A PROPOSED EARTH SCIENCE CURRICULUM FOR GRADES 8 AND 10 IN BRITISH COLUMBIA HIGH SCHOOLS

by

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ABSTRACT

During the past two decades, evidence has been mounting in favour of the theory of plate tectonics. At the present time, the earth science sections of the junior secondary school science curriculum prescribed by the British Columbia Ministry of Education are deficient in information relating to this theory. The present curriculum is also deficient in examples and explanations of the earth sciences as they relate specifically to British Columbia.

This thesis attempts to rectify a need perceived by the author, the B.C. Ministry of Education, and Prentice-Hall of Canada Ltd. for a new earth science program, by proposing a revised curriculum incorporating plate tectonic theory, and based firmly upon B.C. regional phenomena. The revision is designed in such a way that it may be put to immediate use by a practising classroom teacher. With the aid of the supplementary Teachers' Guide, even an inexperienced teacher with minimal knowledge of earth science would probably be able to implement the proposed curriculum successfully.

The proposed curriculum is divided into two parts. The first of these, intended for students in Grade 8, covers the gradational aspects of geology. The second part, suitable for grade 10 students, covers diastrophism, volcanism, plate tectonics, and earth history. Brief excursions are made into mapping, rock and mineral identification, and paleontology. In both parts, the teaching method used is that of "guided discovery", involving a mixture of student laboratory exercises and
demonstrations, supplemented by informational narratives.

The proposed curriculum contains a number of elements unique to the teaching of earth science. These range from the application of new strategies to the teaching of well known topics, to the inclusion of material not found in any presently existing earth science curriculum. In the latter case, much of this material has been so recently discovered that it has not yet found its way into junior secondary curricula, or is of such strong B.C. regional interest so as to preclude its inclusion in curricula intended for Canadian national or North American continental usage.

Early drafts of the proposed curriculum were classroom tested by a number of practising teachers in several junior secondary schools over a period of two years. The results of this extensive testing were incorporated into the present form of the proposed curriculum. In conclusion, it appears that this proposed earth science curriculum is suitable for students in grades 8 and 10 of the British Columbia school system.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>Contents</td>
<td>iv</td>
</tr>
<tr>
<td>Figures</td>
<td>v</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Statement of Purpose</td>
<td>1</td>
</tr>
<tr>
<td>Rationale</td>
<td>1</td>
</tr>
<tr>
<td>Methods</td>
<td>5</td>
</tr>
<tr>
<td>Philosophical Basis</td>
<td>5</td>
</tr>
<tr>
<td>Course Objectives</td>
<td>6</td>
</tr>
<tr>
<td>Proposed Curriculum</td>
<td>8</td>
</tr>
<tr>
<td>General Outline</td>
<td>8</td>
</tr>
<tr>
<td>Selected Areas, Part 1</td>
<td>19</td>
</tr>
<tr>
<td>Selected Areas, Part 2</td>
<td>88</td>
</tr>
<tr>
<td>Discussion</td>
<td>191</td>
</tr>
<tr>
<td>General Conclusion</td>
<td>192</td>
</tr>
<tr>
<td>Teachers' Manual</td>
<td>194</td>
</tr>
<tr>
<td>Bibliography</td>
<td>276</td>
</tr>
<tr>
<td>Addendum</td>
<td>286</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------</td>
</tr>
<tr>
<td>1a.</td>
<td>Layers of the Earth</td>
</tr>
<tr>
<td>1b.</td>
<td>Currents within the Earth</td>
</tr>
<tr>
<td>1c.</td>
<td>The Earth in the past</td>
</tr>
<tr>
<td>1d.</td>
<td>Sandstone</td>
</tr>
<tr>
<td>2.</td>
<td>Conglomerate</td>
</tr>
<tr>
<td>3.</td>
<td>Granite</td>
</tr>
<tr>
<td>4.</td>
<td>Basalt</td>
</tr>
<tr>
<td>5.</td>
<td>Gneiss</td>
</tr>
<tr>
<td>6a.</td>
<td>Coal and shale, Ellesmere Island</td>
</tr>
<tr>
<td>6b.</td>
<td>The rock cycle</td>
</tr>
<tr>
<td>7.</td>
<td>Geologic map of the Port Moody area</td>
</tr>
<tr>
<td>8.</td>
<td>Outline map for Investigation 7</td>
</tr>
<tr>
<td>9.</td>
<td>Outline map of the Fraser River delta</td>
</tr>
<tr>
<td>10.</td>
<td>Satellite photograph of Fraser delta</td>
</tr>
<tr>
<td>11.</td>
<td>Delta front</td>
</tr>
<tr>
<td>12.</td>
<td>Nile delta</td>
</tr>
<tr>
<td>13.</td>
<td>MacKenzie delta</td>
</tr>
<tr>
<td>14.</td>
<td>Squamish delta</td>
</tr>
<tr>
<td>15.</td>
<td>Flood plain</td>
</tr>
<tr>
<td>16.</td>
<td>Outline of delta front</td>
</tr>
<tr>
<td>17.</td>
<td>Pitt River delta</td>
</tr>
<tr>
<td>18.</td>
<td>Trilobites</td>
</tr>
<tr>
<td>19.</td>
<td>Lambeosaurus</td>
</tr>
<tr>
<td>20.</td>
<td>Outline maps of Canada</td>
</tr>
<tr>
<td>21.</td>
<td>Side view of a glacier</td>
</tr>
<tr>
<td>22.</td>
<td>Crevasse</td>
</tr>
<tr>
<td>23.</td>
<td>Alpine glaciers</td>
</tr>
<tr>
<td>Number</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>24.</td>
<td>Athabaska Glacier snout</td>
</tr>
<tr>
<td>25.</td>
<td>Valley glacier</td>
</tr>
<tr>
<td>26.</td>
<td>Emerald glacier</td>
</tr>
<tr>
<td>27.</td>
<td>Medial moraines on Coronation Glacier</td>
</tr>
<tr>
<td>28.</td>
<td>Glacial landforms</td>
</tr>
<tr>
<td>29.</td>
<td>Leckie Creek valley</td>
</tr>
<tr>
<td>30.</td>
<td>Cirque</td>
</tr>
<tr>
<td>31.</td>
<td>Glacial landscape</td>
</tr>
<tr>
<td>32.</td>
<td>Fiord</td>
</tr>
<tr>
<td>33.</td>
<td>Raised beaches</td>
</tr>
<tr>
<td>34.</td>
<td>Glacially polished rocks</td>
</tr>
<tr>
<td>35.</td>
<td>Trilobites</td>
</tr>
<tr>
<td>36.</td>
<td>Shark tooth</td>
</tr>
<tr>
<td>37.</td>
<td>Ammonite</td>
</tr>
<tr>
<td>38.</td>
<td>Crinoid stems</td>
</tr>
<tr>
<td>39.</td>
<td>Brachiopods</td>
</tr>
<tr>
<td>40.</td>
<td>Pelecypods</td>
</tr>
<tr>
<td>41.</td>
<td>Gastropod</td>
</tr>
<tr>
<td>42.</td>
<td>Reptile vertebra</td>
</tr>
<tr>
<td>43.</td>
<td>Reptile bone weathering out of rock</td>
</tr>
<tr>
<td>44.</td>
<td>Carbonized leaves</td>
</tr>
<tr>
<td>45.</td>
<td>Silicified wood</td>
</tr>
<tr>
<td>46.</td>
<td>Fossil formation</td>
</tr>
<tr>
<td>47.</td>
<td>Canyon</td>
</tr>
<tr>
<td>48.</td>
<td>Fossil sketches</td>
</tr>
<tr>
<td>49.</td>
<td>Outline map of B.C.</td>
</tr>
<tr>
<td>50.</td>
<td>Graph axes</td>
</tr>
<tr>
<td>51.</td>
<td>Graph axes</td>
</tr>
</tbody>
</table>
52. Hot spring operation
53. Banff hot spring
54. Use of geothermal water
55. Cenozoic volcanoes of B.C.
56. Mount Edziza
57. Eve Cone
58. Mount Garibaldi and the Table
59. The Barrier
60. Garibaldi Lake
61. Black Tusk
62. Black Tusk
63. Cinder Cone
64. Mount Baker
65. Crater, Mount Baker
66. Fault, Hanning Bay
67. Fault, Hanning Bay
68. Fault zone, Hawaii
69. Road damaged by faulting
70. Mercalli intensities, south Okanagan
71. Buildings damaged by an earthquake
72. School damaged by an earthquake
73. Earthquake damage in Anchorage
74a. Railway damaged by an earthquake
74b. Canadian earthquake hazard zones
74c. Demonstrating a P-wave
75. Demonstrating an S-wave
76. Seismograms
77. P-wave
<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>78.</td>
<td>P-wave and S-wave</td>
</tr>
<tr>
<td>79.</td>
<td>Travel time graph</td>
</tr>
<tr>
<td>80.</td>
<td>Earthquake recording stations</td>
</tr>
<tr>
<td>81.</td>
<td>Tsunami damage</td>
</tr>
<tr>
<td>82.</td>
<td>Tsunami damage</td>
</tr>
<tr>
<td>83.</td>
<td>World map</td>
</tr>
<tr>
<td>84.</td>
<td>Alfred Wegener's map of the world prior to continental drift</td>
</tr>
<tr>
<td>85.</td>
<td>Wegener's model of continental drift</td>
</tr>
<tr>
<td>86.</td>
<td>Plate motion</td>
</tr>
<tr>
<td>87.</td>
<td>Wegener's map of Pangea</td>
</tr>
<tr>
<td>88.</td>
<td>Plate tectonic map of Pangea</td>
</tr>
<tr>
<td>89.</td>
<td>Major plates</td>
</tr>
<tr>
<td>90.</td>
<td>Landsat photograph of Indian plain and the Himalayas</td>
</tr>
<tr>
<td>91.</td>
<td>San Andreas fault</td>
</tr>
<tr>
<td>92.</td>
<td>San Andreas fault location</td>
</tr>
<tr>
<td>93.</td>
<td>San Andreas fault, Carrizo Plain</td>
</tr>
<tr>
<td>94.</td>
<td>Landsat photograph of San Andreas fault</td>
</tr>
<tr>
<td>95.</td>
<td>Fault locations near San Francisco</td>
</tr>
<tr>
<td>96.</td>
<td>Coastal features of B.C.</td>
</tr>
<tr>
<td>97.</td>
<td>Plate movement near the B.C. coast</td>
</tr>
<tr>
<td>98.</td>
<td>B.C. coalfields</td>
</tr>
<tr>
<td>99.</td>
<td>B.C. mining operations</td>
</tr>
<tr>
<td>100.</td>
<td>Profile from Investigation 12</td>
</tr>
<tr>
<td>101a.</td>
<td>Hydrologic cycle apparatus</td>
</tr>
<tr>
<td>101b.</td>
<td>Small scale map</td>
</tr>
<tr>
<td>102.</td>
<td>Medium scale map</td>
</tr>
<tr>
<td>103.</td>
<td>Large scale map</td>
</tr>
<tr>
<td>104.</td>
<td>Drawing a profile</td>
</tr>
<tr>
<td>105.</td>
<td>Outline for profile</td>
</tr>
<tr>
<td>106.</td>
<td>Physical weathering</td>
</tr>
<tr>
<td>107.</td>
<td>Chemical weathering</td>
</tr>
<tr>
<td>108.</td>
<td>Biological weathering</td>
</tr>
<tr>
<td>109.</td>
<td>Water reservoirs</td>
</tr>
<tr>
<td>110.</td>
<td>Filtering apparatus</td>
</tr>
<tr>
<td>111.</td>
<td>Braided stream</td>
</tr>
<tr>
<td>112.</td>
<td>Canyon on the Athabaska River</td>
</tr>
<tr>
<td>113.</td>
<td>Yellowstone Canyon</td>
</tr>
<tr>
<td>114.</td>
<td>Fraser Canyon</td>
</tr>
<tr>
<td>115.</td>
<td>Bryce Canyon</td>
</tr>
<tr>
<td>116.</td>
<td>Fraser Valley</td>
</tr>
<tr>
<td>117.</td>
<td>Meandering River</td>
</tr>
<tr>
<td>118.</td>
<td>Parsnip River</td>
</tr>
<tr>
<td>119.</td>
<td>Landslide, Takini River</td>
</tr>
<tr>
<td>120.</td>
<td>Frank Slide</td>
</tr>
<tr>
<td>121.</td>
<td>Hope slide</td>
</tr>
<tr>
<td>122.</td>
<td>Fossil leaves</td>
</tr>
<tr>
<td>123.</td>
<td>Ammonite</td>
</tr>
<tr>
<td>124.</td>
<td>Allosaurus</td>
</tr>
<tr>
<td>125.</td>
<td>Tyrannosaurus</td>
</tr>
<tr>
<td>126.</td>
<td>Iguanodon</td>
</tr>
<tr>
<td>127.</td>
<td>Camptosaurus</td>
</tr>
<tr>
<td>128.</td>
<td>Diplodocus</td>
</tr>
<tr>
<td>129.</td>
<td>Rhamphorhynchus</td>
</tr>
<tr>
<td>130.</td>
<td>Pteranodon</td>
</tr>
</tbody>
</table>
131. Ankylosaurus
132. Eryops
133. Monoclonius
134. Eogyrinus
135. Brachiosaurus
136. Dimetrodon
137. Ichthyosaurus
138. Hesperosuchus
139. Elasmosaurus
140. Coquitlam River field trip area
141. Northern field trip area
142. Southern field trip area
143. Graph axes
144. Earth's crust
145. Radioactive decay graph
146. Human skeleton
147. Dimetrodon skeleton
148. Forelimbs
149. Miller's apparatus
150. Limestone, south Wales
151. Sandstone
152. Conglomerate
153a. River mouth
153b. Operation of a volcano
154. Cinder cone
155. Stratovolcano
156. Nauna Loa
157. Melting wax
158. Internal structure of a stratovolcano
159. Mauna Kea
160. Mauna Ulu
161. Mount Garibaldi
162. Volcanoes, central Oregon, U.S.A.
163. Mount Newberry
164. Mauna Ulu
165. Mount Baker
166. Wizard Island
167. Crater Lake
168. Dyke
169. Lava tube
170. Giant's Causeway
171. Black sand beach
172. Fissure eruption
173. Flood lavas of B.C.
174. Olympus Mons
175. Comparison of Olympus Mons and B.C.
176. Outline map of world
177. Basalt
178. Granite
179. Gneiss
180. Rock cycle
181. Demonstrating inertia
182. Model seismograph
183. Outline map of B.C.
184. Outline map of world
185. Graph for ocean floor cross-section
186. Steepness exaggeration of cross-section 438
187. Continental outlines 443
188. Continental shelf outlines 449
189. Representation of lava layers 451
190. Representation of spreading lava 451
191. Outline map of north Atlantic Ocean 456
192. Former magnetic pole positions 458
193. Fitting of polar wandering curves 458
194. Plates sliding 461
195. Continental plates colliding 461
196. Continental and oceanic plates colliding 462
197. Oceanic plates spreading 462
198. Grid for plotting earthquake data 463
199. Cleavage patterns of minerals 470
INTRODUCTION

Statement of Purpose

This proposed curriculum is a combined text-book and laboratory manual designed for junior high school science, whose fundamental goal is to help students to understand the origin of typical landforms found in British Columbia, and their relationship to similar structures in other parts of the world. To this end, the curriculum deals with both the gradational and orogenic aspects of geology, concentrating upon modification of the local landscape by water and ice, and upon gross deformation of the Earth's surface by the forces of plate tectonics.

Rationale

Philosophers of science—notably T. S. Kuhn—have pointed out that major scientific advances frequently occur as reorganizations of already existing observational data. Many branches of science have developed from the practical experience and knowledge of such men as prospectors, farmers and fishermen. At first, each branch of science was merely the compilation of the accumulated experience of individuals, passed on from one generation to the next. In this form, it was no more than a set of facts which provided little basis for prediction. Eventually, a point was reached where anomalies and seeming contradictions began to appear in the observational data. These anomalies were resolved by the introduction of new theoretical constructs, termed "paradigms" by Kuhn. The appearance of such paradigms,
integrating and explaining previously puzzling data, allowed science to progress until a point was reached where a new paradigm became necessary. As a classical example of this process, Kuhn (1970) cites the discarding of the Ptolemaic belief that the Earth is the centre of the solar system in favour of the Copernican viewpoint. This opened the way for Galileo, Kepler and Newton, whose theories held sway until they in turn were perceived as only special cases of the more general theories of Albert Einstein.

In the earth sciences, the point where a new paradigm became necessary was reached in the late 1950's, when the accumulation of oceanographic data presented surprising results from the seabed. Mountain ranges of unprecedented length, and trenches of incredible depth headed a list of topographic features vastly different from anything seen on the continental surfaces. These structures demanded an explanation, and were the direct cause of the emergence of plate tectonic theory. This revolution in thought, quite unlike anything which had taken place before in the earth sciences, had the effect of taking the study of such apparently disparate phenomena as deep sea trenches and mountain building and uniting them into a single coherent theory. It would appear to be essential then, that any treatment of the earth sciences in a secondary school be centred around this theory.

From a societal viewpoint, recent events in world history point to a need for students to understand the potential and the limitations of the planet on which they
live. Phrases such as "oil shortage", "non-renewable resource" and "solar power" are commonplace, and indicate the type of world the student will occupy as an adult. It seems unthinkable that just as mankind is starting to realize the true importance of the earth sciences to the continued welfare of our race, an educational system should exist which does not provide an opportunity for junior high school students to investigate their planet. Unfortunately, this is apparently the case in British Columbia.

The reasons for this lack are many and diverse. Williams (1973) points out a number, including deficient teacher training in the earth sciences, lack of instructional time due to school timetable constraints, and teacher bias towards fields perceived as being "more important" than earth science. Probably one of the chief factors working against adequate instruction in earth science is the lack of up to date information, both factual and theoretical, in the books prescribed as texts for junior high school science by the British Columbia Ministry of Education. A brief perusal of these, (Schmid, Murphy, 1977; Schmid, 1970; Anastasiou, 1968; Woodrow, 1970) shows that virtually no mention is made of plate tectonics. Furthermore, references to examples and conditions found in British Columbia, the student's home territory, are few and far between.

For many students, the junior high years represent their last formal contact with science. A large number of students, for reasons ranging from inability to disinterest, exercise their option to not enrol in a science course in
grade 11 or 12. Of the students who do choose to continue in science, the majority enrol in chemistry, physics or biology rather than in earth science. It follows then, that in order to properly carry out the requirements of a general education, junior high school science should include as part of its mandate as a survey course, a substantial portion of earth science.

This need was originally recognized in 1967-68 when the junior high school science revision committee operative at that time set out the present course of studies, resulting in the current laboratory manuals and readers. In 1978, after representations made to the British Columbia Ministry of Education by the present author, on behalf of the B.C. Science Teachers' Association, the Ministry officials recognized that the current course of studies was in need of review. Their decision was not to revise the course completely, but to bring it up to date by metrification, and inclusion of the results of recent scientific research. The decision was also made to make the studies more relevant to the students' lives by including a great many more examples of situations peculiar to British Columbia.

To help accomplish this end, the present author was engaged by Prentice-Hall of Canada Ltd., publishers of the prescribed texts, to write and test in the classroom an earth science section for a revised edition of Extending Science Concepts in the Laboratory (Schmid, 1970). This appointment was based upon the author's experience as a currently practising junior high school science
teacher, his knowledge of British Columbia gained through extensive travel and study, and his broad collection of samples and photographs built up over many years.

METHODS

Philosophical Basis

The philosophical basis for this curriculum is the conviction that students learn by doing. In junior high school, the students will normally be from twelve to sixteen years old. According to Piaget (Flavell 1963; De Cecco 1968), this range of ages represents a transitional phase when children's learning patterns are changing from the concrete operational stage to the formal operational stage. Some students in the course will still be in the concrete operational stage, where concepts must be seen as concrete realities in order to be learned. Others will have already progressed to the formal operational stage, where concepts may be learned as abstractions without the necessity for concrete reality. To facilitate learning by both groups, most exercises are designed as laboratory investigations where the student makes direct observations during concrete experimental procedures. Formal operations are introduced by questions in which the student is expected to generalize from the observations.

The type of investigation used is the so-called "guided discovery method". In most laboratory investigations, the student is given explicit instructions regarding the use of equipment. Questions to be answered during the course of the experiment direct the processes of observing and
recording. The answers to these questions provide the factual content of the exercise. In this way, a reasonable balance is maintained between content and process. Those parts of the course which can not be conveniently investigated in a school laboratory setting are described in short expository narratives, supplemented by questions requiring both objective knowledge and the skills of analysis and synthesis.

Course Objectives

While following this course of study, it is hoped that the students will develop particular skills and attitudes, and acquire certain pieces of factual knowledge. Although they are quite comprehensive, the following lists of objectives make no pretense of being complete.

a) Development of Skills

i) process skills: - identifying problems
   - observing
   - recording and organizing data
   - interpreting data
   - formulating hypotheses
   - predicting
   - seeking further evidence

ii) communication skills: students will be required to communicate, both orally and in writing as they record information, express ideas and listen to others. They will also be required to read, both to progress through each exercise and to acquire ancillary information.
iii) motor skills: while working on the laboratory investigations, students will learn how to handle apparatus, to use measuring instruments, and to follow safe laboratory procedures.

b) Development of Attitudes
As well as learning the aforementioned easily definable skills, it is hoped that the students will also learn the following attitudes:

- increased curiosity about the natural world
- responsibility for the state of their environment
- co-operation with others in a joint venture
- independence in learning

c) Acquisition of Factual Knowledge
As well as process skills and attitudes, students would normally be expected to gain some factual knowledge from each exercise. This material, which is far too great to be described here, is stated in the Objectives for each individual exercise.
PROPOSED CURRICULUM

General Outline of the Curriculum

The course of study presented in this proposed curriculum would normally take about eighty hours of classroom work, probably spread over two school years. If this were fitted into the present junior science curriculum specified by the British Columbia Ministry of Education, these two years would normally be Grade 8 and Grade 10. Accordingly, the sequence of the proposed curriculum has been ordered to present first those topics more easily understood by the younger students, followed by the more difficult theoretical material. Part 1 covers the erosional and depositional aspects of geology, concentrating upon the modification of the landscape by water and ice, phenomena common in British Columbia. Particular examples are taken where possible from the Port Moody area, twenty kilometres east of Vancouver, where many of these processes may be observed in microcosm. Part 2 introduces the internal structure of the Earth, including volcanism and earthquakes, culminating in a study of plate tectonics. Emphasis is placed upon plate movement in the vicinity of British Columbia, and the resulting effects upon our province. Both Part 1 and Part 2 include sections on earth materials and earth history, introduced in Part 1, and reviewed and extended in Part 2. Throughout the course, reference is continually made to previously learned material.
Selected Areas of the Curriculum

As described above in the General Outline, the proposed curriculum is divided into a number of topic areas. From each of these, selected student exercises have been excerpted for description and analysis. The remaining portions of the proposed curriculum, including the Teachers' Manual, may be found in the Addendum to this volume.

Part 1

The main topic areas covered in Part 1 are those considered to be most easily understood by students in grade 8. In the order covered, these are: Rocks, Mapping, Weathering and Erosion, Ancient Life, and Glaciation. The section concludes with an example of a field trip suitable for grade 8 students, in which a number of the processes described previously may be observed in action.

Rocks

From a student's viewpoint, the main substance of our planet is rock. While a geologist may argue in favour of minerals, a student travelling through British Columbia would very seldom come in contact with an isolated mineral in a single mass large enough to be recognizable. For this reason, rocks rather than minerals have been chosen for the initial area of study of the materials of the Earth.

In all of the junior high school texts consulted (e.g. Mathews, 1978; Jackson & Evans, 1973; Ramsey et al, 1978), rocks are presented to the student in a strictly
descriptive form. The student is expected to read a lengthy narrative covering the formation, classification and description of rocks. If a laboratory exercise exists, it is confined to the identification of specific varieties of rock.

In this proposed curriculum, a unique approach is taken to the topic of rocks. The student is confronted immediately with a number of specimens which he is expected to describe, but not to identify (Investigation 1, below). Since most students have had very little practise in the art of writing physical descriptions, aid is given in the form of a data table with pre-selected headings such as colour, texture, porosity etc. In this way, the student learns to direct his powers of observation along the most profitable paths. Following the description, students are expected to organize their descriptions so that the rocks are classified into groups, (Investigation 2, below), thereby introducing the process of simplification of data by classification. No direction is given as to the type of grouping expected, so from a class of thirty or more students, many different classification systems naturally emerge.

A comparison of the students' classification systems (for details, refer to the Teachers' Manual in the Addendum), points out the need for consistency among systems. Following this, the well worn paths of description and identification are followed (Narrative 3, Investigations 4 and 5 below). Since the proposed curriculum is intended to have a strong
British Columbia regional bias, the rocks selected are those most commonly found in this province, with a few others added to round out the groups. In this way, a student is equipped with the knowledge necessary to identify rocks he may find during local travel. The same approach is useful to a teacher who may prefer to collect rather than purchase specimens.

The following pages contain the student exercises on rock identification referred to above.
INTRODUCTION

You live on a giant space ship. It is shaped like a huge ball 12,700 km across, and has a mass of more than 1,900,000,000,000,000,000,000 tonnes! Each year it carries you a distance of nearly 950 million km through space. It provides you with food, water, clothing and shelter. During the day it protects you from harmful radiation given off by the Sun. At night, it prevents you from being instantly frozen. This space ship is called Earth, our planet, and it is a very unusual place.

During your courses in Earth Science, you will explore the planet as it is today, and the way it used to be in the past. You will study some of the materials of which it is made, and how these came to be formed. You will learn that over three billion years ago the first living being formed, and that through the centuries its descendents multiplied, changed, and spread. Today, there are over a million different types of living beings, everywhere from the poles to the equator. In Earth science you will study some of the animals and plants which lived in the past, and see how they may have gradually changed into the life forms we recognize today.

Although our planet feeds, clothes and protects us, it can also be a very dangerous place to live. In 1902 Mt. Pelée, a volcano on the island of Martinique in the Caribbean Sea, killed nearly 30,000 people in the nearby town of St. Pierre. In 1976 an earthquake in T'ang-shan, China, killed more than 650,000. If people knew more about the Earth, these
disasters might have been avoided. In Earth Science, you will learn about the causes and effects of these and other sudden changes in our planet's surface.

In British Columbia, disasters like those in St. Pierre or T'ang-shan have not happened in our lifetimes. The surface of our part of the planet is still being changed however, but much more slowly. Every year the rain and snow fall, water freezes into ice and melts again, gradually wearing down and breaking apart the rocks which make up our mountains. Every year, millions of tonnes of tiny pieces of worn down rock, sand and mud are carried to the sea by rivers like the Fraser. Slowly but surely, our land is being worn down and washed out to sea. The process is usually too slow to notice, but it is just as effective as giant earthquakes and landslides. Even if a mountain is three kilometres high, and is worn down at only one centimetre every hundred years, it will be completely gone in only thirty million years. Our planet has been here for more than 4600 million years. Why has our province not been worn absolutely flat by now?

The answer begins deep within our planet. There, where no person has ever been, we think that there are immensely thick layers of rock and iron (Figure 1a). It is so hot down there that even solid rock can bend and flow very slowly, just as asphalt from a road can be made to bend and flow on a hot day in summer. Over millions of years, these slowly flowing rocks have formed giant currents within the Earth, as they rise, move across the surface,
Figure 1a. The layers of the Earth. The lithosphere is the solid crust; the asthenosphere is the layer of slowly moving rock beneath the crust; the lower mantle is a layer of solid rock between the asthenosphere and the liquid iron of the outer core, and the solid iron of the inner core.
Figure 1b. Slowly moving currents of rock in the asthenosphere keep large areas of the crust, including the continents, moving from one place to another on our planet.
During the past 200 million years, the map of the Earth has changed drastically as the continents have broken apart and moved to different positions on the globe.

Figure 1c. During the past 200 million years, the map of the Earth has changed drastically as the continents have broken apart and moved to different positions on the globe.
and sink again (Figure 1b). These currents are so huge that they can move entire continents, sometimes even break continents apart! Throughout the billions of years, the continents have been carried like giant rafts, floating on these currents of slowly moving rock. Sometimes the continents collide and crumple, pushing up ranges of mountains similar to those in our province. Other times they split and move apart (Figure 1c), creating small seas like the Red Sea, or huge ocean basins like the Atlantic. Every year the currents move the continents a few centimetres. In your lifetime they may move one or two metres. In a billion years they could travel twenty-five times around the planet!

Our world is constantly changing. The forces of wind and weather slowly grind its surface down. The currents of rock deep within the planet build it up again. In your courses in Earth Science you will learn about these processes, and how they affect all of our lives.
THE WORLD OF ROCK

What are mountains made of? If you dig down through the layers of soil under a farmer's field, what will you come to? If you were to dive into the depths of the ocean, and continue on down through the mud on the bottom, what would you eventually reach? All three of these questions may be answered with the same word, ROCK. The entire surface of our planet, whether mountain, desert, or ocean floor is made of rock.

You probably know already that not all rocks are the same. You may even know the names of some types of rock: granite, sandstone, or marble for example. Did you know that there are over five hundred named kinds of rock? In this section you will study a few of these, and learn how to name and identify them.

INVESTIGATION 1 Describing Rocks

Purpose: to examine and describe a number of different rocks.

Procedure

A. Make up a data table with the following headings:

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Colour</th>
<th>Roughness</th>
<th>Shape</th>
<th>Hardness</th>
</tr>
</thead>
</table>

Holes | Consistency | Layers | Crystals | Other Things |

B. List the sample numbers in the first column of your data table.
C. Examine each rock sample and write its characteristics in your data table. These are some of the things you should look for:

- **Colour**: is it the same colour all over, or made up of differently coloured pieces? What are the colours?
- **Roughness**: rough or smooth?
- **Shape**: are the edges rounded or sharp?
- **Hardness**: hard, or soft and crumbly?
- **Holes**: solid, containing a few holes, or many holes?
- **Consistency**: does it seem to be made of one single solid piece of material, or does it seem to be made of many different pieces all stuck together?
- **Layers**: is it made of layers or not? If so, how thick are they? Are they smooth or wrinkled?
- **Crystals**: is it made up of crystals? If so, how large are they? Are they different colours?
- **Other Things**: anything else you may notice about the rock which you think is interesting.

**Questions**

1. Can two people always agree on what to call the colour of a rock?
2. How could two people who can not agree on what to call the colour of a rock solve their problem?

**Conclusion**

What did you learn to do in this Investigation?
INVESTIGATION 2  Grouping Rocks

It is nearly impossible for one person to learn about all the different types of rock. To simplify this, rocks may be classified into families, or groups of similar types of rock. For example, all the black rocks may be placed in one group, and all the red rocks in another. Perhaps all the soft rocks might go in one group, and the hard ones in another. Purpose: to classify rocks into groups.

Procedure
A. Make up a data table like this:

<table>
<thead>
<tr>
<th>Group Name or Description</th>
<th>Sample Numbers of Rocks in Each Group</th>
</tr>
</thead>
</table>

B. Use your descriptions from Investigation 1 to help you classify the samples into groups. Try to have not more than six different groups. When you have finished, compare your groups with those made by other students.

Questions
1. Did all students make up the same groups, or were some of them different?
2. Did some of your samples fit into more than one group?
3. Did you have difficulty placing some of your samples in a group?
4. What difficulties would geologists have if each one used a different method of grouping rocks? How could geologists solve this problem?

Conclusion

What did you learn to do in this Investigation?
A System for Grouping Rocks

In Investigation 2 you learned about some of the difficulties which could arise if each geologist used his own system for classifying rocks. To avoid these problems, geologists around the world have all agreed to use the same system. It is not based upon the appearance of the rock, but upon how the rock was originally made. In this narrative you will learn about this system, and the names that geologists use for their groups.

The first group is called SEDIMENTARY. Sedimentary rock is formed from layers of SEDIMENT. Sediment consists of pieces of rock, usually quite small, such as pebbles, sand or silt. Sediment can be moved around, or carried by wind or water. If the sediment is carried by water, it may settle to the bottom of a sea or lake. If it has been carried by the wind, it may form a sand dune. Over many years, ground water may deposit material between the grains of sediment which will cement them together. This, combined with the pressure from above may harden the sediment into rock.

Sedimentary rocks may be recognized by their layers. Some may still show signs of the original pieces from which they were made, particularly if these were pebble-sized. If the bodies of animals or the leaves of plants were trapped in the sediment as it settled, their remains may appear as fossils. Figures 1 and 2 show sedimentary rocks.

The second group is called IGNEOUS. Igneous rocks are formed when very hot molten rock cools to become a solid. Igneous rocks are divided into two sub-groups.
PLUTONIC igneous rocks are those which cooled very slowly, deep underneath the surface of the Earth. Over many thousands of years, pressure from inside the Earth has pushed them to the surface, where the material covering them has been washed away. Plutonic rocks are usually very hard. They are formed of quite large (greater than 1 mm) crystals. Figure 3 shows an example of an igneous plutonic rock.

VOLCANIC igneous rocks are those which cooled rapidly, near the surface of the Earth. They may be hard or soft. Some may be full of bubbles. Like plutonic rocks, they are also made up of crystals, but these crystals are very small. Usually they may be seen only with the aid of a microscope. Sometimes the rocks cooled so rapidly that no crystals formed, and the rock resembles glass. A volcanic igneous rock may be seen in Figure 4.

METAMORPHIC rocks are rocks which have been changed from their original form. They began as sedimentary or igneous rocks which were buried deep under the surface of the Earth. There, heat and pressure has changed them. This heat and pressure may have changed the shape and composition of the crystals in igneous rock. It may have destroyed the layers or fossils in sedimentary rock. Under special conditions, bands may form in metamorphic rock, but these are quite different from the layers in sedimentary rock. Metamorphic rocks are the most difficult to recognize! You can see some metamorphic rocks in Figure 5.

(Ref.: B.C. Dep't of Mines and Petroleum Resources, 1968).
Fig. 1d. Sandstone is a sedimentary rock formed when grains of sand are squeezed and cemented together.

Fig. 2. Conglomerate is a sedimentary rock formed when pebbles are squeezed and cemented together.
Fig. 3. Granite is a plutonic rock formed when molten rock cools slowly, deep underground. The large interlocking crystals are clearly visible.

Fig. 4. Basalt is a volcanic rock which forms when molten rock cools rapidly. The crystals are difficult to see without a magnifier.
Fig. 5. Gneiss is a metamorphic rock found in British Columbia. The crystals line up into irregular "bands".

Fig. 6. Layers of coal and shale on Ellesmere Island in the Canadian arctic. (Photograph courtesy of the Geological Survey of Canada).
Questions
1. What clue tells you that the rocks shown in Figure 6 are sedimentary?
2. How are fossils formed in sedimentary rock?
3. Explain why it is unlikely that fossils would form in igneous rock.

INVESTIGATION 4 Classifying Rocks

In Investigation 2, you found that different people sometimes have different methods of grouping rock samples. To avoid this problem, geologists have agreed to use the same system all the time.

Purpose: to classify rocks by using the geologists' system.

Procedure
A. Make a data table like this:

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Group</th>
</tr>
</thead>
</table>

B. List the sample numbers in the first column. Examine each sample and decide whether it is sedimentary, igneous plutonic igneous volcanic, or metamorphic. Write the correct group name for each sample in the second column.

Questions
1. What is sediment? How can it form into rock?
2. How is igneous rock formed?
3. How is metamorphic rock formed?
4. Explain the difference between volcanic and plutonic rock.

Conclusion

What did you learn about rocks in this Investigation?
NARRATIVE 5

A System for Naming Rocks

So far, you have examined a number of rocks and classified them into groups. Now you will learn how to recognize and name particular types of rock. Remember though, that the names you learn will be only a few of the many different names that geologists use.

SEDIMENTARY rocks are usually named according to the size and shape of the original pieces of sediment.

<table>
<thead>
<tr>
<th>Sediment</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rounded pebbles</td>
<td>Conglomerate</td>
</tr>
<tr>
<td>Sharp, angular pebbles</td>
<td>Breccia</td>
</tr>
<tr>
<td>Sand</td>
<td>Sandstone</td>
</tr>
<tr>
<td>Mud, clay or silt</td>
<td>Shale</td>
</tr>
<tr>
<td>Crushed shells of sea animals</td>
<td>Limestone</td>
</tr>
<tr>
<td>Crushed plant material</td>
<td>Coal</td>
</tr>
</tbody>
</table>

Note: limestone may also be recognized by its fizzing reaction with dilute hydrochloric acid.

IGNEOUS PLUTONIC rocks are named according to the materials of which their crystals are made. Since you have not studied these materials, you will use crystal colour to identify these rocks.

<table>
<thead>
<tr>
<th>Crystal Colour</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mostly light crystals</td>
<td>Granite</td>
</tr>
<tr>
<td>Light and dark crystals, about eveny mixed</td>
<td>Quartz Diorite</td>
</tr>
<tr>
<td>Mostly dark crystals</td>
<td>Gabbro</td>
</tr>
</tbody>
</table>
IGNEOUS VOLCANIC rocks also may be named according to their colour.

<table>
<thead>
<tr>
<th>Description</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light colour</td>
<td>Rhyolite</td>
</tr>
<tr>
<td>Medium colour</td>
<td>Andesite</td>
</tr>
<tr>
<td>Dark colour</td>
<td>Basalt</td>
</tr>
<tr>
<td>Volcanic glass</td>
<td>Obsidian</td>
</tr>
<tr>
<td>Lightweight,</td>
<td></td>
</tr>
<tr>
<td>&quot;frothy&quot; material</td>
<td>Pumice</td>
</tr>
<tr>
<td>Coarse crystals</td>
<td></td>
</tr>
<tr>
<td>embedded in much</td>
<td></td>
</tr>
<tr>
<td>finer material</td>
<td>Porphyry</td>
</tr>
</tbody>
</table>

METAMORPHIC rocks are named according to the original sedimentary or igneous rock from which they are made. In this course you will study only four types which are common in British Columbia.

Quartzite is formed from sandstone. It may resemble sandstone, but is much harder. The grains are crushed together much more tightly in quartzite than in sandstone.

Slate is formed from shale. It has very fine grains like shale. Slate is much harder than shale. It splits into fairly smooth sheets, but these splits are **not** in the same direction as the layers in the original shale.

Marble is formed from limestone. It usually has crystals, and fizzes with dilute hydrochloric acid.

Gneiss may be formed from several different kinds of rock. It has crystals, and often shows bands. These bands are **not** the same as sedimentary layers.
(Hamilton et al., 1974; Zim, Shaffer, 1957; B.C. Dep't of Mines and Petroleum Resources, 1968).

Questions
1. Identify each of the rocks shown in Figures 1 to 5.
2. Define the word "rock". (DO NOT copy a definition out of a dictionary. Write your OWN definition!).

INVESTIGATION 6 Naming Rocks
Purpose: to give specific names to each of the rocks studied in Investigation 4.

Procedure
A. Make a data table like this:

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Rock Name</th>
</tr>
</thead>
</table>

B. List the sample numbers in the first column of your data table. Examine each specimen and write its name beside its sample number. For the names, you may have to refer to Narrative 5.

Questions
1. Which has larger crystals, granite or rhyolite?
2. Which is usually harder, slate or shale?
3. In some countries, slate is used as a roofing material for houses. What property of slate makes it particularly useful for this purpose?
4. Which is more likely to contain fossils, shale or andesite?
5. Which two types of rock fizz with dilute hydrochloric acid?
6. Pumice and obsidian are both made of volcanic glass.
Explain the difference between them.

7. At one time, British Columbia indians used obsidian for making arrowheads and axes. What property of obsidian made it particularly useful for this purpose?

Conclusion

What did you learn about rocks in this investigation?
Rocks and Minerals - an alternative approach.

The world beneath your feet is made up of three things, minerals, rocks and soil. Minerals are the basic chemical substances which make up the other two. Rocks are mixtures of minerals. Soil is fine pieces of broken down rock, together with plants, animals, and their remains. In this section you will study two of these, rocks and minerals.

Part 1 Grouping rocks
A. Compare the specimens of sand stone and granite. Use a magnifier to look more closely. Examine the piece of freshly broken granite first. Is granite made up of the same material all the way through, or is it made up of several different materials? How many are there? Are the pieces irregular or rounded in shape? What are their colours? Now examine the sandstone. Answer the same questions that you answered for granite. Re-read your answers above, and write a few short sentences describing the differences between granite and sandstone.

You have just examined two completely different types of rock. Granite was formed deep within the Earth, perhaps 15 or 20 km underground, when molten rock cooled and became solid. It is made of mineral crystals. Each individual piece that you can see is a crystal, all interlocked together with the other crystals.

Sandstone was formed on the surface of the Earth. Grains of sand were washed around by water, perhaps on a beach or by a river. As the pieces rubbed against each other,
their sharp corners were broken off, and the grains became rounded. When they finally settled into place, pressure from above combined with materials deposited between the grains by the water hardened the loose sand into solid rock.

Geologists classify rocks into three main groups. You have just examined samples from two of these. Rocks like sandstone, formed when grains of material are crushed and cemented together are called sedimentary rocks. Rocks like granite, formed when molten material cools and hardens are called igneous rocks. Write these two terms and their definitions in your notebook.

B. Examine the specimens provided. Which are sedimentary and which are igneous? Give a reason for each of your choices.

C. Examine the samples of granite and gneiss (pronounced "nice"). Each is formed of crystals. How are the crystals in gneiss arranged differently to the crystals in granite? Gneiss is an example of a metamorphic rock. Metamorphic rocks are those which have been changed from their original form by heat, pressure, or chemical action. Write this term and its meaning in your notebook. Gneiss is formed when heat and pressure cause new crystals to grow in parallel streaks or bands. This can only happen when the rocks are buried deep underground.

D. You have just learned about the three groups of rocks used by geologists: sedimentary, igneous, and metamorphic. In the next few parts of this exercise, you will learn more about each group.
Part 2 Sedimentary rocks

E. Remember that these are made of material deposited by water (and occasionally wind), then hardened into rock by pressure and cement. Examine samples of shale, conglomerate and sandstone, and look at the grains which make up each rock. Which has the largest grains? which has the smallest? Which would have needed fast flowing water to move its grains? Which could have had its grains moved by very slow flowing water?

F. Copy the table below into your notebook:

<table>
<thead>
<tr>
<th>Rock Name</th>
<th>Grain Size</th>
<th>Place where grains were deposited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conglomerate</td>
<td>medium grains</td>
<td></td>
</tr>
<tr>
<td>Sandstone</td>
<td>very fast flowing water</td>
<td></td>
</tr>
<tr>
<td>Shale</td>
<td>very small grains (mud or clay)</td>
<td>large grains (pebbles or boulders)</td>
</tr>
<tr>
<td></td>
<td>very slow water</td>
<td>medium speed water</td>
</tr>
</tbody>
</table>

Now write each of the following phrases in its correct place in the table: medium grains; very fast flowing water; very small grains (mud or clay); large grains (pebbles or boulders); very slow water; medium speed water.

G. Compare samples of conglomerate and breccia. How can we tell that the grains in breccia were not rolled around in a stream or on a beach before they were deposited? Try to describe a place in which breccia could be formed.

H. Compare two samples of limestone - one with fossils and one without. Can you identify any of these fossils? In what sort of place did limestone form? Put a drop of dilute hydrochloric acid on each sample. Describe what happens.
What is an easy way to identify limestone?

G. Examine a geologic map of your home area. Describe the location of a place where sedimentary rocks might be found. What kinds of rock are there? Try to describe what this place might have looked like at the time the grains making up the rocks were deposited. If you live near the Rocky Mountains you will be able to find many kinds of sedimentary rocks to look at.

Part 3 Igneous rocks

H. Examine samples of gabbro and basalt. Which has the larger crystals? Gabbro, like granite, was formed when molten rock cooled very slowly, deep underground. When rocks are made this way, they form large crystals and are called plutonic igneous rocks. Basalt was formed when molten lava, perhaps from a volcano, cooled rapidly near the surface of the Earth. When rocks are made this way, they form small crystals and are called volcanic igneous rocks.

I. Igneous rocks are named according to the type of minerals they contain. You will look mainly at the colours of these minerals.

<table>
<thead>
<tr>
<th>Mineral Colour</th>
<th>Name of Plutonic Rock</th>
<th>Name of Volcanic Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mostly light</td>
<td>Granite</td>
<td>Rhyolite</td>
</tr>
<tr>
<td>Light &amp; dark, evenly mixed</td>
<td>Quartz diorite</td>
<td>Andesite</td>
</tr>
<tr>
<td>Mostly dark</td>
<td>Gabbro</td>
<td>Basalt</td>
</tr>
</tbody>
</table>

Examine a number of igneous rock samples. Identify each using a name from the table above.
J. Examine a geologic map of your home area. Describe a place where igneous rocks may be located, and the types of rocks found there. Try to write an explanation of how they may have got there. If you live near the Coast Mountains of British Columbia there should be many plutonic igneous rocks nearby. Central B.C. has many volcanic igneous rocks.

Part 4 Metamorphic rocks

K. Metamorphic rocks are made when another rock is changed from its original form by heat, pressure, or chemical action. Several changes may take place. Sometimes the original minerals may simply grow larger. At other times, new minerals may form in the rock. A third possible change is the development of foliation which allows the rock to split into sheets or flakes. A number of metamorphic rocks may be found in British Columbia.

Marble: limestone which has grown larger crystals forms marble. It will have the same fizzing reaction with dilute hydrochloric acid that limestone has.

Quartzite: sandstone which has been bound together so tightly by quartz cement that the resulting rock is extremely hard and tough. When the rock is broken, it breaks through both cement and grains, whereas sandstone breaks around the grains.

Slate, schist and gneiss are all foliated (able to split) rocks. Examine a labelled sample of each, and write a brief description of its appearance. They are all formed when other rocks are buried deeply, heated and compressed.
L. Examine a geologic map of your home area. Describe a location where metamorphic rocks may be found, and say which rocks are there. Try to write an explanation of how they may have been formed.

Part 5 The rock cycle

You have already learned that rock can be changed from one type to another. For example, the sedimentary rock shale may become deeply buried in the Earth where it is heated and compressed to become the metamorphic rock slate or perhaps gneiss. If it is buried deeply enough, it may melt completely, then cool again to become an igneous rock, quartz diorite. If over millions of years, the igneous is pushed to the surface of the Earth, it may form part of a mountain. Eventually the mountain may be worn down by the weather, and the broken pieces of rock may become sand. The rock has gone through a complete cycle from sediment, to sedimentary rock, to metamorphic rock, to igneous rock, and back to sediment again. This change from one type of rock to another is called the rock cycle, and it could take hundreds of millions of years. Figure 6b shows the rock cycle as a diagram. Each arrow represents a possible route that a rock could take. What could happen to a metamorphic rock to change it directly to sediment? How could a sedimentary rock become an igneous rock, without becoming a metamorphic rock first?

M. Try making a large copy of the rock cycle on a piece of cardboard. Glue samples of each type of rock and sediment
at its correct place in the cycle. You may have to use small transparent containers for the sediment.

Part 6 The minerals in rocks
N. Examine a few millilitres of crushed granite. Try to separate the grains into three separate piles of similar grains. Each pile is one of the different minerals which make up granite. The two lighter coloured minerals are quartz and feldspar. Try to label each pile from the following descriptions:

<table>
<thead>
<tr>
<th>Quartz</th>
<th>Feldspar</th>
</tr>
</thead>
<tbody>
<tr>
<td>glassy</td>
<td>dull</td>
</tr>
<tr>
<td>transparent</td>
<td>cloudy</td>
</tr>
<tr>
<td>grey</td>
<td>white, grey, red, pink, green</td>
</tr>
<tr>
<td>irregular shape</td>
<td>rectangular shape</td>
</tr>
<tr>
<td>irregular broken surface</td>
<td>flat broken surface</td>
</tr>
</tbody>
</table>

The darker third mineral may be mica or amphibole. Mica will be in thin, flat flakes. Amphibole will be in larger solid pieces.

O. Compare a piece of granite with a piece of quartz diorite. Which has more quartz? Which has more feldspar? Which has more dark minerals? These four types of mineral make up many of the igneous rocks in British Columbia.

P. Examine a piece of calcite. Describe its appearance. Calcite is the main mineral found in limestone. Place a drop of dilute hydrochloric acid on the calcite. Describe what happens. Calcite is also found in many types of sandstone. Use a magnifier to examine a piece of sandstone containing calcite. Can you see the grains of sand? Which mineral do
you think they are made of? Drop dilute hydrochloric acid on the sandstone. What happens? Where do you suppose the calcite is located in the rock? The calcite was deposited in the rock by water, and is the cement which holds the grains of sand together.

Conclusion

What have you learned about rocks and minerals in this exercise?

Figure 6b. The rock cycle.
Mapping

One of the major objectives of this proposed curriculum is the familiarization of the students with both their local area and their province. Obviously this would best be accomplished by a series of field trips, however most teachers would probably find this impractical. The next best method is through a study of maps, and this is the approach taken here.

Since the students have just completed several days work on the identification of rocks, this section is started with an exercise on geologic mapping. First, a class exercise simulating geologic mapping (Teachers' Manual, Addendum) is completed, followed by an examination of a geologic map. While the exercise as written (Investigation 7, below) centres on the Port Moody area, the principles it embodies are easily transferrable to a map of any area. First the student is asked to label a selection of local landmarks on a blank outline map. This builds up familiarity with locations that he may have already visited. Next, the student locates and colours areas of various types of bedrock, thereby learning about local conditions, and simultaneously reviewing his knowledge of rocks.
The remainder of the Mapping section of the proposed curriculum (refer to the Addendum) consists of exercises involving the use of symbols, scales, altitudes, contour lines and profile drawing. All of these exercises use maps of the Port Moody area, however the principles involved may be easily transferred to any National Topographic System map.

The following pages contain the student exercise on geologic mapping referred to above.
THE WORLD OF GEOLOGIC MAPPING

Geologists in Canada spend much of their time examining the rocks which make up this country. By doing this, they are able to locate valuable resources such as mineral deposits, oil wells and natural gas fields. From their results, they draw maps so that other people may use their observations.

Canada is so large that it has not yet been mapped completely, even though the Geological Survey has been working since 1842!

In the next Investigation you will use a section of a map prepared by the Geological Survey of Canada to determine what kinds of rock occur in a small section of southwest British Columbia.

INVESTIGATION 7 Making a Geologic Map

Purpose: to make a geologic map of the Port Moody area.

Procedure

A. On the outline map of the Port Moody area, locate and label each of these landmarks. Use a sharp pencil, and print neatly.

<table>
<thead>
<tr>
<th>Burrard Inlet</th>
<th>Admiralty Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indian Arm</td>
<td>Buntzen Lake</td>
</tr>
<tr>
<td>Bedwell Bay</td>
<td>Sasamat Lake</td>
</tr>
<tr>
<td>Belcarra Bay</td>
<td>Elsay Lake</td>
</tr>
<tr>
<td>Deep Cove</td>
<td>Goldie Lake</td>
</tr>
<tr>
<td>Buntzen Bay</td>
<td>Cypress Lake</td>
</tr>
<tr>
<td>Berry Point</td>
<td>Cosy Cove</td>
</tr>
</tbody>
</table>
Fig. 7. Geologic map of the Port Moody area. The colours and markings represent various kinds of rock.
Fig. 8. Outline map for Investigation 7.
LEGEND

- Granite
- Granodiorite
- Quartz Diorite
- Diorite
- Gabbro
- Migmatite
- Alluvial, marine & glacial deposits
- Sandstone, shale & conglomerate etc.
- Tuff, breccia, agglomerate, andesite.
- Hornblende-granulite, amphibolite, gneiss, etc.
Roche Point    Twin Islands
Burns Point    Raccoon Island
Brighton Beach Jug Island
Turtle Head    Seymour River
Gopher Lake    Theta Lake
Clegg Lake     Mount Seymour
Capitol Hill   Burnaby Mountain
Eagle Mountain Mount Elsay
Buntzen Ridge (between Buntzen Lake and Indian Arm)

B. Examine the geologic map carefully. Notice how the various colours and symbols show the types of rock in each area. On the map you prepared in Procedure A, draw the boundaries between each rock type. Colour the squares representing each rock type on the Legend, then use the same colours on your map.

Questions
1. Why do you suppose that geologic maps use colours instead of just symbols to show the rock types?
2. Is it possible for a geologist to examine the rock in every part of an area?
3. What things could cover the rock, preventing a geologist from examining it?
4. Can a geologist be absolutely sure of the types of rock to be found in an area?

Conclusion
What did you learn about geologic mapping in this investigation? (Roddick, 1965)
Weathering and Erosion

One of the major sections in Part 1 of the proposed curriculum involves the gradational and depositional aspects of geology. Since these are processes easily observable by students, their causes and effects are treated at some length. The section begins in a fairly standard way with a series of narratives and laboratory investigations involving simulation of weathering processes (Investigation 14, Addendum), the water cycle (Investigation 14, Narrative 15, Addendum) and stream abrasion (Investigation 17, Addendum).

Investigations 18 and 19 (below) introduce data not easily available to the average teacher, but of great importance to British Columbia. These figures are the long term monthly averages of water and sediment transported by the Fraser River, one of the major drainage systems of the province. To aid the student in assimilating the meaning of these figures, he is asked to draw a pair of simple bar graphs, thereby transforming the figures into visual form. Once these exercises have been completed, the students have a better feeling for the amounts of material involved, and the changes in flow caused by differing climatic conditions throughout the year.

Investigation 23 (below) is a regional study of the Fraser delta, one of the major areas of sediment deposition in British Columbia. Here, the student studies a map and a satellite photograph of the delta, and uses these to discover which areas may be experiencing growth, and which may be static or declining. This is followed by Narrative 24
(below), a brief description of the Pitt Lake delta, an unusual landform caused by reversal of water flow, whose existence is unknown to most teachers.

The remaining exercises in this section on gradational and depositional processes (refer to the Addendum) include a microscopic study of sandy sediments, and a rather dramatic account of the Frank Slide of 1903.

The following pages include the student exercises on erosion and deposition referred to above.

INVESTIGATION 18  Sediment Flow

Every little stream running down a mountainside carries a load of sediment. Some sediment comes from soil washed away from the stream banks. More sediment comes from the abrasion of rocks, formed in the way that you studied in Investigation 17. As the small streams join together to form larger streams and rivers, their loads of sediment also join. Large rivers like the Fraser or the Skeena carry huge amounts of sediment down to the sea each year. In this investigation, you will study how this amount of sediment changes over the course of a year.

Purpose: to study the amount of suspended sediment carried by the Fraser River during a year.
Procedure

A. The Fraser River starts in the Rocky Mountains just west of the town of Jasper. It flows north, then turns south near Prince George. At the village of Hope, the river turns west, and flows through the Fraser Valley, past the cities of Mission and New Westminster to the sea. The Fraser drains an area of approximately 230 000 km\(^2\).

Use your atlas to measure the approximate length of the Fraser in kilometres.

B. The table below shows the average sediment flow in the Fraser, measured at Mission. The figures are the daily average for each month during the years 1965 to 1976.

<table>
<thead>
<tr>
<th></th>
<th>Sediment Flow at Mission (tonnes per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>3 720</td>
</tr>
<tr>
<td>Feb.</td>
<td>1 760</td>
</tr>
<tr>
<td>Mar.</td>
<td>5 730</td>
</tr>
<tr>
<td>Apr.</td>
<td>34 300</td>
</tr>
<tr>
<td>May</td>
<td>188 000</td>
</tr>
<tr>
<td>Jun.</td>
<td>230 000</td>
</tr>
<tr>
<td>Jul.</td>
<td>101 600</td>
</tr>
<tr>
<td>Aug.</td>
<td>36 000</td>
</tr>
<tr>
<td>Sep.</td>
<td>16 000</td>
</tr>
<tr>
<td>Oct.</td>
<td>11 400</td>
</tr>
<tr>
<td>Nov.</td>
<td>7 520</td>
</tr>
<tr>
<td>Dec.</td>
<td>3 540</td>
</tr>
</tbody>
</table>

Use the above data to plot a bar graph showing the daily sediment flow for each month. Use a suitable scale such as 1 cm = 10 000 t/day. (Inland Waters Directorate, 1978b)

Questions

1. In which month does the Fraser carry the most sediment? Calculate the total amount of sediment carried during this month.

2. Try to explain why the Fraser carries more sediment in June than in February.
3. During the years shown, an average of approximately 20,000,000 tonnes of sediment are washed past Mission each year. Try to imagine that this sediment is carried, not by a river, but by trains. Imagine that each train has 100 cars, and each car carries 100 tonnes.

a) How much sediment would each train carry?
b) How many trains would be needed each year?
c) How many trains would be needed each day?
d) During June, the Fraser carries 230,000 tonnes of sediment each day. About how many trains would be needed each hour to carry this amount of sediment?

Conclusion

In this investigation, what did you learn about the amount of sediment carried by the Fraser River?

INVESTIGATION 19   Water flow

The last investigation showed you how the amount of sediment carried by a river changes throughout the year. You probably suspected that the amount of sediment carried depended upon the amount of water flowing in the river. In this investigation, you will study the changes in water flow in the Fraser River throughout the year.

Purpose: to study the amount of water carried by the Fraser River throughout the year.

Procedure

A. The table below shows the average daily water flow in the Fraser River for each month during the years 1965 to 1976. Make a bar graph of the information. Use a suitable
vertical scale such as 2 cm = 1000 m³/s.

**Water Flow at Mission**  
(cubic metres per second)

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan. 1360</th>
<th>Feb. 1290</th>
<th>Mar. 1320</th>
<th>Apr. 2150</th>
<th>May 5870</th>
<th>Jun. 8790</th>
</tr>
</thead>
</table>

(Inland Waters Directorate, 1978c)

B. Compare this graph with the one you drew in Investigation 18. Do the high points occur in the same month? Do the low points occur in the same month? Explain why this similarity occurs.

Questions

1. During the month of June, an average of 8790 m³/s of water flow past Mission. How much water flows in
   a) one minute?
   b) one hour?
   c) one day?
   d) the entire month (30 days)?

2. Explain why the greatest water flow occurs in June, and the least in February. (Hint: it has something to do with the weather).

Conclusion

In this investigation, what did you learn about the amount of water carried by the Fraser River?
INVESTIGATION 23  Deltas

All rivers carry sediment, some more than others. Eventually the river flows into a body of quiet water such as the sea or a large lake. Here the force of gravity overcomes the ability of the water to keep the sediment afloat, and so the sediment sinks to the bottom. These deposits of sediment at the mouth of a river form a delta. Purpose: to study a number of deltas.

Procedure
A. On an outline map of the Fraser Delta (Figure 9), print the following labels. Obtain your information from a topographic map. Use a sharp pencil, and print neatly.


Waterways: Georgia Strait, Burrard Inlet, Indian Arm, Coquitlam Lake, Coquitlam River, Pitt Lake, Pitt River, English Bay, Boundary Bay, Mud Bay, Fraser River, North Arm, Middle Arm, South Arm.

Land Areas: Lulu Island, Sea Island, Westham Island, Annacis Island, Point Roberts.

Delta Front Areas: Spanish Bank, Sturgeon Bank, Roberts Bank, Boundary Bay Tidal Flats.

B. Examine Figure 10, a satellite photograph of the Fraser Delta and Georgia Strait. On your map, shade in lightly and label the area where sediment is being swept into Georgia Strait. Which of the delta front areas named in Procedure A are growing larger at present as sediment
Figure 9. Outline map of the Fraser River delta.
is being swept on to them? Which areas do not appear to be growing at present?

C. Figure 12 shows the delta of the river Nile in Egypt. Explain why the delta shows the dark colour of vegetation, while all around is light coloured desert.

D. Aklavik, a town built on the delta of the Mackenzie River in Canada's Northwest Territories is shown in Figure 13. Examine the photograph and try to suggest one of the hazards of living on a delta, and the reason why Aklavik has been largely abandoned.

E. Figure 14 is a photograph of the Squamish River delta, about 50 kilometres north of Vancouver. Two industries are located on this delta, a sawmill and a small chemical manufacturing plant. Why are deltas often chosen as suitable sites for industrial areas?

F. Set the stream table on an angle of \(20^\circ\). With your finger, make a straight shallow groove to guide the water. Start the water flow and wait for several minutes for a delta to form. Does the water always follow the same path when depositing the sediment? Sketch a top view of the resulting delta.

Questions

<table>
<thead>
<tr>
<th>Fraser River Records</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum flow 15177 m(^3)/s May 31, 1948</td>
</tr>
<tr>
<td>Minimum flow 340 m(^3)/s Jan. 8, 1916</td>
</tr>
</tbody>
</table>

(Inland Waters Directorate, 1978c)

1. The amount of water carried by a river can vary greatly from day to day and from month to month. Above are the record high and low flow rates for the Fraser River. The year
Fig. 10. A satellite photograph of the Fraser delta, Georgia Strait, and southern Vancouver Island.

Figure 11. Delta front.
Fig. 12. The delta of the river Nile in Egypt. (NASA photograph).

Fig. 13. The town of Aklavik is built on the delta of the MacKenzie River in Canada's North West Territories.
Fig. 14. A chemical plant and a sawmill have been built on the Squamish River delta.
1948 produced the most disastrous floods ever known in the Fraser Valley. 1916 was a year of record low temperatures.

a) Why does the greatest water flow usually occur in the late spring or early summer?

b) Why should the winter temperature affect the rate of water flow?

2. Figure 15 shows a cross-section of a river in two different seasons. During the spring floods, it spreads across the plain and deposits its load of sediment. During the rest of the year, it is confined to a central channel.

a) Why is a flood plain a good place for agriculture?

b) What is one of the hazards of living on a flood plain?

c) How could floods be prevented?

d) What will be the eventual effect upon the fertility of the land if floods are prevented?

3. Figure 16 is a diagram of a delta front. Copy this diagram into your notes.

a) Will the heavy sediment be dropped close to the river, or farther out to sea?

b) Will the fine sediment like silt be dropped close to the river, or farther out to sea?

c) Label on your diagram the places where conglomerate, sandstone and shale could possibly be forming in this delta.

4. Why would a dam built across a muddy river like the Fraser eventually become useless?

Conclusion

What is a delta, and why does it form?
Figure 15. Flood plain of a river.

Figure 16. Outline of a delta front. (Steepness greatly exaggerated).
The Mystery of Pitt Lake

In Figure 17, you can see a map of the south end of Pitt Lake, a large body of water 50 kilometres east of Vancouver. The water flows into Pitt Lake from the north, and flows out through the Pitt River, into the Fraser. Normally, deltas occur where a river flows into quiet water, and not where it flows out of a lake. Yet here, a large delta is quite clearly being formed where the Pitt River leaves the lake! How can this happen?

We must look to the sea and its tides for an explanation. During very high tides, sea water flooding into the mouth of the Fraser raises the water level in the river. This in turn pushes water from the Fraser into the Pitt, causing the Pitt to flow backwards for a short while. During these periods of reverse flow, sediment is washed back into Pitt Lake and deposited, forming this most unusual delta. (Roddick, 1965)

Ancient Life

Any study of earth science must include a study of earth history since the present Earth is obviously a product of its own past. In the grade 8 section of this proposed curriculum, earth history is described in terms of the plants and animals which lived during the past, and is investigated directly through the study of fossils. The topic is introduced in Narrative 27 (below) by a
Figure 17. An unusual delta, formed where the Pitt River flows out of Pitt Lake.
unique comparison between the time divisions of the geologic column and the time divisions of our everyday calendar. In this way, the student is able to fit unfamiliar terms such as eon and era into an already familiar pattern. Narrative 27 continues with a very brief description of the life forms abundant during the Phanerozoic eon. This is followed by Investigation 28 in which the student organizes information found in this and other books into the form of a chart.

The study of fossils, a topic which appears to have intrinsic interest for junior science students, begins with Investigation 29 (below). Essentially, this is a guessing exercise in which students attempt to deal with a number of unfamiliar fossils. The looseness of this investigation as it is written enables the teacher to tailor it to the specific needs and abilities of the class. Investigation 30 (below) continues the study of fossils by introducing specific specimens, and directing observation towards particular points of interest. Emphasis is placed upon specimens which might be found at locations in British Columbia.

The section concludes (see Addendum) with narratives and investigations covering the topics of fossilization and dinosaurs. The following pages contain the student exercises on earth history referred to above.
THE WORLD OF ANCIENT LIFE

Most people have heard of fossils, the remains of plants and animals preserved for millions of years by being buried in rock. Geologists are extremely interested in fossils because they provide the only record of what kinds of living beings inhabited the Earth in ancient times.

Before we begin our study of fossils however, we should learn the names that geologists use for various times in the past.

NARRATIVE 27

The Geological "Calendar"

Just as we divide years into sections called months, weeks and days, geologists have divided the entire life of the Earth into sections. These sections are called eons, eras, and periods.

Our Calendar

- Year
  - Month
  - Week
  - Day

Geological Calendar

- Life of Earth
  - Week
  - Day
  - Era
  - Period
  - Eon
Although the methods of dividing up time are similar, the lengths of the sections are quite different. Even the shortest of the geological time divisions are millions of years in length.

Just as our months and days have different names, the divisions of the geological calendar also have names. The Earth's history is divided into only two eons, the Cryptozoic Eon and the Phanerozoic Eon. The word "cryptozoic" comes from two Greek words meaning "hidden life". This term was chosen because we know very little about what kinds of plants or animals were alive then. The word "phanerozoic" means "visible life", and it was chosen because we have a large number of fossils from this eon.

The Cryptozoic Eon covers about the first $9/10$ of the Earth's history. During this eon, the only life present on Earth that we know about consisted of bacteria, soft-bodied animals, and simple plants. Most of these left no fossil record for us to see. In Canada, a few fossil bacteria preserved in 2 billion year old rocks near Thunder Bay, Ontario, represent some of the oldest living things ever found. (Barghoorn, 1971)

The Phanerozoic Eon covers the remaining $1/10$ of the Earth's lifetime, about 600 million years. This eon is divided into three eras. These are called the Paleozoic Era, meaning "ancient life", the Mesozoic Era meaning "middle life", and the Cenozoic Era or "recent life".

The Paleozoic Era could be called the "age of invertebrates. Invertebrates are animals without backbones."
Fig. 18. Fossil trilobites. These animals lived on the bottom of a shallow sea many hundreds of millions of years ago.

Fig. 19. Lambeosaurus. This dinosaur skeleton is on view in the Geology building at the University of British Columbia.
This era began with the appearance of many small sea animals such as trilobites (Figure 18), brachiopods, (a type of shellfish), and snails. The trilobites are believed to be the ancestors of present day crabs and lobsters. Paleozoic fossils may be found in the Rocky Mountains of eastern British Columbia.

The Mesozoic Era, known as the "age of reptiles", was the time when the great dinosaurs roamed the Earth. Much of Alberta is covered by sedimentary bedrock deposited during the Mesozoic Era. Within these rocks are found the fossil skeletons of reptiles (Figure 19). In British Columbia, Mesozoic rocks are located on Vancouver Island, and in the Peace River area. Reptile skeletons have been found near the Peace River, but not on Vancouver Island.

The Cenozoic Era, which includes the present day, has sometimes been called the "age of mammals", for this is the time when a great variety of mammals first appear in the fossil record. Cenozoic fossils formed during the last 1 million years may be found in many parts of British Columbia, including Coquitlam. (Casanova, 1957).

INVESTIGATION 28  Cenozoic, Mesozoic and Paleozoic
Purpose: to learn about the three most recent eras of the Earth's history.
Procedure
A. Make a large copy of the following table in your notes, then fill in the blanks. Obtain your information from a reference book such as Reading About Science 1, Chapter 53.
<table>
<thead>
<tr>
<th>Era</th>
<th>Began (millions of years ago)</th>
<th>Ended (millions of years ago)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenozoic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesozoic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paleozoic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Duration (millions of years)</th>
<th>Main Forms of Life</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

INVESTIGATION 29  Fossil Study

Purpose: to observe and try to identify a number of fossils.

Procedure

A. Copy this table into your notebook.

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>What is it?</th>
<th>Answers to Questions</th>
</tr>
</thead>
</table>

B. For each specimen, fill in the table. Try to identify the fossil if possible. Answer any questions which appear with each specimen.
Conclusion

What did you learn about fossils in this exercise?

INVESTIGATION 30  Fossil Identification

Many people can recognize a fossil when they find one, but very few can give the correct name of it. In this exercise you will learn to identify a number of fossils.

Purpose: to learn how to identify and draw a selection of common fossils.

Procedure

Using the specimens provided, complete each of the following sections.

A. Trilobites
   a) What does the prefix "tri" suggest? Into how many parts can the trilobite be divided?
   b) Does the trilobite more closely resemble a lobster, clam or octopus?
   c) Sketch the specimen as neatly and accurately as possible.

B. Solitary Corals
   a) Use a reference book to find out whether a coral is an animal or a plant. Record your answer.
   b) Why is the corallite smaller at one end?
   c) Look up the meanings of the words "solitary" and "colony". What might be a major difference between the ways that solitary corals and colonial corals live?
   d) Draw a top view and a side view of your specimen.
C. Brachiopods

These were common animals throughout most of the Paleozoic Era, but today there are only a few species living. Some people confuse brachiopods with clams, but their external shells and their internal body structure is quite different.

a) How many pieces are there to a brachiopod shell?
b) Sketch the brachiopod.

D. Mollusks

These are a group of soft bodied animals which often have shells for protection. There are numerous fossil mollusks, and over 15,000 species living today. There are three common groups of fossil mollusks:

a) Gastropods (the snail group). These animals have a shell which is wound into a series of coils. Some species live in salt water, others in fresh water, and still others on land. Fossil gastropods are common in the Fraser Valley.

i) How many parts does a gastropod shell have?
ii) Sketch a gastropod shell.

b) Pelecypods (the clam and oyster group). These are often called "bivalves" because they have a two part hinged shell. Fossil pelecypods are common in B.C. (Wagner, 1959)

i) Name another edible pelecypod besides the clam and the oyster.
ii) Sketch two different types of pelecypod.

c) Cephalopods (the ammonite and squid group). Most present day cephalopods like the octopus and squid do not have external shells. Many of their fossil relatives however,
did have shells. The largest fossil ammonite ever found in Canada was located near the village of Fernie, in southeast British Columbia. Its shell was about 1.5 metres in diameter. (Frebold, 1964)

i) What is the major difference in shape between an ammonite shell and a gastropod shell?

ii) Sketch the ammonite shell.

E. Crinoids

Crinoids look more like plants than animals. They are attached to the sea bottom by a flexible stem, with the main body of the animal living in a cup-like shell above.

a) Sketch a section of crinoid stem.

F. Sharks.

Sharks do not have a bony skeleton. Their skeleton is made up of a material called "cartilage", which is similar to very tough gristle. The parts of sharks most frequently fossilized are their teeth and hard fin spines.

a) What are the main differences between the shape of a shark tooth and the shape of a human front tooth?

b) Sketch the fossil shark tooth.

G. Reptiles

The parts of reptiles most commonly preserved are their bones. Petrified bone is very hard, and usually brownish in colour. Occasionally, whole skeletons have been found in Alberta. Preserved dinosaur footprints have been found along the Peace River in northeast British Columbia. (Swinton, 1965)

a) Describe one way in which your specimen resembles bone.
b) How can you tell that the bone has been petrified?
c) Sketch the bone specimen.

H. Plants

Plants are fossilized when leaves or stems are trapped in layers of fine sediment. Many fine specimens may be found near the town of Princeton in southern British Columbia. (Rice, 1960; Tidwell, 1975)
a) Why do you suppose that complete fossilized leaves are fairly rare?
b) Sketch the specimen leaves.
c) Use a reference book to find out how coal is formed. Summarize your findings in a few short sentences.

Questions
1. What is a fossil?
2. Describe three different things that a study of fossils could tell us about the distant past.

Conclusion

What did you learn about fossils in this investigation?

Glaciation

British Columbia is a product of the ice age. Less than 10 000 years ago, practically all of our province was covered with glacial ice. Significant portions of the Coast Mountains, the Interior Ranges, and the Rocky Mountains are still covered by glaciers. Accordingly, if a student is to have an appreciation of the origins of the provincial landscape, a study of glaciation and glacial landforms
is essential.

Most earth science courses aimed at junior science students (e.g. Mathews, 1978) devote comparatively little space to glaciation, presumably as a result of their United States authorship, that area being very little affected by continental glaciation. Even those written by a Canadian author (e.g. Janes, 1974) tend to concentrate on the depositional landscape of Ontario. The one text which does deal with alpine glaciation (Schmid, Murphy, 1977) tends to gloss over continental glaciation. This proposed curriculum deals with both the results of the ice age, and with the causes and effects of present glaciation.

The section is introduced by an investigation of the extent of continental glaciation (Investigation 35, below) and a comparison with present day glaciation. Students are asked a number of leading questions, designed to help them to "discover" the reasons for the present glaciers in British Columbia. Investigation 36 (below) continues the study with the formation of glaciers, their structure, and the ways in which they modify the landscape. The study is completed in Investigation 37 (below) in which the student learns about how the glacial landforms frequently observed in British Columbia were produced.

The following pages contain the exercises on glaciation described above.
THE WORLD OF ICE

Many people in other parts of the world think of Canada as being a very cold country. In the wintertime, this impression is quite correct. Except for a narrow coastal strip of British Columbia, Canada is mostly covered with snow for four or five months of the year. Fortunately, this snow melts away during the summer, otherwise we would find ourselves in the grip of another ice age.

INVESTIGATION 35 The Ice Age

Purpose: to study the ice age in Canada.

Procedure

A. Examine the map of ice age Canada. On the first outline map (Figure 20), sketch lightly in pencil the edges of the area covered by ice. Use a coloured pencil to shade the ice-covered area very lightly in blue. Label the edge of the ice-covered area neatly as the "Maximum extent of ice, 18000 years ago". Title this map, "Canada During the Ice Age".

B. The ice did not form everywhere at once, but spread out from four centres. Label these neatly as follows:
   a) In the middle of Greenland, "Greenland Ice Sheet".
   b) East of Hudson Bay, "Labrador Ice Sheet".
   c) Northwest of Hudson Bay, "Keewatin Ice Sheet".
   d) Along the length of the Rocky Mountains, "Cordilleran Ice".

C. Fortunately, most of the ice has melted. The Glacial Map of Canada shows in dark blue those areas of our country
Figure 20. Outline maps of Canada for Investigation 35.
which are still covered by ice. On your second outline map, shade these areas (approximately) in blue. Although it is not part of Canada, shade Greenland with blue since it is also covered with ice. Title this map, "Present Day Ice Sheets and Glaciers".

D. As you might expect, most of Greenland and some of Canada's arctic islands are ice covered. Make a list of the other places in Canada where many glaciers are found.

Questions

1. Ice forms when snow is compressed. (Remember what happens when you make a hard snowball). In nature, this happens when so much snow falls during a winter that the bottom layers are squeezed into ice by the weight of snow on top. Sometimes the ice does not completely melt during the next summer. If this process continues for several years, a glacier will start to grow.

   a) On the west coast of Canada, which ocean provides the water to make snow?

   b) Where do the cold winds necessary to freeze the water into snow come from?

   c) Look at your answers to (a) and (b), then try to explain why there are more glaciers in the Coast Mountains than in the Rocky Mountains.

2. Scientists exploring northern Canada have found evidence to show that plants, animals, and even men were living there during the height of the ice age (Guthrie, 1972).

   a) During the ice age, which part of northern Canada was not covered with ice?
b) Look again at your answers to Question 1, then try to explain why this area was not ice-covered.

3. The island of Greenland is still in an ice age. Name the large area in the southern part of the Earth which is also ice-covered.

4. If another ice age started, what would Canadians have to do in order to survive?

Conclusion

What did you learn about ice age Canada in this investigation?

INVESTIGATION 36 Glaciers

Although we are no longer in an ice age, large areas of Canada are still covered by glaciers. In this investigation you will study how glaciers form, and the ways in which they erode rock.

Purpose: to study glacier formation and erosion.

Procedure

A. A glacier is a large mass of ice formed on land. It is made when snow is compressed into ice by the weight of more snow on top. Write the word "glacier" and its definition in your notebook.

B. What happens to an ice cube if you hit it with a hammer? Near the surface of a glacier, the ice is brittle. It can split to form deep crevasses (Figure 22). Why is it sometimes dangerous for mountain climbers to cross glaciers?

C. If the ice is deep enough, its form changes. Instead of being brittle, it is able to bend and flow slowly. Deep in
Growth zone where more snow falls than melts

Shrinkage zone where more snow melts than falls

Brittle ice

Flowing ice

Crevasses

Bedrock cracks

Moraine

Figure 21. Side view of a glacier.

Figure 22. Mountain climbers crossing glaciers should be careful to avoid crevasses like this one in the Athabaska Glacier.
Fig. 23. Alpine glaciers on Mount Fay in Banff National Park, Alberta.

Fig. 24. The snout of the Athabaska Glacier, where the ice finally melts away.
a glacier, the pressure is so great that the ice is able to change shape without cracking. Because the ice near the base of a glacier can flow slowly, glaciers are able to move.

Examine Figure 21. At which end of a glacier, upper or lower, will the most snow fall and the least snow melt? At which end of a glacier will the least snow fall and the most snow melt? Where will the glacier grow larger? Where will the glacier grow smaller?

D. Figure 23 is a view of an alpine glacier in Banff National Park. Does the fresh snow appear on the upper or lower part of the glacier? What happens to the ice at the snout of the Athabaska Glacier, shown in Figure 24?

E. (Demonstration) Make two blocks of ice by freezing water in a tray. Scatter some sharp sand on the bottom of one of the trays before pouring in the water. When the water has frozen, remove the ice blocks from the trays. Rub the block of plain ice across a wooden board. Does the plain ice scrape the board very much? Is it likely that plain ice can erode very much rock? Now rub the ice containing sand across the board. Which scraped the board more, plain ice or ice containing sand? Which could erode rock more easily, plain ice or ice containing broken rock?

F. Examine Figure 21. As a glacier moves, the ice works its way into cracks in the bedrock. Pieces of broken rock become trapped in the ice on the bottom and sides of a moving glacier. These rocks act like sandpaper to scrape at the sides and bottom of the valley, making it wider and
section of glacier removed to show inside the ice

Figure 25. A valley glacier.

Figure 26. The two piles of rock are lateral moraines formed by the Emerald Glacier in Yoho National Park, near the village of Field, B.C.
Figure 27. The medial moraines show clearly on the Coronation Glacier, located on Baffin Island in the Canadian arctic. (Photograph courtesy of the Geological Survey of Canada).
deeper. All of the rock carried by a glacier is called moraine. Write this word and its meaning in your report. Some moraine is finer than flour. Other moraine is made up of huge boulders.

G. Examine Figure 25. Moraine carried along the side of a glacier is called lateral moraine. Where two glaciers come together, their lateral moraines join to form a medial moraine. Write these terms and their meanings in your report. By carefully counting the spaces between lateral and medial moraines, it is possible to find the number of smaller glaciers that have flowed together to make a large glacier. How many glaciers have come together to form the glacier in Figure 27?

Questions
1. Why are valley glaciers sometimes called "rivers of ice"?
2. If possible, examine a sample of rock over which a glacier once flowed. Explain how the grooves on its surface were formed.
3. a) As a glacier melts away at its snout, what happens to the large pieces of moraine that it carries?
   b) What will happen to the smallest pieces of moraine, called "glacial flour", as the glacier melts?
   c) Why are streams which flow away from glaciers usually full of fine sediment?

Conclusion

What are glaciers, and how do they erode rock?
Figure 28. Landforms produced by glacial erosion.

Figure 29. A glacier once flowed down the valley of Leckie Creek in the Bridge River area of British Columbia. (Photograph courtesy of the Geological Survey of Canada).
INVESTIGATION 37  Glacial Landforms

Most of British Columbia was covered by ice during the ice age. Many of our mountains still have glaciers on them today. As a result, many of the landforms we see around us are a result of glacial erosion. In this exercise, you will learn how some of these landforms were produced.

Purpose: to examine the effects of glacial erosion.

Procedure

A. Look at Figure 29, showing the valley of Leckie Creek, where a glacier once flowed. Does this valley have a V-shape or a U-shape? What will gradually happen to the shape of the valley if the stream in it continues to flow?

B. Figure 28 shows a number of landforms produced by glacial erosion. A **cirque** is a deep hollow carved in the side of a mountain by ice. Write this term and its meaning in your notebook. How does snow enter a cirque? What causes the ice to leave a cirque? Explain how the ice makes a cirque larger. How many cirques are there in Figure 30?

C. An **arete** is a high rock ridge formed between two cirques or glacial valleys. Write this term and its meaning in your notes. How many aretes are visible in Figure 31?

D. A **horn** is a pyramid shaped peak, formed when glaciers erode several sides of a mountain. Write this term and its meaning in your notes. How many horns are visible in Figure 31?

E. A **hanging valley** is formed when a glacier has eroded the end of a smaller valley, leaving a steep cliff. Sometimes a waterfall flows over the cliff. Write the term "hanging
Fig. 30. This bowl shaped cirque was once occupied by a huge glacier near Jasper, Alberta.

Fig. 31. Glaciers shaped these mountains and valleys in Glacier National Park in the Selkirk Mountains between Revelstoke and Golden, B.C.
Fig. 32. Howe Sound is a fiord near Vancouver, B.C.

Fig. 33. As the land around Hudson Bay rebounded upwards after the last ice age, the sea formed this succession of "raised beaches".
Fig. 34. Ice age glaciers polished these rocks along the shores of Howe Sound, north of Vancouver, B.C.
valley" and its meaning in your notes. How many hanging valleys are visible in Figure 31?

F. During the ice age, glaciers stretched many kilometres from the coast of British Columbia, out into the ocean. As they melted, ocean water flowed into the glacial valleys, forming long, narrow inlets. These inlets are called fiords. Write this term and its meaning in your notes. In Figure 32 you can see a picture of Howe Sound, a fiord near Vancouver. Why do fiords make good harbours? Explain why there are not many good sandy beaches along the sides of fiords. What is the name of the long fiord just north of Port Moody? (Post and Lachapelle, 1971)

G. During the ice age, the terrific weight of the ice pushed down the land. After the ice melted, the land slowly rose up again. If this happened along a coast where the sea could make beaches, the rising of the land would gradually lift these beaches above sea level. These ancient beaches, now lifted above the present level of the sea are called raised beaches. Write this term and its meaning in your notes. Figure 33 shows a number of raised beaches near Hudson Bay. A careful observer in North Vancouver can find evidence of raised beaches there. (Eisbacher, 1973)

Questions

1. Explain why a river valley may be V-shaped, while a glacial valley may be U-shaped.

2. What caused the sea level to be much lower during the ice age than it is now?

3. Examine Figure 34. Explain how a glacier could produce
such a smooth polish on hard rock.

Conclusion

What have you learned about glacial landforms in this exercise?

Part 2

The second part of this proposed curriculum covers material more abstract and mathematical than that presented in Part 1. As a result, it is considered more appropriate for older students, and is therefore aimed at those in Grade 10. In the order presented, the main topic areas are: earth structure, earth history, volcanism, earthquakes, plate tectonics, and earth resources. The principal focus of Part 2, particularly in the sections on volcanism, earthquakes and plate tectonics, is to give the student an appreciation of the dynamic nature of the Earth, and a knowledge of how it has changed in the past and will probably continue to change in the future. As in Part 1, Part 2 also contains a regional bias towards British Columbia.

Earth Structure

When designing a junior earth science curriculum, it is important to avoid a "can't see the forest for the trees" approach. That is, one must avoid dwelling upon surficial aspects of the topic such as rock identification for example, at the expense of a discussion of the Earth as a whole. Most texts written for junior science students,
(e.g. Ramsey et al, 1978), do contain a descriptive section on the internal structure of the Earth, usually illustrated with a cut-away diagram. None of those consulted however, appear to have an activity associated with the description. Investigation 1 of the proposed curriculum (below) involves an activity which, though simple, appears to be effective in increasing the students' awareness of the relative thickness of the various layers of the Earth. Basically, this involves nothing more than providing the students with the data required to draw their own diagram of the Earth's internal structure.

This section on earth structure continues with an activity concerning a comparison between the thickness of the lithosphere and the sizes of a number of surface features, and a narrative describing the atmosphere. These may be referred to in the Addendum. The following pages contain the investigation of the layers of the Earth referred to above.

**INVESTIGATION 1  Inside the Earth**

Studies of the Earth, mainly the analysis of earthquake waves, have shown us that the interior of the planet is probably made up of a series of layers, like the layers in an onion. If we include the water and air surrounding the planet, then we can summarize the information in a short list.

1. Atmosphere: the blanket of air surrounding the planet.
2. Hydrosphere: the layer of water covering parts of the surface.

3. Lithosphere: the rocky crust on the surface of the Earth, up to 160 km thick.

4. Asthenosphere or Upper Mantle: the slightly flexible layer upon which the crust moves, up to 560 km thick.

5. Lower Mantle: the rocky inner layer of the mantle, probably 2200 km thick.

6. Outer core: the liquid layer of the core, probably made of molten iron, about 2250 km thick.


Purpose: to draw a scale diagram of the layers inside the Earth.

Procedure

A. Summarize the information given above by completing the following table in your notes.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness (km)</th>
<th>Depth of top from surface of Earth (km)</th>
<th>Distance of top from centre of Earth (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithosphere</td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Asthenosphere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Mantle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outer Core</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner Core</td>
<td></td>
<td></td>
<td>1200</td>
</tr>
</tbody>
</table>

B. Using a full page, and a suitable scale such as 1 mm = 100 km, draw with a compass a series of circles representing the layers of the Earth. Use the numbers in the last column of your table to set your compass for each
layer. Label each layer in your diagram.

Conclusion

What have you learned about the Earth in this exercise?

Earth History

This section of the proposed curriculum continues and extends the study of earth history that was started in Part 1. It begins with a description (Narrative 4, Addendum) of the origin and development of the Earth, starting with the cold accretion theory, and continuing with the molten earth theory to account for the planet's internal layering. This is followed by an exercise in which notable events of the past 4.6 billion years are plotted on a time scale model, and a description of the methods of radiometric dating (Investigation 5, Narrative 6, Addendum).

A lengthy exercise on prehistoric life is found in Investigation 7 (below). Since fossils are our only evidence of life in the distant past, it is felt that students should have the opportunity to work with them directly, rather than merely reading about their descriptions. The specimens chosen are those frequently found in British Columbia, and general descriptions of fossil localities within the province are given.

Investigation 8 (Addendum) provides the student with a simulation exercise on the way in which a paleontologist might work in relating apparently dissimilar fossils. Narrative 9 (Addendum) gives a description of the history of life, from Precambrian algae through to Cenozoic primates.
Narrative 10 (below) presents another unique feature of this proposed curriculum - an attempt to deal directly with the dispute between evolution and creation. While evolutionists may point out quite correctly that the creationist viewpoint has no place in a science text, they can not deny that a substantial portion of the public does believe in special creation, and that it is sometimes difficult to ignore this group. Some texts (Jackson & Evans, 1973) skirt around the problem in an attempt to please both sides, while others (Schmid, 1970) avoid the problem entirely. This proposed curriculum meets the issue head on by clearly presenting both sides of the controversy in parallel narratives. The two sides are presented entirely dispassionately, with no attempt to influence the reader. As a result of this approach, the teacher may use the section as a basis for class discussion without being accused of attempting to undermine the moral authority of the students' parents.

This section on earth history ends (Investigation 11, Addendum) with a review of sedimentary rocks, the study of which began in Part 1. The following pages contain the exercises referred to above. The remainder may be found in the Addendum.
INVESTIGATION 7

Prehistoric Life

Probably everyone in your class has heard of the dinosaurs. How do we know they existed? In Investigation 5, approximate times were given for the first appearance of various life forms. How could these have been determined? No written records of these times exist, and so far as we know, no-one has yet invented a time machine to allow us to travel into the distant past. Our only evidence for the existence of these long extinct creatures comes from fossils. A fossil is the preserved remains of prehistoric life. In this investigation, you will examine a number of fossils similar to those found in western Canada to see what types of animals and plants once lived here. The study of fossils
and ancient life is called paleontology.

Purpose: to use fossils to study some of the prehistoric life of western Canada.

Procedure

Part 1 Examining Fossils

A. Copy the data table below into your notes.

<table>
<thead>
<tr>
<th>Plants</th>
<th>Animals</th>
</tr>
</thead>
</table>

Examine each of the specimens, or the photographs in Figures 35 to 44, then write its name in the appropriate column of your table. Are most of the animals creatures which lived on land or in the sea? How do we know that large areas of western Canada were once covered by ocean?

B. The trilobite (Figure 35) was an animal which crawled or swam along the bottom of shallow seas. It had a tough upper shell (the dorsal shield) like a modern day lobster. Its underside was soft. Trilobite fossils are common in the Rocky Mountains near the village of Field, British Columbia. Make a sketch of a trilobite in your notes. The lines on the dorsal shield probably represent flexible joints. Of what use might flexible joints be? Usually, only the impression of the dorsal shield is fossilized. What do you suppose might have happened to the remainder of the animal? Trilobites became extinct near the end of the Paleozoic Era. About how many years ago was this (see Investigation 5)? Make a list of three modern sea animals which may be descended from the trilobites.

C. The sharks (Figure 36) are one of the oldest species of
sea animals. They have been in existence for about 400 million years. Sharks do not have a true bony skeleton. Their skeleton consists of stiff cartilage, similar to the material which stiffens the end of your nose. Shark fossils are not common in western Canada. Sketch the shark tooth. Describe how its shape differs from the shape of a human front tooth. How does its shape differ from that of a human back tooth? What does the shape of the tooth tell you about the type of food that a shark eats? Try to give a reason why shark teeth are frequently the only part of the animal which is fossilized.

D. The ammonites (Figure 37) were sea animals which were common during the Mesozoic Era. The insides of their shells were divided into a number of closed compartments. The animal itself lived in the last section at the outer end of the coil. Some of the empty compartments were filled with gas, keeping the ammonite afloat in the water. The ammonite was equipped with tentacles with which it captured its prey. Many ammonite fossils have been found on Vancouver Island. Other areas of British Columbia, such as Manning Park, Nelson, and Telegraph Creek also have rocks which contain ammonite fossils.

Sketch the ammonite shell. Draw in a number of tentacles as you think they might have appeared when the animal was alive. Name a modern day sea animal, also equipped with tentacles, which may be related to the ammonites.

E. At first, many people mistake the crinoid (Figure 38) for a plant. In fact it is an animal which is attached to the
Fig. 35. These trilobites once swam in a shallow sea which covered a large area of western North America.

Fig. 36. Shark tooth.
Fig. 37. All that remains of this ammonite is a cast of its shell.

Fig. 38. Two pieces of crinoid stem.
Fig. 39. Brachiopod fossils are common in the Rocky Mountains of eastern British Columbia.

Fig. 40. These pelecypods lived near beaches in southwestern British Columbia at the end of the last ice age. The animal on the right was killed and eaten by a type of gastropod called a "drill".
Fig. 41. Gastropod shell.

Fig. 42. This is a piece of the backbone of a small reptile which lived in Alberta about 70 million years ago.
Fig. 43. A piece of reptile bone, gradually weathering out of the rock in which it was fossilized.

Fig. 44. Carbonized leaves found near Princeton, B.C. Similar plants are found living on the coast of our province today.
bottom of the ocean by a flexible stem. At the top of the stem is a bulb-shaped animal with long feathery branches. It feeds upon microscopic animals and plants floating in the water. Crinoids are still common today, living in clear, moderately deep water. They are sometimes called "sea lilies" because of their resemblance to plants. Fossilized crinoid stems are common in the Rocky Mountains.

Sketch the crinoid stem.

F. Brachiopods (Figure 39) were shelled animals which were very common in the seas during the Paleozoic and Mesozoic Eras. Only a few species survive today. At first glance, they may appear to be similar to clams, but their internal organs are completely different. Like clams however, they feed upon microscopic particles in the water. Brachiopod fossils may be found in the Rocky Mountains.

Sketch a brachiopod. Explain how its shape differs from the shape of a pelecypod (Figure 40).

G. The pelecypod group includes clams, scallops, oysters, and many other bivalved (two shelled) sea animals. They have been common since the Paleozoic Era, and thousands of species may be found in the seas today. Pelecypods feed upon microscopic particles floating in the water. Fossils may be found in the Fraser Valley, in clay banks which were once beaches near the end of the last ice age. They are also common in Mesozoic sandstone on the Queen Charlotte Islands and southern Vancouver Island.

Sketch two different types of pelecypod shell. Name four different edible pelecypods.
H. Gastropods (Figure 41) are snails. These have been common since the Paleozoic Era, living both on land and in the water. The animal has a single shell, coiled into a conical spiral. Some gastropods feed on plants, while others attack and eat other shelled animals. Gastropod fossils are found in the same areas as the pelecypods mentioned in Procedure G.

Sketch the gastropod fossil. Are some gastropods edible? Gastropod and ammonite shells are both coiled. What is the main difference in their shape?

I. Petrified reptile bone (Figure 42) is very hard, and usually brownish in colour. Occasionally, whole skeletons have been found in Mesozoic rocks of Alberta (Figure 43). No specimens have yet been found in the Mesozoic rocks of Vancouver Island.

Sketch a piece of reptile bone. How can you tell that it has been petrified? In what ways does it resemble present day bone?

J. Leaves (Figure 44). Land plants first appeared in the Paleozoic Era, about 440 million years ago. Some of the finest leaf fossils in Canada are found in the buff coloured shale (see Investigation 11) beds near Princeton in southern British Columbia. These were formed about 20 million years ago.

Sketch two fossil leaves, one broad leaf and one conifer leaf. Why do you suppose that unbroken fossil leaves are quite rare? Examine Figure 44, and by studying the types of leaves try to describe the climate near Princeton about 20 million years ago. Use a reference book to help you
write a short paragraph describing how coal is formed.

K. Petrified wood (Figure 45). Wood may be fossilized in two different ways. Examine your specimens and describe the appearance of each. What evidence is there that each was once a piece of wood? (Nelson, 1970; Tidwell, 1975).

Part 2 How Fossils are Formed

A fossil is formed (Figure 46) when the body of an animal is rapidly covered over with sediment such as mud or sand. If more sediment is deposited on top over the years, the pressure will harden the sediment below into rock. Eventually, millions of years later, weathering and erosion may wear away the overlying rock, exposing the fossil to view.

Before it is exposed, the fossil may be altered in a number of different ways, leading to a number of different types of preservation.

a) Actual preservation. Although this is very rare, it can occur when bacterial action and decay have been stopped. An entire Musk ox, recovered from the ice and permafrost of Alaska is an excellent example (Guthrie, 1972). Other animals have been preserved in bogs and tar pits.

b) Permineralization. Minerals from ground water gradually fill in the air spaces in bones. This tends to make the bone heavier, without changing its original shape or size. Many dinosaur skeletons have been preserved in this way.

c) Replacement. The original shell or skeleton is dissolved away, one atom or molecule at a time, and replaced
Fig. 45. Silicified wood. It is still possible to see the rings of the original tree.

Figure 46. Formation of a fish fossil.
by a different material. Wood is frequently "petrified" in this manner, when the wood is replaced by silica (silicon dioxide, SiO₂).

d) **Carbonization.** The hydrogen and oxygen atoms from the original material are lost, leaving only black or brown carbon atoms behind. Leaves are often fossilized in this way.

e) **Moulding and casting.** The original shell or bone is completely dissolved by ground water. The cavity left behind is called a **mould**. If the mould is later filled with another material, the resulting fossil forms a **cast**. Shells are frequently fossilized as moulds or casts.

f) **Tracks** of animals may be fossilized if the soft mud in which they are made hardens into rock. Dinosaur tracks from the Peace River area of northeastern British Columbia are displayed outside the Provincial Museum in Victoria.

g) **Coprolites** are fossilized excrement or dung. Analysis of these can tell us much about the eating habits of early life. (Casanova, 1957)

L. Copy the data table below into your notebook. Examine each of your specimens, then list its name and its method of preservation in your table.

<table>
<thead>
<tr>
<th>Specimen Name</th>
<th>Method of Preservation</th>
</tr>
</thead>
</table>

**Part 3: Uses of Fossils**

The most exciting use of fossils is the obvious one. They are our only evidence of the type of organisms which
Figure 47. Trace the layers across the canyon.

a) \( \)  b) \( \)  c) \( \)  d) \( \)  e) \( \)

Figure 48. Name the fossil in each sketch.

Figure 49. Outline map of British Columbia.
once inhabited the Earth. By careful examination of the fossils within a layer of rock, a paleontologist can reconstruct what life may have been like on an ocean bottom hundreds of millions of years ago. He can describe from their bones, the dinosaurs that once roamed western Canada. If he is lucky, he may even be able to trace the ancestry of some of the species of animals and plants living today.

Geologists working for oil companies study microfossils (very small fossils) carefully. They know that certain of these are associated with oil. When they find these microfossils in a layer of rock, they know that oil may be nearby.

By examining fossils in layers of rock, a geologist can also find out what rocks may have been in a particular place before they were removed by erosion.

M. Trace the diagram of the canyon in Figure 47 into your notebook. Match up the fossils on both sides of the canyon, then draw lines across the canyon to show how the layers might have looked before the river eroded them away.

Questions
1. What is a fossil?
2. Name each of the fossils sketched in Figure 48.
3. Name the type of fossilization which occurred in each case:
   a) A mouse is buried in volcanic ash. Water dissolves the body, leaving a cavity.
   b) A "petrified tree" made of silica is found.
   c) A shell is buried, then dissolved away. The cavity is filled with fine sand which hardens into sandstone.
   d) A black outline of a willow leaf is found printed
on very fine grained rock near Princeton, B.C.

4. Explain why fossils are seldom found in volcanic rocks.

5. How can fossils tell us about the climate in the past?

6. From Figure 4-9, trace the outline map of B.C. into your notebook. Make a numbered key of the fossil locations mentioned in Part 1 of this investigation. Use an atlas to help you find these locations, and mark them on your map.

NARRATIVE 10

Evolution or Creation? - The Controversy

So far, we have looked at only one theory of the origin and development of our Earth and the life upon it. Other less popular theories exist, among them the theory of "Special Creation". In this narrative we will consider briefly some of the claims made for both theories.

Evolution

The origin of the universe is a mystery.

The sun and planets formed over a period of several million years from a cloud of dust and gas in our galaxy. This took place about five billion years ago.

Naturally occurring processes produced the chemical building blocks of life in the oceans.

By a complex process, the

Special Creation

A divine being (God) has existed forever, and created the universe.

God created the universe, including our Earth, during a period of six 24-hour days. This took place several thousand years ago.

During the six days of creation, all the life forms we know about were created in the exact form we see them
building blocks group
together into droplets and
devlop the ability to carry
on chemical reactions within
themselves. The droplets are
said to be "alive" when they
are able to manufacture exact
copies of themselves.
During this time, about a
billion years, the geological
processes of weathering,
erosion, mountain building
etc. are carrying on at about
the same rate as they are
today.

Mutations cause changes in
genes which produce new
species. Those organisms
better able to find food and
reproduce themselves survive.
Those which compete
unsuccessfully become extinct.

today.

A vast global flood, recounted
in the Bible by Noah, produced
worldwide geological effects.
Weathering and erosion occurred much faster than they
do now because of the
tremendous amount of water
that was moved around. Many
species of plants and animals
were exterminated. Many
fossils were formed at this
time, as well as huge deposits
of coal and oil.
Those organisms which
survived the flood
re-establish themselves.
The controversy between the two sides of this argument has been strong since 1859. In that year, Charles Darwin published his famous book, "On the Origin of Species", recounting his idea of evolutionary development. Since then, Darwin's theory has been developed further, and modified by the discovery of Mendel's Laws and our understanding of what happens within cells during reproduction.

Scientists and churchmen on both sides of the argument claim that both the geological evidence and the fossil record prove that their viewpoint is true, and that the opposing viewpoint is false.

The evidence which both evolutionists and creationists use to support their views is very complex. If, during the next few years, you wish to study the problems of the origin of the Earth and the development of life further, ask your teachers to recommend books which present both sides of the story as fairly as possible. (Nelkin, 1976; Morris, 1970)

Questions
1. Which do you prefer, evolution or special creation? Write a short essay explaining and supporting your position.

Volcanoes

There are several reasons why students should learn about volcanoes during a course on earth science. One is the intrinsic interest of volcanoes to junior students, as objects of violence, fear and beauty. Another is the historic place that volcanoes hold in the development of plate
tectonic theory. Yet another reason is that whether they know it or not, British Columbia residents inhabit one of the major (if presently inactive) volcanic areas of the Earth - a 1500 km segment of the so-called "Pacific Ring of Fire" - and familiarity with the landscape of the province must therefore include familiarity with its volcanoes.

Very few students will dispute the fact that the interior of the Earth is hot, but few if any could make a quantitative statement about its temperature. The first exercise in this section, Investigation 12 (below) provides the student with actual subsurface temperature readings from two widely separated areas of the Earth. By plotting graphs and making simple calculations, the student is able to determine a depth at which rock could be molten.

Once the fact that the interior of the Earth is very hot has been established, Narrative 13 (below) brings out some possible uses of this heat. This passage on geothermal energy points out to the student the uses, benefits, and drawbacks of present technology, and describes the current status of geothermal exploration in British Columbia, information unavailable in any other junior science text consulted.

Next, the student is introduced to various types of volcanoes, (Investigation 14, Addendum), and to a number of volcanic landforms. Considering the present lack of active volcanism in British Columbia, a knowledge of landforms is essential in order for the travelling student to appreciate
the volcanic nature of this province. Investigation 15 (Addendum) lays the groundwork for plate tectonic theory by having the students plot the positions of a number of volcanoes on a world map, thereby "discovering" that they are not randomly positioned, but form a definite pattern.

Narrative 16 (below) returns the student to British Columbia with a detailed description of three volcanic areas of the province, illustrated with a number of excellent photographs unavailable in any other text.

Finally, the section concludes with a review of igneous and metamorphic rocks (Investigation 17, Addendum), a topic begun in Part 1, and an explanation of the theory of the rock cycle (Narrative 18, Addendum).

The following pages include the student exercises referred to above. The remainder may be found in the Addendum.

INVESTIGATION 12

Heat Within the Earth

Would you like to be a South African gold miner? The depths of the mines are so hot that the workers have to be trained in steam baths! Those who can not withstand the high temperatures and humidity are unable to work in the mines.
Have you ever swum in the water from a hot spring? There are many hot springs in western Canada. Banff, Radium and Harrison are probably the best known. The gold mines of South Africa, and the hot springs of western Canada provide plenty of evidence that the interior of the Earth is hot. But how hot is it? In this exercise you will determine just how deep we would have to go to find molten rock.

Purpose: to calculate a geothermal gradient, and apply it to finding the depth of molten rock.

Procedure

A. The introduction to this investigation gives two pieces of evidence that the interior of the Earth is hot. Describe a third example that you may have heard of.

B. Below is a list of temperatures recorded at various depths in two widely separated areas of the world, a South African gold mine and an Icelandic fishing village.

<table>
<thead>
<tr>
<th>Depth (km)</th>
<th>Temperature (°C)</th>
<th>Depth (km)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>18</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>0.5</td>
<td>23</td>
<td>0.2</td>
<td>23</td>
</tr>
<tr>
<td>1.0</td>
<td>29</td>
<td>0.4</td>
<td>36</td>
</tr>
<tr>
<td>1.6</td>
<td>35</td>
<td>0.6</td>
<td>47</td>
</tr>
<tr>
<td>1.9</td>
<td>38</td>
<td>0.8</td>
<td>59</td>
</tr>
<tr>
<td>2.7</td>
<td>46</td>
<td>1.0</td>
<td>72</td>
</tr>
<tr>
<td>3.5</td>
<td>54</td>
<td>1.2</td>
<td>80</td>
</tr>
<tr>
<td>3.8</td>
<td>58</td>
<td>1.4</td>
<td>90</td>
</tr>
</tbody>
</table>

(White 1974) (Palmason 1970)

Plot these two sets of values separately on the same graph, using the top left hand corner as the origin (Figure 50). Draw a smooth line through each set of points. Label each line as "South Africa" or "Iceland".
Figure 50. Graph axes for Procedure B.

Figure 51. Graph axes for Procedures G and I.
C. The **geothermal gradient** is the average amount of temperature increase for each kilometre of depth. It is expressed in "degrees Celsius per kilometre", (°C/km). Write the term geothermal gradient and its meaning in your notebook.

D. From the graphs you drew in Procedure B, calculate the geothermal gradient for each area by this method: choose one depth on each line and find the temperature at that depth. Use those figures in this formula:

\[
\text{geothermal gradient} = \frac{(\text{depth temperature}) - (\text{surface temperature})}{(\text{depth})} = \frac{\text{°C}}{\text{km}}
\]

Which area has the higher geothermal gradient, South Africa or Iceland?

E. Now you will use your results from Procedure D to estimate the temperature at greater depths. To find the temperature at any depth, **multiply the geothermal gradient by the depth**. What is the estimated temperature at a depth of 10 km in South Africa? What is the estimated temperature at a depth of 10 km in Iceland?

F. Copy the tables below into your notebook. Using the method of Procedure E, complete the temperature column in each table.

<table>
<thead>
<tr>
<th>South Africa</th>
<th>Iceland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (km)</td>
<td>Temperature (°C)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

G. Using the data from Procedure F, plot another graph
similar to the one you plotted in Procedure B. Figure 51 shows you how to draw the axes. Label each line with the location it represents.

H. Examine each of the two rock samples. Granite is typical of rocks found in coastal British Columbia. Basalt is found in many volcanic areas of the Earth. Write a brief description of the appearance of each sample.

I. Below are tables of the melting temperatures of granite and basalt at various depths. Plot the two sets of points on the graph you drew in Procedure G. Draw a smooth line through each set of points, and label each line with the name of the rock it represents.

<table>
<thead>
<tr>
<th>Depth (km)</th>
<th>Granite Temperature (°C)</th>
<th>Basalt Depth (km)</th>
<th>Melting Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>900</td>
<td>0</td>
<td>1100</td>
</tr>
<tr>
<td>1</td>
<td>890</td>
<td>10</td>
<td>1130</td>
</tr>
<tr>
<td>5</td>
<td>825</td>
<td>20</td>
<td>1160</td>
</tr>
<tr>
<td>10</td>
<td>740</td>
<td>30</td>
<td>1190</td>
</tr>
<tr>
<td>20</td>
<td>720</td>
<td>40</td>
<td>1220</td>
</tr>
<tr>
<td>30</td>
<td>690</td>
<td>50</td>
<td>1250</td>
</tr>
<tr>
<td>40</td>
<td>680</td>
<td>60</td>
<td>1280</td>
</tr>
<tr>
<td>50</td>
<td>675</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>670</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Lambert 1978)

J. Using your graph from Procedure I, at what depth would granite be molten beneath Iceland? beneath South Africa? At what depth would basalt be molten beneath Iceland? Would you expect volcanoes to be more common in South Africa or Iceland?

Questions
1. How do we know that the interior of the Earth is hot?
2. a) Using the Icelandic figure for the geothermal gradient, calculate the estimated temperature at the centre
of the Earth - a depth of 6360 km.

b) Considering that the surface temperature of the sun is about 6000°C (Ramsey 1978), does your value for the temperature at the centre of the Earth seem reasonable?

c) How do we know that the temperature does not continue increasing all the way to the centre of the Earth?

3. a) Which country has the generally warmer climate, South Africa or Iceland?

b) Which has the higher geothermal gradient, South Africa or Iceland?

c) How do we know that the heat within the Earth has nothing to do with climate, that it is not caused by the heat from the sun?

4. Design a way to obtain useful work from the heat energy within the Earth. Make a sketch of your design.

Conclusion

What have you learned about the temperature within the Earth, and about the depth at which rock melts?

NARRATIVE 13

Geothermal Energy

Energy is the driving force of industry. Indeed, without energy the progress of civilization would come to a halt. At present, the possibility of our finding new sources of energy is not good. The world's supply of fossil fuel - oil, coal and natural gas - is running low. Nuclear power produces extremely hazardous waste materials. Soon there will be no new rivers left to dam for hydroelectric energy.
Solar energy, wind and tidal power seem to be useful, but we have not yet learned how to harness them efficiently. What is left? Geothermal energy – heat energy from within the Earth.

Underneath our feet, deep within the Earth, is an almost limitless supply of heat energy. The interior of the Earth has been cooling slowly for about four billion years, and yet it is still molten! If we could use even a small fraction of that heat, we could solve our energy problems for thousands of years to come.

Many methods have been devised for extracting heat energy from the Earth. Most of these use water as a carrier for the heat. The simplest scheme uses a natural flow of hot water or steam from the Earth, such as a hot spring or geyser (Figure 52). Steam may be used to turn electrical generators. Hot water may be used to heat homes or factories. Many hot springs such as the one at Banff (Figure 53) have been developed as tourist resorts.

If the hot water or steam does not work its way to the surface naturally, it can sometimes be reached by drilling a well. In northern Italy, steam wells were first drilled in 1830. In 1904 the first experimental generation of electricity from natural steam began, and in 1913 continuous commercial production started. Iceland, another pioneer in geothermal development, has been using hot water for heating buildings since 1898. In the capital city of Reykjavik, over 90% of the homes now receive geothermal water for heating. (Press, Siever 1978).
Figure 52. Cold ground water, heated by hot rock rises to the surface to make a hot spring.

Figure 53. The swimming pool at Banff hot springs; a recreational use of geothermal energy.
Figure 54. Geothermal water passed through a heat exchanger raises the temperature of clean water. The hot clean water is then used for home or industrial purposes.
Sometimes the geothermal steam and hot water contain a lot of dissolved minerals. If this water were used directly, the minerals could be deposited in the machinery, causing it to clog up. In this case the geothermal water is passed through a heat exchanger where it heats clean water, then pumped back underground. The clean water is then used for heating purposes.

In western Canada, serious exploration for geothermal resources began in 1972. Federally, the Earth Physics and Geological Survey branches of the Department of Energy, Mines and Resources have been conducting a general study of the area. Provincially, the British Columbia Hydro and Power Authority are responsible for local exploration.

British Columbia, with over eighty hot springs (McDonald 1978), seems to have a great deal of geothermal potential. A number of hot springs in the province have been developed for recreational use since the early part of the century. Unfortunately, none of the sites explored so far are producing enough natural steam to operate electrical generators. The next stage in development is to drill exploratory wells, possibly near Meager Mountain, 150 km north of Vancouver. If these produce enough high energy steam, then major geothermal development could be started in the area (Souther 1978).

Unfortunately, geothermal power does have some serious drawbacks. Although the total amount of heat within the Earth is just about limitless, the amount of heat available to a geothermal development can be used up. If natural hot
water is pumped out of the ground faster than it is naturally replaced, then eventually the water supply dries up and power generation stops. Another problem is pollution. Natural waters frequently carry dissolved sulphurous gases. Releasing these gases into the atmosphere can result in serious air pollution.

The greatest difficulty with geothermal power is the problem of using up all the heat in the development area. As heat is extracted from the rock, it must be replaced by more heat conducted from deeper within the Earth. Heat conduction through rock is very slow. If heat is extracted faster than it is replaced, then eventually power generation must cease. (Press, Siever 1978).

Despite these difficulties however, in some areas of the Earth, geothermal development is an attractive source of energy.

Questions

1. Volcanoes are more common on the west coast of Canada than on the east coast. Explain why geothermal development is likely to be more practical on the west coast.

2. Use your results from Investigation 12 to explain why Iceland is a likely place for geothermal development.
Volcanoes of British Columbia

Although British Columbia forms a 1600 km link in the "Ring of Fire" surrounding the Pacific Ocean, its volcanic areas (Fig. 55) are not well known. This is probably because there have been no known eruptions in B.C. within the time of recorded history. Legends of the Tahltan and Tsimshian indians however, tell of eruptions in the northern part of the province less than 200 years ago. At the turn of the century, an old woman in the area told of her childhood memories of hearing thunder louder than a thousand thunderstorms, of feeling the earth shake, and watching the skies...
centres of volcanic activity

Figure 55. Cenozoic volcanoes of British Columbia. (after Holland, 1964)

Figure 56. Glaciers have formed inside the crater of Mount Edziza. (Photograph courtesy of Beautiful British Columbia Magazine).
Fig. 57. Eve Cone is an almost perfectly formed cinder cone near Mount Edziza. (Photograph courtesy of Beautiful British Columbia magazine).

Fig. 58. Mount Garibaldi is a volcano which erupted onto the surface of an ice age glacier. The peculiar flat-topped mountain is called the Table. It was formed by lava which melted a hole in the glacier.
Fig. 59. The Barrier is a 250 metre cliff, formed when lava flowed up against an ice age glacier.

Fig. 60. Lava built a dam across this valley, which filled with water to make beautiful Garibaldi Lake.
Fig. 61. The Black Tusk. This peak in Garibaldi Park was once part of a huge volcano. Now, most of the volcano has been eroded, and only this hard lava flow remains.
Fig. 62. Compare this view of the Black Tusk with the one in Figure 140. Every year, hundreds of hikers climb this peak.

Fig. 63. A small cinder cone in Garibaldi Park. When this photograph was taken, the crater at its summit was still filled with snow.
Fig. 64. This group of climbers is camped half way to the summit of Mount Baker.

Fig. 65. Clouds of steam pour from a crater just below the summit of Mount Baker.
turn red and the day turn into night from clouds of ash blotting out the sun. Recently, geological scientists have found at least three lava flows nearby which are less than 1300 years old. Perhaps the eruption of one of these was the one remembered by the old woman.

The highest peak in the volcanic area is named Edziza (Fig. 56), which means "cinders" in the Tahltan dialect. The lava flows surrounding Mount Edziza form a great shield over 80 km long and 16 km wide. Edziza itself is a strato-volcano, 2788 m high, surrounded by dozens of small lava and cinder cones, craters and pumice fields (Fig. 57). Recently, the 130 400 hectares surrounding Mount Edziza have been declared a provincial park. The provincial Parks Branch however, warns would-be visitors that there are no facilities, and that "It is no place for the ill-equipped, or for persons unable to fend for themselves". (Souther, 1972).

In the Mount Edziza area there are a number of hot springs with water temperatures ranging from 50°C to 75°C (Souther, Halstead 1973). The geothermal gradient in a test hole drilled 8 km from the volcano was 35°C/km (Souther 1978), about half the Icelandic geothermal gradient you calculated in Investigation 12. The area looked promising for geothermal development, but all exploration was stopped when the provincial park was declared.

In southern British Columbia, the best examples of volcanism are found in Garibaldi Provincial Park, 80 km north of Vancouver. Here, the volcanic eruptions occurred
between 25,000 and 10,000 years ago, at the height of the last ice age. Mount Garibaldi itself is a stratovolcano which actually poured lava on to the top of the ice sheet. When the ice melted, the side of the volcano was left unsupported, and it collapsed into the valley below. Nearby is a very strange, almost circular, flat-topped peak called the Table (Fig. 58). It is made up of horizontal layers of lava, like the layers in a cake. The table is believed to have formed when lava erupting from below melted an almost circular hole through the overlying ice.

Near the trail leading into Garibaldi Park is the Barrier (Fig. 59), a vertical cliff over 250 m high. Here, lava flowing from Mount Price froze against the gigantic ice age glacier filling the valley. When the ice melted, the cliff remained. In 1855, a 45 million tonne section broke away from the cliff and roared down the valley in a massive landslide. Geologists think that this could happen again, but are unable to say when. Behind the Barrier, water filled the blocked valley, creating beautiful Garibaldi Lake, shown in Figure 60.

Evidence of more ancient volcanism is found in the Black Tusk (Figs. 61 and 62). Once a great volcano, it has mostly been removed by erosion. Only a portion of a hard lava flow remains. Eventually, it too will crumble. (Mathews 1975).

A volcano well known to people living in southwestern British Columbia is Mount Baker. Strictly speaking, Mount Baker is not in B.C. However, many of the residents of the
lower Fraser Valley think of it as "their" volcano. A strato-volcano with a height of 3316 m, it dominates the skyline to the southeast of Vancouver (Fig. 64). Mount Baker is last known to have erupted in 1870, when it emitted great clouds of smoke. Recently, in 1975, a crater near the summit started to produce large amounts of steam, and the heat melted a portion of the surrounding glacier (Fig. 65). Geologists studying the mountain stated that an eruption of lava was unlikely at that time. They were concerned however, that the increased heat could melt the snow and ice, causing landslides or mudflows. If these were to flow into Baker Lake at the foot of the mountain, the dam at the end of the lake could be damaged. Failure of the dam would endanger the lives of thousands of people living in the valley below. Lava flows and explosions are not the only dangers posed by volcanoes! (Harris 1976).

Questions

1. What type of volcano is Eve Cone, shown in Figure 57?
2. What would have been the major disadvantage to geothermal development in the Edziza area?
3. Draw a series of diagrams to show how the Barrier formed.
4. If Mount Baker were to erupt, would the city of Vancouver be endangered? Describe what could or could not happen.

Earthquakes

The reasons for having students learn about earthquakes are similar to those given in the section on volcanoes. Initially, students seem to have a natural interest and
awe of the potential violence of an earthquake. Secondly, earthquakes hold an important historical place in the development of plate tectonic theory. Finally, many students living in coastal British Columbia are on the fringes of a very active seismic zone, and many of them have and will experience directly the results of an earthquake.

This section begins with a description, (Narrative 19, below), explaining to the student the relationship between earthquakes and fault movements, the meanings of the Richter Magnitude Scale and the Mercalli Intensity Scale, and the differences between the two scales. This narrative also describes the relationship between building construction and possible damage, and the potential for hazardous earthquakes in Canada. While the information on faults, Richter Magnitude and Mercalli Intensity may be found in numerous curricula, that on the Canadian experience is generally available only in academic, government, or university level publications, sources which are difficult for the average junior high school student or teacher to consult. Since this proposed curriculum is intended to have a strong regional bias, it was considered appropriate to include this material.

The introductory description referred to above lays the groundwork for a number of laboratory investigations of earthquakes. The first of these, (Investigation 20, Addendum), shows the student the principles of operation of a seismograph. This is followed (Investigation 21, below), by an exercise in analysing a seismogram to locate the epicentre of an earthquake. While similar exercises already appear in
some texts, (Schmid 1970, Mathews 1978), none of these relate to actual earthquakes in British Columbia. The event chosen for this curriculum, actually occurred on the B.C. coast. Exercises on areas which the students know are close to home appear to have much greater impact than those located in distant lands.

Following the exercise of locating an earthquake, the student plots the positions of a number of historic earthquake disasters on a world map (Investigation 22, Addendum), thereby "discovering" the pattern formed, and its close resemblance to the pattern of volcano locations. The section ends with another descriptive passage, (Narrative 23, below), giving the causes and effects of tsunamis, and recounting the local experience of the wave caused by the great Alaska earthquake of 1964.

The following pages contain the sections of the proposed curriculum referred to above. The remaining sections on the topic of earthquakes may be found in the Addendum.

NARRATIVE 19

Earthquakes

"Thousands Killed!", "A City Collapses!", "Gigantic Earthquake!". Every year, these and similar headlines appear in newspapers. Of all the possible natural disasters which can strike, a great earthquake is perhaps the most terrifying. One can run away from fire or flood, and shelter from wind or storm, but where can one hide when the Earth itself starts to shake?
Earthquakes are caused by movements in the Earth's crust. One section of the crust moves past another along a plane called a fault. Sometimes friction causes the two sides of the fault to lock together. As movement tries to continue, strain forces build up. When the built-up force is strong enough to overcome the friction, the two sides of the fault slide past each other with gigantic "jerks". The resulting vibrations in the ground are felt as an earthquake.

On March 27, 1964, a great earthquake occurred in Alaska. Figures 66 and 67 show one of the faults as it cuts across the mouth of Hanning Bay. When the earthquake happened, the rock on one side of the fault was lifted three metres higher than the rock on the other side. In Investigation 14 you learned that small earthquakes are sometimes associated with volcanic eruptions. Figures 68 and 69 show what can happen if a fault line crosses a roadway.

The place where the rock first breaks is frequently deep underground. Sometimes it is as much as 700 km beneath the surface. This location underground is called the focus of the earthquake. On the surface, the most violent shaking usually occurs straight above the focus. This point, directly above the focus is called the epicentre of the earthquake. Scientists showing earthquakes on maps are plotting the positions of the epicentres.

The strength of an earthquake is measured numerically in two different ways. In the newspapers, the strength is reported as a number on the Richter Magnitude Scale. This
Fig. 66. This line across Hanning Bay is a fault where the earth cracked during the 1964 Alaska earthquake. The area to the right of the fault is white with the shells of sea animals whose home was lifted above sea level by the earthquake. (Photograph courtesy of U.S. Geological Survey).

Fig. 67. A closer view of the Hanning Bay fault shown in Figure 66. (Photograph courtesy of U.S. Geological Survey).
Fig. 68. Motorists are warned in areas of Hawaii where faults are common.

Fig. 69. A section of road destroyed by faulting.
number between 0 and 10, is a measure of the amount of energy actually released by the earthquake at its focus. On this scale, each number represents an energy release about 30 times greater than a number one unit less. Thus, an earthquake of magnitude 7.4 is about 30 times stronger than one of magnitude 6.4. The table below relates the Richter magnitude to an estimate of the probable damage caused by an earthquake in an inhabited area.

**Richter Magnitude Scale**

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>Estimated Number of Earthquakes Each Year</th>
<th>Damage at Epicentre</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Possible, but never recorded</td>
<td>Probably felt over whole Earth.</td>
</tr>
<tr>
<td>9</td>
<td>Extremely rare</td>
<td>Felt over large area of Earth.</td>
</tr>
<tr>
<td>8.0 to 8.9</td>
<td>Infrequent</td>
<td>Extreme damage.</td>
</tr>
<tr>
<td>7.4 to 7.9</td>
<td>4</td>
<td>Great damage.</td>
</tr>
<tr>
<td>7.0 to 7.3</td>
<td>15</td>
<td>Serious. Railway tracks bent.</td>
</tr>
<tr>
<td>6.2 to 6.9</td>
<td>100</td>
<td>Widespread damage to buildings.</td>
</tr>
<tr>
<td>5.5 to 6.1</td>
<td>500</td>
<td>Moderate damage.</td>
</tr>
<tr>
<td>4.3 to 5.4</td>
<td>6 000</td>
<td>Felt by most people in the area.</td>
</tr>
<tr>
<td>3.5 to 5.3</td>
<td>30 000</td>
<td>Felt by a few.</td>
</tr>
<tr>
<td>2.0 to 3.4</td>
<td>150 000</td>
<td>Recorded by instruments.</td>
</tr>
<tr>
<td>Less than 2.0</td>
<td>1 000 000</td>
<td>Recorded only by very sensitive instruments. Seldom felt.</td>
</tr>
</tbody>
</table>

(after Janes 1976)
A second way of measuring the strength of an earthquake is with the Modified Mercalli Scale of Earthquake Intensity. This scale uses estimates of damage in a particular area. The farther away from the epicentre of an earthquake, the lower the intensity. An earthquake will have only one Richter magnitude, but may have many Mercalli intensities. The table below tells you how to estimate the Mercalli intensity of an earthquake in your area.

**Modified Mercalli Scale of Earthquake Intensity**

I. Not felt except by a very few under especially favourable circumstances. Birds and animals uneasy. Delicately suspended objects may swing.

II. Felt only by a few persons at rest, especially on upper floors of buildings.

III. Felt noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Parked cars may rock slightly. Vibrations like the passing of light trucks. Duration of shaking can be estimated.

IV. Felt indoors by many, outdoors by a few. If at night, some awakened. Dishes, windows, doors disturbed. Walls creak. Sensation like the passing of heavy trucks. Parked cars rocked noticeably.

V. Felt by nearly everyone. Some dishes, windows etc. broken. A few instances of cracked plaster. Unstable objects overturned. Disturbances of trees, poles and other tall objects sometimes noticed.

VI. Felt by all. Many frightened and run outdoors. Some
heavy furniture moved. Books knocked off shelves, pictures off walls. A few instances of fallen plaster or damaged chimneys. Otherwise, damage is slight.

VII. Everybody runs outdoors. Difficult to stand up. Negligible damage in buildings of good design and construction; slight to moderate in well built structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.

VIII. Damage slight in specially designed structures; partial collapse in ordinary buildings. Panel walls thrown out of frame structures. Chimneys, factory stacks, columns, monuments and walls fall. Heavy furniture overturned. Small amounts of sand and mud ejected from cracks in the ground.

IX. Damage considerable in specially designed structures, partial collapse of substantial buildings. Buildings shifted off foundations, ground cracked. Serious damage to reservoirs and underground pipes. General panic.


Figure 70. Observed Mercalli intensities from the South Okanagan earthquake of January 29, 1975. (After Wetmiller 1977)

In general, locations farther away from the epicentre of the earthquake have lower Mercalli intensities than those close to the epicentre. Look at Figure 70 which shows the effect of a mild earthquake in the Okanagan Valley of southern British Columbia. Notice how the intensity is lower at greater distances from the epicentre.

The 1964 Alaska earthquake was one of the greatest to occur in North America in recent history. Figures 71 to 74 show some of the damage which resulted. Compare the damage to the two buildings shown in Figure 71. Notice how the concrete block structure has been badly damaged, while the wood frame house next door is untouched. This happened since wood is much more flexible than brick. When wood buildings are shaken, they tend to bend a little bit before breaking. However, even a wood building will break if the force is great enough (Figure 72). In the downtown area of the city of Anchorage, a landslip caused one side of Fourth Avenue to drop straight down about three metres. Figure 73 shows all the buildings on the right-hand side of the street are about three metres lower than those on the left, with the crack running down the middle of the street. After an earthquake, it is frequently difficult to bring help to the survivors, and this was certainly the case in Alaska. Most of the road and rail links were
Fig. 71. Compare the damage to these two buildings during the 1964 Alaska earthquake. The apartment block was built with concrete floor slabs and unreinforced block walls. The house next door was a wood frame structure. (Photograph courtesy of U.S. Geological Survey).

Fig. 72. Ground collapse demolished this elementary school in the city of Anchorage during the 1964 Alaska earthquake. Fortunately, there were no people in the school at the time.
Fig. 73. A landslide during the earthquake caused the right side of this street in Anchorage to drop three metres below the level of the original level. (Photograph courtesy of U.S. Geological Survey).

Fig. 74a. Railway lines damaged by earth movement during the 1964 Alaska earthquake. (Photograph courtesy of U.S. Geological Survey).
cut (Figure 74a), which meant that most rescue workers had to travel there by sea or air.

In our own country, the west coast of Canada is the area where earthquakes occur most frequently. On the coast of British Columbia and the nearby ocean floor there are an average of 300 earthquakes each year. In comparison, Alberta, Saskatchewan and Manitoba together average only two earthquakes per year (Stevens 1973). Fortunately, most coastal earthquakes are too small to be felt, and can be recorded only by very sensitive instruments. Large earthquakes with a Richter magnitude over 6.5 occur about once every three years (Stevens 1973). Most of these are located in the ocean floor off our coast, and therefore cause no damage. If any of these had occurred in a major population centre, the damage would have been severe - probably buildings damaged and people killed.

Since 1912 when accurate record keeping began in western Canada, there has been only one earthquake of magnitude 8.0. Occurring in 1949, it was located near the Queen Charlotte Islands. Because the area was so lightly populated, very little damage was reported. In 1946, an earthquake of magnitude 7.3 happened in the Strait of Georgia between Powell River and Courtenay. Many buildings in the town of Courtenay were damaged, including the elementary school whose chimney collapsed through the roof. Fortunately, there were no injuries. (Hodgson 1965).

In Canada, the Earth Physics Branch of the federal Ministry of Energy, Mines and Resources is responsible for
the study of earthquakes. They operate a network of over thirty earthquake observatories spread across the country. The observatory at Alert, on Ellesmere Island only 800 km from the north pole is the most northerly station in the world. The continuous records produced by these stations allow the scientists to locate regions of possible earthquake hazard. Both the British Columbia coast and the St. Lawrence Valley of Quebec are areas where the likelihood of major earthquake damage is high. When locating a power plant in Quebec, a dam in British Columbia, or a pipeline in the Yukon, a detailed knowledge of the local earthquake risk is essential. The scientists of the Earth Physics Branch have prepared an Earthquake Risk Map (Figure 74b), as a guide for engineers, and can on request provide the very latest figures on earthquake hazard for any point in Canada.

Questions
1. Explain the difference between the focus and the epicentre of an earthquake.
2. Explain why an earthquake has only one Richter magnitude, but many Mercalli intensities.
3. Estimate the Mercalli intensities of the 1964 Alaska earthquake at the locations shown in Figures 71 and 72.
5. In which earthquake hazard zone would you find each of the following Canadian cities: Vancouver, Prince Rupert, Calgary, Winnipeg, Toronto, Ottawa, Quebec City, Halifax, and St. John's.
Figure 74b. This map shows the chances of an earthquake in various parts of Canada. In which zone do you live?

(Energy, Mines & Resources - Canada: "New Seismic Zoning Map, 1970)
INVESTIGATION 21

Reading Seismograms

At 2:48 a.m. Pacific Standard Time on November 30, 1975, while most people in British Columbia were asleep, southern Vancouver Island and the lower Fraser Valley were shaken by an earthquake. Wooden buildings creaked and groaned, dishes on shelves rattled, and a few people were

Figure 74c. Using a coil spring to demonstrate a P-wave.

Figure 75. Using a coil spring to demonstrate an S-wave.
awakened from their sleep. The earthquake was a mild one, registering 4.9 on the Richter magnitude scale. It caused no serious damage.

At Victoria, Port Alberni and Haney, the seismic recording stations made a record of this earthquake on their graphs. In this exercise you will learn how to read these graphs, called seismograms, and how to find the precise location of an earthquake.

Purpose: to read seismograms, and use them to locate an earthquake.

Procedure

Part 1 P and S Waves
A. Stretch a coiled spring or slinky out on the classroom floor. Have your partner hold one end of the spring in a fixed position. Gather a number of coils of the spring at one end to form a compressed section (Figure 74c). Release the compressed section while still holding the end of the spring. In which direction does the compression travel? In which directions does each individual coil of the spring move? How does each coil cause the next coil to move?
B. The wave you have just made is an example of a P-wave. The letter P stands for either Primary or Push. In solid rock, this type of wave occurs when an earthquake causes one rock particle to push on the next particle, which pushes the next, and so on. Immediately, the first particle rebounds to its original position, then the next particle, and so on. Write the term P-wave and its description in your notebook.
C. Stretch the spring on the floor and have your partner hold one end steady. Jerk your end sideways to produce a
Fig. 76. Seismograms of the November 30, 1975 earthquake. (Courtesy of W. Milne, Pacific Geoscience Centre)
Figure 77. Example of a P-wave on a seismogram.

Figure 78. Example of a P-wave and an S-wave on a seismogram.
wave (Figure 75). In which direction does the wave travel? In which directions does each individual coil of the spring move? How does each coil cause the next coil to move?

D. The wave you have just made is an example of an S-wave. S stands for either Secondary or Shake. In solid rock, this type of wave occurs when an earthquake causes one rock particle to drag the next particle sideways, which drags the next, and so on. After the wave passes, each particle rebounds to its original position. Write the term S-wave and its description in your notebook.

E. Stretch two identical 3 cm diameter coiled springs on the floor. At the same time, start a P-wave in one spring and an S-wave in the other. Which wave travels faster? Which wave arrives at the other end of the spring first?

Part 2 Reading a Seismogram

F. Figure 76 shows the seismic records of the November 30, 1975 earthquake, made at three different locations. The top and bottom traces are time markings, where each mark indicates one second. How many seconds long is the entire trace?

G. When no earthquakes are being recorded, the seismometer records a nearly straight line. Movement caused by earthquake waves is recorded by upward and downward movements of the lines. The farther the movement, the stronger the waves. At which station were the strongest waves recorded? At what time were the strongest waves recorded at this station, (estimate to the nearest 0.1 seconds)?

H. Copy the data table below into your notebook.
I. The P-waves, which travel fastest, are the first to arrive at a recording station. They are shown by a sudden change in the direction of the line (Figure 77.). From Figure 76, read the arrival times of the P-waves at each station. Estimate these to the nearest 0.1 seconds, and record them in your data table.

J. The S-waves, which travel more slowly, arrive next at the recording station. They are shown by a sudden increase in the movement of the line (Figure 78.). From Figure 76, read the arrival times of the S-waves to the nearest 0.1 seconds and record these in your data table.

K. If you were standing right at the focus of an earthquake, the P and S waves would arrive together. The farther away you are from the focus, the greater the difference in their arrival times. You will use this difference to find the distance from each station to the earthquake. Subtract the P and S wave arrival times to find the travel time difference at each station. Record these differences in your data table.

L. The graph in Figure 79 relates the travel time difference to the distance from the epicentre of the earthquake. For example, if the travel time difference is 15 seconds, look
Figure 79. Travel time graph for finding distance to epicentre.
Figure 80. Earthquake recording stations in southwestern British Columbia.
for the place where the lines are 15 seconds apart, then read the corresponding distance from the vertical axis, which is 131 km. In other words, if the travel time difference is 15 seconds, the epicentre is 131 km away.

Use Figure 79 to find the distance to the epicentre from each recording station. Write these distances in your data table.

M. Your teacher will supply you with a copy of the map in Figure 80. Set your compass at the scale distance to the earthquake from Victoria. Draw a circle on the map, using the Victoria station as a centre. Can a single station tell the distance to an earthquake? Can a single station tell the direction to an earthquake? Can a single station find the exact location of an earthquake?

N. Repeat Procedure M using the data from Port Alberni. Can two stations find the direction to an earthquake? Can two stations find the exact location of an earthquake?

O. Repeat Procedure M using the data from Haney. What is the least number of stations required to locate an earthquake? Where was the epicentre of the earthquake of November 30, 1975 located? Put an X on your map at this point. (Note: if your circles do not cross at a single point, choose a location as close as possible to their crossing points).

Questions

1. Which would probably cause more damage and injury:
   a) an earthquake in Vancouver or one at Williams Lake?
   b) an earthquake at 2:00 p.m. Tuesday, or one at
7:00 a.m. Sunday?

2. Explain how the amount of destruction caused by a severe earthquake depends on it time and location.

3. From the following data, plot on a map the approximate position of the earthquake of February 10, 1977.

<table>
<thead>
<tr>
<th>Station</th>
<th>P-wave arrival time</th>
<th>S-wave arrival time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Alberni</td>
<td>04h 49m 29.1s</td>
<td>04h 49m 41.9s</td>
</tr>
<tr>
<td>Victoria</td>
<td>04h 49m 32.6s</td>
<td>04h 49m 49.3s</td>
</tr>
<tr>
<td>Pender Island</td>
<td>04h 49m 36.0s</td>
<td>04h 49m 52.8s</td>
</tr>
<tr>
<td>Haney</td>
<td>04h 49m 45.0s</td>
<td>04h 50m 12.0s</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Station</th>
<th>P-wave arrival time</th>
<th>S-wave arrival time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haney</td>
<td>07h 56m 13.0s</td>
<td>07h 56m 17.4s</td>
</tr>
<tr>
<td>Victoria</td>
<td>07h 56m 15.8s</td>
<td>07h 56m 25.5s</td>
</tr>
<tr>
<td>Port Alberni</td>
<td>07h 56m 29.8s</td>
<td>07h 56m 51.9s</td>
</tr>
</tbody>
</table>

(All earthquake data provided by courtesy of W. Milne, Pacific Geoscience Centre).

Conclusion

What have you learned about seismograms and earthquakes?

NARRATIVE 23

Tsunami

When is a tidal wave not a tidal wave? When it is a tsunami. A tsunami (the word is Japanese) is an ocean wave caused by an earthquake, and it has nothing to do with the
tides. When an earthquake causes a sudden uplift or drop in the ocean floor, the movement of the water can cause a wave to start.

In the open ocean, a tsunami travels very quickly, about 740 kilometres per hour. However, since its crest is only a few centimetres high, and there is about 160 km between crests, the tsunami is hardly even noticeable.

Only when a tsunami approaches a shore does it become dangerous. The shallow water causes the wave to slow down to perhaps 50 km per hour, and the height of the crest to rise up to 20 or 30 metres. (Press, Siever 1978). Can you imagine a shoreline being hit by a 30 metre wave travelling at 50 km per hour? Figures 81 and 82 show some of the results of the tsunami which followed the 1964 Alaska earthquake. In 1883, the explosion of the volcano Krakatoa in Indonesia caused a tsunami which drowned an estimated 36 000 people. In the Sanriku area of Japan, which has been hit by many tsunamis, 27 000 people died in 1896, and several thousand more in 1933.

Tsunamis can affect any of the Pacific Islands, and all countries on the Pacific Rim. Hawaii, located near the centre of the ocean, has been hit by 32 tsunamis in this century. In 1946, and again in 1960, many people drowned and millions of dollars damage was done in the city of Hilo. (MacDonald, Abbott 1970).

During the night of March 28, 1964, British Columbia was hit by a tsunami caused by the great Alaska earthquake. From up and down the coast, reports of damage came in from
Fig. 81. Waves at Whittier, Alaska, drove this piece of timber through the truck tire during the 1964 earthquake. (Photograph courtesy of U.S. Geological Survey).

Fig. 82. The tsunami which struck the town of Kodiak, Alaska after the 1964 earthquake, caused this damage.
towns and villages: Bull Harbour - wave 17 feet high; Winter Harbour - oil company dock ripped out to sea; Port McNeill - four million board feet of lumber drifting after booms smashed by waves; Port Alice - twenty craft washed away from moorings; Hot Springs Cove - five houses demolished by first waves, eleven others later lifted bodily off their foundations and deposited 300 feet away; Spring Cove - 34 foot troller sunk; Sarita Inlet - Bamfield lifeboat evacuates community; Amiah Inlet - search and rescue parties pick up all inhabitants after all houses damaged by waves; Holberg Bay - trees with five foot butts snapped off and carried a mile inland; San Jose Bay - waves 25 feet high. In all, damage from the 1964 Tsunami was fairly light since most of our coast is uninhabited. (Vancouver Sun, 1964)

In the twin cities of Alberni and Port Alberni however, the situation was much more serious. Eyewitness reports tell the story: "People screamed and began running towards me - the second wave was in the streets. It covered cars, crashed into stores and buildings, and toppled a power line. Then I was running to escape too." "I was amazed to see two big houses - 30 feet by 50 feet and two floors high - floating out in the Somass River. They gradually broke up and sank." "Then I saw men running as the second wave came up and into the street. When the wave rolled down the main street it covered cars and trucks and hit buildings. I got separated from my dad. I think he got into his car with some others. I got into a car too, and got to high ground." In all, 300 houses were destroyed in Alberni and Port Alberni. Miraculously,
no-one was killed. (Vancouver Sun, 1964).

In order to save lives from future tsunamis, the countries around the Pacific rim have co-operated to form the International Tsunami Warning System. As soon as a tsunami is detected, scientists immediately calculate its speed and direction. Warnings are then sent out to threatened areas, telling inhabitants to leave the shore and move to higher ground. Although nothing can be done to prevent damage to buildings and property, at least the people can be saved. There will always be tsunamis in the Pacific Ocean, but international co-operation will reduce their danger to peoples lives. (Janes 1976).

Questions

1. What would be the effect of a tsunami on:
   a) a ship in the middle of the Pacific Ocean?
   b) a boat moored in a shallow harbour?

2. You have just received a tsunami warning, and you have thirty minutes in which to leave your home and start moving to higher ground. List the things you will take with you if:
   a) you have to walk or run.
   b) you are able to drive.

Plate Tectonics

The Earth is a dynamic planet. As the millenia pass, the geography of the Earth changes. Continents collide and separate, oceans open and close, mountains are thrust up and eroded away. Any understanding of the Earth and its
development must therefore include a knowledge of the reason for these changes - plate movement.

British Columbia is located on the boundary between two major plates, the Pacific plate and the North American plate. Between these two are a number of minor plates. The movement of these plates is responsible for much of the landscape of this province. It therefore follows that in order to understand the origins of local landforms, the student must have a knowledge of plate tectonics.

Much of the initial evidence for plate movement was garnered from studies of the ocean floors. This section of the proposed curriculum begins by introducing the student to the shape of the floor of the Atlantic Ocean (Investigation 24, Addendum), emphasizing the mid-Atlantic ridge and its central rift system. This is followed by a description (Narrative 25, below) of the theory of continental drift as proposed by Alfred Wegener, and the evidence he used to support it. Although a number of texts (e.g. Ramsey 1978) include material on plate tectonics, none of those consulted show the evolution of the theory from Wegener's original hypothesis. This recounting of the development of the theory is unique to this proposed curriculum, intended to show the student that scientific theories are not immutable, but do change over time as new information becomes available.

The following three exercises, (Investigations 26 and 27, Narrative 28, Addendum), present evidence for plate movement such as the jigsaw fit of the continents bordering on the Atlantic Ocean, the age and magnetic striping of the
sea floor along the oceanic ridges, and the symmetry of polar wandering curves. Narrative 29 (below) continues the development of plate tectonic theory started in Narrative 25, showing how Wegener's theory developed into its present form.

Once the students have become familiar with the concept of moving plates, they are introduced to the types of collision which can take place along plate boundaries (Investigation 30, Addendum). Many students have heard of the San Andreas fault, and will tend to ask questions about it at this point in the curriculum. To aid teachers in answering these, and to provide the student with factual information about the fault, Narrative 31 (below) presents a detailed description and photographs. Although the detail given is much greater than that found in other junior high school texts (e.g. Jackson & Evans 1973), it has been found to be quite understandable by students of this age.

The unit on plate tectonics concludes with another feature unique to this proposed curriculum, a description of the effects of plate movement along the coast of British Columbia. This description (Narrative 32, below), was compiled from academic publications of the last ten years, and presents information which would be very difficult for many junior high school students and teachers to locate. As noted in other parts of this proposed curriculum, it is felt that descriptions and examples of local features are of more interest to the student than information about distant areas. The following pages include the student exercises referred to above. The remainder may be found in the Addendum.
The Moving Continents

Look at a map of the Atlantic Ocean (Figure 83). Can you see how the continents on either side of the ocean could be fitted together like a crude jigsaw puzzle? As early as 1620, Francis Bacon an English scientist, commented on this in one of his books. During the next two centuries, other people tried to invent theories to account for this strange correspondence in the shapes of the coastlines. Some people thought that the Atlantic was a huge river valley whose sides had become separated during Noah's Flood. Others believed in a mythical continent that they called "Atlantis", and that it had sunk beneath the waters to form the Atlantic Ocean. A few scientists proposed the theory of continental drift. This theory states that the continents were once part of a single land mass - a "supercontinent" - which broke apart many millions of years ago. Since the breakup, the continents have slowly moved across the globe to occupy their present positions.

In this century, the first man to present evidence to support the theory of continental drift was a German meteorologist named Alfred Wegener. He believed that since rocks could be pushed up vertically to form mountains, they could also move sideways. To support the theory, Wegener studied not only the shapes of the continents, but also the rocks of which they are made, and the fossils preserved in these rocks. He found a striking similarity in the rocks and fossils on opposite sides of the Atlantic.
One of the fossils studied by Wegener was *Mesosaurus*, a small reptile that lived late in the Paleozoic Era, about 270 million years ago. This fossil was found in Brazil and in South Africa, but nowhere else. Wegener argued that it was unlikely that Brazil and South Africa had ever been joined by a land bridge so *Mesosaurus* could walk across. He also believed that the reptile could not swim well enough to cross an ocean. The only remaining possibility was that South America and Africa had once been part of the same continent, and that this continent had split and the halves had drifted apart (Hallam 1972).

Wegener also noted that large blocks of particularly ancient rock occur both in Africa and South America. If the continents are brought together, the blocks line up precisely. Wegener compared this to matching up lines of print on pieces of torn newspaper, then concluding that the pieces had once been part of a single sheet. (Hallam 1975).

As might be expected, Wegener sketched a map of how he thought the world looked before the supercontinent broke apart. This sketch is shown in Figure 84.

Was Alfred Wegener right or wrong? In the next few exercises, you will look at some of the evidence.

Questions
1. What pieces of evidence would have to be discovered in order to prove that Atlantis, complete with people and cities, had sunk beneath the ocean?
Figure 83. The world as it appears today.

Figure 84. Alfred Wegener's idea of what the world looked like before the continents drifted apart. (After Hallam 1975).
Plate Tectonics and Continental Drift

Since Alfred Wegener's time, the theory of continental drift has changed considerably as new facts have been discovered. Even the name of the theory has changed from "continental drift" to "plate tectonics". Wegener used the term continental drift because he thought that only the continents moved. He believed that the lower parts of the Earth's crust acted like a very stiff fluid through which the continents slowly drifted, pushed by forces related to
the rotation of the Earth (Figure 85).

In the modern theory, we believe that large rigid sections of the Earth's crust, called plates, move over the upper mantle or asthenosphere. The continents are carried as "passengers" on these plates (Figure 86). Movement is caused when hot material pushing up from below forms new ocean floor and pushes the plates apart. This occurs along the midocean ridges such as the Mid-Atlantic Ridge. Where two plates collide, one is subducted or pushed under the other. Eventually the subducted plate reaches the asthenosphere where it probably melts. Where subduction occurs, the ocean floor is pushed down to form a deep ocean trench.

The maps shown in Figures 87 and 88 allow you to compare two views of Pangea (the name for the supercontinent) before it broke up. The most noticeable difference between Wegener's view and our modern view is in the position of India. We now believe that India broke away from southern Africa, then drifted towards Asia. Eventually, India collided with Asia, where it remains today.

Our view of the present day world is shown in Figure 89. The crust consists of six major plates and a number of minor plates. Arrows show the directions in which the plates are moving. Plates are being pushed apart along the midocean ridges, and being subducted along the deep ocean trenches. New ocean floor is constantly being created, and old ocean floor is being destroyed.

The theory of plate tectonics explains a number of
Figure 85. Alfred Wegener's model of continental drift. The continents moved through the crust of the Earth, pushed by forces caused by the rotation of the Earth. This theory has now been modified into the present theory of plate tectonics. (After Hallam 1975).

Figure 86. Plate tectonics theory has the continents riding as "passengers" on rigid plates which move over the asthenosphere. The plates are pushed apart by new hot material rising from the asthenosphere to form new sea floor. (After Hallam 1975).
Figure 87. Alfred Wegener's idea of how the world appeared 200 million years ago, before Pangea broke apart. (After Hallam 1975).

Figure 88. Modern idea of how the world appeared 200 million years ago. Notice the position of India. (After Hallam 1975).
Figure 89. This map shows the major plates of the Earth's crust.
Figure 90. In this photograph taken by a Landsat satellite, you can see the plain of India, and the Himalaya Mountains. The Himalayas were pushed up when the plate carrying India collided with the Asian plate.
observations which have puzzled earth scientists for many years, such as earthquakes, volcanoes and mountain building. Compare the map in Figure 89 with the maps of volcano and earthquake locations that you made in Investigations 15 and 23. Notice how the earthquakes and volcanoes seem to occur along the boundaries between plates. Earthquakes happen where plates collide or slide past each other. Volcanoes are found where the frictional heat caused by sliding plates can melt rock. Mountain ranges are formed where continents are "crumpled" as plates collide. For example the Himalaya Mountains, highest in the world, were formed where India collided with Asia. Figure 90 shows a satellite photograph of one of the places where this collision occurred. Imagine the force needed to push up mountains to a height of over 8000 metres! Other land features which you may study in the future, such as island arcs, rift valleys and mineral deposits may also be explained by the theory of plate tectonics.

Earth scientists are now investigating the possibility that plate movement has been going on for the entire history of the Earth. It is possible that before Pangea existed, the continents were moving separately. They may have collided to form Pangea, and are now separating again. Will the continents all come together again as a single land mass at some time in the far distant future? We now know that the map of the world does not remain the same for all time. Each year it changes by a few centimetres, every million years by a few kilometres. What will the world look
like, one hundred million years from today? (Press, Siever 1978).

Questions

1. Examine Figure 89 and list the names of the six largest plates.
2. Use you atlas to find the name of the ocean ridge where the Nazca plate is separating from the Pacific plate.
3. Name the deep ocean trench where the Pacific plate is being subducted beneath the Philippine plate.
4. Use plate tectonics to explain why many volcanoes are found in Iceland.
5. Which two plates were responsible for the 1978 earthquake in Iran which killed about 25,000 people?
6. In Investigation 22 you plotted the position of the Queen Charlotte Fault. Between which two plates is this fault a boundary?

NARRATIVE 31

The San Andreas Fault

On April 18, 1906, the city of San Francisco was shattered by a great earthquake. It had a Richter magnitude of 8.3, and a maximum Mercalli intensity of IX. As a result, nearly 700 people lost their lives, and the city suffered many millions of dollars of damage. This disaster was a result of earth movement along the San Andreas Fault, a great crack in the Earth's crust where the Pacific plate
is slowly moving past the American plate (Figure 91).

The San Andreas Fault is one of the most studied geological features on the Earth. In detail, it is a complex zone of crushed and broken rock about 1000 km long, up to 2 km wide, extending down into the Earth's crust for at least 30 km. It stretches for most of the length of California (Figure 92). Examination of almost any excavation in the fault zone shows thousands of small fractures, pulverized rock, and few pieces of solid rock. From the air, the fault appears as a straight line arrangement of ridges, lakes, bays and valleys. On the ground, the fault zone can be recognized by long, low, straight cliffs and narrow ridges. It shows up most clearly on the dry grassland of the Carrizo Plain in southern California (Figure 93).

Precise measurement along the fault shows that its western side is moving northward at a rate of approximately 5 cm per year. Of course, this does not mean that 5 cm of movement occurs every year. For a number of years, the Earth's crust "takes up the strain" by slowly bending. When a certain limit is reached, the rock suddenly breaks and snaps to a new position. It is this sudden snap which we feel as an earthquake. During the 1906 earthquake, some parts of the ground on the western side of the fault moved northward by as much as seven metres! In total, over the last 100 million years, geologists believe that the total amount of movement has amounted to over 500 km.

Before people realized that the San Andreas Fault was there, hundreds of thousands had moved to California. Since
Figure 91. The San Andreas Fault is the boundary where the Pacific plate moves past the American plate.

Figure 92. Location of the San Andreas Fault in California.
Figure 93. The line of low ridges and gullies marks the trace of the San Andreas Fault across the Carrizo Plain in California. (Photograph by J.R. Balsley, U.S. Geological Survey).
Figure 94. In this photograph taken by a Landsat satellite you can see the traces of two great faults in California. The San Andreas Fault passes within 40 kilometres of the outskirts of Los Angeles.
Figure 95. Fault locations in the San Francisco area. (After U.S.G.S. 1969)
then, millions more have built two great cities in the vicinity of the fault. Figure 94 is a satellite photograph of Los Angeles, showing its location only 70 km from the San Andreas Fault. Figure 95 shows how the fault passes right through the outskirts of San Francisco. A major earthquake could demolish either of these cities.

No-one yet knows how to predict exactly when the next earthquake will occur along the San Andreas Fault. Great earthquakes seem to happen only once or twice in a century. Smaller earthquakes, recorded only by sensitive seismographs, occur almost every day. San Francisco was destroyed in 1906. Since then, it has been built in exactly the same location. A few geologists now call San Francisco "the city which waits to die". (Anderson 1971, U. S. Geological Survey 1969).

Questions
1. Suppose that geologists have determined that there is a 75% chance of a major earthquake occurring in San Francisco within two days.
   a) What problems would arise in arranging an orderly evacuation?
   b) What problems would arise if an evacuation was ordered, and the earthquake did not happen?
   c) What problems would arise if an evacuation was not ordered, and the earthquake happened?
   d) How would you deal with people who refused to obey an evacuation order?
Plate Tectonics of British Columbia

Geologically, British Columbia is a very complicated place. To describe how the area developed, plate tectonics theory must answer a number of questions:

1) How have the mountains been formed?

2) Why are there volcanoes along the coast? Why are the Cascade volcanoes (e.g. Mount Baker) active, while the Garibaldi volcanoes are inactive?

3) What causes coastal earthquakes?

4) Where is the boundary between the Pacific plate and the American plate?

At present, we have no definite answers to these questions. Current theory does however, provide a good start towards the explanation of these features.

Off the north coast of British Columbia, just west of the Queen Charlotte Islands, the Pacific plate appears to meet the American plate at a single boundary. This boundary is the Queen Charlotte fault, whose position you plotted in Investigation 22. Along this fault, the Pacific plate is sliding to the northwest, similar to the movement along the San Andreas fault in California. Canada's strongest recorded earthquake which had a Richter magnitude of 8.0, was caused by movement of the Queen Charlotte fault in 1949. (Milne 1976).

At first, scientists thought that our mountains were simply caused by pressure between the American plate and the Pacific plate. However, the real situation appears to be
much less simple. As the Pacific plate moved northwards in the past, it brought blocks of land from the south up towards British Columbia. When these blocks collided with the American plate, they were "welded" on to the coast, where they have remained. The force of these collisions apparently resulted in a number of our mountain ranges. The last of these blocks of land, arriving about 140 million years ago, included Vancouver Island. Following this collision, pressure from below forced up the Coast Mountains. (B.C. Ministry of Education 1978).

Plate movement near southern British Columbia is not as easy to explain as that along the Queen Charlotte fault. West of Vancouver Island, instead of a single fault, there is a complex system of ridges and faults. Figure 96 shows a simplified diagram of these features. Magnetic studies of the seafloor on both sides of the Explorer and Juan de Fuca ridges show that spreading is taking place. Volcanism brings up new rock from the asthenosphere, and new seafloor is created as the sides of the ridges spread apart. This means then, that here the Pacific plate does not meet the American plate directly. Between them, there are two minor plates named the Explorer plate and the Juan de Fuca plate. The location of the boundary between these two plates is not clear. (Riddihough, Hyndman 1976).

As the Explorer and Juan de Fuca plates move eastwards, they are pushed under the American plate along the line of the continental slope (Figure 97). As they are pushed downwards, the motion of the rock causes the 300 or so
earthquakes recorded each year along our coast. Eventually, when the plates are pushed deep enough, they become hot enough to melt. Some of the molten rock finds its way to the surface, resulting in the coastal volcanoes. Measurements show that the Juan de Fuca plate is moving from 2 to 3 centimetres per year, while the Explorer plate is moving at only half this speed. Some scientists have suggested that this speed difference may explain why the Cascade volcanoes are still active, while the Garibaldi volcanoes are not (Riddihough 1978).

The theory outlined above only begins to explain what is happening along our coast. Many more years of study will be required before earth scientists have a complete understanding of plate tectonics in British Columbia.

Questions

1. How could a block of land brought in by the Pacific plate cause mountains to be built in British Columbia?
2. a) Which would produce more magma, a plate being subducted rapidly, or one subducting slowly?
   b) How does a speed difference between the Explorer and Juan de Fuca plates account for the difference in activity between the Cascade and the Garibaldi volcanoes?
Figure 96. Coastal features of British Columbia.

Figure 97. Plate movement near the British Columbia Coast.
Earth Resources

The final unit of this proposed curriculum concentrates on the mineral resources of the Earth, with an emphasis on the economic minerals of British Columbia.

The section opens (Narrative 33, below) with an historical sketch of mining in British Columbia, followed by a description of the present industry. Included is some information on the location and exploitation of fossil fuel deposits. Like many other sections of the proposed curriculum, this unit continues the British Columbia regional emphasis, and presents information unavailable in other junior high school curricula. The section continues with an exercise on identification of minerals (Investigation 34, Addendum), concentrating upon those with economic importance. The Conclusion (Narrative 35, Addendum), is in the form of a short summarizing note expressing a hope for the future.

The student exercise referred to above may be found on the following pages. The remaining exercise may be referred to in the Addendum.
Earth Resources in British Columbia

Modern society could not exist without resources taken from the earth. Metals, coal, oil, natural gas, cement, gravel - all these are extracted from the earth to support our way of life. Without them, food and water supply, shelter, clothing, medicine, transportation and communication would be reduced to the primitive level of 10 000 years ago.

Coal was the first material to be mined in British Columbia, as part of the business of the Hudson's Bay Company on Vancouver Island during the days of the coastal fur trade (Akrigg 1975). These operations however, had little effect upon the province. Mining became an important part of the economy in 1858 with the first gold rush. The impact of the gold seekers is hard to imagine. In January of 1858, Victoria was a small colonial outpost with only 300 white inhabitants. By December of that year, 30 000 miners had passed through on their way to the gold fields, and Victoria now had 3000 permanent residents (Akrigg 1977).

As the nineteenth century ended and the twentieth century began, attention turned from gold and silver to lead, zinc and copper. Over the next forty years, the extraction of these metals gradually expanded. World War II created an interest in chromium, molybdenum, and tungsten, metals which can be alloyed with iron to make various grades of steel (Gunn 1978).

All three major fossil fuels - coal, oil, and natural gas - are found in British Columbia. Coal was first
discovered on Vancouver Island over a century ago, but since then has been found in many other parts of the province (Figure 98). At present, most of our coal is exported to other countries, but in the future we may start to use it within the province for the generation of electricity.

Oil and natural gas, found mostly in the northeastern part of British Columbia near Fort St. John, Fort Nelson, and Dawson Creek, were first produced in commercial quantities in the early 1950's. Today, we appear to have enough natural gas to fill our needs for some years to come. The oil however, is being used up rapidly. Unless large new discoveries are made, we will very soon have to import all of our oil from other parts of Canada and the world (Gunn 1978).

Mining for other materials such as metal ores depends very much on the world demand. For example, if the world price for copper is high, then operating a copper mine is worthwhile. If the world price drops so that the mine owners can not make enough money to pay all expenses and produce a profit, then the mine must be closed. Every year, new mines open and others close as the world demand for various materials changes.

Mining, and its related industries such as smelting and refining, is one of British Columbia's most important income producers. Of every dollar earned in B.C., approximately 23¢ comes directly or indirectly from mining. (For comparison, in 1978 53¢ came from forestry, and 18¢ from tourism). For some small towns like Stewart or Logan Lake, their entire
Figure 98. Locations of coalfields in British Columbia.
Figure 99. Locations of mining operations in British Columbia.
existence depends on the nearby mine. If the mine closes, the people leave and the town becomes a "ghost town". Mining gave our province its start in 1858, and will continue to play an important part in our development for many years into the future.

Questions
1. If your town depends on a mine, write a short paragraph about the material produced, and about what happens to this material once it leaves the mine.
It was the clear intent of the author of this thesis to write a practical curriculum which could be put to immediate use by classroom teachers. To ensure that this would be possible, the proposed curriculum was classroom tested and modified during two successive school years before reaching its present form. Initial testing took place during 1977-78, followed by extensive modification and further testing in 1978-79.

Most of these trials took place in Moody Junior Secondary School, a junior high school located in Port Moody, British Columbia, enrolling some seven hundred students in grades 8, 9, and 10. The timetable system under which this school operates is based on the division of the school year into four quarters, each of which contains approximately 46 instructional days. Classes meet for one hour each day for an entire quarter. This particular timetable system facilitated testing of the proposed curriculum by making it possible to introduce each part as a science "option" course for students having a particular interest in earth science. Part 1 was introduced for grade 8 students, while Part 2 was available as a more advanced course for students in grade 10. Completion of Part 1 was not required as a prerequisite for taking Part 2. During 1978-79, 32 students from grade 8, and 74 from grade 10 enrolled in the course.

In addition to the testing which took place in Moody Junior Secondary, large portions of the proposed
were tested by other practising classroom teachers in other schools. The results of these tests were incorporated into the proposed curriculum. At this point, the author would like to extend his thanks to Mr. A. J. Williams of Dr. Charles Best Junior Secondary School, and Mr. S. Kellas of Centennial High School for their invaluable assistance with this task.

A copy of Part 2 of the proposed curriculum was sent to Prentice-Hall of Canada Ltd., and subsequently distributed by them to five anonymous teachers for testing and review. A number of the changes suggested by these people have also been incorporated into this present version. Here, the author wishes to thank Ms. S. Sparling of Prentice-Hall, and her five anonymous teachers for their appraisal and commentary.

Since the proposed curriculum contained a great many topics not presently a part of the provincially prescribed curriculum for junior high school science, no comparative testing or statistical analysis could be carried out. However, if it is finally published and adopted by the Ministry of Education, statistical testing and analysis may prove to be a fruitful area for further research.

GENERAL CONCLUSION

An examination of the earth science sections of the presently prescribed junior secondary school science curriculum in British Columbia showed a lack of current plate tectonic theory, and an insufficient number of
references to local phenomena. In order to fill a need perceived by the author, the B.C. Ministry of Education, and Prentice-Hall of Canada Ltd., a laboratory centred curriculum was devised, based upon the most recently available accepted theory, and wherever possible illustrated with examples from British Columbia. Over a period of two school years, this curriculum was tested and revised in a number of junior secondary schools, and found to be suitable at the Grade 8 and Grade 10 levels.
Teachers' Manual and
Answer Key
Part 1
THE WORLD OF ROCK

General objectives of the section:

After completing this unit, the student should be able to:

a) State reasons for the necessity of a classification system for rocks.

b) Describe the origin of sedimentary, volcanic, plutonic and metamorphic rocks.

c) On sight, classify common rocks into one of the groups named in (b) above.

d) On sight, name a limited number of common rocks.

INVESTIGATION 1

Objective: After completing this exercise, the student should have developed an increased ability to observe and record data.

Materials Required

At least one sample each of the following types of rock:

Sedimentary: conglomerate, breccia, sandstone, shale, limestone, coal.

Plutonic: granite, diorite, gabbro, porphyry.

Volcanic: rhyolite, andesite, basalt, obsidian, pumice.

Metamorphic: quartzite, slate, marble, gneiss.

To reduce loss, and for ease of observation, samples should have a minimum size of 10 cm x 10 cm x 5 cm.

Teaching Suggestions

Encourage the students to use proper descriptive terms. They should avoid the use of words involving value judgements.
such as "pretty" or "ugly".

Answers to Questions

1. Two people may sometimes disagree on what to call the colour of a rock.

2. The problem could be solved by setting up a series of standardized colours.

INVESTIGATION 2

Objectives: After completing this exercise, the student should be able to:

   a) organize discrete observations into a coherent classification system.

   b) explain the reasons for the necessity of such a system.

Materials Required

   Rock samples used for Investigation 1.

Teaching Suggestions

   Tell the students to use their data from Investigation 1, but allow them to look at the specimens again if they wish to do so.

Answers to Questions

1. Different students probably made up different groups.

2. Some samples may possibly have fitted into more than one group.

3. Some students may have had difficulty in deciding in which group to place a sample.

4. Geologists using different methods of grouping rocks would have difficulty in communicating with each other. They
could solve this problem by setting up a standardized grouping system.

NARRATIVE 3
Objective: After reading this narrative, the student should be able to describe the origin of sedimentary, igneous and metamorphic rocks.
Teaching Suggestions
This narrative is intended mainly as pre-reading for Investigation 4.

Answers to Questions
1. The presence of layers shows that the rocks in Figure 6 are probably sedimentary.
2. Fossils are formed when animals or plants are buried in sediment which later hardens into rock.
3. Fossils seldom form in igneous rock because the heat would destroy the animal or plant.

INVESTIGATION 4
Objective: After completing this exercise, the student should be able to classify rocks as sedimentary, plutonic, volcanic or metamorphic.

Materials Required
Rock samples used for Investigation 1.
Hand lenses or stereoscopic microscopes.

Teaching Suggestions
Introduce this investigation by using the students' own classification systems from Investigation 2. Ask one
student to list the specimen numbers from one of his groups. Place the rocks where all students can see them, then ask another student to guess the method by which these rocks were grouped together. After they have tried this a few times, usually with mixed success and failure, introduce the idea that geologists all over the world have agreed upon a single classification system.

Answers to Questions
1. Sediment is pieces of broken down rock. It can be formed into new rock when squeezed and cemented.
2. Igneous rock is formed when molten rock cools and hardens.
3. Metamorphic rock forms when another rock is changed from its original form by heat and pressure.

Student References

NARRATIVE 5
Objective: After reading this narrative, the student should be able to identify a number of common rocks.

Teaching Suggestions
This narrative is intended mainly as pre-reading for Investigation 6.

Answers to Questions
1. The rocks shown are: Figure 1 sandstone; Figure 2 conglomerate; Figure 3 granite; Figure 4 basalt; Figure 5
gneiss.

2. Student definitions will differ widely. A typical one might be, "A rock is a piece of hard stuff found in the ground".

**INVESTIGATION 6**

Objective: After completing this exercise, the student should be able to identify a number of common rocks.

Materials Required

- Rock samples used for Investigation 1.
- Hand lenses or stereoscopic microscopes.
- Dilute hydrochloric acid (1.0 M) in dropper bottles.

Teaching Suggestions

Correct the students' results from Investigation 4 before proceeding with this exercise.

Point out that the names they are learning are only a few of the hundreds used by geologists. The precise name of a rock usually depends upon its mineral content, but since mineralogy is not a part of this course a simpler system based on colour and grain size has been developed.

Do not allow unrestricted access to the acid bottles.

Answers to Questions

1. Granite has larger crystals than rhyolite.
2. Slate is usually harder than shale.
3. Slate is used as a roofing material because it splits into thin flat sheets which may be used like shingles.
4. Shale is more likely to contain fossils than andesite.
5. Limestone and marble both fizz with dilute acid.
6. Pumice is full of bubbles, whereas obsidian is massive.

7. Obsidian is useful for arrowheads because it takes a very sharp edge.

Student References

THE WORLD OF GEOLOGIC MAPPING

General Objectives of the Section:

After completing this unit, the student should be able to:

a) read a geologic map to obtain information about the bedrock in a particular area.

b) read a topographic map.

INVESTIGATION 7

Objective: After completing this exercise, the student should be able to read a geologic map to determine the type of bedrock in a particular area.

Materials Required

Class set of geologic maps. This exercise as written uses Geologic Survey of Canada map 1153A Coquitlam, but this may be changed to suit local needs. Coloured pencils.

Teaching Suggestions

Introduce this section with the "Mystery Mapping Exercise". Chalk a simple coloured pattern on the blackboard. Cover this with a large piece of brown paper taped to the board. Each student in turn is asked to point out a place
on the paper. Use a razor blade (careful!) to cut a 1 cm square from the paper at this point, exposing the colour below. All the students then record this information on their own pieces of paper. As the exercise progresses, students will start to choose their locations more carefully to obtain information about the colours below. When each student has had a turn, ask them to reconstruct the hidden pattern from their limited amount of information. After a few minutes, remove the paper from the board so they can compare their patterns with the original. Point out the similarity between this exercise and the way in which a geologist constructs a map from observations recorded at a limited number of rock outcrops.

Answers to Questions

1. Geologic maps use colours because the differences between areas on the map are more visible at a glance.
2. It is usually impossible for a geologist to examine the rock in every part of an area.
3. Vegetation or water could cover the rock.
4. Usually, a geologist can not be absolutely sure of the rock in all parts of an area.

NARRATIVE 8

Objective: After reading this narrative, the student should be able to explain the difference between a geologic map and a topographic map.

Answers to Questions

1. Topographic maps are made from aerial photographs because
mapping from ground notes would take too long in a country as large as Canada.

2. Topographic maps must be revised more frequently than geologic maps because ground level features such as roads and buildings may change frequently, whereas bedrock does not change, except in the case of an error in the original geologic map.

INVESTIGATION 9

Objective: After completing this exercise, the student should be able to use the legend to obtain information about cultural symbols on a topographic map.

Materials Required

Class set of topographic maps. This exercise uses National Topographic Series map 92G/7, but this may be modified to suit local needs.

Answers to Procedure Questions

A. 1. Blue represents water, green represents vegetation, white represents non-forested area, and red represents a built-up area.

   2. The symbols are:

   school ♦
   church †
   post office P
   mine ✩
   quarry ☠
   navigation light ✷

   3. The symbols are:

   four lane freeway ———
   trail ————
   single track railway ————
INVESTIGATION 10

Objective: After completing this exercise, the student should be able to measure scale distances on a topographic map.

Materials Required

Maps used for Investigation 9.

Teaching Suggestions

Introduce this exercise by showing a number of maps of the same area, each drawn to a different scale.

Answers to Procedure Questions

A. 1. The scale of this map is 1:50 000

3. a) 2500 m  
   b) 1100 m  
   c) 3900 m  
   d) 300 m  
   e) 800 m

   f) 1000 m  
   g) 900 m  
   h) 5000 m  
   i) 20 000 m  
   j) 760 000 m²

INVESTIGATION 11

Objective: After completing this exercise, the student should be able to read altitude from a topographic map.
Materials Required

Maps used for Investigation 9.

Teaching Suggestions

Avoid spending too much time on the meaning of contour lines. Most students can learn to use them in a mechanical way quite quickly.

Answers to Procedure Questions

A.  

<table>
<thead>
<tr>
<th>Location</th>
<th>Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buntzen Lake</td>
<td>407 ft</td>
</tr>
<tr>
<td>Burwell Lake</td>
<td>2720</td>
</tr>
<tr>
<td>Mount Bishop</td>
<td>4946</td>
</tr>
<tr>
<td>Mount Elsay</td>
<td>4653</td>
</tr>
<tr>
<td>Mount Seymour</td>
<td>4766</td>
</tr>
<tr>
<td>Seymour Lake</td>
<td>750</td>
</tr>
<tr>
<td>Coquitlam Mountain</td>
<td>5193</td>
</tr>
<tr>
<td>Widgeon Peak</td>
<td>4701</td>
</tr>
<tr>
<td>Golden Ears</td>
<td>5598</td>
</tr>
<tr>
<td>Coquitlam Lake</td>
<td>511</td>
</tr>
<tr>
<td>unnamed peak</td>
<td>4546</td>
</tr>
</tbody>
</table>

B.  

<table>
<thead>
<tr>
<th>Location</th>
<th>Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eagle Mountain</td>
<td>3400 ft</td>
</tr>
<tr>
<td>Burnaby Mountain</td>
<td>1100</td>
</tr>
<tr>
<td>Capitol Hill</td>
<td>600</td>
</tr>
<tr>
<td>Mount Felix</td>
<td>3800</td>
</tr>
<tr>
<td>Cypress Lake</td>
<td>2500</td>
</tr>
<tr>
<td>Cypress Mountain</td>
<td>2600</td>
</tr>
<tr>
<td>Dennett Lake</td>
<td>3100</td>
</tr>
<tr>
<td>Obelisk Peak</td>
<td>5800</td>
</tr>
<tr>
<td>Coquitlam Island</td>
<td>1000</td>
</tr>
<tr>
<td>Hill N of Burns Point</td>
<td>900 ft</td>
</tr>
<tr>
<td>Hill E of Bedwell Bay</td>
<td>500</td>
</tr>
<tr>
<td>Gopher Lake</td>
<td>2800</td>
</tr>
<tr>
<td>Croker Island</td>
<td>400</td>
</tr>
<tr>
<td>Moody Jr. Sec. School</td>
<td>100</td>
</tr>
<tr>
<td>Sheridan Hill</td>
<td>400</td>
</tr>
<tr>
<td>Mount Dickens</td>
<td>2800</td>
</tr>
<tr>
<td>Mike Lake</td>
<td>800</td>
</tr>
<tr>
<td>Widgeon Lake</td>
<td>2600</td>
</tr>
</tbody>
</table>

Answers to Questions

1. A person hiking along a contour line would be walking along a level path.

2. Contour lines can never cross because that would mean the crossing point had two different altitudes.

3. Sea level would have an altitude of 0 m.
INVESTIGATION 12

Objective: After completing this exercise, the student should be able to draw a land profile by using the contour lines on a topographic map.

Materials Required

Maps used for Investigation 9
Full page copy of Figure 105

Teaching Suggestions

Introduce the exercise by drawing a very simple profile on an overhead projector mock-up, while the students follow along on their own copies. Remind the students that if the grid lines on the profile sheet are not drawn on the same scale as the map, the steepness of the terrain may be exaggerated or reduced (usually exaggerated).

Answers to Procedure Questions

See Figure 100.

THE WORLD OF WEATHERING AND EROSION

General Objectives of the Section:

After completing this unit, the student should be able to:

a) describe the gradational processes working to reduce the relief of the land.

b) describe the sedimentation processes resulting from (a).

NARRATIVE 13

Objective: After reading this narrative, the student should
Figure 100: Profile from Investigation 12.
be able to classify weathering processes as physical, chemical or biological.

Answers to Questions

1. Three ways in which rock can be weathered by non-living things are: a) Rainwater may dissolve rock.
   b) Water freezing may wedge rocks apart.
   c) Windblown sand may grind rock away.

There are of course many others.

2. Three ways in which living things may weather rock are:
   a) Roots may wedge rocks apart.
   b) Animals' feet may wear rock away.
   c) Earthworms pass rock particles through their digestive tracts, making the particles smaller.

There are many other methods.

3. Lichen releasing acid would probably be considered a combination of biological and chemical weathering.

Student References


INVESTIGATION 14

Objectives: After completing this exercise, the student should be able to define the word weathering, and classify weathering processes as physical, chemical or biological.

Materials Required

- metal capped glass bottle
- steel wool
- freezer
- 3 beakers and covers
limestone chip
dilute hydrochloric acid (1.0 M)
plaster of paris
soaked corn or bean seeds

Teaching Suggestions

Stress the difference between weathering - the breakdown of rock, and erosion - the removal of rock debris.

Answers to Procedure Questions

A. Weathering is the process by which large pieces of rock are broken down into small pieces of rock.
B. The bottle broke. This occurred because the water expanded upon freezing. This is an example of physical weathering.
C. The dry wool in the dry beaker remained unchanged because there was no reaction between the steel and oxygen. The wool in the beaker of water rusted because of a reaction between steel and dissolved oxygen in the water. The damp wool in the dry beaker rusted because the wool reacted with oxygen in the air. These demonstrations are examples of chemical weathering.
D. The limestone lost its sharp edges, becoming slightly smaller. This occurred because of a reaction between the limestone and the acid, representing chemical weathering.
E. The sprouting seeds broke their way out of the plaster because of expansion upon growth. This represents biological weathering.

Answers to Questions

1. Two examples of biological weathering are roots splitting rock and animals feet wearing rock away.
2. Two examples of physical weathering are windblown sand wearing away rock, and running water tumbling and wearing rock.
3. Acid rain will slowly dissolve limestone. The chemical reactions associated with the process are:

\[
\text{carbon dioxide} + \text{water} \rightarrow \text{carbonic acid}
\]
\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3
\]
\[
\text{carbonic acid} + \text{limestone} \rightarrow \text{calcium bicarbonate (soluble)}
\]
\[
\text{H}_2\text{CO}_3 + \text{CaCO}_3 \rightarrow \text{Ca(HCO}_3)_2
\]

These equations are for the use of the teacher. They are not intended to be discussed by the students.

4. Acid rain will slowly dissolve stone facings on buildings.

5. This combination of weather conditions will cause frost wedging which weathers rock.

Student References


**INVESTIGATION 15**

Objective: After completing this exercise, the student should be able to describe the operation of the hydrologic cycle.

Materials Required

- small aquarium rocks glass cover for aquarium
- heat lamp ice tray

Teaching Suggestions

Set up the apparatus (Figure 101) at least an hour before it is required. After completing the exercise, guide class discussion by drawing a composite of the students'
Figure 101a. Hydrologic cycle apparatus for Investigation 15.
hydrologic cycles on a blackboard or overhead projector.

Answers to Procedure Questions

A. See Figure 101a.

B. a) The light bulb represents the sun.
   b) The ice tray represents the cold upper atmosphere.
   c) The water represents the oceans.
   d) The rocks represent the land.

C. Water droplets form beneath the ice tray. These return to the bottom of the tank by dropping, representing rain.

D. Mist forms on the sides of the tank. Water travels upwards by evaporation, similar to the process on Earth. Water travels back to Earth in the form of rain, or in the form of snow if the temperature is less than 0°C.

Answers to Questions

1. The average water use will probably be about 360 L, but this can vary widely.

2. \[ 360 \times 365 = 131400 \text{ L}. \]

3. \[ 131400 \times 22000000 = 289080000000 \text{ L}. \]

NARRATIVE 16

This narrative is intended to supply the student with a number of additional facts about the hydrologic cycle.

INVESTIGATION 17

Objectives: After completing this exercise, the student should be able to describe the causes of stream abrasion, and describe the effects of stream abrasion on rock.
Materials Required (per group)

100 - 200 g of crushed limestone, washed free of silt and fine particles.
A generous supply of paper towels.

Equipment Required (per group)

- centigram balance
- plastic container

Teaching Suggestions

Make sure that the students shake the container sufficiently hard. Gentle "sloshing" is not sufficient.

Answers to Questions

1. The rocks were soaked beforehand so that absorption of water during the experiment would not obscure the results.
2. The shaken rocks will be smoother, with fewer sharp edges.
3. A "very large number" of shakes would be required to wear the rock away completely.
4. The causes of the abrasion are firstly, abrasive contact with other rocks and the sides of the container and secondly, dissolving of a small amount of the limestone by the water.
5. Abrasion causes scarring and rounding of the rocks, and a slight reduction in mass.
6. Stream abrasion is most likely to occur in late spring and early summer when melting snow causes a high rate of flow in streams and rivers.

INVESTIGATION 18

Objectives: After completing this exercise, the student should be able to state in which months the Fraser River
carries the most sediment.

Materials Required

graph paper

Answers to Procedure Questions

A. The Fraser River is approximately 1370 km long.

Answers to Questions

1. The Fraser carries an average 6 900 000 t of sediment during June.

2. Water flow is higher in June than in February, therefore the river can carry more sediment.

3. a) Each train carries 10 000 t of sediment.
   b) 2000 trains would be needed each year.
   c) Approximately 5.5 trains would be needed each day.
   d) 23 trains each day, or approximately one train per hour would be required.

INVESTIGATION 19

Objectives: After completing this exercise, the student should be able to state in which months the Fraser River carries the most and least water.

Materials Required

graph paper

Answers to Procedure Questions

B. The high and low points occur in the same months for both water and sediment flow. The similarity occurs because the greater water flow can carry more sediment.

Answers to Questions

1. a) 527 400 m³/minute
214

b) 31 644 000 m³/hour

c) 759 460 000 m³/day

d) 22 784 000 000 m³/month

2. The greatest water flow occurs in June because the warm weather is melting the winter snowpack.

NARRATIVE 20

Objective: After reading this narrative, the student should be able to describe the three different ways in which a river may carry sediment.

Answers to Questions

1. Sediment carried by a river eventually ends up in a large lake (temporarily) or in the ocean.

2. The amount of sediment carried by a river could be affected by the water speed, the quantity of water, and the type of material over which the river flows.

INVESTIGATION 21

Objectives: After completing this exercise, the student should be able to:

a) State the meanings of bed, suspended and dissolved sediment load.

b) Determine the amount of suspended and dissolved sediment in a water sample.

Materials Required

filter paper  bucket of muddy water

Equipment Required (per group)

centigram balance  graduated cylinder  funnel
ring stand and ring evaporating dish
asbestos gauze bunsen burner

Teaching Suggestions

Emphasize accuracy in weighing. Do not overheat the evaporating dish, otherwise spattering may occur.

Answers to Questions

2. The average sediment load of Fraser River water is 0.25 g/L.
3. When dissolved, the molecules of sediment are so evenly distributed in the water that their size makes them invisible.
4. a) Sediment carried by a braided stream is mostly bed load.
   b) The greatest amount of sediment is carried in late spring or early summer when the water flow is greatest.

INVESTIGATION 22

Objectives: After completing this exercise, the student should be able to:

   a) Describe the processes of valley formation
   b) Describe the relationship between water speed and valley shape.
   c) Describe the formation of a meandering river and an oxbow lake.

Equipment Required (per class)

stream table

Teaching Suggestions

For best operation of a stream table, the sand should be fairly fine and free of silt. The water should run slowly.
Answers to Procedure Questions
A. The rivers appear to be flowing rapidly. The valley has the shape of the letter V.
B. The river cuts a deep narrow valley. The river in Figure 1.15 probably flowed rapidly.
C. The rivers appear to be flowing slowly. The Fraser Valley is wide and flat.
D. The rivers appear to flow slowly.
E. The water continues to make a wide flat valley. Slow rivers form wide flat valleys.
F. Oxbow lake formation

\[ \text{\begin{tikzpicture}
\draw[->] (0,0) -- (1,0);
\draw[->] (0,0) -- (0,1);
\draw[->] (1,0) -- (2,1);
\draw[->] (1,0) -- (2,0);
\draw[->] (2,1) -- (3,1);
\draw[->] (2,0) -- (3,0);
\end{tikzpicture}} \]

Answers to Questions
1. A river can erode a deep canyon by tumbling rocks and sediment against the bottom and sides.
2. A fast river in a deep rock canyon would probably erode its bottom more than its sides.
3. A slow river in a valley of soft soil would probably erode its sides more than its bottom.

INVESTIGATION 23
Objectives: After completing this exercise, the student should be able to:
   a) Describe the formation of deltas and flood plains.
   b) Describe the geologic hazards associated with
deltas and flood plains.

c) Describe the agricultural advantages of deltas and flood plains.

Materials Required

Map, National Topographic System 92G

Full page copy of Figure 9

Teaching Suggestions

If possible, introduce the exercise by showing a colour slide of Figure 10. Discuss the appearance of the sediment, and what happens to it once it reaches the ocean.

Answers to Procedure Questions

B. Spanish Bank, Sturgeon Bank and Roberts Bank are probably growing. The Boundary Bay tidal flats are probably not growing.

C. Water is available to vegetation in the delta area.

D. Aklavik has been abandoned because of repeated flooding.

E. Deltas are suitable for industry because of their closeness to water transportation.

F. The water path varies when depositing the sediment.

Answers to Questions

1. a) The greatest water flow occurs in late spring or early summer because the warm temperatures melt the winter snowpack.

   b) The winter temperature affects the rate of water flow by freezing the rivers.

2. a) A flood plain is a good place for agriculture because of the fertility of the sediment deposited there.
b) Living on a flood plain is hazardous because of the floods!

c) Floods could be prevented by damming the river upstream, or by building dykes,

d) If floods are prevented, fertility of the soil will decline.

3. a) Heavy sediment will be dropped close to the river.
   
b) Fine sediment will be dropped farther out to sea.

4. A dam across the Fraser would eventually silt up.

NARRATIVE 24

Objective: After reading this narrative, the student should be able to describe a set of conditions under which a delta is built at the outlet of a lake.

INVESTIGATION 25

Objectives: After completing this exercise, the student should be able to:

a) Describe the characteristics of a sand.

b) Relate a sand to its originating rock.

Materials Required

- sample of olivine
- a number of different sands (Hawaiian recommended)

Equipment Required

- class set of hand lenses or stereomicroscopes
- petri dishes
- GSC Map 1153A (from Investigation 7)

Teaching Suggestions

Every time a friend, acquaintance or student goes to Hawaii, give him three vials and ask him to bring back sand
samples. After a while, you will have enough to make this exercise possible. The local sample may come from just about any stream, provided you can obtain a geologic map of the upstream area. Do not allow unrestricted access to the acid bottles.

Answers to Procedure Questions
D. Widgeon Lake is surrounded by granodiorite and quartz diorite. The colour of the sand sample resembles these rocks.
E. Basalt is black with small crystals.
F. The green sand most closely resembles olivine.

Answers to Questions
1. The sand at a river mouth is made from weathered upstream rocks.
2. Grains of soft minerals are seldom found in sands because they are generally washed away.
3. This sand would form limestone, then marble.
4. The black sands come from basalt, a volcanic rock.

NARRATIVE 26

Objective: After completing this exercise, the student should be able to describe a catastrophic form of erosion.

Teaching Suggestions

Very little introduction is usually required. The story is quite gripping.

Answers to Questions
1. Coal was being mined in Turtle Mountain.
2. Turtle Mountain was made of limestone.
3. a) Water can cause cracks by freezing and expanding
b) Mining could help cause the slide by weakening the mountain.

4. The slide debris could form breccia.

Student References


THE WORLD OF ANCIENT LIFE

General Objectives of the Section

After completing this section, the student should be able to:

a) Describe a generalized history of life on Earth.
b) Identify a limited number of common fossils.
c) Describe a number of methods of fossil preservation.
d) Describe some life forms and environmental conditions of the Mesozoic Era.

NARRATIVE 27

Objective: after reading this narrative, the student should be able to name the principal divisions of the Earth's history.

Teaching Suggestions

This narrative is intended mainly as pre-reading for the following exercises.

INVESTIGATION 28

Objective: After completing this exercise, the student should
be able to name the three eras of the Phanerozoic Eon, and
to describe the main life forms of each era.

Teaching Suggestions

Emphasize how little we really know about most of the
Earth's history. All of our evidence comes from studying
the rocks and the fossils they contain. The reference
given below contains a very limited amount of information.
Students who complain that there is no description of the
Cenozoic Era should be reminded that they are living in it.

Student Reference

Anastasiou, Clifford et al, Reading About Science 1,

INVESTIGATION 29

Objective: After completing this exercise, the student
should be able to describe the diversity of fossil life.

Materials Required

As large a variety of fossils as possible, preferably
with some rock matrix still attached.

Teaching Suggestions

Fossils you have personally collected are far more
useful than commercial specimens. Students will almost
invariably ask where a particular specimen came from,
and it adds to their interest if you can relate a personal
anecdote. Mammalian coprolites, available from Wards
Scientific, are an invaluable interest generator in any
collection!

Your questions should be tailored to the specimens,
but could include such thought provoking topics as: What is it? What present day life form does it resemble? Why might sea life be found in the mountains? What was the climate at the time the fossil was alive?

Student Reference


**INVESTIGATION 30**

Objective: After completing this exercise, the student should be able to identify a number of common fossils.

Materials Required

- fossil specimens (per group)
- trilobite
- gastropod
- crinoid stem
- horn coral
- pelecypod
- shark tooth
- brachiopod
- ammonite
- reptile bone
- gymnosperm leaf
- angiosperm leaf

Loss may be reduced if the smaller specimens are enclosed in Riker mounts.

Teaching Suggestions

If possible, provide the students with the age of each specimen, and the approximate location where it was found.

Little is to be gained by taking junior secondary students on actual collecting trips, especially if the site visited is at all fragile. Many good fossil localities have been ruined by indiscriminate collecting.
Answers to Procedure Questions

A.  a) "Tri" suggests the number three. A trilobite's body is divided into three parts.
    b) The trilobite most closely resembles a lobster.

B.  a) A coral is an animal.
    b) The small end of the corallite is formed when the animal is younger and smaller.
    c) Solitary corals live alone, colonial corals live in groups.

C.  a) A brachiopod shell has two parts.

D.  a) i) A gastropod shell has one part.
    b) i) Mussels and scallops are both edible.
    c) i) An ammonite shell is coiled flat, while a gastropod shell is coiled conically (usually).

E.  a) A shark tooth is pointed, while a human front tooth is flat or chisel shaped.

G.  a) The shape of the specimen resembles bone. The marrow may be visible.
    b) The bone is brown in colour, and heavier than present day bone.

H.  a) Most leaves break apart rapidly after falling.
    c) Coal is formed where thick layers of vegetation are fossilized underground.

Answers to Questions

1. A fossil is preserved evidence of prehistoric life.
2. Fossils can tell us what kind of animals and plants lived in the past, and the environment and climate of the area in which they lived.
NARRATIVE 31
Objective: After reading this narrative, students should be able to describe a number of methods by which fossils are formed.
Teaching Suggestions
This narrative should be considered as supplementary reading. Students at this level frequently have difficulty distinguishing among the various methods of preservation, therefore it should be assigned only to the most capable.

INVESTIGATION 32
Objective: After completing this exercise, the student should be able to describe some of the characteristics of dinosaurs.
Teaching Suggestions
Dinosaurs are usually a popular topic. Try to capitalize on this by the use of supplementary books and posters. However, be wary of the possibility that the topic may already have been "done to death" in previous grades.
Answers to Procedure Questions
A. In many cases, form of movement is open to debate. It depends chiefly upon the animal's actions at a particular moment. (Even birds spend a lot of time walking or standing).
B. a) Look at the teeth to determine eating habits.
   b) Allosaurus and Tyrannosaurus appear to eat meat.
   Iguanodon and Camptosaurus appear to eat plants.
   c) The meat eaters probably ran, while the plant eaters probably walked.
C.  
a) Rhamphorhynchus would fly away from danger.  
b) Monoclonius would defend itself with horn and head armour.  
c) Tyrannosaurus would either run away or defend itself with its teeth.  
d) Ankylosaurus would crouch to protect its underside, while using its tail as a club.  

D.  
a) Hesperosuchus is the smallest at 70 cm high.  
b) Brachiosaurus is the tallest at 16 m.  
c) Diplodocus is the longest at 30 m.  
d) Pteranodon's wing span is approximately 12 m.  

E. Tyrannosaurus and Allosaurus differ in shape of head, length of teeth, length of arms, and number of fingers.  

F.  
a) Pteranodon and Rhamphorhynchus would have had light hollow bones so as to reduce their weight for ease of flying.  
b) Brachiosaurus would have had thick heavy leg bones to support its great bulk.  

NARRATIVE  
Objective: After reading this narrative, students should be able to describe conditions in Dinosaur Provincial Park 76 million years ago.  
Teaching Suggestions  
Introduce this narrative by asking students to give their impressions of conditions at this time. Afterwards, the reading should dispel some of their illusions about the likelihood of human survival.
Answers to Questions
1. Biting insects, poisonous plants and predatory animals would make life unpleasant.

INVESTIGATION 34
Objective: After completing this exercise, the student should be able to describe a number of possible reasons for the extinction of the dinosaurs.
Teaching Suggestions
This is an exercise in creativity. At present, the reasons for the massive extinction at the end of the Mesozoic Era are not known. Students may propose floods, plague, lack of food, climatic change or similar catastrophes. Currently popular theories include climatic change caused by continental drift, or destruction of the ionosphere by geomagnetic reversal or a nearby supernova, thereby exposing the Earth to harmful solar radiation.

THE WORLD OF ICE
General Objectives of the Section:
After completing this unit, the student should be able to:

a) Describe the appearance of Canada during the Ice Age.
b) Describe the formation and structure of glaciers.
c) Describe the landforms caused by glacial erosion.

INVESTIGATION 35
Objectives: After completing this exercise, the student
should be able to:

a) Describe the appearance of Canada during the ice age.
b) Name locations of present glaciers in Canada.
c) Describe the process of glacier formation.

Materials Required

Geologic Survey of Canada maps 1257A and 1253A

Teaching Suggestions

Introduce the section by asking students about their impressions of life in Canada during the ice age.

If snow is available, demonstrate the formation of ice by pressure.

Answers to Procedure Questions

D. Glaciers may be found in the Pacific Coast Mountains, and the Rocky Mountains.

Answers to Questions

1. a) The Pacific Ocean provides the water for snow.
   
   b) The cold winds blow south from the Arctic.
   
   c) There are more glaciers in the Coast Mountains because there is a greater supply of water nearby.

2. a) Parts of the Yukon Territory were ice free.
   
   b) There was a lack of open water to evaporate and provide snow.

3. Antarctica is still ice covered.

4. In order to survive an ice age, Canadians would probably have to move south.

INVESTIGATION 36

Objective: After completing this exercise, the student should
be able to:

a) Describe the structure of a glacier.

b) Describe the mechanism of glacial erosion, and the formation of moraine.

Materials Required

a sample of glacially striated rock

Answers to Procedure Questions

A. A glacier is a large mass of ice formed on land.
B. Mountain climbers may fall into crevasses while crossing glaciers.
C. The most snow falls and the least snow melts at the upper end of a glacier. The least snow falls and the most snow melts at the lower end of a glacier. The glacier will grow larger at the upper end and smaller at the lower end.
D. The fresh snow appears at the upper end of the glacier. The ice at the snout of the Athabaska Glacier is melting.
E. The plain ice does not scrape the board much, so it is not likely that plain ice can erode very much rock. Ice containing sand scraped the board more. Ice containing broken rock could erode more easily.
F. Moraine describes all of the rock carried by a glacier.
G. A lateral moraine is rock carried along the side of a glacier. A medial moraine is rock carried in the middle of a glacier. Six glaciers have joined to form the glacier in Figure

Answers to Questions

1. Glaciers are sometimes called "rivers of ice" because they are made of ice which flows slowly.
2. The grooves in glacially striated rock are caused by the glacier dragging rocks over the surface.

3. a) The moraine is piled up at the snout of the glacier. 
   b) The glacial flour is washed away in the melt water. 
   c) The streams flowing away from the glacier carry the glacial flour as sediment.

**INVESTIGATION 37**

Objective: After completing this exercise, the student should be able to:

   a) Describe the mechanism of glacial erosion.
   b) Describe the formation of various glacial landforms.

Teaching Suggestions

Show the students as many photographs as possible of glacial landforms native to their home area.

Answers to Procedure Questions

A. This valley has a U-shape. If the stream continues to flow, the valley will become V-shaped.

B. Snow enters a cirque by falling into the top. The ice leaves a cirque when pressure forces it over the edge. Ice makes a cirque larger by plucking rocks from the walls. There is one cirque in Figure 30.

C. There are two arêtes visible in Figure 31.

D. There is one horn visible in Figure 31.

E. There are two hanging valleys visible in Figure 31.

F. Fiords make good harbours because they are sheltered and contain deep water. There are few sandy beaches because the sides of a fiord are so steep. The fiord north of Port
Moody is called Indian Arm.

Answers to Questions

1. A river erodes only the bottom of a valley, whereas a glacier erodes both the sides and the bottom.

2. The sea level was much lower during the ice age because a large amount of water was locked up on land in the form of ice.

3. A glacier carrying a large amount of very fine rock debris could polish rock.

COQUITLAM RIVER FIELD TRIP

Objective: to have the student observe in the field some of the processes and landforms which have been studied in this course.

Equipment Required (per group)

- notebook and pencil, two water sample jars
- one sand sample vial

Teaching Suggestions

The activities and questions are phrased in such a way that the student is directed to observe a feature, then record the observations and deduce further information. On the trip, samples are taken which will be analysed later. This forces a review of previous activities.

Answers to Questions

Part B

Stop #1. Two possible causes of a landslide are (a) an over-steep slope weakened by heavy rainfall or (b) a minor earthquake in the area.
Stop #2.

a) At this point the valley is fairly narrow with quite steep sides. There is no good farmland.

b) The river flows quite rapidly here.

c) The current is fastest in the middle of the river.

d) The water (usually) does not carry much sediment here.

e) The rocks are quite large (30 cm) and rounded. They acquired that shape by being tumbled by the water. They are mostly plutonic and metamorphic, diorite and gneiss, with a few volcanic basalts.

Stop #3

a) The cliff is made of sand and gravel with some larger boulders.

b) If this material were compressed it would form sandstone and conglomerate with possibly some shale.

c) The large rocks are rounded, implying that the material was deposited by water. Since stream abrasion rounds rocks.

d) The coarse layers were deposited by fast water since only fast water could move the large boulders. The absence of boulders in the finer layers implies that they were deposited by slower moving water. Meltwater from ice age glaciers could have produced the quantity of water required to deposit this amount of sediment.

e) The present river has removed the sediment from the centre of the valley.

Drive to Stop #4

a) As we travel downstream, the valley widens.
b) A major sand and gravel industry is located here because of the quantity of suitable material and the ease with which it may be extracted. Sand and gravel is used mainly in construction.

Stop #4

a) The rocks are quite large (15 cm) but smaller than those at Stop #2. They are mostly plutonic and metamorphic, diorite and gneiss, with some volcanic basalts.

b) The river occupies about 20% of its entire bed. It used to carry the most water in June and the least in February. The most water was produced when the winter snow-pack was melting, and the least when most precipitation was in the form of snow.

c) The river is (usually) not carrying much sediment, but more than was observed at Stop #2. Sediment would be added to the river by the gravel operations upstream.

Drive to Stop #5

a) The valley becomes wider and flatter as we travel downstream.

b) Farming is carried on here because the soil is exceptionally fertile.

Stop #5

a) The land surface is called a flood plain.

b) An upstream dam, and dykes prevent flooding. Soil fertility must be maintained by adding fertilizers.

c) The river is meandering. It flows slowly.

d) The river usually carries more sediment here than it does further upstream. It would be mostly fine sediment
because the water flows slowly.

e) No delta is forming where the Coquitlam flows into the Fraser because the current in the Fraser sweeps away the sediment before it can be deposited.

Part C

b) The sand sample consists of light and dark particles about evenly mixed. The originating rock was probably diorite or gneiss.

e) During the last ice age, the valley of the Coquitlam was occupied by a glacier which widened and deepened a pre-existing valley. As the glacier retreated, the meltwater deposited huge quantities of sediment in the valley. The present river has started to excavate this sediment and deposit it further downstream in the form of a flood plain. Construction of a dam and dykes has slowed the erosional and depositional processes.
**EQUIPMENT REQUIRED**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquarium, 25 L with glass cover</td>
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</tr>
<tr>
<td>Asbestos gauze</td>
<td>1 per station</td>
</tr>
<tr>
<td>Beaker, Pyrex, 250 mL</td>
<td>1 per station</td>
</tr>
<tr>
<td>Bottle, dropper</td>
<td>1</td>
</tr>
<tr>
<td>Bunsen burner</td>
<td>1 per station</td>
</tr>
<tr>
<td>Dish, evaporating</td>
<td>1 per station</td>
</tr>
<tr>
<td>Dish, petri (10 mm x 100 mm)</td>
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<tr>
<td>Filter paper, 12.5 cm</td>
<td>2 pkg.</td>
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<tr>
<td>Funnel, 65 mm diam., long stem</td>
<td>1 per station</td>
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<tr>
<td>Graduated cylinder, 25 mL</td>
<td>1 per station</td>
</tr>
<tr>
<td>Hand lens</td>
<td>1 per station</td>
</tr>
<tr>
<td>Masking tape</td>
<td>1 roll</td>
</tr>
<tr>
<td>Microscope, stereoscopic</td>
<td>1 per station (optional)</td>
</tr>
<tr>
<td>Ring stand with 8 cm diam ring</td>
<td>1 per station</td>
</tr>
<tr>
<td>Stream table</td>
<td>1 per class</td>
</tr>
<tr>
<td>Steel wool</td>
<td>1 pkg.</td>
</tr>
<tr>
<td>Balance, centigram</td>
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**CHEMICALS REQUIRED**

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<tbody>
<tr>
<td>Hydrochloric acid (conc.)</td>
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<tr>
<td>Plaster of Paris</td>
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**SPECIMENS REQUIRED**

<table>
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<th>Item</th>
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<tbody>
<tr>
<td>Rocks (hand size)</td>
<td>1 per class</td>
</tr>
<tr>
<td>Andesite</td>
<td></td>
</tr>
<tr>
<td>Breccia</td>
<td></td>
</tr>
<tr>
<td>Basalt</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td></td>
</tr>
<tr>
<td>Conglomerate</td>
<td></td>
</tr>
<tr>
<td>diorite</td>
<td></td>
</tr>
</tbody>
</table>
Gabbro  Gneiss  Granite
Limestone  Marble  Obsidian
Porphyry  Pumice  Quartzite
Rhyolite  Sandstone  Shale
Slate
Fossils
ammonite  horn coral  reptile bone
brachiopod  leaf (broad)  shark tooth
crinoid stem  leaf (conifer)  trilobite
gastropod  pelecypod
Limestone, crushed (1 - 2 cm)  5 kg
Seeds, bean or corn  1 pkg.
Rock, glacially striated  1 per class

MAPS REQUIRED

<table>
<thead>
<tr>
<th>Item</th>
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<tbody>
<tr>
<td>Topographic</td>
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<tr>
<td>92G Vancouver</td>
<td>1 per station</td>
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<tr>
<td>Geologic</td>
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<tr>
<td>1153A Coquitlam</td>
<td>1 per station</td>
</tr>
<tr>
<td>1253A Glacial Map of Canada</td>
<td>1 per class</td>
</tr>
<tr>
<td>1257A Retreat of Wisconsin and Recent Ice in North America</td>
<td>1 per class</td>
</tr>
</tbody>
</table>
RECOMMENDED AUDIO-VISUAL AIDS

16 mm films (Encyclopaedia Britannica Educational Corp.)
1. Rocks that Form on the Earth's Surface (16 min).
2. Rocks that Originate Underground (23 min).
3. The Beach - A River of Sand (20 min).
4. Erosion - Levelling the Land (14 min).
5. Why Do We Still Have Mountains? (21 min).
7. Evidence for the Ice Age (19 min).

8 mm Film Loop (Walt Disney Corp.)
Flash Flood

35 mm colour slides (B.C. Teachers' Federation).
1. Lesson Aid M-1 (103 Geology Slides).
2. Lesson Aid M-51 (38 Athabaska Glacier Slides).
Teachers' Manual and
Answer Key

Part 2
INVESTIGATION 1

Objectives: After completing this exercise, the student should be able to:

a) Name and describe each of the layers of the Earth.

b) Describe the relative thicknesses of the layers of the Earth.

Equipment Required (per student)
compass

Teaching Suggestions

Introduce this exercise by asking the students what they think might be inside the Earth. Remind them of some clues such as drill holes and volcanoes. For Procedure B, some students will require assistance with setting their compasses to scale distances.

Answers to Procedure Questions

A.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness (km)</th>
<th>Depth of top from surface (km)</th>
<th>Distance of top from centre (km)</th>
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</thead>
<tbody>
<tr>
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<td>0</td>
<td>6370</td>
</tr>
<tr>
<td>Asthenosphere</td>
<td>560</td>
<td>160</td>
<td>6210</td>
</tr>
<tr>
<td>Lower Mantle</td>
<td>2200</td>
<td>720</td>
<td>5650</td>
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<tr>
<td>Outer Core</td>
<td>2250</td>
<td>2920</td>
<td>3450</td>
</tr>
<tr>
<td>Inner Core</td>
<td>1200</td>
<td>4120</td>
<td>1200</td>
</tr>
</tbody>
</table>

INVESTIGATION 2

Objective: After completing this exercise, the student should be able to state a comparison between the thickness
of the lithosphere and the size of some surface structures on the Earth.

Materials required

2 sheets of graph paper

Teaching suggestions

Some students will require assistance with choosing a suitable scale for the vertical axis on each bar graph.

Answers to Questions

1. The crust is approximately 1/40 of the Earth's radius.
2. Man-made features are small compared to the size of the Earth.
3. The crust is thicker under the continents because of the additional thickness of the continental rock.
4. Drilling a hole through the crust would be easier on the ocean bottom because the crust is thinner there.
5. a) Pressure increases with depth.
    b) It is possible that the increased pressure squeezes the atoms together so that only the solid phase will form.

NARRATIVE 3

Objectives: After reading this narrative, the student should be able to:

a) Describe the origin of the atmosphere.

b) State the composition of the atmosphere.

Teaching Suggestions

This narrative provides the student with a number of facts about the atmosphere. Emphasize the point that the atmosphere is the outer layer of our planet.
To arouse interest, perform demonstrations with a bell jar and vacuum pump to show what can happen in the absence of an atmosphere. A mixture of ethanol and water will boil very effectively when the pressure is reduced, and a partially inflated balloon will expand and burst.

Answers to Questions
1. The density of hydrogen and helium is lower than that of nitrogen and oxygen, hence they tend to rise.

NARRATIVE 4
Objective: After reading this narrative, the student should be able to:
   a) Describe the origin of the Earth.
   b) Describe two theories accounting for the absence of surface rocks with the same age as the Earth.

Teaching Suggestions
   If possible, show a number of colour slides or pictures of astronomical objects purporting to show the origin of stars.

Answers to Questions
1. If the Earth had formed closer to the sun, the temperature would be higher, and as a result there would probably be no oceans. Life forms would probably be different.
2. If the Earth had formed between Jupiter and Saturn, it would be much colder, and might have a very deep atmosphere of methane and ammonia, hydrogen and helium.
3. Volcanoes show that the interior of the Earth is still hot.
INVESTIGATION 5

Objective: After completing this exercise, the student should be able to state a comparison between the age of our planet and the age of life upon it.

Materials required (per group)

- 5 m of paper tape (ticker tape)
- metre stick

Teaching suggestions

Numbers alone can not give a feeling for the true extent of the age of the Earth. This exercise spreads this life out in visual form.

Point out to students that in terms of the life of the Earth, the age of dinosaurs was comparatively recent. Note the ridiculousness of cartoons showing cave-men and dinosaurs together.

Answers to Questions

1. a) Event Era
   
   Humans Cenozoic
   Land plants Paleozoic
   Rocky Mountains Mesozoic & Cenozoic
   Dinosaurs Mesozoic
   First Insects Paleozoic
   West Coast Mountains Mesozoic
   Last ice age Cenozoic
   First Animals Precambrian
   Formation of Earth Precambrian
b) Cenozoic 70 million years
Mesozoic 155
Paleozoic 375
Precambrian 4000
c) Cenozoic 1.5%
Mesozoic 3.4%
Paleozoic 8.2%
Precambrian 86.9%

2. 100 000 generations have passed since the first recognizable humans appeared.

3. a) Early men never used dinosaurs for food.
    b) Dinosaurs became extinct many millions of years before men evolved.

NARRATIVE 6
Objectives: After reading this narrative, the student should be able to:
   a) Describe historical attempts to measure the age of the Earth.
   b) Describe radiometric dating of rocks.

Teaching Suggestions
This narrative should be assigned only to those students with a good grasp of chemistry.

Answers to Questions
1. The rock is approximately 400 million years old.
2. The rock was approximately 4.5 billion years old.
3. The half-life of the potassium-argon decay process is approximately 1.2 billion years.
4. In very young rocks the amount of material which has decayed is too small to be measureable.

5. a) The lava was 5730 years old.
   b) The leaf was 11460 years old.

6. a) If the rocks had been disturbed, the chemical composition might have changed, and this would produce incorrect ages.
   
   b) The resulting age would be too young.

7. Joly would have had difficulty in measuring the amount of salt added to the oceans each year. He assumed that this rate had remained constant through the ages, and failed to account for salt dissolved from the ocean floor.

   Kelvin did not know the original temperature of the Earth. He failed to account for heat added by radioactive decay within the Earth.

**INVESTIGATION 7**

Objectives: After completing this exercise, the student should be able to:

a) Name and describe a number of fossils common in western Canada.

b) Explain several uses of fossils.

Equipment Required (per group)

Samples of the following fossils:

- trilobite
- crinoid stem
- gastropod
- gymnosperm leaf
- shark tooth
- brachiopod
- reptile bone
- silicified wood
- ammonite
- pelecypod
- angiosperm leaf
- carbonized wood
Teaching Suggestions

Although it is obviously better if the students can work from actual specimens, Procedures A to J may be carried out by using the photographs printed in the text. During the exercise, emphasize both the intrinsic interest of the fossils themselves, and the ancillary information such as climate and environment that may be gained from them. As well as the student specimens, it is sometimes useful to have larger, better quality display specimens available. Loss of student specimens may be reduced by sealing them in Riker mounts.

The value of taking junior secondary students on an actual collecting trip is doubtful. Good fossil localities can be destroyed by indiscriminate collecting.

Answers to Procedure Questions
A. This procedure is intended to introduce students to the most basic paleontological question, "What is it?". The only specimen which may cause difficulty is the crinoid stem, which is part of an animal.
B. Flexible joints enable the animal to move more easily, or to roll up for protection of its soft underside. The remainder of the animal probably rotted, or was eaten. Trilobites became extinct about 225 million years ago. Animals which may be descended from trilobites are the crab, lobster, shrimp, prawn, and crayfish.
C. The shark tooth is pointed whereas a human front tooth is chisel shaped. The human back tooth is flat. The shark probably is a meat eater, since its teeth are designed for
tearing flesh. Shark teeth are frequently the only part fossilized because they are one of the few hard parts of the animal.

D. The octopus or squid may be related to the ammonites.

F. The brachiopod shell has upper and lower halves which are different. The two halves of a pelecypod shell are symmetrical.

G. Clams, scallops, oysters, mussels and many other pelecypods are edible.

H. Some gastropods are edible (escargots). The gastropod shell is coiled conically, whereas the ammonite shell is coiled flat.

I. The colour and weight of the bone show that it has been petrified. Its shape and the indication of marrow resemble modern bone.

J. Unbroken fossil leaves are rare because most leaves break up soon after falling. Figure shows a selection of leaves found in a moist temperate climate today, similar to the climate of the British Columbia coast. Coal is formed when massive amounts of vegetation are fossilized in thick beds.

K. Ring structure may show in good specimens of silicified and carbonized wood.

Answers to Questions

1. A fossil is preserved evidence of prehistoric life.

2. a) trilobite   b) ammonite   c) brachiopod
d) crinoid stem   e) tracks
3. a) mould b) replacement c) cast d) carbonization

4. Fossils are seldom found in volcanic rocks because the heat usually destroys the specimen. However, specimens are frequently found buried in ash, Pompeii being the most famous example.

INVESTIGATION 9

Objectives: After completing this exercise, the student should be able to:

a) Identify homologous structures in different organisms.

b) Explain the reasons for modifications in the limbs of various organisms.

Materials Required (per student)

Full page copies of Figures 147 and 148.

Coloured pencils

Teaching Suggestions

Introduce the exercise by asking students how they would decide whether or not different animals are related, for example monkey and gorilla, dog and wolf. Keep stretching the point by introducing animals in which the resemblance is less and less obvious, such as moose and horse, mouse and elephant, bird and dog etc. until a point is reached where the students decide that there is no relationship at all between a pair of animals. Follow this by introducing the comparison between extinct and modern animals and the idea of tracing lines of descent. Lastly, introduce the specifics of comparing bone structure.
Answers to Procedure Questions

D. The plesiosaur limb has been modified into a flipper for propelling the animal through the water. The three-toes horse has developed a light, strong limb for speed when running. The pteranodon limb is very light, with one digit greatly extended to support the skin of the wing. Like the plesiosaur, the seal forelimb is a flipper designed for propulsion in water, but it also has the strength to support the seal on land. The bat limb is light and strong to support the wing without excessive weight. The sabretooth tiger limb is heavy and strong for speed and killing ability.

Answers to Questions

1. Animal  Environment
   Camel  Desert
   Whale  Ocean
   Mountain sheep  Mountains
   Monkey  Forest or jungle
   Mole  Underground
   Eagle  Air

2. Animal  Reason
   Camel  Do not sink in soft sand
   Whale  Propelling animal through water
   Mountain sheep  "Suction" effect to grip rock
   Monkey  Additional limb to grasp branches
   Mole  Digging
   Eagle  Gliding easily
NARRATIVE 9

Objectives: After reading this narrative, the student should be able to:

a) Describe Miller's attempt to show how life began on Earth.

b) Describe in general terms the history of life.

c) Describe evolutionary theory in terms of survival of the fittest.

d) Describe the origin and development of humans.

Teaching Suggestions

Refer back to Investigations 5 and 7, pointing out that fossils and radiometric dating are our only sources of information for this history.

Answers to Questions

1. A species lives where competition for food is least.

2. A species will survive if it can find a space to live where it can compete successfully for food, and reproduce itself. If another species meets these criteria more successfully in that particular living space, i.e. is "fitter", then it will survive while the other must either adapt to compete more successfully or become extinct.

NARRATIVE 10

Objective: After reading this narrative, the student should be able two describe two alternative theories about the origin and development of the Earth.

Teaching Suggestions

It should be quite clear that this course is strongly
biased in favour of evolutionary theory. This narrative may be assigned for information only, or used as a basis for class debate. Teachers should be wary of offending students' or parents' religious beliefs.

INVESTIGATION 11

Objectives: After completing this exercise, the student should be able to:

a) Explain how sedimentary rocks are formed.

b) Identify and name a number of common sedimentary rocks.

Equipment Required

- per group: 250 mL beaker, 600 mL beaker, metre stick, platform balance
- per class: mixture of sand and silt, local geologic map, clean dry sand, 1M HCl in dropper bottle, samples of: shale, sandstone, conglomerate, breccia, halite, massive limestone, fossiliferous limestone, dolomite, chert, and coal.

Teaching Suggestions

Emphasize origin of sedimentary rocks, rather than identification.

Answers to Procedure Questions

A. The sand settles first. The material settles in layers.

B. Layering is the most noticeable feature of these rocks.

F. The student can not state whether or not the weight is sufficient to squeeze sediment into rock, however, the number of grams involved is impressively large.
Answers to Questions

1. Water Speed | Type of Sediment Carried | Name of Rock Formed
   Fast         | Pebbles, sand, silt    | Conglomerate
   Medium       | Sand, silt             | Sandstone
   Slow         | silt                   | Shale

2. Conglomerate would form at A, sandstone at B, and shale at C.

3. Halite would probably form in a hot, dry climate which would aid evaporation.

INVESTIGATION 12

Objectives: After completing this exercise, the student should be able to:

   a) Define the term "geothermal gradient"
   b) Present evidence that the interior of the Earth is hot.
   c) Relate the geothermal gradient to the depth at which magma will form.

Materials Required

   2 sheets graph paper

Teaching Suggestions

   This exercise should be considered supplementary to the basic course. All students will agree that volcanism shows the interior of the Earth to be hot. This investigation extends this observation quantitatively.

Answers to Procedure Questions

A. Most students will present volcanism as a third example showing that the interior of the Earth is hot.
D. Icelandic geothermal gradient is approximately $62^\circ C/km$. South African figure is about $11^\circ C/km$.

E. The estimated temperature at a depth of 10 km is $620^\circ C$ in Iceland and $110^\circ C$ in South Africa.

J. Granite would melt at approximately 12 km beneath Iceland, and 60 km beneath South Africa. Basalt would melt about 18 km beneath Iceland. Volcanoes would be more common in Iceland.

**Answers to Questions**

1. Volcanoes, hot springs, and geysers show that the interior of the Earth is hot.

2. a) The estimated temperature would be $394 \, 320^\circ C$ at the centre of the Earth.

   b) Compared to the temperature of the sun, this result seems to be unreasonable.

   c) If the temperature increased all the way to the centre of the Earth, the resulting temperature there is impossibly high.

3. a) South Africa's climate is generally warmer than Iceland's.

   b) Iceland has a higher geothermal gradient than South Africa.

   c) If the heat within the Earth were caused by heat from the sun, then the geothermal gradient in South Africa would be higher than that in Iceland.

**NARRATIVE 13**

Objective: After reading this narrative, the student should be able to describe how useful energy may be extracted
from geothermal heat.

Teaching Suggestions

Relate this narrative to newspaper articles which periodically describe geothermal development in western Canada.

Answers to Questions

1. The presence of volcanoes indicates high temperatures close to the surface of the Earth. This means that the potential for geothermal steam or water is much greater.

2. Subsurface temperatures in Iceland are so hot that the possibility of geothermal water being present is extremely high.

INVESTIGATION 14

Objectives: After completing this exercise, the student should be able to:

a) Describe a volcano as a cinder cone, shield cone or stratovolcano.

b) Explain the relationship between volcanic form and the characteristics of the lava which produced it.

c) Describe and name a number of typical volcanic landforms.

Equipment Required

2 - 250 mL beakers  600 mL beaker
mixture of sand and small pebbles  sand
wax  ring stand and ring  bunsen burner
cardboard sheet

Teaching Suggestions

Volcanoes are always a high interest subject. Illustrate
with some of the many good films and slides available. If possible, have the students keep a "volcano watch" with a world map and newspaper or television reports.

Answers to Procedure Questions

B. A cinder cone is small with fairly steep sides. A shield volcano is large with long sloping sides. A stratovolcano is large with gentle slopes at the base, and steep slopes near the summit.

C. The sides of the cone are steep. A cinder cone is formed by the eruption of solid, lumpy pieces of rock.

D. The sides of the model volcano are gently sloping. A shield volcano is formed by the eruption of liquid lava.

Answers to Questions

1. Figure 159 is a shield Figure 163 is a shield
   160 shield 164 shield
   161 stratovolcano 165 stratovolcano
   162 cinder cone 166 cinder cone

2. Figure 167 is a caldera Figure 170 shows columns
   168 dyke 171 black sand
   169 lava tube

3. The landform being produced could be either a dyke or a lava plateau (flood lava).

4. Magma is molten rock underground. Lava is magma which has reached the surface.

5. a) This landform is a flood lava.
   b) The area covered is approximately 120 000 km$^2$.

6. a) Olympus Mons is a shield volcano.
   b) Olympus Mons covers an area of about 450 000 km$^2$. 
c) The depression at the summit of Olympus Mons is a caldera.

7. a) Pressure of magma pushing up beneath a volcano could cause it to swell.
    
    b) Huge masses of molten rock moving beneath a volcano could cause small earthquakes.
    
    c) Scientists could predict eruptions by measuring the swelling of a volcano, or detecting small earthquakes in its vicinity.

INVESTIGATION 15

Objective: After completing this exercise, the student should be able to describe the pattern formed by the locations of volcanoes.

Materials Required

world map, North America centred

Teaching Suggestions

This exercise could be accompanied by a "volcano watch", whereby students plot the locations of volcanic eruptions reported by newspapers and television.

Answers to Questions

1. The Pacific Ocean is surrounded by volcanoes.

2. The Atlantic Ocean has a line of volcanoes down its centre. This chain is called the Mid-Atlantic Ridge.

3. a) The Earth's crust is thicker under the continents.
    
    b) Magma is probably nearer the surface under an ocean.
    
    c) Perhaps the crust in the centres of continents is too thick to allow magma to reach the surface.
NARRATIVE 16

Objective: After reading this narrative, the student should be able to describe the characteristics of a number of volcanoes in and near British Columbia.

Teaching Suggestions

Some students may have hiked or skied in the areas mentioned. They may be able to provide slides or photographs. Reports of activity on Mount Baker appear in the newspapers from time to time.

Answers to Questions

1. Eve Cone is a cinder cone.

2. Mount Edziza is far away from present centres of population and energy usage. Construction of power lines would be expensive and difficult.

4. Vancouver could be endangered by an eruption of Mount Baker if an easterly wind were to carry ash towards the city. It is unlikely that lava or mudflows would endanger Vancouver because of the distance involved and the hilly ground over which they would have to travel.

INVESTIGATION 17

Objectives: After completing this exercise, the student should be able to:

a) Describe the origin of igneous and metamorphic rocks.

b) Identify a number of igneous and metamorphic rocks.

Equipment Required

hand lens or stereo microscope
Materials Required
samples of: granite quartz diorite gabbro
rhyolite andesite basalt
obsidian pumice porphyry
gneiss marble slate
quartzite

Answers to Procedure Questions
A. Igneous rock contains crystals. Sedimentary rocks seldom contain these.
B. The crystals are generally large enough to be seen without a microscope.
C. Usually a hand lens or microscope is required in order to see the crystals in volcanic rock.
E. The clue will depend upon the sample examined. Generally it will involve the lack of layering, or the presence of banding.

Answers to Questions
1. a) Plutonic rocks are formed deep underground.
   b) For plutonic rocks to be exposed, the overlying rocks must be eroded.
2. a) Slow cooling causes the formation of large crystals.
   b) Rocks underground cool more slowly because they are insulated by the overlying rock.
3. Gas bubbles in the original lava form bubbles in pumice.
4. Obsidian cools very rapidly.
5. Andesite is named for the Andes Mountains.
**NARRATIVE 18**

Objective: After reading this narrative, the student should be able to describe the rock cycle.

Teaching Suggestions

Many students tend to think of the surface of the Earth as unchanging. Point out that some changes occur so slowly that they are very difficult to see in a single lifetime. The rock cycle is one of these.

Answers to Questions

1. Igneous rock can be eroded. The resulting sediment may be washed into an ocean where pressure eventually turns it into sedimentary rock.

2. Igneous rock may be heated and squeezed by volcanic action, thereby turning it to metamorphic rock.

3. Plutonic rock could be melted, and the resulting magma forced to the surface of the Earth as lava.

**NARRATIVE 19**

Objective: After completing this exercise, the student should be able to:

a) Describe the causes of earthquakes

b) Describe the Richter and Mercalli scales, and explain the differences between them.

c) Define the areas of high and low earthquake risk in Canada.

Teaching Suggestions

Many students or their parents have experienced earthquakes. Try to obtain descriptions from these people.
Answers to Questions
1. The focus is the place where the rock actually breaks. The epicentre is the point on the surface of the Earth directly above the focus.
2. The Richter magnitude measures only one thing, energy released by the earthquake. The Mercalli intensity changes with distance from the epicentre.
3. Figure 154 shows Mercalli intensity VII. Figure 155 shows intensity X.
5. These cities are found in the following earthquake hazard zones: Vancouver - 3, Prince Rupert - 3, Calgary - 0, Winnipeg - 0, Toronto - 1, Ottawa - 2, Quebec City - 3, Halifax - 1, St. John's - 2.

INVESTIGATION 20
Objective: After completing this exercise the student should be able to explain the principles upon which a seismograph works.

Equipment Required
- model seismograph

Teaching Suggestions
Before starting this exercise, try to show at least one film about earthquakes. Most of these films have sequences showing seismographs operating. Use these sequences as an introduction to this investigation. Model seismographs are notoriously difficult to operate. Unless you have an unusually capable class, it might be better to perform this investigation as a demonstration.
Answers to Procedure Questions

A. When pulled slowly, the paper causes the book to move. If the paper is given a quick jerk, the book will not move.
B. The penholder has inertia, and resists moving at first. The table moves underneath the pen.
C. When no earthquake is happening, the seismograph records a straight line.
D. During a small earthquake, the seismograph records a line with small "wiggles".
E. During a strong earthquake, the seismograph records a line with violent "wiggles".

Answers to Questions

1. a) Inertia is resistance to rapid changes in motion. b) A seismograph uses inertia to hold the pen still, while the earth moves beneath it.
2. To record back and forth motion, rotate the position of the seismograph 90°.
3. Try mounting the seismograph on springs, while the paper is still attached to the ground.

INVESTIGATION 21

Objective: After completing this exercise, the student should be able to use seismograms to locate the epicentre of an earthquake.

Materials Required

2 coil springs (slinky) full page copy of Figure 80
Teaching Suggestions

Despite a first impression of difficulty, most students can be taught how to use seismograms to locate the epicentre of an earthquake. The point to be stressed is that this is one of the first steps in analysing an earthquake that "real" scientists carry out at the Pacific Geoscience Centre. Of course, their studies go much further, but the initial steps can be learned quite easily by a student in Grade 10.

Answers to Procedure Questions

A. The compression travels down the length of the spring. Each coil moves back and forth in the same direction as the spring. Each coil causes the next to move by pushing upon it, then rebounding to its original position.

C. The wave travels down the length of the spring. Each coil moves sideways across the spring. Each coil causes the next one to move by dragging it sideways, then rebounding to its original position.

E. The P-wave travels faster, and arrives at the other end of the spring first.

F. The entire trace is 53 seconds long.

G. The strongest waves were recorded at Port Alberni at 02h 48m 45.8s.

I to 0.

<table>
<thead>
<tr>
<th>Station</th>
<th>P-wave</th>
<th>S-wave</th>
<th>Travel time</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victoria</td>
<td>48m34.3s</td>
<td>48m44.0s</td>
<td>9.7s</td>
<td>85 km</td>
</tr>
<tr>
<td>Port Alberni</td>
<td>48m35.5s</td>
<td>48m45.6s</td>
<td>10.1s</td>
<td>89 km</td>
</tr>
<tr>
<td>Haney</td>
<td>48m33.9s</td>
<td>48m43.0s</td>
<td>9.1s</td>
<td>81 km</td>
</tr>
</tbody>
</table>
0. The earthquake's epicentre was located in the middle of the Strait of Georgia, on almost a direct line between Haney and Port Alberni.

Answers to Questions
1. a) An earthquake in Vancouver would probably cause more damage and injury than one at Williams Lake.
   
   b) An earthquake at 2:00 p.m. Tuesday would probably cause more injury than one at 7:00 a.m. Sunday.
2. An earthquake occurring in a large city when many people are congested into a small number of crowded buildings would probably cause more destruction than an earthquake occurring in a rural area when people are at home, spread out into a large number of small buildings.
3. This earthquake was located in the Pacific Ocean, just west of the Strait of Juan de Fuca.
4. This earthquake was located in the U.S.A., south of Haney.

INVESTIGATION 22
Objectives: After completing this exercise, the student should be able to describe the locations of major fault zones in British Columbia and around the world.

Materials Required
   full page copies of Figures 183 and 184

Teaching Suggestions
   Stress the point that scientists do not locate earthquakes just for the sake of locating earthquakes. They look for a pattern in order to predict where earthquakes are likely to occur in the future.
Answers to Procedure Questions

C. Seattle is subject to earthquake hazard.

Answers to Questions

1. Earthquakes seem to occur more in some areas than in others.

2. The earthquake zones are similar to the volcano zones.

3. a) This is a matter for debate.

INVESTIGATION 24

Objective: After completing this exercise, the student should be able to describe the topography of the floor of the North Atlantic Ocean.

Materials Required

- one sheet of millimetre graph paper

Teaching Suggestions

Many students have the mistaken idea that the sea floor is flat and featureless. Use this exercise to convince them otherwise. Point out that as we continue to use up the resources of the land, we must learn more about the seas if our civilization is to continue to thrive.

Answers to Procedure Questions

A. The ocean floor is mountainous. The mountains are generally located in the centre of the ocean, while the deep flat areas are located along their edges. The shallow flat areas are located along the edges of continents.

F. The shape of the Atlantic Ocean floor is generally symmetrical.
Answers to Questions
1. The Mid-Atlantic Ridge is about 16,000 km long.
2. Most river sediment is deposited on the continental shelf.
3. Scientists might obtain rock samples from the ocean floor by using a submarine or a ship mounted drill.

NARRATIVE 25
Objective: After reading this narrative, the student should be able to describe some of the evidence used by Alfred Wegener to support the theory of continental drift.
Teaching Suggestions
Stress again that geologic processes can happen so slowly that they are not discernible in a human lifetime.

Answers to Questions
1. Evidence of cities dredged from the ocean floor would probably suffice.

INVESTIGATION 26
Objective: After completing this exercise, the student should be able to describe the accuracy of the jigsaw fit of the continents bordering on the Atlantic Ocean.
Materials Required (per student)

- Full page copies of Figures 187 and 188
- 2 sheets of 1 cm graph paper
- glue
- scissors

Teaching Suggestions
Warn the students that they should keep the continents in the same relative positions that they occupy today.

Answers to Procedure Questions
D. The edges of the continental shelves provide a better fit
than the edges at present day sea level. A supporter of the theory of continental drift would choose the edge of the continental shelf as the "true" edge of the continent.

Answers to Questions

1. The apparent symmetry of the continental edges made scientists think that these continents might once have been joined.

2. Discovery of the continental shelves supported this theory by providing a better fit.

3. a) During the ice age, the sea level was lower than it is today.

   b) There is no reason why the present sea level should be considered the true edge of the continents.

4. a) The Mid-Atlantic Ridge runs down the centre of the Atlantic Ocean.

   b) These mountains are volcanic rock.

   c) Lava is filling the gap.

INVESTIGATION 27

Objectives: After completing this exercise, the student should be able to:

   a) Describe how the Earth's magnetic field can be recorded in rock.

   b) Describe the magnetic pattern recorded on the floor of the Atlantic Ocean.

   c) Describe how this magnetic pattern supports the theory of continental drift.
Materials Required (per class)

- set of compasses
- 5 boxes
- 5 bar magnets
- 10 file cards
- set of full page copies of Fig. 191

Teaching Suggestions

For demonstration purposes, place one bar magnet in each box, taped into position. Pile the boxes one on top of the next so that the magnetic polarities alternate. Before presenting the demonstration to the class, test it yourself.

Answers to Procedure Questions

B. Over long periods of time, the direction of the Earth's magnetic poles has reversed.
C. Reversal of the magnetic poles may have occurred between deposition of successive layers of lava.
E. The youngest rocks are located close to the centre of the pattern. The oldest rocks are located at the edges of the pattern. If the processes of ocean floor spreading and magnetic reversal continue, the pattern will look similar but wider.
G. The Mid-Atlantic Ridge is located along the line of present day rock. Farther from the ridge, the rocks are older. The rock at station 31 is younger than 8 million years. At station 28 - older, station 15 - younger, station 25 - older than 8 million years. The ocean floor is moving outwards at 90° to the Mid-Atlantic Ridge.
H. The distance from the ridge to one set of 8 million year old rocks is approximately 80 km, or 80 000 000 cm. The ocean floor is moving at approximately 1 cm per year.
The ocean floor is spreading at 2 cm per year. In 90 years, the ocean will be about 180 cm wider.

Answers to Questions

1. If Europe and North America were once joined, the pattern of magnetic reversals should continue to the edge of the continental shelf.

2. The patterns match because they were formed in the same place at the same time, then spread apart.

3. The patterns match because they formed in the same place at the same time, then spread apart.

4. a) It is approximately 3400 km from Canada to Europe.
   b) This calculation shows a time of 170 000 000 years since Canada and Europe split apart.

NARRATIVE 28

Objective: After reading this narrative, the student should be able to describe how the phenomenon of "polar wandering" supports the theory of continental drift.

Teaching Suggestions

This narrative should be used as supplementary reading for the more able students.

NARRATIVE 29

Objective: After reading this narrative, the student should be able to:

   a) Describe the causes of plate movement
   b) Describe the types of landforms produced at plate boundaries.
Teaching Suggestions

This narrative may be used not only as a discussion of plate tectonic theory, but as an example of how scientific theories are modified as new evidence becomes available.

Answers to Questions

1. The six largest plates are the Pacific, American, African, Eurasian, Indian - Australian, and Antarctic plates.
2. The Nazca plate is separating from the Pacific plate along the East Pacific Ridge.
3. The Pacific plate is subducting beneath the Phillipine plate along the Marianas trench.
4. Many volcanoes are found in Iceland because it is located on the Mid-Atlantic Ridge where magma is pushing two plates apart.
5. The Arabian and the Eurasian plates caused the 1978 earthquake in Iran.
6. The Queen Charlotte fault lies between the Pacific and the American plates.

INVESTIGATION 30

Objectives: After completing this exercise, the student should be able to describe how earthquakes may be used to determine a plate boundary.

Equipment Required

World Seismicity Map Copy of Figure 198 (per student)

Teaching Suggestions

The World Seismicity Map may be obtained from the U.S. Geologic Survey at a cost of $1.50.
Answers to Procedure Questions
A. The dots represent earthquakes of magnitude 4.5 to 8.0 during the years July 1963 to December 1972. The circles represent earthquakes of magnitude greater than 8.0 during the years 1897 to 1972.
B. Red represents shallow earthquakes, green intermediate, and blue deep.
C. Figure 197 represents the Mid-Atlantic Ridge, and Figure 195 represents the Himalaya Mountains.
E. Inland from the coast, the earthquakes become deeper. Figure 196 best shows what is happening in South America. Here, the Nazca plate is being subducted beneath the American plate, pushing up the Andes Mountains.

Answers to Questions
1. Subduction on the west coast of South America is taking place along the Peru - Chile Trench.
2. When this magma finds its way to the surface, it produces a volcano.
3. Students have no basis for a "correct" answer to this question. The best compromise would be a combination of Figures 194 and 196

NARRATIVE 31
Objective: After reading this narrative, the student should be able to describe plate movement along the San Andreas Fault.
Teaching Suggestions
Many students will have already heard of the San
Andreas Fault. This narrative gives them some factual material upon which discussion may be based. Use the narrative to raise the question of whether or not people should be allowed to live in earthquake zones.

Answers to Questions
1. All answers are highly speculative, and subject to personal opinion.

NARRATIVE 32

Objective: After reading this narrative, the student should be able to describe plate movement near British Columbia, and use it to explain a number of coastal landforms.

Teaching Suggestions

All the information contained in this narrative is of fairly recent origin. As research continues, some details may change. Use this to point out what earth scientists are doing in British Columbia right now.

Answers to Questions
1. The collision between a block of land on the Pacific plate, and the stationary American plate could cause mountains to be pushed up.
2. a) A plate subducting rapidly would produce more magma than one subducting slowly.
   b) Since the Juan de Fuca plate is subducting more rapidly and thus producing more magma than the Explorer plate, the volcanoes above it should be more active.
NARRATIVE 33
Objective: After reading this narrative, the student should be able to describe the importance of mining to British Columbia.

Teaching Suggestions
If you live in an area where mining is of particular importance, this narrative could be used as a starting point for a study of this facet of community life.

INVESTIGATION 34
Objective: After completing this exercise, the student should be able to perform the common field identification tests upon mineral specimens.

Equipment Required (per class)
- streak plates
- glass plates
- knives
- steel files
- samples of: sulphur, garnet, magnetite, chromite, hematite, chalcopyrite, quartz (massive), limonite, feldspar, fluorite, talc, galena, barite, pyrrhotite, calcite (crystal), mica, gypsum, pyrite, quartz crystal, pyrite crystal, galena crystal, tourmaline crystal, skutterudite, molybdenite.

Teaching Suggestions
This exercise is best set up as a number of "stations" through which the student progresses. The number of stations and hence the number of specimens required will depend upon the individual preference of the teacher. Most specimens, with the exceptions of sulphur, calcite crystal, and pyrite crystal are in the Prospectors Set of Minerals, available
for a nominal charge from the Geologic Survey of Canada.

Answers to Procedure Questions

Refer to any good reference book on rocks and minerals. Specific answers depend upon the exact specimen tested.

Answers to Questions

1. A mineral is a naturally occurring element or compound.
2. a) Granite is made up of a number of minerals.
   b) A rock is a mixture of mineral crystals.
3. Colour is the shade of a bulky piece of mineral. Streak is the shade of a thin layer of powdered mineral.
<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbestos gauze</td>
<td>1 per class</td>
</tr>
<tr>
<td>Beaker, pyrex, 250 mL</td>
<td>1 per group</td>
</tr>
<tr>
<td>Beaker, pyrex, 600 mL</td>
<td>1 per group</td>
</tr>
<tr>
<td>Box, cardboard, small</td>
<td>5 per class</td>
</tr>
<tr>
<td>Burner, bunsen</td>
<td>1 per class</td>
</tr>
<tr>
<td>Cardboard, sheet</td>
<td>1 per class</td>
</tr>
<tr>
<td>Compass, geometric</td>
<td>1 per group</td>
</tr>
<tr>
<td>Compass, magnetic</td>
<td>1 per group</td>
</tr>
<tr>
<td>Dropper bottle</td>
<td>2</td>
</tr>
<tr>
<td>File cards</td>
<td>10</td>
</tr>
<tr>
<td>Glass plate, 10 cm square</td>
<td>1 per group</td>
</tr>
<tr>
<td>Graph paper, 1 cm</td>
<td>1 per group</td>
</tr>
<tr>
<td>Hand lens (or stereo microscope)</td>
<td>1 per group</td>
</tr>
<tr>
<td>Knife</td>
<td>1 per group</td>
</tr>
<tr>
<td>Magnet, bar</td>
<td>5 per class</td>
</tr>
<tr>
<td>Metre stick</td>
<td>1 per group</td>
</tr>
<tr>
<td>Paper tape (ticker tape)</td>
<td>1 roll per class</td>
</tr>
<tr>
<td>Platform balance</td>
<td>1 per group</td>
</tr>
<tr>
<td>Ring stand with ring</td>
<td>1 per class</td>
</tr>
<tr>
<td>Seismograph model</td>
<td>1 per class</td>
</tr>
<tr>
<td>Slinky (coil spring)</td>
<td>1 per group</td>
</tr>
<tr>
<td>Steel file</td>
<td>1 per group</td>
</tr>
<tr>
<td>Streak plate</td>
<td>1 per group</td>
</tr>
<tr>
<td>Coloured pencils</td>
<td>1 set per group</td>
</tr>
<tr>
<td>Item</td>
<td>Quantity</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Hydrochloric Acid (conc.)</td>
<td>1 L</td>
</tr>
<tr>
<td>Pebbles (pea size)</td>
<td>2 kg</td>
</tr>
<tr>
<td>Sand</td>
<td>2 kg</td>
</tr>
<tr>
<td>Silt</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossils</td>
<td></td>
</tr>
<tr>
<td>Ammonite</td>
<td></td>
</tr>
<tr>
<td>Angiosperm leaf</td>
<td></td>
</tr>
<tr>
<td>Brachiopod</td>
<td></td>
</tr>
<tr>
<td>Crinoid Stem</td>
<td></td>
</tr>
<tr>
<td>Rocks (hand size)</td>
<td></td>
</tr>
<tr>
<td>Andesite</td>
<td></td>
</tr>
<tr>
<td>Basalt</td>
<td></td>
</tr>
<tr>
<td>Breccia</td>
<td></td>
</tr>
<tr>
<td>Chert</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td></td>
</tr>
<tr>
<td>Conglomerate</td>
<td></td>
</tr>
<tr>
<td>Dolomite</td>
<td></td>
</tr>
<tr>
<td>Gabbro</td>
<td></td>
</tr>
<tr>
<td>Minerals (thumb size)</td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td></td>
</tr>
<tr>
<td>Calcite (crystal)</td>
<td></td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td></td>
</tr>
<tr>
<td>Chromite</td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Quantity</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Atlantic Ocean Floor (Nat. Geog. Soc.)</td>
<td>1 per group</td>
</tr>
<tr>
<td>World Seismicity Map (U.S. Geol. Survey)</td>
<td>1 per group</td>
</tr>
</tbody>
</table>
RECOMMENDED AUDIO-VISUAL AIDS

16 mm Films (Encyclopedia Britannica Educ. Corp.)
1. Earth in Change
2. Earthquakes: Lesson of a Disaster
3. Heartbeat of a Volcano
4. Rock that Originates Underground
5. Rocks that Form on the Earth's Surface
6. San Andreas Fault
7. Volcanic Landscapes
8. Volcanoes: Exploring the Restless Earth
9. Why Do We Still Have Mountains?
16 mm Film (National Film Board of Canada)
1. Face of the Earth

16 mm Film (Moonlight Productions)
1. Fire Under the Sea

35 mm Colour Slides (B.C. Teachers Federation)
1. Lesson Aid M-1 : (103 Geology slides)
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Vancouver Sun (newspaper), March 28, 1964.


ADDENDUM

Part 1
Proposed Curriculum
for Grade 8
INTRODUCTION

Can you imagine a world without water? without air? without sunshine? without even a solid surface upon which to stand? Such places do exist! The planet Mercury has no liquid water, the Moon has no air, Pluto has no sunshine, and Jupiter has no solid surface. Our Earth is the only planet in our solar system which has all of these. In this unit you will learn more about the surface of our planet, and about some of the forces which cause it to change.
Before a geologist travels into an area to look at the rocks, he first examines a topographic map. Topographic maps are made from photographs taken from aeroplanes. They show only the surface features of the land—mountains, rivers, forests—and man-made objects—roads, buildings. They do not tell us anything about the rocks. In the next few Investigations, you will look at some of the things which may be learned from a topographic map of part of southwestern British Columbia.

Questions

1. Why do you suppose that topographic maps are made from aerial photographs rather than from notes and measurements made by people on the ground?

2. Why do you suppose that topographic maps must be revised much more frequently than geologic maps?

INVESTIGATION 9 The Legend on a Map

The legend. Most topographic maps cover quite a large area of the country. Although it is possible to show individual roads and buildings, there is usually not enough room to describe or name each in printed words. Instead, map-makers use a set of standard symbols. The table explaining the meaning of each of these symbols is called the legend. In this Investigation, you will learn to use the legend on a topographic map.
Purpose: to use the legend on a topographic map

Procedure
A. Examine the legend on the back of the map, showing the meaning of the various symbols, then answer the following questions about the Port Moody area.

1. What do these colours represent when they cover a large area of the map: blue, green, white, red?

2. Draw and label the symbols which represent a: school, church, post office, mine, quarry, navigation light.

3. Draw and label the symbols which represent a: four lane freeway, trail, single track railway, double track railway, power transmission line, city boundary.

4. How many of each of the following are found within the city boundaries of Port Moody? Schools, churches, sawmills, mines, oil refineries, wineries, post offices, navigation lights?

Conclusion
What did you learn about maps in this Investigation?

INVESTIGATION 10  The Scale of a Map

The scale. A one page map of Canada could not possibly show the position of your school accurately. A map large enough to show your school could not easily show the whole of Canada. Maps are drawn to different scales, depending upon how much area has to be covered, and upon how much detail has to be shown.

Purpose: to use the scale on a topographic map.
Fig. 101b A small scale map covers a large area, but can not show very small details.

Fig. 102 A medium scale map is able to show more detail than the small scale map.
Fig. 103 A large scale map covers a very small area, but is able to show details which are too tiny to be seen on small scale maps.
Procedure
A. Examine the scales on the lower edge of your map, then answer the following questions.

1. Map scale is frequently given as a ratio such as 1:250 000. This would mean that 1 cm on the map represents 250 000 cm on the ground. What is the scale of your map?

2. The scale may also be shown as an actual measurement, which may look like this:

```
1000 0 1000 2000 3000 4000
```

Metres

On older maps, this scale shows feet or miles. Newer maps show metres or kilometres. Make a neat sketch of the scale (or scales) shown on your map.

3. To use the scale, you need a piece of paper with at least one straight edge. To find the distance between two landmarks, place the paper so the edge touches both, and make a small mark by each. Then move the paper to the scale and estimate the distance between the two marks.

On the map of the Port Moody area, find the approximate distance in metres between the following pairs of landmarks.

a) Turtle Head to Roche Point.

b) Jug Island to Lone Rock.

c) The length of the underground aqueduct (water tunnel) between Coquitlam Lake and Buntzen Lake.

d) The length of Como Lake.

e) The width of the narrowest part of Indian Arm.

f) The distance from this school to the point where Noons Creek flows under a railway track.
g) The width of the inlet, from Reed Point to Sunnyside Beach.

h) The approximate length of Mossom Creek.

i) The approximate length of Indian Arm, from the Indian River to Burrard Inlet.

j) Find the approximate area of Croker Island. (Multiply length by width).

Conclusion

What is the scale on a map used for?

INVESTIGATION 11 Altitude on a Map

Altitude. Topographic maps are used to show the height of the land above sea level at various locations. This height is called the altitude. This is done either by giving a point altitude, or by tracing contour lines. On older maps, these altitudes are given in feet. On newer maps they are given in metres.

Purpose: to determine the altitude of various landmarks by using a topographic map.

Procedure

A. A point altitude is usually used for a mountain peak or a lake. It is shown as a small number printed beside the peak, or on the surface of the lake. Make a list showing the altitude of these landmarks:

- Buntzen Lake
- Burwell Lake
- Mount Bishop
- Mount Elsay
- Mount Burke
- Coquitlam Mountain
- Widgeon Peak
- Golden Ears
Mount Seymour  Coquitlam Lake  
Seymour Lake  
The unnamed peak about 3000 metres southwest of the north end of Coquitlam Lake.

B. **Contour lines** are lines printed on the map, usually light brown in colour. They connect together all the locations at a particular altitude. For instance, all the points 100 metres above sea level would be connected by a contour line. All the points 200 metres above sea level would be connected by another contour line. Likewise, 300 metres, 400 metres, and so on. Where the land is very steep, the contour lines appear very close together on the map. Where the land is almost flat, the contour lines are quite far apart. Make a list showing the altitude of these landmarks:

<table>
<thead>
<tr>
<th>Location</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eagle Mountain</td>
<td>Hill N of Burns Point</td>
</tr>
<tr>
<td>Burnaby Mountain</td>
<td>Hill E of Bedwell Bay</td>
</tr>
<tr>
<td>Capitol Hill</td>
<td>Gopher Lake</td>
</tr>
<tr>
<td>Mount Felix</td>
<td>Croker Island</td>
</tr>
<tr>
<td>Cypress Lake</td>
<td>Moody Jr. Sec. School</td>
</tr>
<tr>
<td>Cypress Mountain</td>
<td>Sheridan Hill</td>
</tr>
<tr>
<td>Dennett Lake</td>
<td>Mount Dickens</td>
</tr>
<tr>
<td>Obelisk Peak</td>
<td>Mike Lake</td>
</tr>
<tr>
<td>Coquitlam Island</td>
<td>Widgeon Lake</td>
</tr>
</tbody>
</table>

Questions.

1. If a person were able to hike along the course of a contour line, would he be walking uphill, downhill, or level?
2. Why can contour lines on a map never cross each other?

3. What contour line or point altitude would you expect to find at sea level?

Conclusion

What information have you learned to obtain from maps in this exercise?

INVESTIGATION 12 Drawing a Land Profile from a Map

Profiles. Contour lines on topographic maps can also be used to help draw a sideways view, or profile of the land surface.

Purpose: to use contour lines to help draw a profile of the land surface.

Procedure

A. Examine Figure 104 showing how to draw a profile. Use the same method to draw a profile of the land surface from the south end of Raccoon Island to the dam at the south end of Coquitlam Lake. Use the 500 foot contour lines when making your marks.

B. On your finished profile, label the locations of Indian Arm, Buntzen Ridge, Buntzen Lake, Eagle Mountain, and Coquitlam Lake.

Conclusion

In this Investigation, what did you learn to do with a topographic map?
Figure 104. How to draw a profile from a contour map.
<table>
<thead>
<tr>
<th>4000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>3500</td>
<td>3500</td>
</tr>
<tr>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>2500</td>
<td>2500</td>
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<td>1000</td>
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<tr>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 105. Outline sheet for drawing profile.
The surface of our Earth is constantly changing. Many powerful forces are working to wear it down. Trees break rocks apart, rain washes dirt downhill, and wind blows dust away. Fortunately, other forces are working equally hard to build up the surface, otherwise the Earth would be completely flat! Volcanoes pile up lava, and collisions between the slowly moving continents crumple the surface to make mountains. In this section, we will study weathering and erosion, the forces which break down the Earth's surface.

NARRATIVE

Weathering

Weathering is the process by which large pieces of rock are broken down into smaller pieces of rock. The forces which weather rock are classified into three groups:

a) **Physical weathering** is the process of wearing away rock by non-living things. The actual chemical makeup of the rock is not changed. The rock is simply ground down into smaller pieces. For example, rain and wind can wear rock away.

b) **Chemical weathering** is the process of breaking the rock down chemically. As an example of chemical weathering, rocks which contain iron will eventually rust.

c) **Biological weathering** is the breaking down of rock by living things. For example, tree roots can split rocks apart. (Janes, 1976)
Fig. 106. Physical weathering near Oliver, B.C. Soft shale is weathering out from between layers of harder sandstone.

Fig. 107. Chemical weathering in the Yukon Territory. The stains on the mountainside are caused by chemical weathering of metal ore deposits.
Fig. 108. Biological weathering. Tree roots are able to split apart layers of rock.
Questions
1. List three ways in which non-living things can weather rock.
2. List three ways in which living things can weather rock.
3. A plant called a lichen releases small amounts of acid which weather rock. What kind of weathering does this represent?

INVESTIGATION 14  Rock Weathering
Purpose: to study weathering of rock.
Procedure
A. Write the term "weathering" and its meaning in your notebook.
B. (Demonstration) Fill a small glass bottle with water and seal it with a metal screw cap. Put the bottle inside a plastic bag, and place it in a freezer. Wait 24 hours. Describe what has happened to the bottle? Explain why this happened. If something similar happened to a rock, would it be an example of physical, chemical or biological weathering?
C. (Demonstration) Take three pieces of steel wool. Place one in a dry beaker, the second in a beaker half filled with water. Wet the third piece, then place it in a dry beaker. Cover all three beakers. Wait 24 hours. Describe what has happened to each piece of steel wool. Explain why each result occurred. If something similar happened to a rock, which type of weathering would it represent?
D. (Demonstration) Place a small piece of limestone in a weak solution of hydrochloric acid. Wait 24 hours.
Describe what has happened to the limestone. Explain why this occurred. If something similar happened to a rock, which type of weathering would it represent?

E. (Demonstration) Make a mixture of plaster of paris and soaked corn or bean seeds. Allow it to harden. Wait several days. Describe what happens to the artificial rock. Explain why this occurs. Which type of weathering does this represent?

Questions

1. Give two examples of biological weathering not already mentioned in this report.

2. Give two examples of physical weathering not already mentioned in this report.

3. Rainwater dissolves a small amount of carbon dioxide from the air to form a weak solution of carbonic acid. What will this do to limestone?

4. Oil refineries similar to those in Port Moody frequently release gases containing sulphur into the air. These gases dissolve in rainwater to form acids. What might this do to buildings with stone facings?

5. In southern British Columbia, warm days often alternate with cold nights, especially in spring and autumn. Explain how, in a wet climate, this combination of conditions can cause rock to weather rapidly.

Conclusion

What have you learned about weathering in this investigation?
INVESTIGATION 15  Water on the Earth

Water. You drink it, you eat it, you wash with it. If you have a mass of 50 kilograms, your body contains between 30 and 35 kilograms of water (Otto et al, 1977). You could not live without water. Without water there would be no oceans, lakes or rivers, no clouds in the sky, no rain or snow, no glaciers or icebergs. No living things (as we know them) could exist on Earth. Our planet would be one gigantic desert, hot, rocky and dry. In this investigation, you will study how water moves from one part of the Earth to another.

Purpose: to examine how water moves from one place to another on the Earth.

Procedure
A. Make a sketch of the apparatus which represents the Earth. Label each part of your sketch.
B. What do these parts of the model represent on the real Earth: a) light bulb  b) ice tray  c) water in the bottom of the tank  d) rocks?
C. What do you observe forming on the glass beneath the ice tray? How does the water return to the bottom of the tank? What natural process does this represent?
D. What do you observe forming on the sides of the tank? How does water travel upwards from the bottom of the tank? On Earth, what causes water to travel upwards from the ocean into the atmosphere? How does water travel from the clouds back to the earth? In what form does water travel from the clouds back to the earth if the temperature is
less than 0°C?

E. Water is found in many different places on Earth. These places are called reservoirs. A few reservoirs are named below.

- atmosphere
- lakes
- glaciers & ice sheets
- streams & rivers
- oceans
- soil moisture
- biosphere (living things)
- ground water

Figure 109. Water reservoirs

F. Using a full page, copy the diagram from Figure 109 into your notes. Draw an arrow from "oceans" to "atmosphere" and label it "evaporation". This is the process by which water travels from the oceans to the atmosphere. Next draw an arrow from "atmosphere" to "lakes". Label this arrow with the name of the process which moves water from the atmosphere to a lake.

G. Draw more arrows on your diagram, labelling each one as you go. When you are finished, you must have at least one
arrow entering each box, and at least one arrow leaving each box.

Questions

1. Estimate how much water you use each day.

Hints: 1 toilet flush = 30 litres
       1 dishwash (by hand) = 18 L
       1 bath = 110 L
       1 short shower = 75 L
       1 "glass" of water = 0.25 L
       1 tooth-brushing with water left running = 1.5 L
       1 washing machine load of laundry (estimate your share of the load) = 175 L

2. Multiply your answer to Question 1 by 365. How much water do you use in a year?

3. Multiply your result for Question 2 by 22 000 000, (the approximate number of people in Canada). How much water do Canadians use in one year? Note that your result only accounts for personal use of water. Industry uses much more. For example, it takes 120 000 litres of water to produce 1 tonne of steel.

Conclusion

What did you learn about movement of water in this Investigation?
The Hydrologic Cycle

In Investigation 15, you learned how water is constantly moving from one reservoir to another. This movement of water is called the hydrologic cycle. During a year, huge amounts of water move through various parts of the cycle. These amounts are estimated in cubic kilometres (km$^3$). A cubic kilometre of water is like a huge tank, one kilometre long, one kilometre wide, and one kilometre high. It contains 1 000 000 000 cubic metres of water. This is equivalent to 1 000 000 000 000 litres of water.

Each year, about 361 000 km$^3$ of water evaporate from the ocean. At the same time, about 62 000 km$^3$ evaporate from the land. Most of this water falls back into the ocean as rain, but 99 000 km$^3$ falls back on the land. Notice that the amount of water falling on the land is greater than the amount of water evaporating from the land. The extra 37 000 km$^3$ annually flows and seeps from the land back into the ocean.

Much of the water evaporated from the land is first used by plants and animals. A field of wheat may use an amount of water equivalent to a layer 45 to 60 centimetres deep over the field. Trees use even more water than wheat. Along the British Columbia coast, well known for being wet, a forest of Douglas fir may annually pump into the atmosphere the equivalent of a layer of water 1.2 metres deep over its area.

Glaciers store large amounts of water on land. If the
present glaciers were to melt, sea level would rise about 60 metres! Do you live more than 60 metres above sea level? Most of the heavily populated cities of the Earth would be drowned!

The huge amount of water falling on the land can do an impressive amount of work. The amount of power available has been estimated as nine billion kilowatts. If all this power were used to erode the land, it would be equivalent to having one horse-drawn scraper at work on each 4000 m$^2$ of land, day and night, all year long. Imagine the amount of work that could be done! Of course, a lot of this energy is wasted. All the same, water does in fact carry worn down rock to the sea almost as fast as if horse-drawn scrapers were at work on small plots of land all over the Earth. (Bloom, 1969).

**INVESTIGATION 17  Simulating Stream Abrasion**

So far, you have learned how water moves about the surface of the Earth, and how it can be involved in weathering rock. In this investigation, you will examine more closely the effect that running water has on the pebbles found on the bottom of a stream.

**Purpose:** to simulate stream abrasion of rock, and to examine its effect upon limestone.

**Procedure**

A. Copy this data table into your report:
B. Choose between 100 and 200 grams of rock. Set aside one piece for later comparison.

C. Use the balance to weigh the rocks. Record the result in your data table.

D. Place the rocks in the container, half fill it with water and put the lid on tightly.

E. Shake the container 100 times. Remove the rock, rinse each piece and blot off the excess water with a paper towel. Reweigh the rock and record the result in your data table.

F. Repeat Procedures D and E four more times, (a total of 500 shakes), making sure to record your data after each shaking.

G. Put the pieces aside to soak for 24 hours, then repeat Procedures D, E, and F an additional five times, (an additional 500 shakes).

H. Draw a graph of your results
Questions

1. Why do you suppose the pieces of rock were left soaking in water for 24 hours before you started the experiment?
2. Choose three pieces which have been shaken 1000 times, and compare them with the piece set aside in Procedure B. Describe the differences, and sketch all four pieces.
3. Estimate the number of shakes required to wear the rock away completely.
4. List the causes of the rock wearing away.
5. List the changes in the rocks caused by the abrasion.
6. During which season of the year is stream abrasion most likely to occur? Give a reason for your answer.

Conclusion

What causes rocks to be worn down by a stream?
Weathering breaks rocks into smaller pieces, and these pieces may be washed away by running water. The pieces of broken and ground up rock are called sediment. Sediment may be in the form of large boulders, or it may be ground up finer than flour. Rivers may carry sediment in three different ways:

1) **Bed load.** This consists of rocks, pebbles and sand which are pushed and rolled along the bed of the stream. These pieces of sediment are too large and heavy to be picked up and carried by the water.

2) **Suspended load.** This material is carried by the water, above the bed of the stream. The pieces of suspended load are usually much smaller than the pieces of sediment in the bed load.

3) **Dissolved load.** Sediment which is actually dissolved in the water. It is invisible.

The amount of sediment carried by a large river can be enormous. The Fraser River carries an average of about 55 000 tonnes of sediment each day, or about 20 million tonnes each year. The sediment load of the Fraser is however, dwarfed by the load of the Mississippi River. Each year, the Mississippi carries about 750 million tonnes of sediment to the sea! (Janes, 1976)

Questions

1. Where does the sediment carried by a river eventually end up?
2. List three things which could affect the amount of sediment carried by a river.

INVESTIGATION 21  Measuring Sediment

When studying a river, scientists frequently measure the amount of sediment that it carries. In this investigation, you will study the method that they use.

Purpose: to measure the amount of suspended and dissolved sediment carried by a river.

Procedure
A. Set up the filtering apparatus as shown in Figure 110.
B. Copy this data table into your report.

<table>
<thead>
<tr>
<th>Determination of suspended sediment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of filter paper + sediment</td>
<td>___g</td>
</tr>
<tr>
<td>Mass of filter paper</td>
<td>___g</td>
</tr>
<tr>
<td>Mass of suspended sediment</td>
<td>___g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Determination of dissolved sediment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of evaporating dish + sediment</td>
<td>___g</td>
</tr>
<tr>
<td>Mass of evaporating dish</td>
<td>___g</td>
</tr>
<tr>
<td>Mass of dissolved sediment</td>
<td>___g</td>
</tr>
</tbody>
</table>

C. Measure the mass of the filter paper and record it in your data table. Use a pencil to write your initials on the filter paper. Measure the mass of the evaporating dish, and record this also in your data table.
D. Fold the filter paper and place it in the funnel.
Figure 110. Filtering apparatus for Investigation 21.
Fig. 111. A braided stream in the Yukon Territory. (Photograph courtesy of D. Kelly).
Moisten the paper with a few drops of water to hold it in place.

E. Remove a beaker of water from the bucket of river water. Before the sediment settles to the bottom of the beaker, measure out 20 mL of water into the graduated cylinder. Pour the 20 mL into the filter paper. If any sediment is left in the graduated cylinder, wash it into the filter with a little clean water.

F. When all the water has drained from the filter, lift the paper carefully from the funnel (it tears easily) and put it in the place indicated by your teacher so that it may dry overnight.

G. Set up a ring stand, asbestos gauze and bunsen burner. Heat the evaporating dish to evaporate the water. If any material spatters out of the dish, reduce the heat quickly by moving the bunsen burner away.

H. When all the water has evaporated and the dish has cooled, weigh it and the dry sediment. Record the result in your data table. Subtract to find the amount of dissolved sediment in your water sample.

I. When your filter paper is dry, weigh it and record the result in your data table. Subtract to find the amount of suspended sediment in your water sample.

Questions
1. What was the total amount of sediment in your sample?
2. The average flow of the Fraser River is 2 630 000 litres per second. If the average sediment load is 657 500 grams per second, calculate the average number of grams of
sediment in each litre of Fraser River water. (Remember that even this small quantity of sediment in each litre still moves 20,000,000 tonnes each year!)

3. Why could you not see the dissolved sediment before you evaporated the sample?

4. Figure 11 shows an example of a braided stream. Its load of sediment is so large that the stream channels are frequently blocked, causing the stream to change course.

   a) Is the sediment carried by a braided stream mostly bed load, dissolved load, or suspended load?

   b) During which season of the year will this stream move the greatest amount of sediment? Give a reason for your answer.

Conclusion

In this investigation, what did you learn about finding the amount of sediment in a sample of water?

INVESTIGATION 22 Valley Formation

About one-third of the water which falls on land flows back to the sea in rivers and streams, or seeps through as ground water. The remainder evaporates. Rivers are major changers of the Earth's surface. Some carve narrow canyons and deep gorges. Others form wide fertile valleys and deltas.

In southwestern British Columbia, the Fraser River has produced superb examples of all of these landforms. North of the village of Hope where the river emerges from the mountains, is the Fraser Canyon, one of the best
Fig. 112. A canyon on the Athabaska River near Jasper, Alberta.
Fig. 113. The canyon of the Yellowstone River, Wyoming, U.S.A.
Fig. 114. The Fraser River canyon at Hell's Gate.
Fig. 115. A river once flowed here. Bryce Canyon, Utah, U.S.A.
known scenic regions of Canada. From Hope to the sea, the river flows for nearly 200 kilometres through the wide, flat, Fraser Valley, one of the most productive farming areas in British Columbia. Finally, where the river discharges into the sea is the Fraser Delta, a feeding ground for hundreds of species of fish and birds.

Purpose: to study the formation of valleys

Procedure

A. Examine Figures 112, 113 and 114. How fast do the rivers appear to be flowing? What letter of the alphabet does the shape of the valley in Figure 113 resemble?

B. Set up a stream table with a slope of about 20°. With your finger, make a shallow groove in the sand to direct the water flow in a straight line. Start the water flowing and wait for a few minutes. Does the water cut a wide flat valley or a deep narrow valley? Figure 115 shows a canyon which once contained a river. Did this river probably flow rapidly or slowly?

C. Examine Figures 116, 117 and 118. Do these rivers appear to be flowing rapidly or slowly? Is the Fraser Valley in Figure 116 wide and flat or steep and narrow?

D. Figures 117, 118 and 119 show meandering rivers. These are rivers whose paths wind in wide sweeping curves back and forth across their valleys. Look at the shape of their valleys and state whether the rivers flow rapidly or slowly.

E. Set up a stream table with a slope of about 10°. With your finger, make a shallow groove in the shape of a meandering river. Start the water flowing and wait for
a few minutes. Does the water continue to make a wide
flat valley, or does it start to make a canyon? What
kind of valleys do slow rivers produce?
F. Figure 119 is an aerial photograph of a section of the
bank of a meandering river. The river has washed soil
away from the lower part of the bank, causing the landslide.
If this process continues, the course of the river will
eventually change. Sometimes this happens in such a way
that a section of river channel is cut off, forming a
lake such as those in Figures 117 and 118. This type of
lake is called an oxbow lake. Draw a series of four
diagrams in your notes, showing how changes in the course
of a meandering river can form an oxbow lake.
Questions
1. Water by itself does not wear away rock very easily.
Explain then, how a river is able to erode a deep canyon.
(Recall Investigation 17).
2. Which would a fast river in a deep rock canyon tend
to erode more, the bottom or sides of its valley?
3. Which would a slow river in a wide, flat valley of
soft soil tend to erode more, the bottom or sides of the
river bed?
Conclusion
Summarize this investigation by describing in a
few short sentences how the shape of a valley depends upon
the speed of a river, and by the hardness of the soil or
rock along the sides of the valley.
Fig. 116. The Fraser Valley near Mission, B.C.

Fig. 117. A meandering river and oxbow lake in the Yukon Territory. (Photograph courtesy of D. Kelly).
Fig. 118. Meanders and an oxbow lake on the Parsnip River in northern B.C.

Fig. 119. Landslide on the Takini River in the Yukon Territory. A second landslide is about to occur beside the first. As this process continues, the river gradually changes course. (Photograph courtesy of D. Kelly).
INVESTIGATION 25  Sand

Much of the sediment carried by a large river like the Fraser is in the form of sand. By examining sand, we can learn much about the original rock from which the sediment was formed, even though it may be many kilometres away.

Purpose: to examine a selection of sands

Procedure

A. Copy this data table into your notebook:

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Overall Colour</th>
<th>Colours of Separate Grains</th>
<th>Shapes of Grains (Round or Jagged)</th>
<th>Unusual Features</th>
<th>Original Rock</th>
</tr>
</thead>
</table>

B. Spread a small amount of each sample in a petri dish, and examine it with a magnifying glass or stereo-microscope. Record your observations in the first four columns of your data table.

C. Record your observations from these "unusual features" tests in the fifth column of your table.
   a) Magnetism: test each sample with a magnet.
   b) Life: look for evidence of animal life in each sample.
   c) Acid test: put one drop of dilute hydrochloric acid on each sample.

D. Examine a geologic map of Coquitlam. What kinds of rock
form the mountains surrounding Widgeon Lake? Does your sand sample from Widgeon Creek resemble these rocks in any way? Describe the resemblance. Record the names of these rocks in the last column of your data table, opposite the sample from Widgeon Creek.

E. What kind of rock is black, with very small crystals? Record your answer opposite the black Hawaiian sand.

F. Examine the sample of olivine rock. Describe its appearance. Record the name "olivine" opposite the sand which most closely resembles this rock.

G. The remaining Hawaiian sand is made from the skeletons of once living sea animals and plants which inhabit the coral reefs surrounding the islands. Although it is not really a rock, record the originating rock of this sample as "coral reef".

Questions

1. Why is it reasonable to assume that the makeup of a sand near the mouth of a river is similar to the makeup of the rocks upstream?

2. Why are grains of soft or easily broken minerals seldom found in sands?

3. If the sand which fizzed with acid were crushed and compressed into a sedimentary rock, which rock would it form? If this sedimentary rock were then changed into a metamorphic rock, what would the name of that rock be?

4. Hawaii is famous for its volcanoes. If you did not know this, how could sand samples tell you that the Hawaiian
Islands were volcanic?

Conclusion

What can be learned by studying sand?

NARRATIVE 26

Landslides

Rivers deposit sediment slowly. Landslides deposit sediment very rapidly. The next few pages are excerpts from an account of one of the most famous landslides in Canadian history. In 1903, the town of Frank in southwestern Alberta was wiped out by

THE FRANK SLIDE

Suddenly, there was a horrendous sound high above them, like an almighty, final clap of thunder, as seventy million tons of rock broke away from Turtle Mountain. As it began plummeting down the precipitous slope, it sent a blast of freezing air racing before it.

Like a screaming juggernaut, the rock careened down the mountain side, sweeping over the mine entrance, erasing it entirely; crashing against the mine tipple and hurling Clark, Farrington and Tashigan far out into eternity. It caught the blacksmith shop and the solitary railway car and flung them two miles across the valley, twisting the mine spur tracks like threads of silk. Seconds after the racing engine and its stupefied crew cleared the bridge, the rocks hit one end of the wooden superstructure. Icy water sprayed high into the air as the bridge swung
sideways and then subsided into the Old Man River. By then, however, the rocks were already far across the eastern flats.

Ahead of the deadly rock fall, a solid wall of air raced across the valley, toppling the flimsy houses, shacks and tents, hurling men, women and children hundreds of yards. Those asleep had no time to waken, and those awake never knew what was happening as behind the wind came the churning, grinding mass of rocks which made the night unbelievable with the noise and the sparks as massive boulders leaped high into the air and clashed with each other.

The power plant was obliterated in an instant and the seething mass hurtled out onto the valley floor, splaying out like a fan. While the main stream of rocks shot ahead, smashing the remains of the temporary dwellings; cascading over the livery stable and the Dawes Cabin, the construction camp and the boxcar of dynamite before expending itself over the farm of Alex Graham and the cemetery behind; another spur shot eastward, cascading over the farm of James Graham and the bunkhouse and the two storey farmhouse, burying the buildings with all occupants a hundred feet deep. At the same time, another spur, following with almost fanatical precision the east bank of Gold Creek, pushed an icy wall of gray mud ahead of it and sent it crashing against the row of miners' cottages on the outskirts of Frank. A five hundred ton boulder, drunk with its own power, jumped the creek and spun to rest within the very village itself.
A hundred seconds after its fateful plunge, the biblioclasm of rocks had slid across the valley and come to rest five hundred feet up the opposite slope beyond the tracks.

Over the scene, a swirling mass of grey dust hung like a natural shroud.

It was 4:10 a.m., April 29th, 1903.

Joseph Dobeck, who was oiling engines in the train shed two hundred yards from the disaster, felt the earth shake and heard the monstrous noise. He stepped outside and peered eastward, but could see nothing in the darkness. With a philosophical shrug of his shoulders, he returned to his job.

"Mormon Bill", a well known local character, was standing on the street in front of the Miners' Hotel, cooling off after a strenuous night of poker. He was rocked on his feet by the blast of wind, heard the unholy din, and stood listening. In less than two minutes, all was still. Although all around him men and women were beginning to rush into the street in their night attire, Mormon Bill pulled himself together, wrote the sensations off to too much liquor and went home to his shack to sleep soundly.

John Anderson, a more sedate and methodical man, who had gone to bed at a respectable hour, was awakened by a terrible blast of wind that shook his house from shingles to sub-cellar. Bounding to the window in nightshirt, he was just in time to see what he thought was a cloud of
smoke cascading past his home, only a few scant yards from Gold Creek. Unaware that the smoke, or dust, was actually a sea of limestone hurtling past, Anderson waited until the noise ceased and then went back to bed, unaware that in the morning he would look out of the same window in utter disbelief.

A hundred miles to the north, two young gallants who had just taken their girl friends home after a dance at Cochrane, reined in their team. Both had heard what they thought was the sharp report of a giant rifle being fired in the mountains to the south. They checked their watches and saw that it was 4:10 a.m.

The Entombed Miners

As Joe Chapman and his nineteen men walked up the spur line to the mine entrance that morning of April 29th, 1903, they had no premonition of danger. It was true that strange things had been happening in the mine; two-foot timbers set one night had been found splintered by the day crew, and upraises where the coal had been removed had mysteriously, silently closed overnight. But, these occurrences had taken place four or five months before, and since then the belly of the Turtle had been quiet. There had been a minor earthquake the year the mine opened, but this had had no apparent ill effect. The mine had been relatively free from serious cave-ins or accidents. Two young miners had been killed in a gas explosion the previous October, but it was understood that they had entered the mine
wearing the old style open flame lamps instead of the new safety lights.

Leaving Tashigan at the mine tipple, where he operated the scales and coal washing equipment, the rest entered. The drift mine entered an outcrop of nearly vertical coal seam about thirty feet above the river level. The seam itself, which varied from 9 to 30 feet in width, came from the direction of goat mountain, passed under the town of Frank and went through Turtle Mountain in an almost north and south direction, paralleling the axis of the mountain itself. From the mouth of the mine, the drift rose sharply to a height of nearly twelve hundred feet. Already the mine had been worked back some five thousand feet from the entrance. Because of the nearly vertical nature of the main vein, mining was a simple operation. The coal was merely worked loose and allowed to fall down the incline to the main manway, where it was loaded on the mine cars and hauled by horse to the tipple on the outside.

At one time the mine had employed nearly 300 men in the workings, but in the winter of 1902 nearly 100 of these had been weeded out. The mine was then only operating one day shift, with a night crew for timbering and maintenance purposes.

As they penetrated the mine tunnel, the men dropped off one by one to attend to their duties. Alex Grant and his driver took one of the five horses stationed at the entrance and began checking the trackage. Fred Farrington and Alex Clark took other horses and began hauling out cars
of coal left by the day shift. William Warrington, the timberman, set about his never-ending task of checking the mine timbers, testing them, replacing damaged ones, or setting up new ones.

As the night wore on, lamps glowed dimly in the tunnels and upraises. Men worked alone, or in pairs, occasionally passing one another in the workings, but essentially theirs was lonely work that took them alone to different parts of the workings.

Towards four o'clock, Clark and Farrington took loads of coal out to the mine tipple and sat down to eat their lunches with Tashigan. None of them were ever seen alive again by their companions.

Alex W. Grant and his driver felt a shock, like a severe bump, just after four in the morning. Thinking it was a gas explosion, and fearing that it might be followed by after-damp, they raced towards the mine entrance. The tunnel around them was heaving and twisting, sending down small showers of rock and coal. They reached the end of the tunnel, only to find a shattered mass of timbers and fallen rock. As they gazed in stupification, they were joined by three or four others who came running from the depths of the mine. One man panicked at the sight of the blocked tunnel and turned to flee. As he did so, his foot caught in the tracks, throwing him violently to the ground and wrenching his leg severely. The shock of the pain sobered him abruptly.

Farther back in the manway, Joe Chapman felt the
shudder of the earth. Then, a blast of hot air racing down the tunnel picked him up and slammed him against the side of the passage. When he picked himself up, he ran down the crazily heaving tracks almost a mile to the entrance.

Dan McKenzie, the tall, lean bespectacled Nova Scotian, had been working in an upraise some three quarters of a mile back when the sudden rush of wind, followed by a shower of falling coal, flung him against the side of the mine, cutting his head. Realizing that something unusual had happened, he ignored the wound in his scalp and raced down the manway.

At the blocked exit, trapped and breathless from their frantic dashes for safety, the seventeen miners rested momentarily and then considered their position. One of them, who had worked the mine from its opening day and who knew intimately every inch of the timbering and tracks, examined the inside of their prison and concluded that they were trapped at least three hundred feet from the outside. The news dismayed them, even though some others, more optimistic, felt that they could not be more than fifty or sixty feet back. Leaving Warrington, whose leg had been severely squeezed in the heaving tunnel, the rest made their way to the lower level, hoping to find the exit there still intact, but were shocked to find that the lower manway was already filling with water from the Old Man River. Even as they studied it, they saw that the water was rapidly backing up into the mine.

The mine was deathly quiet and the floor had ceased to
shudder as they made their way back to the entrance where Warrington and the other injured man waited. But, there was consciousness of new dangers. Cut off by the rising water, sealed in by the blocking of the main entrance, they realized that if the air shafts had also been pinched their supply of air would be quickly fouled. It was possible, also, that the upheaval had loosened pockets of gas that would begin collecting in the upper regions of the tunnels.

Maintaining their calm, they returned bravely to their original work spots and got their tools. Once back at the entrance they began methodically to try to drive their way through the shattered timbers and crumpled rocks.

While they were working, Dan McKenzie and two others climbed three hundred feet up ladders to the Nicholson Level as the old workings of the mine were called. While gas was already collecting in the upper level, their investigations also revealed that the air shafts had been completely sealed off by the catastrophe. They had to return in defeat to their comrades below.

The men working at the entrance were making little or no progress against the snarled mass of timber and rocks, and panic began to rise in the throat of each man. At that point, one man took charge. Some say it was Joe Chapman, the foreman; others say that it was Dan McKenzie; while others believe that it was Charlie Farrell. Realizing that a seam of coal outcropped on the mountain some distance back, this man set his mates to digging upward through the narrow seam of coal, believing that they were sufficiently
close to the surface at this point to make such a scheme feasible. There was no certainty as to how far they were from the surface, nor whether they might encounter some insurmountable obstacle; only the growing appreciation that the air was becoming less vital, less able to sustain their efforts.

Despite their cramped quarters, the men kept doggedly at their task, working in relays of two or three at a time. Starting sometime between 8:30 and 9:00 in the morning, they laboured steadily, slowly, painstakingly; giving way grudgingly to rest when others took over. Towards mid-afternoon, three of the miners returned to the main entrance to examine once again the jumble. The impossibility of escape that way became even more impressed upon them.

Under the increasing strain and diminishing oxygen supply, some of the men became excited, others morose. Where in the beginning they had sung songs to sustain their courage, now they were quiet, hoping to conserve the fast faltering supply of air. Towards five o'clock in the afternoon, while men slumped with exhaustion against the mine wall, or sat dejectedly with head in hands, only McKenzie and two other men still persevered.

Suddenly, unexpectedly, McKenzie's pick drove through the hardpan and broke into the open. A beam of brilliant sunlight blinded him and a rush of clean air bathed his face.

The fresh air revived the exhausted men, renewing their hopes and giving them fresh strength and courage. Even though their first opening came at a spot where falling
rocks, still cascading down the mountainside, prevented their escape, they set to work to drive another shaft upwards through the thirty-six feet of coal and clay. Then, thirteen hours after the slide had sealed them in, they broke out into the daylight behind some embedded boulders which shielded them from the minor rock falls.

Dan McKenzie, the first man out, stared in awe and astonishment at the scene below. The slide, plunging down the north slope of the mountain, had fanned out from the base and lay like a stubby-fingered giant's hand of destruction on the floor of the valley. Antlike figures were scrambling over the rocks, searching, searching ... From a broken mass of timbers, where a row of miners' houses had stood, white smoke curled lazily up into the late afternoon sky. Fifty yards below and to the left, a little knot of men were buzzing around the spot where the mine entrance had been.

McKenzie called out and the men looked up and saw him. There was a mad, scrambling rush across the treacherous slope; a joining of hands in the joyous relief from overwhelming tension; and the passage of news.

The seventeen men were hustled down the mountainside and across the makeshift ferry. Since neither Farrington, Clark nor Tashigan were among them, the tabulators had to add their names to the growing casualty list. A waiting wagon carried Warrington up the main street, where eager photographers were on hand to snap pictures of the little cavalcade, and across the flat to Dr. Malcolmson's hospital.
While the other miners sought out friends or relatives, one or two stopped gratefully at a hotel bar to wet throats still dry from fear and thirst.

Miracles are seldom worked by one person alone, and the escape of the miners entombed in the belly of the Turtle was no exception. It had taken an ingenious and daring suggestion to lead them out, but it had taken the courage and strength of all seventeen to follow that plan. To that ingenuity and courage, they all owed their lives.

Reprinted from
"The Frank Slide Story"
by Frank W. Anderson.

Questions
1. What was being mined in Turtle Mountain?
2. What type of rock made up Turtle Mountain?
3. Geologists examining the slide afterwards found evidence of large cracks in the mountain above the slide area.
   a) How could water and freezing temperatures have produced and enlarged cracks in the rock?
   b) How could mining in the mountain have helped to cause the slide?
4. If the debris from a landslide were eventually compressed and hardened into a new sedimentary rock, what would be the name of that new rock?
Fig. 120. The Frank Slide. In 1903, 76 people died when a huge mass of limestone swept down from Turtle Mountain.

Fig. 121. The Hope Slide. Fifty million tonnes of rock slid from this nameless mountain in the early morning of January 9, 1965.
How Fossils Are Made

In general, a fossil may be formed when part of an animal or plant is buried in sediment. After burial, a number of different things may happen which will preserve the specimen.

It is possible in some cases that the animal is not changed in any way after burial. This is known as "actual preservation". Many shell fossils found in the Fraser Valley
Fig. 122. These fossil leaves once grew in a forest near Princeton, B.C., about 20 million years ago.

Fig. 123. Ammonite shell. This animal lived in a sea which covered Alberta about 70 million years ago. (Photograph courtesy of B. Poelman).
are preserved in this manner.

Sometimes, minerals from ground water gradually fill in the air spaces in bones. This tends to make the bone heavier, without changing its original shape. Many dinosaur skeletons have been preserved in this way.

In some cases, the ground water dissolves away the original shell or skeleton, one atom at a time, and replaces it with a different material. Wood is frequently "petrified" in this manner when the wood is replaced by silica. If the original shell or bone is dissolved without being replaced, the resulting cavity forms a type of fossil called a "mould". If the mould is later filled in by another material, the fossil is called a "cast". Shells are often fossilized as moulds or casts.

Leaves, which are quite soft, are fossilized by a method called "carbonization". Here, the hydrogen and oxygen atoms from the original material are lost, leaving only the black or brown carbon atoms behind. Figure 122 shows a carbonized leaf.

Tracks of animals may be fossilized when the soft mud in which they are made becomes hardened into rock. Dinosaur tracks from the Peace River area of northeastern British Columbia are displayed outside the Provincial Museum in Victoria.

Certain conditions seem to favour the formation of fossils. First, the animal should have hard body parts like teeth or bones. Next, it should be buried rapidly by fine, moist sediment. Afterwards, the burial site should
remain at a constant temperature, with no rapid freezing or thawing. There should be lots of minerals in the ground water. Considering all this, probably the best place in British Columbia to form fossils at present is the edge of the Fraser delta, preferably at a time when the river is carrying lots of sediment. (Casanova, 1957).

Questions
1. Is there a place near where you live, where fossils might be forming at present?

**INVESTIGATION 32  Dinosaur Study**

Just about everybody has heard about the dinosaurs, those giant reptiles that lived upon the Earth during the Mesozoic Era. In previous years, you have probably studied the habits of some of these animals. In this investigation, you will look briefly at some of the ways in which scientists classify dinosaurs and differentiate among them.

**Procedure**

A. Usual ways of movement.

Copy the data table below into your notes.

<table>
<thead>
<tr>
<th>Runners</th>
<th>Walkers</th>
<th>Swimmers</th>
<th>Flyers</th>
<th>Crawlers</th>
</tr>
</thead>
</table>

Examine the pictures of the dinosaurs in Figures 124 to 139, looking carefully at the legs. List the name of each dinosaur under the heading of your table which best describes the way in which it probably moved.
B. Eating habits.

Examine the pictures of Allosaurus, Tyrannosaurus, Iguanodon and Camptosaurus, Figures 124 to 127.

a) Which part of the body should you look at to decide whether each animal ate plants or other animals?

b) Which of these four dinosaurs appear to be meat eaters, and which appear to be plant eaters?

c) Which were probably walkers, and which were probably runners when gathering food?

C. Defense.

How might each of these animals either avoid attack, or defend itself?

a) Rhamphorhynchus (Fig. 129).

b) Monoclonius (Fig. 133).

c) Tyrannosaurus (Fig. 125).

d) Ankylosaurus (Fig. 131).

D. Size.

Dinosaurs are usually thought of as being giants. This was not always the case, as you can see from the pictures. In each picture, the little girl is supposed to be one metre tall.

a) Which is the smallest dinosaur shown? Estimate its height in metres.

b) Which is the tallest, from the ground to the top of its head? Estimate its height.

c) Which is the longest, from head to tail? Estimate its length.

d) Estimate the wing span of Pteranodon (Figure 130).
Figure 124.
Allosaurus.
(Figs. 124 to 139 after Christman, 1977).

Figure 125.
Tyrannosaurus.
Figure 126. Iguanodon.

Figure 127. Camptosaurus.
Fig. 128. Diplodocus.

Figure 129. Rhamphorhynchus.

Figure 130. Pteranodon.
Figure 131. Ankylosaurus.

Figure 132. Eryops.

Figure 133. Monoclonius.
Figure 134. Eogyrinus.

Figure 135. Brachiosaurus.

Figure 136. Dimetrodon.
Figure 137. Ichthyosaurus.

Figure 138. Hesperosuchus.

Figure 139. Elasmosaurus.
E. Body structure.

Students often confuse Tyrannosaurus with its ancestor, Allosaurus. In fact, Tyrannosaurus did not appear until about 50 million years after Allosaurus became extinct. Examine the pictures of each, (Figures 124 and 125), and describe three major ways in which the bodies of the two animals were different.

F. Bone structure.

Just as the bones of modern animals differ in many ways, the bones of dinosaurs also differed.

a) Which dinosaurs might have had very light, hollow bones? Give a reason for your answer.

b) Why did Brachiosaurus (Figure 135) have very thick, heavy leg bones?

Conclusion

What did you learn about dinosaurs in this exercise?

NARRATIVE 33

Dinosaur Provincial Park

A few kilometres northeast of the city of Brooks, Alberta, is an area where many dinosaur skeletons have been discovered. This area has now been set aside as a public park, where visitors may see how these fossils are removed from the rocks.

The following article describes how Dinosaur Provincial Park might have appeared, 76 million years ago.
A Walk in the Park

How could you live in Dinosaur Provincial Park as it was, 76 million years ago?

The probability of surviving for any length of time would not be very great. If you must go, dress in a long-sleeved shirt and trousers, and wear a mosquito net around your hat, for biting insects will be abundant. Put a knife, machete, cord, light raincoat, hammock and mosquito netting in your knapsack, as well as mosquito repellent and matches. These conveniences will help you in the beginning – enabling you to become familiar with your surroundings and increasing your chances of long term survival. So will a high powered rifle and several hundred rounds of ammunition.

If you are fortunate, you will arrive on a wooded, stationary sand bar near the middle of a broad stream. If not, make your way to the nearest clump of trees where herbivorous dinosaurs are grazing quietly and undisturbed, indicating that there may be no tyrannosaurs in the immediate area. Promptly climb a tall open-branched tree where you can hang your hammock at least 10 metres above the ground. The most dangerous animals for you are the tyrannosaurs, both half-grown and adult, and you must learn their habits as soon as possible. These animals are agile and swift, not the ponderous giants pictured in children's books, and your only realistic hope of escape, once seen, is to climb high in the branches of a tree. They depend on their keen vision to locate their prey, and may be least active at night, particularly during the cool pre-dawn hours.
It would almost certainly be futile to attempt to shoot a tyrannosaur, particularly in the course of an attack. Their brains are very small and are well protected by bone. If the animal were hit in almost any other part of its body, it would not be diverted, even if mortally wounded. Smaller, man-sized carnivorous dinosaurs would also be extremely dangerous, but here there would be some chance for self-defence with the use of the rifle or, at close quarters, a bark shield and machete. Their claws are their most formidable weapons of attack.

When you have examined your immediate surroundings and are thoroughly satisfied that there are no carnivorous dinosaurs nearby, you may descend and explore the area for food. Do not touch plants that have waxen compound leaves like those of poison ivy, for members of this plant family will certainly be present. You may find breadfruit or edible nuts. A more reliable source of food, however, will be turtles and turtle eggs. You may be able to spear sturgeons, but watch for the crocodilians which, though not exceptionally large, may be bold. The different kinds of dinosaurs that live in the region of the Park should be watched carefully. Observe their habits and in what way they might be dangerous to you.

If you can kill an ostrich dinosaur outright, by shooting it in the head or heart so that its body can be recovered without undue risk, you might find their broiled flesh to be excellent. Although wild mushrooms will be plentiful in the woods, it would be best not to eat your
ostrich-dinosaur steak with mushroom gravy. These fungi must be identified precisely in order to separate edible and poisonous kinds, and it is not certain that many modern varieties will be present. The small, relatively intelligent Stenonychosaurus might possibly be domesticated if raised from a hatchling. Of all the creatures present it is the only one that could, to any degree, fill the role of a dog.

Ultimately, you will have to decide whether or not your chances of avoiding tyrannosaurs for long are very great. You would probably be safest in the high, cool mountains to the west, but if you find your situation in the Park precarious, the probability that you could survive a 300 kilometre trek across open terrain would be small indeed. It would be therefore be better to construct a raft of small trees and float 100 kilometres downstream to the cypress swamps near the coast. There you could live within the double protection of the water and the trees, relying on fish for food.

Reprinted from "A Vanished World, The Dinosaurs of Western Canada" by D. A. Russell, National Museums of Canada.

Questions
1. List three things which would make life uncomfortable or dangerous in Dinosaur Provincial Park, 76 million years ago.
INVESTIGATION 34  Dinosaur Extinction

Most people know that at the end of the Mesozoic Era, the last of the dinosaurs died off within a very short period of time. What is not generally known is that at the same time, about $2/3$ of all the species on earth also became extinct! The reasons for this great extinction are still unknown.

Purpose: to invent a theory to account for the extinction of the dinosaurs.

Procedure

Try to think of two different possible causes for this massive extinction, and write a short paragraph explaining each. Remember that you must kill off not only the dinosaurs, but also $2/3$ of all the species of animals, birds and insects on every continent, as well as $2/3$ of all the species of animals, fish and shellfish in every ocean, lake and river.
COQUITLAM RIVER FIELD TRIP

During this course you have studied a great many topics, including rocks, maps, weathering, erosion, sedimentation, deltas, flood plains, landslides, fossils and glaciation. On this field trip you will apply your knowledge of these topics to a study of the Coquitlam River, a typical British Columbia coastal stream. Although the character of the river has been changed by man, it still represents many of the landforms discussed in this course.

Part A (In the laboratory)

On your map of the Coquitlam River (Figure 140), label the following features:

Coquitlam Lake
Watershed gate (Stop #1)
Stops #2 and #3
Pipeline Road
Gravel Pits
Lougheed Highway
Canadian Pacific Railway
Lions Park (Stop #4)
Port Coquitlam
Pitt River Road Bridge
Colony Park Farm (Stop #5)
Fraser River

Part B (In the field)

Stop #1

On the west side of Pipeline Road, just south of the watershed gate is an old landslide. Vegetation now covers it, but the scar is still visible. The slanting trees indicate that the slope is still unstable.

Write a short paragraph giving two possible causes of a landslide in this area.

Stop #2

a) Describe the shape of the valley at this point. (Is it wide and flat with lots of good farmland, or quite narrow
LEAF 355 OMITTED IN PAGE NUMBERING.
with fairly steep sides?).

b) Walk to the river and look upstream and downstream. Does the river flow quite rapidly or very slowly near here?

c) Is the current fastest in the middle or at the sides?

d) Look at the water. Does it appear to be carrying much sediment? Take a water sample. Later, back in the lab, you will analyse the water for sediment content.

e) Describe the size and shape of the rocks in the river bed. How did they become shaped that way? Look closely at the rocks. Are they mostly sedimentary, volcanic, plutonic or metamorphic? Name the most common varieties of rock.

f) Take a sample of sand from the edge of the river. Later, back in the lab, you will study it with a magnifier.

Stop #3

Walk back to the road. Look at the cliff on the west side of the valley.

a) What types of material appear to make up this cliff?

b) What types of rock would be formed if this material were compressed?

c) Describe the shape of the large rocks in the cliff. Was this material deposited by water or ice? Explain how you arrived at your answer.

d) Make a sketch of the cliff, labelling the type of material in each of the main layers. Which layers were deposited by fast running water, and which by slow water? Explain how you arrived at your answer. What could have produced enough water to deposit this material so far
above the bottom of the valley?

e) At one time, the entire valley was filled with the same type of material observed in the cliff. What has removed the material from the centre of the valley?

Drive to Stop #4

During the drive, answer these questions:

a) How does the shape of the valley change as we travel downstream?

b) What major industry is located in this valley? Why is it located here? What is the product used for?

Stop #4 (Lions Park)

a) Look at the bed of the river. Describe the size and shape of the rocks therein. How do the sizes differ from those observed at Stop #2? What rock types are found here? Name the most common rocks.

b) How much of the entire bed between the steep banks does the river presently occupy? The amount of water in the river is now controlled by a dam at the outlet of Coquitlam Lake. Before this dam was built, in which months of the year would you expect the river to carry the most and the least amount of water. Explain how you reached your answer.

c) Look at the water in the river. Does it appear to be carrying much sediment? Does it appear to be carrying more or less sediment than at Stop #2? Explain what might have caused any difference. Take a water sample for later sediment analysis.

Drive to Stop #5

During the drive, answer these questions:
a) How does the shape of the valley change? What is the general shape of the land surface now?

b) One of the main industries in part of the valley is farming. Why is this a good area for farms?

Stop #5 (Colony Farm)

Walk along the path towards the point where the Coquitlam River flows into the Fraser River.

a) What is the name for the type of land surface on each side of the river?

b) Give two ways in which the river is now prevented from flooding the surrounding land. Now that floods are prevented, what must man do to maintain the fertility of the land?

c) The river here flows in wide, sweeping curves. What is the name for this type of river? Does the river flow rapidly or slowly here?

d) Does the river appear to be carrying much sediment here? Compare the amount of sediment to that observed at Stops #2 and #4. Would you expect this stretch of river to carry mostly coarse or fine sediment? Explain how you arrived at your answer.

e) Is there a delta forming where the Coquitlam River flows into the Fraser? If your answer is "yes", Explain why such a delta is forming. If you answer "no", explain why a delta is not being formed at this location.
Part C (Back in the laboratory)

a) Analyse each water sample for suspended and dissolved sediment. Use the method of Investigation 21, with the following changes:

i) Use 100 mL of water instead of 20 mL.

ii) Use a 250 mL beaker to catch the water from the filter. Measure 20 mL of this water into the evaporating dish.

b) As in Investigation 25, study the sand sample under a magnifier. Write a brief description of your observations. State the name of the type of rock from which the sand was probably formed.

c) On your map of the Coquitlam River, print a very brief (one short sentence) description of the river and its valley beside the locations of each of Stops #2, #4, and #5.

d) Rewrite your field notes into a neat, concise explanation of what is to be found at each stop on the field trip. Remember that you will be expected to turn in both your field notes and your final written report.

e) Study your observations, then write a short history of the valley from a time just before the start of the last ice age, up to the present day. (Rorstad, 1977)
Figure 141. Northern section of field trip area.
(B.C. Government Air Photo)
Figure 14-2. Southern section of field trip area.
(B.C. Government Air Photo)
Part 2

Proposed Curriculum

for Grade 10
INTRODUCTION

Man has always had legends about the Earth. The ancient Hindus believed that it was brought up from the bottom of the sea by a god shaped like a boar. The Greeks thought that it rested upon the back of Atlas, a legendary strong-man. The Romans believed that volcanoes were the result of Vulcan, a blacksmith, working at his forge. In 1650 A.D., Archbishop Ussher calculated from his study of the scriptures that the Earth was created at 9:00 a.m. on Sunday, October 23, in 4004 B.C. We may laugh at some of these theories now, but at the time, they were based upon the best information that the people had. Our latest theories are based upon information gathered by astronomers. (Jastrow, 1967)

About twenty billion years ago, a huge cloud of dust and gas somewhere on the outer edge of our galaxy started to contract under the force of gravity. As it became smaller and smaller, the colliding atoms broke apart and reformed, releasing a flood of light and heat into the surrounding space. Thus, the star we call our Sun was born. At the same time, smaller bodies orbiting around the sun also formed, colliding with each other and growing larger. These resulted in the planets we know today. The process still continues as meteorites collide with our Earth. (Press, Siever, 1978)

This theory is the best we have, based on current observations. Just as other theories changed in the past, this theory will probably change in the future as new information about the universe is discovered.
Throughout history, man has been curious about the Earth, and attempted to find out as much as he could about it. How large is it? What is its shape? How old is the Earth? What causes volcanoes and earthquakes? Why are fish fossils sometimes found on mountain tops, far from the sea? Why has erosion not worn down all of the mountains? How does the Earth differ from other planets? To some of these questions we now have answers. Others still require more investigation.

INVESTIGATION 2  The Lithosphere

During the past 10 000 years, man has made many changes to the Earth. Above the surface, he has built great towers whose tops reach into the clouds. Beneath the surface, he has dug mines so deep that people are barely able to work
in them. In this exercise you will compare the sizes of some of these man-made structures with the sizes of some of natures structures.

Purpose: to compare the sizes of some of man's structures with the size of the lithosphere.

Procedure
A. Draw axes on a piece of graph paper. Choose a suitable scale to cover the range from 0 to 50 km, and number the vertical axis (Figure 143).

B. Plot the following information as a bar graph. Label each bar.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of Earth's crust below continents</td>
<td>11 to 50</td>
</tr>
<tr>
<td>Thickness of Earth's crust below oceans</td>
<td>5 to 16</td>
</tr>
<tr>
<td>Highest point above sea level (Mt. Everest)</td>
<td>8.8</td>
</tr>
<tr>
<td>Highest point above sea level in Canada (Mt. Logan)</td>
<td>6.0</td>
</tr>
<tr>
<td>Highest point above sea level entirely in British Columbia (Mt. Waddington)</td>
<td>4.0</td>
</tr>
<tr>
<td>Average height of continents above sea level</td>
<td>0.8</td>
</tr>
<tr>
<td>Average depth of ocean</td>
<td>3.8</td>
</tr>
<tr>
<td>Deepest part of ocean (Marianas Trench)</td>
<td>11.0</td>
</tr>
<tr>
<td>Deepest gas well (Oklahoma, U.S.A)</td>
<td>9.6</td>
</tr>
<tr>
<td>Empire State Building (New York, U.S.A.)</td>
<td>0.4</td>
</tr>
<tr>
<td>C.N. Tower (Toronto, Ontario)</td>
<td>0.56</td>
</tr>
</tbody>
</table>

(Schmid, 1970)

C. Draw axes on a second piece of graph paper. Choose a suitable scale to cover the range 0 to 6500 km, and number the vertical axis. Plot the following information as a bar
Figure 143. Start the graph for Procedure A of Investigation 2 like this.

Figure 144. Why is the Earth's crust thicker under a continent than under an ocean?
graph, and label each bar.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average depth to the centre of the Earth</td>
<td>6360</td>
</tr>
<tr>
<td>Depth to the inner core</td>
<td>5170</td>
</tr>
<tr>
<td>Depth to the outer core</td>
<td>2920</td>
</tr>
<tr>
<td>Depth to the asthenosphere (maximum depth of crust)</td>
<td>160</td>
</tr>
<tr>
<td>Deepest gas well</td>
<td>9.6</td>
</tr>
<tr>
<td>Mount Everest</td>
<td>8.8</td>
</tr>
<tr>
<td>C.N. Tower</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Questions

1. What fraction of the Earth's radius (6360 km) is the maximum thickness of the crust (approximately 159 km)? Reduce your answer to lowest terms.

2. Are man-made features large or small compared to the size of the Earth?

3. Examine Figure 144 and try to give one reason why the Earth's crust is thicker under the continents than under the oceans.

4. If you were going to drill a hole through the crust, would you drill in the ocean bottom or on a continent? Explain the reason for your choice.

5. a) As depth under the surface of the Earth increases, would you expect the pressure of the rock to increase or decrease?

   b) Give one possible reason for the inner core being solid rather than liquid.

Conclusion

What have you learned about the size of the Earth?
The Atmosphere

Earth scientists consider the atmosphere to be the outermost layer of our planet. It is a layer of gas over 2500 kilometres deep. Close to the surface of the Earth where we live, it is made up of two main gases, nitrogen ($N_2$) and oxygen ($O_2$). At higher altitudes it is composed mostly of hydrogen and helium.

The Earth's atmosphere has not always contained the same gases. We believe that the atmosphere was first produced from the gases spewed out by erupting volcanoes soon after the Earth was formed. By studying the gases given off by volcanoes today, we can get an idea of the composition of the Earth's original atmosphere. These volcanic gases consist mainly of water vapour ($H_2O$) and carbon dioxide ($CO_2$). We also believe that the early atmosphere contained two other gases, methane ($CH_4$) and ammonia ($NH_3$). As time progressed, chemical reactions altered the atmosphere until it contained mostly carbon dioxide and nitrogen. Venus appears to have this type of atmosphere today. Jupiter and Saturn still have enormous amounts of methane and ammonia.

More chemical reactions eventually removed most of the carbon dioxide from the atmosphere. Oxygen was first released into the air by simple life forms such as bacteria. Gradually, the amount of oxygen increased until there was enough to support the type of life forms we know today. At present, the fossil evidence suggests that this sudden increase in the amount of oxygen occurred about 600 million years ago.
Today, green plants use the process of photosynthesis to remove carbon dioxide from the atmosphere, and release oxygen as a waste product. In turn, animals use the oxygen for respiration, and return carbon dioxide to the atmosphere.

The Earth's atmosphere has changed in the past, and today it is still changing. Since the start of the Industrial Revolution in the eighteenth century, man has been burning ever-increasing quantities of wood, coal, oil and gas. The burning of these so-called "fossil fuels" has added carbon dioxide to the atmosphere at a rate faster than green plants can remove it. Since carbon dioxide has the ability to "trap" heat energy from the sun, too much could have disastrous effect upon the Earth. If the temperature were to rise too much, the polar ice caps would melt, raising the sea level and drowning most of our coastal cities. An extreme temperature rise could turn the Earth into a lifeless desert. Fortunately, the slight increase in the level of carbon dioxide in our atmosphere so far, is still too small to have any noticeable affect.

The chart following this narrative summarizes a number of facts about the atmosphere. Like the interior of the Earth, the atmosphere is also divided into layers. The division between layers is based upon changes in temperature. As you might expect, the temperature decreases above the surface of the Earth, (why is snow found on high mountains, even in summer?), for the first few kilometres. However, at very high altitudes the temperature of the atoms of gas in the atmosphere is nearly $1000^\circ$C! This occurs because at
these altitudes, the energy of the sun's rays is very easily absorbed by the atoms of gas.

Although the temperature of the individual atoms of gas in this part of the atmosphere is very high, a man in an unheated space suit in the Earth's shadow would freeze to death! This would happen because the total number of atoms at this altitude is very small. As a result, even though they are at a very high temperature, there are not enough atoms to supply the man with enough heat energy to prevent him from freezing. (Goody, Walker 1972).

Questions
1. Why do you suppose that hydrogen and helium are found high in the atmosphere and not close to the ground? (Hint: what happens to a helium balloon if you let go of the string?)
### The Atmosphere

<table>
<thead>
<tr>
<th>Height (km)</th>
<th>Temp. (°C)</th>
<th>Layers</th>
<th>Gases</th>
<th>Pressure (kPa)</th>
<th>Other Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500</td>
<td>+927</td>
<td>Exosphere</td>
<td>Mostly hydrogen atoms (H)</td>
<td></td>
<td>The exosphere is the region from which atoms of gas can escape from the Earth's gravity into space.</td>
</tr>
<tr>
<td>2000</td>
<td>+927</td>
<td></td>
<td>Mostly helium with hydrogen atoms. (He &amp; H)</td>
<td>0.0000000001</td>
<td></td>
</tr>
<tr>
<td>1500</td>
<td>+927</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>+927</td>
<td></td>
<td></td>
<td>0.00005</td>
<td>Landsat photographic satellites orbit at 900 km altitude.</td>
</tr>
<tr>
<td>500</td>
<td>+922</td>
<td></td>
<td>Mostly oxygen atoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>+886</td>
<td>Thermosphere</td>
<td>with helium (O &amp; He)</td>
<td></td>
<td>Some radio waves reflect back to earth from the ionosphere, at 300 km.</td>
</tr>
<tr>
<td>300</td>
<td>+720</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>+420</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>+237</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>-33</td>
<td></td>
<td></td>
<td></td>
<td>The aurorae or northern lights are produced about 200 km.</td>
</tr>
<tr>
<td>90</td>
<td>-63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>-87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>-63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>-13</td>
<td>Mesosphere</td>
<td>Mostly nitrogen and oxygen (N₂ &amp; O₂)</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>-3</td>
<td></td>
<td></td>
<td></td>
<td>99% of the total mass of the atmosphere is below 30 km</td>
</tr>
<tr>
<td>40</td>
<td>-13</td>
<td>Stratosphere</td>
<td></td>
<td></td>
<td>75% of the total mass of the atmosphere is below 10 km</td>
</tr>
<tr>
<td>30</td>
<td>-38</td>
<td></td>
<td></td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>-63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>-43</td>
<td>Troposphere</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>+17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Ordway, 1966)
Origin and Development of the Earth

As was mentioned in the Introduction, we believe that our solar system developed when a huge cloud of dust and gas contracted under the force of gravity. The original planets may have been much larger than those we see today. As the sun flared into life, its heat may have "boiled off" much of the material forming the inner planets. This theory may explain why Mercury, Venus, Earth and Mars are quite small, rocky planets, while Jupiter, Saturn, Neptune and Uranus are large balls of gas. (Pluto is a mystery). The inner planets had most of their gas blown away by the sun, but the outer planets, being farther away and therefore cooler, were able to keep their gas.

Studies of rocks from the Moon and meteorites lead us to believe that the planets formed about 4.6 billion years ago. The oldest rocks on Earth, located in Greenland, and (Moorbath, 1977) are about 3.8 billion years old. What happened to the Earth between 4.6 and 3.8 billion years ago? There are two possible theories to account for the missing 0.8 billion years.

1) We know that rock on the Earth's surface is continually being eroded away and reformed into new rock. Perhaps this process has altered the Earth so much that there is now none of its original surface left unchanged.

2) Possibly the Earth took a very long time to form. During this time, the heat from the Earth's interior, part of which is still molten, may have melted and changed most
of the surface.

At present, the second theory seems to be the most likely, since it also accounts for the layers within the Earth. If the Earth were once molten, it would have been easy for the heavy iron to sink to the centre to form the core. The lighter rock could have moved to the surface to make the crust. The only problem is: where did the heat come from to start the process?

We know that there are many atoms of radioactive elements, uranium for example, within the Earth. Radioactive elements are those which break down spontaneously, forming new, lighter elements. During this process, heat is released. Measurements have shown that this heat is enough to keep the interior of the planet very hot. Perhaps in the past when the number of radioactive atoms was much higher, the heat they produced was great enough to melt a large portion of the Earth, including the surface.

Since that time, lighter rocks collected high on the surface to create the continents. Heavier rocks collected lower down, making the ocean basins. Volcanoes brought gases and water to the surface to produce the atmosphere and oceans.

The surface of the Earth is continually changing. Weathering and erosion break down rocks and wash the pieces into the ocean. Mountain building processes push up huge areas such as the Rockies and the Himalayas. Even the continents appear to have moved during the billions of years since the Earth was made. Later in this unit, you will
look at some of these processes. (Press, Siever, 1978)

Questions

1. Give two ways in which the Earth would be different if it had formed closer to the sun.
2. Give two ways in which the Earth would be different if it had formed in an orbit between the orbits of Jupiter and Saturn.
3. Give one piece of evidence which shows that the interior of the Earth is still very hot.

INVESTIGATION 5

The Geological Time Scale

The Earth appears to be about 4.6 billion (4600 million) years old. A very old person may live to an age of 100 years. In a single human lifetime it is impossible to observe many of the changes which take place on the surface of the Earth. Mountain ranges are lifted up and eroded away; enormous glaciers cover entire continents, then melt and vanish; continents drift like giant rafts across the face of the Earth; all of these changes take place so slowly that we can not observe them directly. This exercise will help you to appreciate the true length of the time periods which geologists use to measure the history of our planet.

Purpose: to study the length of the Earth's lifetime, and some of the significant events which have occurred.

Procedure

A. Make a pencil mark near one end of the paper tape. Label it "Today, 0 years". Using a scale of 1 mm = 1 million years
to measure backwards from "Today", mark and label each of the following events on your tape.

<table>
<thead>
<tr>
<th>Event</th>
<th>Estimated Time, Millions of Years Ago</th>
</tr>
</thead>
<tbody>
<tr>
<td>Today</td>
<td>0</td>
</tr>
<tr>
<td>End of last ice age in British Columbia</td>
<td>0.008 (8000 years)</td>
</tr>
<tr>
<td>Beginning of last ice age</td>
<td>1</td>
</tr>
<tr>
<td>First recognizable humans (Africa)</td>
<td>2</td>
</tr>
<tr>
<td>First elephants</td>
<td>40</td>
</tr>
<tr>
<td>Last dinosaurs. Mammals become abundant</td>
<td>65</td>
</tr>
<tr>
<td>Formation of Rocky Mountains</td>
<td>70</td>
</tr>
<tr>
<td>Formation of west Coast Mountains</td>
<td>140</td>
</tr>
<tr>
<td>First Birds</td>
<td>180</td>
</tr>
<tr>
<td>First dinosaurs and mammals</td>
<td>225</td>
</tr>
<tr>
<td>First insects</td>
<td>345</td>
</tr>
<tr>
<td>First land animals</td>
<td>400</td>
</tr>
<tr>
<td>First land plants</td>
<td>440</td>
</tr>
<tr>
<td>First animals with backbones (fish)</td>
<td>500</td>
</tr>
<tr>
<td>First known animals (soft bodied)</td>
<td>1200</td>
</tr>
<tr>
<td>Oldest plants found in Canada (algae, Ontario)</td>
<td>2000</td>
</tr>
<tr>
<td>First known plants (algae)</td>
<td>3200</td>
</tr>
<tr>
<td>Oldest known Earth rocks (Greenland)</td>
<td>3750</td>
</tr>
<tr>
<td>Oldest known Moon rocks</td>
<td>4500</td>
</tr>
<tr>
<td>Formation of Earth</td>
<td>4600?</td>
</tr>
</tbody>
</table>

(Mathews et al, 1978)
B. Geologists have given names to the various parts of the Earth's life. On your paper tape, mark the beginning and end of each of these eras.

<table>
<thead>
<tr>
<th>Name</th>
<th>Began, Millions of Years Ago</th>
<th>Ended, Millions of Years Ago</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenozoic Era</td>
<td>70</td>
<td>still continuing</td>
</tr>
<tr>
<td>Mesozoic Era</td>
<td>225</td>
<td>70</td>
</tr>
<tr>
<td>Paleozoic Era</td>
<td>600</td>
<td>225</td>
</tr>
<tr>
<td>Precambrian Era</td>
<td>4600</td>
<td>600</td>
</tr>
</tbody>
</table>

Questions

1. a) Copy the table below into your notebook, then match the name of the correct era against each event.

<table>
<thead>
<tr>
<th>Event</th>
<th>Era</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humans</td>
<td></td>
</tr>
<tr>
<td>Land plants appeared</td>
<td></td>
</tr>
<tr>
<td>Rocky Mountains formed</td>
<td></td>
</tr>
<tr>
<td>Dinosaurs</td>
<td></td>
</tr>
<tr>
<td>First insects</td>
<td></td>
</tr>
<tr>
<td>West Coast Mountains formed</td>
<td></td>
</tr>
<tr>
<td>Last ice age</td>
<td></td>
</tr>
<tr>
<td>First animals</td>
<td></td>
</tr>
<tr>
<td>Formation of the Earth</td>
<td></td>
</tr>
</tbody>
</table>

   b) List the names of the four eras, then beside each write the number of years that it lasted.

   c) Calculate the percentage of the Earth's life represented by each of the four eras.

2. If one human generation takes 20 years, how many
generations have there been since the first recognizable humans appeared in Africa?

3. a) Did early men ever use dinosaurs for food?
    b) Explain how you reached your answer to (a).

Conclusion

What did you learn about the length of the Earth's lifetime in this investigation?

NARRATIVE 6

Measuring the Age of the Earth

During the nineteenth century, scientists made many attempts to determine the age of the Earth. In 1899, John Joly tried to estimate the rate at which salt was being added to the world's oceans by rivers. He thought that if he knew how much salt was already in the oceans, and how much new salt was being added each year, he could work back to find a date when there was no salt in the oceans. This, Joly believed, would tell him the age of the Earth. His measurements and calculations gave a result of approximately 90 million years.

About the same time, Lord Kelvin studied the rate at which heat was being lost from the interior of the Earth as it cooled. He believed that if the Earth was once molten, and if he knew the rate of heat loss, he could calculate how long it would take for the Earth to reach its present temperature. He concluded that the Earth was 24 million years old.

A number of other scientists studied the rate at which
rock was being eroded from the continents, and deposited on the ocean floor as sediment. By knowing this rate, and measuring the thickness of sediments in various parts of the world, they also tried to calculate the Earth's age. Their estimates ranged from 17 million to 1600 million years.

Although these methods were crude and inaccurate, they did serve one very useful purpose. All showed that the Earth was many times older than the few thousand years produced by studying the scriptures.

In 1896 Henri Becquerel, a French scientist, discovered radioactivity. This is a process in which atoms of certain elements break down spontaneously to form atoms of new, lighter elements. For example, Uranium with an atomic mass of 238 breaks down to form Lead 206. Using this principle, in 1905 an American chemist B. B. Boltwood attempted to determine the age of rocks. The method he devised is basically the same one we use today.

In the process of radioactive decay, atoms of some elements change spontaneously into atoms of other elements. It is impossible to predict which individual atoms will change (decay), but scientists have observed that in a certain length of time, exactly half of the atoms will decay. In the next identical length of time, half of the remaining atoms will decay. The process continues until all of the atoms have decayed. This time taken for half of the atoms to decay is called the half-life of the element, and it can be measured in a laboratory.

If a geologist measures the amount of Uranium 238 and
the amount of Lead 206 in a rock, and if he knows the
half-life of Uranium, he can calculate how much time has
passed since the rock was formed.

Figure 145 is a graph showing two different radioactive
decay rates. Follow the example shown as a dotted line on
the graph. If 25% of the Uranium atoms have changed to
Lead, then the rock must be 1.6 billion years old.
(Peterson, Rigby. 1974)

Questions
1. A geologist measuring the amount of potassium and argon
in a rock found that 25% of the potassium atoms had changed
to argon. How old was the rock?
2. In another rock, 50% of the uranium atoms had decayed to
lead. How old was the rock?
3. What is the half-life of the potassium-argon decay process?
4. Explain why it might be very difficult to find the ages of
very young rocks by using either the potassium-argon or the
uranium-lead methods.
5. A method of radiometric dating used for very new material
is based on the decay of a special type of carbon called
carbon-14. While it is alive, every living organism takes in
small amounts of carbon-14 from the atmosphere. When the
organism dies, the carbon-14 in its body undergoes radio-
active decay and changes into nitrogen. The half-life of
this process is 5730 years.

a) A piece of charred wood was found in a lava flow. If
50% of the original carbon-14 atoms remained unchanged, how
old was the lava?
Figure 14-5. Decay rates for uranium-lead and potassium-argon processes.
b) A fossil leaf was found in some sedimentary rock. If 25% of its carbon-14 atoms remained undecayed, how old was the leaf?

6. a) In radiometric dating, why would it be important to make sure that the rock samples had not been changed or disturbed since the rocks were formed?

   b) In a laboratory, a rock being dated by the uranium-lead method was accidentally contaminated with some excess uranium. Would the resulting incorrect age be too old or too young?

7. Explain several reasons why the methods used by John Joly and Lord Kelvin to find the age of the Earth were so inaccurate.
INVESTIGATION 8

Homologizing Bones

Scientists believe that throughout the ages, new species of animals have developed from older species. The evidence for this is particularly strong in horses. Their ancestry can be traced through fossils, back to a small dog-sized mammal which lived some 60 million years ago. (Otto 1977)

In many ways, the skeletal bones of modern animals have the same general shape and position as similar bones in extinct animals. Skeletal bones which appear in similar places in different organisms are called homologous structures. They are considered to be related, even though their functions may be different. For example, the arm of a human has bones homologous with those in the wing of a bird and the fore-leg of a cat. It is even possible that animals with homologous structures may all be descended from a single common ancestor. In this investigation, you will be identifying homologous structures in the skeletal bones of
Figure 146. Human skeleton with some of the bones labelled. (After Peterson & Rigby, 1974).
Figure 147. The skeleton of Dimetrodon, an extinct fin-backed reptile. (After Peterson & Rigby, 1974).
Figure 14-8. Forelimbs of a number of animals. A- modern seal; B- pterodactyl, an extinct flying reptile; C- modern bat; D- plesiosaur, an extinct swimming reptile; E- extinct sabre-tooth tiger. (After Peterson & Rigby, 1974).
various animals, both living and extinct.
Purpose: to identify and study homologous structures.
Procedure
A. Write the term homologous structures and its meaning in your notebook.
B. Various bones are identified on the skeleton of a human in Figure 14.6. On a full page diagram of Dimetrodon (Figure 14.7) provided by your teacher, label each of the bones homologous with the human bones. The Dimetrodon was a sail-backed mammal-like reptile which lived late in the Paleozoic Era, about 250 million years ago.
C. Your teacher will supply you with a full page diagram of Figure 14.8 showing the front limbs of a number of animals. Identify and colour the homologous bones in each limb. Colour the scapula red, the humerus blue, the radius yellow, the ulna green, the metacarpals and carpals purple, and the phalanges brown.
D. For each of the diagrams in Figure 14.8, write a few short sentences summarizing the reasons for the modifications in each limb. For example, you might point out that the limb of the plesiosaur has been modified into a flat flipper, suitable for swimming in the ocean.
Questions
1. Copy the table below into your notes. Complete the second column with the name of the type of environment where each animal lives.
2. Copy the table below into your notes. For each animal, give a reason for the particular body adaptation.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Adaptation</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camel</td>
<td>Wide flat feet</td>
<td>Do not sink in sand</td>
</tr>
<tr>
<td></td>
<td>Flippers</td>
<td></td>
</tr>
<tr>
<td>Whale</td>
<td>Concave hoofs</td>
<td></td>
</tr>
<tr>
<td>Mountain sheep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monkey</td>
<td>Grasping tail</td>
<td></td>
</tr>
<tr>
<td>Mole</td>
<td>Thick front claws</td>
<td></td>
</tr>
<tr>
<td>Eagle</td>
<td>Large wings</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion

What have you learned about homologous structures in this investigation?

NARRATIVE 9

The History of Life

Why is the history of life usually discussed during the study of geology rather than biology? This is a question often asked by science students. After all, isn't biology the science of life, and geology the study of the Earth? Although it may seem odd, life history has always been closely linked with Earth history. The only direct evidence of ancient life is provided by fossils - the remains of long dead animals and plants preserved in layers of rock. Geology
and biology combine to form the science of paleontology, the study of ancient life. In this narrative, you will learn about the progression of life through the ages, from the single celled organisms of three billion years ago to the almost countless variety of life forms today.

Scientists generally agree that life began in the sea, about 3 or 4 billion years ago. Just how this happened is not known, but we do have some ideas. In 1953 in Chicago, an American chemist S. L. Miller performed an experiment to show how the process may have started. In a glass apparatus, he heated a mixture of steam, methane, ammonia and hydrogen, gases though to have been present in the Earth's early atmosphere. Next he discharged electrical sparks through the gas, trying to imitate lightning bolts. After a week of this treatment, the water in the apparatus had become deep red and cloudy. Miller analysed the water and found that it contained a complex mixture of amino acids, the basic chemical building blocks of living protein.

Miller's apparatus did not create life. It did not even make protein. All he did was manufacture the chemicals from which protein is made. It is an incredibly long step from a mixture of amino acid molecules to a living cell which can reproduce itself. The process by which this happened is still a mystery which many scientists are trying to solve.

Regardless of the process by which it was developed, we know that life in the form of bacteria and algae was well established three billion years ago. At some unknown
Figure 149. Miller's apparatus for simulating conditions on the early Earth.
time during the following two billion years, more complex life forms arose. The earliest animal fossils we have are only 700 million years old. These are not the remains of the animals themselves (worms), but the traces of burrows and trails that they made in the ancient sea bottom. By 650 million years ago, in the region we now know as Australia, jellyfish had developed. Then, starting about 600 million years ago, there was a tremendous increase in the number and variety of life forms. No-one is absolutely sure why this occurred, but some scientists have connected it to a possible increase in the amount of oxygen in the atmosphere.

During the Paleozoic Era, life developed rapidly. First came the trilobites and brachiopods, followed by sponges, corals and crinoids. About 450 million years ago, the first fish appeared. Called ostracoderms, they were not like the fish we know today. Instead of being covered with scales, and having a skeleton made of bone, they were covered with a hard armour and had a skeleton made of cartilage.

The middle Paleozoic saw plants spread from the sea onto the surface of the land. With food now available on land, animals soon followed. The first of these were the amphibians. These appear to have evolved from a type of fish which had developed primitive lungs. Although they could move easily on land, the amphibians could never travel far from water since only in water could their eggs develop and hatch.

Towards the end of the Paleozoic Era, the first reptiles arose, developing from primitive amphibian ancestors. They
were no longer dependent on water since their eggs could survive being laid on land. About the same time, a large number of species which lived in the sea, including the trilobites, became extinct.

During the Mesozoic Era, starting some 225 million years ago, the diversity and number of life forms increased. In the seas, pelecypods, gastropods, crinoids and ammonites were abundant, and the first primitive crabs appeared. On land, grasshoppers, beetles, dragonflies, termites and ants developed. In the rocks of this era, the fossils of the first ancestral bird have been found. Named Archaeopteryx, it had a reptile-like skeleton and bird-like feathers.

The Mesozoic Era however, is known by most people as the Age of Dinosaurs. For over 150 million years they were the dominant life form on Earth. (Compare this with mankind's 2 million years). Dinosaurs evolved forms which lived in a great variety of habitats. There were the huge swamp-dwelling Brontosaurs, and the meat-eating Tyrannosaurs. Plesiosaurs swam and hunted in the oceans, while Pterosaurs glided through the air. For their time, the dinosaurs were remarkably well equipped for survival.

During most of their time on Earth, the dinosaurs shared the world with a group of small, hairy, active animals - the mammals. These are most interesting because it was from this source that humans eventually developed. Study of mammalian fossils shows that they evolved from reptile ancestors, and that their skeletons gradually changed their characteristics from reptile to mammal over a period of 100 million years.
In the Mesozoic Era, many of the types of land plants that we know today developed. First came the coniferous trees, followed by the flowering plants and trees. This tremendous diversity of plant life provided food for the huge number of animals which now populated the Earth.

Then came disaster. We do not know whether it took one thousand or ten thousand years, but over a very short period of time (geologically speaking), two-thirds of all the animal species on Earth became extinct. The dinosaurs disappeared from the land and the ammonites from the sea. We do not know what caused this great dying. Some scientists think that an unknown factor suddenly changed the climate of the Earth. Others blame the massive extinction on deadly radiation from a nearby supernova (exploding star). Whatever the cause, the only animal species which survived seem to be those whose members had a mass of less than ten kilograms.

The last 70 million years, the Cenozoic Era, completes the story of the development of life to the forms we recognize today. Birds, horses, trees, spiders, fish and humans gradually evolved into their modern species. Each animal or plant species adapted itself to the environment which suits it best, and where competition from other species is least. Palm trees grow on tropical islands, while giant cedar trees grow on wet temperate coasts. Wolves hunt in cool northern forests, and tigers prowl the jungles of Asia. Each species struggles with its neighbour - the stronger survives and the weaker becomes extinct. (Casanova, 1957; McAlester, 1968).
The story of the evolution of man has been pieced together from fossils discovered all over the world. It is far from certain, but we think we now know the general details of our ancestry. Sometime between 4 and 10 million years ago, man and the other primate animals (monkeys, gorillas etc.) developed from a common mammal ancestor. By 3 million years ago, hominids (man-like animals) were walking upright and had a brain size of about $450 \text{ cm}^3$. Within half a million years, (2.5 million years ago), they were starting to make tools, and a larger brain size was developing. About 1.5 million years ago, the first true man, Homo erectus appeared. Many stone tools from this time have been discovered. Not until 100 000 years ago did Homo sapiens appear in the form of Neanderthal man. He was a stocky individual with a heavy skull, slightly flatter than ours. By this time, brain size had increased to about $1400 \text{ cm}^3$. Only 40 000 years ago modern man, Homo sapiens sapiens arrived. His skull is less heavy than that of Nenderthal man, and his brain size is slightly smaller. About 10 000 years ago, man's transition from hunting to farming started, and the era of written history began. (Washburn, 1978; Isaac, 1979).

Where will evolution take us from here? If mankind is to survive then we must remember the unbreakable rule: "Survival of the Fittest". If the multiple problems of overpopulation and political strife are not solved, mankind will have proven itself unfit. Then, like the dinosaurs, mankind will pass from the scene and another species will
Questions
1. What determines the location where a species lives?
2. Evolution appears to follow the rule "survival of the fittest". Use this to explain why some species become extinct, while others survive.

INVESTIGATION 11

Sedimentary Rocks

In Grade 8, you may have learned about weathering and erosion, the processes which wear down rock, then carry the broken pieces away. These broken pieces may be as large as boulders or as fine as flour. All are known as sediment. If the sediment is carried by water, it eventually ends up
in the ocean, where it settles to the bottom. Over the centuries, the sediment piles up, and the weight of the sediment on top squeezes the sediment below into rock. In this exercise you will learn to recognize and identify sedimentary rocks.

Purpose: to recognize and identify sedimentary rocks.

Procedure

Part 1 The Origin of Sedimentary Rocks

A. Mix some sand, silt and water in a 250 mL beaker. Allow the mixture to settle for a few minutes. Does the sand or the silt settle to the bottom first? Does the material mixed with the water settle evenly or in layers?

B. Examine Figure 150. What is the most noticeable feature of these sedimentary rocks?

C. Copy the data table below into your notebook.

<table>
<thead>
<tr>
<th>Mass of beaker and sand g</th>
<th>Mass of beaker g</th>
<th>Mass of sand g</th>
</tr>
</thead>
</table>

D. Use the platform balance to find the mass of a 600 mL beaker. Record this in your data table. Fill the beaker to a depth of 5 cm with dry sand. Find the mass of the beaker and sand, and record this in your data table. Subtract to find the mass of the sand alone.

E. Now you will find the mass of various depths of sand. Copy the following data table into your notes.
Limestone in south Wales. What clue tells you that these rocks are sedimentary?
(Photograph courtesy of A. Williams)

Sandstone. This rock is formed when grains of sand are squeezed and cemented together.
Depth of Sand | Mass of Sand
---|---
5 cm | 
10 cm | 
100 cm (1 m) | 
1 km (1000 m) |

Record the mass for the 5 cm depth in the second column of your table. Multiply to find the weights of various depths of sediment. Does the weight at 1 km depth seem like enough to start squeezing sediment into rock?

Part 2 Identifying Sedimentary Rocks

Sedimentary rocks can form in any of three different ways, mechanically, chemically, or organically.

a) Mechanical origin. Rocks on the surface of the Earth are weathered and eroded. The resulting sediment settles to the bottom of lakes and oceans where the pieces are squeezed and cemented together to form new sedimentary rock. The rocks are generally layered. If animals or plants are trapped in the sediment they form fossils. This type of rock is named according to the size of the original pieces of sediment.

<table>
<thead>
<tr>
<th>Name of Rock</th>
<th>Type of Sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale</td>
<td>Mud, clay, or silt</td>
</tr>
<tr>
<td>Sandstone</td>
<td>Sand</td>
</tr>
<tr>
<td>Conglomerate</td>
<td>Rounded pebbles (gravel)</td>
</tr>
<tr>
<td>Breccia</td>
<td>Sharp, angular pebbles</td>
</tr>
</tbody>
</table>

Descriptive adjectives may be applied to these names. For example, a sandstone may be described as "coarse" or "fine".

b) Chemical origin. The particles in these rocks are formed by chemical precipitation or evaporation. The particles are usually too fine to be seen, even with a hand
<table>
<thead>
<tr>
<th>Name of Rock</th>
<th>Origin and Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halite (Rock salt)</td>
<td>Sodium chloride produced by evaporation. Often has large cubical crystals. Identified by taste.</td>
</tr>
<tr>
<td>Limestone</td>
<td>Calcium carbonate, produced by evaporation or precipitation. Fizzes with dilute hydrochloric acid.</td>
</tr>
<tr>
<td>Dolomite</td>
<td>Calcium magnesium carbonate, produced by precipitation or evaporation. When powdered, fizzes with dilute acid.</td>
</tr>
<tr>
<td>Chert</td>
<td>Quartz (silicon dioxide) precipitated from solution. Appears in many forms, agate for example.</td>
</tr>
</tbody>
</table>

c) **Organic origin.** These rocks are produced from the remains of living organisms.

<table>
<thead>
<tr>
<th>Name of Rock</th>
<th>Origin and Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone</td>
<td>Compressed and cemented sea shells and other marine debris from the ocean floor. Fizzes with dilute acid.</td>
</tr>
<tr>
<td>Coal</td>
<td>Layers of compressed and carbonized plant material. May be black or brown. Burns.</td>
</tr>
</tbody>
</table>

F. Copy the data table below into your notebook.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Identifying Characteristics</th>
<th>Rock Name</th>
</tr>
</thead>
</table>

Examine each of the rock samples. In your data table, write down the sample number, the characteristics you used to identify the rock, and its name.

**Part 3 Where Are Sedimentary Rocks Found?**

G. Examine the key on a geological map of your local area. Which colours are used to represent sedimentary rocks? Name some places where sedimentary rocks may be found, and state which rocks may be found there.
Figure 152. Conglomerate is a sedimentary rock formed from rounded pebbles.

Figure 153a What type of sediment is being deposited at each location?
Questions

1. a) Copy this table into your notes:

<table>
<thead>
<tr>
<th>Water Speed</th>
<th>Type of Sediment Carried</th>
<th>Name of Rock Formed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) In the second column, fill in the type or types of sediment carried by each water speed: pebbles, sand, or silt.

c) In the third column, fill in the name of the type of rock which would be formed when the sediment settled to the bottom: shale, sandstone, breccia or conglomerate.

2. Examine Figure 153a showing a very fast river flowing into the ocean. Name the type of rock, sandstone, shale or conglomerate which could be forming in each of the areas labelled A, B and C.

3. In what sort of climate, hot and dry, or cool and wet, would halite be most likely to form?

Conclusion

In this investigation, what did you learn about sedimentary rocks?

INVESTIGATION 14

Volcanoes

In ancient times, the people who lived near the island of Vulcano between Italy and Sicily thought that they were looking at the work of the gods. To them, the island was the
chimney over a giant blacksmith's forge. When the volcano erupted, they knew that Vulcan the blacksmith was at work, manufacturing thunderbolts for Jupiter the chief god, or beating out weapons for Mars the god of war. Although we no longer believe in Vulcan, we are still impressed by the violent beauty of volcanoes.

In this investigation, you will study some volcanic landforms and the types of eruptions that produce them.

Purpose: to study volcanoes and volcanic landforms.

Procedure

Part 1 Types of Volcano

A. In Investigation 12 you learned that the temperature within the Earth is much higher than the temperature at the surface. Twenty to fifty kilometres beneath the surface, the temperature is high enough to melt rock. This molten rock is called magma. If there is a weak spot in the Earth's crust, the magma can work its way to the surface and pour out to form a volcano. The molten rock which erupts from a volcano is called lava. Trace Figure 153b into your notebook. Label the magma, lava, and volcano. In your notes, write the words magma, lava, and volcano and their meanings.

B. Examine Figures 154, 155, and 156. In your notes, make a sketch of the approximate shape of each volcano. Title your sketch of Figure 154 as a cinder cone. Title Figure 155 as a composite cone or stratovolcano, and Figure 156 as a shield volcano. Which type of volcano is quite small with fairly steep sides? Which is large with long sloping sides that are not very steep? Which is large with gentle slopes at the
Figure 153b Operation of a volcano.

Figure 154. A cinder cone in central Oregon, U.S.A.
Fig. 155. A stratovolcano or composite cone in the West Indies.

Fig. 156. On the skyline is Mauna Loa, a giant shield volcano on the island of Hawaii.
Figure 157. Melting wax in a double boiler.

Figure 158. Internal structure of a stratovolcano.
base and steep slopes near the summit ("dished" sides)?

C. Fill a 250 mL beaker with a mixture of coarse sand and small pebbles (pea sized). Pour the mixture slowly into a shallow pan so that a cone is formed. Are the sides of the cone steep, "dished", or gently sloping? In your notes, sketch a side view of your cone and label it with the name of the type of volcano it represents. Which type of volcano is formed by the eruption of solid, lumpy pieces of rock? Examine a piece of volcanic cinder and write a description of its appearance in your notes.

D. (Demonstration). Melt a block of paraffin wax in a double boiler (Figure 157). Add a piece of wax crayon to make the wax more visible. When the molten wax has cooled until it is just about ready to solidify again, pour it slowly on to a small cone of sand on a large sheet of cardboard, so that a type of cone is formed. Are the sides of the model volcano steep, dished, or gently sloping? In your notes, sketch a side view of the model and label it with the name of the type of volcano it represents. Which type of volcano is formed by the eruption of very liquid, fluid molten lava?

E. A stratovolcano or composite cone is formed by alternating eruptions of solid and liquid material. In your notes, make a sketch similar to Figure 158, showing the internal structure of a stratovolcano. (van Rose, 1974)

Part 2 Volcanic Landforms

During past ages, volcanoes were found on many parts of the Earth. Although weathering and erosion have removed most of these, their existence can be seen by the many
volcanic landforms they left behind. Many of these are located in British Columbia.

F. Read the descriptions below. From each description, make a labelled sketch in your notebook.

a) **Dyke**: lava which pushed into a vertical crack in the surrounding rock, then cooled.

b) **Sill**: lava which pushed into a horizontal crack in surrounding rock, then cooled.

c) **Columnar jointing**: lava which split into long, pillar-like columns when it cooled. Perfect columns are six-sided.

d) **Lava tube**: a tunnel through which lava once flowed. Lava cools and solidifies on the top and sides first. Molten lava still flows inside. If the source of the lava is cut off, the liquid lava inside drains away, leaving a long tunnel behind.

e) **Caldera**: many volcanoes have a small depression on the top called a crater. Sometimes under special circumstances, the entire top of a volcano can collapse inwards and downwards to form a very large depression called a caldera. Many calderas have filled with rainwater, forming lakes.

f) **Black sand beach**: (do not try to sketch). Where lava flows reach the ocean, the sudden cooling can sometimes cause the rock to be shattered into sand. If this sand is washed back onto the shore, it can form a black sand beach. Explain why it can be very painful to walk barefoot on a black sand beach on a hot sunny day.

g) **Flood lavas**: (do not try to sketch). In the past,
very large eruptions have flooded huge areas of the Earth with thin layers of lava. If this occurs many times, the thin layers can build on top of each other to pile up lava beds hundreds of metres thick. One such flow to the south of British Columbia, in the states of Washington and Oregon covered an area of over 50 000 km$^2$. (McKee, 1972) (Francis, 1976).

Questions

1. Identify the type of volcano, cinder cone, stratovolcano or shield volcano shown in each of the photographs in Figures 159 to 166.

2. Name the volcanic landform (see Procedure F) shown in each of the photographs in Figures 167 to 171.

3. Figure 172 shows a fissure eruption by Kilauea volcano in Hawaii. The lava is pushing up through a crack in the ground. Name the volcanic landform being produced here.

4. Explain the difference between lava and magma.

5. Figure 173 shows the areas of British Columbia covered by layers of lava during the past 70 million years.
   a) What is this type of volcanic landform called?
   b) If British Columbia has a total area of 930 600 km$^2$, estimate the area covered by these lavas.

6. Figure 174 shows Olympus Mons, a huge volcano on the planet Mars. With a height of 24 000 metres, it is the largest known volcano in the solar system (Hartmann, Odell 1974). (Mount Everest is 8843 m high).
   a) Does Olympus Mons appear to be a cinder cone, stratovolcano or shield cone?
Fig. 159. The Canada-France-Hawaii telescope is used by astronomers on top of this volcano which is 4180 metres high.

Fig. 160. Many of the trees in this photograph have been killed by eruptions from this volcano.
Fig. 161. Mount Garibaldi is a volcano near the town of Squamish in southern British Columbia.

Fig. 162. These two small volcanoes are located in central Oregon, U.S.A.
Fig. 163. On the skyline is Mount Newberry, a large volcano located in central Oregon, U.S.A.

Fig. 164. Mauna Ulu, a volcano on the island of Hawaii, formed when lava erupted between 1969 and 1974.
Fig. 165. Mount Baker is well known to residents of southwestern British Columbia.

Fig. 166. Wizard Island is a small volcano located in Crater Lake National Park, Oregon, U.S.A.
Figure 167. Approximately 6600 years ago, following a violent eruption, the summit of Mount Mazama collapsed downwards, leaving a huge hole on top of the mountain. The hole gradually filled with water to form Crater Lake, now located in one of the most beautiful National Parks in Oregon, U.S.A. (Photograph courtesy of the U.S. Geological Survey).
Figure 168. A road cut exposed this band of lava which forced its way through a crack in the surrounding rock north of Squamish in southern British Columbia.
Figure 169. This volcanic landform is a long tunnel on the island of Hawaii. (Photograph courtesy of the Hawaii Natural History Association).
Fig. 170. This strange feature, located in Northern Ireland, is called the Giant's Causeway.

Fig. 171. Hawaiian beaches like this can become so hot they can burn bare feet!
Fig. 172. Lava pouring out of a long crack in the ground is called a "fissure eruption". (Photograph courtesy of the Hawaii Natural History Association).
Figure 173. Areas of British Columbia covered by flood lavas.

Figure 174. Olympus Mons, a huge volcano on the planet Mars, is three times as high as Mount Everest. Notice the caldera at the summit. (NASA photograph).
Figure 175. Area of British Columbia which would be covered by Olympus Mons.
b) What is the name for the huge depression at the summit of Olympus Mons?

c) From Figure 175, estimate the land area covered by Olympus Mons.

7. a) Before an eruption, the summit of a volcano frequently swells slightly. What could cause this?

    b) Before an eruption, many small earthquakes are frequently felt in the vicinity of a volcano. What could cause this?

    c) Explain two methods that scientists could use to predict a volcanic eruption.

Conclusion

What did you learn about volcanoes in this investigation?

INVESTIGATION 15

Volcano Location

Volcanoes are found in many areas of the Earth, including western Canada. In British Columbia, they are not very noticeable since none have erupted recently. In this exercise you will study the locations of the world's major volcanic areas.

Purpose: to map the locations of volcanic areas of the world.

Procedure

A. Use your atlas to locate the volcanic areas listed below. On your map of the world, mark the positions of individual volcanoes with a red X. Outline larger volcanic areas by shading them in red.
North America
Mt. Baker (U.S.A.)
Mt. Rainier (U.S.A.)
Mt. Hood (U.S.A.)
Mt. Shasta (U.S.A.)
Lassen Peak (U.S.A.)
Aleutian Islands (Alaska)
Mt. Garibaldi (B.C.)
Mt. Downton (B.C.)
Edziza Peak (B.C.)
Aiyansh (B.C.)

Central America & Caribbean
Popocatapetl (Mexico)

Lesser Antilles Islands

Europe
Mt. Vesuvius
Mt. Etna
Stromboli

Africa
Kilimanjaro
Mt. Kenya

South America
Aconcagua
Chimborazo
Cotopaxi
Ojos del Salado

Asia
Kamchatka Peninsula
Kurile Islands
Japanese Islands
Mt. Fujiyama
Phillipine Islands
Celebes Islands
New Guinea
New Hebrides Islands
Sumatra
Krakatau
Java
Timor

Atlantic Ocean
Iceland
Azores Islands
Ascencion Island
St. Helena
Tristan da Cuhna
Gough Island
Bouvet Island

Pacific Ocean
Hawaii
Galapagos Islands
Ruapehu (New Zealand)
Ngaruhoe (New Zealand)
Mt. Egmont (New Zealand)

(Delury et al, 1978)
Figure 1.76. Plot the positions of world volcanoes on a copy of this map.
Questions
1. Which ocean has a ring of volcanoes surrounding it? (This has sometimes been called the "Ring of Fire").
2. a) Which ocean has a line of volcanoes stretching down its centre?
    b) Use your atlas to find the name of this chain of volcanic mountains.
3. a) Is the Earth's crust thicker under the continents or under the oceans?
    b) Would you expect to find magma nearer the surface under an ocean or under a continent?
    c) Give one possible explanation for the fact that there are very few volcanoes in the centres of continents.
Conclusion
    What did you learn about volcanoes in this exercise?
INVESTIGATION 17

Igneous and Metamorphic Rocks

In Investigation 11 you studied sedimentary rocks, which are formed from layers of compressed sediment. In this exercise, you will study two other groups of rocks, igneous and metamorphic.

Igneous rocks are formed from molten rock which has cooled and solidified. They are generally divided into two sub-groups, volcanic and plutonic. Igneous rocks which form when molten rock cools rapidly near the surface of the Earth are called volcanic. Those which form when molten rock cools slowly, deep underground, are called plutonic.

Metamorphic rocks are formed when sedimentary or igneous rocks are changed from their original nature by heat, pressure or chemical action deep underground.

Purpose: to learn to recognize and name igneous and metamorphic rocks.

Procedure

Part 1  Igneous Rocks

A. Write the term igneous rock and its meaning in your notebook. Examine a piece of broken igneous rock. Explain at least one clue which tells you that the rock is not sedimentary.

B. Write the term plutonic rock and its meaning in your notebook. Examine a piece of broken plutonic rock. It is made up of interlocking crystals. Are the crystals large enough to be seen without a microscope? How many different colours of crystals are there? When rock cools slowly, large crystals are formed.
C. Write the term **volcanic rock** and its meaning in your notebook. Examine a piece of broken volcanic rock. Can you see any crystals? Now examine the rock with a ten-power hand lens or stereo-microscope. Can you see any crystals now? When rock cools rapidly, small crystals are formed.

D. Igneous rocks are named according to the materials which make up their individual crystals. Study the information below, then identify each of the rock samples you have been given. Organize your results into a table similar to the one in Investigation 11.

<table>
<thead>
<tr>
<th>Plutonic Rocks</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal Colour</td>
<td>Rock Name</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mostly light crystals</td>
<td>granite</td>
<td>light &amp; dark, evenly mixed</td>
<td>quartz diorite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mostly dark crystals</td>
<td>gabbro</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volcanic Rocks</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Colour</td>
<td>Rock Name</td>
<td></td>
<td></td>
</tr>
<tr>
<td>light grey</td>
<td>rhyolite</td>
<td>medium</td>
<td>andesite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>very dark or black</td>
<td>basalt</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unusual Cases</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Rock Name</td>
<td></td>
<td></td>
</tr>
<tr>
<td>volcanic glass</td>
<td>obsidian</td>
<td>light &quot;frothy&quot; volcanic glass</td>
<td>pumice</td>
</tr>
<tr>
<td>full of bubbles</td>
<td></td>
<td>large crystals embedded in a background of microscopic crystals</td>
<td>porphyry</td>
</tr>
</tbody>
</table>

Part 2  Metamorphic Rocks

E. Write the term **metamorphic rock** and its meaning in your notebook. Examine a piece of broken metamorphic rock. Explain
one clue which tells you it is neither sedimentary or igneous.

F. Metamorphic rocks are named according to the type of sedimentary or igneous rock from which they are formed. In this exercise you will look at only four metamorphic rocks common in British Columbia.

Gneiss (pronounced "nice") is formed when heat and pressure cause new crystals to form, even though the rock is not melted. The crystals form irregular "bands" which may be confused with sedimentary layers.

Marble is metamorphosed limestone. It fizzes with dilute hydrochloric acid.

Quartzite is metamorphosed sandstone. Examination with a microscope shows that the grains of sand have been reshaped and "welded" together.

Slate is metamorphosed shale. It may split into flat sheets. The direction of the splits is not the same as the direction of the original layers in the shale however.

Identify each of the samples of metamorphic rock. Organize your results into a neat table. (B.C. Dep't of Mines 1968)

Questions
1. a) Where are plutonic rocks formed?
   b) What must happen to the overlying rock in order for plutonic rocks to be exposed on the surface of the Earth?
2. a) Does slow cooling or fast cooling cause the formation of large crystals?
   b) Explain why rocks deep underground cool more slowly than rocks close to the surface.
Fig. 177. Basalt is a dark coloured volcanic rock.

Fig. 178. Granite is a mostly light coloured plutonic rock. It is made up of large interlocking crystals.
Fig. 179. Gneiss is a metamorphic rock common in British Columbia. The crystals line up into irregular "bands".
3. How are the bubbles formed in a piece of pumice?
4. A piece of obsidian has no crystals. Would you expect obsidian to have cooled very rapidly or very slowly?
5. Andesite is named after a range of volcanic mountains in South America. Use your atlas to find the name of these mountains.

Conclusion

What did you learn about rocks in this investigation?

NARRATIVE 18

The Rock Cycle

You may recall work on the water cycle in previous years. Ocean water evaporates into the atmosphere, falls on the land as rain, and eventually reaches the ocean again. Water can take anywhere from several hours to several thousand years to move through this cycle. In a fashion similar to water, rocks may also move through a cycle. However, the rock cycle (Figure 180) may take from several hundred to several billion years.

Sooner or later, the processes of weathering and erosion grind all rock into sediment. As you learned in Investigation 11, this sediment may become sedimentary rock. Examine Figure 148 carefully. The arrows show the various paths that sedimentary rock can take before becoming sediment again. Possibly it may be buried so deeply that heat and pressure convert the sedimentary rock into a metamorphic rock, slate. If the slate is buried deeply enough, it may become gneiss. Possibly the gneiss will melt to form a magma, which may
Figure 180. The rock cycle.
cool underground to form plutonic igneous rock. On the other hand, the magma may rise to the surface and erupt as lava to build a volcano. Eventually, the volcano will be weathered and eroded to sediment, and the rock will have come full circle. In Figure 180, the arrows show a number of "shortcuts" which can be made across the circle.

This entire sequence is known as the **rock cycle**. The theory is useful, but in practise, very few rocks have travelled around the full circle. Even the 4.6 billion year life of the Earth has not provided enough time for all rocks on Earth to have completed the full cycle. (Ernst, 1969; McKee, 1972).

**Questions**

1. Describe a sequence of events which could turn igneous rock into sedimentary rock.

2. Describe a sequence of events which could change igneous rock to metamorphic rock.

3. Explain how a plutonic rock could become a volcanic rock.
cool underground to form plutonic igneous rock. On the other hand, the magma may rise to the surface and erupt as lava to build a volcano. Eventually, the volcano will be weathered and eroded to sediment, and the rock will have come full circle. In Figure 180, the arrows show a number of "shortcuts" which can be made across the circle.

This entire sequence is known as the rock cycle. The theory is useful, but in practise, very few rocks have travelled around the full circle. Even the 4.6 billion year life of the Earth has not provided enough time for all rocks on Earth to have completed the full cycle. (Ernst, 1969; McKee, 1972).

Questions
1. Describe a sequence of events which could turn igneous rock into sedimentary rock.
2. Describe a sequence of events which could change igneous rock to metamorphic rock.
3. Explain how a plutonic rock could become a volcanic rock.
INVESTIGATION 20

Recording Earthquakes

Each year, the world is shaken by over one million earthquakes. Fortunately, most of these are too small to be noticed. Even small earthquakes however, are useful to scientists. To learn more about the interior of the Earth, they try to record the location and magnitude of as many earthquakes as possible. The instrument used for recording earthquakes is called a seismograph.

Purpose: to learn how a seismograph operates.

Procedure

A. Place your textbook near the edge of your desk, with a piece of paper underneath it (Figure 181). Pull the paper slowly. Does the book move with the paper? Now give the paper a quick jerk. Does the book move as much as the paper? Is it possible to jerk the paper out from under the book, without moving the book? We say that the book has inertia. Inertia means resistance to rapid changes in movement. Write this term and its meaning in your notebook. Objects with a lot of mass have a lot of inertia.

B. Set up the model seismograph (Figure 182). Does the part of the seismograph which holds the pen have inertia? Shake the table sideways to simulate an earthquake. Does the penholder resist moving at first? Does the table move underneath the pen?

C. Pull the paper tape slowly underneath the pen. Describe the shape of the line made on the paper. What sort of a record does a seismograph make when no earthquake is happening?
Figure 181. Demonstrating inertia by pulling a piece of paper from underneath a book.

Figure 182. Demonstration model seismograph.
D. Pull the paper tape while shaking the table very lightly. What sort of record does a seismograph make during a small earthquake?

E. Pull the paper tape while shaking the table more strongly. What sort of record does a seismograph make during a strong earthquake?

F. If possible, paste the records from Procedures C, D, and E into your notebook. Label each as no, weak, or strong earthquake.

Questions
1. a) What is inertia?
   b) How does a seismograph use inertia to help it record an earthquake?
2. The seismograph model you used recorded only sideways motion during the earthquake. How would you place the model to record back and forth motion?
3. Design a seismograph to record up and down motion of the ground. Make a labelled sketch of your design.

Conclusion
   How does a seismograph record earthquakes?

INVESTIGATION 22

Earthquake Patterns

In Narrative 19 you learned that earthquakes occur where strain forces along faults in the Earth's crust are suddenly released. In this exercise you will determine from
earthquake locations just where major faults are located near British Columbia, and elsewhere around the world. Purpose: to locate major fault zones in British Columbia and the world.

Procedure

Part 1 Earthquakes in Western Canada

A. Write the words earthquake and fault and their meanings in your notes.

B. Between 1899 and 1970 there were 52 earthquakes on the west coast of Canada having Richter magnitudes greater than 6.0. A list of these and their locations is given below. On a copy of the British Columbia map in Figure 183, plot each of these positions with a small X.

Major Earthquakes on the West Coast of Canada 1899-1970

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 or greater</td>
<td>60°N 140°W</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>142</td>
<td></td>
</tr>
<tr>
<td>53.6</td>
<td>133.2</td>
<td></td>
</tr>
<tr>
<td>7 to 8</td>
<td>59</td>
<td>141</td>
</tr>
<tr>
<td>59</td>
<td>141</td>
<td></td>
</tr>
<tr>
<td>57.4</td>
<td>137.1</td>
<td></td>
</tr>
<tr>
<td>55.9</td>
<td>136</td>
<td></td>
</tr>
<tr>
<td>54.5</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td>53.2</td>
<td>133.7</td>
<td></td>
</tr>
<tr>
<td>53.9</td>
<td>132.1</td>
<td></td>
</tr>
<tr>
<td>52.8</td>
<td>129.5</td>
<td>6 to 7</td>
</tr>
<tr>
<td>51.7</td>
<td>131.5</td>
<td></td>
</tr>
<tr>
<td>51.8</td>
<td>129.2</td>
<td></td>
</tr>
<tr>
<td>50.9</td>
<td>131</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 to 8</td>
<td>49.9</td>
<td>128</td>
</tr>
<tr>
<td>7 to 8</td>
<td>49.8</td>
<td>126.7</td>
</tr>
<tr>
<td>7 to 8</td>
<td>49.9</td>
<td>124.9</td>
</tr>
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<td>7 to 8</td>
<td>47.5</td>
<td>122.6</td>
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<tr>
<td>7 to 8</td>
<td>47.1</td>
<td>122.9</td>
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<tr>
<td>7 to 8</td>
<td>46.9</td>
<td>122.8</td>
</tr>
<tr>
<td>7 to 8</td>
<td>48.7</td>
<td>128.5</td>
</tr>
<tr>
<td>7 to 8</td>
<td>48.4</td>
<td>130</td>
</tr>
<tr>
<td>6 to 7</td>
<td>59</td>
<td>139.3</td>
</tr>
<tr>
<td>58.9</td>
<td>139</td>
<td></td>
</tr>
<tr>
<td>59.5</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>136</td>
<td></td>
</tr>
<tr>
<td>Magnitude</td>
<td>Latitude</td>
<td>Longitude</td>
</tr>
<tr>
<td>-----------</td>
<td>----------</td>
<td>-----------</td>
</tr>
<tr>
<td>6 to 7</td>
<td>56°N</td>
<td>136.2°W</td>
</tr>
<tr>
<td>54</td>
<td>132.5</td>
<td></td>
</tr>
<tr>
<td>53.5</td>
<td>132</td>
<td></td>
</tr>
<tr>
<td>52.9</td>
<td>131.9</td>
<td></td>
</tr>
<tr>
<td>52.5</td>
<td>132.1</td>
<td></td>
</tr>
<tr>
<td>52.4</td>
<td>132.1</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>131.6</td>
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</tr>
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<td>52</td>
<td>131</td>
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<tr>
<td>51.5</td>
<td>130.8</td>
<td></td>
</tr>
<tr>
<td>51.1</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>50.8</td>
<td>130.8</td>
<td></td>
</tr>
<tr>
<td>50.7</td>
<td>130.9</td>
<td></td>
</tr>
<tr>
<td>50.5</td>
<td>129.6</td>
<td></td>
</tr>
</tbody>
</table>

C. On your map, draw a straight heavy line showing the probable location of a major fault zone off the west coast. Label this line as the "Queen Charlotte Fault". Draw another line to show the possible location of a fault across northern Vancouver Island. Label this line as the "Nootka Fault".

Which major U.S. city in the map area is subject to earthquake hazard? (If necessary, use your atlas). (Milne 1976)

Part 2 Earthquakes Around the World

D. Throughout history, hundreds of thousands of people have been killed by earthquakes. Most of these deaths were caused by the collapse of poorly constructed buildings, or by starvation and disease following the disaster. A list of some of these major earthquakes is given below. Plot the
Figure 183. The positions of British Columbia earthquakes should be plotted on a copy of this map.
Figure 184. Plot the positions of world earthquakes on a copy of this map.
position of each of these with a small X on a copy of the world map in Figure 184.

### Major Historical Earthquakes

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Deaths</th>
<th>Richter Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>526</td>
<td>Antioch, Syria</td>
<td>250,000</td>
<td>unknown</td>
</tr>
<tr>
<td>856</td>
<td>Corinth, Greece</td>
<td>45,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1290</td>
<td>Chihli, China</td>
<td>100,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1293</td>
<td>Kamakura, Japan</td>
<td>30,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1531</td>
<td>Lisbon, Portugal</td>
<td>30,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1730</td>
<td>Hokkaido, Japan</td>
<td>137,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1737</td>
<td>Calcutta, India</td>
<td>300,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1755</td>
<td>Lisbon, Portugal</td>
<td>60,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1755</td>
<td>Northern Iran</td>
<td>40,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1797</td>
<td>Quito, Ecuador</td>
<td>41,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1822</td>
<td>Aleppo, Syria</td>
<td>22,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1868</td>
<td>Peru &amp; Ecuador</td>
<td>40,000</td>
<td>unknown</td>
</tr>
<tr>
<td>1906</td>
<td>San Francisco, U.S.A.</td>
<td>452</td>
<td>8.3</td>
</tr>
<tr>
<td>1906</td>
<td>Valpariso, Chile</td>
<td>20,000</td>
<td>8.6</td>
</tr>
<tr>
<td>1908</td>
<td>Messina, Italy</td>
<td>83,000</td>
<td>7.5</td>
</tr>
<tr>
<td>1920</td>
<td>Kansu, China</td>
<td>100,000</td>
<td>8.6</td>
</tr>
<tr>
<td>1923</td>
<td>Tokyo, Japan</td>
<td>99,330</td>
<td>8.3</td>
</tr>
<tr>
<td>1927</td>
<td>Nan-shan, China</td>
<td>200,000</td>
<td>8.3</td>
</tr>
<tr>
<td>1935</td>
<td>Quetta, Pakistan</td>
<td>30,000</td>
<td>7.5</td>
</tr>
<tr>
<td>1939</td>
<td>Chillan, Chile</td>
<td>28,000</td>
<td>8.3</td>
</tr>
<tr>
<td>1939</td>
<td>Erzincan, Turkey</td>
<td>30,000</td>
<td>7.9</td>
</tr>
<tr>
<td>1946</td>
<td>Courtenay, B.C.</td>
<td>0</td>
<td>7.3</td>
</tr>
<tr>
<td>1949</td>
<td>Queen Charlotte Is., B.C.</td>
<td>0</td>
<td>8.0</td>
</tr>
<tr>
<td>1950</td>
<td>Assam, India</td>
<td>1,530</td>
<td>8.7</td>
</tr>
<tr>
<td>Year</td>
<td>Location</td>
<td>Deaths</td>
<td>Richter Magnitude</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------</td>
<td>--------</td>
<td>-------------------</td>
</tr>
<tr>
<td>1954</td>
<td>Northern Algeria</td>
<td>1,250</td>
<td>6.8</td>
</tr>
<tr>
<td>1956</td>
<td>Northern Afghanistan</td>
<td>2,000</td>
<td>7.7</td>
</tr>
<tr>
<td>1960</td>
<td>Agadir, Morocco</td>
<td>12,000</td>
<td>5.8</td>
</tr>
<tr>
<td>1960</td>
<td>Southern Chile</td>
<td>5,000</td>
<td>8.3</td>
</tr>
<tr>
<td>1963</td>
<td>Skopje, Yugoslavia</td>
<td>1,100</td>
<td>6.0</td>
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<tr>
<td>1964</td>
<td>Valdez, Alaska</td>
<td>1,14</td>
<td>8.5</td>
</tr>
<tr>
<td>1966</td>
<td>Eastern Turkey</td>
<td>2,520</td>
<td>6.9</td>
</tr>
<tr>
<td>1968</td>
<td>Northeastern Iran</td>
<td>12,000</td>
<td>7.4</td>
</tr>
<tr>
<td>1970</td>
<td>Northern Peru</td>
<td>66,794</td>
<td>7.7</td>
</tr>
<tr>
<td>1972</td>
<td>Managua, Nicaragua</td>
<td>5,000</td>
<td>6.2</td>
</tr>
<tr>
<td>1976</td>
<td>Guatamala</td>
<td>22,778</td>
<td>7.5</td>
</tr>
<tr>
<td>1976</td>
<td>New Guinea (West Irian)</td>
<td>443</td>
<td>7.1</td>
</tr>
<tr>
<td>1976</td>
<td>Indonesia (Bali)</td>
<td>500</td>
<td>5.6</td>
</tr>
<tr>
<td>1976</td>
<td>Tangshan, China</td>
<td>655,235</td>
<td>8.2</td>
</tr>
<tr>
<td>1976</td>
<td>Phillipine Is.</td>
<td>8,000</td>
<td>7.8</td>
</tr>
<tr>
<td>1977</td>
<td>Bucharest, Romania</td>
<td>1,541</td>
<td>7.5</td>
</tr>
<tr>
<td>1977</td>
<td>Northwest Argentina</td>
<td>100</td>
<td>8.2</td>
</tr>
<tr>
<td>1978</td>
<td>Tabas, Iran</td>
<td>25,000</td>
<td>7.4</td>
</tr>
</tbody>
</table>

(Delury 1978)

E. Draw a heavy line on your map to show the major "earthquake belt" through North and South America. Draw similar lines through southern Europe and Turkey to India, and through Japan southwards.

F. There are many earthquakes each year in areas where few people live. Draw lines on your map indicating these areas.
### Pacific Ocean Area
- East Pacific Ridge
- Chile Rise
- Aleutian Islands
- Kamchatka Peninsula
- Kuril Ridge
- Marianas Trench
- New Hebrides
- Cocos Ridge
- Kermadec Trench
- Pacific-Antarctic Ridge

### Atlantic Ocean Area
- Mid-Atlantic Ridge
- Atlantic-Indian Ridge
- South Sandwich Trench
- Puerto Rico Trench
- Windward Islands

### Indian Ocean Area
- Southwest Indian Ridge
- Carlsberg Ridge
- Mid-Indian Ridge
- Southeast Indian Ridge
- Andaman Islands

**Questions**

1. Do earthquakes seem to occur more in some areas than in others?

2. Is there any similarity between the earthquake zones and the volcanic areas you plotted in Investigation 15?

3. a) Should people live in active earthquake zones?

   b) Do you live in a major earthquake hazard area? (If necessary, look at Figure 183.)

### Conclusion

What have you learned about earthquakes in this exercise?

**INVESTIGATION 24**

**The Ocean Floor**

Most geologists believe that life on Earth originated in the oceans. In a sense, the ocean is man's original home. And yet, even today we know very little about them. The two-thirds of our planet's surface which lies beneath the
ocean is largely unexplored. In this exercise, you will learn a little about the shape of the floor of the North Atlantic Ocean.

Purpose: to draw a profile of the floor of the North Atlantic Ocean, and to name some of its features.

Procedure

A. Look at a map of the floor of the North Atlantic Ocean. Is it flat or mountainous? Are most of the mountains generally located in the centre of the ocean or along the edges? Where are the deep flat areas generally located? Where are the shallow flat areas generally located?

B. To get a better idea of what the ocean floor looks like, you will next draw a cross-section. Cut a piece of 1 mm graph paper lengthwise into three pieces. Tape the ends together, lining up the markings, so you have a graph about 85 cm long and 7 cm high. (Figure 185).

C. Draw axes on your graph paper so that the horizontal axis represents the ocean surface, and the vertical axis represents depth. Use a scale of 1 cm = 100 km on the horizontal axis, and 1 cm = 1000 m on the vertical axis. (Figure 185).

D. The table below represents distance and depth across the Atlantic from North America to Europe. Plot each point on your graph paper, and connect the points in order with straight lines.
Figure 185. Taping together graph paper for a cross-section of the Atlantic Ocean Floor.

Steepness on the cross-section

Actual steepness

Figure 186. Demonstrating the exaggeration of steepness on the cross-section of the Atlantic Ocean floor.
<table>
<thead>
<tr>
<th>Point Distance (km)</th>
<th>Depth (m)</th>
<th>Point Distance (km)</th>
<th>Depth (m)</th>
</tr>
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<tbody>
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<td>1</td>
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<td>29</td>
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<tr>
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<td>200</td>
<td>30</td>
<td>2900</td>
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<td>400</td>
<td>31</td>
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<td>440</td>
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<td>35</td>
<td>3100</td>
</tr>
<tr>
<td>9</td>
<td>560</td>
<td>36</td>
<td>3190</td>
</tr>
<tr>
<td>10</td>
<td>640</td>
<td>37</td>
<td>3200</td>
</tr>
<tr>
<td>11</td>
<td>660</td>
<td>38</td>
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<td>12</td>
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<td>1400</td>
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<td>1875</td>
<td>47</td>
<td>4090</td>
</tr>
<tr>
<td>21</td>
<td>1890</td>
<td>48</td>
<td>4100</td>
</tr>
<tr>
<td>22</td>
<td>2075</td>
<td>49</td>
<td>4110</td>
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<td>2090</td>
<td>50</td>
<td>4190</td>
</tr>
<tr>
<td>24</td>
<td>2100</td>
<td>51</td>
<td>4225</td>
</tr>
<tr>
<td>25</td>
<td>2210</td>
<td>52</td>
<td>4750</td>
</tr>
<tr>
<td>26</td>
<td>2420</td>
<td>53</td>
<td>4760</td>
</tr>
<tr>
<td>27</td>
<td>2440</td>
<td>54</td>
<td>4770</td>
</tr>
</tbody>
</table>
Point Distance (km)  Depth (m)  Point Distance (km)  Depth (m)
55    4780      4600    61    5625      4600
56    4825      4400    62    5675      4000
57    5150      4200    63    5875      3700
58    5160      200     64    6050      2700
59    5170      4200    65    6075      200
60    5390      4400    66    6100      0

(data after Press, Siever 1978)

E. Just as there are specific names for surface features on the land, such as mountain, valley, plateau etc., there are names for features on the ocean floor. Read the descriptions below, then label an example of each on your cross-section.

a) Continental shelf: shallow area extending seaward from the shoreline.

b) Continental slope: steep area extending from the edge of the continental shelf.

c) Continental rise: gentle slope between the continental slope and the deep ocean floor.

d) Abyssal plain: flat surface on the deep ocean floor.

e) Abyssal hill: relatively small hill, usually less than 1000 m high on the deep ocean floor.

f) Seamount: mountain, probably volcanic, with a steep slope and a small summit, usually more than 1000 m high.

g) Guyot: flat-topped seamount.

h) Mid-Atlantic Ridge: a broad arch occupying approximately the central half of the ocean.

i) Mid-Atlantic Rift: a deep valley near the crest of the Mid-Atlantic Ridge.
F. When something can be folded in half so that the opposite sides match, it is called symmetrical. Fold your cross-section in half at the Mid-Atlantic Rift, then hold it up to the light so you can see the lines you drew. Is the shape of the floor of the Atlantic Ocean approximately symmetrical?

G. The cross-section you drew greatly exaggerates the steepness of parts of the ocean floor. To compare the actual steepness with the graphical steepness, draw two right-angled triangles using the measurements given in Figure 186. Title one triangle, "Actual Steepness of the Continental Slope", and the other triangle, "Steepness of the Continental Slope as Shown on Graph".

Questions

1. What is the approximate length of the Mid-Atlantic Ridge? (Use your atlas).
2. On which part of the ocean floor is most of the sediment from rivers deposited?
3. Describe two different ways in which geologists might obtain rock sample from the ocean floor.

Conclusion

What did you learn about the floor of the Atlantic Ocean in this investigation?
INVESTIGATION 26

Continental Drift

For many years after the South Atlantic Ocean was explored, earth scientists were puzzled by its shape. They noticed the curious similarity in the shapes of the coastlines of Africa and South America, and wondered if they might once have been joined. From this idea grew the theory of continental drift. This theory states that at one time in the distant past, all the continents were joined together into one huge "supercontinent". Then the supercontinent broke apart and the continents slowly moved or "drifted" to their present position on the globe. In this exercise you will check on just how closely the four continents surrounding the Atlantic Ocean fit together.

Purpose: to fit North and South America, Europe and Africa together, and to determine the true edge of each continent.

Procedure

A. Figure 187 shows the outline of each continent along the present day sea level. From a full page copy of Figure 187, use scissors to cut out each continent and Greenland. Starting with the continents in the same general position as they appear today, slide them together until they fit like a jigsaw puzzle. The pieces will not fit perfectly, but do the best you can without overlapping. When you have found the best fit possible, glue the pieces on to a sheet of 1 cm graph paper.

B. Using your jigsaw from Procedure A, count the approximate number of square centimetres of "gap" left between the
continents. Write this number in your notebook.

C. Figure 188 shows the outline of the continental shelf surrounding each continent. Repeat Procedure A with the full page copy of this diagram.

D. As in Procedure B, count the number of square centimetres of gap left between your continents. Write this number in your notebook. Which fit more closely together, the edges of the continents at present day sea level, or the edges of the continental shelves? Would a supporter of the theory of continental drift choose the present day sea level, or the edge of the continental shelf as the "true" edge of each continent?

Questions

1. What made scientists first think that North America, South America, Europe and Africa might once have been joined?

2. How did the discovery of the continental shelves help support this theory?

3. a) During the ice age, 10,000 years ago, was the sea level higher or lower than it is today?
   b) Is there any reason why the present day sea level should be considered to be the true edge of the continents?

4. a) What is the name of the ridge of mountains running down the middle of the Atlantic Ocean?
   b) Which type of rock are these mountains made of, sedimentary, plutonic or volcanic?
   c) If the surface of the Earth is "splitting" along this ridge, how is the gap being filled?
Figure 187. Outlines of continents at the present day sea level.
Figure 188. Outlines of continents along the edges of the continental shelves.
Conclusion

What did you learn about how well the four continents surrounding the Atlantic Ocean fit together?

INVESTIGATION 27

Sea Floor Magnetism

How does a compass work? You probably know already that the Earth acts like a giant magnet, and that a compass needle points to the north and south magnetic poles. Did you know that the magnetic poles move? Their positions actually change slightly from year to year. At present, the north magnetic pole is located on Bathurst Island in the Canadian arctic. Its position is about 1600 kilometres away from the north geographic pole.

Over millions of years, the magnetic field of the Earth has changed considerably. The changes have been studied by scientists, and they can tell us much about the movements of the Earth's crust. In this exercise, you will study some of the results of these studies.

Purpose: to study changes in the Earth's magnetic field recorded on the ocean floor.

Procedure

Part 1 Layers of Lava

A. Which side of your room is north? Examine your compass. How is the needle marked to show which end points north?

B. Look at the pile of boxes put out for you to work with. Each box represents an old lava flow which cooled and hardened. When lava hardens, the iron minerals in the rock
Figure 189. Pile of boxes representing layers of cooled and hardened lava.

Figure 190. Lifting and spreading cards to represent lava spreading from a midocean ridge.
are magnetized in the direction of the Earth's magnetic field. By testing layers of lava, scientists can tell where the Earth's magnetic poles were located, millions of years ago. Copy Figure 189 into your notes. Use your compass to test each model layer of lava (each box). On your diagram, label the magnetic north and south pole directions for each layer. How does the direction of the Earth's magnetic poles change over long periods of time?

C. What you found with the model lava layers is the same as what geologists have found in layered rocks in many parts of the world. What do you think may have happened to cause these results?

Part 2 Undersea Volcanoes

D. (Demonstration). You have seen how lava layers can tell the direction of the Earth's magnetic field millions of years ago. Now you will see what happens when volcanoes erupt lava along a midocean ridge. Your teacher will lift pairs of cards up between a pair of tables (Figure 190), representing eruptions of lava. The direction of the magnetic field is recorded on each card.

E. In your notebook, draw a diagram of the resulting pattern of cards, as seen from above. Record the direction of the magnetic field in each part of the pattern. Where are the youngest rocks located? Where are the oldest rocks located? If the processes of ocean floor spreading and magnetic reversals continue, how will the pattern look in the future?

Part 3 The Ocean Floor

F. Geologists have collected age and magnetic data from rocks
453

on the ocean floor near the Mid-Atlantic Ridge, southwest of Iceland. On a full page copy of Figure 191, mark the data in the table below. Stations 1 and 2 have already been plotted as examples.

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Magnetic Field Symbol</th>
<th>Age (Millions of Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58.8°N</td>
<td>29°W</td>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>58.5</td>
<td>29</td>
<td>Reversed</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>58.8</td>
<td>30</td>
<td>Reversed</td>
<td>X</td>
</tr>
<tr>
<td>4</td>
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<td>31.9</td>
<td>Reversed</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>59</td>
<td>31</td>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>59</td>
<td>29.6</td>
<td>Reversed</td>
<td>X</td>
</tr>
<tr>
<td>7</td>
<td>59</td>
<td>29</td>
<td>Normal</td>
<td>0</td>
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<td>Normal</td>
<td>0</td>
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<tr>
<td>9</td>
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<td>Reversed</td>
<td>X</td>
</tr>
<tr>
<td>10</td>
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<td>31</td>
<td>Normal</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
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<td>30.7</td>
<td>Reversed</td>
<td>X</td>
</tr>
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<td>30</td>
<td>Normal</td>
<td>0</td>
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<td>0</td>
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<td>X</td>
</tr>
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<td>Normal</td>
<td>0</td>
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<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>21</td>
<td>60</td>
<td>28.2</td>
<td>Reversed</td>
<td>X</td>
</tr>
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<td>Station</td>
<td>Latitude</td>
<td>Longitude</td>
<td>Magnetic Field Direction</td>
<td>Symbol</td>
</tr>
<tr>
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<td>----------</td>
<td>-----------</td>
<td>--------------------------</td>
<td>--------</td>
</tr>
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<td>59.8°N</td>
<td>27.8°W</td>
<td>Reversed</td>
<td>X</td>
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<td>Normal</td>
<td>0</td>
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<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>28</td>
<td>61</td>
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<td>Reversed</td>
<td>X</td>
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<td>60.6</td>
<td>31</td>
<td>Reversed</td>
<td>X</td>
</tr>
<tr>
<td>30</td>
<td>61</td>
<td>30</td>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>31</td>
<td>60.8</td>
<td>29</td>
<td>Reversed</td>
<td>X</td>
</tr>
<tr>
<td>32</td>
<td>60.5</td>
<td>28</td>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>33</td>
<td>61</td>
<td>26.7</td>
<td>Reversed</td>
<td>X</td>
</tr>
<tr>
<td>34</td>
<td>60.5</td>
<td>27</td>
<td>Reversed</td>
<td>X</td>
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<td>36</td>
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<td>X</td>
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<tr>
<td>37</td>
<td>61</td>
<td>25</td>
<td>Reversed</td>
<td>X</td>
</tr>
<tr>
<td>38</td>
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<td>30</td>
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<td>0</td>
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<td>Normal</td>
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<td>0</td>
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<td>42</td>
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<td>27</td>
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<td>X</td>
</tr>
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<td>43</td>
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<td>25</td>
<td>Normal</td>
<td>0</td>
</tr>
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<td>44</td>
<td>62</td>
<td>29</td>
<td>Reversed</td>
<td>X</td>
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<td>45</td>
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<td>27.2</td>
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<td>X</td>
</tr>
<tr>
<td>47</td>
<td>62</td>
<td>26.3</td>
<td>Normal</td>
<td>0</td>
</tr>
</tbody>
</table>
Station Latitude Longitude Magnetic Symbol Age (Millions of Years) Field Direction

48 61.7°N 25.6°W Reversed X Present
49 61 27.8 Normal 0 Present

(Woodrow 1970)

G. Use your ruler to draw a straight line through the stations where the rocks are of the present age. Parallel to this, draw straight lines through each of the two groups of 8 million year old rocks. Where do you think the Mid-Atlantic Ridge is located on your map? As you move farther away from the ridge, do the rocks become older or younger? Would you expect the rock at Station 31 to be older or younger than 8 million years? Would you expect the rock at Station 28 to be older or younger than 8 million years? Station 15? Station 25? If the ocean floor is moving, draw arrows on your map to show in which directions the various parts are moving.

H. Use the scale on your map to find the number of kilometres from the Mid-Atlantic Ridge to one of the sets of 8 million year old rocks. Write this distance in your notebook. Change this number of kilometres to centimetres by multiplying by 100 000. Calculate the speed at which the ocean floor near Iceland is moving by dividing your result by 8 000 000 years. How fast is the ocean floor moving, in centimetres per year? Remember that the ocean floor is moving on both sides of the ridge. How fast is the ocean floor spreading in centimetres per year? If you live to the age of 90, how much wider will the Atlantic Ocean
Figure 191. Area of the North Atlantic Ocean where magnetic data was obtained from the sea floor. (After Beck, 1977).
become in your lifetime?

(Beck 1977)

Questions

1. If Europe and North America were once joined, how far out from the Mid-Atlantic Ridge would you expect to find the pattern of magnetic reversals on the sea floor?

2. Explain why the magnetic pattern on one side of the Mid-Atlantic Ridge matches the pattern on the other side of the ridge.

3. Explain why the pattern of rock ages on one side of the Mid-Atlantic Ridge matches the pattern on the other side of the ridge.

4. a) Use your atlas to find an approximate distance across the Atlantic Ocean from Europe to Canada.

   b) Use your results from Procedure H to calculate how long ago Europe and Canada split apart.

Conclusion

How does the evidence presented in this investigation help support the theory of continental drift?

NARRATIVE 28

Polar Wandering

You learned in Investigation 27 that magnetism preserved in rocks may be used to find the direction of the Earth's magnetic field at various times in the past. This rock magnetism may also be used to find approximately where the north magnetic pole was located millions of years ago. When this is done, a strange picture emerges. Figure 192
Figure 192. Former positions of the Earth's north magnetic pole. The numbers represent millions of years ago. (After Tarling 1971).

Figure 193. Moving the continents to match their polar wandering curves produces a fit close to the one obtained by the "jigsaw" method. (After Tarling 1971).
shows the positions of the magnetic pole, using data from South America and from Africa. The path of the pole's movement appears in two different places! Could the north magnetic pole have been in two places at the same time? Is it possible that there might have been two separate north magnetic poles? Both of these suggestions seem to be unlikely. The theory of continental drift however, can be used to explain these unusual results.

If South America and Africa are placed side by side, as you did in Investigation 26, we find that the polar wandering paths coincide. Figure 193 shows how this happens. It appears that for a period of nearly 150 million years, South America and Africa formed a single continent. Then this continent broke apart to form the South Atlantic Ocean. The polar wandering curves provide yet another piece of evidence that the theory of continental drift may be correct. (Peterson, Rigby 1974).

INVESTIGATION 30

Earthquakes and Colliding Plates

Since earthquakes occur wherever rocks are being pushed against and past each other, a great deal of earthquake activity takes place along the edges of plates. In this exercise you will learn how earthquakes can be used to tell us how plates are moving.

Purpose: to see how earthquake location depends on the type of plate boundary.

Procedure
A. Examine a copy of the World Seismicity Map. Read the
information in the "Explanation" box on the map. What magnitude of earthquake do the dots represent? During which years did these earthquakes occur? What magnitude of earthquake do the circles represent? During which years did these earthquakes occur?

B. On the World Seismicity Map, colours are used to indicate the depth of an earthquake. Copy the table below into your notes, then complete the second column.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow (0 to 70 km)</td>
<td></td>
</tr>
<tr>
<td>Intermediate (71 to 300 km)</td>
<td></td>
</tr>
<tr>
<td>Deep (301 to 700 km)</td>
<td></td>
</tr>
</tbody>
</table>

C. Examine Figures 194 to 197 showing four different types of plate boundary. Which diagram best illustrates plate movement along the Mid-Atlantic Ridge? Which diagram best illustrates plate movement in the Himalaya Mountains between India and Asia?

D. The table below gives data about the depth and location of earthquakes along the west coast of South America. Draw graph axes as shown in Figure 198 then plot the data on your graph.

<table>
<thead>
<tr>
<th>Earthquake number</th>
<th>Earthquake depth (km)</th>
<th>Distance (km) and direction from coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>70 West</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>330 East</td>
</tr>
<tr>
<td>3</td>
<td>350</td>
<td>250 E</td>
</tr>
<tr>
<td>4</td>
<td>260</td>
<td>80 E</td>
</tr>
<tr>
<td>5</td>
<td>190</td>
<td>230 E</td>
</tr>
<tr>
<td>6</td>
<td>450</td>
<td>550 E</td>
</tr>
</tbody>
</table>
* Earthquakes.

Figure 194. Plates may slide past each other.

* Earthquakes

Figure 195. Plates carrying continental crust may collide with each other.
Earthquakes

Figure 196. A plate with oceanic crust may be pushed beneath a plate with continental crust.

Earthquakes

Figure 197. Plates with oceanic crust may be pushed apart.
Figure 198. Grid for plotting South American earthquake data in Investigation 29.
<table>
<thead>
<tr>
<th>Earthquake number</th>
<th>Earthquake depth (km)</th>
<th>Distance (km) and direction from coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>130</td>
<td>40 W</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>30 E</td>
</tr>
<tr>
<td>9</td>
<td>650</td>
<td>420 E</td>
</tr>
<tr>
<td>10</td>
<td>280</td>
<td>340 E</td>
</tr>
<tr>
<td>11</td>
<td>70</td>
<td>150 E</td>
</tr>
<tr>
<td>12</td>
<td>440</td>
<td>260 E</td>
</tr>
<tr>
<td>13</td>
<td>520</td>
<td>625 E</td>
</tr>
<tr>
<td>14</td>
<td>90</td>
<td>60 W</td>
</tr>
<tr>
<td>15</td>
<td>500</td>
<td>470 E</td>
</tr>
<tr>
<td>16</td>
<td>50</td>
<td>30 W</td>
</tr>
<tr>
<td>17</td>
<td>270</td>
<td>160 E</td>
</tr>
<tr>
<td>18</td>
<td>80</td>
<td>40 E</td>
</tr>
<tr>
<td>19</td>
<td>170</td>
<td>140 E</td>
</tr>
<tr>
<td>20</td>
<td>630</td>
<td>560 E</td>
</tr>
<tr>
<td>21</td>
<td>520</td>
<td>370 E</td>
</tr>
<tr>
<td>22</td>
<td>360</td>
<td>400 E</td>
</tr>
<tr>
<td>23</td>
<td>350</td>
<td>150 E</td>
</tr>
</tbody>
</table>

E. Moving inland from the coast, do the earthquakes become deeper or shallower? Which of the plate boundaries shown in Figures 194 to 197 best seems to show what is happening in South America? Name the plates which are colliding there. Which plate is being subducted beneath (pushed under) the other? Name the range of mountains which has been created by this collision.

F. Examine the World Seismicity Map again. Notice the pattern of coloured dots showing earthquake depths in South America.
Name three other places in the world which appear to have plate boundaries similar to the one in South America. For each location you named, give the names of the two plates involved, and say which one is being subducted beneath the other. (Lowman 1978)

Questions

1. Use your atlas to find the name of the deep sea trench where subduction is taking place on the west coast of South America.

2. As the subducted plate is pushed deeper, it melts to form magma. What type of mountain is produced if some of this magma finds its way to the surface of the Earth?

3. Describe the type of plate boundary which best accounts for the earthquake activity along the Queen Charlotte Fault, just off the coast of British Columbia.

Conclusion

What have you learned about earthquakes and plate boundaries in this investigation?
INVESTIGATION 34

Identification of Minerals

Do you recall your study of plutonic rocks in Investigation 17? In that exercise you found that plutonic rocks were made up of large crystals, all interlocked. Each of those crystals could be called a mineral. A mineral is a naturally occurring element or compound. For example, the transparent crystals in granite are all crystals of the mineral quartz. No matter where they are found, all pieces of quartz are made of the same chemical compound, silicon dioxide. All pieces of quartz have the same chemical formula, \( \text{SiO}_2 \). Another (more valuable) example is gold. All nuggets of the mineral gold are made of the same element with the chemical symbol Au.

A prospector must be able to recognize valuable minerals when he finds them. To do this, he uses a number of simple identification tests. In this exercise, you will learn how to perform some of these tests.
Purpose: to learn some identification tests for minerals.

Procedure

Part 1 Testing Minerals

A. Colour. Some minerals may be easily identified by their colour. Others may be less easy to identify. Record the colours of each of the named samples in a table.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur</td>
<td></td>
</tr>
<tr>
<td>Garnet</td>
<td></td>
</tr>
<tr>
<td>Magnetite</td>
<td></td>
</tr>
<tr>
<td>Chromite</td>
<td></td>
</tr>
</tbody>
</table>

B. Streak. Rubbing a mineral across a plate of unglazed porcelain leaves a mark on the plate. The mark is called a streak, and the porcelain plate a streak plate. The colour of the streak is the same as the colour of the finely powdered mineral. In a table, record the streaks of the named minerals.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Streak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromite</td>
<td></td>
</tr>
<tr>
<td>Magnetite</td>
<td></td>
</tr>
<tr>
<td>Hematite</td>
<td></td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td></td>
</tr>
</tbody>
</table>

C. Lustre. This term refers to the appearance of the light reflected from a mineral. The following words are used to describe the lustre of a mineral:

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic</td>
<td>Shines like a metal</td>
</tr>
<tr>
<td>Adamantine</td>
<td>Diamond-like</td>
</tr>
</tbody>
</table>
Record the lustre of the following minerals, using the terms above.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Lustre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td></td>
</tr>
<tr>
<td>Limonite</td>
<td></td>
</tr>
<tr>
<td>Feldspar</td>
<td></td>
</tr>
<tr>
<td>Fluorite</td>
<td></td>
</tr>
<tr>
<td>Talc</td>
<td></td>
</tr>
<tr>
<td>Galeha</td>
<td></td>
</tr>
</tbody>
</table>

D. Hardness. Hardness is the resistance of a mineral to scratching. A German mineralogist, Friedrick Mohs, arranged certain minerals into a hardness scale.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Hardness number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talc</td>
<td>1</td>
<td>Very soft, soapy feel</td>
</tr>
<tr>
<td>Gypsum</td>
<td>2</td>
<td>Scratched by a fingernail</td>
</tr>
<tr>
<td>Calcite</td>
<td>3</td>
<td>Scratched by a copper penny</td>
</tr>
<tr>
<td>Fluorite</td>
<td>4</td>
<td>Easily scratched by a needle</td>
</tr>
<tr>
<td>Apatite</td>
<td>5</td>
<td>Scratched by a needle</td>
</tr>
<tr>
<td>Feldspar</td>
<td>6</td>
<td>Scratched by a steel file</td>
</tr>
<tr>
<td>Quartz</td>
<td>7</td>
<td>Scratches steel and hard glass</td>
</tr>
</tbody>
</table>
A hardness scale using common materials is:

<table>
<thead>
<tr>
<th>Name</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fingernail</td>
<td>2.5</td>
</tr>
<tr>
<td>Copper penny</td>
<td>3</td>
</tr>
<tr>
<td>Knife blade</td>
<td>5.5</td>
</tr>
<tr>
<td>Scratches glass</td>
<td>5.5</td>
</tr>
<tr>
<td>Steel file</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Find the hardness of each of the following minerals.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galena</td>
<td></td>
</tr>
<tr>
<td>Garnet</td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td></td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td></td>
</tr>
</tbody>
</table>

E. Cleavage. This describes the tendency of a mineral to split or cleave more easily in certain directions. Cleavage may occur on one, two, or more planes (Figure 199). Examine the following minerals, and state how many cleavage planes each has.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Number of cleavage planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcite</td>
<td></td>
</tr>
<tr>
<td>Feldspar</td>
<td></td>
</tr>
<tr>
<td>Mica</td>
<td></td>
</tr>
</tbody>
</table>
Cleavage patterns of minerals.

Figure 199. Cleavage patterns of minerals.
F. Density. Density is the mass of a specific volume of material, determined by its atomic structure. It is usually expressed in kilograms per cubic metre, or sometimes in grams per cubic centimetre. A geologist in the field seldom has the equipment to measure density precisely, so he must learn to estimate. Examine the following approximately equal sized mineral specimens. By holding the samples in your hand to compare their masses, list them in order of increasing density.

Galena, gypsum, barite, pyrite.

G. Crystal form. Occasionally, minerals may be found shaped in regular geometric forms. These are crystals. The shape of the crystal of a mineral depends upon the way in which its atoms are arranged. Examine and sketch crystals of the following minerals.

Quartz, calcite, pyrite, galena, tourmaline.

Part 2 Identifying Minerals

Many prospectors are interested only in minerals which are worth mining. From the following descriptions, identify the following ore samples. Record your results in a table.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Mineral</th>
</tr>
</thead>
</table>

Skutterudite (cobalt ore): hardness - 5.5; colour - steel grey; lustre - metallic; streak - greyish black; density - 6 g/cm$^3$.

Galena (lead ore): hardness - 2.5; colour - lead grey; lustre - metallic; streak - greyish black; density - 7.5 g/cm$^3$;
crystal shape — cubic.

**Pyrite (fool's gold):** hardness — 6 to 6.5; colour — pale brass yellow; lustre — metallic; streak — greenish brownish black; density — 5.0 g/cm³; crystal shape — cubic.

**Magnetite (iron ore):** hardness — 5.5 to 6.5; colour — black; lustre — slightly metallic; streak — black; density — 5.2 g/cm³; magnetic.

**Hematite (iron ore):** hardness — 5 to 6; colour — red, brown or black; lustre — metallic, dull or earthy; streak — red or reddish brown; density 5.0 g/cm³.

**Molybdenite (molybdenum ore):** hardness — 1 to 1.5; colour — bluish lead grey; lustre — metallic; streak — greenish grey, bluish grey on paper; density — 4.7 g/cm³. (Zim 1957).

Questions

1. What is a mineral?
2. a) Is granite made up of only one mineral?
   b) Explain the difference between a rock and a mineral.
3. Explain the difference between colour and streak.

Conclusion

What did you learn about minerals in this exercise?

**NARRATIVE 35**

**A Final Thought**

In this course you have learned about a great many topics — rocks, fossils, and plate tectonics to name just a few. At one time, people studied the Earth in order to use it for the greatest monetary gain. Now we learn about the Earth so we can preserve it. Without care and
understanding, the planet will die, and so will we.