**Ore Exploration Game**

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Context: A 3-week laboratory exercise in Geology 101, Introductory Geology, carried out after coverage of minerals, rocks, maps, structures, ore deposits, and relative time.

Overall goal: To give students the opportunity to solve a real-world problem as a geologist would, by integrating and applying their knowledge on rock types, structures and ore deposits.

**Ore Exploration Game**

**Goals of the Game:**

One way in which our understanding of bedrock geology is applied is in the search for mineral deposits. In order to find ore deposits, especially ones that are not exposed at the surface, geologists must have a comprehensive understanding of the rocks in the area. What rock types are present? How did they form? What structures are present? When did they form? When in this geologic history were conditions right for formation of various types of ore deposits? If a mineral deposit did form, where is it now? Understanding the answers to these questions is basic to searching for mineral deposits.

Ultimately, the search for buried ore deposits comes down to drilling an exploration hole, extracting a column of drill core from the hole, and seeing if any ore is intersected. Here, the science of geology intersects with the discipline of economics. The most straightforward way to find ore would be simply to grid the entire planet with closely spaced drill holes. Clearly the costs, both economic and environmental, of such an endeavor would be outrageous. So a successful exploration geology program is guided by science and by economics. The objective is to use an understanding of geology to guide a drilling program to ore with a minimum of expense.

Finally, exploration is a competitive business. In many states, mining rights are obtained by lease. Thus, having found ore, a company must submit the high bid on the property in order to gain mining rights. This adds an element of gaming to the mix. How much will be enough to win the mining rights? Has anyone else found this deposit or can we low ball the bid and still win?

The result of all of this is that mineral exploration can be viewed as both a puzzle (where is the ore?) and a game (how little can we spend and still “win” the ore deposit). This lab attempts to recreate these elements. You will be given a map that is keyed to a set of rocks. Using these materials and what you have learned in this class, you will be able to put together an understanding of the geologic history of the area and to form hypotheses about the possible locations of deposits. You will also be given an exploration budget, with which you will be able to buy more information such as drill-hole data and stream-sediment analyses. With these data you can refine your understanding of the geology and test your hypotheses about the location of ore deposits. We will arrange more than one round of play, so that your early results can guide later work. In the last lab, each team will submit bids, using remaining cash, and the winners will be crowned victorious!

To win, your team must think clearly about the geology in order to drill ore with a minimum of barren holes. You must conserve cash for the bidding, and then you must out-guess your competitors in the bidding.

**Materials to Hand In**

1. Map (10 points)

* Colored
* Fold symbols
* Arrows or U&D on faults
* All known surface ore colored black or red
* All buried ore marked with red or black stripes

2. 2 cross sections (40 points)

* Colored
* Arrows on faults
* All known ore colored red or black

3. Map explanation/history – typed (80 points)

* Rocks in order by age, ***oldest at the bottom.***  Use brackets to link rocks of the same age.
* Rocks described (see examples below)
* Events in proper places and described (see examples given on explanation form)
* Sequences of sedimentary rocks (regressions and transgressions) explained

4. Paper on ore deposits (2 pages) – typed (20 points)

* For each type of ore deposit, give :
	+ The metal(s) that are concentrated
	+ The mineral(s) containing the metal(s)
	+ Any minerals found with the ore
	+ The environment in which the ore formed, based on the textures in the ore samples (see Minerals lab)
	+ The kind of rock that contains the ore (see your map)
	+ The name of the ore deposit and how it formed
	+ Where the deposit is found, both on the surface and hidden. Be sure to describe all occurrences of the ore, even those on which you are not going to bid.
* Explain your bidding strategy

In addition to the project points you can earn up to 10 bonus points:

Bonus! for locating ore: up to 5 pts

Bonus! for winning bid: 5 pts (for all who have at least one winner)

**Grading**

Your grade will be based primarily on the quality of your interpretation of the geology and how well you play the game, so you don't have to worry about your grade being hurt by your being unlucky in the bidding. Each individual will submit an interpretation, each team will submit bids.

A large part of your grade will be your map explanation describing the basic geology of the area, and your paper describing the basis for your bids. During the earlier labs, you described the minerals and rocks you will need to know. To start this project, you should describe the samples that are keyed to the map. Make sure you have notes on the minerals present, the texture, and the name of each sample. You will be graded on these descriptions.

You are encouraged to work as teams, but **each individual** will complete:

* a map (with U & D on all the faults and fold symbols) and 2 cross sections
* a detailed map explanation
* the 2 page paper described above

*The map explanation* should be typed and is basically a detailed key to the map that includes rock units and depositional events, the formation of mineral deposits, structures (folds and faults), and erosional events (unconformities). You will be sent a template for this via email. The map units should be presented with youngest unit at the top and the oldest at the bottom. If you know an absolute age of a particular unit, include it in the explanation. See next page for an example of map explanation.

Rather than using patterns (as is shown on next page), the boxes on the map should be color-coded so that they match the colors you used on the map and cross-sections.

NOTE: In lab, you will work with your group to fill in a number of work sheets, but each student needs to write a separate map explanation. We expect that a group that works closely together will have similar information in their map explanations but the explanations *should not be identical.* Several students have gotten into trouble in the past when they plagiarized other students’ work. **Plagiarism will result in a failing grade.**

Each individual will submit a map, 2 cross-sections, a map explanation, and a mini-paper on the ore and bids. Each team will submit bids.

**Schedule**

This project is scheduled to last three weeks. In the first week, you will be given the basic elements of the game - a map, rock samples, a budget and worksheets. You will spend the lab identifying the rocks, constructing geological cross sections, and working to understand the geologic history of the area. In the second lab, you will work to locate ore. We will discuss report writing, and help with any problems you may have had with cross sections. On the day of the third lab, you will have a short time to finish up your work, then hand in your paper and submit your bids. We will go over the geology of the area and then announce the winning bids.

Information for filling out the map explanation:

For **Sedimentary** rocks- write a description of each rock, starting with the oldest, which includes its rock type, rock name, texture, minerals present, and environment of deposition. After you have described each sedimentary rock, you should discuss what the *sequence* of rocks tells you about how environments changed during time of deposition (for example, sea level rising or falling).

For **Metamorphosed sediments**: Describe each metamorphic rock, including rock type, rock name, texture, minerals present, parent rock, and the cause of the metamorphism and how you determined this.

For **Igneous rocks**: Again, describe each igneous rock, giving its rock type, rock name, minerals present, texture, its cooling history and how you determined this.

Include **ore** in the map explanation, identifying the type of deposit, the ore minerals, and the enclosing rocks.

**Structures** (folds and faults) and **Unconformities**- describe structures and explain in what sort of environment they might have formed. Describe unconformities and explain what created them.

 Sample rock descriptions for map explanation:

**Q**

Quartzite (**rock name**). Crystalline nonfoliated (**texture**) metamorphic (**rock type**) rock composed of quartz (**mineral present**). Formed by contact metamorphism (**type of metamorphism**), when Gabbro G intruded **parent rock** Quartz Sandstone T (**cause of metamorphism**) as can be seen by relations on map and cross section A-A’ (**evidence**). Age of formation of the quartzite is coincident with intrusion.

**G**

Gabbro **(rock name)**. Igneous **(rock type)** withpyroxene and plagioclase (**minerals present**) Coarse-grained (**texture**) therefore formed beneath the Earth’s surface by slow crystallization from magma **(cooling history)** because large crystals need time to grow **(evidence)**. Intruded Sandstone S and created Quartzite Q

U/D

Normal faulting **(name of structure).** Faults are oriented NE-SW and dip 60 degrees to the SE The NW side moved up relative to SE side **(description).** Faulting occurred because of NW-SE extension **(cause)**

**A**

Arkose **(rock name).** Sedimentary **(rock type).** Red-brown, contains orthoclase, plagioclase, and quartz (**minerals present**). Clastic medium- grained (**texture**)**.** Formed in a mountain stream **(depositional environment)** as evidenced by immature mineral assemblage **(evidence)** during a period of sea-level fall from rock U to A **(sequence).**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Rock Name | Type | Texture | Minerals present | Other information |
| A |  |  |  |  |  |
| B |  |  |  |  |  |
| C |  |  |  |  |  |
| D |  |  |  |  |  |
| E |  |  |  |  |  |
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| G |  |  |  |  |  |
| H |  |  |  |  |  |
| I |  |  |  |  |  |
| J |  |  |  |  |  |
| K |  |  |  |  |  |
| L |  |  |  |  |  |
| M |  |  |  |  |  |

Rock Type: Sedimentary, metamorphic, or igneous

Textures: If sedimentary – clastic or crystalline; bedded or massive

If igneous – intrusive (plutonic) or extrusive (volcanic). Note if the sample is porphyritic

 If metamorphic – foliated or nonfoliated

Minerals present: List only what you can see. If the rock is fine-grained, the answer may be “none visible.”

Other information: List such information as environment of deposition (sedimentary), parent rock and cause of metamorphism (metamorphic) and cooling history (igneous).

**This worksheet is to help you in gathering observations; do not hand in.**

|  |  |  |  |
| --- | --- | --- | --- |
| Type of Fold | Description | Youngest rock folded | Oldest rock not folded |
|  |  |  |  |
|  |  |  |  |
| Type of Fault |  | Youngest rock faulted | Oldest rock not faulted |
|  |  |  |  |
|  |  |  |  |
| Type of Unconformity |  | Youngest rock below | Oldest rock above |
|  |  |  |  |
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Note: The number of blank rows does not necessarily equal the number of each kind of structure.

**This worksheet is to help you in gathering observations; do not hand in.**

Map Explanation

Name\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

In the split rows, put the rock letter in the smaller box and the rock description in the larger. Put events (e.g. folding, faulting, uplift and erosion, intrusion, regional metamorphism, contact metamorphism, ore formation) and their descriptions in the continuous rows. After you print this, color the sample letter boxes to match the map and cross sections.

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Geology 101

Mineral Exploration Game Budget Sheet

Names\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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| --- | --- | --- | --- | --- |
| Exploration Budget | $500,000  |  |  |  |
| Drilling @ $50,000 | Stream Survey @ $15,000 | Surface Survey @ $5,000 | Ore Intercepts @ $25,000 | Total |
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Amount left for bid(s): \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Ore Exploration Game Bid Sheet**

Each team will turn in a bid sheet on the last day of the project. Here are a few guidelines and suggestions:

* You should use all of the money that you have left after exploring for ore.
* Only bid on squares where you think there is ore at the surface or hidden below the surface. You may bid on up to 20 squares or you may choose to bid on fewer, even as few as one.
* The minimum bid is $1,000.
* If your team submits the highest bid on a square that has ore at the surface or concealed at depth, you win the bid and will be awarded 5 bonus points.
* In your mini-paper on the ore deposits, you should discuss your bidding strategy as well as the overall distribution and origin of ore in the map area. Make sure you describe all the locations in which you believe ore exists, not just those on which you plan to bid.

Group name\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Money available for bidding\_\_\_\_\_\_\_\_\_\_\_\_\_

Fill in bids below:

 Square $ Bid Square $ Bid Square $ Bid Square $ Bid

1. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 6. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 11.\_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 16. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_

2. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 7. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 12.\_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 17. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_

3. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 8. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 13.\_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 18. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_

4. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 9. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 14.\_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 19. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_

5. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 10. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 15.\_\_\_\_\_\_ \_\_\_\_\_\_\_\_ 20. \_\_\_\_\_\_ \_\_\_\_\_\_\_\_