Fossil Fuels (Part II), The Geology of Oil: Topographic Mapping, Crustal Deformation, Rock Porosity, and Environmental Pollution

SPN LESSON #36

TEACHER INFORMATION

LEARNING OUTCOME: After completing topographic maps, analyzing the geologic history of sections of Earth's crust, and finishing laboratory investigations of the factors controlling porosity, students describe how, why, and where petroleum and natural gas deposits accumulate within Earth's crust. Also, students use emissions-avoidance data supplied by the school's DAS system to evaluate the environmental cost of our dependence on petroleum-derived energy.

LESSON OVERVIEW: Using cross sections of geologic structures associated with oil deposits, students review an interpretation of geologic history and relate it to the formation of oil deposits. They explore and explain factors controlling the porosity and permeability of sediments and sedimentary rocks. Also, they interpret topographic maps and construct topographic profiles.

GRADE-LEVEL APPROPRIATENESS: This Level II or III lesson is intended for use with students in grades 8–12 who are enrolled in Regents Earth Science (Physical Setting).

TEACHING THE LESSON: This is the second of three SPN lessons dealing with the topic of fossil fuels, their formation, and their geology (see also SPN #s 35 and 37). This lesson is divided into four parts. They are fairly self-explanatory but you should review each one to see if your students need further introduction. Part 1 should take three class periods and two nights of homework. You may want to approach cross section A as a class activity using the overhead projector. Part 2 involves at least two days of laboratory work and perhaps one night of homework. Part 3 should require one day and one night to complete. Part 4 is probably best done as a long-term research project with two days set aside for reporting out, or discussing, in class.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION:

Part 1: Responses to cross sections:

A.	**B.**	**C.**
1. Deposition of clay	1. Deposition of clay	1. Deposition of clay with sand lenses
2. Deposition of sand	2. Deposition of silt	

3. Deposition of clay
4. Deposition of sand
5. Deposition of clay
6. Deposition of sand
7. Deposition of clay
8. Deposition of sand
9. Deposition of sediments above?
10. Compaction and cementation
11. Folding (gentle)
12. Uplift and erosion
TS: Inland of continental margin
NoT: Upward fold capped w/ shale
SR: Bottom two shale layers

3. Deposition of sand
4. Deposition of clay
5. Accumulation of $CaCO_3$ organic debris
6. Deposition of seds above?
7. Compaction and cementation
8. Faulting
9. Uplift and erosion
TS: Stretching continental interior
NoT: Impervious shale at the fault
SR: Lower-left shale layer

2. Deposition of silt
3. Compaction and cementation
4. Uplift and erosion
TS: Continental Edge
NoT: Overlying Impervious Shale
SR: Shale Layers

D.
1. Accumulation of unknown rocks
2. Intrusion of magma
3. Slow solidification
4. Uplift and extensive erosion
5. Subsidence
6. Deposition of sand
7. Deposition of silt
8. Deposition of clay
9. Deposition of sand with some clay
10. Deposition of clay
11. Compaction and cementation
12. Uplift and erosion?
TS: Older continent section that was formerly collisional plate boundary
NoT: Impervious igneous and shale rocks
SR: Lower beds of shale or unseen shale lower in the section

E.
1. Deposition of evaporites
2. Deposition of other sediments below present cross section
3. Deposition of clay
4. Deposition of sand
5. Deposition of silt
6. Deposition of sand
7. Deposition of clay
8. Accumulation of organic $CaCO_3$ debris
9. Density upward flow of salt
10. Uplift and erosion
11. Concurrent compaction and cementation of sediments to sedimentary rock
TS: Sedimentary basin of thick accumulation
NoT: Impervious salt and shale
SR: Lower shale layers

Essay Questions 1 and 2:

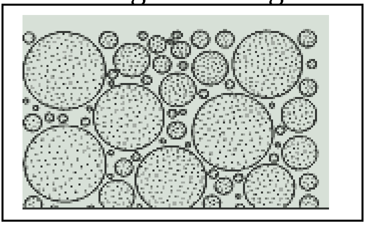
1. An increase in the velocity of water current flow brought larger-sized sediments (sand instead of clay) to this area on occasion.
2. The igneous rock was hot when it came into contact with the sedimentary rock: it was an igneous intrusion.

Part 2:

A: Porosity

1. a. Students should see pore space among the sand particles, and perhaps among the coarser silt samples. b. The beaker with sand particles

2. a. The silt particles have filled some of the pore space among the sand grains.
   b. The drawing should resemble this:



3, 4. Responses will vary, depending on several factors including grain shape and grain packing. Responses for the single-sized sediments should be ~10 mL of pore space. The mixed-sized sample should be somewhat less than 10 mL.

5. Responses will vary. However, clay, silt, and sand should approximate 40%, while the mix of silt and sand should be closer to 30%.
6. Students should know that the response should be sand, but experimental results may not verify this. The correct answer may have to be derived during post-lab discussions of the effects of packing and post-depositional mineral and mineral-cement growth.

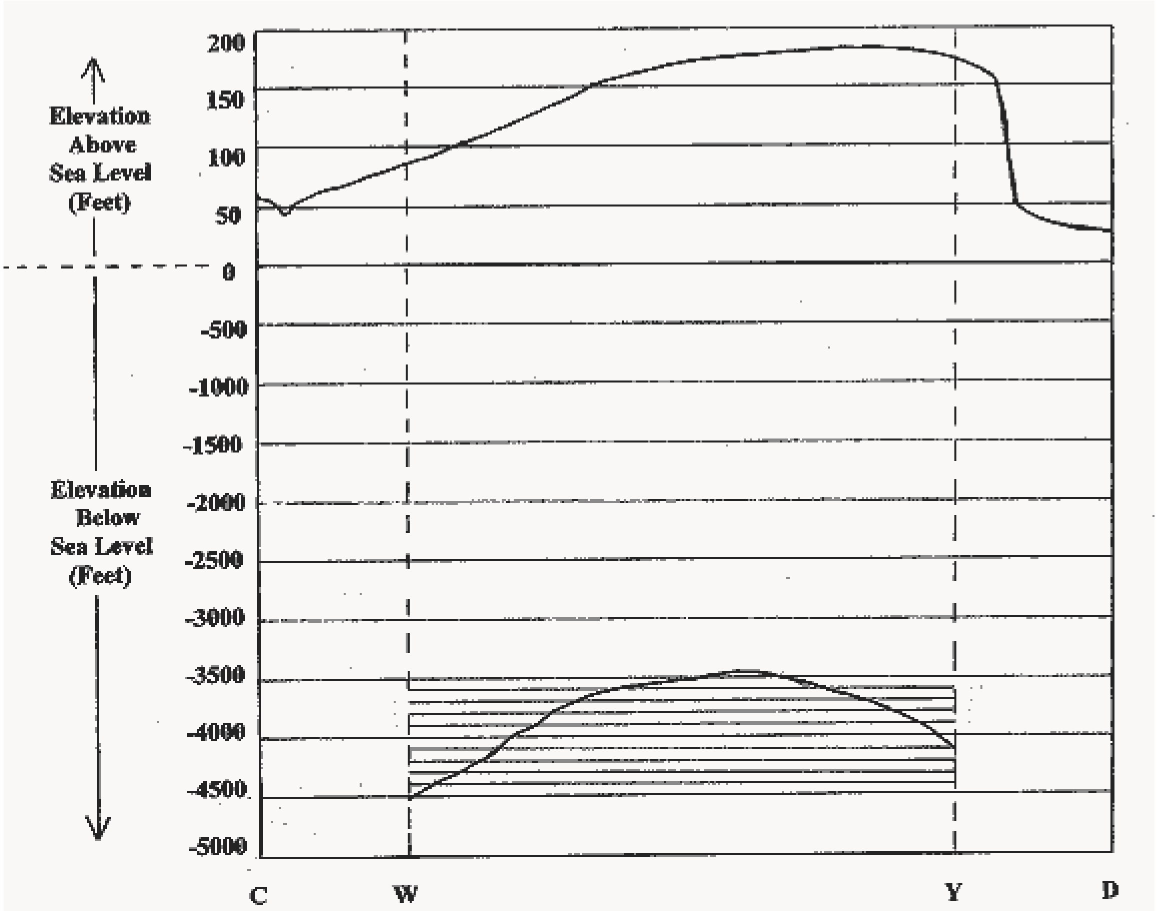
B: Permeability

1. Sand has large pore spaces.
7. a. Times will vary, but the smaller beads should take longer to drain.
   b. Once again rates should vary but the smaller beads should have the slower rate.
8. The larger the pore spaces, the less the friction, the faster the drainage.
9. The sand grains could grow to fill in the pore spaces or the addition of mineral cement could fill the spaces.
10. Shale
11. The clays and micas that become shale are flattened grains that align and overlap during the compression caused by burial. This compression blocks water and oil flow. Also, these grains grow larger as heat and pressure increase.

Part 3: Topographic Maps

1. Upper-left-hand corner has the highest elevations.
2. Southeast (or SSW)
3. The contour lines bend upstream.
4. 100 feet/mile
5. a. No b. 5,280 feet / 175 feet = ~ 30X exaggerated elevation
6. a.—— **..**—— **..**—— c. Not really, but the rocks could be up-folded

7 a. and 6 b.



7. b. Anticlinal (up) fold c. Sandstone (other rocks also serve as reservoir rocks) d. Shale
8. Responses will vary but many students will probably answer "drill holes." Some might answer "using seismology."
9. a. All 12 vibration curves jump up and down at the same time.
   b. The arrival of the second reflection (from the lower limestone bed)

Part 4: The Environmental Costs of Oil Use

Results of this research will vary greatly according to the dedication and abilities of the students. Teachers may wish to assign some of the task to each group so that students are not overwhelmed by the enormity of the project.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ACTIVITY: This is not an adapted lesson.

BACKGROUND INFORMATION: Factors controlling porosity and permeability of sediments and rocks are complex, extending well beyond the scope of normal high school Earth Science classrooms. However, they certainly can be simplified with a degree of accuracy for these students. The compression of shales to drive out the accumulated organic materials that were becoming oil and gas can be likened to squeezing a wet sponge as the clay minerals align themselves perpendicularly to the direction of pressure from above. Also, clays, over time and with increased temperatures, become converted to higher percentages of illite crystals. These crystals develop and grow in this same plain, creating a typically impermeable seal that blocks the movement of fluids. As the clay turns to shale, this seal is generally maintained unless fracturing of the rock becomes too severe.

Sands as well as clays are subjected to compaction but have a high variability in overall porosity. The larger particles provide larger pore spaces. Large pore spaces are especially important because they maintain the permeability of sands, thereby allowing the migration of fluids that escape from nearby clays. Permeability is directly proportional to the diameter of pore spaces. Both porosity and permeability of sand are greatly altered by the addition of mineral cements as the sand turns to rock. The continued permeability of sandstone depends in part on the fracturing of brittle sandstones, and this fracturing creates cracks within the rock.

REFERENCES FOR BACKGROUND INFORMATION

Bateman: *The Formation of Mineral Deposits*, Wiley, 1966.
Blatt, Berry, and Brande: *Principles of Stratigraphic Analysis*, Blackwell, 1991.
Ehlers and Blatt: *Petrology*, Freeman, 1982.
Pettijohn, Potter, and Siever: *Sand and Sandstone*, Springer-Verlag, 1972.
Strahler: *The Earth Sciences*, Harper and Row, 1971.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

Standard 1—Analysis, Inquiry, and Design: Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Mathematical Analysis Key Idea 1: Abstraction and symbolic representation are used to communicate mathematically.

Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions.

Key Idea 3: Critical thinking skills are used in the solution of mathematical problems.

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

Key Idea 2: Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.

Key Idea 3: The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.

Standard 6—Interconnectedness: Common Themes: Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Key Idea 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

Key Idea 3: The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems.

Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions.

Standard 7—Interdisciplinary Problem Solving: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Key Idea 1: The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision-making, design, and inquiry into phenomena.

Key Idea 2: Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results.

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 1: The Earth and celestial phenomena can be described by principles of relative motion and perspective.

1.2: Describe current theories about the origin of the universe and solar system.

1.2g: Earth has continuously been recycling water since the outgassing of water early in its history. This constant recirculation of water at and near Earth's surface is described by the hydrologic (water) cycle.

- Water is returned from the atmosphere to Earth's surface by precipitation. Water returns to the atmosphere by evaporation or transpiration from plants. A portion of the precipitation becomes runoff over the land or infiltrates into the ground to become stored in the soil or groundwater below the water table. Soil capillarity influences these processes.
- The amount of precipitation that seeps into the ground or runs off is influenced by climate, slope of the land, soil, rock type, vegetation, land use, and degree of saturation.

1.2j: Geologic history can be reconstructed by observing sequences of rock types and fossils to correlate bedrock at various locations.

- The characteristics of rocks indicate the processes by which they formed and the environments in which these processes took place.
- Fossils preserved in rocks provide information about past environmental conditions.

- Geologists have divided Earth history into time units based upon the fossil record.
- Age relationships among bodies of rocks can be determined using principles of original horizontality, superposition, inclusions, crosscutting relationships, contact metamorphism, and unconformities. The presence of volcanic ash layers, index fossils, and meteoritic debris can provide additional information.
- The regular rate of nuclear decay (half-life time period) of radioactive isotopes allows geologists to determine the absolute age of materials found in some rocks.

Key Idea 2: Many of the phenomena that we observe on Earth involve interactions among components of air, water, and land.

2.1: Use the concepts of density and heat energy to explain observations of weather patterns, seasonal changes, and the movements of Earth's plates.

2.1j: Properties of Earth's internal structure (crust, mantle, inner core, and outer core) can be inferred from the analysis of the behavior of seismic waves (including velocity and refraction).

- Analysis of seismic waves allows the determination of the location of earthquake epicenters, and the measurement of earthquake magnitude; this analysis leads to the inference that Earth's interior is composed of layers that differ in composition and states of matter.

2.1k: The outward transfer of Earth's internal heat drives convective circulation in the mantle that moves the lithospheric plates comprising Earth's surface.

2.1l: The lithosphere consists of separate plates that ride on the more fluid asthenosphere and move slowly in relationship to one another, creating convergent, divergent, and transform plate boundaries. These motions indicate Earth is a dynamic geologic system.

- These plate boundaries are the sites of most earthquakes, volcanoes, and young mountain ranges.
- Compared to continental crust, ocean crust is thinner and denser. New ocean crust continues to form at mid-ocean ridges.
- Earthquakes and volcanoes present geologic hazards to humans. Loss of property, personal injury, and loss of life can be reduced by effective emergency preparedness.

2.1m: Many processes of the rock cycle are consequences of plate dynamics. These include the production of magma (and subsequent igneous rock formation and contact metamorphism) at both subduction and rifting regions, regional metamorphism within subduction zones, and the creation of major depositional basins through down warping of the crust.

2.1n: Many of Earth's surface features such as mid-ocean ridges/rifts, trenches/subduction zones/island arcs, mountain ranges (folded, faulted, and volcanic), hot spots, and the magnetic and age patterns in surface bedrock are a consequence of forces associated with plate motion and interaction.

2.1p: Landforms are the result of the interaction of tectonic forces and the processes of weathering, erosion, and deposition.

2.1q: Topographic maps represent landforms through the use of contour lines that are isolines connecting points of equal elevation. Gradients and profiles can be determined from changes in elevation over a given distance.

2.1r: Climate variations, structure, and characteristics of bedrock influence the development of landscape features including mountains, plateaus, plains, valleys, ridges, escarpments, and stream drainage patterns.

2.1v: Patterns of deposition result from a loss of energy within the transporting system and are influenced by the size, shape, and density of the transported particles. Sediment deposits may be sorted or unsorted.

2.1w: Sediments of inorganic and organic origin often accumulate in depositional environments. Sedimentary rocks form when sediments are compacted and/or cemented after burial or as the result of chemical precipitation from seawater.

Key Idea 3: Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity.

3.1: Explain the properties of materials in terms of the arrangement and properties of the atoms that compose them.

3.1a: Minerals have physical properties determined by their chemical composition and crystal structure.

- Minerals can be identified by well-defined physical and chemical properties, such as cleavage, fracture, color, density, hardness, streak, luster, crystal shape, and reaction with acid.
- Chemical composition and physical properties determine how minerals are used by humans.

3.1b: Minerals are formed inorganically by the process of crystallization as a result of specific environmental conditions. These include:

- cooling and solidification of magma
- precipitation from water caused by such processes as evaporation, chemical reactions, and temperature changes
- rearrangement of atoms in existing minerals subjected to conditions of high temperature and pressure.

3.1c: Rocks are usually composed of one or more minerals.

- Rocks are classified by their origin, mineral content, and texture.
- Conditions that existed when a rock formed can be inferred from the rock's mineral content and texture.
- The properties of rocks determine how they are used and also influence land usage by humans.

Produced by the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
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Should you have questions about this activity or suggestions for improvement,
please contact Bill Peruzzi at billperuz@aol.com

(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date ____________________________________

Fossil Fuels (Part II), The Geology of Oil: Topographic Mapping, Crustal Deformation, Rock Porosity, and Environmental Pollution

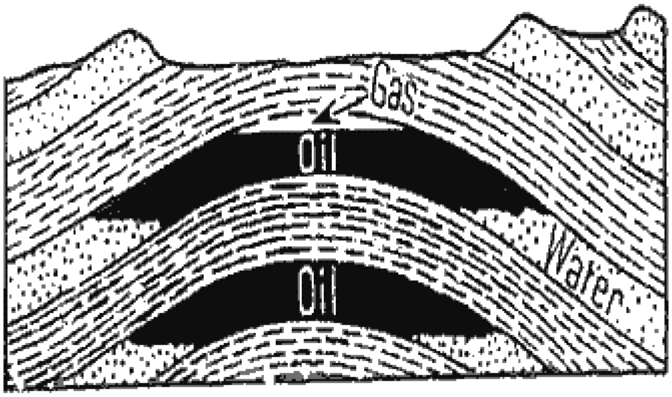
SPN LESSON #36

Part 1: Where Is Oil Found?

As we learned in SPN #35, oil is formed gradually from the accumulated organic materials found in buried sediment deposits. These deposits—usually silts and clays—have been subjected to of the heating and pressure associated with burial under additional sediments, and perhaps, including prolonged mild metamorphism. These pressures squeeze a mix of seawater and oil out of these source beds into surrounding, more porous sediments, usually sands. From these sediments, the seawater and oil rise upward until they are blocked by impervious barriers. Here the oil, water, and natural gas form a pool. The challenge for oil geologists is to locate these oil pools, known as oil traps.

The diagrams below show cross sections of some of the more common types of oil traps. Use the symbols for rock types in your Earth Science Reference Tables to help you interpret the geologic history of each of these cross sections. Fill in the numbered list to indicate the order of the geologic events (uplift and erosion, deposition of silt, folding, compaction and cementation of sediments to rock, faulting, etc.) that occurred in each area. Then complete the box below each diagram: The tectonic setting is where in Earth's crust the type of structure shown in the cross section is most probably found.

Oil Trap Type A:



Tectonic Setting: ________________________

Nature of Trap: __________________________

Lightly Color Most Likely Source Rock of Oil

Geologic History Events:

1________________________

2________________________

3________________________

4________________________

5________________________

6________________________

7________________________

8________________________

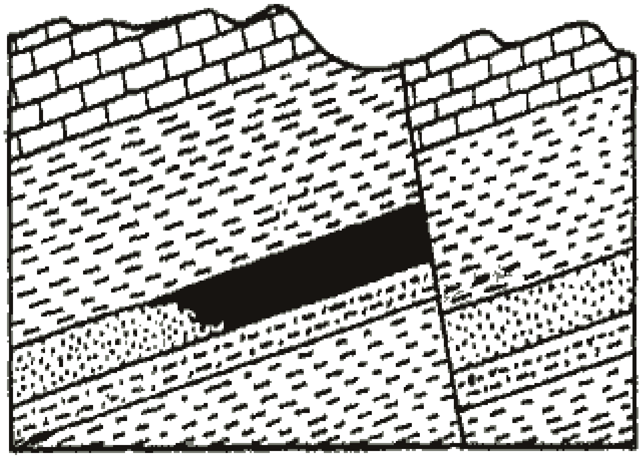
9________________________

10_______________________

11_______________________

12_______________________

Oil Trap Type B:



Tectonic Setting: ________________________

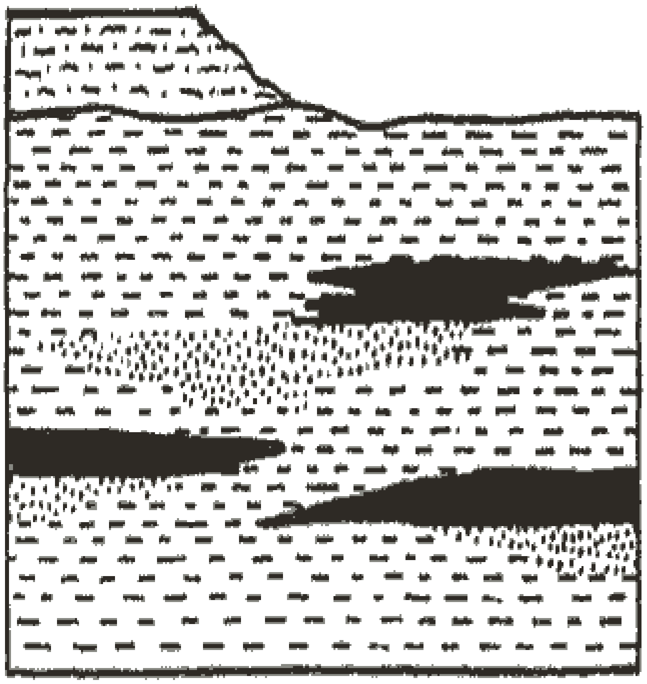
Nature of Trap: ________________________

Lightly Color Most Likely Source Rock of Oil

Geologic History Events:

1. ________________________
2. ________________________
3. ________________________
4. ________________________
5. ________________________
6. ________________________
7. ________________________
8. ________________________
9. ________________________

Oil Trap Type C:



Geologic History Events:

1. ________________________

2. ________________________

3. ________________________

4. ________________________

Tectonic Setting: ________________________

Nature of Trap: ________________________

Lightly Color Most Likely Source Rock

1. During the deposition of the original sediments that formed these rocks, what might have happened that would account for the pockets of sandstone now present within a thick layer of shale?

____

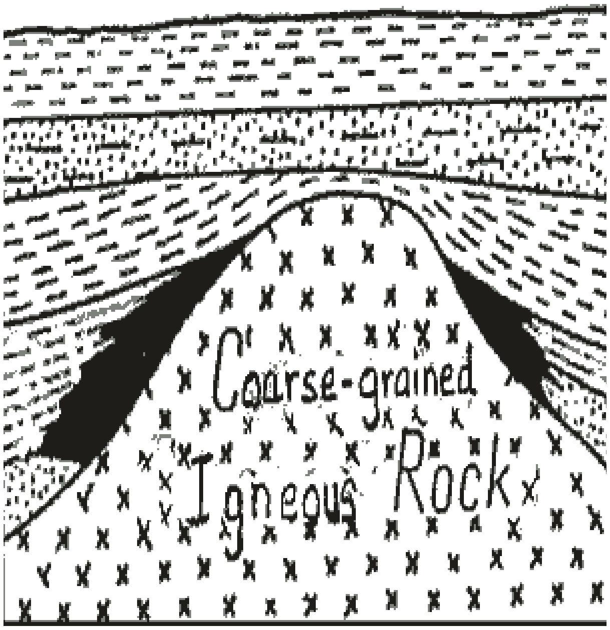
____

Oil Trap Type D:

Notice that there is no indication of contact metamorphism between the igneous rock *x* and the overlying sedimentary rocks; that fact should reveal to you the relative age of the igneous rock compared to the age of the other rocks.

2. What would the presence of contact metamorphism in the edge of the sedimentary rocks touching igneous rock *x* indicate?

____



Tectonic Setting: ________________________

Nature of Trap: __________________________

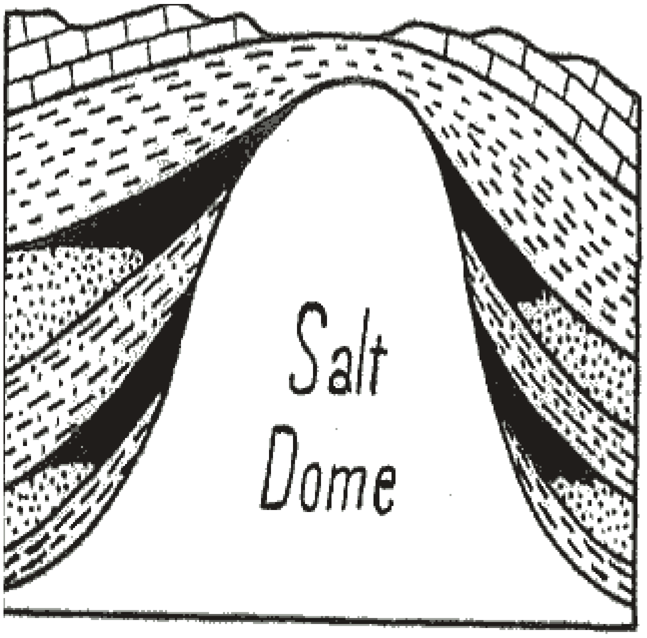
Lightly Color Most Likely Source Rock

Geologic History Events:

1. ________________________
2. ________________________
3. ________________________
4. ________________________
5. ________________________
6. ________________________
7. ________________________
8. ________________________
9. ________________________
10. ________________________
11. ________________________
12. ________________________

Oil Trap Type E:

This may seem to most of us a strange geologic feature, but salt domes are very important oil traps along the Gulf coast in the southern United States. These actively rising concentrations of salt are much less dense than surrounding sediments and rocks. Much like oil and water, the salt tends to rise toward the land surface as the surrounding materials settle downward. The rising dome tilts adjacent rock layers, providing slanting channels of oil.



Tectonic Setting: ________________________

Nature of Trap: _________________________

Lightly Color Most Likely Source Rock

Geologic History Events:

1. ________________________
2. ________________________
3. ________________________
4. ________________________
5. ________________________
6. ________________________
7. ________________________
8. ________________________
9. ________________________
10. _______________________
11. _______________________

Part 2: Porosity and Permeability Laboratory Activity

A: Porosity

Why is sandstone typically the reservoir rock in which oil is found, and why does shale so often block the upward movement of oil? To answer these questions, first determine the porosity and permeability of the sediments of which these sedimentary rocks are made. Next, explore how lithification (the process of turning to stone) changes the characteristics of these sediments.

Materials (per student group):

100 mL graduated cylinder
10 mL graduated cylinder
100 mL beakers (4)
Different-sized sediment samples: clay, silt, sand
Hand lens
Stirring rod

Procedure:

1. Using the 100 mL graduated cylinder, measure 50 milliliters of each of the three sediments. Place each sample in a separate 100 mL beaker. Gently tap the beakers to settle and level the sediments. Look at the particles in each of the beakers from the side through the hand lens.
    a. Can you see pore space between the particles in the beakers? ______

    b. In which beaker are the pore spaces the largest? ______________________

2. In a fourth beaker, place 25 mL each of sand and silt, blend them together with the stirring rod, and then tap the beaker to settle and level the sediments. Look at the particles in this beaker with the hand lens.
    a. How have the pore spaces among the sand grains changed from those seen in the beaker filled with sand alone?

    ____

    b. Make a drawing showing the arrangement of particles in the fourth (mixed) beaker in the box provided to the right. (x30)

3. Fill the 10 mL graduated cylinder to the 10 mL mark so that the meniscus sags to the 10 mL line. Carefully and slowly, one drop at a time, add water to the beaker containing sand. Continue to add water until the water level becomes just visible at the surface of the sand. Record the amount of water you have added by reading the water level remaining in the graduated cylinder.

    Sand: ____________ mL

4. Repeat this procedure with each of the sediment containers and record the amount of water in the spaces provided below.

Silt: ______________ mL

Clay: ______________ mL

Mixture of sand and silt: ______________ mL

5. Construct a bar graph of the % Porosity of each of these materials on the form below.

Clay
Silt
Sand
Mix

0 10 20 30 40 50 60 70 80 90 100
% Porosity

[Note: To calculate % Porosity, follow these instructions. Divide the amount of water you added to each beaker of sediment by the total volume of sediment in each beaker (50 mL), and then multiply by 100.]

6. Which type of sediment has the most room to store liquids such as water and oil?

____

B: Permeability

Yet, porosity is only part of the oil story. As you know, the oil gets squeezed out of the muds (clays and silts) where it has formed from the organic material present. The oil then migrates through other sediments and rocks, especially sand and sandstone, and it concentrates in the open pore space. The ability of the oil to move through the rock material depends on the presence of interconnected pore spaces and cracks within rock material. **Permeability** is the measure of the rate of fluid movement through passageways.

1. What information from your study of porosity might explain why sand typically has high permeability? ____

Now, collect some data regarding permeability rates and particle size and see if your response is correct. Although this laboratory work represents a fairly uncommon situation in the real world of sediment sorting, you will be able to demonstrate the effect of one of the more important variables controlling the rate of fluid movement through sediments.

Materials (per student group):
Ring stands (2)
Tube clamps (2)
1-meter-long plastic tubes with drainage hose and hose clamps (2)
Bottom screens (2)
12 mm plastic beads
3 mm plastic beads
1,000 mL beakers (2)
Water
Digital stopwatch
Nonpermanent marker
Metric ruler

Procedure:

1. Attach two tube clamps to each ring stand. Make sure the bottom screen is installed in each plastic tube.
2. Firmly clamp each tube with the two clamps in an upright position on the ring stand.
3. Carefully add the 12 mm beads to one of the tubes to a depth of 20 cm. Add the 3 mm beads to the same depth in the other tube.
4. Using the metric ruler to accurately measure the distances, draw horizontal lines 5 cm and 30 cm above the top of the beads in each tube.
5. Close the drainage hose on each plastic tube with the hose clamp.
6. Place one of the 1,000 mL beakers under the drainage hose of one of the plastic tubes. Carefully pour water into the tube to a depth approximately 5 cm above the 30 cm line. As one team member readies the stopwatch, completely open the drainage hose. Time how long it takes the water level to drop from the 30 cm line to the 5 cm line. Repeat this procedure with the same tube. Enter your data in the table below.
7. a. Repeat this procedure twice using the tube with the other size beads. Calculate the average time for each bead size and record your results in the table.

Bead Size	First Trial	Second Trial	Average Time	Permeability Rate
mm	sec	sec	sec	cm^3/sec
mm	sec	sec	sec	cm^3/sec

   b. Calculate the permeability rate for each bead size by calculating the volume of water contained in the plastic tubing between the 30 cm line and the 5 cm line: (25 cm)(π)(radius of tube)^2. Divide the volume by the average time for each bead size.

8. Why was the drainage rate (permeability rate) faster in one tube than the other?

9. Why might sandstone have neither a high porosity nor a high permeability?

____

As important as oil migration is in forming oil deposits under natural conditions, the blocking of the oil movement by *impermeable* rock is also an important part of the process. This blocking allows the oil to accumulate in the underground traps as previously described.

10. What type of rock is typically the impermeable barrier?

____

11. Why is this rock typically impermeable?

____

Part 3: Topographic Maps

The job of the oil exploration geologist is to find these various oil-bearing rock layers and the structural oil traps that confine them. Topographic features and the maps that represent them are the usual starting point for this exploration. The ability to read these maps is an essential skill for these scientists.

Figure 1 below shows how topographic maps represent the shape of the land's surface through the use of lines of equal elevation called contour lines. The top section of the map shows a topographic map of a region of Earth's surface. The curving lines on the map are contour lines that have been labeled to show elevation above sea level in feet. Every point on a particular contour line has the same elevation. Points in between these lines have elevations with values between those of the lines above and below.

1. Where are the highest elevations on this map?

____

2. In which direction does the creek (stream) flow?

____

3. In addition to the changes in elevation along the creek, notice the shape of the contour lines in the vicinity of the creek. In which direction do the lines bend as they cross the creek?

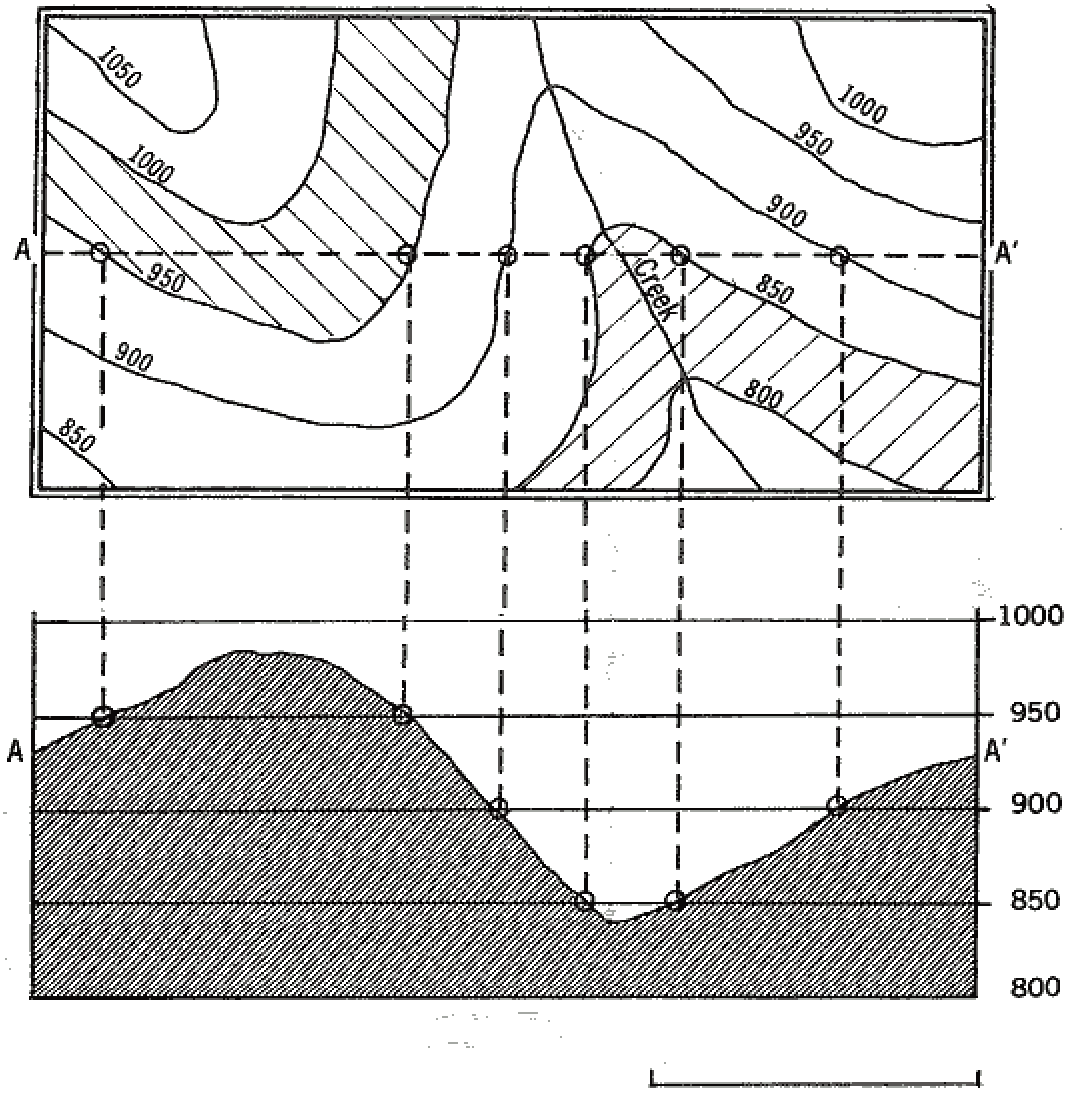
____

4. What is the gradient of the creek from the 900-foot contour line to the 800-foot contour line? (Use the formula for average gradient on the front page of your Earth Science Reference Tables.)

Show your work:

The average gradient is ______________________ feet/mile

Figure 1: Topographic Map and Topographic Profile



1 Scale Mile

[modified from *AGI Geology and Earth Sciences Sourcebook*, Holt Rinehart Winston, 1970, p. 402]

The lower portion of figure 1 shows a topographic profile, which represents the changes in elevation along line *A – A'* across the map. A profile can be constructed by placing the edge of a piece of paper along line *A– A'* on the map, marking the points where the contour lines intersect the edge of the paper (the small circles), and then transferring those elevations to an elevation grid as shown by the dashed lines. Be sure to mark the endpoints *A* and *A'* so you can correctly mark the distances of the elevation points. Also, notice the diagonally marked portions of the map and see how the profile line is drawn in these regions. Both of these areas are between points of the *same* elevation on the profile but lie between points of *different* elevation on the map. Notice that the profile of the hill rises above 950 feet and that the valley falls below 850 feet in these two instances.

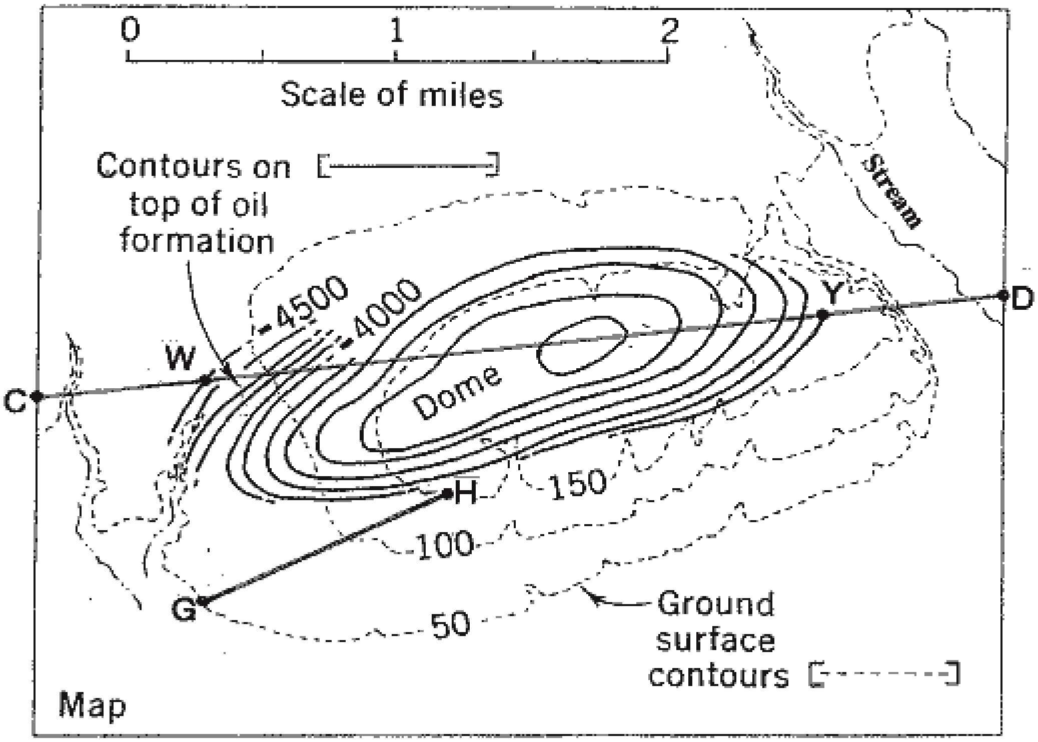
5. Take a piece of paper and see if you can construct the same profile shown in figure 1, using the method described above.
    a. Is the vertical scale of the profile the same as the horizontal distance scale of the map and the profile? ________
    b. How much vertical exaggeration is there in the profile? (To obtain this value, divide 5,280 feet [the mile shown on the horizontal scale at the bottom of figure 1] by the number of feet in elevation that the length of the mile line represents on the vertical scale.)

Show your work:

The vertical scale is exaggerated approximately _______ times.

6. Figure 2 below shows a topographic map from an oil trap in California. Notice that there are *two* sets of contour lines on this map. This may seem confusing at first but the oil geologist's task is to find oil underground. If you concentrate on one set of lines at a time, the map will become easier to understand.

Figure 2: Topographic Map of Surface Features and of Subsurface Oil Deposit



[modified from Strahler: *The Earth Sciences*, Harper Row, 1971, p. 383]

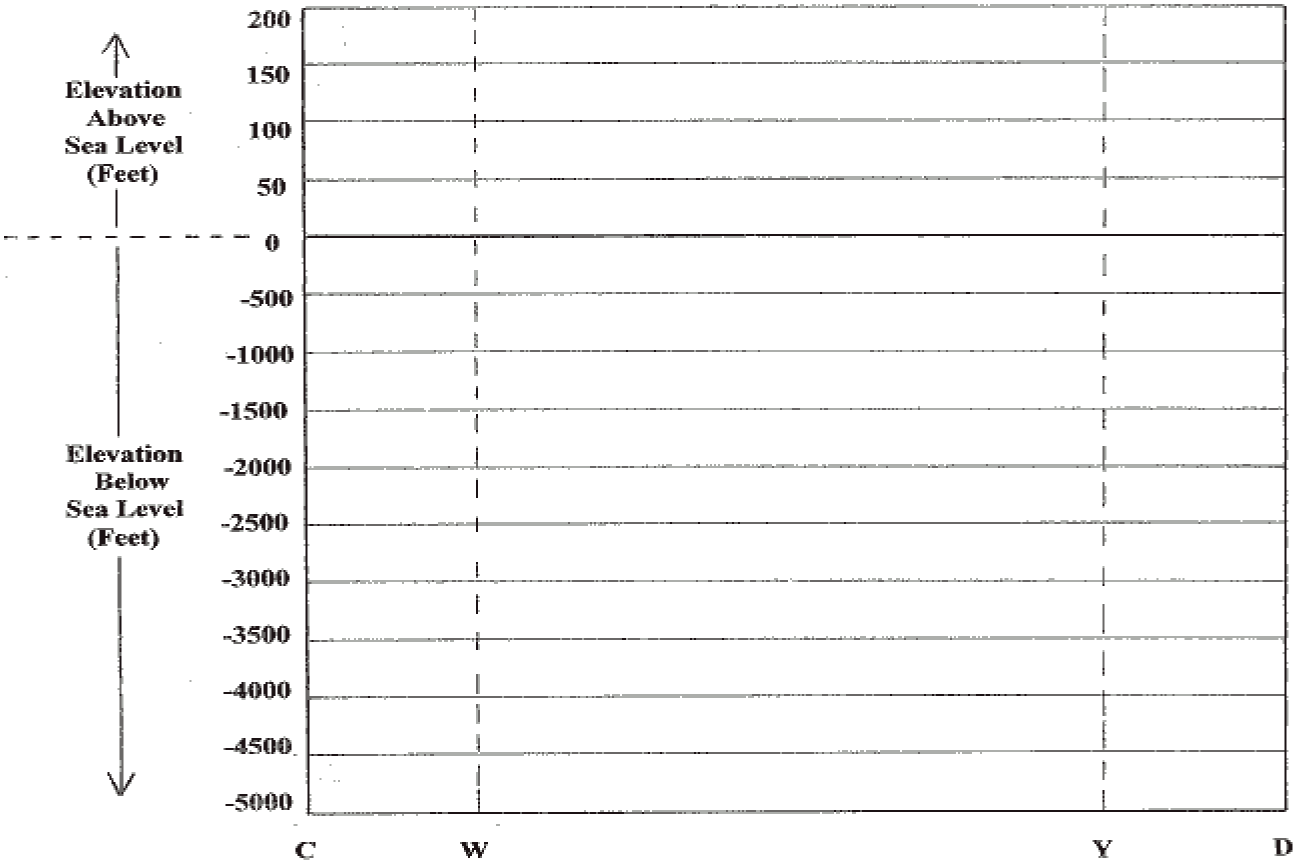
a. The dashed set of contour lines is used to show the elevation of the land surface in feet above sea level. Draw the symbol used to show the streams on this map. ____________________________

b. On the top section of figure 3 below, construct a topographic profile of the land surface from point *C* to point *D* using the method shown in figure 1.

c. Is there any indication in the surface topography that an oil trap exists in the rock below?

____

Figure 3: Form for the Construction of Topographic Profiles



7. The dark, solid lines show the *depth below sea level* of the top of the oil-bearing layer of rock discovered by the oil geologists.
   a. Reading only these solid lines, construct a profile of the shape of this oil-bearing layer in the bottom section of figure 3 above. [Note that the vertical scales of these two profiles are different.]
   b. What kind of oil trap structure is this?

   ____

   c. What kind of porous rock is holding the oil?

   ____

d. What is probably the impermeable cap rock that traps the oil?

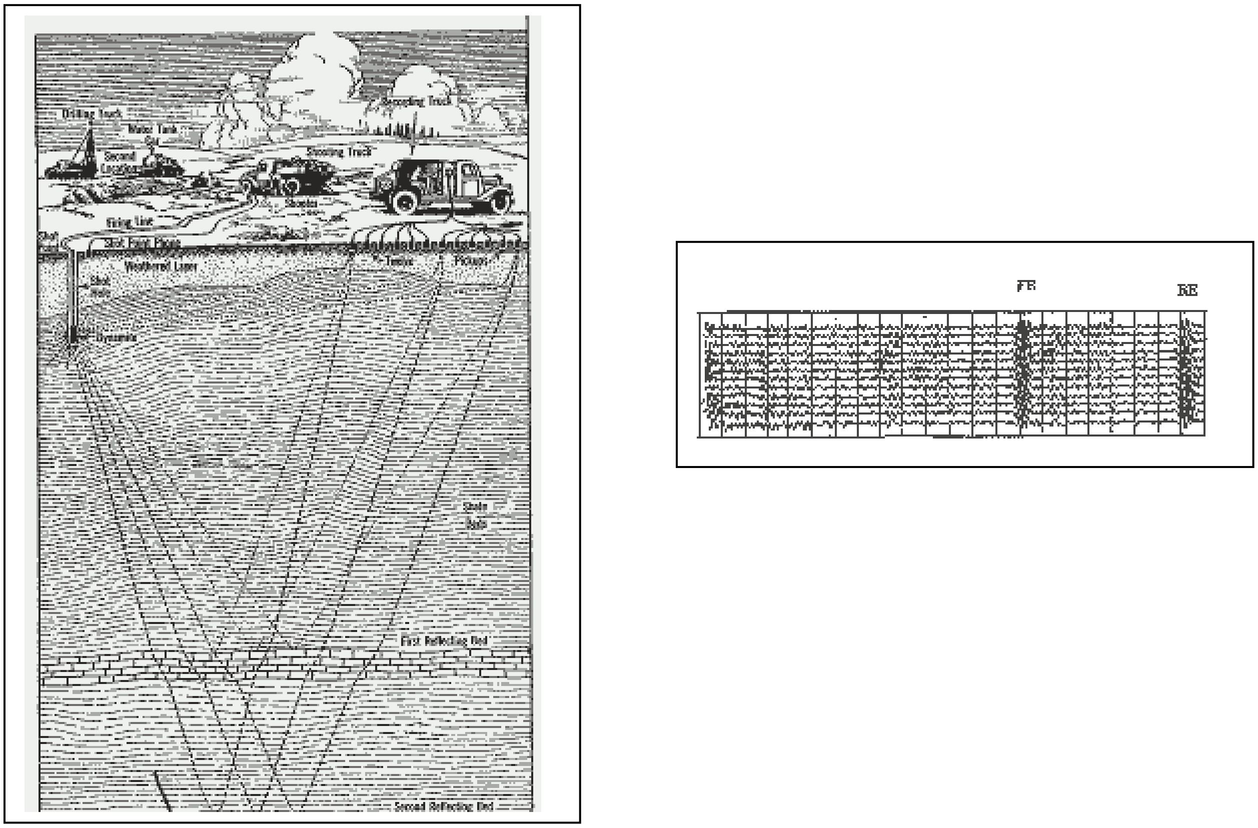
____

8. How do oil geologists find subsurface structures such as this? What's your inference?

____

If you said, "by drilling several holes in the ground," you might be right—but realize that drilling through rock down to these depths becomes very expensive, and until oil is found there is no return on the investment. A more likely method is the tool geologists have used to interpret much of the basic structure of Earth's interior: seismology. Figure 4 below shows one of the seismology methods used extensively by oil geologists. Only a shallow hole is drilled so that a dynamite charge can be inserted and exploded (diagram left), sending out vibrating waves comparable to earthquake waves. Geologists have found that changes in the characteristics of rocks underground act as reflective surfaces for these waves, bouncing them back to the surface where sensors (pickups in the diagram) receive them. A record of their arrival is made. The seismogram recording shown to the right in figure 4 shows the vibrations picked up by each of the 12 receivers.

Figure 4: Seismic Reflection Method (showing resulting seismogram at right)



[modified from Bateman: *The Formation of Mineral Deposits*, Wiley, 1966, p. 292]

9. a. How does the seismogram show the arrival of the reflection from the first reflecting limestone bed?

    ____

    b. What does *RE* represent on the seismogram?

    ____

Part 4: The Environmental Costs of Oil Use

Working in teams and using your school’s DAS system, determine the amount of air pollution that results from burning 100 gallons of oil to produce electricity. Investigate further in your library and on the Internet to complete each of the following tasks.

1. Determine the products produced by oil combustion.
2. Describe how each of these materials affects the environment.
3. Determine the natural processes that help remove some of these materials from the environment.
4. Evaluate the long-term environmental costs of continued oil combustion.
5. Determine the additional costs of oil production and use.
6. Compare oil usage costs to those of using solar energy: try to evaluate in dollars the dollar cost of each / kilowatt-hour using each energy source.
7. Be prepared to take part in a classroom discussion of each of these points.