut around the surface of the clay model to simulate a coral reef. As water level continues the rise the 'coral reef' grows upwards, continued subsidence results in the complete submergence of the volcano, so that the reef encloses a circular lagoon and thereby produces an atoll. How then have some guyots, the flat surfaces of which often are covered by the remains of shallow water marine animals, come to be over 1 000 m beneath the surface of the sea?

The Oceanic Ridges

15. Study the distribution of oceanic ridges and rises. See the illustration in TOU (Unit 24) on p. 43. The initial study of oceanic ridges should focus on description and students should be required to draw a cross-section of either a hypothetical ridge or a real one. Important parts of the physiography of the ridge should be labeled such as median valley or axial rift.

16. Oceanic ridges are composed of basalt. Give the student a piece of basalt and speculate that it was recovered from some part of the Mid-Atlantic Ridge. Indicate to the student that the basalt came from either the axial rift or the central high mountains. Bearing in mind the rock type the student should express an opinion about the process responsible for the formation of that part of the ridge. Study pp. 43-46 in TOU (Unit 24).

17. Study a geologic or physiographic map of the Atlantic Ocean basin. Note that oceanic ridges do not continue without interruption across the oceans; they are cut by fracture zones. These zones are a type of fault unique to ocean basins and called a transform fault. Cut out Figure 45 in TOU (Unit 24) on p. 67. Cut out the back cover of TOU (Unit 25) showing an oceanic ridge cut by two transform faults. Insert fold 1 (Fig. 45) into slot 1, fold 2 into slot 2, fold 3 into slot 3. Pull the folds through from the underside of the back cover (baseboard). Then as you pull the paper out through the slots (see diagram on back cover of TOU (Unit 25), the relative movements along the transform faults will be seen. Make your own model of two transform faults from actual maps of the North Pacific ocean floor adjacent Vancouver Island and demonstrate the movement along the transform faults there.

18. Study the charts showing the physical features of ocean basins such as the one available from the Geological Society of America or from Time, Incorporated. Note that at some points along mid-ocean ridges, such as Iceland and Tristan da Cunha, an excessive outpouring of lava has built active volcanic islands that are **connected** to the shores of adjacent continents by lateral ridges. If the "hot spots" under these islands have existed since the oceans began to open, their excess lava could have built those lateral ridges. The progressively older islands northwest of the active island of Hawaii could also have formed over such a hot spot. Report on this phenomenon after reading "Continental Drift" by J. Tuzo Wilson in **Continents Adrift** (pp. 41-55).

19. Present the controversy that exists over the origin and reconstruction of the Indian Ocean. Read and compare the two ideas presented in "Continental Drift" by J. Tuzo Wilson in **Continents Adrift** (pp. 41-55) and "The Confirmation of Continental Drift" by P.M. Hurley in the same book (pp. 57-67).

20. The topography of the ocean floor has been mapped by means of seismic reflection profiles. From the profile the topographic features and shallow structure of features on the ocean floor can be recognized. Study pp. 154-159 in Exercises in Physical Geology and answer the questions on pp. 155-156 and 158.

21. Excellent physiographic maps have now been completed of the ocean floors. Consult the Earth Science 11 guide (p. A6) for a list of the most important maps showing the physical features of the ocean basins. Study Fig. 180 (p. 161) in Exercises in Physical Geology and answer the questions on p. 160.

22. A part of the Pacific Ocean floor is portrayed in Fig. 181 (p. 163) in Exercises in Physical Geology. Note the numerous guyots and the distribution of the deep trenches. Relate the position of the Japan Trench to your understanding of the movement of the Pacific Plate and answer the questions on p. 162 of Exercises in Physical Geology.

23. A careful study of the western margin of the Pacific Ocean floor and the eastern coast of Asia reveals the striking fact that continental shelves are most commonly missing where the immediate hinterland is not only mountainous (due to geologically recent orogenic activity), but is characterized by the presence of active, or recently active, volcanoes. In addition, the shelf feature is often replaced by an elongated trench or ocean deep, lying close off shore and roughly parallel to the coast. Study pp. 45-49 in TOU (Unit 24) and suggest an explanation that ties in the concept of plate tectonics, the movement of the Pacific Plate and directions of underthrusting around the Pacific. Study Fig. 40 in TOU (Unit 24) carefully before you formulate your answer.

Plate Boundary Studies (Transform Faults)

24. The California San Andreas Fault is an outstanding example of a transform fault that offsets the Mid-Pacific Rise (a sea floor spreading centre). The San Francisco Bay area is well known as a city where geologic history illustrates the dramatic rapidity of changes in land and sea that occur in an active belt of faulting. The geologic problems of California related to movement along the San Andreas fault are not unlike potential problems of earth movement related to the Queen Charlotte Fault and earthquakes along the Pacific Rim of Canada. Study pp. 191-196 in Laboratory Studies in Earth History (Chapter 13, A Study of Crustal Movement: San Francisco Bay). A Geologic map of the San Francisco Bay area is provided and it shows the trace of the San Andreas Fault. Students should study this map and trace the San Andreas Fault System on the Geologic Map of North America. It illustrates a strike-slip fault with right lateral movement. What implications does the movement have regarding the Pacific Plate? Students should answer the questions and study the photographs on pp. 191-196. Note several objections to the concept of great lateral movement raised on p. 194.

25. The Tectonics of North America is the subject of Chapter 17 (pp. 146-153) in Exercises in Physical Geology. This is an excellent opportunity for students to become acquainted with the major structural components (greatly simplified) of the North American continent and how they fit into the plate tectonics theory. Opportunities for distinguishing the structure and history of shield areas versus folded mountain belts and rift zones are presented in two important maps (Figs. 167 and 168). How does the geology of these three subdivisions differ and what implications can be drawn about the history of the North American plate?

26. The readings compiled by J. Tuzo Wilson in **Continents Adrift** (Readings from Scientific American) provide excellent supplementary studies for students seeking to delve more deeply into the concept of plate tectonics. The history of the continental drift theory would make an excellent student report with the paper entitled "Continental Drift" by J. Tuzo Wilson, a Canadian, providing most of the important information.

27. The first indications that plate motion acting against the force of gravity must be pulling the crust down beneath the trenches and dragging sediments into the earth were presented in a landmark paper entitled "The Trenches of the Pacific" by R.L. Fisher and Roger Revelle (pp. 10-15 in **Continents Adrift**). By plotting up the epicentres of continually occurring earthquakes the students can document that trenches are important zones of tectonic activity. Have your students conduct an earthquake watch. (See 1-7 in Investigating the Earth (Teacher's Guide, Part 1) where the sequence of activities is presented on pp. 49-50. You will need to order Epicentre Cards by writing to the Environmental Science Services Administration (ESSA) Coast and Geodetic Survey, Rockville, Maryland 20852 at least one month prior to beginning this activity. The Epicentre Cards will list the following types of data. (1) Date of earthquake (2) Greenwich Mean Time (the time at zero degrees longitude, the Prime Meridian (3) Latitude (4) Longitude (5) Region (geographic location of epicentre) (6) Depth (depth of focus in kilometres (6) Magnitude (severity of earthquake on the Richter Scale, given in **Investigating the Earth,** Teacher's Guide, pp. 145-153.

28. The concept that ocean trenches and island arcs evolve into subsiding belts (sometimes termed geosynclines) and later uplifted to form mountain belts is presented in Marshall Kay's article "The Origin of Continents" in **Continents Adrift** (pp. 16-20). Other types of subsiding belts begin with rifting and also can collect an astonishing array of sediments and volcanic material such as are now found along the shores of Great Slave Lake. Students can construct a 'collecting basin' for sediments by using a variety of materials such as clay, silt, sand, plaster, etc. and then deform it by squeezing it together in a 'Squeeze Box'. Later by flooding the model with water the creating of island arcs and ocean trenches becomes apparent.

29. The concept that the asthenosphere is at least partially molten and that the lithosphere is cool enough to be rigid and strong, extending to a depth of about 100 km, provided a new look at the relationship between the crust of the earth and the 'mantle'. The paper entitled "The Plastic Layer of the Earth's Mantle" by D.L. Anderson in **Continents Adrift** (pp. 28-35) presents the data that confirmed that existence of a low-velocity or fluid zone beneath the crust and upon which the plates 'drift' about. The concept can be demonstrated quite simply by using soup and crackers and heating the soup to the point where convection currents rise and force the crackers apart. Afterwards, a good lunch can be enjoyed by all.

30. Tear a pile of 10 newspaper pages (at the same time), shuffle the pages and then try to match them up. The principle of continental fit by matching coastlines is not the only criteria to be used in reconstructing ancient supercontinents. The matching of the proper pages (page numbers have been eliminated) requires that the print be matched across the tear. In the same way geologists look for structural trends such as faults and fold mountain belts, that can be traced from one continent into another **after** the continental margins have been pushed together to confirm the existence of a supercontinent.

31. Study the fit of the continents illustrated on p. 56 of "The Confirmation of Continental Drift" by P.M. Hurley in **Continents Adrift.** Note that five continental blocks have been fitted together; (1) North America, (2) South America (3) Greenland (4) Western Europe and (5) Africa. Trace this map onto a ditto sheet, and then cut out the five blocks giving each student the problem of fitting them together properly. The teacher should trace the outline of each continent onto the ditto sheet in such a way that they **cannot** be matched until they have been cut out and rearranged. Students should tape or glue them down so as to reconstruct the supercontinent to which they once belonged.

Sea-Floor Spreading

32. Study pp. 19-25 in Crusty Problems (Teacher's Edition). Note that students should already have had a unit on earthquakes and know something about the distribution of earthquake foci in Benioff zones and along mid-ocean ridges and at other plate boundaries. Construct a model of a continent prior to rifting and use sheets of notebook paper or construction paper to simulate the continental plate. See activity 1 on p. 21 of Crusty Problems (Teacher's Edition).

33. Using a bar magnet and two compasses simulate the Earth's magnetic field and detect the field using the compasses. Draw a line on each sheet of paper from activity 1 (above) so as to mark the place of incipient rifting. See aotivity 2 on p. 22 of Crusty Problems (Teacher's Edition).

34. Rift, or split, the supercontinent by placing one hand on each sheet of paper and slowly spreading the papers away from the center (simulating the development of new ocean floor as happens today in the vicinity of the Red Sea). See activity 3 on p. 22 of Crusty Problems (Teacher's Edition).

35. After shading the area of paper that you have pulled out from beneath the table with a crayon, record the magnetic field as determined by the needles of the compasses. Mark the direction of polarity on the colored strip with a black felt pen. See activity 4 on p. 22 of Crusty Problems (Teacher's Edition).

36. Turn the magnet around 180°, so that the end that was away from the paper is now pointing toward the paper. Spread the continents as previously but shade the new area a different colour and again record the direction of polarity (now reversed). See Activity 5 on p. 23 of Crusty Problems (Teacher's Edition).

37. If new material is created in the sea-floor spreading centres what happens to the old sea-floor where it meets a continental boundary? Extend the paper until it reaches a simulated subduction zone (another crack between two tables) and force it back beneath the table (beneath the adjacent continent (simulating the continent with books or clay). Continue creating new sea-floor and destroying old sea-floor in the subduction zone. Pose the question about what happens to the oceanic plate where it descends beneath the continental lithospheric plate. Also, what types of processes operate in this zone (earthquakes, melting, volcanism etc.). Then pose the question about the age of the sea-floor and have students consider the implications of oceanic plate consumption in terms of the age of the Pacific Ocean basin (for example).

38. Investigate features of 'young' fold mountains at continent/ocean boundaries. Study pp. 19-23, TOU (Unit 26). Report on the four main processes operating at the leading edge of a continental plate (the edge which overrides the descending oceanic plate): (1) igneous (2) metamorphic (3) deformational and (4) sedimentary. Figure 6 on p. 21 is an idealized section through a destructive plate margin. Match the appropriate letter with the items on the list (TOU, unit 26).

39. Study and report on the five main lines of evidence which support the theories of continental drift and sea-floor spreading. These are (1) topographic fit between the continents. (2) fit of orogenic belts between the continents, (3) paleoclimatic, paleogeographic and paleontological evidence, (4) paleomagnetic evidence, and (5) ocean floor evidence. (TOU, unit 26, pp. 7-18).

40. Investigate the various types of plate margins in plate tectonic theory. (TOU, unit 26, pp. 20-24.) According to The Open University, Unit 26 (Continental Movement, Sea-Floor Spreading and Plate Tectonics, pp. 20-22) there are four main types of plate margin. These are: (1) constructive or oceanic ridge margins, (2) destructive margins of coastal mountain range and island arc type [B.C. in the Cretaceous], (3) destructive margins of intracontinental type, and (4) conservatime margins [B.C. today]. See if you can select from the array of features listed on p. 23 (TOU, unit 26) those that match the first three types of margin listed. Answers are listed on p. 24.

41. Investigate and read several papers about the causes of plate motion. (TOU, unit 26, pp. 24-26.) The two main theories are: (1) convection currents throughout the mantle and (2) convection currents in the low-velocity zone only.

42. Investigate the evidence for plate tectonic theory and then answer the self-assessment questions presented on pp. 30-31 of TOU, unit 26.

43. Examine an illustration (such as the one in question 7, p. 33, TOU, unit 26) which shows the topographic profile of an ocean floor, together with the magnetic anomaly profile. The anomalies are arbitrarily labelled from left to right. How would you interpret this information? Indicate whether the possibilities given below are likely to be true or false (see question 7, TOU, unit 26, p. 33).

44. Examine the polar wandering curve for two hypothetical continents. When did they begin to drift apart? (See question 8, TOU, unit 26, p. 33.)

45. Examine a diagram which shows the magnetic anomaly profiles for the South Atlantic and the South Pacific. The anomaly pattern for the Atlantic has dates (in Ma) indicated on it; correlate it with the South Pacific profile and work out the spreading rate of the South Pacific during: (a) the last 20 Ma and (b) the period 20-60 Ma ago. (See question 9, TOU, unit 26, p. 34.)

Investigate all the criteria that enable Africa to be matched to South America in the concept of continental drift. The six criteria are: (1) extent of continental shelf and coastline fit. (2) distribution of cratons and orogenic belts. (3) extent of ice cap 250 Ma ago (during the Permo-Carboniferous glaciation, (4) sequence of rocks laid down between 120 Ma and 80 Ma (Jurassic and Cretaceous), (5) palaeomagnetic data and (6) ocean floor age. All data is concisely presented on pp. 16-18 of The Open University (Unit 25) entitled "Continental movement, Sea-Floor Spreading and Plate Tectonics."

46. Construct a drawing to scale of the interior of the earth showing the principle subdivision. Use graph paper and a compass. Colour the various zones and label carefully.

Part. II — Structural Features

The student should be able to:

★ 1. *Find and measure the dip and strike of an outcrop.*

(Activity #15, 16, 18)

★ 2. *Diagram or map the subsurface structures indicated by the dip and strike of an outcrop.*

(Activity #1, 2, 3, 7, 8, 9, 10, 11, 12, 15, 16)

★ 3. *Name and diagram anticlinal, monoclinal, synclinal and plunging folds.*

(Activity #1, 2, 15, 16, 18)

★ 4. *Identify the various types of folds from maps and outcrops.*

(Activity #1, 3, 6, 7, 8, 9, 10, 11, 12, 15, 16, 17, 18)

★ 5. *Describe the environments of formation for the various types of folds.*

(Activity #5, 13, 14)

★ 6. *Name and diagram normal, reverse, thrust, strike-slip and transform faults.*

(Activity #15, 16; See also Part I, Activity #17)

7. *Identify the various types of faults from maps or in the field.*

(Activity #3, 7, 8, 11, 12, 15, 16)

★ 8. *Describe the environments of formation for the various types of faults.*

(Activity #5, 13, 14, 15, 16)

★ 9. *Identify and describe the various forms of unconformity.*

(Activity #15, 16, 17; See also Section B, Part I, Activity #22 and Section B, Part II, Activity #14, 16)

★ 10. *Suggest methods of formation for each type of unconformity.*

(Activity, See Section B, Part I, Activity #22 and Section B, Part II, Activity #14, 16)

References

1. Long, L.E., 1974, *Geology*. Chapter 11 — The Grand Synthesis: Introduction (pp. 322-353).
2. Gilluly, James, et al., 1975, *Principles of Geology*. Chapter 5 — The Tools of Geology — Geologic Maps (pp. 50-73).
3. Stokes, W.L., 1973, *Essentials of Earth History*. Chapter 8 — Structure and Mechanics of the Earth (pp. 168-189).
4. AGI, *Investigating the Earth*, 1973. Chapter 11 — Mountains from the Sea (pp. 233-258).
5. AGI, *Investigating the Earth* 1973, Teacher's Guide. Chapter 11 — Mountains from the Sea (pp. 122-133).
6. ISCS, *Crusty Problems. Teacher's Edition.* Chapter 2 — The Mountains (pp. 27-100).
7. *Continents Adrift.* Paper 13 — Geosynclines, Mountains, and Continent-Building (pp. 124-132).
8. The Open University (TOU) — *Major Features of the Earth's Surface, Continental Movement, Sea-Floor Spreading and Plate Tectonics* (Units 24 and 25). Appendix 2 — Geological Structures (pp. 52-57).
9. Hamblin, W.K. and Howard, J.D., *Exercises in Physical Geology* (4th ed.), Chapter 16 — Geologic Maps (pp. 118-145). Chapter 17 — Tectonics of North America (pp. 146-153).
10. Brice, J.C. and Levin, H.L., *Laboratory Studies in Earth History* (LSEH). Chapter 6 — Inferences from Geologic Maps (pp. 65-74). Chapter 11 — A Study of Folded Strata: The Arbuckle Mountains (pp. 167-173). Chapter 8 — Geologic Provinces (pp. 133-142).
11. Janes, J.R., 1976. *Geology and the New Global Tectonics.*
12. AGI, *Geology and Earth Sciences Sourcebook for Elementary and Secondary Schools.* Chapter 4 — Mountain Building and Rock Deformation (pp. 99-113).

Activities and Investigations

Geologic Structures

1. Study illustrations, slides, filmstrips and models of the following structures: (1) symmetric anticline, (2) symmetric-syncline, (3) asymmetric fold, (4) recumbent fold, (5) recumbent fold and thrust, (6) normal fault (7) reversed fault (8) thrust fault (9) right lateral or dextral fault, (10) left lateral or sinistral fault. Then study the coloured photos in plate B of TOU (unit 25, p. 57) without consulting the descriptions! Write down the names of the structures illustrated, and then consult the descriptions to check if you identified them correctly.
2. Construct models of either paper or clay to illustrate several types of geologic structure.
3. Find examples of each of the geologic structures indicated in activity number 1 on a Geologic Map of British Columbia or of North America.

Note: The following activities are from **Geology and Earth Sciences Sourcebook for Elementary and Secondary Schools.** (GESSESS) (Activities 4, 5, and 6)

4. As the load of sediments increases, the rocks beneath are depressed. See experiment 1 for demonstration of isostasy. GESSESS (pp. 108-110).

5. Experiment with sand "squeeze boxes", buckling pads of paper, or simply wrinkling a rug by pushing on one side cause features to develop similar to the folds and thrusts of the mountain belts. GESSESS (pp. 110-112).

6. The fact that as many as 15 200 m of sediments were deposited in water, which generally was no more than 300 m deep, indicates a close balance between rate of subsidence and rate of sedimentation. Sedimentary rocks in geosynclines are commonly in two parallel belts. The sediments of the belt closer to the continent are the result of erosion from the continent and are mostly clay, silt, sand, lime muds, and reef-building materials. The offshore belt is characterized by unsorted layers, submarine lava flows, and other materials from offshore volcanic islands and their foundation rocks (granite, gneiss, schist, etc.). On a sketch map of British Columbia show the location of the major geosynclines of Mesozoic age. Chapter VIII — Geology of Western Canada in **Geology and Economic Minerals of Canada.** One geosyncline of Mesozoic age is termed the Tyaughton Trough and trended northwest along the Fraser River from the International Border to the vicinity of Quesnel. Another was located in the Rocky Mountain area (the Cordilleran Geosyncline) and a third was situated in the Vancouver Island-Queen Charlotte Islands area (the Insular Trough).

7. Study Fig. VIII-38 (p. 450) in **Geology and Economic Minerals of Canada.** The figure is entitled "Structure-section through southern Cordilleran Orogen" Profile A-A' extends through the Western Cordilleran Fold Belt (Vancouver Island, Georgia Basin, Coast Plutonic Complex and Cascade Fold Belt) to the Eastern Cordilleran Fold Belt (Shuswap Metamorphic Complex, Selkirk Fan Axis and Rocky Mountain Trench, Purcell Anticlinorium, and the Rocky Mountains). Find the following structures along Profile A-A': a pluton, fold mountain belt, metamorphic complex, thrust faults, anticline, syncline, normal fault, reverse fault and overturned fold.

8. In the enlarged section through the Selkirk Mountains and Rocky Mountains locate the following structures: high grade metamorphic terrain (with garnets), high angle thrust faults, low angle thrust faults (overthrusts), faulted anticline, syncline and overturned fold.

9. Where are the oldest rocks located along profile C-C'? Where are they closest to the surface (area of maximum uplift)?

10. The Archean and/or Aphebian rocks are the oldest Precambrian rocks shown on the profile C-C'. If one were to drill a hole through the crust in the Selkirk Mountains, how deep would you have to drill to reach the Archean rocks? What about the Foothills belt, how deep would you have to drill there to reach the Archean rocks? The Archean rocks represent the basement complex of the North American continent.

11. Contrast and compare the structure of Vancouver Island with that of the Georgia Basin. (See profile A-A' in Figure VIII-38 of **Geology and Economic Minerals of Canada,** p. 450.)

12. The newest map showing the geology of British Columbia is available from The Geological Survey of Canada (100 West Pender Street, Vancouver, B.C.). It was prepared to accompany C.I.M.M. Special Volume 15, **Porphyry Deposits of the Canadian Cordillera.** The Geologic map is sold separately for $5 and comes with an overlay entitled "Faults, Porphyry Deposits and Showings, and Tectonic Belts of the Canadian Cordillera."

13. Investigate wedge-shaped mountains and uplift by faulting. Required: 4 strips of modelling clay, 10 cm × 3 cm × 1 cm, in 2 different colours (2 of each colour) knife, 2 rulers or thin blocks of wood. Activities 1-4 **(Crusty Problems, Teacher's Edition).** See pp. 80-82.

14. Uplift of mountains due to folding. Same equipment list as for Activity 13 above plus sheet of paper. According to this theory the crust is pushed up to form mountains as a result of collision of plates drifting about on a fluid zone at the top of the mantle. Collision causes pressure resulting in folding of the crust. Activities 1-4 **(Crusty Problems, Teacher's Edition).** See pp. 83-85.

15. Do the exercises in Chapter 6 (Inferences from Geologic Maps) of **Laboratory Studies in Earth History** (pp. 65-70).

16. Investigate the outcrop patterns of major structural features. Chapter 16 (Geologic Maps) in **Exercises in Physical Geology** (4th edition).

17. Study the geological structures illustrated by colour photos in Plate B, (Unit 24) of the Open University, Major Features of the Earth's Surface **Continental Movement, Sea-Floor Spreading and Plate Tectonics.** (p. 57). Cover up the captions and see how many of the structures you can identify.

18. Sketch from memory the following geologic structures: anticline, syncline, normal fault, thrust fault, overthrust fault. Now take a walk in the mountains and look for some of these structures.

Part III — Earthquakes

The student should be able to:

★ 1. *Suggest several methods of earthquake generation.*

(Activity #2, 13, 14)

★ 2. *Describe the effects of earthquakes on various environments.*

(Activity #7, 8, 9, 14, 15, 16, 17, 20, 22, 25, 26, 27, 28, 29)

★ 3. *Discuss the Richter scale and other methods of measuring earthquake magnitude.*

(Activity #21, 23)

★ 4. *Construct and explain in the functioning of a simple seismograph.*

(Activity #1, 3, 4, 10, 11, 12)

★ 5. *Name and describe the different types of earthquake waves.*

(Activity #2, 3, 4, 10, 11, 12, 17)

★ 6. *Relate methods developed in forecasting earthquakes and preventive measures to be taken to lessen damage and injury.*

(Activity #5, 15, 16, 20, 21, 26)

References

1. Long, L.E., 1974, *Geology*. Chapter 10 — Fields (pp. 272-322).
2. Gilluly, James, et al., 1975, *Principles of Geology*. Chapter 7 — Earthquakes and the Earth's Interior (pp. 89-126).
3. Stokes, W.L., 1973, *Essentials of Earth History*. Chapter 8 — Structure and Mechanics of the Earth (pp. 168-189).
4. AGI, *Investigating the Earth*. 1967. Chapter 11 — Mountains from the Sea (pp. 233-258).
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6. ISCS, *Crusty Problems*. Teacher's Edition. Chapter 1 — A First Look at Earth (pp. 1-26).
7. *Continents Adrift*. Paper 4 — The Interior of the Earth (pp. 21-35) The Open University (TOU) *The Earth, its Shape, Internal Structure and Composition*, (Units 22 and 23). Part 22.4 — Seismic Waves and their Use in Determining the Internal Structure of the Earth (pp. 18-35).
8. Hamblin, W.K. and Howard, J.D., *Exercises in Physical Geology* 4th ed.), Stereo photos 15L/R (San Adreas fault, California) pp. 216-217. Stereo photos 21A/B (San Francisco, California) pp. 228-229. Stereo photos 22L/R (Hope Slide, B.C.) pp. 230-231.
9. Brice, J.C. and Levin, H.L., *Laboratory Studies in Earth History*. Chapter 13 — A Study of Crustal Movement: San Francisco Bay (pp. 191-196).
10. Janes, J.R., 1976. *Geology and the New Global Tectonics*.
11. AGI, *Geology and Earth Sciences Sourcebook*. Chapter 3 — Earthquakes and the Earth's Interior (pp. 79-97).

Activities and Investigations

Earth Structure/Earthquakes

1. Investigating the inside of a sphere (Investigation 13-1, p. 280, **Investigating the Earth**). The hidden interior of an object can be studied without seeing or sampling it. The student is given two spheres of identical size and mass, one with mass uniformly distributed, the other with mass concentrated toward the surface. (The Sphere Dynamics Kit is an ESCP investigation and the materials can be obtained from Hubbard Scientific Company or Arbor Scientific Company — distributor for Ward's in Canada.) Unless the student cuts the spheres open he must rely on differences in the spheres' behaviour in order to make an educated guess as to their interior differences. Success in this investigation should provide insight into how scientists investigate the interior of the earth. (Investigating the Earth, Teacher's Guide, pp. 145-146.)

2. Go outside and place your ear against the building. Listen to the sound made by another student who hits the wall with a board. Describe what you hear. Do sound waves travel faster through the building or through the air?

3. Investigating the epicentre of an earthquake (Investigation 13-4, pp. 283-285, **Investigating the Earth**.) The seismic waves generated during an earthquake provide a powerful and penetrating means for making inferences about the earth's interior. In this investigation, the student develops the means to determine the origin and arrival times of earthquake waves. In dealing with waves as they affect the surface of the earth, the student should gain greater understanding of the action of waves under the surface. The materials required for each group of two people include graph paper, a 20 cm diameter globe, marking crayons, and string. (**Investigating the Earth, Teacher's Guide,** pp. 147-148.)

4. Construct a drawing to scale of the interior of the earth showing the principal subdivisions. Use graph paper and a compass. Colour the various zones and label carefully.

5. The most important recent article on the subject is entitled "Earthquake Prediction" by Frank Press (Scientific American, May 1975, pp. 14-23). With the advent of the theory of plate tectonics the distribution of earthquake belts around the world became understandable. The student should select three or four methods that have been successful in predicting earthquakes and present them to the class or prepare a written report by consulting a few additional references. Another good source of information is the text entitled "Earth" by Frank Press and Raymond Siever, published by W.H. Freeman (1974). See pp. 5, 31, 594-595, 654-655. What attempts have been made to predict earthquakes in Canada? Perhaps a student will wish to communicate with Dr. John H. Hodgson, Chief, Division of Seismology, Dominion Observatory, Ottawa or Dr. W.G. Milne, Dominion Observatory, Victoria. Both have published extensively on earthquakes in Canada. "Earthquakes and Earth Structure" by J.H. Hodgson (Prentice-Hall, Inc., 1964) has an excellent summary of the topic in Chapter 5 (What Can We Do About Earthquakes?) and includes maps showing earthquakes of western Canada and eastern Canada as well as other information about Canada's earthquakes on pp. 5, 7, 9, 21, 36, 45, 64, 80, 133-135, 138, 144 and 159.

6. Investigate how earthquake waves were used to detect the low velocity zone of the Earth's subsurface, a critical piece of evidence for the plate tectonic theory. Read the article entitled "The Plastic Layer of the Earth's Mantle" by D.L. Anderson in **Continents Adrift** (pp. 28-35).

Note: The following activities are from **Geology and Earth Sciences Sourcebook for Elementary and Secondary Schools.**

7. The best introduction to the subject is to experience an earthquake. For those who live in regions where earthquakes are rare, the introduction can be strengthened by using a newspaper account of a recent shock. The teacher can also use descriptions of famous earthquakes of the past.

   Vibrations from passing heavy trucks produce sensations not unlike those of some minor shocks.

8. During discussion develop with the pupils a list of superstitions regarding earthquakes. Seek to project their thinking into the past so that they understand that these ideas were based on the limited knowledge of the time. The teacher may need to supply ideas from the basic list. The student may interview friends and relatives for the causes and explanations of earthquakes, some of which will not differ appreciably from primitive superstitions.

9. Collect and present pictures of earthquake damage. Have students read accounts of famous earthquakes, such as the San Francisco earthquake of 1906, the Tokyo earthquake of 1923, and Alaska's Good Friday earthquake of 1964.

10. Display illustrations of a seismograph and seismogram. A seismograph is an instrument constructed to measure earth tremors. Such movements are recorded by detecting the motion of the ground relative to a suspended mass, such as a pendulum.

11. Demonstration of the principle of the seismograph.

    a. Construct a pendulum by hanging a plumb-bob from a supporting frame.
    b. Use a 60 cm length of string and let the pendulum swing from side to side.
    c. Determine the approximate period (time for a complete swing to and fro) by counting the number of swings in 10 seconds.
    d. Move the support holding the pendulum at a much greater speed than the natural swing of the pendulum. Note that the bob remains fixed in space.

12. Demonstration of a horizontal seismograph. Make a horizontal seismograph.

13. Bend a metrestick or similar strip of wood until it breaks. Call attention to the sudden release of energy when the metrestick snaps. Place the ends of a metrestick on its side edge, in C-clamps on a table. Hold one of the clamps in position and move the other one along the table until the stick snaps. Note the position of the broken metrestick after the break.

14. Build two identical model buildings with plastic toy bricks. The walls should be at least 10 cm high. Place chimneys on one building. Be sure the roof is attached to the walls of each model. Shake the table lightly and observe the behaviour of the buildings and decorations. Continue the artificial shock until the buildings are shaken down. Record your observations, noting any similarities or differences in the models.

15. Starting again with the identical model buildings, construct one on a foundation of sand or clay at least half as deep as the building is tall, and construct the other on the hard tabletop. Tape the second building to the tabletop. The buildings now simulate construction on fill and on bedrock. Shake the table and record your observations, as in the previous experiments.

16. Finally, build two identical model buildings with plastic toy bricks, and place horizontal stringers across both buildings extending from wall to wall. Anchor the stringers to the walls of one building with tape. Shake the table and observe which building withstands the earthquake better. Notice which parts of each structure withstand the shock best.

17. Earthquake waves follow closely a well-established timetable from the focus out to a distance of 11 200 km or about 100 degrees of arc. Beyond 11 200 km, both the P waves and the S waves disappear. The P waves reappear again at about 143 degrees from the source, but non-reflected S waves are not recorded by seismographs on the side of the earth opposite to its focus.

    Build a model of the earth's internal structure to show the crust, mantle, core and inner core. Using plastic clay of different colours, place concentric rings on the board indicating different layers of material within the earth. Label the rings by making flags of paper triangles attached to toothpicks.

18. Alternatively, make a small ball of plastic clay of one colour (3 cm in diameter). Cover it with successive layers of plastic clay, using different colour for each earth layer. Cut through the clay with a sharp knife or razor blade taking out a section. Label the layers with paper flags attached to toothpicks.

19. The behaviour of earth materials that break and generate earthquake waves, yet flow over long intervals of time (for example, in mountain building) can be represented crudely but informatively with "Silly Putty". The putty can be bounced on the floor, yet it can be permanently deformed by slowly but firmly pushing or pulling it, or by allowing it to deform under its own weight during a classroom session. The putty fractures, if it is jerked or struck a sudden, sharp blow.

20. Have students read accounts of tsunamis of the past, and have a pupil report on the Hawaiian warning system. (Within 15 minutes enough earthwaves from an Aleutian quake reach Hawaii to permit computation of distance. A tsunami, if started by the same quake, takes 4 1/2 hours to reach Hawaii's shores.)

21. Have the students assemble data on the amount of energy involved in natural and artificial processes. A good compilation appears in the illustration on the bottom of pages 14 and 15 in the volume on **Energy**, Life Science Library, 1963. This is a good opportunity to discuss the concept of energy and how the concept can be used in analyzing how physical systems work. Go over the modified Mercalli Intensity Scale.

22. Study a seismic risk map of Canada and note the area of British Columbia included in the high risk belt. The summer (1976) issue of **GEOS** magazine includes an article entitled "Earthquake — Studies of the Seismic Risk in British Columbia" by W.G. Milne and shows the Seismic Zoning Map of Canada. **GEOS** is available free of charge to teachers from Editor, GEOS, Energy, Mines and Resources, 588 Booth Street, Ottawa, Ontario K1A 0E4 and copies of this article are distributed without charge on request. But don't wait too long to ask for your copy!

23. Have students obtain information on major earthquakes which have occurred in Canada. Plot on a map the epicentres for each of these quakes. Discuss structural stability of each epicentre area.

24. Have students plot on a world map major volcanic areas and major areas of earthquake occurrence. Discuss their relationship to plate tectonic theory.

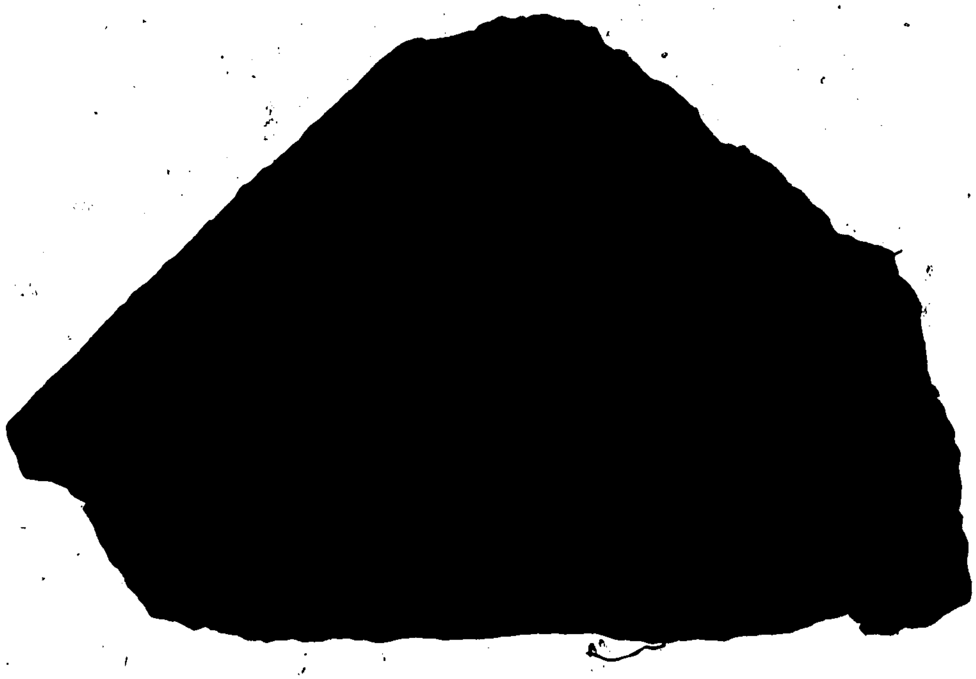
25. Describe the experiences one might encounter during an earthquake using data obtained from past earthquakes in your area.

26. Make a map of the areas of fill in your local school district. Note whether any large structures have been constructed on deposits of fill. Invite a structural engineer to discuss the Building Code of Canada and the precautions that are taken to construct high buildings to resist earthquake damage.

27. Study a geologic map of British Columbia and note the presence of the Queen Charlotte Fault. This fault is an extension of the San Andreas fault system of California. The earthquakes under the ocean west of the populated area of southern British Columbia are usually not a threat to the well-being of people, but, farther north, the major earthquake of 1949 shook the Queen Charlotte Islands very severely. It is an example of the large earthquakes that tend to be associated with transform faults. The 1949 earthquake generated long period waves of sufficient strength that chandeliers in Jasper, Alberta, were caused to swing and a surveyor in the Arctic and an astronomer in Ottawa found it difficult, if not impossible, to keep their telescopes trained upon a fixed star during the passage of these great earthwaves.

28. Study the severe earthquakes that have affected the west coast of Vancouver Island. An earthquake there in 1918 was felt over a large region. Lesser versions of this event occurred in 1957 and 1972. Earthquakes, so far of a moderate size, in the San Juan and Gulf Islands area of the southern Strait of Georgia shook Vancouver and Victoria in 1909 and 1920, and to a much lesser degree shake the area more or less annually. On June 23, 1946, at about 10:15 on a Sunday morning a severe earthquake occurred at the north end of the Gulf of Georgia near Courtenay and indirectly caused the loss of one life and much property damage. It was felt strongly as far away as Victoria. Talk to local residents that might have experienced some of these earthquakes or look at old newspaper clippings and find out what happened in your area.

29. Investigate seismic risk in the Fraser Valley of British Columbia. An earthquake in 1872 severely shook the whole lower Fraser River area and in fact was felt strongly as far north as Quesnel. The exact location or size of the event has not been accurately determined, but it must be ranked as a major earthquake with an epicentre east of the Vancouver region and possible south of the forty-ninth parallel. What effect would such an earthquake have in the Fraser Valley today?



HISTORICAL GEOLOGY

LEARNING OUTCOMES AND SUGGESTED ACTIVITIES

Time & Measurement of Time
The Fossil Record
Interpreting the Geological Record

Teacher Resource Material is indicated by number in the parentheses following most Learning Outcomes. Details regarding references, activities and investigations follow the respective sections of the Geology 12 course. (These are suggested activities only and may be used at the discretion of the teacher.)

HISTORICAL GEOLOGY

TIME & MEASUREMENT OF TIME

One of the chief contributions by Geology to philosophy and science has been the concept of the immensity of time. Therefore it is important for students to be aware of the methods of measuring time, and of the vast scale of time necessary for Earth History to unfold.

LEARNING OUTCOMES

The student should be able to:

★ 1. *Explain how the half-life of a radioactive element is used in estimating age of rock, fossil, or artifact.*

(Activity #8, 9, 10, 15, 21, 29, 33)

★ 2. *Use a half life graph to compute the age of a specimen, given the necessary data.*

(Activity #9, 21, 29)

★ 3. *Recount assumptions made in calculating ages by radioactive dating.*

(Activity #8, 9, 10, 21, 29, 33)

★★ 4. *Deduce relative ages of strata, dikes, intrusions using principles of cross-cutting and superposition.*

(Activity #5, 6, 20, 23, 24, 25, 37; Reference #4)

5. *Discuss critically the various methods (historically) used to calculate the ages of the earth.*

[illegible] #4, 5)

[illegible] *en relative and absolute ages.*

[illegible] 16, 22, 23, 24, 25, 26, 27, 28, 34, 35, 37)

[illegible] *in billions of years events such as:*

[illegible] red — Man appeared
[illegible] nated — Pleistocene Glaciation
[illegible] — Pacific Coast Orogeny
[illegible] d — Rocky Mountain Orogeny
[illegible] nated — Appalachian Orogeny
[illegible] ted

[illegible] 1, 13, 14, 16, 17, 18, 23, 25, 27, 34, 36, 37, 38)

8. *Discuss the methods used to determine the relative ages of fossils.*

(Activity #10, 11, 13, 14, 35, 37, 39)

References

1. Jackson, J.H., and Evans, E.D., 1973, *Spaceship Earth — Earth Science* (Teacher's Edition). Chapter 16 — Geologic Time (pp. 461-488).
2. Intermediate Science Curriculum Study, 1972, *Crusty Problems — Probing the Natural World (Teacher's Edition)*. Silver Burdett, General Learning Corp. Chapter 1 — Unit 2 — Rock Layers, Fossils, and Continental Drift (pp. 14-16).
3. Long, L.E., 1974, *Geology*, Chapter 8 — Life and Time (pp. 196-225).
4. Stokes, W.L., 1973, *Essentials of Earth History*, Chapter 2 — Time and Its Measurement (pp. 12-33).
5. Janes, J.R., 1976, *Geology and the New Global Tectonics*, Chapter 11 — Time and the Fossil Record (pp. 325-368).
6. American Geological Institute, 1973, *Investigating the Earth* (Revised Edition) Houghton Mifflin Company, Chapter 15 — Measuring Time (pp. 323-342).
7. Gilluly, James, Waters, A.C., and Woodford, A.O., 1974, *Principles of Geology* (4th Edition). W.H. Freeman and Company, Chapter 7 — Fossils, Strata and Time.
8. American Geological Institute, 1973, *Teacher's Guide, Investigating the Earth*, Houghton Mifflin Company. Chapter 15 — Measuring Time (pp. 168-177).
9. Brice, J.C., and Levin, H.L., 1969, *Laboratory Studies in Earth History*, Wm. C. Brown Co., Chapter 5 — Time Sequence of Events (pp. 49-64).
10. *Continents Adrift*, Readings from Scientific American, 1970, Paper 12 — Continental Drift and Evolution (pp. 114-123).

Additional References

11. Eicher, D.L., 1968, *Geologic Time*, Prentice-Hall, Inc., 150 pages.
12. Eisbacher, Gerhard, 1973, *Vancouver Geology*, Geological Association of Canada, 56 pages.

Activities and Investigations

1. Have you ever seen a million of anything? Count sand grains and see how big a pile 1 000 000 grains would be. Do this by sampling rather than actual counting. Count the grains in one ml and extrapolate. (Reference 1, p. 461).
2. How many lifetimes are there in 1 000 000 years? (Reference 1, p. 461).
3. How many copies of a ditto sheet (use a master ditto sheet and run off part of the required number) filled with asterisks would you need to have 1 000 000 asterisks? (Reference 1, p. 461).

4. How could a burglar tell that the owner of a house has been away for almost a week? (Reference 1, p. 462). This illustrates an indirect method of measuring time, a common practise in geology.

5. Illustrate a method of measuring time indirectly by studying varves. (Reference 1, p. 463).

6. Illustrate a method by which trees can be used to place events in time. (Reference 1, p. 464-467).

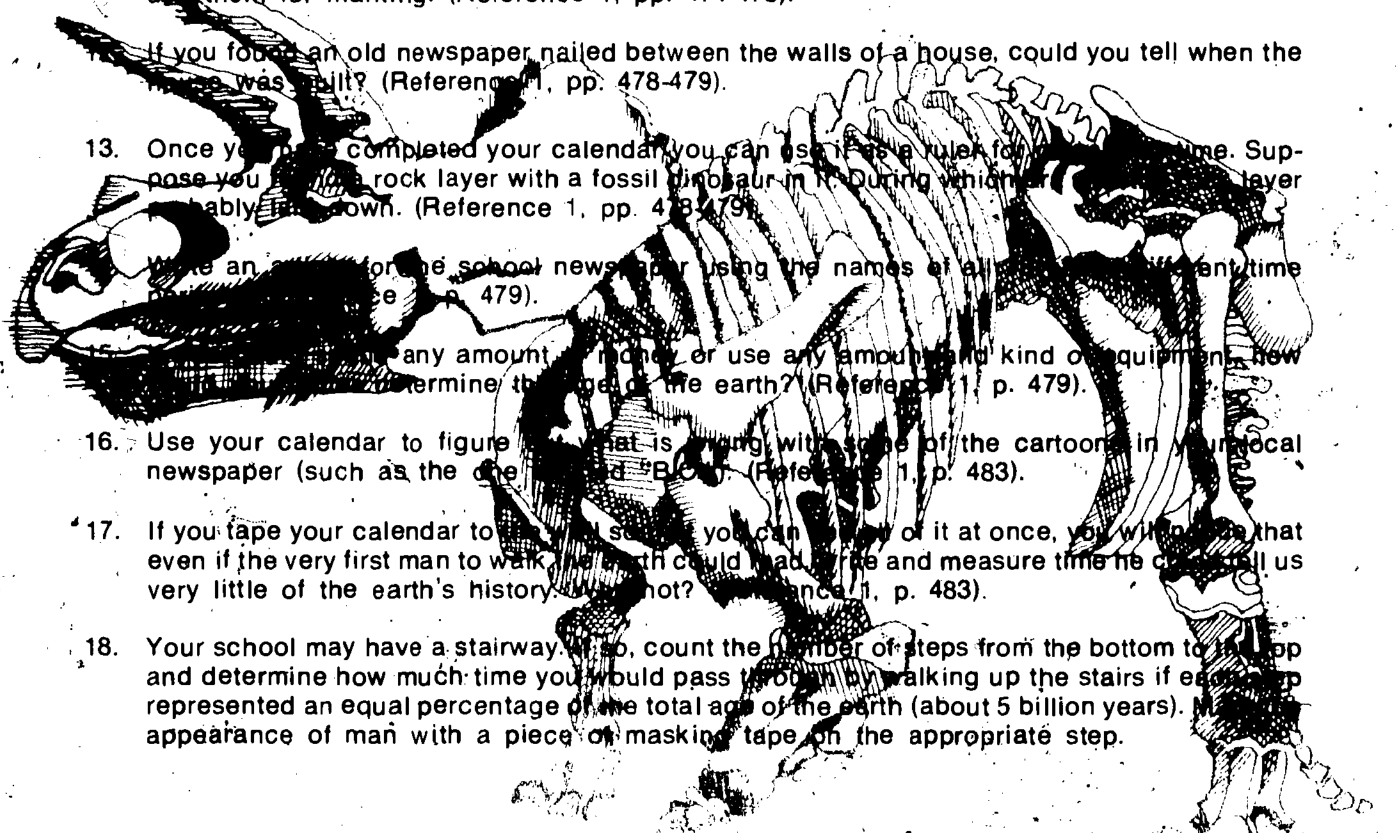
7. If you were locked in a room with no windows (but plenty of air, food and water), how could you measure the passage of time so that you would know the day of the week when you would finally be let out? (Reference 1, p. 468).

8. Two kinds of carbon can be found in wood. The main type is called carbon-12, and the other kind is called carbon-14. Discuss the difference between these two kinds of carbon and illustrate how the ratio of the two types of carbon can be used to determine the absolute date of organic material. (Reference 1, p. 468-471).

9. Uranium can be used for dating. Demonstrate a Geiger counter on a rock that contains radioactive minerals such as uranium, which decays in steps. Geologists can tell the difference between lead that came from uranium and lead that was there all the time, because the weights are different. List some radioactive materials and indicate how the decay of one of these substances can be used to determine the age of a rock. (Reference 1, pp. 472-474).

10. What methods could be used to date a series of objects such as (a) a wooden mummy case from Egypt, (b) a fossil fern found in shale, (c) a mammoth found frozen in a glacier, (d) coal found in Antarctica, (e) a very old sequoia tree, (f) a spear point from a prehistoric campfire, (g) a "fire-arrow" oldest known Chinese gun and (h) moon rock? (Reference 1, p. 475).

11. Both fossils and mountain building can be put on a kind of geologic calendar called a geologic time scale or geologic column. To make a calendar of your own, you will need a metrestick and a strip of adding machine tape 5 metres long. If you have coloured pencils u[illegible] them for marking. (Reference 1, pp. 474-478).



[illegible] If you fo[illegible] an old newspaper nailed between the walls of a house, could you tell when the [illegible] was [illegible]ilt? (Referen[illegible], pp. 478-479).

13. Once y[illegible] completed your calenda[illegible] you can [illegible]. Suppose you [illegible] rock layer with a fossil [illegible] During which [illegible] layer [illegible]ably [illegible] down. (Reference 1, pp. 4[illegible]479).

[illegible]e an [illegible] for the school news[illegible] using the names [illegible] time [illegible] 479).

[illegible] any amount [illegible] or use any amount [illegible] kind of equipment. How [illegible]ermine t[illegible] earth? (Refere[illegible] 1, p. 479).

16. Use your calendar to figure [illegible] with some of the cartoons in your local newspaper (such as the [illegible] "B.C."). (Reference 1, p. 483).

17. If you tape your calendar to [illegible] you can [illegible] of it at once, you will [illegible] that even if the very first man to walk the earth could read, write and measure time he c[illegible]ll us very little of the earth's history. [illegible] not? [illegible]nce 1, p. 483).

18. Your school may have a stairway. If so, count the number of steps from the bottom to the top and determine how much time you would pass through by walking up the stairs if each step represented an equal percentage of the total age of the earth (about 5 billion years). Mark the appearance of man with a piece of masking tape on the appropriate step.

19. Given a cross-section of a tree, can you determine when the tree was cut down? (Reference 1, p. 484).

20. If you were given a varve sequence in which the oldest varve had been dated, would you be able to date a fragment of bone found somewhere in the middle of the section? Students could be given such a drawing and asked to determine the age of the bone. (Reference 1, pp. 484-485).

21. A flood washed an old log out of a river bank. It should contain 0.28 grams of carbon-14 if the log were still alive. Geiger counter readings showed that the log contained 0.035 grams of carbon-14. How old was the log? (Reference 1, p. 484).

22. An introduction to a unit on the measurement of time might include the following exercise. Use any method you can think of, except your watch, to determine the duration of a five-minute period. Cover all clocks and watches in the room. Choose one student to be a timekeeper. The timekeeper will place a mark on the blackboard when you are to start to measure a five-minute period of time. When you think five-minutes have passed, signal the timekeeper. The timekeeper will make a mark each time someone signals and the teacher will record the actual time each student stands (if possible). Reference 6, p. 324).

23. You can mark the passage of time by relating it to a series of events. This is termed relative time. List four events of your past life. Put the most recent event at the top of your list. Now add to your list the events that one or two of your classmates listed. Try to place all of these events in the order they happened. (Reference 6, p. 324).

24. Show students illustrations such as are depicted on p. 326 of Investigating the Earth (Revised Edition). See if you can find signs of changes that have happened in the recent past. (Reference 6, pp. 326-327).

25. In a time-ordered sequence of events, event A happened before event B, which in turn happened before event C. Event D, however, happened before event B, but after event A. Can you represent these events in their proper order. (Reference 6, p. 327). Answers for investigations numbers 25-28 are given in Reference 8.

26. Can you think of any events that do not involve change? (Reference 6, p. 327).

27. Why is it important that earth scientists be able to determine relative and measured geologic time? (Reference 6, p. 327).

28. How would you define time? (Reference 6, p. 327).

29. Obtain a small amount of uranium ore or a specimen of uranium-bearing mineral from your teacher and place it in a cloud chamber. A cloud chamber can be obtained from Arbor Scientific Ltd., Box 113, Port Credit, Ontario. The chamber consists of a clear plastic dish about the size of a cottage cheese container and lined at the top with a felt strip. The covered chamber is set on dry ice until the alcohol saturated felt strip produces a vapor. In the dark using the beam of a flashlight the students can see the track of beta particles emitted from a piece of radioactive ore. (Reference 6, p. 59).

30. On a hot day we can observe a "shimmering" effect that extends upward above pavement or soil. These are popularly called "heat waves". What produces the shimmering effect? (Reference 6, p. 59).

31. What happens to the enormous amount of the sun's radiant energy that does not strike the earth? (Reference 6, p. 59).

32. What are the various sources of energy received by the earth's surface? (Reference 6, p. 59).

33. All the nuclei of radioactive elements do not decay at the same time. The decay process involves chance. Although atoms cannot avoid decay, it is impossible to tell when it will happen for any particular nucleus. Since even a small sample of a radioactive element contains billions of atoms, the average rate of decay can be determined. To illustrate the concept of half-life you can develop a simple model illustrating probability in radioactive decay. (Reference 6, pp. 328-329).

34. Were the earliest methods of classifying geologic time relative or measured? Why were such methods used? (Reference 6, p. 339)

35. How does the correlation of fossil species relate to the development of a Geologic Time Scale? (Reference 6, p. 339)

36. How could you develop a Geologic Time Scale for your local area if one were not available? (Reference 6, p. 339).

37. Study an outcrop near your school and determine the sequence of sediments present there. Determine the relative age of the different beds and discuss the problems of measuring the exact age of each bed in years.

38. The magnetized bodies in the ocean floor have provided an amazingly complete history of magnetic-field reversals that now extends back about 76 million years, into the Cretaceous period. The classic paper on this subject is one entitled *Reversals of the Earth's Magnetic Field* by Allan Cox, G. Brent Dalrymple and Richard R. Doell (**Scientific American,** February 1967). By comparing the ages they assigned to specific reversals of the geomagnetic field with the distance of the corresponding anomalies from the ridge axis it is possible to determine the rate at which the sea-floor has spread in the various oceans. Study the pattern of sea-floor spreading shown on pp. 72-73 of an article entitled *Sea-Floor Spreading* by J.R. Heirtzler in Continents Adrift (Reference 10, pp. 68-78). Using the time scale given on p. 75 (Reference 10) determine the age of the following events (a) birth of Iceland, (b) opening of the Gulf of Aden, (c) separation of Australia from Antartica, (d) separation of New Zealand from Antarctica, (e) separation of South America from Africa and (f) separation of North America from Eurasia. (Reference 10, pp. 68-78).

39. The initial development of the Geologic Time Scale was based on the fossil record. It clearly showed that there were periods of time characterized by the abrupt multiplication and diversification of certain animal and plant groups. It is now thought that continental drift played an important role in explaining this phenomenon. The age of reptiles, for example, lasted 200 million years and gave rise to only 20 reptilian orders, or major groups of reptiles. On the other hand the age of mammals, which followed the age of reptiles, lasted for only 65 million years but gave rise to more than 30 mammalian orders. The difference between the number of reptilian orders and the number of mammalian ones may partially be explained by the fact that for most of the age of reptiles the continents were collected in two supercontinents, whereas early in the age of mammals the two supercontinents broke up into the continents of today. Write an essay on the effect of these events on the evolution of living organisms and how this has influenced the development of the geologic time scale. (Reference 10, pp. 114-123).

THE FOSSIL RECORD

Charles Darwins' arguments in support of the theory of organic evolution might never have gained acceptance if it were not for the supporting evidence provided by the newly developing science of geology in the mid-nineteenth century. Darwins' hypothesis was predicated on the cumulative effects on almost imperceptable changes over long periods of time. The science of geology has contributed to the theory of evolution through the establishment of an acceptable time scale and the provision of fossil evidence of evolutionary change in living things.

The fossil record of evolutionary change is far from complete. About 300 000 fossil species have been described yet the number that have ever existed is estimated at three billion. Several thousand new species are identified each year yet the piecing together of the evolutionary jigsaw remains a slow process.

The purpose of this section of the course is to provide students with an opportunity to investigate the relationships and time scales suggested by the fossil record.

LEARNING OUTCOMES

Part I — Fossils

Nature & Occurrence

The student should be able to:

★ 1. *Describe the processes of carbonization, replacement, permineralization, mold formation and cast formation.*

(Activity #2, 3, 4, 5, 11, 12)

2. *Identify the process of formation of given fossils.*

(Activity #2, 3, 4, 5, 11, 12)

3. *Suggest hypothetical environmental conditions which would result in the formation of a given fossil.*

(Activity #3, 4, 5, 8, 9, 11, 12)

4. *Prepare sample 'fossils' in a laboratoty situation.*

(Activity #2, 3, 4, 9)

★ 5. *Discuss the conditions necessary for the preservation of 'hard' parts in contrast to those necessary for the preservation of 'soft' parts.*

(Activity #1, 6, 7, 8, 9)

★ 6. *Define fossil.*

(Activity #11, 12, References #2, 5)

References

1. American Geological Institute, *Geology & Earth Sciences Sourcebook*, 2nd ed., 1970. Chapter 13, pp. 297-321.
2. Anstey & Chase, 1974, *Environments Through Time*, Chapter 3, pp. 71-76.
3. Brice, J.C., and H.L. Levin, 1976, *Laboratory Studies in Earth History*, Chapter 7, pp. 75-132.
4. C.R.M. Books, 1974, *Geology Today* (Revised printing), pp. 382-408.
5. Janes, J.R., 1976, *Geology and the New Global Tectonics*, Chapter 11, pp. 325-364.
6. Long, L.E., 1974, *Geology*, Chapter 8, pp. 197-225.
7. McAlester, *The History of Life*, Prentice-Hall.
8. Stokes, W.L., 1973, *Essentials of Earth History*, 3rd ed., Chapter 5, pp. 84-117.

Activities and Investigations

1. Compare fossils with preserved examples of similar types of modern plants and animals. Have students note which parts are most commonly preserved.
2. Produce carbon imprints of leaves. **Geology and Earth Sciences Sourcebook,** p. 302.
3. Make models of molds and casts. **Geology and Earth Sciences Sourcebook,** pp. 302-303.
4. Demonstrate petrifaction and replacement. **Geology and Earth Sciences Sourcebook,** p. 301.
5. Dissolve silicified fossils from a limestone matrix. **Geology and Earth Sciences Sourcebook,** pp. 301-302.
6. Use fossil assemblages or 'slabs' to identify the members of fossil communities. **Environments Through Time,** Chapter 3, p. 35.
7. Determine life habits for a variety of fossil forms. **Environment's Through Time,** Chapter 3, p. 35.
8. Have students attempt to relate environmental conditions to fossil assemblages. Attempts should be made to relate environments of deposition to present environments. **Environments Through Time,** Chapter 3, p. 35.
9. Have students relate the processes of carbonization, replacement, permineralization, mold formation and cast formation to the possible fossilization of (a) bees blossoms and birds, (b) fresh water fish, (c) clams and oysters, (d) snakes, lizards and frogs, (e) leaves and branches and (f) humans and apes. **Geology and the New Global Tectonics,** Chapter 11, pp. 325-367.
10. Using sets of fossil and modern preserved organisms, classify them according to the environments listed in Figures 5.1 and 5.2 (pp. 42-43) of **Environments Through Time, E.T.T.** (Chapter 5).
11. Examine preservation of fossils as on p. 76 of **Laboratory Studies in Earth History.**
12. Read Chapter 11 in **Geology and the New Global Tectonics.**

Part II — Interpreting the Fossil Record

The Origin of Life

The student should be able to:

1. *Describe the general nature and structure of amino acid, protein, R.N.A. and D.N.A. molecules.*

   (Activity #1)

2. *Propose a mechanism for the formation of a self-reproducing giant molecule.*

   (Activity #1, 2)

★ 3. *Discuss possible atmospheric conditions suitable for the formation of organic molecules and primitive 'cells'.*

   (Activity #2)

The Theory of Organic Evolution

★ 4. *Define the terms habitat and niche and relate them to the concept of selective environmental pressure.*

   (Activity #10)

5. *Discuss the concepts of Mendelian genetics and mutations as they relate to variation within a species.*

   (Activity #1, 3, 11)

6. *Propose hypothetical responses of modern species to various selective pressure.*

   (Activity #3)

★ 7. *Suggest selective pressures which led to evolutionary changes as exhibited in the fossil record.*

   (Activity #3)

8. *Solve problems dealing with mutation rates, selective pressures and population diversity.*

   (Reference #5)

★ 9. *Generally [illegible] stages of evolution [illegible] vertebrates as an example*

The Fossil Record and Evolution; Diversity

★ 10. *Describe and identify relations of major groups of modern plants and animals to their fossil predecessors.*

(Activity #7, 8, 9)

★ 11. *Describe the evolutionary trends exhibited by major groups of plants and animals.*

(Activity #7, 8, 9).

12. *Propose hypotheses as to why given evolutionary trends have been unsuccessful.*

(Activity #4, 5, 7, 8, 9)

★ 13. *Describe the probable environment suggested or indicated by a variety of fossil forms.*

(Activity #20; Reference #2).

References

1. American Geological Institute. *Geology and Earth Sciences Sourcebook*, 2nd ed., Chapter 13, pp. 297-321.
2. Anstey & Chase, 1974. *Environments Through Time*, Chapter 5, pp. 41-48; Chapter 6, pp. 49-54; Chapter 16, pp. 127-132.
3. Brice, J.C., and Levin, H.L., 1969. *Laboratory Studies in Earth History*, Chapter 7, pp. 75-132.
4. Stokes, W.L., 1973. *Essentials of Earth History*, 3rd ed., Chapter 5, p. 84; Chapter 10, p. 210; Chapter 17, p. 422; Chapter 18, p. 442; Chapter 20, p. 486.
5. B.S.C.S., 1973. *Biological Sciences, An Ecological Approach*, Chapter 17, p. 559; Chapter 18, p. 605.

Activities and Investigations

1. Have students do investigation 17.5, p. 599 in **Biological Science, An Ecological Approach.**
2. Read Chapter 10 of **Essentials of Earth History** (p. 210).
3. Read Chapters 17 and 18 of **Essentials of Earth History** (pp. 422, 442).
4. Read Chapter 20 of **Essentials of Earth History** (p. 486).
5. Have students propose hypotheses for the apparently rapid diversification and extinction of the dinosaurs.
6. Have students solve problems such as those found on pp. 310-313 in **Geology and Earth Sciences Sourcebook.**

7. Visit local fossil beds (have students locate them on maps first) and have students propose an hypothetical history for the outcrop.

8. Examine fossils as indicators of age and environment as on p. 125 of **Laboratory Studies in Earth History.**

9. Have students examine and identify the phyla of representative plant and animal fossils as in Chapter 7 of **Laboratory Studies in Earth History** and Chapter 3 in **Environments Through Time.**

10. Read Chapter 3 (p. 63) in **Biological Science, An Ecological Approach.**

11. Read Chapter 17 (p. 559) in **Biological Science, An Ecological Approach.**

Part III — Ecology and Paleoecology

The student should be able to:

★ 1. *Reconstruct hypothetical environments using fossil and other geological evidence.*

(Activity #4, 5, 6, 7, 8)

2. *Briefly discuss the origin of food chains and their changes through geologic time.*

(Activity #4)

★ 3. *Classify modern areal, marine and terrestrial environments.*

(Activity #1, 4, 5, 6)

★ 4. *Be able to construct a cross-section from the beach to an oceanic deep and label the following environments: littoral, neritic, bathyal, abyssal and hadal.*

(Activity #1, 2, 4, 5, 6)

★ 5. *Deduce the kind of sediment that is available from a source area given its rock type, climate and topographic elevation.*

(Activity #3)

★ 6. *Be able to identify and discuss the significance of each of the following primary structures:*

- — cross-stratification
- — ripple marks
- — mud cracks
- — sole markings
- — graded bedding

(Activity #1)

References

1. Anstey & Chase, 1974, *Environments Through Time*, Chapters 1, 2, 5, 6, 7, 8, 9, 12, 13, 17.

2. Brice, J.C., and Levin, H.L., 1969, *Laboratory Studies in Earth History*, Chapters, 4, 5 and 7.

Activities and Investigations

1. Read and complete the exercises in Chapter 8, p. 68 of **Environments Through Time.**
2. Have students investigate roundness and sorting as on pp. 1-10 of **Environments Through Time.**
3. Examine the origins of source materials, transport and depositional environments as on pp. 11-19 of **Environments Through Time.**
4. Have students relate modern food webs to those existing in paleoecosystems as discussed in Chapter 3 of **Environments Through Time.**
5. Have students practise inferences from outcrops using the exercises in Chapter 4 of **Laboratory Studies in Earth History.**
6. Select local outcrops (fossil bearing if possible) and have students prepare an inferred history of the formation.
7. Have students examine methods of inferring time sequences as in Chapter 5 of **Laboratory Studies in Earth History.**
8. Have students prepare sample time sequences as problems for each other.

INTERPRETING THE GEOLOGIC RECORD

Much of the interpretation and analysis of geologic history is based on a knowledge of sedimentary features and environments. Interpretation and analyses are higher order skills which few students are given an opportunity to exercise. This section provides students with opportunities to apply knowledge of fossils, sedimentary features and other geologic structures in the interpretation and analysis of the geologic record.

LEARNING OUTCOMES

Part I — Correlation

The student should be able to:

★ 1. *Describe the different divisions of the geologic time tables and state in order of oldest to youngest the different eras, periods and in the case of the Cenozoic Era, the epochs.*

(Activity #1, 2, 45)

2. *Interpret local geologic history using facts if given a geologic map and cross-section.*

(Activity #2, 3, 6, 15, 17, 19, 20, 21, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 37)

★ 3. *Discuss the kind of sediment, and hence, the kind of rock that will result in each of the following sedimentary environments:*

- — Marine: Neritic or shallow (water depth less than 180 metres)
  Bathyal or deep (water depth between 180 and 4 000 metres)
- — Transitional: Deltaic
  Lagoonal
  Littoral (submerged at high tide, and emerging at low tide)
- — Nonmarine: Desert
  Fluvial (river, floodplain, piedmont)
  Swamp
  Lake

(Activity #3, 4, 5, 6, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 43, 44)

4. *Describe a time-rock unit, giving the advantages of this type of mapping.*

(Activity #1, 2, 7, 8, 19, 20, 21, 22, 35, 37, 45)

5. *State what is meant by "geologic correlation".*

(Activity #1, 2, 5, 7, 9, 20, 21, 22, 37, 45)

★ 6. *Given three stratigraphic sections, correlate them.*

(Activity #7, 8, 20, 21, 22, 34)

★ 7. *Describe what is meant by guide (index) fossils and state the characteristics of a fossil that would make a good index fossil.*

(Activity #46)

8. *Make a sketch of one guide fossil for each of the geologic periods or be able to identify them from a drawing or slide.*

References

1. Long, L.E., 1974, *Geology,* Chapter 8 — Life and Time (pp. 196-225). Chapter 5 — Recycled Rocks (pp. 100-129). Chapter 13 — Depositional Systems (pp. 378-421).

2. Gilluly, James, et al., 1975. *Principles of Geology.* Chapter 6 — Fossils, Strata and Time (pp. 74-88). Chapter 17 — Sedimentary Rocks as Historical Documents.

3. Stokes, W.L., 1973, *Essentials in Earth History.* Chapter 2 — Time and Its Measurement (pp. 12-33). Chapter 4 — Layered Rocks and the Law of Superposition (pp. 58-83). Chapter 5 — Fossils and the Succession of Life on Earth (pp. 84-117). Chapter 6 — Organizing and Correlating the Record (pp. 118-149).

4. AGI, *Investigating the Earth,* 1973. Chapter 16 — The Record in the Rocks (pp. 343-364). Chapter 17 — Life, Present, Past and Future (pp. 365-382). Chapter 18 — Development of a Continent (pp. 395-412).

5. AGI, *Investigating the Earth — Teacher's Guide,* 1973. Part 2, Chapter 16 — The Record in the Rocks (pp. 178-192); Chapter 17 — Life, Present, Past and Future (pp. 193-206); Chapter 18 — Development of a Continent (pp. 207-217).

6. ISCS, *Crusty Problems.* Teacher's Edition. Chapter 3 — The Midlands, A Pathway to the Sea (pp. 101-170).

7. *Continents Adrift,* (Readings from Scientific America. Paper 12 — Continental Drift and Evolution (pp. 114-123).

8. The Open Univeristy, 1971, *Earth History I and II,* (Units 26 and 27). Unit 26.1 — The Present is the Key to the Past (pp. 9-16. Unit 26.2 — Interpreting the Rock Record (pp. 17-23). Unit — Appendix 2 (The Stratigraphic Column) and Appendix 3 (The Coastal Environment) pp. 25-36.

9. Hamblin, W.K., and Howard, J.D., 1975, *Exercises in Physical Geology.* Chapter 4 — Sedimentary Rocks (pp. 36-50). Table 5 — Classification of Sedimentary Rocks (pp. 41-52).

10. Brice, J.C., and Levin, H.L., 1969, *Laboratory Studies in Earth History.* Chapter 1 — The Natural History of Sand (pp. 1-14). Chapter 2 — Sedimentary Rocks Under the Microscope (pp. 15-22). Chapter 3 — Sedimentary Rocks in Hand Specimen (pp. 23-28). Chapter 6 — Inferences from Geologic Maps (pp. 65-74). Chapter 5 — Time Sequence of Events (pp. 49-65) and Chapter 7 — Fossils and their Living Relatives (pp. 75-132).

11. AGI, *Geology and Earth Sciences Sourcebook.* Chapter 14 — Sedimentation and stratigraphy (pp. 323-362).

12. Geological Survey of Canada, 1970, *Geology and Economic Minerals of Canada.* Chapter VIII — Geology of Western Canada (pp. 365-488).

13. Janes, J.R., 1976, *Geology and the New Global Tectonics.* Chapter 11 — Time and the Fossil Record.

Activities and Investigations

1. Investigating the Geologic Time Scale. (Investigation 15-8), **Investigating the Earth,** pp. 335-337. The student is given a list of events along with the ages of each event in years before present. The student must decide how to represent these in a time-ordered sequence. A roll of paper tape is provided on which he plots a graphical model. The inclusion of events that can be related to local or British Columbia geology makes the investigation more interesting. The student should devote some time to thinking about the graphic representation of the vastness of geologic time as well as to the mechanical preparation of the model. **Investigating the Earth**, Teacher's Guide, Investigation 15-8, p. 173.

2. Introduce the Law of Superposition and the Law of Cross-Cutting Relationships so that the student understands the two principle methods of determining the relative ages of rock units. Investigate how earth scientists determine the relative ages of a rock sequence such as that shown in Figure 15-8, **Investigating the Earth,** p. 173. Then examine a simplified version of how earth scientists calibrate the time scale using data such as that provided on pp. 336-339 of **Investigating the Earth,** applying it to the rock sequence shown in Figure 15-8. The interpretation of this rock section is given on pp. 174-175, **Investigating the Earth,** Teacher's Guide.

3. Investigating the origin of a sedimentary rock. Students should carefully study pp. 344-351 of **Investigating the Earth.** This unit should not be attempted until the student can identify the texture, mineralogy, and primary structures seen in sedimentary rocks. If field investigations of these features cannot be conducted, hand specimens, slides, and/or filmstrips of sedimentary rocks and structures should be studied. Answer the questions related to Figs. 16-1 to Fig. 16-9 inclusive, pp. 344-351 in **Investigating the Earth.** A useful guide for discussions about the interpretation of these figures is provided in **Investigating the Earth,** Teacher's Guide, pp. 178-188. The dominant theme of this investigation is that the structure, texture, and composition of rocks reflect their origin and history.

4. Place a small tray of wet mud beside a radiator or in a sunny window for several days. Examine the cracks that form on the surface. Imagine similar cracks on a mud layer that has been changed to rock. How could you use these cracks to recognize the top of the layer?

5. Investigating an ancient stream channel. (Investigation 16-4, **Investigating the Earth,** pp. 351-353. The data for investigating an ancient stream channel is illustrated in Figure 18-13. The map shows the locations at which the thicknesses of the rocks beneath the surface have been measured by means of drillholes. Small arrows represent the direction of the current indicated by cross-beds and ripple marks. By placing a piece of tracing paper over the map and using a soft pencil the student can draw the shape of the ancient stream channel. Answer the questions posed on pp. 352-353, **Investigating the Earth.** Set out samples or slides of cross-bedding and ripple marks for display. The investigation can be made much more meaningful if students visit local gravel pits and gather data on thickness, direction of cross stratification and current ripple marks so as to interpret the origin of a local sedimentary unit. A completed map is given in Guide Figure, 16-1 of **Investigating the Earth,** Teacher's Guide, p. 181.

6. Investigate the texture and mineral content of local sedimentary rocks. The size of the sedimentary grains is a clue to the velocity of the depositing current. The shape of the sedimentary particles also indicates something about the length of time, source-rocks, and distance the particles have traveled. Some kinds of minerals that occur in sediments indicate something about the location of the area and the type of source rock from which the sediment was derived. For example, if garnet grains are observed in a sandstone the source-rock was probably a high grade metamorphic terrain that must have been exposed prior to the deposition of the grains in the sandstone. Provide samples of sedimentary rocks, as well as a few samples of the same rocks that have been pulverized so that they can be studied under a binocular or petrographic microscope. Such rocks as conglomerate and sedimentary breccias provide interesting case studies of differing geologic history.

7. Place a series of numbered boxes containing fragments of rocks and fossils or models of fossils in different parts of the classroom. Allow a limited amount of time in which to study and describe the contents of each box. Students record their observations in a notebook. Which of the boxes can be grouped together and why? This is a good introductory exercise in rock unit correlation (Investigation 16-6, **Investigating the Earth,** pp. 355-357). The major idea illustrated by the investigation is that reconstruction of earth history from the record in the rocks is dependent on accurate correlation of rock units from one area to another area.

8. Study unit 16-7 in **Investigating the Earth** (pp. 357-359). It attempts to present the principles of rock unit correlation. An example of a problem in correlation is shown in Figure 16-15 (p. 353). Students should be able to answer the questions posed about the Figure on p. 355.

9. Study Chapter 1 (The Natural History of Sand) in **Laboratory Studies in Earth History.** Collect a few large pebbles and determine (1) dimension, in mm (2) roundness class and (3) composition. Pebbles can become rounded in only a few miles of transport along a stream channel. Compare and make sketches of pebbles in plan view from a beach and a river deposit. Account for any differences in shape, if possible.

10. Observe and measure the properties of a mature sand, an immature sand and a carbonate sand. Examples of these sands are illustrated in Chapter 1 (The Natural History of Sand) in **Laboratory Studies in Earth History.** The basis for determining the degree of maturity in a sand is (1) sorting, (2) rounding and (3) mineral and/or rock composition. Collect several beach sands from the British Columbia coastline and compare them to sands from other areas and environments. The procedure for observation of sand under the microscope is given in Table 1-2, p.5 of **Laboratory Studies in Earth History.**

11. The more sophisticated and math oriented student may wish to pursue the grain size analysis of sedimentary materials on p. 6-9 of **Laboratory Studies in Earth History.**

12. The procedure for size analysis based on fall velocity is presented on p. 10-14 of **Laboratory Studies in Earth History.**

13. Investigate a peel or thin section of carbonate rock and sandstone. If thin sections of sandstone are used, provision should be made for viewing these between crossed polarizers. For non-polarizing microscopes, two polarizing films mounted in 35 mm slide binders can be used: one of these is placed over the light source and the other over the thin section. Textures of carbonate rock and sandstones as seen in thin section under the microscope are shown on p. 16 of **Laboratory Studies in Earth History.** Types of contacts between grains in sandstone are illustrated in Figure 2-3 (p. 16). Use the guides for observation of carbonate rocks and sandstones under the microscope for compilation of the data (p. 19 and 21, Laboratory Studies in Earth History). Procedure for making a peel of a prepared rock surface is given on p. 22 of LSEH (Laboratory Studies in Earth History).

14. Review identification of sedimentary rocks in hand specimen before continuing activities 15-30. A useful study section is presented in Chapter 3 (Sedimentary Rocks in Hand Specimen) of LSEH.

15. The method of multiple working hypotheses is the basis for interpreting earth history from evidence such as the properties of sedimentary rocks and from premises such as the "law" of superposition. Answer the questions on p. 30 of LSEH.

16. Investigate the inferences that can be made from **primary** sedimentary structures. A primary sedimentary structure is formed during deposition of sediment, in contrast with secondary structural features such as folds and faults. The most important primary structures are (1) bedding (2) bedding plane markings (inorganic); ripple marks, mud cracks, scour marks and load casts and (3) structures of organic origin such as reefs, structures of algae, tracks, burrows and plant impressions. Study a classroom display of these features or a filmstrip until they can be recognized easily in the field. Visit a local outcrop and report on the types of sedimentary structures observed and photograph them for use in an oral report to the class on the interpretation of the environment of deposition (LSEH, pp. 31-34).

17. **Investigate the types of sedimentary environments and summarize the properties of sedimentary materials from which inferences are made. (pp. 35-36, LSEH).**

18. **Investigate the association of beds found in your local area. (pp. 37-38). Study a geologic report of your local area and report on the thickness and areal distribution of the associations of rock types found there. Determine which sedimentary environments are represented and infer the tectonic settings in which the sediments were deposited. (Study Figure 4-6 on p. 38 of LSEH).**

19. If it is impossible to study the local rocks in the field a very useful set of photographs and problems is presented in Chapter 4 (Inferences from Outcrops) on pp. 39-48 of **Laboratory Studies in Earth History** (LSEH). Study the photographs and answer the questions in your notebook.

20. Episodes in the geologic history of a locality can be inferred from the strata at a single outcrop but a full reconstruction of earth history requires that the strata be studied throughout their areal extent. Eventually, one must relate the rock section seen at one locality to those seen at other places in the area. This involves the procedure of correlation. Correlation is defined as the demonstration of the equivalence of either rock units or time-rock units. Study Chapter 5 (Time Sequence of Events) in LSEH. Answer the questions on pp. 51-56.

21. Investigate the spatial relations of rock units so as to be able to relate the sequence of events in earth history. Study the section entitled "Time Sequence from Spacial Relation" in Chapter 5, p. 56 of LSEH. Answer the questions on pp. 57-58 in LSEH.

22. Investigate the significance of unconformities and determine the number and type represented in the local rock column. An unconformity is defined as a buried erosion surface that represents a break of significant duration in the geologic record. Answer the questions pertaining to unconformities on pp. 59-61 of LSEH.

23. Investigate the classical concept of mountain building illustrated on pp. 62-63 of LSEH. Tectonic settings do not remain constant through time. The area in which you live has, no doubt, gone through several major changes in its tectonic setting during the last 500 million years. Reconstruct the sequence of events during the geologic history of the Phanerozoic Eon for the region of British Columbia in which you live. Is it possible to make block diagrams depicting each major tectonic setting? What stage of mountain building, if any, is represented by the present tectonic setting of the area in which you live.

24. Investigate the meaning of a geologic map. A geologic map shows the distribution of rock formations, faults, and other structural features as they are exposed at the surface of the earth. It is a scale model of the rock bodies of the crust and a fundamental tool for analyzing and interpreting geologic data. Study Chapter 16 (Geologic Maps) in **Exercises in Physical Geology** and be able to recognize the symbols used on geologic maps (p. 118 of EPG).

25. Interpret the outcrop patterns of (1) horizontal strata, (2) inclined strata, (3) domes, (4) basins, (5) plunging folds, (6) angular unconformities, faults, intrusives, strike-slip faults, and (7) surficial deposits. Answer the questions on pp. 120-129 of **Exercises in Physical Geology.**

26. The interpretation of geologic maps in many parts of British Columbia is a difficult procedure for grade 12 students. A good map to begin with is the geologic map of Michigan (pp. 134-135, EPG) where the geology is relatively simple. Answer the questions on p. 134.

27. A somewhat more complicated map of a fold mountain belt in which major thrust faults cut the section is illustrated by the geologic map of Mount Eisenhower, Alberta (pp. 140-141, EPG). Answer the questions on p. 140.

28. Investigate the outcrop pattern of folds, both plunging and non-plunging. Answer the questions on p. 66 of Laboratory Studies in Earth History (LSEH).

29. Many parts of British Columbia are broken by faults. Investigate the different kinds of faults shown on p. 67 of LSEH. Answer the questions on p. 67 of **Laboratory Studies in Earth History.** Study a map of your local area and determine if any faults are present. What type are they? If possible, take a field trip into a faulted area and investigate the evidence for faulting at first hand.

30. One of the most important activities that students can be involved in is the interpretation of geologic maps by construction of structure cross-sections. The step-by-step procedure followed for construction of geology structure sections is discussed on pp. 68-69 of **Laboratory Studies in Earth History.** Make a structure cross-section of the northern part of the Black Hills (Figure 6-6 of LSEH).

31. Select a geologic map of some part of Canada and attempt to construct a geologic structure section. The map should show dip and strike symbols to be useful for this exercise. The vertical exaggeration should be as little as possible.

32. Investigate the interpretation of structure sections from outcrop data. Complete the block diagrams shown on p. 70 of LSEH.

33. The basement rocks of most of eastern Canada are of Precambrian age. These rocks underlie about two million square miles of the Canadian Shield. Investigate Precambrian history of North America. (Chapter 9: A Study of Precambrian Geology in Laboratory Studies of Earth History.)

34. Investigate the geologic provinces or tectonic regions of British Columbia. Make a map showing the boundaries of each region. Summarize the characteristics of each tectonic province. Consult the chapter on the Cordilleran Region in **Geology and Economic Minerals of Canada.** Study the generalized information in Chapter 8 of **Laboratory Studies in Earth History,** pp. 133-142.

35. Investigating the history of a model. (Investigation 16-8, pp. 359-360, **Investigating the Earth.**) If you examine a rock outcrop carefully, you will find that you can piece together the sequence of events that formed the outcrop. In this investigation several members of the class make geological models of various areas out of some modeling material. They keep a list showing the exact sequence of the steps that they took to make the models. Once the models have been completed, other students in the class are asked to examine them and determine the sequence of steps necessary to construct the models. The teacher should be ready to suggest geologic features that a student can display in his model of bedrock. This investigation permits the student to make and interpret some three-dimensional models showing various bedrock geologic features (p. 211, **Investigating the Earth,** Teacher's Guide.

36. Investigating how rocks reveal ancient climates. (Investigation 16-9, pp. 360-362 **Investigating the Earth.**) Rocks contain evidence that climates have changed radically during the geologic past. Interpret Text Figure 18-17 for homework. Then use it as the basis for a class discussion. If the student can make a logical interpretation of the geologic history represented in these cross-sections, he will be developing the interpretive skills at which the course is aiming. See also the questions that pertain to Figure 16-9 showing the climatic zones in North and Central America and how they have changed since early Cenozoic time (Investigating the Earth, pp. 361-362).)

37. Investigating the growth of the North American continent. (Figure 18-9, **Investigating the Earth,** p. 401.) The way the dates are grouped in the three stages of growth shown indicates that parts of North America may have been added to the continent at different times in the past. Growth may have taken place at the edge of the continent. Suggest how this data may be related to plate tectonic theory.

38. Investigating Precambrian rocks near Blind River, Ontario (north shore of Lake Huron). (Investigation 18-2, **Investigating the Earth,** pp. 396-399.) Study Figure 18-1, p. 396. It shows a series of cross-sections that represent Precambrian rocks found along the north shore of Lake Huron near Blind River, Ontario. List the rocks shown in each of these cross-sections in the order in which they formed. The teacher provides the students with a list of radioactively determined ages of some rocks shown in the cross-sections. Does the sequence indicated by these ages agree with the order worked out by the student from the cross-sections? Why or why not? This investigation is important because Precambrian rocks represent the oldest on the North American continent, and a study of North America's development begins with them. (Investigation 18-2, **Investigating the Earth,** pp. 208-209 of the Teacher's Guide.

39. Investigating the Great Ice Age, Study Figure 18-13 on p. 445, **Investigating the Earth.** On a sketch map of North America show the position of the three major centres of ice accumulation and indicate the maximum advance of the four great ice sheets over the continent.

40. Investigating the Ice Age puzzle. (Investigation 18-8, **Investigating the Earth,** pp. 410-411.) In this investigation the student examines an area that was formerly covered by part of a continental ice sheet. Across the map are numbers indicating certain stations on the landscape. Information is given for each station. Using a scale, plot the elevation of each station on graph paper. Connect the elevation points to make a topographic profile. Plot on the profile the information from the data table. Make a cross-section using different colours for symbols or rock and glacial deposits. Note two kinds of till are present. Answer the questions on p. 411. In summary, the investigation teaches the student to use the evidence left by glaciers to reconstruct the events that shaped the landscape. (**Investigating the Earth,** Teacher's Guide, pp. 211-212.)

41. Investigate the kind of topography that develops on the snout of a stagnating ice sheet. This type of topography is common between Aldergrove and Abbotsford in the Fraser Valley. To illustrate how the melting of buried ice blocks can produce an irregular surface on glacial deposits, have the student try the following at home: Fill a pan with sand or dirt to a depth of about 10 cm. Bury several ice cubes in the sand, smooth the surface, and let stand overnight. Observe the results before leaving for school in the morning and be prepared to discuss them. The student should have no difficulty relating the rough surface produced on the sand to the rough surfaces found on some glacial deposits. This type of topography only develops during the waning stages of glaciation and is termed knob and kettle topography.

42. Investigate the effects of isostatic rebound on the north shore of Vancouver, British Columbia. Although glacial ice is of much lower density (about 0.89 g/cm^3) than bedrock of continents (about 2.7 g/cm^3) the great mass of the accumulated ice in glaciers has been sufficient in the past to depress the crust. In some instances, old beaches and other coastal features such as marine deltas were created during high-water stages or when the land was depressed immediately following deglaciation. Several large and nearly flat gravel deposits along Capilano River and Lynn Canyon were deposited when the land was much lower. How much lower? Study topographic maps of the North Shore and determine the highest elevation of gravel deposits below the canyons of the Capilano and Lynn Creek. Examine other effects of isostatic rebound in the Hudson Bay region and the Baltic area of northern Europe.

43. Activities and investigations about earth history beginning with Activity No. 43 are based on Science Foundation Course Units 26 and 27 from **The Open University** (Earth History I and II). Students participating in these activities are not expected to have much factual recall of the material presented. Students will, however, enjoy studying these concepts and, whilst doing so, will gain some insight into the methods by which Earth history has been and is being deciphered. Explain the principle of uniformitarianism and show at least one example of a geologic process that is operating near your school.

44. Investigate British Columbia's coastal environment. By learning something about the kinds of sediments and processes operating along the British Columbia coast, the student should be able to recognize ancient coastal environments in the geologic record. A list of measurements that can be carried out in a beach environment is provided on p. 11, TOU (Unit 26).

45. Investigate the energy of a modern environment. Any feature of sediments and their fauna and flora can be related to what is called energy of environment. For example, high energy conditions are characterized by the surf zone, where waves are constantly breaking and producing turbulent currents of extremely high velocity. In contrast to this, low energy conditions exist in sheltered marsh areas, which are seldom affected to any degree by tidal currents, or by wind-driven water currents. Investigate a salt marsh, collecting samples of its sediment, flora and fauna. Compare and contrast this environment to a rocky headland or inlet such as exist in many places along Howe Sound, the Sunshine Coast, or Vancouver Island. Take photographs, record changes related to seasonal conditions and measure water conditions and internal and external structures in the sediments such as cross-bedding and ripple marks.

46. Investigate the origins of the stratigraphic time terms. Study Table 1 on p. 17 of TOU (Unit 26).

Part II — Layered Rocks and the Law of Superposition

The student should be able to:

★ 1. *State and be able to apply the Law of Superposition.*

(Activity #2, 6, 12, 15; See also Part I, Activity #1, 2, 7, 15, 35)

★ 2. *State and recognize methods that can be used to determine the top and the bottom of sedimentary layers.*

(Activity #6, 9, 10, 11, 14, 15; See also Part I, Activity #3, 4, 7, 16, 19, 35)

★ 3. *Determine the relative ages of several formations.*

(Activity #12, 13, 14, 16; See also Part II, Activity #2, 7, 15, 16, 19, 20, 22)

4. *State examples where the Law of Superposition will not work.*

(Activity #13)

★ 5. *Define the terms — strata, bed, formation, unconformity, contact.*

(Activity #6, 7, 12, 13, 14, 15; See also Part I, Activity #3, 7, 19)

★ 6. *Interpret the history of sedimentary rock strata, using texture, mineralogy, sorting, bedding, and primary structures such as ripple marks and mud cracks as guides.*

(Activity #3, 4, 5, 9, 10, 11, 17; See also Part I, Activity #3, 4, 5, 6, 9, 10, 11, 12, 13, 14, 16, 17, 19)

★ 7. *Determine the "up" direction and list in order (oldest first) the age of the rocks shown in a series of sketches or slides.*

(Activity #9, 10, 11, 14, 15, 16; See also Part I, Activity #4, 7, 19)

References

1. Long, L.E., 1974, *Geology*. Chapter 8 — Life and Time (pp. 196-225).
2. Gilluly, James, et al., 1975, *Principles of Geology*. Chapter 6 — Fossils, Strata, and Time (pp. 74-88).
3. Stokes, W.L., 1973, *Essentials of Earth History*. Chapter 4 — Layered Rocks and the Law of Superposition (pp. 58-83).

4. AGI, 1973, *Investigating the Earth.* Chapter 16 — The Record in the Rocks (pp. 343-362).

5. AGI, 1973, *Investigating the Earth. Teacher's Guide.* Chapter 16 — The Record in the Rocks (pp. 343-362).

6. ISCS, *Crusty Problems. Teacher's Edition.* Chapter 3 — The Midlands, A Pathway to the Sea (pp. 101-152).

7. The Open University (TOU), *Earth History I and II* (Units 26 and 27). Appendix 2 — The Stratigraphic Column (pp. 25-26). Appendix 2 — Law of Faunal Succession (pp. 26-28). Appendix 2 — Early Attempts at Dating (pp. 29-30). Appendix 2 — Key Developments in Stratigraphy (p. 33). Appendix 2 — The Coastal Environment (pp. 34-36) and Plate A (pp. 48-49).

8. Hamblin, W.K., and Howard, J.D., 1975, *Exercises in Physical Geology* (4th ed.) Chapter 16 — Geologic Maps (pp. 118-145).

9. Brice, J.C., and Levin, H.L., 1969, *Laboratory Studies in Earth History.* Chapter 5 — Time Sequence of Events (pp. 49-64).

10. James, J.R., 1976, *Geology and the New Global Tectonics.* Chapter 11 - Time and the Fossil Record.

11. AGI, *Geology and Earth Sciences Sourcebook for Elementary and Secondary Schools.* (Chapter 14 — Sedimentation and Stratigraphy (pp. 323-362).

12. Laporte, L.F., 1968, *Ancient Environments.* Prentice-Hall, Inc., 116 p.

Activities and Investigations

1. Investigate the origin of three types of sedimentary rock: (1) a conglomerate, (2) a fossiliferous limestone and (3) a shale bearing plant fossils. Describe the features of these specimens. What is the probable origin of each rock?

2. Show a slide of dipping sedimentary rocks. Imagine yourself standing in front of this rock outcrop somewhere in British Columbia. Describe what you see. In order to tell a story so that it makes sense, you must start at the beginning. Where does the story begin in a pile of layered rocks, at the top or at the bottom? Are the layers horizontal or tilted? What does this mean about the history of the rocks in this outcrop?

3. Show a close-up of the sedimentary rock so that the bedding is clearly indicated: a channel sandstone showing stream-type cross-bedding would be a useful slide. Suppose you go up to this outcrop and examine it closely. You discover that it looks like this slide. If you examine the rock even more closely, you will see the texture (show a slide of higher magnification of a coarse grained sandstone in which the grains are clearly visible). How do the beds become layered? Why are the beds inclined? How do the fragments that make up this rock seem to fit together? What does this kind of texture indicate about the origin of the rock? (emphasize the importance of energy and currents in any sedimentary environment.)

4. Compare the settling of sedimentary particles in water in which there is no current (A) and water that is in motion (B, C, and D). Use a stream table. (**Investigating the Earth,** The Record in the Rocks (Chapter 18, pp. 392-393).

5. Provide an illustration of a typical sedimentary sequence in a delta in which the sediments grade from gravel to sand to clay. Note: A single layer of sediment that covers several square kilometres may also vary in appearance from one place to another. How can you explain the variation in grain size from gravel to clay away from the source? Use a stream table to demonstrate how size sorting occurs.

6. Not all layered rocks are sedimentary. Investigate a thick pile of lava such as is common in the Interior of British Columbia or on the Columbia Plateau (Use slides). Can you apply the Law of Superposition to these rocks? What differences in the rocks would help you to distinguish these volcanic layers from sediments deposited in water? (Pass out samples of basalt.)

7. Study the origin of columns in columnar basalt and use them to indicate the top and bottom of a volcanic flow. (Use a slide and collect a column of basalt from either Mt. Baker or along the Squamish Highway near Mt. Garibaldi.)

8. Pass out samples of volcanic rocks in which the long crystals are oriented roughly parallel to the flow. What can they tell you about the direction of flow in the lava? (**Investigating the Earth,** The Record in the Rocks (Chapter 16, pp. 348-349.)

9. Why are cross-beds and ripple marks important? (Use large display specimens, slides and field trips to a local beach to study these features.) (**Investigating the Earth,** p. 350

10. Study slides showing asymmetrical and symmetrical ripple marks. In which direction did the current flow? Use symmetrical ripple marks to tell "top" from bottom in a sedimentary sequence. (Turn the slide of symmetrical ripple marks upside down to demonstrate with a large display specimen.)

11. Fossils in rocks can also be used to determine whether a layer is upside down. Have you ever noticed the way clam shells come to rest on a beach? Waves or currents usually turn them over so that the hollow or concave side is down. Investigate the orientation of clam shells on a local beach and make a statistical study of the number turned over within a 3 metre square area.

12. Visit two areas where a sedimentary sequence is exposed. Select areas where at least one unit is common to both sections. Measure a section and record all of the properties of each rock unit. Determine the criteria that you found most useful in making the correlation.

13. Use three colours of clay or make a "normal" sedimentary sequence in which the oldest unit is on the bottom. Now deform the section to make either an overturned fold or fault it in such a way as to repeat the section (a high angle reverse fault or overthrust fault will result in a repeated section). Discuss the problems of determining the correct sequence in highly deformed areas.

14. Visit a local outcrop and point out the following features: strata, bed, formation, unconformity and contact. Is the section right side up or upside down? What criteria did you use to determine this? (Slides can also be used to define these terms.)

15. Visit a local outcrop and record the different types of sedimentary structures. Answer the following questions. Is the section right side up? Was the deposit laid down in quiet water or running water? What evidence of current action did you find? What types of ripple marks are present? Examine the mineralogy with a hand lense. Where did the grains come from? (Quartz and feldspar are most likely derived originally from igneous rocks.) Can you put together enough data to determine where the source of the sedimentary particles was? (Use mineralogy and cross-bedding.)

16. Given several index fossils and hand specimens determine the following: the correct ages and hence the order in which the rocks were deposited? In what environments were the sediments deposited? Do you have any evidence of unconformities in the sequence? (Students should be given fossils that, when placed in the correct order, indicate that one geologic period is not represented.)

17. Study a coastal environment in which two or more of the following are present: salt marsh, sand dunes, storm beach, beach and sand, pebble beach, and swamp. Point out that sediment is accumulating in all of these environments **at the same time.** Discuss what would happen if the sea covered this area and laid down a blanket of sand and/or mud. What problems of environmental interpretation and correlation would be presented to future generations of geology students? The Open University, Appendix 3 (The Coastal Environment) pp 34-36. See also the coloured photos of various coastal environments on p. 49 (Plate A) of the same book (TOU, **Earth History I and II,** Units 26 and 27).

EARTH RESOURCES

LEARNING OUTCOMES AND SUGGESTED ACTIVITIES

Economic Geology
Resource Problems

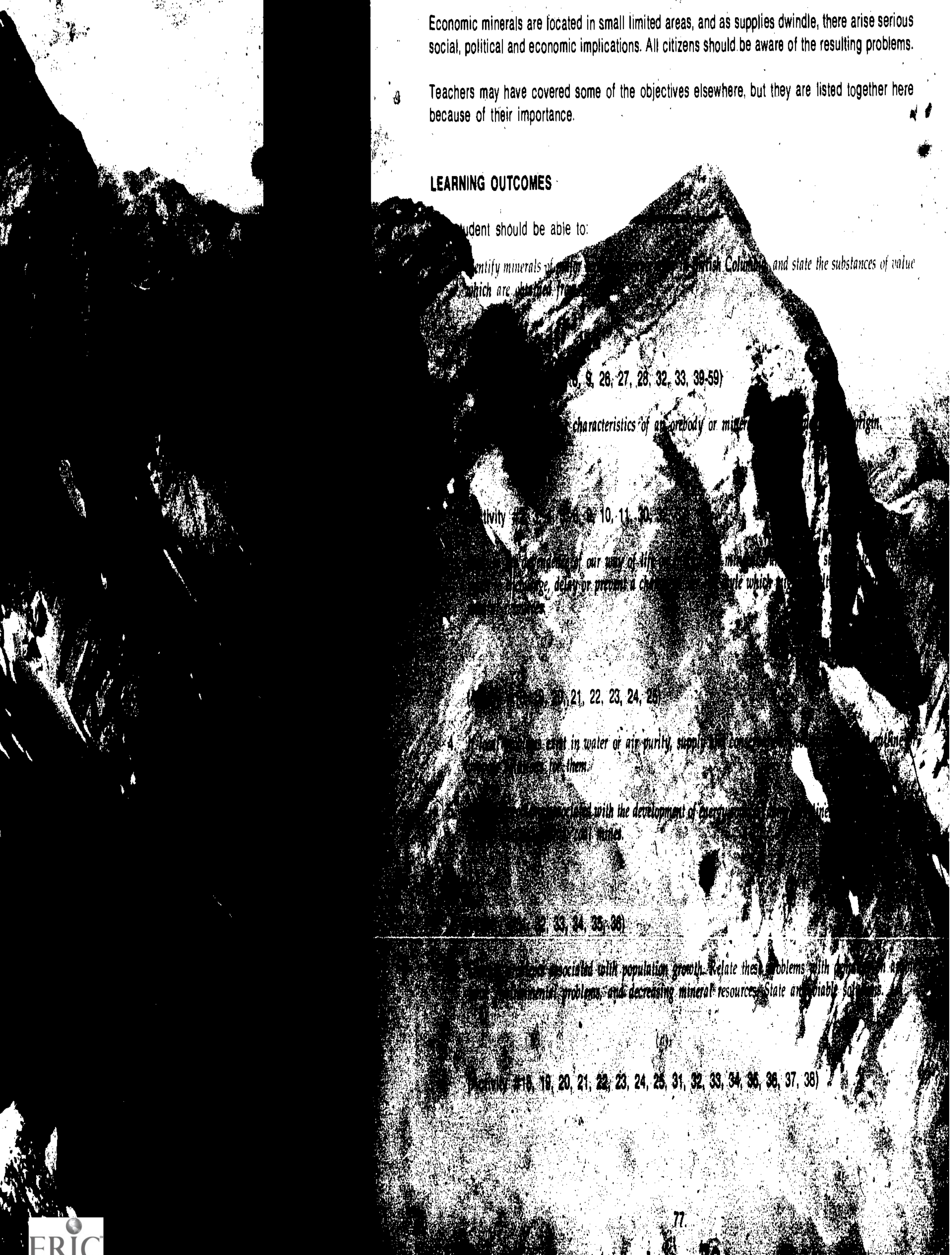
Teacher Resource Material is indicated by number in the parentheses following most Learning Outcomes. Details regarding references, activities and investigations follow the respective sections of the Geology 12 course. (These are suggested activities only and may be used at the discretion of the teacher.)

SECTION C EARTH RESOURCES

Our way of life is dependent on minerals, which are exhaustable and irreplaceable. Cities and civilizations have withered as their supplies of minerals have become depleted.

Economic minerals are located in small limited areas, and as supplies dwindle, there arise serious social, political and economic implications. All citizens should be aware of the resulting problems.

Teachers may have covered some of the objectives elsewhere, but they are listed together here because of their importance.



LEARNING OUTCOMES

[illegible] udent should be able to:

[illegible] ntify minerals of [illegible] British Columbia and state the substances of value which are obtained from [illegible]

[illegible] 9, 26, 27, 28, 32, 33, 39-59)

[illegible] characteristics of an orebody or mi[illegible] origin.

[illegible] tivity [illegible] 9, 10, 11, 30 [illegible]

[illegible] of our way of life [illegible] change, delay or prevent a ch[illegible] which [illegible]

[illegible] 20, 21, 22, 23, 24, 25)

4. [illegible] in water or air purity, supply [illegible] for them.

[illegible] with the development of energy [illegible] coal mines.

[illegible] 32, 33, 34, 35, 36)

[illegible] associated with population growth. Relate these problems with [illegible] environmental problems, and decreasing mineral resources. State any viable solutions.

(d)

Activity #15, 19, 20, 21, 22, 23, 24, 25, 31, 32, 33, 34, 35, 36, 37, 38)

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Activities and Investigations

1. Make a collection of ore minerals from western Canada by writing to various mining companies. Addresses are available in a publication entitled **Sources of Free Materials for Canadian Earth Science Teachers and Students,** J.L. Rau, 1976. See supplementary references.

2. Study the location of the Eastern and Western Mineral Provinces in western Canada. Although similarities in stratigraphy and structure persist in places for some distance across the border between these two provinces and similar types of mineral deposits are known in both, the differences between them are impressive. List the primary ore types available in both provinces and be able to characterize the differences in the geology between these two regions. (Geology and Economic Minerals of Western Canada, pp. 491-521.)

3. The eastern mineral province of western Canada contains deposits reflecting broad regional warping and/or subsidence, simple deformation and only local metamorphism and plutonism. Important examples of the lead-zinc-silver deposits of this province are illustrated by Pine Point, Monarch and Kicking Horse and the Kootenay King mines. Select one of these mines and describe as simply as possible the following: (1) location of the mine on a map of western Canada, (2) the basic geology surrounding the mine, (3) the type of deposit in which the ore minerals are found and (4) the kinds of ore minerals found in each. The keen student may wish to study the origin of these ore minerals and collect examples of each for a class display. (Geology and Economic Minerals of Western Canada, pp. 494-497.)

4. Invite an economic geologist to visit your class and discuss some aspect of geology as it relates to mineral deposits in western Canada. Such requests should be directed to the B.C. and Yukon Chamber of Mines, 840 West Hastings Street, Vancouver, B.C. V6C 1C8.

5. Complete the exercise entitled The Yellowknife Gold District, Northwest Territories (Laboratory Studies in Earth History, p. 158.)

6. Complete the exercise entitled An Oklahoma Oil Field North of the Arbuckles (Laboratory Studies in Earth History, p. 173).

7. Complete the exercises on environmental geology in the laboratory manual. (Exercises in Physical Geology, pp. 180-186.)

8. Visit the B.C. Mining Museum at Britannia Beach and write a report on the history of mining in British Columbia or on methods of underground mining. Tours are arranged by writing the B.C. Mining Museum, Britannia Beach or by phoning 112-688-8735.

9. Study the occurrence of sulphide mineralization in the outcrops surrounding the mine at Britannia Beach and collect examples of chalcopyrite, apatite, pyrite, pyrrhotite. Make an oral presentation to the class on the geology around and within the Britannia mine.

10. Set up a sluice in the laboratory and use pyrite to simulate gold. Write a brief report on the methods by which gold is extracted from placer deposits and discuss the methods by which placer deposits accumulate.

11. Demonstrate the proper technique for panning for gold by using pyrite or chalcopyrite to simulate gold.

12. Use a hydrometer, or Jolly balance or any ordinary balance or scale to measure the specific gravity of some ore minerals. Explain to the rest of the class the significance of specific gravity in the accumulation of placer deposits.

13. Demonstrate the use of an ordinary balance in measuring specific gravity. Even a fairly large piece of rock may be studied by hanging the piece by a string to the scale, taking the weight in air, say 50 grams, then lowering it into a beaker of water and reading the weight, say 30 grams. These two readings are subtracted giving 20 grams, which divided into the first reading (50 grams) gives 2.5 as the relative density of the sample.

14. Demonstrate the property of fusibility as a method of identifying certain ore minerals. The ease with which minerals melt in a flame is designated by the number 1 to 7. Typical minerals and their approximate fusion points are given below.

(1) **Stibnite:** fuses easily in the luminous flame, in a closed tube and in a match or candle flame; about 525°C.

(2) **Chalcopyrite:** fuses easily in the blowpipe flame but with difficulty in the luminous flame or closed tube; about 800°C.

(3) **Almandite:** fuses easily in the blowpipe flame but is not fused in the closed tube or luminous flame. Finest splinters only rounded on the point in the gas flame; about 1050°C.

(4) **Actinolite:** thin edges fuse easily in the blowpipe flame but larger masses are difficult to fuse; about 1200°C.

(5) **Orthoclase:** fuses on the edges with difficulty, in the blowpipe flame; larger masses are not fused, only rounded; about 1300°C.

(6) **Enstatite:** fused and rounded only on the thinnest edges and points of the smallest pieces; about 1400°C.

(7) **Quartz:** infusible even on the thinnest edges and points of small pieces; over 1400 C.

Note: In using this scale, the hottest or oxidizing flame is used and the thinnest possible splinter of the mineral is tested. These should be held in the tip of the forceps or tweezers, so as to conduct away as little heat as possible. If the sample decrepitates so that splinters can not be used, it should be ground to a powder, mixed with a little water to form a paste, spread in a thin layer on charcoal and heated slowly then strongly until it forms a thin coherent mass that can be held in the forceps and tested in the oxidizing flame.

If a substance fuses easily in the blowpipe flame, but is infusible in the luminous flame or closed tube, it is said to have a fusibility of 3; if it is barely affected by the luminous flame it has a fusibility of 2.5.

15. Ultraviolet rays, also known as "black-light", have found a very definite place in the mineral sciences during the past 30 years. Ultraviolet rays cause certain minerals to glow or release their own light — a phenomenon called fluorescence — and this emission of "cold light" has proven of decided value in the detection and identification of many minerals and ores. Though there are limitations in the use of ultraviolet light, as only a few important economic minerals fluoresce, the simplicity and expediency of this agent have demonstrated that a fluorescence test is essential in all prospecting as well as in mining certain ores. Its greatest usefulness is in the identification of scheelite, zircon, willemite, mercury and petroleum. Other minerals which may or may not fluoresce are agate, aragonite, barite, calcite, chalcedony, fluorite, sphalerite and semi-opal. Try it out in the laboratory and then take the "black-light" to a local beach at night and see how many ore minerals can be found. Limestone terrains are favourable for this type of prospecting.

16. The percentage of a given element in a compound can be determined in the following way. If, for instance, we wish to know the theoretical percentage of copper in chalcopyrite we proceed as follows. The chemical formula is $CuFeS_2$, which means that there is 1 atomic mass of copper, 1 of iron and 2 of sulfur in each molecule. Ref[illegible] to the table of chemical elements we find that the atomic mass of copper is 63.57, [illegible] and of sulfur 32.06. Adding these together in the propor[illegible]exist in th[illegible]le we have:

$$1 \times 63.57 = 63.57$$
$$1 \times 55.84 = 55.84$$
$$2 \times 32.06 = 64.12$$

Mass of molecule 183.53

Dividing the mass of copper by the mass of the entire molecule and multiplying the result by 100 we get the percent of copper, thus: 63.57/183.53 = 0.3463 × 100% = 34.63% copper.

Compute the percentages of metals in the following ore minerals:

Galena	PbS
Cinnabar	HgS
Cassiterite	SnO_2
Aresenopyrite	$FeAsS$
Scheelite	$CaWO_4$
Pyrite	FeS_2
Hematite	Fe_2O_3
Chromite	$FeCr_2O_4$

17. Some simple chemical tests for various elements should be performed by students interested in the mineralogy of ore minerals as well as those interested in prospecting for ore minerals.

(1) **Sodium Carbonate Bead Test.** Treat a speck of the mineral in the soda bead on the platinum loop with the oxidizing flame. Effervescence indicates a silicate; manganese will color it green; chromium colors it yellow. Crush the bead on a silver coin and moisten with water. A darkening of the coin indicates sulfide, selenide or telluride.

(2) **Ammonium Molybdate Test.** Add 1 ml of the solution to a mixture of 1 ml of ammonium molybdate reagent and 1 ml of concentrated nitric acid, and warm. A yellow precip[illegible] indicates phosphate or arsenate.

The ammonium molybdate reagent is made as follows: mix 10 g of MoO_3 with 40 ml of distilled water and 8 ml of concentrated NH_4OH. When solution is complete, pour slowly with constant stirring into a mixture of 40 ml of concentrated HNO_3 and 60 ml of water. Let stand in a warm place for several days. Decant or filter before using. Many other simple chemical tests are given in Identification and Qualitative Chemical Analysis of Minerals, O.C. Smith, Van Nostrand Co.

18. Distinguish between renewable and nonrenewable resources. Make a list of each and collect data on the amounts of nonrenewable resources remaining in the world.

19. Many of the world's remaining resources are unevenly distributed. Empires have flourished repeatedly through history because of their control over rich and easily exploited mineral resources, but they withered with the same frequency as the riches expired. Consider one of the world's most important metals — chromium. What is it used for? Where are chrome deposits located? Some have speculated that this metal alone can change the future of the world because of its present location. Discuss implications of this metal with respect to its present location and its availability to the world's super powers. Do the same for several other metals.

20. A healthy, hard-working person can produce just enough energy to keep a 100-watt light bulb burning. Muscle power is really very puny. Our ancestors found it necessary to develop supplementary sources of energy. First animals, then sails, water wheels, wind mills, steam and internal combustion engines, and eventually motors. Supplementary energy now exceeds muscle power and comes from coal, oil, and uranium. Reverting to muscle power alone would bring chaos. Nature would quickly reduce the population. Discuss one alternative to the present sources of energy and discuss when this alternative might become an important source of energy to the world. What has to be done first?

21. Study a growth rate of the Earth's human population. What is meant by "population doubling time"? By what date will the present world population double again?

22. Despite the so-called green revolution and great advances in farming methods the population is increasing faster than food production. Even with great efforts to expand production from all sources, including the oceans, it is inevitable that the population must cease growing. The earth's theoretical carrying capacity is approximately 33 billion people (U.S. National Academy of Sciences). What is the present world population and by what date will it reach 33 billion if present growth rates continue?

23. Balance and control of population will demand societal responsibility beyond any that mankind has ever attained. There is a strong element of personal choice in all decisions regarding populations. Choice of life styles differ. How will individuals, individual countries, and regions decide what their living standards and their stable populations will be?

24. Discuss the meaning of exponential growth rate.

25. Can exponential growth continue forever? World consumption of mineral resources is still growing exponentially. Geographic consumption of mineral resources is not uniform. Consider the very uneven per capita consumption of aluminum. If the present rate of consumption of this metal in North America and Europe continues the known reserves of this metal will not last long. Write an essay on the possible alternatives to present metal consumption in North America.

26. Canada and Norway supply 74% of the world's nickel. Where is nickel mined in Canada and what is it used for?

27. Canada and South Africa supply 85% of the world's asbestos. Where is it mined in Canada and what is it used for? Are there any environmental problems associated with the development and processing of asbestos?

28. Canada, Nigeria and Zaire supply 97% of the world's tantalum. What is it used for and where is it mined in Canada?

29. Surinam, Jamaica and Australia supply 96% of the world's aluminum ore. What common items in the home are made of aluminum. Can you suggest a method by which the demand for aluminum can be reduced so as to prolong the present reserves?

30. Most mineral resources are derived from the crust. It is predominantly composed of minerals that are crystalline solids with specific and rather simple compositions. Any walk through the mountains will reveal, minerals are not randomly distributed. Limestone is a rock consisting mostly of the mineral calcite ($CaCO_3$). Quartzite is mostly quartz (SiO_2). Chemical elements are distinctly segregated. The richest local concentrations are ore deposits. An ore mineral has economic value but only because it has an exceedingly high local concentration and a low average concentration in the crust. Ore deposits can be said to be high grade accumulations of minerals that are ordinarily too widely dispersed to be of economic value. What geologic processes operate to concentrate valuable minerals in local deposits?

31. The supplementary energy used by man, from all sources, is now about 3.0 × 10^{20} joules per year. Although this number is enormous, it is small by comparison with the solar energy received by the Earth each day: 1.5 × 10^{22} joules. What recent developments have occurred to focus man's attention on the sun as a source of energy and how can the sun's energy be harnessed?

32. Coal is one of British Columbia's most important fossil fuels. It is the oldest economic mineral mined in western Canada having first been produced by settlers on Vancouver Island in 1836. Where are western Canada's coal resources located? Desirable as coal may be for a fuel, many difficulties attend its use. All coal contains from 0.2 to 7.0% sulfur, present as the iron sulfide mineral, pyrite, FeS_2, as ferrous sulfate, $FeSO_4.7H_2O$ or gypsum, $CaSO_4.2H_2O$. When coal is burned the sulphur is released to the atmosphere. Treatment costs are high. How reliable are extraction methods for sulphur in coal? What does it do to the water? Would you like to see western Canada's coal production greatly increased, as it will have to be if we are to limit the use of nuclear power plants in British Columbia. What other environmental hazards are associated with coal development?

33. Crude oil and natural gas, the liquid and gaseous components of petroleum, occur together and have common origins. Crude oil and natural gas are composed chiefly of hydrocarbons and are found in sedimentary rocks. What kinds of rocks are best suited to trap petroleum? Where are they located in British Columbia? What are the petroleum reserves in British Columbia? Note that petroleum, like coal is widespread but unevenly distributed. Many large oil fields have been found beneath off-shore waters. What problems are encountered with the development of off-shore reservoirs such as may exist in the Strait of Georgia?

34. Oil which is particularly thick and viscous is called heavy oil, or, more colloquially, tar or asphalt. Heavy oil is a crude oil in that it contains large molecule hydrocarbons. The largest deposit of heavy oil in the world is found in northern Alberta and is known as the Athabaska Tar Sands. These sands are now being exploited in a small way — about 6 500 tonnes of oil are recovered each day from a 100 000 tonnes-per-day mining operation. If we assume a 50 per cent recovery, the reserve of oil that can be recovered is estimated to represent 0.31 × 10^{22} joules of energy. What problems have been encountered in developing the tar sands and why is development proceeding slowly. What kind of investment has been required to develop the Athabaska Tar Sands and where has the capital come from? Do you think that this oil belongs to all Canadians or to the province of Alberta or to the local landowners in the upper Peace River country? What legal right do British Columbians have to Alberta oil, if any? What is meant by mineral rights and who owns them in Alberta? In British Columbia? Invite a petroleum geologist to discuss the occurrence of oil in British Columbia and if possible do the same for someone that has worked on the tar sands.

35. Hot springs are very common in parts of British Columbia, especially in the Rocky Mountains. Where does the heat come from that warms the waters of the earth? Anyone who has been down a mine knows that rock temperatures increase with depth. Measurements made in deep drill holes from around the world show increases from 15°C to 75°C per kilometre; by projection this means that temperatures of 5 000 C or more must be reached in the core. Considering the size of the Earth, a vast amount of energy is stored within it. This heat may be termed geothermal energy. It is very difficult to locate places where this energy is so concentrated that it may be mined and exploited by man. What special circumstances offer a good deal of promise for geothermal power? Experts suggest that geothermal power will be locally important but globally insignificant. Nevertheless, British Columbia may be one of the few areas where it will become locally important! Make a map showing the location of areas that you think deserve special study and evaluation for possible sources of geothermal power. (Hint. Consult a map of the hot springs of British Columbia.) An important reference is Elworthy, R.T., 1925, Hotsprings in western Canada: their radioactive and chemical properties; investigations of mineral resources in the mining industry. 1925; Can. Dept. Mines, Mines Br., No. 669.

36. Nuclear energy is becoming more important as a source of power in eastern Canada but so far has met with intense resistance in British Columbia. What factors about nuclear reactors and their spent fuel pose threats to life and property throughout the world? Uranium is the chief source of fissionable atoms but measured resources of uranium in rich deposits are unfortunately not so large as we might hope. Where is uranium found in Canada? Your research should reveal that it is principally located in rich vein deposits in the Great Bear Lake region, Northwest Territories and in the Blind River district north of Lake Huron in Ontario. How long will these reserves last? What will take the place of U^{235} — consider the breeder reactor and the process of fusion?

37. British Columbia has been a province that has traditionally relied upon its hydroelectric power to satisfy its power needs. Where does the power come from that is used in your community? How does it get to you? What problems do you forsee if your local power needs triple or quadruple? Do you think that dams should be built on the main stem of the Fraser River? Write an essay on the "fish-problem".

38. Read the booklet entitled 100 ways to Save Energy and Money in the Home. Keep a record of any energy saving devices you have employed and compute the value of the savings after the end of a given period. The booklet is available free of charge from the Department of Energy, Mines and Resources, Ottawa or any local office of the Department such as 100 W. Pender Street, Vancouver.

39. Study the geology and occurrence of ore minerals in one of the following mines or of a mineral bearing property near your school.

Brenda Mine, Cassiar, Yellowknife, Kimberley, Craigmont, Endako, Gibraltar, Granduc, Granby, Lornex, Similkameen, Utah, Western (Addresses of corporate offices are available from the B.C. and Yukon Chamber of Mines, 840 West Hastings Street, Vancouver, British Columbia V6C 1C8.)

40. Porphyry copper deposits are very important in British Columbia. Study the report entitled Porphyry Deposits of the Canadian Cordillera and also the generalized geological map of the Canadian cordillera that accompanies it. Make an oral presentation on the geology of porphyry copper deposits in British Columbia and pass around samples of ores from these deposits. The report is available from the Department of Mines or from the Geological Survey of Canada (Vancouver).

41. An experienced mining engineer proclaimed the development of the Granduc mine, near the Alaskan border in the Coast Range of British Columbia some 970 km north of Vancouver, man's triumph over some of the severest obstacles nature has ever placed in the path of mineral discovery and mine development. Nothing in the Granduc development was easy. The deep orebody is partially covered by a glacier, so open pit mining is not feasible. The terrain is too rugged, direct access to tidewater overland too difficult and the weather too treacherous to permit building a concentrator at the mine site. From the nearest feasible concentrator site, an 18 km tunnel had to be driven under intervening mountain ranges and glaciers to the mine, and a mountain road, subject to heavy snowfall, had to be built to Stewart, the nearest port, 51 km away. Study the history of prospecting and development at Granduc copper mine. It is an exciting story. Write Granduc Operating Company, 890 West Pender Street, Vancouver, British Columbia for its excellent illustrated booklet entitled "Granduc".

42. The mining industry plays an important part in the development of the Canadian economy over the last 10 years. Were it not for this basic resource industry, Canada's export earnings would have been much lower, there would have been significantly less new investment spending and there would have been less improvement in the Canadian standard of living. In 1974, mineral production in Canada (excluding coal, oil and gas) was valued at $6.5 billion, the equivalent of 4.6 per cent of the total output of goods and services as measured by the value of Canada's Gross National Product, and about ten per cent of the value of the total

output of goods-producing industries. In 1974 the mining industry directly and indirectly provided employment for about ten per cent of Canada's total employed labour force and spent nearly $800 million on new capital expenditures. Write an essay on the mining industry in British Columbia emphasizing the critical role played by the world price of copper in the development of copper mines in British Columbia.

43. Make a map showing the location of British Columbia's copper mines and outline an exploration program which might lead to the discovery of a new mine in British Columbia. Which geologic factors are most important in locating a copper mine?

44. Play GET THE ZINC OUT, a game developed by VEEP at the University of British Columbia and for sale as a lesson aid by the B.C. Teacher's Federation.

45. Canada's uranium deposits are becoming more important as more nuclear reactors are developed throughout the world for power supply. Canada's most extensive uranium deposits are quartz-pebble conglomerate beds in the Elliot Lake region mid-way between Sudbury and Sault Ste. Marie near the north shore of Lake Huron. Denison Mines Limited and Rio Algom Limited have been mining these beds since the 1950's and expect to be mining them until after the turn of the century. Madawaska Mines Limited was recently incorporated to recover uranium from the dormant Canadian-Faraday mine near Bancroft, Ontario. The uranium ores occur in pegmatite bodies there.

In eastern Labrador two deposits (Kitts and Michelin) have been outlined near Kaipokok Bay by Brinex Limited, a subsidiary of Brinco Ltd. Eldorado Nuclear Limited's Beaverlodge operation in the vicinity of Uranium City a few kilometres from the north shore of Lake Athabasca in northern Saskatchewan recovers uranium from pitchblende-bearing veins and related deposits.

Consolidated Rexspar Minerals and Chemicals Limited has outlined a deposit in the Birch Island area near Kamloops, British Columbia. A significant fraction of the company is owned by Denison Mines Ltd.

Write an essay on the assessment of Canada's uranium resources and include the projected production capacity as well as Canadian uranium requirements and the possible world demand by the year 2000. Write for the free booklet entitled 1974 Assessment of Canada's Uranium Supply and Demand, Department of Energy, Mines and Resources, Ottawa. Discuss methods of uranium exploration.

46. One of the largest producers of copper concentrates in Canada is the Island Copper Mine, located near Port Hardy, British Columbia at the northern end of Vancouver Island. It is operated by Utah Mines Ltd. Estimated reserves are near 250 million tonnes of copper-molybdenum ore with an average grade of 0.52% copper, 0.027% molybdenum sulphide. The capital cost required to start-up the mine was $88 million and the first shipment was made in December of 1971. The original discovery on the present Island Copper property was made late in 1965 by a local prospector, Gordon Milbourne, who exposed indications of pyrite and chacopyrite mineralization in a depression under two overturned trees. The Island Copper deposit is a typical copper porphyry. Mineralization occurs in volcanic andesites which have been intruded by a quartz feldspar porphyry. Write a report on the geology and milling operations at Island Copper Mine. Make use of an excellent booklet available from the company entitled "Island Copper Mine". Write Utah Mines Ltd., Suite 1600, 1050 West Pender Street, Vancouver, British Columbia, V6E 3S7. For specimens of the ores found in the Island Copper deposit write Utah Mines Ltd., P.O. Box 370, Port Hardy, British Columbia V0N 2P0.

47. The offshore oil reserves of eastern Canada were first tapped in 1971 when a Halifax newspaper printed the massive headline "IT'S OIL!" The oil, natural gas and condensate (liquids associated with natural gas) were discovered in a well that was drilled on lonely Sable Island, 290 km southeast of Halifax. Study the exciting prospect of offshore oil and its future in supplying Canada's energy needs. Write for the booklet entitled "Resources Under the Sea" available from the Department of Energy, Mines and Resources, Ottawa.

48. Anvil Mine in Canada's great North country is a major lead-zinc discovery located about 170 km below the Arctic Circle in the Yukon Territory. Anvil represents a major element in the economic picture of Canada's North. It provides hundreds of jobs where none existed. It brought to life the second largest community in the Yukon where there was only sub Arctic wilderness. On June 5, 1965 a Vancouver geologist and U.B.C. graduate named Aho unknowingly camped on top of the orebody near Vangorda Creek in the Yukon Territory. After extensive initial exploration revealed the potential of the area Dynasty Explorations Ltd., a Vancouver company, was formed to develop the mine. Eventually Cyprus Mines Corporation entered into a joint venture agreement in 1965 and Anvil Mining Corporation was formed. A minimum reserve of 57 million tonnes of ore containing 9% combined lead and zinc and more than 31 grams of silver per tonne was outlined. Discuss the geology and ore minerals of this exciting new development in the Yukon. An outstanding, multicolour booklet with many good bulletin board type display materials is available from Anvil Mining Corporation, Ltd., 1550 Alberni Street, Vancouver, British Columbia and ore samples are available from Anvil Mining Corporation, Ltd., Box 1000, Faro, Yukon Territory.

49. The Highland Valley of British Columbia has been the scene of intense mineral exploration and mining activity at various periods since the early part of the century. Early in this period, high-grade copper vein deposits were mined on a small scale with the ore being hauled to Ashcroft in horse-drawn wagons. In recent years, however, advances in mining technology and higher copper prices, until 1974, have permitted the large low-grade mines to come into being. One of the important ore bodies is the Lornex deposit, approximately 45 km by road from Ashcroft and directly south of Bethlehem Copper Corporation's mine on the north side of the valley. The Lornex orebody contains an estimated ore reserve of 266 million tonnes with an average grade of 0.427 per cent copper and 0.014 per cent molybdenum. The capital cost of financing the initiation of mining at Lornex is estimated to be $138 million. The Lornex deposit is contained in a roughly-elliptical area 1.200 km in length, 490 m in width and at least 600 m in depth and still open. The principal minerals in the sulphide zone are chalcopyrite, bornite, and molybdenite with minor pyrite, magnetite, hematite, rhenium, osmium, gypsum, epidote, calcite and chlorite. The mineralization occurs mainly as fracture fillings either in quartz carbonate veins up to 30 cm in width or along joints, slips, and minute fractures, and as sparsely-disseminated mineralization generally replacing hornblende and biotite. Fracture density and strong alteration appear to be keys to the higher-grade copper-molybdenum values. The staff of Lornex Mining Corporation Ltd. has discussed in considerable detail the entire operation from geology to milling in a booklet that is available by writing: Lornex Mining Corporation. Ltd., 580 Granville Street, Vancouver, British Columbia. Ore specimens may be obtained by writing Lornex Mining Corporation, Ltd., P.O. Box 1500, Logan Lake, British Columbia.

50. Placer Development Limited is a Canadian mining company with international interests. It brought the Gibraltar copper mine, one of Canada's largest base metal mines in terms of daily throughput, into production. It also developed and manages the Craigmont copper mine at Merritt and the Endako molybdenum mine at Fraser Lake. Placer has developed an excellent summary of the science of mining in a booklet entitled "The Mine Development Process", available from their offices at 700 Burrard Building, 1030 West Georgia Street, Vancouver, British Columbia V6E 3A8. Ore specimens may be obtained by writing Craigmont Mines Limited, P.O. Box 3000, Merritt, British Columbia V0K 2B0, where copper bearing minerals are obtained from an underground mine. Endako Mine, the world's second largest molybdenum mine, began production in 1965 and is located about 160 km west of Prince George. Ore minerals containing molybdenum may be obtained by writing Canex Placer Ltd., Endako Mines Division, Endako, British Columbia VoJ 1L0. Gibraltar Mines began operations in 1972. It is a large open pit copper producer near Williams Lake in the Cariboo. Write to Gibraltar Mines Limited, P.O. Box 130, McLeese Lake, British Columbia V0L 1P0 for ore specimens.

51. A multi-coloured map showing the PRINCIPAL MINERAL AREAS OF CANADA is available free of charge from the Department of Energy Mines and Resources, Ottawa. The map (900A) is in its 21st edition and is printed at a scale of 2.54 cm to 193 km.

52. An excellent summary of the changing pattern of energy sources in Canada and a discussion of environmental issues involving energy use is available from the Department of Energy, Mines and Resources, Ottawa. It is entitled INTRODUCTION TO ENERGY IN CANADA.

53. One of the best all around sources of information on Canada's mining industry from the urban planning of the mine site to progress on pollution control and space-age mining is available from The Mining Association of Canada, 20 Toronto Street, Toronto, Ontario M5C 2C2. It is entitled WHAT MINING MEANS TO CANADA, 63 pages. It includes many coloured photos and a glossary of some mining terms and tools. A sample from the glossary is **concentrate** — to treat ore so that the result — "concentrates" — will contain less waste and a higher amount of the valuable mineral. In many mining operations, ore is concentrated in a concentrator or mill on the surface, then shipped to a smelter, whose product is then sent on to a refinery for the recovery of the mineral content by eliminating impurities.

54. The Whitehorse Copper Belt, is an important zone of copper mineralization first discovered by miners on their way to the Klondike in 1897. No staking was done until 1898, when Jack McInyre staked the Copper King in July of that year. By 1899 the district had been well prospected and most of the presently known deposits had been staked. The property was intermittently active from 1900 to 1912 but between 1912 and 1917 major shipments were made from the Pueblo property. The Pueblo was closed by a major disaster in March of 1917 when ground movements trapped nine men underground; three were rescued but six lost their lives. Subsequent activity took place periodically between 1927 and 1973, but was mostly inactive until after world war II. In 1971 a joint venture was formed with Hudson Bay Mining and Smelting and Amcan. The copper belt lies on the west side of the north westerly trending Yukon River valley. The main known deposits lie [illegible] western edge of the Whitehorse batholith in skarn zones developed where Trias[illegible] are in contact with the intrusive. Information on this belt may be obtained by writing Whitehorse Copper Mines Ltd., P.O. Box 4280 Whitehorse, Yukon Territory.

55. Similkameen Mining Company, Ltd. has a major copper mine near Princeton, British Columbia. Early copper showings have been known on what is now company property since before the turn of the century. Various amounts of unsuccessful development work were done before 1923 when the Copper Mountain area west of the Similkameen River was acquired by the Granby Consolidated Mining, Smelting, and Power Company. During the periods 1926-1930 and 1937-1957 Granby successfully produced copper from the area, with approximately 31 million tonnes of ore, grading about 1% copper, being mined and concentrated. In December 1967 Newmont Mining Corporation purchased all of the Granby holdings and in July 1970 a go-ahead decision was made by Newmont.

The Ingerbelle and Copper Mountain orebodies lie within a 4 300 km by 1 100 km belt of Nicola rocks. These rocks are composed of andesitic tuffs and agglomerates, lessor amounts of flows, and some lensy siltstone layers. The volcanic belt is bounded on the south by the Copper Mountain stock consisting of diorite, monzonite and pegmatitic syenite. Chalcopyrite mineralization at Ingerbelle o[illegible]s as disseminations, discontinuous fracture-fillings and coarse blebs. Sulphide veins up to several centimetres thick are rare. The host rocks are mainly altered tuffs and agglomerates. Ore reserves recoverable by open pit mining at Ingerbelle are estimated at 41 million tonnes of 0.53% Cu. Two smaller pits are located on the east side of the valley and these contain an additional 27 million tonnes of 0.52% Cu. A booklet entitled THE SIMILKAMEEN PROJECT describes the mine and its geology. Write Similkameen Mining Company, Ltd., P.O. Box 520, Princeton, British Columbia V0X 1W0.

56. Several excellent brochures are available from Cominco Ltd., 200 Granville Square, Vancouver, British Columbia V6C 2R2. These are entitled: COMINCO AT WORK, HISTORY OF COMINCO, QUICK FACTS ABOUT COMINCO, HOW WE DO IT AT TRAIL, HOW WE DO IT AT YELLOWKNIFE, HOW WE DO IT AT KIMBERLEY. The Cominco mine's most famous ore deposit at Kimberley, British Columbia is termed the Sullivan orebody. The surface outcrop of the orebody was found near the present site of Kimberley, British Columbia in 1892. Building of a small copper-gold smelter was begun October 10, 1895 by F. Augustus Heinze at Trail Creek Landing for the treatment of Rossland ores discovered at Red Mountain. In 1896 Heinze built a narrow-gauge railway from Trail to Rossland calling it the "Columbia and Western Railway" and in 1898 it became part of the Canadian Pacific Railway. By 1974 the Cominco company revenue was a record $792.7 million yeilding net earnings of $86.3 million.

The Sullivan ore body is essentially a sulphide replacement of certain argillaceous and silty beds in the Aldridge formation of late Precambrian age. The deposit is a large lens that occupies part of the crest and eastern flank of an anticlinal [illegible] Galena and sphalerite are the main ore minerals. They are associated with pyrrhotite [illegible] quartz, chlorite, muscovite, tremolite, clinozoisite, titanite, tourmaline, garnet, biotite [illegible]ite. As a result of selective replacement of the original beds, the ore is distinctly layered and folding on a large or small scale is common.

One aspect of the origin of the ore in the Sullivan ore body is related to plate tectonics and Geology 12 teachers may want to make reference to this when they discuss the economic geology of British Columbia. Recent discoveries of metalliferous brines in the Salton Sea area and the Red Sea, a rift zone, have influenced present day concepts of ore genesis in the Sullivan body. Unfortunately, due to the effects of regional metamorphism the critical relationships required to prove that the zinc and lead at Kimberley were derived this way cannot be proven. A conventional hydrothermal replacement origin is supported by the association of the massive and sometimes transgressive ore with extensive alteration zones in both the footwall and hanging wall of the upper mine. This theory however has difficulty in explaining the delicate and faithful reproduction of what appear to be **sedimentation features** in the lower parts of the mine. One of the best papers on the origin of the orebody at Kimberley is entitled "On the Origin of the Sullivan Orebody, Kimberley, British Columbia" Can. Inst. Min. Met. Special Vol. 8 by Freeze, A.C., (1966).

57. Over a hundred years ago 5000 men were searching for gold in the Cassiar area of British Columbia. That was nearly thirty years before news of the great Klondike gold rush ripped through the world like a raging storm. The Cassiar gold seekers who had struggled inland from the Pacific Ocean spread out along the bars of McDame Creek and commenced the serious business of turning themselves into overnight millionaires. A few became wealthy. But the rest simply came, worked, and then departed. All that is left of those lively days is evidence of the old gold workings and the rotting remains of Centerville, an early gold rush boom town just 32 km down the road from Cassiar. Even in those days the Indians spoke of a "wooly hill" to the north, and birds that built their nests of white fluff that could withstand the raging fires of the forest. And the early gold seekers noted that a prominent green band of serpentine rock slanted across the rugged face of McDame mountain. Others told tales of mountain sheep coated with a yellow-green fluff that came from a nearby mountain sporting a 'white plume'. And the talk went on, but nobody did anything about it. When World War II broke out Victor Sittler of Lower Post was a mechanic working on the Alaska Highway maintenance at Fort Nelson. He had heard all the myths and legends about McDame mountain and reasoned that the deposit must be asbestos. But it was not until 1950 that Sittler and three partners fought their way through the mountainous country to where Cassiar stands today. The four prospectors climbed McDame mountain, and there it was: a great outcropping of yellowish oxidized asbestos. Read the rest of the story in the booklet entitled CASSIAR, an excellent source of many potential bulletin board photos and cross-sections of the mine and the underground mining operation of the future, the open-pit m[illegible]ay. The booklet is obtained by writing: Cassiar Asbestos Corporation, Ltd., Suite [illegible] Guinness Tower, 1055 West Hastings Street, Vancouver, British Columbia V6E 3V3.

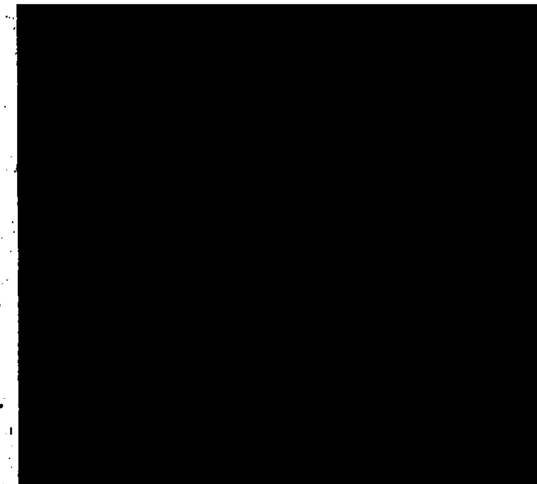
58. The Brenda deposit is 225 km east-northeast of Vancouver and 23 km northwest of Peachland in the southern interior of British Columbia. The area around the depost is typified by gentle rolling, tree-covered upland. During the late 1930's and early 1940's the Sandbergs of Kelowna worked on their "Copper King" property exploring a 30 cm chacopyrite-molybdenite bearing quartz vein. They abandoned their claims in the early 1940's and the property lay dormant until it was rediscovered in 1954 by Bob Bechtel, a weekend prospector from Penticton. Between 1954 and 1964, several examinations and test drillings of the property were conducted but the low copper and molybdenum grades and lack of demand for molybdenum discouraged the investigators. With funds obtained from Nippon Mining Company and private individuals, a detailed exploration program was initiated in 1965. Noranda Mines Limited began providing major financing in June 1966 and now Noranda holds 50% of the issued common shares. At start-up in early 1970 the Brenda orebody had proven reserves of 161 000 000 tonnes grading 0.183% Cu and 0.049% Mo and by January of 1974 reserves were 124 000 000 tonnes of 0.179% Cu and 0.046% Mo. Capital outlay required to develop the Brenda property was $63.5 million.

The Brenda orebody is located within the Brenda Stock, a quartz diorite of Jurassic age which intrudes the stratified tuffs, tuff breccias, argillites, and limestones of the Nicola Group. Mineralization of economic grade occurs in a strongly fractured area 790 m long and 460 m wide. The ore minerals are chalcopyrite and molybdenite along with minor pyrite and occasional magnetite. These ore minerals occur as fillings within fractures. Disseminations are rare except in areas of intense hydrothermal alteration. Write to Brenda Mines Ltd., P.O. Box 420 Peachland, British Columbia V0H 1X0 for their excellent booklet with many coloured photos entitled BRENDA. It includes a very readable summary of the history of ownership, geology, property operations, mining operation, mine production equipment, mineral processing, and tailings-reclaim water systems — one of the most advanced in the industry.

59. The Gibraltar Mines Ltd copper property located 160 km south of Prince George is an excellent focus for students enrolled in schools of Williams Lake. The Gibraltar property was discovered in 1927 and was known as the Hill property. The Pollyanna was discovered in 1910 and at that time, was known as the Rainbow group. After many periods in which claims were allowed to lapse and some intermittent periods of minor production the Duval Corporation Ltd optioned the property in 1964. Duval participated with Canex-Aerial Exploration in 1967 on an equal basis to explore the claims. Later, Canex bought Duval's interest and by 197[illegible] held more than 70% of the issued shares of Gibraltar Mines Ltd.

The geology of the area reveals that in the vicinity of Granite Mountain the oldest rocks are regionally metamorphosed sedimentary and volcanic rocks of the Cache Creek group of Permian age. Batholithic intrusives of Jurassic-Cretaceous age intrude the Cache Creek group in the Granite Mountain area. The batholiths are composed of granodiorite, quartz diorite, diorite and gniessic varieties of the above rocks. In the immediate vicinity of Granite Mountain, a regionally foliated and metamorphosed quartz diorite occurs which has a chlorite rich diorite margin. Calcareous members of the Cache Creek group locally show some skarn development adjacent to the diorite contact. It is within the regionally metamorphosed and foliated quartz diorite that the Gibraltar-Pollyanna copper-molybdenum deposits occur.

Deformation of the quartz-feldspar porphyry intruding the pluton resulted in a fracture system which is controlled by the regional foliation. Within the fractures the sulphide zone is localized. It consists of a chalcopyrite-secondary chalcocite molybdenite zone between a low sulphide core and a pyritic halo. Write Gibraltar Mines Ltd. McLeese Lake, British Columbia for specimens and information.



PLANETOLOGY

LEARNING OUTCOMES AND SUGGESTED ACTIVITIES

The Earth and the Solar System
The Earth-Moon System
The Geology of the Inner Solar System

Teacher Resource Material is indicated by number in the parentheses following most Learning Outcomes. Details regarding references, activities and investigations follow the respective sections of the Geology 12 course. (These are suggested activities only and may be used at the discretion of the teacher.)

PLANETOLOGY [redacted]

In this section, the students will study the Earth along with other inner planets and Moon. They will examine the knowledge gained in the preceding sections from an inter-planetary perspective. An attempt should be made to emphasize that the Earth is not entirely unique in terms of its origin, history of its geological evolution, various tectonic and geomorphological features and the geological processes which continue to affect it from within or outside.

THE EARTH AND THE SOLAR SYSTEM

In this unit, students are introduced to the general features of the Solar System as well as some of the latest discoveries made about the planets.

LEARNING OUTCOMES

The student should be able to:

1. *Describe the members of the solar system.*

   (Activity #1, 2)

★ 2. *Propose and defend the criteria which help divide the planets in two groups: the* **inner planets** *(Mercury, Venus, Earth and Mars) and the* **outer planets.**

   (Activity #2)

3. *Compare the kinds of contributions made by the modern manned/unmanned space probes to those made by early and modern astronomers to the present state of understanding of the Moon and the solar system.*

   (Activity #3, 4, 10, 14)

4. *Discuss the major discoveries about the Moon, the planets and the solar system made during the past two decades.*

   (Activity #3, 4, 6, 7, 8, 10, 14)

5. *Discuss some limiting factors, and the assumptions, to be considered in the study of the solar system.*

   (Activity #1, 5, 11, 14)

Note: See References and Activities and Investigations at end of this Section.

THE EARTH-MOON SYSTEM

This unit deals primarily with the geological structure and evolution of the Moon as it relates to Earth. It should be emphasized how lunar exploration has yielded information about the early history of the Earth-Moon system, as well as the inner solar system.

LEARNING OUTCOMES

The student should be able to:

1. *Describe and distinguish between the different gross physical features observed on the near and far side of the lunar surface.*

   (Activity #3, 4, 11)

2. *Suggest reasons for the differences between the features observed on the two sides of the Moon.*

   (Activity #5, 9, 11, 12)

★ 3. *Compare and contrast some of the physical features observed on the Moon to those seen on the Earth's surface.*

   (Activity #3, 5, 9, 11, 12, 13, 15)

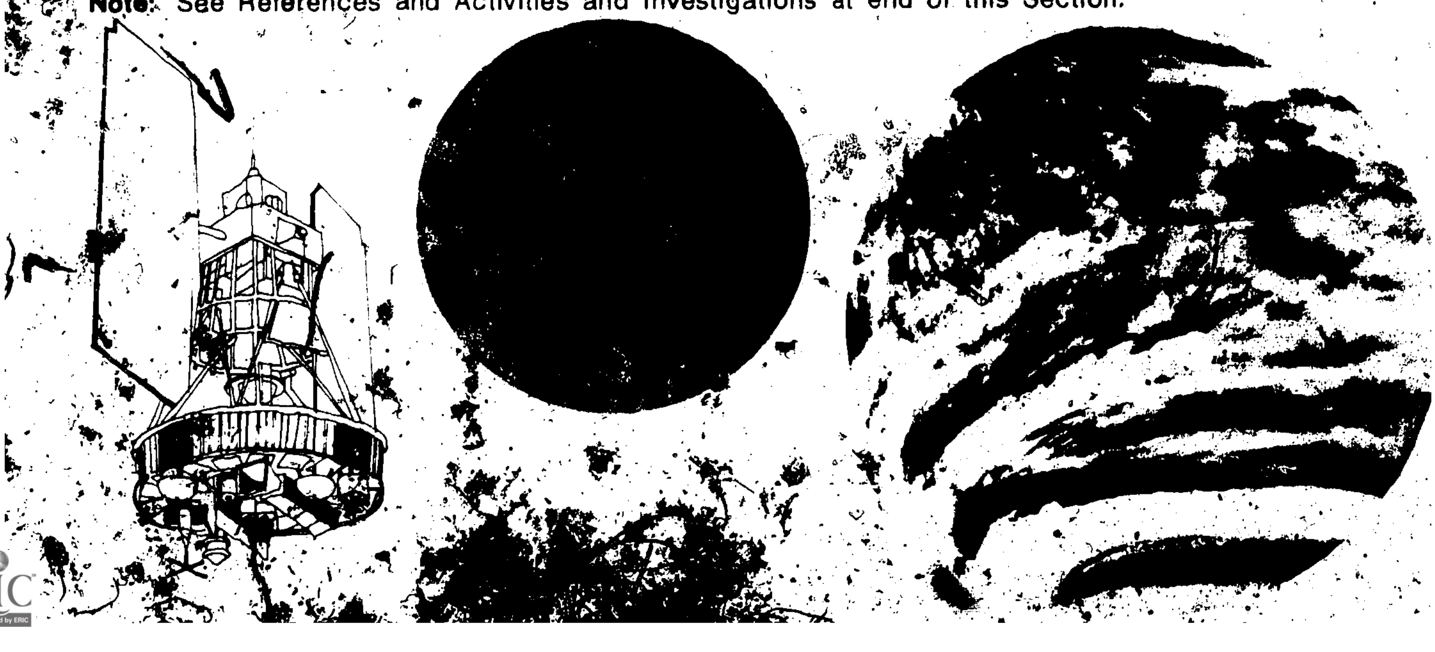
★ 4. *Describe major aspects of lunar geology, internal structure, chemical and mineralogical characteristics of lunar rocks and compare them to those on Earth.*

   (Activity #3, 9, 12, 13, 15)

5. *Describe various kinds of craters identified on the Moon and discuss some theories to explain their origin and geological/chemical evolution of the Earth-Moon system.*

   (Activity #3, 5, 9, 11, 12, 13, 14, 15)

Note: See References and Activities and Investigations at end of this Section.



THE GEOLOGY OF THE INNER SOLAR SYSTEM

Students should be encouraged to use the concepts learned in this and the earlier sections to examine the earth as one of the planetary bodies along with other inner planets. Major ideas about the planets and the new hypotheses about their origin and evolution should be discussed.

LEARNING OUTCOMES

The student should be able to:

★ 1. *Des[illegible] significance of some major topographic and tectonic features identified on Mercury, Ve[illegible]*

(Activity #5, 6, 7, 8, 9, 11, 15)

★ 2. *Discuss current theories which attempt to relate the geology and internal structure of Mercury, Mars, and Venus to those of the Earth and Moon.*

(Activity #13, 14, 15)

★ 3. *Discuss the current theories which attempt to explain the origin and the geological evolution of the inner solar system.*

(Activity #14, 15)

★ 4. *Describe some modern theories which attempt to explain the origin and evolution of the solar system as a whole, and explain the difficulties in formulating a generally acceptable theory.*

(Activity #14, 15)

5. *Identify some unexplained observations and unsolved problems which scientists f[illegible] inner solar system.*

(Activity #10, 13, 14, 15)

Note: See References and Activities and Investigations at end of this Section.

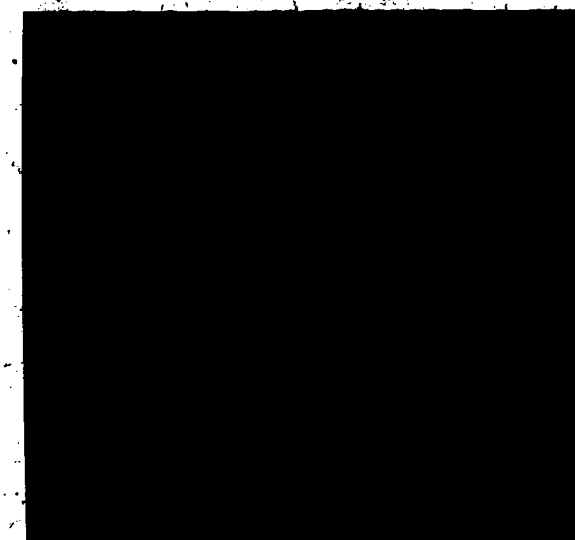
References

Note: Due to the very special nature of this section, several references listed below are not in the lists of Geology 12 prescribed textbooks or supplementary reference texts. Many excellent publications are still in press and will become available in the coming months. In the list of the references below, those marked • are from the lists of prescribed texts and supplementary books of both Earth Science 11 and Geology 12.

• 1. James, J.R., *Geology and the New Global Tectonics*, Macmillan of Canada, 1976.

• 2. Bickford, et al., *Geology Today*, CRM Books, Random House, 1974.

• 3. Hamblin, and Howard, *Exercises in Physical Geology* (4th Ed.), Burgess Publishing Company, 1975.



4. Stokes, W.L., *Essentials of Earth History* (3rd Ed.), Prentice-Hall, Inc. 1973.

5. *The Solar System*, Scientific American Reprinting of September, 1975 issue, W.H. Freeman, 1976.

6. *Exploration of Planets: Mariner, Pioneer and Viking Missions* (Teachers' Guide) B.C. Teachers' Federation Lesson Aid, BCTF Lesson Aids Service, 2235 Burrard Street, Vancouver, British Columbia V6J 3H9, 1977.

7. Long, L.E., *Geology*, McGraw-Hill Book Comapny, 1974.

8. Goldthwait, L., *Earth Science*, Ginn and Company, 1972.

9. King, E.A., *Space Geology: An Introduction*, John Wiley & Sons, Inc., 1976.

10. Bodechtel and Gierloff-Emden, *The Earth From Space* (English translation from German by Mayhew and Evans), David and Charles (Holdings) Ltd., Great Britian, 1974.

11. Tatch, J.H., *The Moon: Its Past Development and Present Behaviour*, Tatch Associates, Sudbury, Mass., 01776, 1974.

12. Soffen, G.A., et al., *Scientific Results of the Viking Mission: Reports*, Science (AAAS), 17 December, 1976, Vol. 194, No. 4271.

13. Ordway, R.J., *Earth Science* (2nd Ed.), D. Van Nostrand Company, 1972.

14. Press and Siever, *Earth*, W.H. Freeman and Company, 1974.

15. *National Geographic Articles*, January, 1977 (Mars: As Viking Sees It and The Search for Life); February, 1975 (Mysterious Jupiter); June, 1975 (Flight to Venus and Mercury); May, 1975 (The Incredible Universe: Seven Men who Solved the Riddles of the Cosmos); February, 1972 (Apollo 15 Explores the Mountains of the Moon); December, 1972 (Apollo 16 Brings Us Visions From Space); and several others.

16. *What's Up?* Probing the Natural World/Level III, Intermediate Science Curriculum Study Module, Silver Burdett/GLC.

Audiovisual Aids:

Note: The following specific audio-visual aids will be found useful for teaching the section on Planetology. Some of these may not be listed in the general list for Geology 12 or Earth Science 11 courses.

Study Print Series from EBE

#5940 The Solar System

[illegible] The Earth-Moon System (Color)

[illegible] The Moon (Color)

#[illegible] Studying the Lunar Rocks (Color)

Films

1. Mars: The Search Begins, NASA
2. The Moon: An Emerging Planet, NASA

PAGES 101-102 MISSING FROM DOCUMENT PRIOR TO ITS BEING SHIPPED TO EDRS FOR FILMING.

BEST COPY AVAILABLE.

4. The exercise above may also be used to explore the origin of the names of lunar and other planetary features. Many of the features on the moon were first named in the 17th century by an Italian astronomer, Riccioli. To him, the largest dark patch on the moon was an "ocean", those a little smaller the "seas" or "gulf" or "lakes", and so on. The terminology is still in use today and reflects the then prevailing hypotheses about the origin of various features on the moon.

The lunar craters derive their names after the famous Greek philosophers (Plato, Ptolemy, Archimedes) or famous Renaissance figures (Copernicus, Kepler). The lunar farside was first photographed by a Soviet Space Probe and features landforms named to honour the Russian scientists.

The students may further be asked to investigate the origin of the names given to major topographic features on Mercury and Mars, such as Olympus Mons, Caloris basin, Kasei Vallis.

5. Surface features on the earth are products of complex interactions between different geological processes often unfamiliar on the other members of the inner solar system. Students may be assigned to study and analyse high altitude photographs of the earth, the moon, Mars and Mercury and investigate the following:

(a) what are the kinds of landforms common on, and distinctive of, each planet? What are their relative abundance, and why?

(b) what are the kinds of geological processes (or their absence) which help create (or destroy) these landforms?

(c) speculate to indicate how the nature of these landforms and the geological processes may have changed in the past, and may change in the future.

See **Bickford**, photographic essay: "Circular Landforms", pp. 114-121; **Hamblin and Howard,** pp. 61, 67, 150, 152, 174-180, 188, 192, 194, 196, 200, 204, 212, 216, 218-229; **'Exploration of Planets'** (BCTF Lesson Aid) slides; **Press and Siever,** Chapter 23, pp. 794-823.

6. Lab exercise in Hamblin and Howard on p. 166 is an excellent way to familiarize the students with the geology, age relationship of the landforms, and the nature of crater 'ejecta', lava flows, and the possible origin of various landforms on the moon.

See **Hamblin and Howard,** Chapter 19 (Geology of the Moon, Mars and Mercury), pp. 166-167, 218-227; **Tatch,** Chapter 12 (Summary and Conclusions), pp. 256-269; **King,** Chapter 6 (The Moon), pp. 153-169; **Bodechtel and Gierloff-Emden,** (The Moon, Satellite of the Earth), pp. 165-176.

7. Lab exercises in Hamblin and Howard on pp. 168, 170, 172, 174-177, and the accompanying Mariner 9 pictures will provide an excellent basis for students to understand the basic concepts of the geology of Mars. The exercise also makes an attempt to compare the Martian surface processes with those on the earth.

These pictures may be supplemented with more provided in the BCTF Lesson Aid 'Exploration of Planets' and the accompanying teachers' guide.

See **Hamblin and Howard,** pages as indicated above; **'Exploration of Planets',** Teachers' Guide; **Janes,** Chapter 13, pp. 439-441; **Ordway,** Chapter 23, pp. 576-580; **Press and Siever,** Chapter 23, pp. 817-824; **The Solar System,** MARS, the article by James Pollack.

8. A lab exercise in **Hamblin and Howard** on pp. 178-179 will also provide a good introduction to the basic concepts of the geology of Mercury and attempts to compare these features to those on the moon.

As in the case of the earlier activity about Mars, additional pictures of Mercury are available in the slide set by BCTF.

It has been suggested that the surface of Mercury resembles that of the moon whereas its interior may be more like that of the Earth. This observation may, however, be only partially acceptable. The students may be given the task of looking closely at selected pictures of the moon, and Mercury, as well as consider other relevant information such as the bulk densities of the three bodies and collect evidence to defend or contradict the statement. Some specific questions which may be considered, are:

(a) what specific evidence has been uncovered to indicate that Mercury may have a metallic core like the Earth?

(b) Long, linear features identified as scarps are seen for hundreds of kilometres displaying a cross-cutting relationship with craters and inter-crater areas on Mercury. What may be their significance in working out the geological history of Mercury?

(c) What catastrophic (or otherwise) incident may have caused the formation of huge impact basin on Mercury called Caloris Basin? What are some similar huge basins on the moon and what is known about them?

9. Cratering is an important planetary process. Students may be asked to investigate the general phenomenon, possibly with the help of self designed experiments and the study of the appropriate photographs. Some aspects which they may consider are, the kinds of craters (impact or volcanic), morphology of craters, relative abundance on a planet, presence of an atmosphere or a lack of it, the value of surface gravity, etc.

Students may also be asked to develop specific criteria which may help identify the two kinds of craters on planets. Some other questions which may be explored are:

(a) where are the volcanic craters on the earth?

(b) are there any meteorite impact craters on the earth? In Canada? On a map of Canada, locate all famous impact craters. What is an 'astroblem'?

(c) why does earth have so few impact craters as compared to the other inner planets?

(d) why do we not see any 'rayed' craters on the earth which are common on the moon?

See, **Janes,** Chapter 13, pp. 419-426; **'Exploration of Planets'**, Teachers' Guide and the slide set; **Ordway** Chapter 5 (Igneous Activity/Volcanic Topography), pp. 124-128; **Bickford,** Chapter 4, pp. 114-121; **King,** Chapter 3 (Craters) and Chapter 4 (Terrestrial Impact Craters), pp. 81-91 and 95-124, respectively.

10. Most schools and the public libraries contain a number of 'out of date' books dealing with planets and astronomy. These books were published more than ten years ago. Students may be asked to study a number of these books to help them answer questions like the following:

(a) what are some earlier models of the planets such as Mercury, Venus, Mars, Jupiter and the origin of the solar system?

(b) what kind of discoveries were claimed to be new and revolutionary in the early and middle 20th century? How do they rate with those being made now?

(c) what is the role of manned/unmanned space probes in the field of planetary astronomy today?

(d) what kind of questions were being asked about the planets about 25 years ago?

(e) what were the expectations of the astronomers in terms of future discoveries in space sciences, before 1950?

11. Detailed geological maps of the moon are already available and those of Mercury and Mars are likely to be published soon. The same is true of the relief maps of these planets. The students should make scale models of the features like the ones listed below;

(a) Martian terrain as seen by the Viking landers.

(b) Olympus Mons, as seen by Mariner 9 and Mauna Loa in Hawaii or Mount Baker, at the same scale.

(c) Lunar Orbiter view of Crater Copernicus.

(d) nearside of the lunar surface, showing major craters, maria and rilles.

(e) general terrain on Mercury, showing craters, ridges and scarps.

Some related aspects to consider are: what kinds of rocks are known to be found on these planets? What will the area look like if the pictures returned were in color? What material will make the models look more realistic? What is the resolution of the pictures being used to make the models? etc.

See, **National Geographic,** issues listed in Reference Cited and several others; **Exploration of Planets** (Teachers' Guide), BCTF Lesson Aid; **Ordway,** Chapter 22, pp. 552-559, Chapter 23, pp. 578-579; **Goldthwait,** Chapter 9, pp. 195-200; **The Solar System, Mars,** the article by Pollack, **Mercury,** the article by Murray; **Long,** Chapter 2 (The Double Planet), pp. 28-39.

12. Several excellent activity and investigation ideas are included in ISCS Program module named 'What's Up?' There are several activities dealing with the processes of formation of craters, impact craters on the earth, photographs of lunar craters taken with varying angles of sun's rays, origin of craters on the moon. As well there are several excellent pictures of lunar features.

See, **What's Up?,** Intermediate Science Curriculum Study Module, pp. 55-89.

13. The students may be asked to investigate the internal structure of the moon, and compare that to the internal structure of the earth. This can be done through a study of the seismic phenomenon which is reasonably well documented. They must be made aware of the fact that there are several seismographs on the moon still continuing to operate and send data to the earth. They should investigate the nature of P, S and L waves and how it helps understand the internal structure of a planet:

Some questions which may be probed through the suggested readings are:

(a) what are different models of the lunar interior?

(b) what specific information has helped scientists reconstruct these models?

(c) what are major differences between the lunar and earth seismicity?

(d) what is known about the structure of the lunar crust?

See. **Long,** Chapter 2. pp. 38-42; **King,** Chapter 6 (The Moon/Lunar Geophysics). pp. 215-219; **Bickford,** Chapter 1 (Earth's Place in Space). pp. 41-42; **Tatsch,** Chapter 7 (Lunar Structure and Composition). Chapter 8 (The Moon's Thermal History). Chapter 9 (Lunar Magnetism). Chapter 10 (The Moon's Seismicity) and Chapter 11 (The Moon's Gravity Field), pp. 130-185; **Stokes,** Chapter 7 (Cosmic Beginnings). pp. 161-164 and Chapter 8 (Structure and Mechanics of the Earth). pp. 168-188.

14. Ask students to read about the theories of the origin of the solar system especially in their proper cosmic context. Students may make a list of some diverse observations which must be accounted for by an acceptable theory. Some of these observations are: why are the inner planets rocky? Why are the inner planets smaller in size? Why are planetary orbits in practically the same plane? Why does the sun possess about 99% of the total mass of the solar system but only 2% of its total angular momentum? etc.

Students may also investigate why it is difficult to come up with a model of the solar system and its origin at the present state of our knowledge. How some of the earlier models have become obsolete in the light of new information about planets. Students should be made to realize that the new data has on one hand provided answers to questions but on the other hand tends to raise new questions.

See, **Stokes,** Chapter 7, pp. 150-166; **Long,** Chapter 1 (Cosmic Beginnings), pp. 2-20; **Bickford,** Chapter 2 (Earth in Evolution), pp. 47-63; **Tatsch,** Chapter 1 (The Origin of the Solar System); **Ordway,** Chapter 12 (Origin and Development of the Earth and Its Crust), pp. 309-312.

15. Students may investigate the chemical makeup of the planets and the inner solar system but finding out about various kinds of meteorites, surface and bulk chemistry of the rocks from the earth, the moon and Mars. A great deal of literature is available about the chemistry of the earth-moon system and meteorites. Some questions worth investigating are: What is the geochemistry of the surface rocks of each planetary body? In what ways are moon rocks different from the terrestrial rocks? What are different kinds of meteorites? What to do when one discovers a meteorite on the Earth? What is a meteoroid, a chondrite, a meteotite, a tektite, etc.?

See, **Bickford,** Chapter 2, pp. 58-63; **Janes,** Chapter 13, pp. 319-426; **Stokes,** Chapter 7, pp. 161-166; **Long,** Chapter 1, pp. 12-15, Chapter 2, pp. 23-31; **King,** Chapter 1 (Meteorites) pp. 1-61, Chapter 2 (Tektites), Chapter 6 (The Moon/Lunar Sample Analysis) pp. 169-219; **Tatsch,** Chapter 5 (The Asteroids, Meteorites, and Tektites), pp. 98-113, Chapter 6 (Lunar Rocks and Minerals), pp. 114-129.

APPENDIX

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GEOLOGY 12

GENERAL SUPPLIES AND EQUIPMENT LIST

The following list is provided as an aid in setting up new laboratories. It will also function as a convenient checklist for schools, where some of the equipment listed will already be available. In deciding on quantities listed, a maximum class of twenty-four (24) students and an organization of two pupils per working station has been used.

Quantities are allotted on the following plan:

Per Station:

A station is two students working as a team. If the laboratory seats twenty-four students and the amount required is one per station, twelve units will be required.

Per Class:

Required for each class using the laboratory, e.g., if two Geology 12 classes use one laboratory, then requirement will be two times the unit issue.

Per Laboratory:

Required per laboratory classroom.

Items that are marked + are desirable for the most effective presentation of the course but may not be essential.

GEOLOGY 12

GENERAL SUPPLIES AND EQUIPMENT LIST

Item	Amount Required	Unit of Supply
Aluminum foil	1 per lab	roll
Aquarium, approx. 75 l	1 per lab	each
Bags, plastic or baggies (local supply)	as needed	
Balance, Centigram type, single pan triple beam, 311 type	8 per lab	each
Beakers, pyrex, 50 ml	3 per station	case of 48
Beakers, pyrex, 100 ml	6 per station	pkg. of 12
Beakers, pyrex, 250 ml	3 per station	each
Beakers, pyrex, 1 litre	2 per lab	each
Blacklight (short wave)	1 per lab	each
Blow-pipe, brass	6 per lab	each
Bottles, dropping, 50 ml polyethylene	4 per station	dozen
Bulbs, show case type, clear, 60 watt	2 per lab	each
Bunsen burner	1 per station	each
+ Camera, 35 mm	1 per lab	each
Clamp, burette, universal	1 per station	each
C — clamp, 8 cm	2 per station	each
Clay, (local supply)	10 per lab	1/2 kg
Clock, sweep second hand, 24 h	1 per lab	each
+ Cloud chamber, dry ice type, students diffusion, radioactive source included (Welch type)	1 per school	each
Compasses, blackboard style	6 per lab	each
Corks, miscellaneous sizes	3 per lab	bag of 100
Cork boring set, 9 pieces	1 per lab	each
Cover glasses, microscope slide, size #2	2 per lab	box
Crayons, wax (local supply)	30 per class	
Crucibles, with covers, size 0	6 per class	each
Cups, paper, unwaxed	30 per class	
Cylinder, graduated, 100 ml	1 per station	each
Cylinder, graduated, 250 ml	1 per station	each
Cylinder, graduated, glass, 2 litre	8 per class	each
Elastic bands, miscellaneous sizes (local supply)	1 per lab	box

Item	Amount Required	Unit of Supply
Fan, electric	1 per lab	each
+ Film ektrachrome high speed	as needed	
+ Film, kodachrome 2	as needed	
Filter paper, 15 cm diameter	2 per class	pkg. of 100
Flasks, Florence, 250 ml	1 per station	each
Food coloring (local supply)	as needed	
Gas lighter, spark renewal type	1 per station	each
Glass cutter for glass tubing	1 per lab	each
Globe, blackboard, 50 cm	1 per lab	each
Goggles, safety	1 per student	each
Hand Lens, Geology (with lanyards) magnification (x12 to x14)	1 per student	each
Hot plates, electric, single control	4 per lab	each
Iron filings, fine	3 per lab	1/2 pkg.
Knife (pocket style, large) (local supply)	1 per student	each
Labels, gummed, 40 × 60 mm (local supply)	2 per lab	box
Magnet, bar-Alnico 15 cm × 1.9 cm × 0.6 cm (approx.), set of 2 in a box	1 per station	set
Magnetic Compass (Brunton type)	1 per lab	
Magnetic Compass (Silva type)	1 per station	each
Metrestick	1 per station	each
Microscope, stereoscopic, powers of 20x and 40x	1 per station	each
Microscope, stereoscopic (with polarizing stage)	1 per lab	each
Mortar and pestle, 10 cm diameter	1 per lab	each
Needles, dissecting	1 per student	each
Overhead projector (Apollo type)	1 per lab	each
Paper, white cardboard, (local supply)	as needed	
Paper, white, 1 m width roll	1 per lab	roll
Paper, graph, log-log type	1 per lab	pkg.
Paper, graph, cm squared	as needed	
Paper, graph, semi-log, four cycle	1 per lab	pkg.
Parawax (local supply)	1 per lab	pkg. of 4 each
+ Pencils, coloured	1 set per station	set of 10
Petri dishes, 150 mm × 20 mm tops and bottoms, clear plastic	1 per lab	case of 24
Plaster of Paris	10 kg per lab	
Plasticine (local supply) 3 colours	10 kg per lab	
Plastic tubes, 5 cm × 100 cm	1 per station	each

Item	Amount Required	Unit of Supply
Plates, glass, 10 cm × 10 cm	1 per station	each
Plates, streak, small white porcelain (unglazed bathroom tiles)	1 per pupil	each
Projector, slide, with remote control and extension cord	1 per science department	each
Prospector's pan, 35 cm diameter	6 per lab	each
Protractor, blackboard style	6 per lab	each
Pump, hand air	1 per lab	each
Radioactive material set	1 per school	set
Radioactive demonstrator with accessories	1 per school	each
Razor blades, single edge (local supply)	3 per lab	pkg. of 10
Rock polishing unit	1 per school	each
Rock saw, 25 or 30 cm diameter, combination trim and slab saw	1 per school	each
+ Rock tumbler	1 per school	each
Ruler, flexible, metric	1 per lab	each
Sand, assorted (Ward's type)	as needed	
Sand, coarse (local supply)	as needed	
Sand, fine (local supply)	as needed	
Scissors, fine point, student laboratory grade	1 per station	each
Screen, projection	1 per lab	each
Scoopulas, dispensing, stainless steel	1 per lab	dozen
Screen sieves (set of 6)	2 sets per lab	set
Seismograph		
Tripod-base ringstand	1 per lab	each
Ringstand rod, 50 cm	1 per lab	each
Machine screws to go through rod	2 per lab	each
Copper wire #22 or #24, 60 cm	1 per lab	each
Dowel, 50 cm long 1.25 cm diameter	1 per lab	each
Brad to insert in end of dowell	1 per lab	each
Strip of sheet lead, (450 g) 5 cm wide	1 per lab	each
or		
Seismograph Model, (Maple Distributors, Vancouver)	1 per lab	each
Sheet plastic, transparent [illegible]cal sup[illegible]	as nee[illegible]	[illegible]
[illegible]illy putty (local suppl[illegible]	100[illegible]	[illegible]
[illegible]ides, microscope, stand[illegible]	1 [illegible]	[illegible]
[illegible]oons, plastic (local suppl[illegible]	3 p[illegible]	[illegible]n
Sp[illegible]slin[illegible], 7.5 [illegible] diameter	1 per[illegible]	[illegible]
S[illegible]ds, glass[illegible]	6 per la[illegible]	[illegible]
Sto[illegible] rub[illegible] 1-holed [illegible]oled [illegible]orted)	1.5 kg	kg

Item	Amount Required	Unit of Supply
Stream table (Demonstration type)	1 per school	each
String, heavy (local supply)	1 per lab	roll
String, nylon (local supply)	1 per lab	roll
String, light (local supply)	1 per lab	roll
Styrofoam cups	1 per lab	gross
Stereoscopic Viewers	1 per student	each
Tape, adding machine 7.5 cm	1 per lab	roll
Tape, cellulose, transparent (Scotch) 1.25 cm width	as needed	
Tape, masking 1.25 cm width	3 per lab	roll
Tape, ticker	1 per lab	package
Test tube 18 × 150 mm, pyrex	2 per lab	pkg. of 72
Test tube brush, medium	3 per lab	each
Test tube supports	1 per station	each
Thermometers, Celsius scale 20 to 110°C, student grade	1 per station	each
Thumbtacks (local supply)	3 per lab	box
Tin shears, straight 25 cm	1 per lab	each
Tissue for cleaning microscope lenses	1 dozen per lab	booklet
Tongs, beaker	1 per lab	each
Tools,		
file, triangular, 15 cm	6 per lab	each
hammer, claw	1 per lab	each
hammer, geologist's	1 per station	each
hammer, sledge	6 per lab	each
pliers, long nose cutting edge	1 per lab	each
pliers, combination	1 per lab	each
screw drivers (combination)	1 per lab	each
screw driver, jewellers	1 per lab	each
spade, folding type	6 per lab	each
Tubing, soft glass, 4 mm, 5 mm and 6 mm	1 of each per lab	450 g
Tubing, polyethylene, 5 mm outside diameter	1 kg per lab	
Wire gauze, asbestos enmeshed centre, 12.5 cm × 12.5 cm	1 per station	each

CHEMICALS

Item	Amount Required	Unit of Supply
Alum	2 kg per lab	kg
Ammonium dichromate	1/2 kg per lab	kg
Ammonium oxalate	1/2 kg per lab	kg
Charcoal blocks (4 cm × 8 cm × 3 cm)	1 box per lab	box
Copper II sulphate (Tech)	2 kg per lab	kg
Hydrochloric Acid	4 kg per lab	kg
Nickel II sulphate hexahydrate	2 kg per lab	kg
Salol	1/2 kg per lab	kg
Sodium chloride	3 kg per lab	kg
Thymol	1/2 kg per lab	kg

GEOLOGICAL SPECIMENS

Item	Amount Required	Unit of Supply
Prospector's set of mineral chips	1 set per student	set
Prospector's set of rock chips	1 set per student	set
Raw materials of Canada: Mineral Industry, 120 specimens	6 sets per class	set

(The above are available from the Geological Survey of Canada)

Item	Amount Required	Unit of Supply
Azurite	1 per student	each
Halite	1 per student	each
Bornite	1 per student	each
Malachite	1 per student	each
Chlorite	1 per student	each
Olivine	1 per student	each
Cinnabar	1 per student	each
Selenite (Gypsum)	1 per student	each
Varieties of Quartz and Cryptocrystalline Quartz	1 per student	each
Obsidian	1 per student	each
Pumice	1 per student	each
Breccia	1 per student	each
Arkose	1 per student	each
Siltstone	1 per student	each
Travertine	1 per student	each
Fossiliferous Limestone	1 per student	each
Chert	1 per student	each
Coal	1 per student	each
Phyllite	1 per student	each
Metaconglomerate	1 per student	each
Marble	1 per student	each

GEOLOGICAL SPECIMENS

Item	Amount Required	Unit of Supply
Geological Thin Sections for each of the following rocks:		
Igneous Rocks: granite, diorite, peridotite, andesite, basalt-amygdaloidal, tuff, syenite, gabbro, rhyolite, basalt, breccia, porphyry-feldspar	1 set per school	set
Sedimentary Rocks: conglomerate, sandstone, greywacke, shale, limestone, dolomite, breccia, arkose, siltstone, travertine, fossiliferous limestone, chert, coal	1 set per school	set
Metamorphic Rocks: quartzite, slate, schist, gneiss, phyllite, marble, metaconglomerate	1 set per school	set

Fossils Recommended for Study In Geology 12

The following list is not meant to be a complete list of the index fossils of western Canada. Teachers can modify the list, if necessary. Local fossils should surely be included. The student should be able to recognize at least one index fossil from each geologic period. If specimens are not available for study it may be possible to study an illustration or a slide. In some cases plaster casts may be made of specimens in University collections. Many of the fossils listed may be purchased from Arbor Scientific Ltd. or from Geofossil Canada Ltd. One classroom set of 20 fossils from western Canada is to be provided but this can be expanded by additions from local collections, etc.

Index Fossils of Western Canada

Item	Amount Required	Unit of Supply
Lower and Middle Cambrian Olenellus (trilobite), Paedeumias (trilobite)	1 set per school	set
Middle Cambrian Elrathina (trilobite), Ogygopsis (trilobite), Bathyuriscus (trilobite)	1 set per school	set
Middle and Upper Cambrian Paradoxides (trilobite), Cedaria (trilobite), Labiostria (trilobite)	1 set per school	set
Ordovician Cryptolithus (trilobite), Flexicalymene (trilobite), Platystrophia (brachiopod), Glyptorthis (brachiopod), Byssonychia (clam), Rhynchotrema (brachiopod), Dinorthis (brachiopod), Monograptus (graptolite), Climacograptus (graptolite)	1 set per school	set

Silurian
Caryocrinites (cystoid)
Eocoelia (brachiopod)
Conchidium (brachiopod)
Atrypa (brachiopod)
Favosites (coral)
Halysites (coral)
Columnaria (coral) .... 1 set per school .... set

Devonian
Amphipora (stromatatoporoid)
Atrypa (brachiopod)
Mesophyllum (coral)
Leiorhynchus (brachiopod)
Hadrorhynchia (brachiopod)
Stringocephalus (brachiopod)
Gypidula (brachiopod)
Theodossia (brachiopod)
Rensselaeria (brachiopod) .... 1 set per school .... set

Mississippian
Cleiothyridina (brachiopod)
Spirifer (brachiopod)
Lithostrotionella (coral)
crinoid stems
Fenestrellina (bryozoa) .... 1 set per school .... set

Pennsylvanian
Punctospirifer (brachiopod)
Neospirifer (brachiopod)
Composita (brachiopod) .... 1 set per school .... set

Permian
Parafusulina (foraminifera)
Neospirifer (brachiopod)
Streptorhynchus (brachiopod)
Spiriferella (brachiopod) .... 1 set per school .... set

Lower Triassic
Ophiceras (ammonite)
Pseudomonotis (clam) .... 1 set per school .... set

Middle Triassic
Terebratula (brachiopod)
Protrachyceras (ammonite) .... 1 set per school .... set

Upper Triassic
Himavatites (ammonite)
Gryphaea (clam)
Monotis (clam) .... 1 set per school .... set

Lower Jurassic and Middle Jurassic
Paracaloceras (ammonite)
Grammoceras (ammonite)
Warrenoceras (ammonite)
Kosmoceras (ammonite) .... 1 set per school .... set

Upper Jurassic
Buchia (clam)
Inoceramus (clam)
Sonninia (ammonite) .... 1 set per school .... set.

Lower Cretaceous
Buchia (clam)
Inoceramus (clam)
Heteroceras (ammonite) .... 1 set per school .... set

Upper Cretaceous

Scaphites (ammonite)
Baculites (ammonite)
Inoceramus (clam)
Ostrea (clam)
Viviparus (snail)
carbonized wood (variable)
silicified wood (variable) .... 1 set per school .... set

Pleistocene (marine)

Serripes (clam)
Mytilus (clam)
Mya (clam)
Natica (snail)
Astarte (clam)
Nuculana (clam)
Chlamys (clam)
Clinocardium (clam)
Balanus (barnacle) .... 1 set per school .... set

PLANTS

Plants

Item	Amount Required	Unit of Supply
Devonian — Carboniferous		
Psilophyton		
Calamites		
Linopteris		
ferns		
scale trees		
Metasequoia (conifer)		
Cercidiphyllum (angiosperm)		
Ginkgo (angiosperm)	1 set per school	set
Mesozoic — Cenozoic		
Sequoia		
Larix		
Pinus		
Carpites	1 set per school	set

Fossils are illustrated in GEOLOGY AND ECONOMIC MINERALS OF CANADA (1970). Many, but not all, of the index fossils listed can be purchased from Arbor Scientific Ltd., Box 113, Port Credit, Ontario.

A set of twenty fossils from western Canada is available from Geofossil Canada Ltd., Box 3651, Postal Station B., Calgary, Alberta, T2M 4M4. The set includes a storage tray, a 25 page descriptive booklet and 20 original 35 mm color slides. The set includes the following fossils:

- Coenites (coral)
- Syringopora (coral)
- Amphipora (stromatoporoid)
- Fenestrellina (bryozoa)
- Viviparus (snail)
- Ostrea (clam)
- Baculites (ammonite)
- Atrypa (brachiopod)
- Spirifer (brachiopod)
- Paedeumias (trilobite)
- Labiostria (trilobite)
- crinoid stem
- dinosaur bone
- "Carbonized wood"
- silicified wood
- Metasequoia (conifer)
- conifer cone
- Ginkgo
- Cercidiphyllum (angiosperm)

It is suggested that storage space be provided for Geological Specimens.

Item	Amount Required	Unit of Supply
10 Drawer Geological Specimen Cabinet (Ward's type)	1 per school	each

AUDIO-VISUAL MATERIALS

MAPS AND WALL CHARTS

Item	Amount Required	Unit of Supply
Maps:		
Geologic Map (local area)	1 per station	each
Surficial Geology Map (local area)	1 per station	each
Geologic Map of Retreat of Wisconsin and Recent Ice in North America	1 per station	each
(The above are available from the Geological Survey of Canada.)		
Geologic Maps of B.C., Canada (Geological Survey of Canada)	1 per station	each
Geologic Map of North America (U.S. Geological Survey)	1 per station	each
Tectonic Map of North America (Geological Society of America)	1 per station	each
Tectonic Map of U.S., U.S. Geological Survey, 1962 (1:2 500 000)	1 per station	each
The Age of the Ocean Basins by W.C. Pitman III et al., 1974, Geol. Society of America	1 per station	each
Glacial Map of Canada, Map 1253A, Geol. Survey of Canada, (1:5 000 000)	1 per station	each
Pleistocene, Eolian Deposits of the U.S., Alaska, and Parts of Canada, Geol. Society of America, 1952, (1:2 500 000)	1 per station	each
Wall Charts:		
Chart showing physical features of ocean basins (Available from: Geological Society of America, Boulder, Colorado)	1 per class	each
Charts showing physical features of ocean basins (Available from: Time, Incorporated, Time-Life Building, New York)	1 per class	each
Deposits Near Medicine Hat, Alberta (Available from Publications Distribution Office, Geological Survey of Canada, 601 Booth Street, Ottawa)	1 per class	each
Surficial Geology Map of North America	1 per station	each

FILMS

Films recommended as support material for Geology 12 are listed below. All films marked (+) are included in the list of films for Earth Science 11, but may also be of value in this course. Films marked (★) are available on a free loan basis from the Provincial Educational Media Centre, 4455 Juneau Street, Burnaby, British Columbia V5C 4C4.

Films marked (T) are available for purchase in video tape format from PEMC through each district's PEMC liaison.

Arrangements for obtaining other listed films may be made through local District Resource Centres.

Notations A, B, C, and D are used to indicate the special relevance of films to a particular section of the course.

All films indicated are in color.

	Name	Source	Time	Section
T +	Earth Resources Technology Satellite	NASA, 1973	27 min.	C
T ★	Mars: The Search Begins	NASA	25 min.	D
T + ★	The Moon: An Emerging Planet	NASA, 1973	13 min.	D
T ★	The Moon: Old and New	NASA, 1970	25 min.	D
T ★	Face of the Earth	NFB, 1975	15 min.	A
T ★	Earth: An Interplanetary Perspective	Macmillan of Canada	15 min.	D
T + ★	Continental Drift	NFB, 1968	10 min.	A
+ ★	Continents Adrift	AEF	17 min.	A
★	Earthquakes: Lesson of a Disaster	EBE	13 min.	A
+ ★	Erosion: Levelling the Land	EBE	14 min.	A
+ ★	Evidence for the Ice Age	EBE	22 min.	A
+ ★	Glacier on the Move	EBE	11 min.	A
+ ★	Heartbeat of a Volcano	EBE	20 min.	A
+ ★	How Solid is Rock?	EBE	22 min.	A
+ ★	Rocks that form on the Earth's Surface	EBE	16 min.	A
+ ★	Rocks that Originate Underground	EBE	23 min.	A
+ ★	The Rise and Fall of the Great Lakes	NFB, 1968	17 min.	A
+ ★	The San Andreas Fault	EBE	21 min.	A
T + ★	Volcanic Landscapes Part 1		45 min.	A
T + ★	Volcanic Landscapes Part 2		45 min.	A
+ ★	Volcanoes: Exploring the Restless Earth	EBE	18 min.	A

	+ ★	Why do we still have Mountains?	EBE	20 min.	A
	+ ★	The Beach A River Of Sand	EBE	20 min.	A
T		Castleguard Caves	NFB, 1975	50 min.	A
T	★	Satellites of the Sun	NFB, 1975	12 min.	D
		Energy for the Future	EBE	17 min.	D
	★	What Makes Rain	EBE	22 min.	C
	★	The Moon: A Giant Step in Geology	EBE	24 min.	D
T		Horizon: Drifting of Continents	BBC	50 min.	
T		Horizon: The Planets	BBC	54 min.	
T	★	Energy Series	GWF		
		a. The Dilemma	GWF	20 min.	
		b. The Nuclear Alternative	GWF	20 min.	
		c. New Sources	GWF	20 min.	
		d. Less is More	GWF	18 min.	

T ★ **THE PLANET OF MAN (SERIES)**

The series hinges on the theory of global plate tectonics. It also reconstructs, in model form, how vast forces of water, wind, ice and the shifting crust, have shaped the earth we walk on today, and show how we may be able to predict future consequences.

	Name	Source	Time	Section
T	Voices of Time (Grand Canyon of Arizona)	OECA	30 min.	A
T	The Jigsaw Fit (Plate Tectonics)	OECA	30 min.	A
T	The Fire Within (Types of Volcanic Activity)	OECA	30 min.	A
T	Trail of Ice Age Blues (Effect of Glaciation on the Features of North America)	OECA	30 min.	A
T	Mountain Heritage — The Appalachians (Plate Tectonics, Volcanism, Mountain building)	OECA	30 min.	A
T	Shield of Plenty (Precambrian Earth)	OECA	30 min.	A
T	Challenge of the Deep (Minerals on the Ocean Floors)	OECA	30 min.	C
T	The Inner Limit (A Cross-Section of the Earth)	OECA	30 min.	A
T	The Cosmic Connection (Meteorite Bombardment)	OECA	30 min.	D

T Beyond A Doubt: A Revolution (Concept of Continental Drift) .... OECA .... 30 min. .... A

T The Uneventful Day (Weathering and Erosion) ... OECA .... 30 min. .... A

This series is available by purchase through your district PEMC liaison.

NASA Films may be obtained from:
National Science Film Library
1762 Carling Street
Ottawa, Ontario

or

NASA Ames Research Centre
(Educational Progarm Office)
Moffet Field
California, U.S.A. 94035

Hubbard Super 8 Filmloops may be obtained from:
Visual Education Centre
115 Berkeley Street
Toronto, Ontario

SUPER 8 FILMLOOPS

Name	Source	Section
Sedimentation: Settling Rates	Hubbard	A
Sedimentation: Turbidity Currents	Hubbard	A
Deltas	Hubbard	A
Alluvial Fans	Hubbard	A
Stream Cut-Offs	Hubbard	A
Stream Erosion Cycle	Hubbard	A
Stream Piracy	Hubbard	A
Development of Shorelines	Hubbard	A
Earth Structures	EBE	A
Mountain Building	EBE	A
Glacial Movement	EBE	A
Ocean Shores	EBE	A
Overthrust Faults	EBE	A
Anatomy of a Volcano	EBE	A

FILMSTRIPS

Name	Source	Section
Field Identification of Minerals	MEM	A
Laboratory Analysis of Minerals	MEM	A
Minerals and Crystals	MEM	A
Minerals of Economic Importance	MEM	A
Rocks and Minerals Kit contains 13 rock samples and 3 filmstrips, map and booklets	NFB	A

Name	Source	Section
SOUND FILMSTRIPS		
Recognizing Rock Making Minerals	EBE	A
Comparing Rocks	EBE	A
Volcanic Rocks	EBE	A
Shale, Sandstone and Conglomerate	EBE	A
Plutonic (Granitic) Rocks	EBE	A
Metamorphic Rocks	EBE	A
The Rock Families	EBE	A
Rocks and Minerals	MEM (McIntyne Educ. Media)	A
Rivers 1	MEM	A
Rivers 2	MEM	A
Rivers 3	MEM	A
Soils 1	MEM	A
Waterfalls and Gorges	MEM	A
Weathering	MEM	A
The Sea: Erosion	MEM	A
The Sea: Deposition	MEM	A
Fold Mountains	MEM	A
Volcanoes 1	MEM	A
Volcanoes 2	MEM	A
Volcanicity	MEM	A
Ice 1	MEM	A
Ice 2	MEM	A
Ice 3	MEM	A
Plate Tectonics	MEM	A
Earthquakes	MEM	A
Evidence that Continents Move	MEM	A
Dating Geological Events	MEM	B
How Fossils are Formed	EBE	B

Name	Source	Section
Collecting and Interpreting Fossils	EBE	B
Fossils and the Relative Ages of Rocks	EBE	B
Fossils and Prehistoric Environments	EBE	B
Fossils and Organic Change	EBE	B

Name	Source	Section
STUDY PRINTS		
Plate Tectonics (8 Study Prints)		A
SLIDES		
Earth Science Slides	BCTF Lesson Aid M1	A
Glaciation: Multimedia Kit (O/H Transparencies, slides, teachers' guide)	NFB	A
Athabasca Glacier: Study of a Valley Glacier	BCTF Lesson Aid M51	A
Exploration of Planets Mariner, Pioneer and Viking Missions	BCTF Lesson Aid	D
Earth from Space and Remote Sensing of Earth Resources	BCTF Lesson Aid	C
MISCELLANEOUS (VISUALS ETC.)		
How to Conduct A Field Exercise to a Mine	BCTF Lesson Aid #2096	C
An Economic Approach To The Mining Industry of B.C.	BCTF Lesson Aid #5857	C

SUPPLEMENTARY REFERENCE TEXTS

1. Derek York, *Planet Earth* (McGraw-Hill).
2. McDonald R., *Years and Years Ago* (Evergreen Press).
3. Hurlbut, C.S., *Dana's Manual of Minerology*, 17th ed. (Ward's Earth Science Books).
4. Read, et al. *Beginning Geology* (George Allen & Unwin Press).
5. Donn, W.L., *The Earth* (Wiley).
6. Searching for Structure Series, *Rocks, Minerals, Fossils.*
7. Strahler, *The Earth* (Harper & Row).
8. Spencer, E.W., *The Dynamic Earth* (Crowell).
9. Foundations of Earth Science Series, Eicher, D.L., *Geologic Time* (Prentice-Hall).
10. Ward, B., *This Blue Planet* (Little Brown).
11. Bates, R.L., *Geology* (Heath).
12. Bird, J.B., *Natural Landscapes of Canada* (Wiley).
13. Foundations of Earth Science Series; Units 24-27.
    — *Earth History I and II.* (Open University Press)
    — *Major Features of Earth's Surface.* (Open University Press)
14. Baird, D.M., *Our Earth in Continuous Change* (McGraw-Hill).
15. Alberta Society of Petroleum Geologists, *The Face of Time* (A Geological History of Western Canada)
    — 612 Lougheed Building, Calgary, Alberta.
16. Hallam, A., *A Revolution in the Earth Sciences* from Continental Drift to Plate Tectonics (Oxford University Press), 1974.
17. Kucera, R.E., *Probing the Athabasca Glacier* (Evergreen Press), 1975.
18. Kucera, R.E., *Lake Louise Moraine Lake* (Evergreen Press), 1974.
19. Pamphlet Series available from B.C.T.F. Lesson Aids, Vancouver, B.C. (Edited by Dr. John Rau, Dept. of Geological Sciences, U.B.C.)
    - i) Geologic Hazards of British Columbia
    - ii) The Ice Age in British Columbia
    - iii) The Volcanoes of British Columbia
    - iv) Earthquake Risk in British Columbia
    - v) Geology of the North Shore
    - vi) Geology of the Upper Fraser Valley (Hope to Abbotsofrd)
20. Skinner, B.J., *Earth Resources* (Prentice-Hall).
21. Skinner, B.J., and Turekian, K.K., *Man and the Ocean* (Prentice-Hall).

PRESCRIBED TEXTBOOK LIST

The textbooks authorized for the Geology 12 courses are listed below. The scale of issue of authorized texts is indicated in the **Prescribed Textbook List.** The Prescribed Textbook List is published annually by the Curriculum Development Branch and is available from the Publication Services Branch.

GEOLOGY 12

1. Janes: *Geology and the New Global Tectonics* (Macmillan).
2. Long: *Geology* (McGraw-Hill).
3. Gilluly: *Principles of Geology* (W.H. Freeman).

Laboratory Manuals

1. Hamblin, Howard: *Exercises in Physical Geology* (Burgess-McAinsh).
2. (a) Anstey, Chase: *Environments Through Time* (Burgess-McAinsh), or
   (b) Brice, Levin: *Laboratory Studies in Earth History*, Wm. C. Brown (Burns & MacEachern).

Student Reference Kit

1. Bickford, et al.: *Geology Today* (CRM Books, Random House).
2. Greely/Schultz: *A Primer in Lunar Geology*, Comment edition (Ames Research Centre, National Aeronautics and Space Administration, Moffett Field, California).
3. Stokes: *Essentials of Earth History*, 3rd edition (Prentice-Hall).
4. *Geology and Economic Minerals of Canada* (Queen's Printer, Ottawa).
5. *Readings From Scientific American Planet Earth* (W.H. Freeman).
6. Foundations of Earth Science Series.
   (a) Laporte: *Ancient Environments* (Prentice-Hall).
   (b) McAlester: *The History of Life* (Prentice-Hall).
   (c) Skinner: *Earth Resources* (Prentice-Hall).