The Case of the Missing Half of the Tyrannosaurus Skeleton

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Objectives

When you have completed this exercise, you should…

1. Thoroughly understand and be able to use the following terms: *strike and dip*
   hanging wall
   footwall
   strike-slip fault
   right-lateral fault
   left-lateral fault
   dip-slip fault
   normal fault
   reverse fault
   thrust fault
2. Be able to distinguish a normal fault from a thrust or reverse fault by examining the offset of dipping beds across the fault.
3. Understand and be able to use the scientific method, inductive reasoning and deductive reasoning.
4. Appreciate how mind-boggling (but, for some people, exciting) it can be to hunt for fossils, especially when you must predict what will (or will not) be found underground.

Your Mission (Should You Choose to Accept it)

You and your team-mates are working for a small museum, digging up the skeleton of the largest and best-preserved Tyrannosaurus ever unearthed. It is a spectacularly preserved skeleton; it reveals a great deal of detail about the anatomy of the infamous *Tyrannosaurus.* The only problem is that the front half of the skeleton is missing--it had been cut and offset by a fault.

Your boss has just reread his 1976 issues of *Economic Geology* (he does this for fun on Friday nights). He ran across an account of how a major underground copper ore body was discovered in the early 1970's near Tucson, Arizona. Miners were working an ore body in the area that was exposed at the surface. One of the mine geologists, David Lowell, noticed that this ore body was cut in half by a major fault. He did a very clever analysis of the fault and was able to predict exactly where, buried underground, the missing half of the ore body was. This second ore body yielded large quantities of copper ore until the very end of the 20th Century.

Your boss decides that this may be exactly the technique needed to find the missing half of the *Tyrannosaurus*. A geologic map (next page) shows the rock types exposed at the dig site. Because this area is in the desert, the ground surface is 100% bedrock (there is no soil and there are no plants). Paleontologists have thoroughly surveyed the area and found no traces of *Tyrannosaurus* bones other than those shown on the map. The topography in the area is nearly flat.

Where is the missing half of the *Tyrannosaurus*? Three possibilities exist: (1) the fault could have lifted it up and erosion could have broken it up and carried it away, (2) the fault could have dropped it down below the surface and out of sight, (3) the fault is a strike-slip fault and the missing half of the *Tyrannosaurus* is some distance away from the area, potentially where a competing museum might find it.

Your museum is one of several museums (i.e. other teams of students in your class) in a race to find the missing half of the *Tyrannosaurus.* As a team, you will write a formal recommendation stating which of the above three possibilities is correct and, if the missing half of the *Tyrannosaurus* has not been eroded away, where to dig to find it. Support your conclusions with plenty of data and logical arguments. A series of questions will lead you through the process to your final conclusion.

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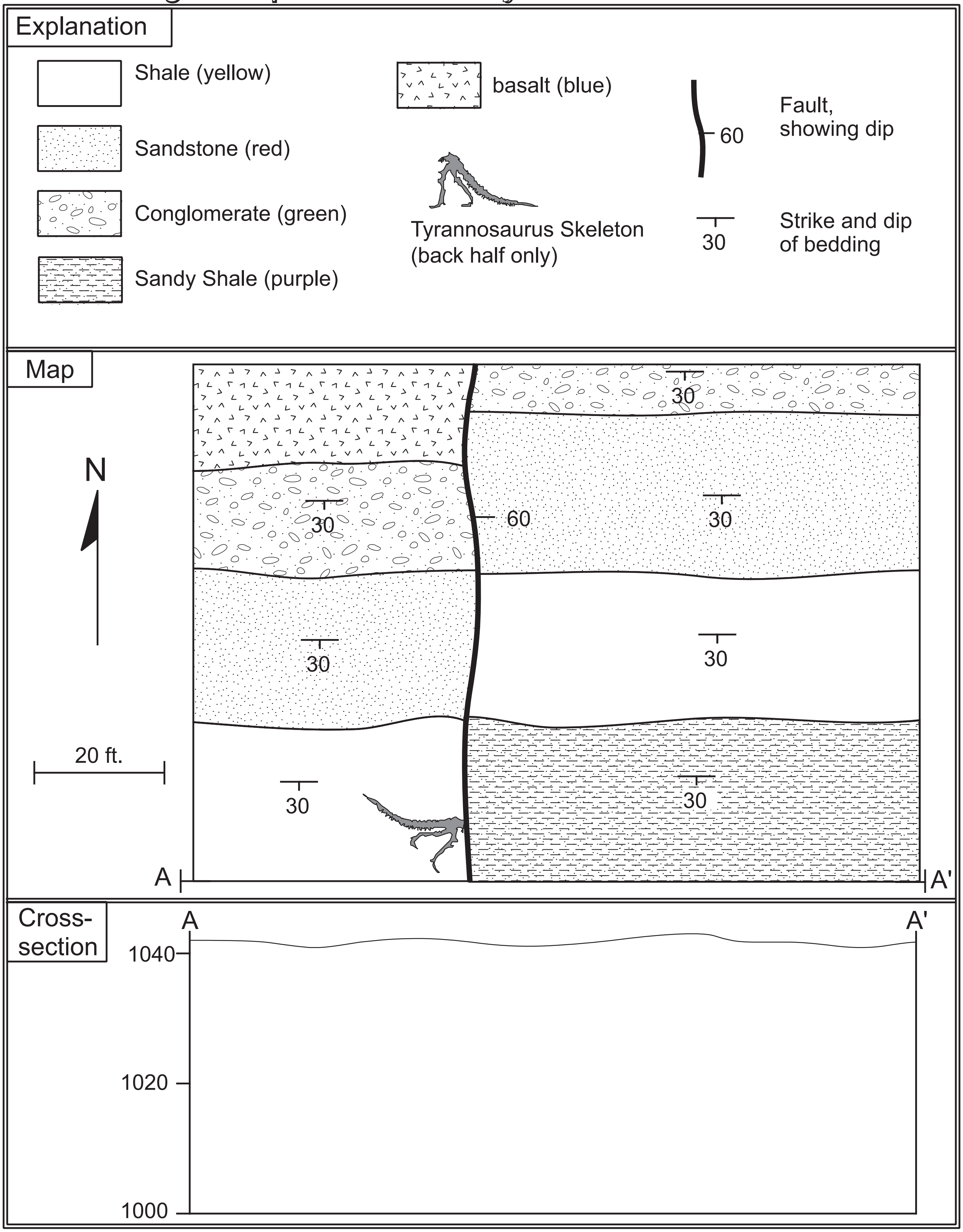
Geologic Map of the Lost *Tyrannosaurus* Field Site



Your first step is to examine the map and—if you wish—color it. Then carefully study a set of eight painted wood blocks provided by your instructor. Use these blocks throughout this lab to help you see the 3-dimensional geometry of the layers and the fault.

Notice that the fault strikes north and dips 60° east (as shown by the dip symbol attached to the fault).

1. **Thus, the <u>eastern</u> side of the fault is the (hanging / foot) wall.**

   while the <u>western</u> side of the fault is the (hanging / foot) wall.

Look for strike-and-dip symbols on the various beds; note that these strikes and dips are the same everywhere on the map.

2. **The strike of bedding is ____________________________**. (what direction?)

   The dip direction is ________________________. **The angle of dip is ____________________**.

3. **Using the law of superposition (the oldest beds are on the bottom), and the law of cross-cutting relationships (faults and intrusions are younger than the rock units they cross-cut), determine the relative ages of the rock units on the map. On the map, show these relative ages by labeling each patch of outcrop with a number between (1) and (5). Label the oldest unit (1) and the youngest unit (5).**

Continue to examine the map and notice that the same beds are not directly across from each other on opposite sides of the fault. In fact, the beds on the west side of the fault are all located farther south than the same beds on the east side of the fault.

4. **Using the scientific method, make a hypothesis and test it.**

   a. **Hypothesis: The fault is a (left / right) lateral strike-slip fault**.
   (circle the correct choice)

   b. **Prediction: If this hypothesis is correct, where should the missing half of the *Tyrannosaurus* skeleton be?**

   c. **Test: Is the missing half of the *Tyrannosaurus* skeleton where you predicted it would be?**

   d. **Conclusion: Is the hypothesis correct or incorrect?**

<u>Back to the old drawing board</u>. What are the other possibilities?

5. **New hypothesis: If the fault is <u>not</u> a strike-slip fault, it must be a _____________-slip fault.****

6. **a. The three main types of dip-slip faults are**

   1) _______________________ 2) ______________________ 3) ________________________

   b. **One of these types of faults cannot dip as steeply as 60° and can be eliminated as a possibility. Which one? ____**

* We will assume that there is not a combination of strike-slip and dip-slip motion on the fault.

You know that the fault in the Lost *Tyrannosaurus* field site is one of these two types, but which one is correct? You are stumped. But your wooden blocks may yet save the day. You can use them, together with a time-honored scientific method called *inductive reasoning*, to discover a general rule that will help you solve the puzzle. In fact, you can use this general rule to figure out what kind of movement occurred on any fault that cuts a stack of dipping beds.

Procedure for Discovering the General Rule

When you use *inductive reasoning*, you study many specific cases and come to a general conclusion based on what you observed in those specific cases. Your team will examine eight cases of faulting; in each case, a fault cuts across dipping beds. All of the faults are *dip-slip* faults: the faulted rock moves up or down, parallel to the dip of the fault. But, after erosion, it will look like the fault moved sideways; there will be a strike-slip **separation** (an apparent strike-slip offset) of the beds.

8. Complete the table on the next page, following the instructions below. The first row of the table is already completed; use it as an example.

a. Put the eight blocks together until the colors match on all adjacent blocks. This represents dipping beds, before faulting.

b. On a blank piece of paper, write “North” on the top, “West” on the left side, “East” on the right side, and “South” on the bottom. Place the blocks on the paper and orient them so that the beds dip south and the fault dips east (see the diagram below and columns A and B on the next page).

c. Lift the stack of blocks on the east side of the fault and slip a piece of scrap wood underneath to hold the stack up. This represents uplift by a reverse fault (the hanging wall moved up). See the diagram below and column C of the table.

d. Mimic erosion by removing the top block from the east (hanging wall) side of the fault. The fault now shows apparent strike-slip offset. It's called “apparent” because--as you saw in step c--there really wasn't any strike-slip motion involved.

e. Now, read the observations that have been written in row 1 of the table.

(i) The offset across the fault appears to be **right**-lateral strike slip (column D).

(ii) The side of the fault that moved up was the **east** side (column E).

(iii) The beds on the uplifted side appear to have moved **south** (column F).

f. Put the blocks back together (as in step a). For rows 2-8 of the table, orient the blocks as described in columns A and B; move the blocks to form the type of fault as given in column C, and remove the top block of the uplifted stack to mimic erosion. Then fill in columns D, E and F. Within your group, take turns arranging the blocks; you learn better by doing than by watching.

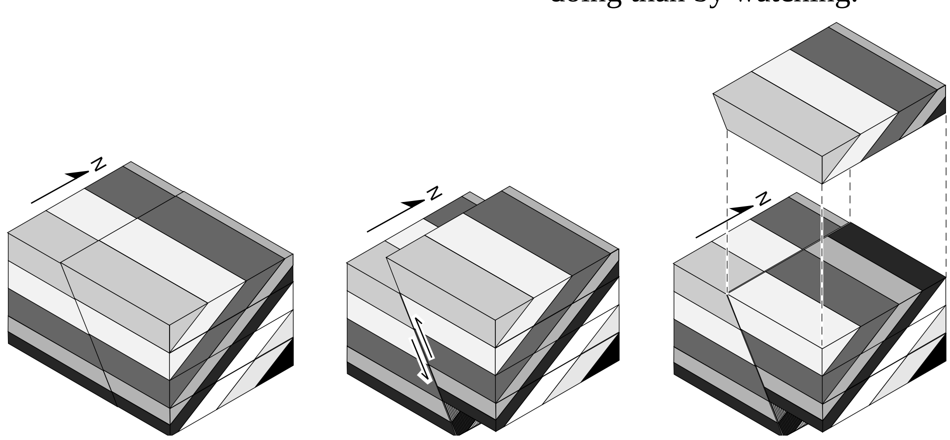


Table of Experimental Results

	A **Dip of Beds**	**B** **Dip of Fault**	**C** **Type of fault**	**D** **Apparent lateral offset (right or left)**	**E** **Which side of the fault moved up (was uplifted)?** ***(east or west)***	**F** **Which direction do the beds on the uplifted side appear to have moved?** ***(north or south)***
1	South	East	Reverse	right	east	south
2	South	East	Normal			
3	North	West	Reverse			
4	North	West	Normal			
5	South*	West*	Reverse			
6	South	West	Normal			
7	North	East	Reverse			
8	North	East	Normal			

*You will have to flip the blocks over to get them into this configuration. Then leave them flipped over for the rest of the table.

A clear pattern emerges from the table. In particular, two of the six vertical columns are identical. We can use this relationship to state a general rule that applies to every specific case.

9. Circle the statement that best states the general rule.

a. The side of the fault that moved up is the same as the dip of the fault.

b. The beds dip in the same direction as the uplifted side dips.

c. The beds on the uplifted side appear to move in the direction of their dip.

d. The uplifted side actually slips horizontally in the direction of the dip of the beds.

You have just used **inductive** reasoning to derive a general rule based on the results from a number of specific cases. Now it is time to use **deductive** reasoning to apply your general rule to a specific case.

10. In the Lost *Tyrannosaurus* field site, the (west / east) side of the fault was uplifted and eroded. (Circle the correct answer)

11. Clearly explain how you used the general rule (from question #9) to decide which side of the fault was uplifted and eroded.

12. **The fault in the Lost *Tyrannosaurus* field site is a (normal / reverse) fault.** (Circle the correct answer)

13. **Draw a cross section along A-A' in the space provided below the geologic map of the Lost *Tyrannosaurus* field site. Be sure to show the *Tyrannosaurus* skeleton. Use arrows alongside the fault to show which way each side of the fault moved.**
(THINK! What should be in your cross section? Look carefully at the blocks).

14. **Number the events below in chronological order, using #1 for the oldest event and #8 for the youngest event. Event #6 is already numbered.**

#6 **tilting or folding of the beds.**

______ **erosion.**

______ **deposition of the shale (and the death of the *Tyrannosaurus*).**

______ **deposition of the sandstone.**

______ **deposition of the conglomerate.**

______ **deposition of the sandy shale.**

______ **extrusion of the basalt**

______ **fault movement.**

15. **The missing half of the *Tyrannosaurus* skeleton is…** (circle the correct answer)

    a. **gone; uplifted and later destroyed by erosion.**

    b. **below the surface within the Lost *Tyrannosaurus* field site (if you choose this alternative, mark the map with an "X" showing where a vertical hole should be dug in order to find the missing half of the *Tyrannosaurus* skeleton).**

    c. **near the surface outside of the Lost *Tyrannosaurus* field site (if you choose this alternative, state whether the half skeleton is located north or south of the area).**

16. **Write your formal recommendation,** stating which of the above three possibilities is correct and, if the missing half of the *Tyrannosaurus* skeleton has not been eroded away, where to dig to find it. Be sure to support your statements with plenty of data and logical arguments.