topic XIII

How Can Geologic History Be Interpreted?

Time Emphasis: 15 days

TOPIC OUTLINE

INVESTIGATION		A-1a	A-1b	B-1a	C-1a	C-1b	C-2a	D-1a	FE - #1
Estimated Time (Periods)		2	1	0½	1½	1½	1½	2	
A. Geologic events									
A-1 Sequence of geologic events	*How Can the Order in Which Geologic Events Occurred Be Determined?*								
A-1.1 Chronology of layers	A-1.11		■						■
A-1.2 Igneous intrusions, and extrusions	A-1.21		■						
A-1.3 Faults, joints, and folds	A-1.31	■	■						
A-1.4 Internal characteristics	A-1.41								
	A-1.42								
B. Correlation techniques									
B-1 Correlation	*How Can Rocks and Geologic Events in One Place Be Matched to Another?*								
B-1.1 Continuity	B-1.11	■	■						
B-1.2 Similarity of rock	B-1.21	■	■						
B-1.3 Fossil evidence	B-1.31		■	■					
	B-1.32			■					
	B-1.33	■							
B-1.4 Volcanic time markers	B-1.41		■						
B-1.5 Anomalies to correlation	B-1.51								
C. Determining geologic ages									
C-1 Rock record	*What Does the Rock Record Suggest About Geologic History?*								
C-1.1 Fossil evidence	C-1.11				■	■			
C-1.2 Scale of geologic time	C-1.21								
	C-1.22				■				
	C-1.23				■				
C-1.3 Erosional record	C-1.31		■			■			
C-1.4 Geologic history of an area	C-1.41					■			
C-2 Radioactive decay	*How Can Geologic Ages Be Measured by Using Radioactive Decay?*								
C-2.1 Decay rates	C-2.11								
	C-2.12						■		
	C-2.13						■		
	C-2.14								
C-2.2 Half lives	C-2.21								
	C-2.22						■		
C-2.3 Decay product ratios	C-2.31								

			A-1a	A-1b	B-1a	C-1a	C-1b	C-2a	D-1a	FE - #1
	INVESTIGATION		A-1a	A-1b	B-1a	C-1a	C-1b	C-2a	D-1a	FE - #1
	Estimated Time (Periods)		2	1	0½	1½	1½	1½	2	
TOPIC OUTLINE	D. The fossil record									
	D-1 Ancient life		*What Does the Fossil Record Suggest About Ancient Life?*							
	D-1.1 Variety of life forms	D-1.11								
		D-1.12							■	
	D-1.2 Evolutionary development	D-1.21							■	
		D-1.22							■	
		D-1.23							■	
PROCESS OF INQUIRY OBJECTIVES	Mathematical Skill	PIO-1	■			■		■	■	■
	Measurement Skill	PIO-2	■			■				■
	Creating Models	PIO-3	■	■	■	■	■	■		■
	Analysis of Error	PIO-4				■				
	Data Analysis	PIO-5	■	■			■	■	■	
TITLES			Geologic History of N.Y.S.	Geology of the Grand Canyon	Footprint Puzzles	Geologic Time Line	Correlating Rock Outcrops	Radioactive Decay	Variation Within a Species	School Building and Grounds

Multimedia: Check Multimedia Section of Supplement for reference to this topic.

Challenging (2)

XIII-A-1a: GEOLOGIC HISTORY OF N.Y.S.

QUESTION:

How can the order in which geologic events occurred be determined?

MATERIALS:

1. Student handout sheets and supplementary sheet.
2. Optional materials include:
    a) Educational leaflet #20, Geology of N.Y.S., a short account.
    b) N.Y.S. road map
    c) Slides or photographs of rock outcrops and surface features along each one of the cross-sectional routes

SUGGESTED APPROACH:

1. Ask the students to study the N.Y.S. geologic map for the particular symbols used, scale, etc. Ask the students to suggest possible cross-sectional models that would explain the pattern of rock outcrops observed on their geologic map.
2. Have students determine over which rock layers they would move if they traveled from Olean to Buffalo, and from Binghamton to Syracuse to Watertown.
3. Have the students examine the Geologic Structure Section (see supplementary sheet #1). Be sure they understand the symbols used and the concept of a structure diagram.

PRECAUTIONS:

1. Make certain students understand that the cross-sectional diagrams have an exaggerated vertical scale.
2. The cross sections are drawn to a larger scale than their geologic maps.

MODIFICATIONS:

1. Use New York State locations other than those suggested above. If at all possible, use your own location.
2. See Investigation 20-1, *Investigating the Earth*, 1965 edition. (paperback).
3. Give students necessary data, such as dip of bedrock, elevation of outcrops, direction of dip, type of bedrock, etc., and have them construct a structural cross section.

4. Have the students use stereo pairs of photographs, and, on a transparent plastic overlay, have them trace a particular formation along its outcrop. This would be similar to walking the outcrop. This can be done in one of the stereo booklets available from several suppliers.

   If the stereo-pair booklet is not available, individual stereo pairs may be obtained from the Map Information Office, U.S. Geological Survey, General Services Administration Building, Washington, D. C. 20242, at a cost of $1.00 per 9"x9" photograph. The following are recommended:

   Arizona set #4 - consisting of 3 photos
   Wyoming set #7 - consisting of 2 photos

   For other possibilities, refer to U. S. Geologic Survey Professional Paper #590, Selected Aerial Photographs of Geologic Features in the U. S.

REFERENCES:

1. *Geology of New York*, Educational Leaflet #20, New York State Museum and Science Service (this includes both a descriptive text and a geologic map; one copy is free to each New York teacher who requests it, (additional copies are $1.).

2. For information regarding the following areas: Watkins Glen, Niagara Falls, Cayuga and Keuka Lakes, Lake Ontario, see *Problem Book* and *Teacher's Guide*, SRA, Inquiry Development Program in Earth Science.

Do Not Print

XIII-A-1a: GEOLOGIC HISTORY OF N.Y.S.

QUESTION:

How can the order in which geologic events occurred be determined?

INTRODUCTION:

What type of bedrock is beneath the soil you walk on? How old is it? How did it form? How far would you have to go to find a different kind of bedrock? In which direction?

OBJECTIVES:

When you have finished this investigation, you should be able to:

1. determine from a geologic map the type of bedrock present at a given location, and relate a subsurface cross section to it.

2. deduce, from the type of rock present, a general geologic history of the area.

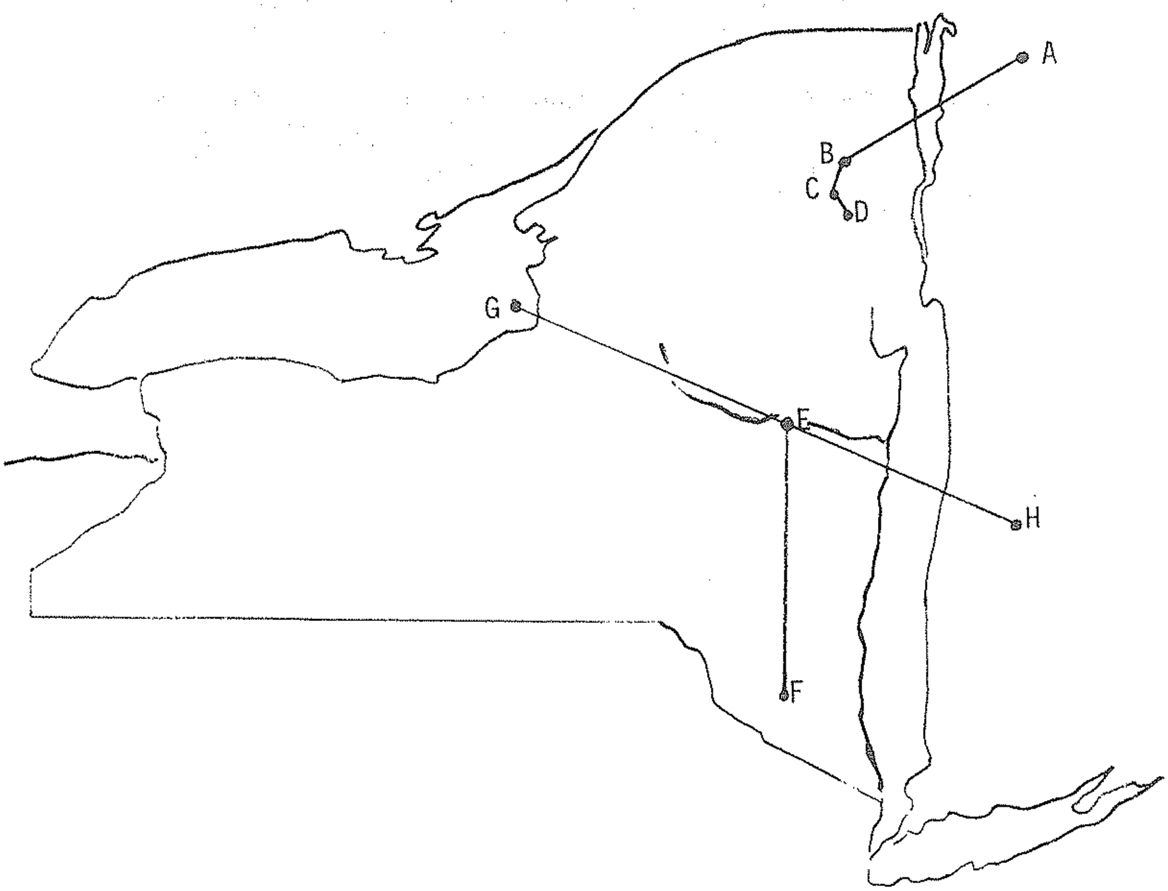
METHOD:

1. Study your geologic map of New York State carefully. (See Student Reference Tables.) Determine the meaning of all symbols used as well as the scale.

2. Study the Geologic Structure sections on the Supplementary Sheet. On the Diagram (next page), the points A, B, C, D, etc., are positioned for you. They are not drawn to the same scale as your geologic map.

3. Locate on your geologic map the general positions of lines: A-B-C-D, E-F, and G-H (If you wish to draw them on your map, use a lead pencil so the lines can be removed.)

4. A New York State road map may be helpful in locating some of the towns mentioned.



QUESTIONS:

1. If you could drill a hole at Binghamton, what rock layers would you pass through? List them in order of age. How do you know?

2. Approximately how thick is each of the layers listed in the answer to question one? How do you know the thickness of the top and bottom layers?

3. Does the area between Binghamton and Syracuse have the same geologic history as the northeastern part of the State? The same rock type? Which area is older? Explain.

(B-1.11) 4. If you walked along the banks of the Mohawk River, where would you find outcrops of Ordivician rock? Of Silurian rock?

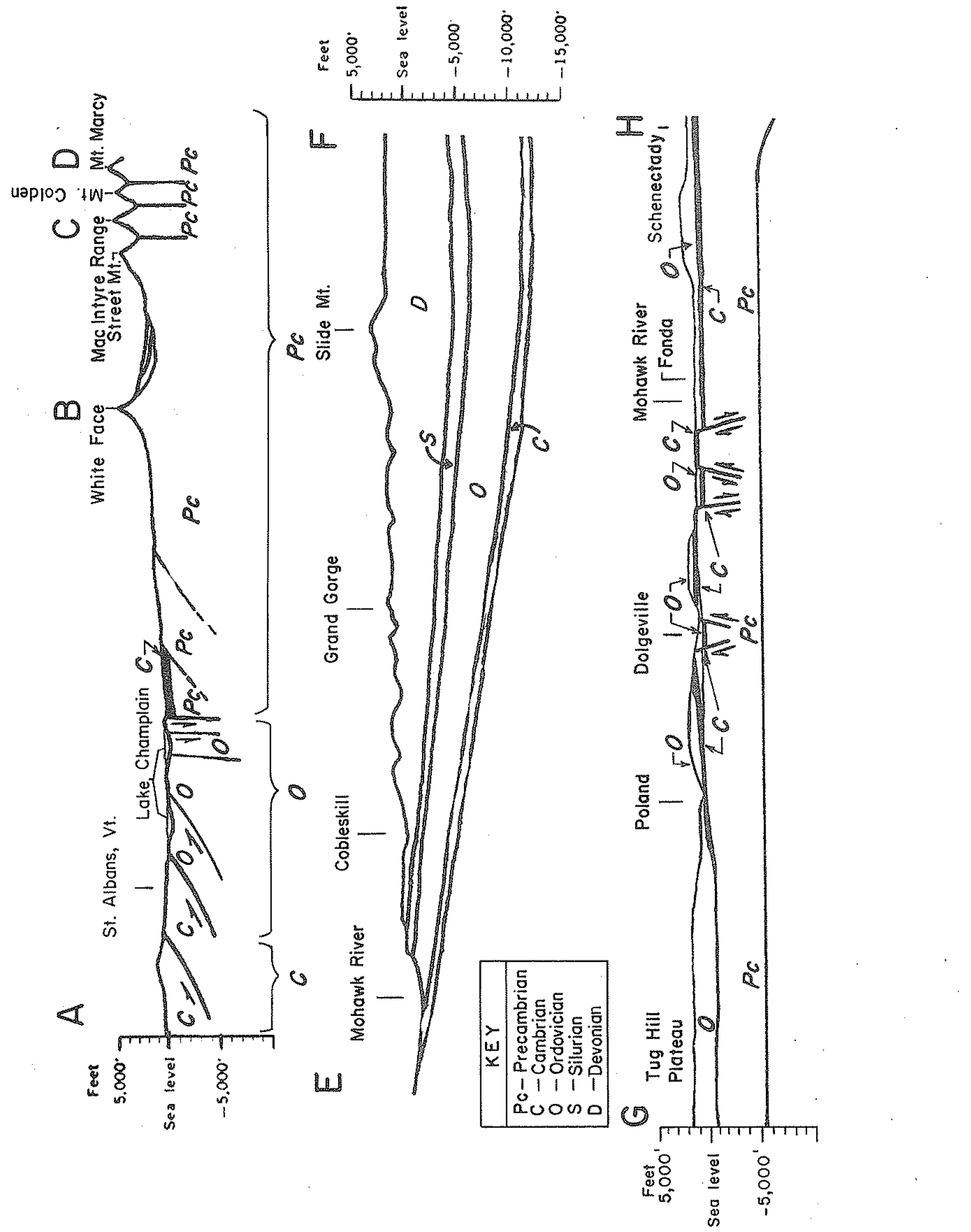
(A-1.31) 5. Note the arrows near Dolgeville on cross section (G-H). What do they represent? What is their age relative to the rocks in which they are found? Explain.

(B-1.11) 6. How could you trace the extent of a particular rock layer, for the purpose of drawing a geologic map of an area?

(B-1.21) 7. What evidences would you use to determine if you were on the same rock layers as you traveled along a route?

(B-1.33) 8. Certain fossils, such as, favosites which are found mainly in Silurian rocks of New York State are also found in other parts of the world. What does this suggest about the rocks in these other areas?

GEOLOGIC STRUCTURE SECTIONS



LIST OF GUIDEBOOKS AVAILABLE FROM NEW YORK STATE GEOLOGICAL ASSOCIATION

Information on Field Guidebooks

Please understand that the Association is not in the publishing business and that the Office of the Permanent Secretary has no salaried staff but operates free-of-charge as a service to the geological profession.
Financial transactions, therefore, must be kept at a minimum.

Orders for guidebooks (see listing of contents) will be filled postpaid upon receipt of cash, check, or money order made payable to Philip C. Hewitt, Secretary, New York State Geological Association, State University College, Brockport, New York, (see price list below). Please order by year of publication.

1957 through 1965 guidebooks......... $2.50 per copy
1966 and 1967 guidebooks............. $3.25 per copy
1968 guidebook....................... $6.00 per copy

IMPORTANT: Invoices, order forms, standing orders, etc. cannot be processed.

NOTE: The Association maintains a nearly complete permanent file of field notes and guidebooks of the Association Meetings (1925 to present) which may be consulted by interested parties at the Office of the Permanent Secretary, Department of Geology and Earth Science, State University College at Brockport, New York 14420.

List of Field Guidebooks

1957	29th Annual	Meeting, Wellsville, N.Y. (N.Y. State Geological Survey) (60 printed pages, 3 fold-out maps)	$2.50
1958	30th Annual	Meeting, Peekskill, N.Y. (The City College of N.Y.) Field Trips and Pertinent Articles: (62 printed pages, 7 fold-out maps)	2.50
1959	31st Annual	Meeting, Ithaca, N.Y. (Cornell University) (48 printed pages)	2.50
1960	32nd Annual	Meeting, Clinton, N.Y. (Hamilton College) (66 printed pages, 3 fold-out maps)	2.50
1961	33rd Annual	Meeting, Troy, N.Y. (R.P.I.) (101 printed pages)	2.50
1962	34th Annual	Meeting, Port Jervis, N.Y. (Brooklyn College) (81 printed pages, 4 fold-out maps)	2.50
1963	35th Annual	Meeting, Binghamton, N.Y. (Harpur College) (98 printed pages, 5 fold-out maps)	2.50
1964	36th Annual	Meeting, Syracuse, N.Y. (Syracuse University) (126 printed pages, 1 fold-out map)	2.50
1965	37th Annual	Meeting, Schenectady, N.Y. (Union College) (122 printed pages, 2 geologic color maps)	2.50
1966	38th Annual	Meeting, Niagara Falls, N.Y. (State Univ. of N.Y. at Buffalo) (139 printed pages)	3.25
1967	39th Annual	Meeting, Newburgh, N.Y. (State University College at New Paltz) (150 printed pages, 3 fold-outs with map & sections)	3.25
1968	40th Annual	Meeting, Flushing, N.Y. (Queens College, City University of N.Y.) (253 printed pages, 5 fold-out maps)	6.00
1969	41st Annual	Meeting, Plattsburgh, N.Y. (State University College)	
1970	42nd Annual	Meeting, Cortland, N.Y. (State University College)	

Do Not Print

Easy (1)

XIII-A-1b: GEOLOGY OF THE GRAND CANYON

QUESTION:

How can the order in which geologic events occurred be determined?

MATERIALS:

Student sheets, slides, maps, plastic models, stereo aerial photographs, and/or fossils of the Grand Canyon.

SUGGESTED APPROACH:

1. Discuss terms such as intrusion, unconformity, fault, etc.
2. Slides or filmstrip of Grand Canyon may be shown if available.
3. Permit students to complete the lab as a homework assignment.

PRECAUTIONS:

1. The Grand Canyon is such a vast area that you should center student attention on only portions of it at any one time. They can be successful in interpreting single events, but do not ask them to interpret the history of the entire Canyon all at once.
2. Be prepared to help, by questioning, students who quickly become "lost" in the complexity of the Canyon.
3. Encourage students to constantly relate back to the materials used in step 1 while answering the questions.

BACKGROUND INFORMATION:

At the base of the Grand Canyon is the Vishnu Schist, a sedimentary-derived rock. The first step was probably the deposition of sediments in a shallow sea. The thickness of the material is estimated to exceed 5 miles. Based on studies of the rock's composition, the rate of deposition approximately equaled the rate of subsidence in the depositional basin. The Vishnu materials were further buried deeply enough to initiate metamorphism of the materials along with associated volcanic activity.

Uplift, as at least deformation of the crust, caused the metamorphism to be completed. At this time, igneous intrusions and/or recrystallization produced granitic material.

Uplift and succeeding erosion produced a peneplane-like surface. Next, subsidence and deposition resulting in the Grand Canyon series, more than 12,000 feet thick, occurred. In turn, these were uplifted, block faulted, and eroded.

Submergence and deposition occurred repeatedly to produce the various unconformities that appear in the layers.

As a "final" step, the Colorado River eroded a channel, and as uplifting continued, the river became entrenched and the canyon deeper until the present depth of more than 1 mile was achieved.

XIII-A-1b: GEOLOGY OF THE GRAND CANYON

QUESTION:

How can the order in which geologic events occurred be determined?

INTRODUCTION:

One of the foremost tourist attractions in the U.S. today is the Grand Canyon. To the average person, it is a place of beauty and wonder, too large for the mind to comprehend. To the earth scientist, it represents one of the best examples of geologic history in the world.

On the upper levels of the canyon, normal seasonal changes are observed, while on the canyon bottom the climate remains the same the year around.

The exposed rock ranges from Precambrian age through Paleozoic and Mesozoic to Eocene. It is, at the same time both young and old, inviting and forbidding, peaceful, and violent.

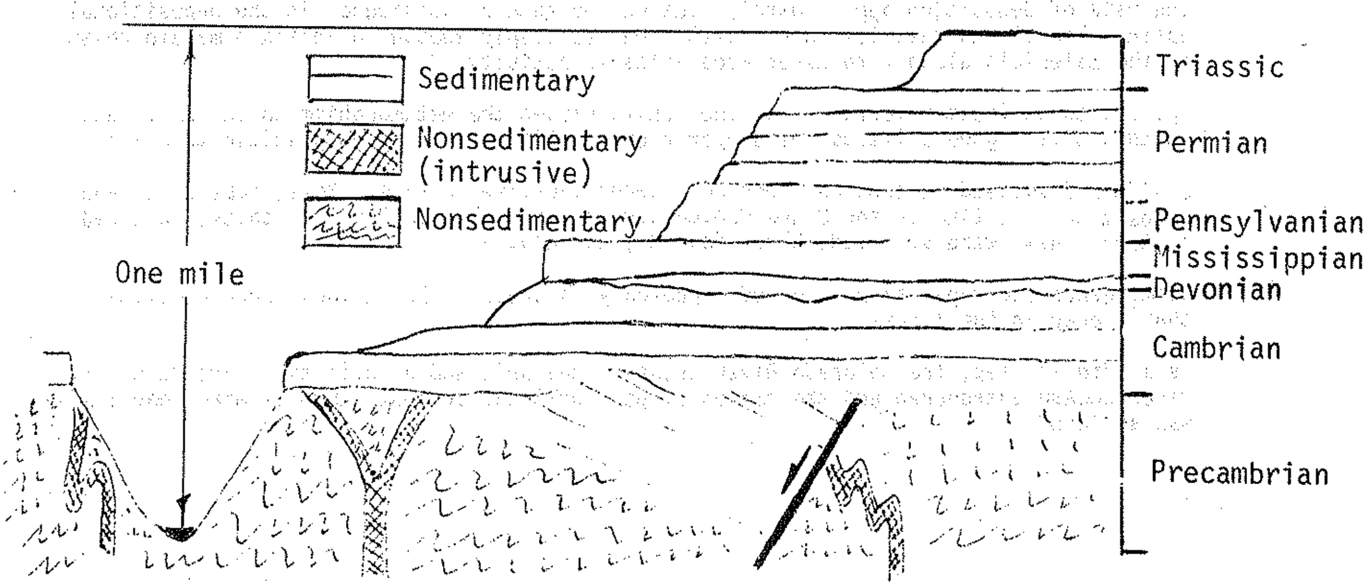
OBJECTIVES:

When you finish this investigation, you should be able to:

1. determine relative ages of rocks and make inferences about the geologic events which produced them.

METHOD:

Examine the diagram below and answer the following questions:



QUESTIONS:

(A-1.11)
(A-1.21) 1. Which rocks are older, the sedimentary or nonsedimentary ones? Explain.

(A-1.21) 2. What is the age of the intrusive rocks relative to the rocks surrounding them?

(C-1.31) 3. What does the irregular surface between the sedimentary and nonsedimentary rocks suggest?

(A-1.31) 4. Notice the arrow indicating movement along a fault. What is the age of this fault relative to the Precambrian rocks? To the Cambrian rocks?

(B-1.11) 5. If you wanted to trace the boundary of Triassic rock in order to draw a surface map, how could you do it?

(B-1.21) 6. How could you determine if a rock at a particular elevation on one side of the canyon was the same as one at an identical elevation on the other side?

(B-1.31) 7. In which rocks would you most likely find fossils? In which ones would they most likely not be present? Explain.

(B-1.41) 8. From the diagram, and your knowledge of earth science, give a brief geologic history of this particular region of the Grand Canyon.

Easy (.5)

XIII-B-1a: FOOTPRINT PUZZLES

QUESTION:

How can rocks and geologic events in one place be matched to another?

MATERIALS:

Student sheet containing first section of fossil footprints, transparencies containing entire puzzle which can be blocked out in sections. (See Supplementary Sheet #1)

SUGGESTED APPROACH:

1. As a homework assignment, give students the first section of the footprint puzzle. Ask them to interpret what might have taken place to result in such footprints and whether they can tell anything about the size or type of animals that made them. Do not mention that there is more to come until the second day when the new-found evidence is introduced.

2. Remind students that the paleontologist is a type of detective who tries to reconstruct the past, and, in doing so, he forms a number of hypotheses, the best of which are supported by the greatest amount of evidence. Use a transparency of the homework section of footprints, and have students describe their interpretations and their evidence.

3. Show a transparency of the second portion of the footprints, and ask if anyone wants to modify his interpretation or has evidence for a new one.

4. Project the completed puzzle, and ask for completion of the interpretation. Accept any reasonable interpretation that is consistent with all the evidence. Encourage students to criticize each other's interpretations and to defend their own with evidence. Remember, there is no one right answer.

5. Remind the students of I-A-1b - Puddle Observations.

PRECAUTIONS:

1. Do not reproduce Supplementary Sheet #1 for student use.

2. Do not prejudice students toward accepting one interpretation as the correct one.

3. Be sure students make interpretations that are directly derived from the data and are consistent with them.

4. If you feel it is important for students to realize they are working with dinosaur footprints you may have to tell them so. Most students seem to favor birds unless reminded of the age or told a size scale.

TYPICAL RESULTS:

A class can develop several hypotheses that are defensible. Some examples are enemies fighting, a mother picking up a baby, one of the animals flies away, and the tracks have been made at separate times.

MODIFICATIONS:

Have students:

1. Make casts and molds of present-day animal tracks.
2. Interpret present-day animal tracks.
3. Make their own tracks in as many different ways as possible (running, hopping, crawling, skipping, etc.), and present them to each other as puzzles.

REFERENCES:

Investigating the Earth, p. 416, Teacher's Guide, pp. 522-523, 525-527

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XIII-B-1a: FOOTPRINT PUZZLES

QUESTION:

How can rocks and geologic events in one place be matched to another?

INTRODUCTION:

The scientists who study fossils, paleontologists, are like detectives, trying to reconstruct the geologic past from scattered clues and incomplete evidence. Like detective work, the clues and evidence always can be interpreted in more than one logical way; there are only better and worse hypotheses, not right and wrong ones. In this investigation, you will work with a set of fossil footprints and, based on the evidence, hypothesize the action that might have taken place to produce them.

OBJECTIVES:

When you finish this investigation, you should be able to:

1. interpret the footprints as a record of some event that occurred in the geologic past.
2. describe a probable action occurring during the event.

METHOD:

1. Study the fossil footprints. Write an interpretation of what may have taken place.

A

QUESTIONS:

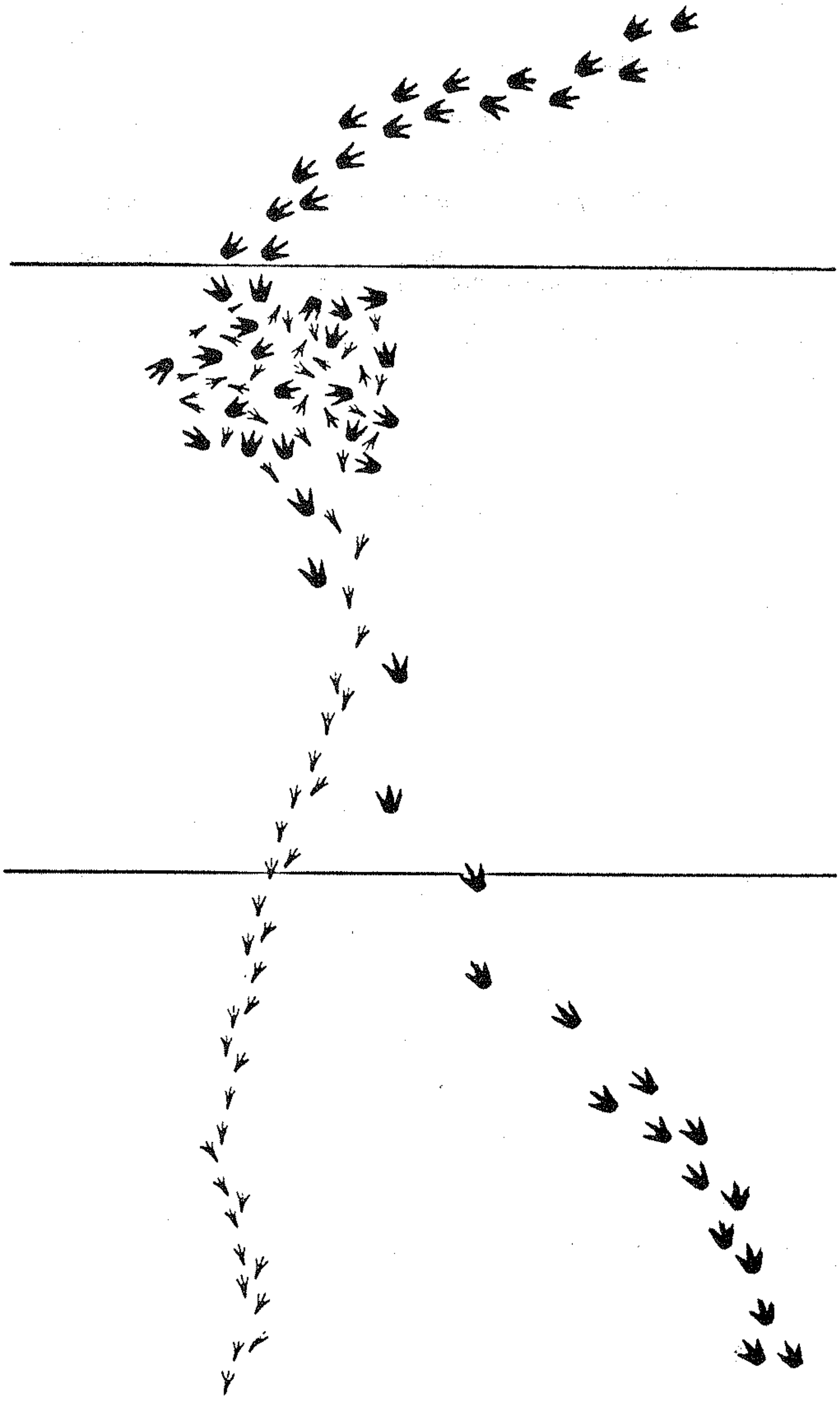
1. What kind of animals do you think made the footprints? How big were they? Why do you think so?

2. What event occurred that caused the footprints? Why do you think so?

3. Could any other events have caused the footprints? Why?

(B-1.32) 4. What sort of environment do you think this was at the time the footprints were made? Why?

(B-1.31) 5. Were the footprints found in sedimentary or nonsedimentary rock? Explain.



Adapted from:
Investigating the Earth, Teacher's Guide

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XIII-C-1a: GEOLOGIC TIME LINE

QUESTION:

What does the rock record suggest about geologic history?

MATERIALS:

Adding machine tape, at least 5 meters long per student, list of events and ages of things in the geologic past (see Supplementary Sheet), and meter sticks.

SUGGESTED APPROACH:

1. Briefly discuss the expanse of geologic time with the students. Ask them how a model could be constructed to represent the expanse of geologic time.
2. Give the students the list of events and ages, and instruct them to make a time line that will include every item on the list. Suggest that they decide on the scale they want to use before making any marks on the adding machine tape. If any students want more or less than 5 meters of tape, allow them to have it.
3. Have the students compare their time lines; this can be done easily by lining up the lines on the floor or taping them to the wall. Discuss with them any questions or problems resulting from the time line.
4. If possible, permit the students to use an area of the gym or corridor so they can get a better idea of the relative lengths of time.
5. In postlab, impress upon the students ideas such as:
   A. man's recent arrival upon the scene
   B. the long periods which were apparently "lifeless," or at least left few or no fossils
   C. there are popular misconceptions such as the cave man living during the age of dinosaurs

PRECAUTIONS:

1. Some students have a great deal of difficulty establishing a scale and marking it on the tape. Check every student after the first few minutes of work.
2. Don't turn this into an art project. However, neatness and accuracy should be encouraged.
3. Allow enough time at the end of the period to roll up the longer strips of paper.
4. The teacher may want to update the chart yearly to keep the numbers accurate.

TYPICAL RESULTS:

Unless students are careless, most of them should have their tapes scaled correctly and most of the items placed correctly on the time line. Many will have difficulty with the more recent dates and will want to change their scales so that they can fit in everything. You might ask several students to determine how long a strip they would need in order to fit everything on it. In some cases, it may extend to over 30 meters.

MODIFICATIONS:

1. If you have included astronomy in your course, you may want to have students make a double-scaled time line and on the second scale place astronomical objects and their estimated distances in light-years.

REFERENCES:

Investigating the Earth, pp. 384-387, Teacher's Guide, pp. 475-478

XIII-C-1a: GEOLOGIC TIME LINE

QUESTION:

What does the rock record suggest about geologic history?

INTRODUCTION:

Most of the geologic events we have studied happened a very long time ago, but it is difficult for most of us to comprehend the vastness of time that has passed since these events occurred. In this investigation, you will make a geologic time line which will help you to visualize the relationship of these past events to present events in geologic time.

OBJECTIVES:

When you finish this investigation, you should be able to:

1. construct a time line which includes these dates.
2. compare the existence of living things on the earth with the entire extent of geologic time.
3. compare man's existence on the earth with the entire range of geologic time.

METHOD:

1. Examine the list of events and ages. Determine a scale for your time line and obtain a section of adding machine tape long enough to include all the events.
2. Plot the time line according to your scale. Include all the listed events.
3. Plot the geologic eras (e.g. Pre-Cambrian, Cambrian, Ordivician, etc.) using your reference table as a source of information.
4. Compare your time line with those of others.

QUESTIONS:

(C-1.23) 1. How does man's existence on earth compare with the duration of geologic time?

(C-1.22) 2. For what percentage of time has there been evidence of life on earth?

3. Did you have difficulty plotting any of the events on the list? Why?

(C-1.11) 4. What information, prior to recorded knowledge, was used to place the events in geologic history in order? Before this information can be used in this manner, what ideas or concepts must be accepted? Explain.

SUPPLEMENTARY SHEET

Geologic Time Line

1.	Inferred age of the earth (based on meteorite and moon rock evidence)	4.5×10^{9} yrs. (before the present)
2.	Oldest rocks found on earth	3.3×10^{9} yrs.
3.	Carbon from plants (algae) Rhodesia	2.6×10^{9} yrs.
4.	Fungi - Canada	1.7×10^{9} yrs.
5.	Early sponges (archaeocyathids)	6.0×10^{8} yrs.
6.	Ostracoderm (jawless fishes, earliest vertebrate)	4.8×10^{8} yrs.
7.	Coal age forests and Appalachian Mountains	3.3×10^{8} yrs.
8.	First mammal-like reptiles	2.25×10^{8} yrs.
9.	Rise of dinosaurs	2.0×10^{8} yrs.
10.	First birds (Archaeopteryx), huge dinosaurs	1.5×10^{8} yrs.
11.	Dinosaurs died, Rocky Mountains rose	8.0×10^{7} yrs.
12.	Modern mammals, first horse (Hydrachotherium)	5.0×10^{7} yrs.
13.	The Great Plains, elephants come to North America	1.8×10^{7} yrs.
14.	First man (Homo habilis) - Africa	1.72×10^{6} yrs.
15.	Last U.S. continental glacier	1.0×10^{4} yrs.
16.	Beginning of Julian calendar	1.974×10^{3} yrs.
17.	Mt. Vesuvias destroys Pompeii	1.891×10^{3} yrs.
18.	Columbus discovers America	4.78×10^{2} yrs.
19.	Galileo's first telescope	3.61×10^{2} yrs.
20.	American Civil War	1.00×10^{2} yrs.
21.	First U.S. satellite in orbit	1.2×10^{1} yrs.
22.	Man lands on the moon	1.0×10^{0} yrs

Difficult (1.5)

XIII-C-1b: CORRELATING ROCK OUTCROPS

QUESTION:

What does the rock record suggest about geologic history?

MATERIALS:

Student handout sheets and Supplementary Sheets #1 and #2, one Earth Science Curriculum Project Basic Fossil set for each group of two or three students (optional), appropriate real fossils (optional).

SUGGESTED APPROACH:

1. Ask the students how they might correlate, in terms of relative age, rock outcrops found in widely scattered areas.
2. Develop the concept of "index fossils" and how they are used to correlate rock units.
3. If you have the basic fossil sets available, allow the students time to become familiar with the appearance of their "index fossils."
4. Assign the exercise of correlating the rock units as homework.
5. During a postlab discussion, use the chalkboard or overhead projector to work out the sequence. You may want a student who feels that he or she has successfully completed the investigation to do this in your place.

TYPICAL RESULTS:

The outline below represents a series of logical deductions which will lead to one possible interpretation of the relative ages of the rock units. This outline should be used in conjunction with the probable solution diagram on a following page.

Key: 9/15 indicates that 9 is younger than 15

A) 5/2 & 20; 5/8; 5/18; 18/11; etc. Therefore, 5 is youngest.

B) 2 & 20/14 & 19; 2 & 20/13; 13/1 & 18; 18/7; etc. Therefore, 20 and 2 are second youngest.

C) 5/8; 8/1; 8/7; 8/16; etc. Therefore, 8 can be placed somewhere between 5 and 1 & 18.

D) 14 & 19/13; 13/1 & 18; 1/7; etc. Therefore, 14 & 19 are third youngest.

E) 13/1 & 18; 1 & 18/17; 1/7; etc. Therefore, 13 is fourth youngest.

F) 1/7; 1 & 18 are found together; 1 & 18/17; etc. Therefore, 1 & 18 are fifth youngest.

G) 1 & 18/17; no further data on 17. Therefore, it is somewhere below 1 & 18.

H) 1/7; 7/12; 12/11; etc. Therefore, 7 is sixth youngest.

I) 12/11; 7/12; etc. Therefore, 12 is seventh youngest.

J) 12/3 & 15; no further data on 3 & 15. Therefore, 3 & 15 are somewhere below 12.

K) 11/10 & 16; 10/4. Therefore, 11 is eighth youngest.

L) 10/4; 10 & 16 are found together. Therefore, 10 & 16 are ninth youngest.

M) 4/9; 4/6. Therefore, 4 is tenth youngest.

N) Therefore, 9 (and/or 6) is oldest.

The geologic age diagram gives you the actual location and age.

MODIFICATIONS:

1. Use photographs of actual outcrops, instead of the block diagrams, on which the above mentioned fossil zones have been sketched in. Note: the sequence of zones is the important point here, and not the veracity of the photographs. (Slides also could be used in this case.)

2. Use real instead of plastic fossils.

3. Cut "geologic columns" or "core samples" out of strips of paper. To represent fossil zones, place either the numbers of the fossils, pictures of the fossils, or the appropriate fossils on the column, in the proper sequences. So as to simulate outcrops, place the columns around the room, and have the students "visit" them to gather data.

   a. insert some unidentified fossils into the column.

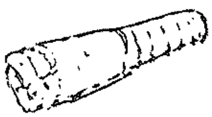
   b. invert one or more of the columns, and bring in the concept of overturned anticlines.

4. Use the block diagrams and the associated fossils in an attempt to interpret the past history of the area.

REFERENCES:

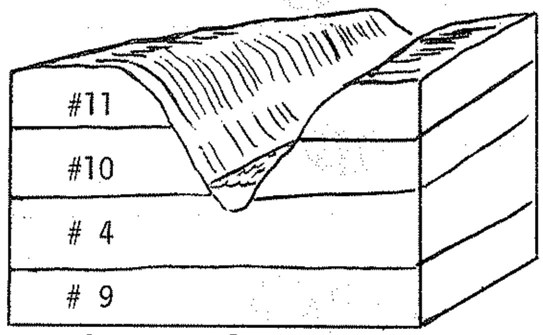
Investigating the Earth, pp. 414-420, Teacher's Guide, pp. 521-527

LIST OF FOSSILS

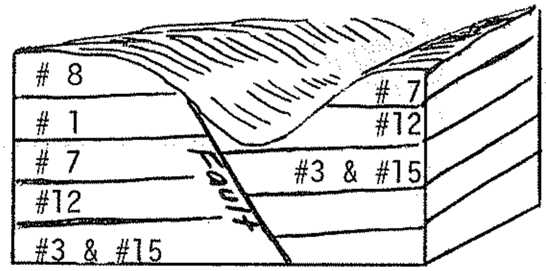
1. ACANTHOSCAPHITES 	11. MUENSTEROCERAS 
2. CARCHARODON TOOTH 	12. NEOSPIRIFER 
3. CRINOID STEM 	13. OLENEOTHYRIS 
4. EOSPIRIFER 	14. PECTEN 
5. EQUUS TOOTH 	15.  PENTREMITES
6. FLEXICALYMENE 	16. PHACOPS 
7. MEEKOCERAS 	17. SPIRIFER 
8. MERYCHIPPUS TOOTH 	18. TETRAGAMMA 
9. MICHELINOCERAS 	19. TURRITELLA 
10. MUCROSPIRIFER 	20. VENERICARDIA 

SUPPLEMENTARY SHEET #2

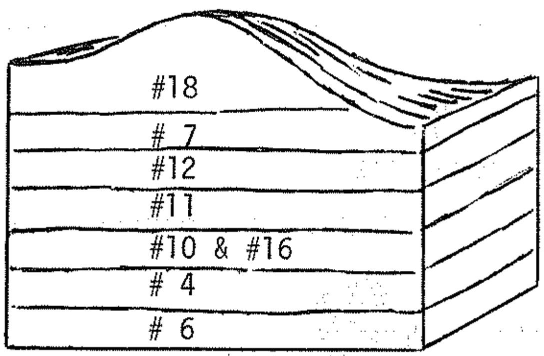
SIX WIDELY SCATTERED ROCK OUTCROPS



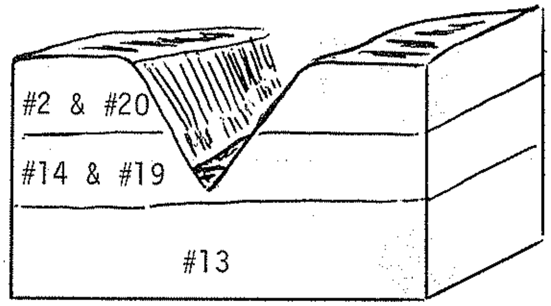
Outcrop #1



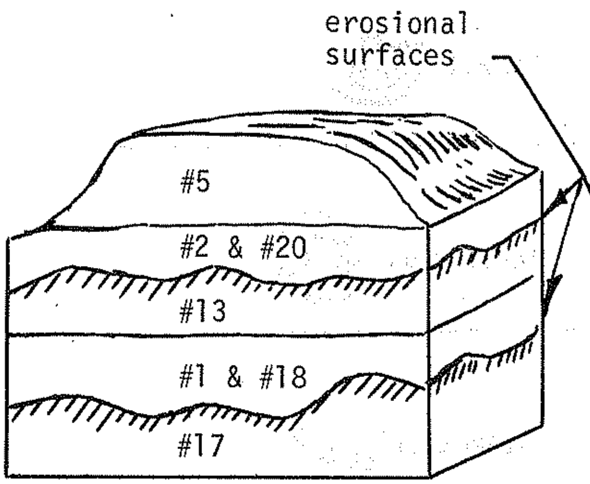
Outcrop #2



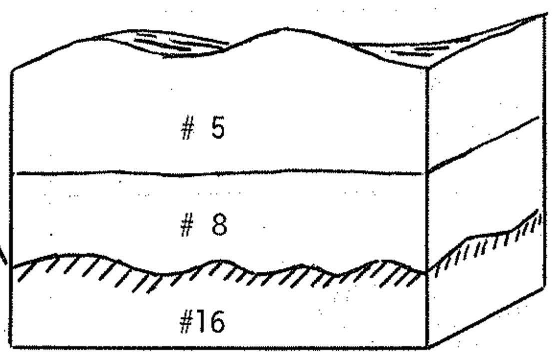
Outcrop #3



Outcrop #4



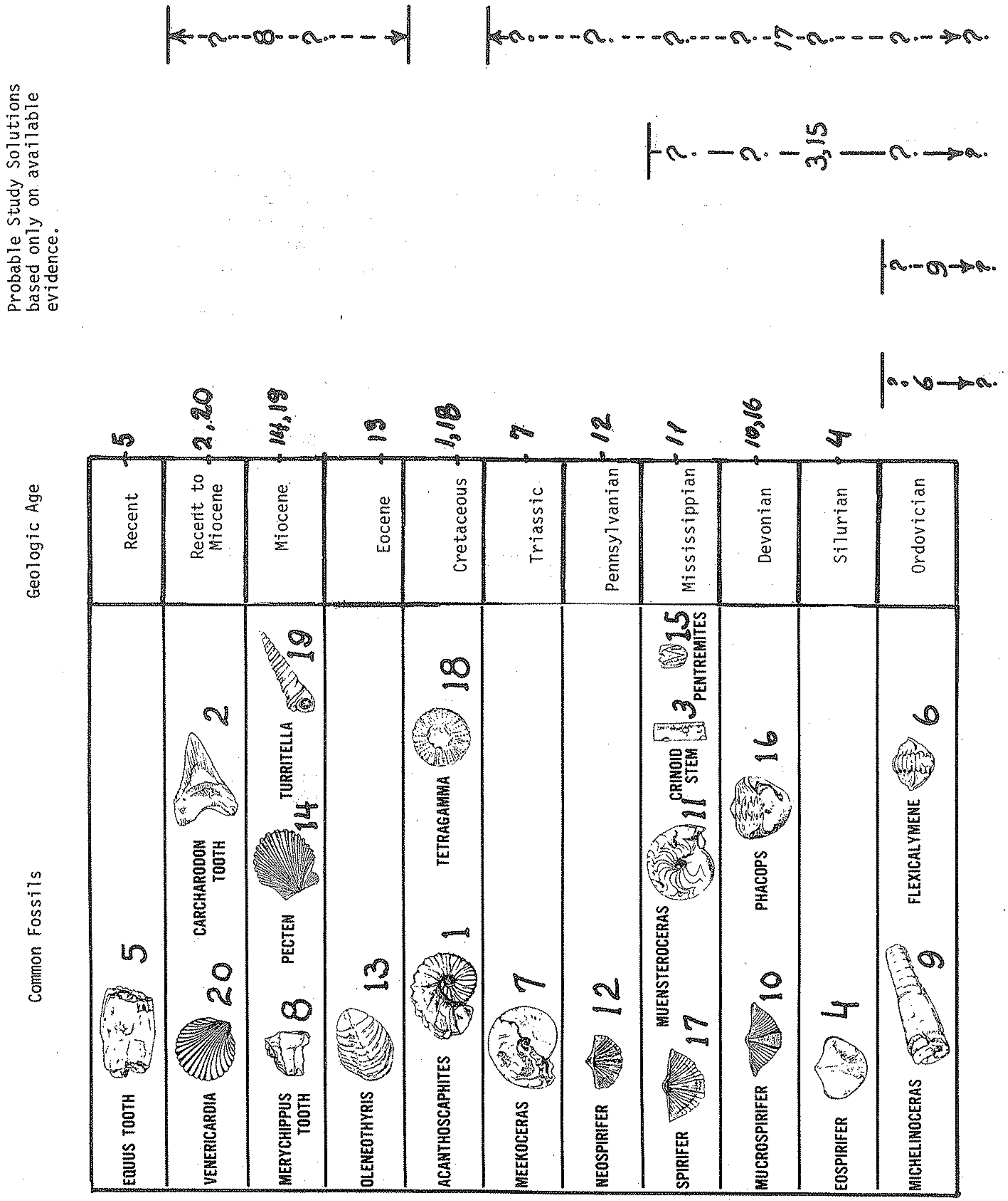
Outcrop #5



Outcrop #6

TYPICAL RESULTS:

PROBABLE SOLUTION DIAGRAM



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XIII-C-1b: CORRELATING ROCK OUTCROPS

QUESTION:

What does the rock record suggest about geologic history?

INTRODUCTION:

The early geologists attempted to put order into this puzzling array of fossil types which confronted them. In this investigation, you will attempt to find the relative age of a number of fossils. Try to think of the problem as an early geologist would. See if you can appreciate some of his problems.

OBJECTIVES:

When you finish this investigation, you should be able to:

1. determine the relative age of rock units using index fossils.
2. make inferences as to why fossils are used as one basis for the theory of evolution.
3. make inferences as to why the sequence of fossils in some cases varies from column to column.

METHOD:

1. Look at the block diagrams of rocks containing fossil zones. (Supplementary Sheet #2)
2. Arrange the fossils in order from youngest to oldest. Be sure to record your reasons for the sequence in which you place them.

QUESTIONS:

(C-1.11) 1. Which of the fossils appeared first? How do you know?

(C-1.11) 2. Which of the fossils appeared most recently? How do you know?

(C-1.31) 3. What reason can be given to explain why layers 7 and 12 can be found under 18, and also under 1, but not under the combination (1 and 18)?

(C-1.41) 4. Notice that some fossils, such as 10 and 16, can be found together in some cases but not in all. Give a reason for this occurrence.

Easy (1.5)

XIII-C-2a: RADIOACTIVE DECAY

QUESTION:

How can geologic ages be measured by using radioactive decay?

MATERIALS:

Shoeboxes with lids, 50-100 pennies (or pieces of dried field corn) per group of 2-3 students, graph paper.

SUGGESTED APPROACH:

1. If possible, demonstrate radioactive decay with a Geiger counter and a sample of some radioactive rock or mineral; ask students to describe what they hear (or see). Remind them that radioactive decay is used to measure geologic age and ask them how they think this works. Accept all answers, be sure the idea of half-life is mentioned, then indicate that this investigation deals with a statistical model that illustrates the concept of half-life.

2. Have each group of students place about 100 pennies in their shoebox, with the same sides up. Have them cover the box, hold it level, and give it a single sharp shake. Then open it and remove all pennies that have flipped over. Record the number left in the box. Repeat this until no more pennies are left in the box.

3. Have the students graph the number of shakes vs. number of unflipped pennies left in the box after each shake.

4. Have each group color one penny with nail polish and repeat step 2. Have them find out how many times the box must be shaken before the colored penny flips over. Collect and compare the data.

5. Have the students share their data by placing them on the chalkboard in the following chart form. (Use an * to indicate shake during which colored penny flipped.)

Student Groups	Shake one	Shake two	Shake three	Shake four	Shake five
Group 1					
Group 2					
Group 3					
Group 4					
Averages					

   Have the students graph the average number of pennies flipped during each shake versus number of shakes.

6. Lead students in a discussion which:

   a) answers questions like those on the student sheet, and

   b) analyzes the validity of this investigation as a model of radioactive decay

PRECAUTIONS:

1. Careful analysis of this model shows it to be weak in a number of aspects. Unless used with great care, it can give rise to serious misconceptions. Therefore, students should be led to analyze the model critically, noting all the ways in which it is deficient. They should be encouraged to suggest a more valid model. In such a model, the objects representing nuclei should:

    a) change spontaneously and at random

    b) change without application of external energy

    c) remain "on the scene" instead of being removed

    d) not be able to undergo the reverse change

2. Be sure students hold the top of the box tightly in place.

3. If the Geiger counter is used for the demonstration, be sure to hold the radioactive material far enough away so that individual clicks, not a steady buzz, are heard.

4. The concept of a random event is a difficult one for students to grasp.

TYPICAL RESULTS:

Graphs of class data should be smooth curves closely resembling actual graphs of decay rates of radioactive elements. This will not be true for individual data which is based on a small number. The students should realize from the class data that the chance for a particular penny to flip is random.

MODIFICATIONS:

1. Use thumbtacks, placing them heads down and removing all those which land points down after a single shake.

2. Use grains of corn (dried), removing those which happen to point toward one pre-designated side of the box. This can be repeated using two and then three pre-designated sides of the box. The resulting graphs will be different and can serve as models of the different decay curves obtained for radioactive elements which have different half-lives.

REFERENCES:

Investigating the Earth, pp. 378-379, Teacher's Guide, pp. 471-473, 482-483

XIII-C-2a: RADIOACTIVE DECAY

QUESTION:

How can geologic ages be measured by using radioactive decay?

INTRODUCTION:

You know that the process of radioactive decay of certain elements present in some minerals is used to determine geologic age. What characteristics of radioactive decay enable the geologist to use this method as the most accurate one known? In this investigation, you will work with a statistical model that illustrates the process of radioactive decay.

OBJECTIVES:

When you finish this investigation, you should be able to:

1. graph "particle decay" versus "time."
2. explain why the graph from an individual experience is not as smooth a curve as that derived from pooled class data.
3. relate the model to actual radioactive decay by analyzing the model's strong points and weaknesses.
4. use the graph of class data to predict time elapsed when given percentage of decay, or to predict percentage of decay when given time.

METHOD:

1. Place about 100 pennies in the shoebox, with the same sides up (e.g., all tails). Cover the box,hold it level, and give it a single sharp shake. Open the box and remove all pennies that have flipped over. Record the number of pennies left in the box.
2. Repeat step 1 until no more pennies are left in the box.
3. Color one penny with nail polish and repeat steps 1 and 2 until the colored penny flips over. Record the number of shakes necessary before this happens. Compare your data with the class by constructing a chart on the chalkboard.
4. Graph your data obtained from steps 1 and 2; plot number of shakes vs. number of unflipped pennies left in the box.

5. Repeat step 4, but use class data in which the entire number of pennies left in all the boxes, after each shake, have been totaled.

QUESTIONS:

1. How is the graph of your own data different from the graph of class data? Why is it different?

2. What is the half-life for the penny model?

(C-2.12) 3. What is the probability of a particular penny being flipped over by a single given shake? How does your answer to this question compare with the observations from step 3?

4. In what ways do the pennies behave like radioactive nuclei? In what ways don't they behave like radioactive nuclei?

(C-2.13) 5. a. There are 5,731 pennies in a shoebox, all heads up. The box is given one sharp shake. About how many pennies will flip over?

b. The box in (a) is repeatedly shaken; after each shake all pennies that have flipped over are removed until 471 pennies remain in the box. About how many shakes have been given to the box?

(C-2.13)
(C-2.22) 6. If organic matter containing carbon-14, which has a half-life of 5,700 years, died only 10 years ago, would you expect to be able to determine an accurate C^{14} age for it? Why? What if it had died 100,000 years ago? Why?

Easy (2)

XIII-D-1a: VARIATION WITHIN A SPECIES

QUESTION:

What does the fossil record suggest about ancient life?

MATERIALS:

Plastic fossil sheets, actual fossil samples, metric ruler, calipers, graph paper.

SUGGESTED APPROACH:

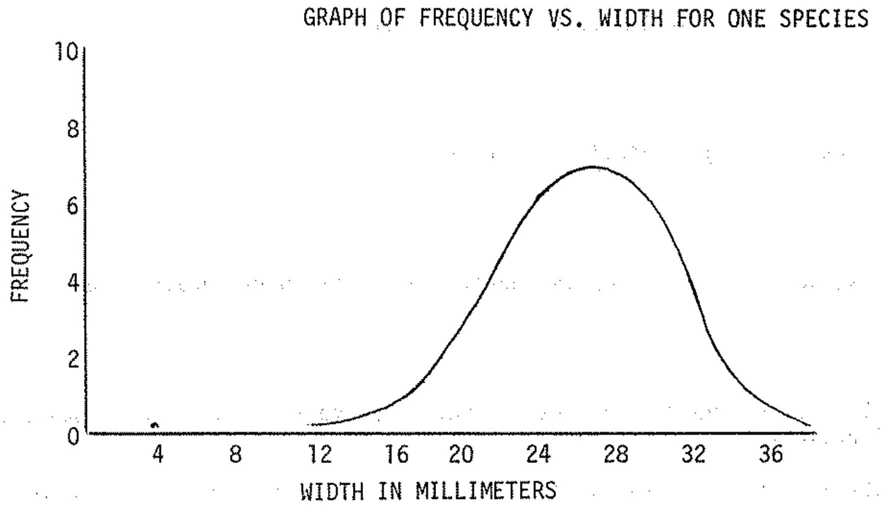
1. Distribute plastic fossil sheets and have students observe and record their observations. Limit them to 5 minutes.
2. Have the students draw a light line with pencil across the sheet to get a random sampling of fossils.
3. Have students measure the length, or width, of each fossil which is touched by their line.
4. Have the students graph frequency (number of individuals with a certain length) vs. length, or frequency vs. width of the fossil (this can be done as homework).
5. Have the students discuss the meaning of the curve in relation to the population mixture and possible reasons for size variation.

PRECAUTIONS:

1. Students will need some technique for identifying those fossils they have measured; small pieces of masking tape work well.
2. Students will require a definition of frequency. They should be instructed to round off their measurement to the closest minimum unit appearing on the graph (e.g., for length and width of brachiopods they should round off to nearest millimeter). They should then record the number of individuals who have a length of 24 millimeters, number with length of 25 mm., 26 mm., etc. This information then can be plotted as frequency.

TYPICAL RESULTS:

1. The student should obtain a good bell-shaped curve with frequency vs. any characteristic.
2. Almost all students will be able to conclude that, within a species, most individuals will have similar characteristics although some minor variations may be observed.
3. The students will give reasons for the existence of atypical individuals within the general population such as climate, age, food supply, and mutation.



MODIFICATIONS:

1. Have the students repeat the process with a second but different sheet and compare their results.

2. Have the students repeat the process with a real fossil population or use a real fossil population in lieu of the plastic sheet.

3. Have the students graph the number of ribs vs. frequency instead of length or width.

4. Have the students graph length vs. width. (A lens-shaped scatter-gram will be obtained.)

5. Have the students measure and record their own heights. They can then plot a curve of height versus frequency that the height occurred within the class. In order to have good results you may have to round the height of each student to the nearest decimeter.

REFERENCES:

Investigating the Earth, pp. 421-423, Teacher's Guide, pp. 529-531

XIII-D-1a: VARIATION WITHIN A SPECIES

QUESTION:

What does the fossil record suggest about ancient life?

INTRODUCTION:

Fossils give evidence of a great many kinds of animals and plants that have lived in the past under a variety of conditions. Fossils are classified into species. Variation within a species can be observed, measured, and described.

OBJECTIVES:

When you finish this investigation, you should be able to:

1. observe and describe, by means of frequency curves, the variations present within a species.
2. describe a species in terms of ranges of characteristics which allow for the observed variations.
3. explain why species variations are necessary to the theory evolution.

METHOD:

1. Record any observations you can make concerning the sample you have been given.
2. Draw a light pencil line across the sample given you.
3. Measure, to the nearest millimeter, and record the characteristics, indicated by your instructor, of each individual the pencil line touches.
4. Graph the characteristic vs. frequency (number of individuals having the same value) of occurrence for each individual measured.

QUESTIONS:

(D-1.21) 1. On what evidence could you decide whether or not this group is a single species population?

(D-1.22) 2. Suggest possible reasons for the variations found.

(D-1.23) 3. Fossils from other geologic times have been found which resemble those which you have examined, but they are not exactly the same. What does this evidence suggest to you?

(D-1.12) 4. Considering the fact that in most environments today more than one type of living organism is found, give an explanation why the fossil sheets contained only one basic life form.