Geology 102

Lab 8: Sedimentary rocks, groundwater, petroleum

Sedimentary rocks are formed when sediment is compacted and cemented (the two steps are called lithification). This happens within the top few kilometers of the earth’s surface, so no heat is necessary to generate this type of rock. In order to make sediment (and the cement that holds the sediment together), existing rocks must be weathered.

1. a. Sedimentary rocks are held together by cement, a non-mineral chemical compound, which forms bonds (though not as strong as chemical bonds) between mineral grains. The three common cements are silica (SiO₂), calcite (CaCO₃) or iron oxide (rust); each of these is generated by the actions of the acids listed above. How would you identify each cement (think of a test for each)?

Iron oxide — Silica —
Calcite —

b. Look at rock samples R23 and R24. What is the cement that holds each together?

R23 _______________ R24 _______________

c. Which sample is more well-cemented?

2. Use the Sedimentary Rock ID flow chart on the following pages to identify the samples in the following tables. For simplicity, the tables have already been divided so that the first question in the flow chart has been answered: sedimentary rocks made of broken rocks are called clastic, and sedimentary rocks made as a result of chemical processes are called chemical.

For the rocks in the table below, determine the average grain size: pebble, sand, silt or clay. Give the grain rounding: well-rounded, sub-rounded, sub-angular or angular. Give the sorting: well-sorted, moderately-sorted, poorly-sorted or unsorted. Give the cementing: well-cemented, moderately-cemented or poorly-cemented. Finally, ID the rock.

Clastic sedimentary rocks

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Grain size</th>
<th>Grain rounding</th>
<th>Sorting</th>
<th>Cementing</th>
<th>Rock name</th>
</tr>
</thead>
<tbody>
<tr>
<td>R23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For chemical sedimentary rocks, the sorting and rounding of the grains does not matter; however, the mineral composition is crucial in identification.

**Chemical sedimentary rocks**

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Most common mineral</th>
<th>Cementing</th>
<th>Rock name</th>
</tr>
</thead>
<tbody>
<tr>
<td>R25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. The **porosity** of the rock is how much void (empty) space is contained within the rock; the **permeability** of a rock is how interconnected the void space is. Examine samples W8 and W9; both rocks contain the same amount of porosity.

   a. What created the void space in each rock (they should be different reasons)?

   W8 (basalt)

   W9 (fossiliferous limestone)

   b. Which rock has the greater permeability? How can you tell?

4. a. Apply the same tests to the rocks examined in question 2. Under each of the permeability and porosity columns, use “high”, “low”, “none” as relative indicators of each of those properties.
b. Which rock of the above would make a good **aquifer** rock?

c. Which rock of the above would make a good **aquiclude** rock?

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**Petroleum resources**

**Petroleum** (oil) is a multi-component liquid refined to generate different **hydrocarbons**, such as heptane (a component of gasoline) and waxes. For the industrial world, petroleum is not only a source of energy, but also a key starting material for making plastics. Geologists use the principles of groundwater flow to narrow the possible locations of this economic resource. The areas which produce petroleum are called **oil fields**. If they generate **natural gas** (methane, ethane and propane) as well, they are called gas fields.

Many geologic factors determine where oil fields occur and the quality of the oil within that field. Though some components of oil are denser than water, oil and natural gas are typically less dense than water and thus will float on top or bubble through water. This means that oil and gas will rise to the surface using fractures and pore spaces within rocks. If the oil and gas reach an impermeable layer can no longer move upward, they are said to be “**trapped**” and the structure in which they are stuck is called an **oil trap**.

Three necessary factors for generating and trapping oil and gas are:
• A hydrocarbon **source rock** where the oil is made. A typical source rock is a marine limestone with plenty of organic material (mostly dead single-celled plankton). The sediments that will become this rock are covered, lithified, pressurized and heated by the burial. By excluding oxygen gas, the trapped organic material becomes more carbon-rich (water is driven out of the remains) through a series of chemical reactions. Organic-rich siltstones and shales also make good source rocks.
  • A porous and permeable **reservoir rock** into which the oil and gas can migrate away from the source, accumulate and later be pumped out. These rocks include arenitic and greywacke sandstones, limestones and other carbonate rocks.
  • An impermeable **cap rock** which acts like an aquiclude to prevent the oil and gas from escaping to the surface (once oil reaches the surface, the lighter molecular weight components simply evaporate!). Shale, evaporites (rock salt) and other fine-grained rocks are good cap rocks.

Note that the source rock is usually not the reservoir rock and that the cap rock is, of course, different from those two.

5. a. Which rock of the set you looked at in question 2 would be a good source rock (if you have any doubts, look at the source rock of the Ojai, California, oil fields at the front of the classroom)?

b. Which rock would make a good reservoir rock? Which rock would make a good cap rock?

c. Why are your answers to question 5b and questions 4b and 4c similar?

d. Examine rock R26. Would this make a good aquiclude? Would this make a good cap rock? Why are the answers to these two questions different?

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6. a. The major **reservoir** rock in this area is the Tfl strata. According to the explanation, what rock is Tfl made of? How well-cemented is this rock, in order that it be a good reservoir rock?

b. Which formation is the **source** rock? (Hint: it can be only one of the formations listed. Think about what the source rock should contain, and remember that most of the oil may have migrated to the reservoir rock, so that very few wells would try to tap into the source rock)
c. Which formation is the cap rock? (Hint: again, it can be only one of the formations listed. What characteristic should the cap rock have? Find a two-word phrase which is this characteristic.)

d. In areas where there is no cap rock but ample reservoir rock, what would you expect to see on the surface? (Hint: this happens in the La Brea district of Los Angeles. Also, look at the rock on the counter from such a surface feature near Ojai, California)

*Flow chart for identifying sedimentary rocks* — If the rock is made of grains or other materials which have been deposited by wind, water or ice, it's a sedimentary rock. For any sedimentary rock, if it contains any fossils, use the adjective *fossiliferous* in front of the rock name.

**One.** If the rock is made of broken up bits of rock (including extremely fine grains) then go to **two**; otherwise go to **three**.

**Two.** Consider the most common grain size in the rock from the following list.

<table>
<thead>
<tr>
<th>cobble or pebble</th>
<th>&gt; 2 mm</th>
<th>easily visible to naked eye; “grains” may contain identifiable minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
<td>0.062 — 2 mm</td>
<td>visible to naked eye;</td>
</tr>
<tr>
<td>silt</td>
<td>0.005 — 0.062 mm</td>
<td>not visible but can be felt between fingers or across teeth</td>
</tr>
<tr>
<td>clay</td>
<td>&lt; 0.005 mm</td>
<td>not visible; cannot be felt between fingers or across teeth</td>
</tr>
</tbody>
</table>

If the most common grain size is cobble or pebble □ **conglomerate**

If the most common grain size is sand □ **sandstone**
  - If the most common mineral is quartz □ **arenitic sandstone**
  - If the many dark minerals are present □ **arkosic sandstone**

If the most common grain size is silt □ **siltstone**

If the most common grain size is clay □ **claystone (shale)**

**Three.** Identify the most common mineral in the specimen (use mineral ID chart if necessary).

- If the most common mineral is quartz □ **chert**
- If the most common mineral is halite □ **rock salt**
- If the most common mineral is gypsum □ **rock gypsum**
- If it is black-colored, not very dense and flaky □ **coal**
  (also look for plant fibers)

If it fizzes, the most common substance is calcium carbonate, usually in the form of the mineral calcite (be careful you are not fizzing the cement)

- If the rock is not very dense and pure white □ **chalk**
- If the rock is made of mostly broken-up shells □ **coquina**
- If the rock is dense and white, gray or black □ **limestone**
You have now looked at a few sedimentary rocks and decided which make good aquifers qualitatively. Now you will quantify how good “good” is.

In the mid-nineteenth century, a French engineer in Dijon named Henry Darcy designed a water system for the town which required only gravity and a difference in elevation for the water to get from the source to the town. In fact, the results of his experiments resulted in the equation which bears his name:

\[ v = K \left( \frac{h_1 - h_2}{d} \right) \]

where \( v \) is the velocity of the groundwater, \( K \) is a measure of the permeability of the material the water flows through, \( h_1 - h_2 \) is the difference in elevation between the source of the water (the individual h's are sometimes called the hydraulic head of the groundwater) and its final destination and \( d \) is the horizontal distance over which the groundwater travels.

The square-bracketed part of the equation above, you may notice, represents merely the hydraulic gradient or slope of the "water table", and is sometimes represented by the symbol "I".

so Darcy’s Law becomes \( v = K I \).

Note that if \( A \) represents the cross-sectional area of the groundwater flow, then \( v \) times \( A \) (the velocity of the flow times the area of the flow) equals \( Q \), the discharge of the groundwater (in other words, the volume of groundwater which flows forth at any given time).

Thus, the form of Darcy’s Law you will use is

\[ Q = K I A \quad \text{or} \quad Q = K \left( \frac{h_1 - h_2}{d} \right) A \]

In this experiment, you will determine the validity of Darcy’s Law and estimate the permeability of some uncommon soil grain sizes: pea gravel, aquarium gravel and coarse sand.

[Note to those of you in MAT 125 (or any other second-quarter calculus class): Darcy’s Law is a specific example of a second order partial differential equation (similar to heat transfer equations). It has the form:

\[ \frac{\partial u}{\partial t} = D \nabla^2 u \]

where \( u \) is the volume of the flow (and therefore the time differential is called the flux), \( K \) is the permeability of the material and the scary second-order partial differential works out to be the hydraulic gradient.]

Some thoughts before you begin the experiment:
7. a. If the only thing you could change was I (which equals \((h_1-h_2)/d\)), then what sort of relationship would I have with Q, the discharge? In other words, if K and A were held constant, then how are I and Q connected?

b. In what two ways could you alter I? (Hint: look at the equation for I in question 1 for the two factors that can be changed)

c. Look at the experimental setup; what physical quantity is represented by \(h_1\)? How will you keep it constant?

d. What physical quantity is represented by \(h_2\)? And what about d?

e. So when you change the quantities above, what are you "really" affecting? In other words, how are you changing the experimental setup?

8. a. How will you measure Q, the discharge? Remember, you will need two pieces of equipment because the discharge is measured in cm\(^3\)/s (cubic centimeters per second)

b. How will you calculate A?

c. How do you think the K (permeability) of the coarse sample will compare to that of the fine sample?

9. Okay, now go take the measurements. On the following pages, you will find tables which are headed by the phrase "Grain size". Choose one of the prepackaged "canisters" and note the grain size written on the side. Assemble the equipment as demonstrated and assign tasks.
Grain size _______________________

<table>
<thead>
<tr>
<th>Trial</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>h₁ (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h₂ (cm)</td>
<td></td>
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<tr>
<td>h₁-h₂ (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>d (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I = (h₁-h₂)/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume collected (cm³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q (cm³/s)</td>
<td></td>
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</tbody>
</table>

Go up to the computer room and open Excel. On the spreadsheet, enter two
column headings in A1 and A2 respectively: "I (hydraulic gradient)" and "Q (discharge in cubic centimeters per second)" (don’t worry about the
words not fitting into the column completely; use the “resize” function of Excel). Enter
the appropriate data from each trial into the columns, and then use the "Chart
Wizard" to plot I versus Q. Don’t print the graph out yet.

10. a. Was your prediction in question 7 accurate? How does your graph show
this relationship?

Make another set of measurements using a different "canister"; note its grain size.
*Use the same I’s as you did for the first ”canister”.*
Grain size _______________________

<table>
<thead>
<tr>
<th>Trial</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>h₁ (cm)</td>
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</tr>
<tr>
<td>h₂ (cm)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>h₁-h₂ (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I = (h₁-h₂)/d</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Volume collected (cm³)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Time (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q (cm³/s)</td>
<td></td>
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</tbody>
</table>

In A3, write "**Q (discharge in cubic centimeters per second)**" and use the "Overlay" function in Chart Wizard to put both sets of data on the same graph. Once the title (think of an appropriate one) and the axes labels are right and the graph looks nice, print it out and attach it.

b. Does the graph of the coarser material canister have a steeper or shallower slope than the graph of the finer material canister? Is this consistent or inconsistent with your prediction in question 8c?

(Extra credit — 2 points) Calculate the **permeability** of each grain size you used. To earn any credit, you must show the **details of the setup** of the calculation and the **units** of the permeability.