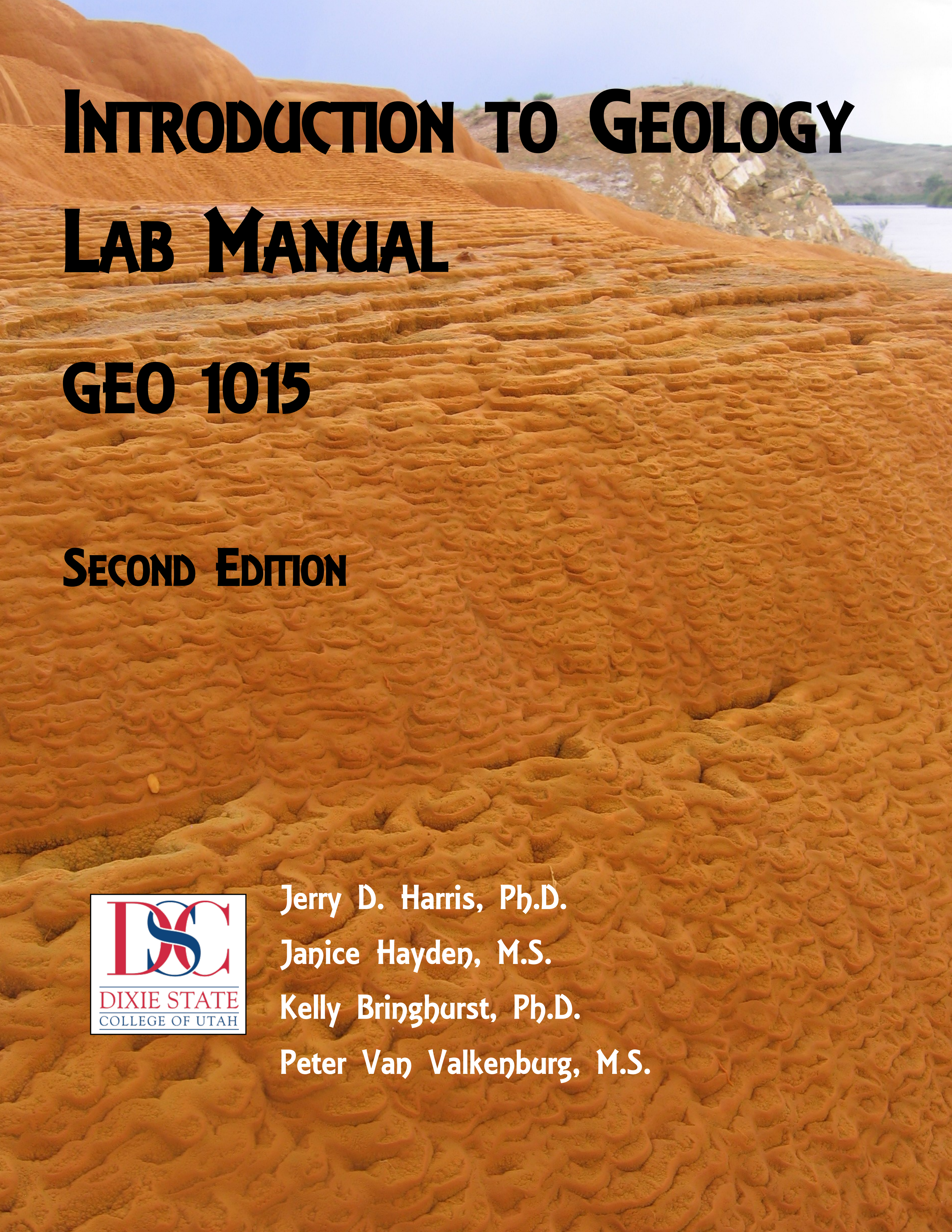

Introduction to Geology Lab Manual

GEO 1015

Second Edition

Jerry D. Harris, Ph.D.
Janice Hayden, M.S.
Kelly Bringhurst, Ph.D.
Peter Van Valkenburg, M.S.

DIXIE STATE COLLEGE OF UTAH

Cover photo: Travertine deposited by Crystal Geyser (an artificially drilled, cold-water geyser) near Green River, Utah. The travertine is white (see outcrops in background), but here is stained orange by rust from an pipe set into the geyser in 1936. Photo by Jerry D. Harris.

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ACKNOWLEDGEMENTS

This book owes its existence to the collective thousands of introductory geology students us geology professors have had over the years that have taught us a great deal about presenting geological concepts to beginners, and who continually point out vagaries and errors in our teachings and invariably want extra credit for having done so. ☺

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PREFACE to the FIRST EDITION

A huge number of geology lab manuals are available from many different publishers, so why did Dixie State College's faculty write their own? Well, for several reasons, all of which are specifically intended to help students enrolled in the GEO 1015 labs:

- First and foremost, essentially *all* of the available geology lab manuals are written for geology majors—people intending to make geology their careers. Introductory geology labs for geology majors are specifically designed to train those majors to be future geologists and give them basic skills and knowledge that forms the foundation for such a career. However, DSC's GEO 1015 lab course (and the accompanying GEO 1010 lecture) is a general education course, and *not* intended for majors. You and other students in this class do not need to be trained as would be future geologists. So the labs in this manual have a very different focus: instead of training future geologists, they are specifically designed to enable you to see how many aspects of geology—and science in general—impact you in everyday life, even in ways that you do not think about. Of course, along the way, you will still learn the basic principles of geology (which are necessary to understand why they affect you).
- While you will do some things that you might expect in these labs—such as learn to identify different mineral and rock types and various geological formations and structures—much of these labs involves using computers to find information about how geology affects you and will continue to affect you in everyday life, whether you realize it or not. In some cases, such as the geologic hazards lab, the potential effects will be quite obvious; in others, such as the plate tectonics lab, they may be less so, but they are there! Having computer-based exercises may seem a strange thing to do in a geology course, but they are specifically designed to enable you to learn how you can find, understand, and use geological information even outside of class. Knowing that such information is accessible, you can use such information in the future to make decisions about geological factors that will impact your life (for example, picking a place to buy a house based on geologic hazards, or why cell phones and other electronics are so expensive, which is a function of the rarity of some of the minerals that are required to make critical components).
- Many of the questions in the lab exercises in this manual have a Utah-based focus. This is to enable you to learn more about the specific geology that you have seen, see every day, and may well encounter in the future elsewhere in Utah, as well as gain an understanding of some of the broader implications of Utah's geological resources for the rest of the world. Utah is an especially rich place in terms of geology, and interacting with its geology is unavoidable! Of course, the principles you learn in this course apply all over the world (and even on other worlds!), so even if you leave Utah, what you learn in this lab will travel with you.
- Other lab manuals are extremely expensive—because they are intended for geology majors, non-majors, such as yourself, would not use substantial portions of those manuals, which just wastes your money!

Please note that your GEO 1015 lab section ***complements*** the GEO 1010 lecture course in which you are also enrolled! The lab schedule (see your syllabus) has been designed, with the cooperation of the GEO 1010 lecture instructors, to purposefully stay *behind* the lecture schedule. This way, the concepts you will be applying in lab will have been introduced in the lectures first. However, this means that **you** are responsible for knowing and understanding that material ***before*** you begin a lab! Your lab instructor cannot spend lab time lecturing in detail on any subject—lab time needs to be devoted to you doing the lab activities. However, your lab instructor will be more than happy to explain concepts with which you have had difficulty from the lecture and/or lecture textbook—after all, the labs are intended to help reinforce the lecture material! If you are having difficulty grasping some concept or set of material, please don't be afraid to approach your lab instructor, as well as your lecture instructor!

Read all questions in this manual very carefully—students often exhibit a peculiar habit of giving an answer that has nothing to do with the question, and they lose points as a result. Don't let that be you!

Key learning points are provided at the beginning of each lab. You should consider these as an ***outline*** (but ***not*** a complete list!) of principles, concepts, and skills you must master and on which you will be tested on your lab exams.

Blank note pages are provided at the end of each lab—you should use these to jot down important information that you learn during the labs because that information may well show up on your mid-term and final exams. They will be useful to you to study for those exams!

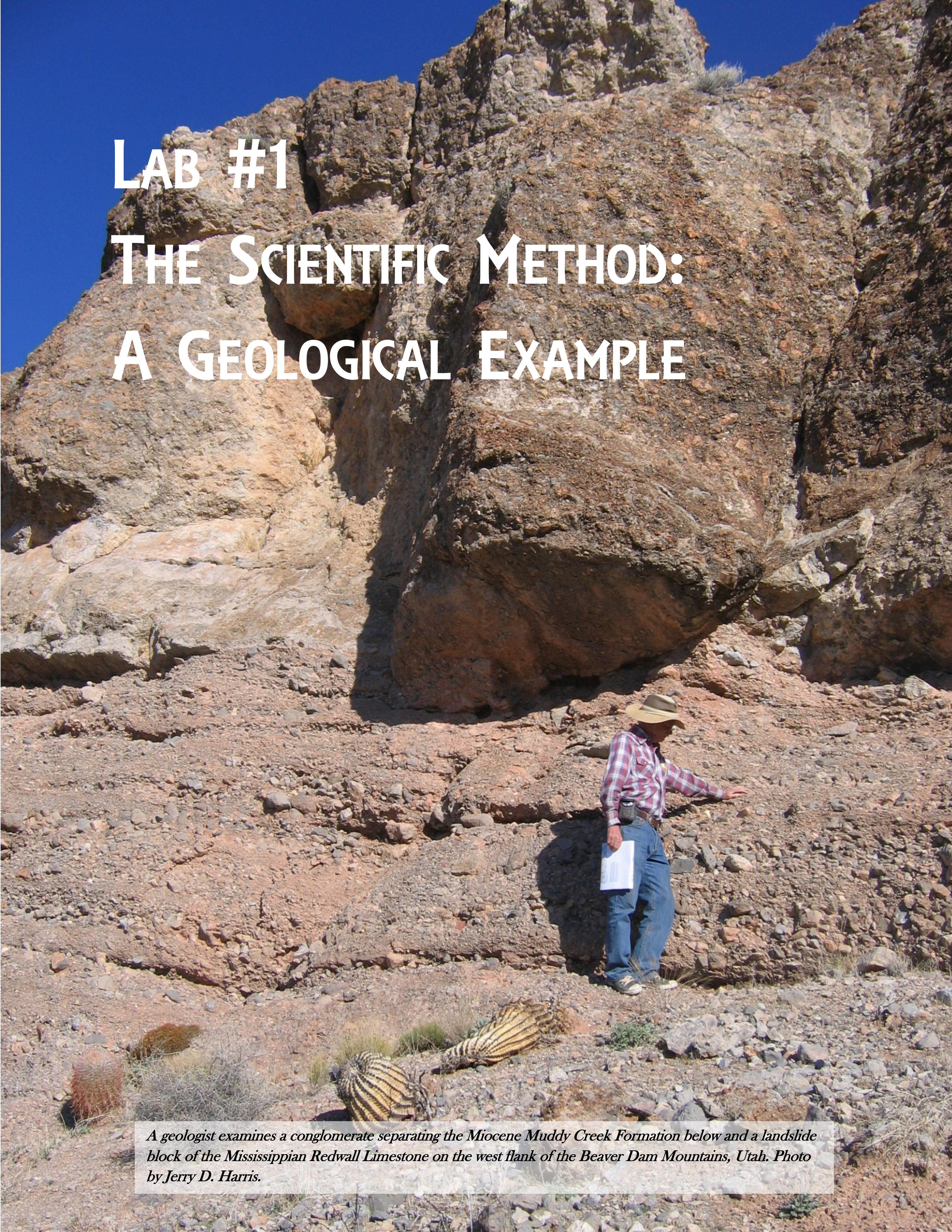
We hope that you find learning about geology in this lab course to be enjoyable and interesting. We are definitely interested in your thoughts about the labs in this manual so that we can improve them for future students, so please feel free to tell your lab instructor what you do and don't like about the labs. In particular, let us know specific suggestions you have for improvements and/or clarifications!

In the meantime: welcome to the world of geology! (Yes, the pun was intended.)

Dr. Jerry D. Harris
Director of Paleontology and Associate Professor
Dixie State College (or whatever we'll end up being called)
January, 2013

A note concerning images used in this manual: As much as possible, photographs used in this manual were taken by the authors, and diagrammatic images are custom-designed by the authors. However, it should be assumed that all images are protected and cannot be copied or modified without the express permission of the person credited with the image. Every effort was made to use public domain images for the remaining images in this manual. If there are any concerns or questions please notify us in writing and we will be happy to remove the image from the next edition of the manual.

Lab #1
The Scientific Method: A Geological Example



A geologist examines a conglomerate separating the Miocene Muddy Creek Formation below and a landslide block of the Mississippian Redwall Limestone on the west flank of the Beaver Dam Mountains, Utah. Photo by Jerry D. Harris.

The purpose of this exercise is to provide you with first-hand experience with the scientific method as it pertains to geology. Geology, like most sciences, combines aspects of both historical science and experimental science: historical sciences must examine the end results of events that happened in the past and attempt to reconstruct those events; conversely, experimental sciences conduct experiments to see what the end results are. Because most of the events that have ever happened on Earth happened in the past, and left only end results to examine today, geology is a bit heavy on the historical aspect. However, for this exercise, you will use both observations of past events and experiments to formulate a hypothesis, modify it as necessary, and apply the hypothesis to a geologic problem.

Key Learning Points:

- The difference between a hypothesis and a theory.
- Hypotheses are based on previous understanding of existing data and the application of logic—they are not guesses and do not involve guessing.
- Hypotheses are adaptive and can (and should) change as new data are discovered.
- Once supported by data, hypotheses about specific phenomena can be applied to construct new hypotheses about broader phenomena in space and time.

This exercise is worth 50 points; point values for each question are given at the end of each question.

*Name:*____ *Lab Section:*__________________________

READ & UNDERSTAND THIS SECTION *BEFORE* DOING THIS LAB!

What Is A Hypothesis?

You have probable learned about the scientific method in your lecture, and/or in some past class. We needn't go through it again here, but this lab focuses on the construction and subsequent refinement of a hypothesis. Hypotheses are, in many ways, the fundamental units in science—scientific investigation begins with a hypothesis, and the scientific method is specifically designed to work with hypotheses. Therefore, you need to understand exactly what a hypothesis is in order to do this lab effectively.

A **hypothesis** is a tentative, empirical (testable, falsifiable, and repeatable) statement about ***why*** something is the way it is, or ***why*** something happens the way it happens. Hypotheses are based on three things:

(1) observations (including sight but also information from any other senses, as well as tools that detect things our senses cannot detect and translate information into a form our senses *can* detect),
(2) any and all previous knowledge you have, and
(3) logic.

In short, a hypothesis proposes a reason why something is the way it is or why something happens the way it happens—the "something" is usually what has been observed, either by the person deriving the hypothesis or other people—and uses previous knowledge and logic as a basis for proposing the explanation. The explanation must be testable in a way that others can replicate it exactly, and the results of the test must have the possibility of demonstrating that the hypothesis is incorrect. Note that hypotheses are, by definition, tentative, meaning that they are neither supported nor refuted by much (if any) actual data (evidence).

That tentativeness is a huge part of what separates a hypothesis from a theory—despite the fact that you almost never hear "hypothesis" used in popular media, and hear "theory" instead, they ***are not*** different words for the same thing! In science[1], a **theory** is a logic-based explanation for why something is the way it is, or why something happens the way it happens, but differs from a hypothesis in that it is supported by ***massive*** amounts of evidence. A theory has been researched by thousands and thousands of people, usually over many decades, or even centuries, and the results of all such research point to the same conclusion—the same explanation for why something is the way it is or why something happens the way it happens. That explanation is a theory. There's no set point at which a hypothesis becomes a theory; usually, a theory encompasses hundreds of individual hypotheses—that is, a theory is kind of a blanket explanation that covers lots of individual instances, and those individual instances were tested as hypotheses.

Along with misusing "theory" when meaning "hypothesis," people often confuse hypotheses (and, sometimes, even theories!) with guesses. But guesses are something altogether different again. Hypotheses are based on previous knowledge and logic, but guesses are not. For

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[1] The definitions given here for "hypothesis" and "theory" are the ones used in the "hard" sciences (geology, biology, chemistry, physics, etc.), but in the social sciences (e.g., psychology) and in education, the tendency is to use these two terms in the opposite way—they use "hypothesis" the way that the "hard" sciences use "theory," and "theory" the way that the hard sciences use "hypothesis." We have no idea why this is or how this difference came about, but the definitions in the "hard" sciences are the long-standing, traditional ones.

example, I could ask you to guess what number I'm thinking of right now. Even if you knew me really well (= have some previous knowledge), none of what you know would enable you to determine what number I'm thinking of. Neither will logic, really. That's where guesses come in—guesses are literally random, basis-less attempts to find a solution. Hypotheses use previous knowledge, and therefore are not guesses (so don't ***ever*** use the word "guess" when talking about a hypothesis!).

Also, many people confuse hypotheses with predictions. But these, too, are different, although related. Because a hypothesis is a (tentative) explanation for why something is the way it is, or why something happens the way it happens, a hypothesis enables you to ***make*** a prediction. You could predict that Y will result if X happens, but you're able to make that prediction because you have a hypothetical explanation for the "why" (the process X). Hypotheses are not predictions, but hypotheses (and theories, too) allow predictions to be made.

Lastly—and this risks treading on some sensitive ground—hypotheses (and theories) are not beliefs. The words "belief" and "believe" have a couple of different definitions and uses, but what's important here is the definition and use that essentially means "held to be true without needing any supporting evidence." The key part of that is, of course, the "without needing any evidence"—that's what differentiates a belief from a hypothesis, or indeed from anything scientific. Science ***always*** requires evidence to support a contention—it is, as part of the definition of "hypothesis" above notes, be empirical. Beliefs, in contrast, do not require evidence, and they don't have to be testable. They don't even have to be logical in any way. While scientists certainly have beliefs (they're human beings, after all!), those beliefs don't factor into their hypotheses. Hypotheses, and the scientific method, are generally belief-free. This is not to belittle beliefs in any way; this is simply to note that scientists do not "believe" that things are the way they are, or that things happen the ways that they happen, for some evidence-free reason; instead, they hypothesize (and, when appropriate, theorize) explanations for why things are the way they are because that's what observations, previous knowledge, logic, and (in the case of theories) evidence supports. Just as you should not use the term "guess" when dealing with hypotheses (or theories), you should not use the terms "believe" or "belief" when dealing with hypotheses (or theories), either.

With this background understanding in mind, we can proceed to construct a basic hypothesis, and then refine it as we gather bits of data (information).

STEP 1: Use what you already know to construct a logical hypothesis

Leaf fossils are relatively common, particularly compared to fossils of bones, shells, etc. This is, in large part, because lots of plants continually shed their old leaves and grow new ones; each shed leaf has the potential to become a fossil. In comparison, animals usually have only a single body (shell, skeleton, etc.) that they keep throughout their entire lives. However, fossil leaves—and especially those that preserve fine details—are generally only found in certain kinds of rocks, usually different rocks than those that preserve shells and bones. Think about your own experiences with leaves (particularly larger leaves from large bushes and trees)—what they look like on living plants, what they look like after they fall off of their plants or if their plants die, how durable leaves are, what happens to the under different conditions (and what those conditions are), etc. Use your previous observations and knowledge to construct a hypothesis below for question #1.

(1) Without seeing any specimens, and using ***only*** what you already know about leaves as a logical basis, what factors and conditions would be required to preserve a leaf as a fossil? Phrase your answer as a single sentence that begins "In order for a leaf to become a fossil…" followed by your list of events and/or conditions that must be met. (Please suppress the temptation to include overly general, tautological things such as "it must be in a rock" and "the leaf must fall off a plant.") Don't worry about how right or wrong you are (although misusing logic, or failing to explain your logic sufficiently, may cost you points!); you'll be refining this hypothesis through the exercise—what's important here is ensuring that you know how to construct a scientific hypothesis! (4 points)

STEP 2: Observations

Examine the fossil leaves provided for you—you are welcome (strongly encouraged, actually!) to pick them up, touch them, examine them with the provided loupes, etc., as long as you are **C A R E F U L** with them. Examine both the fossils and the rocks they are in (not just the parts where the fossils are!) from many different angles as well as close up (use the loupes provided). Many different kinds of plants are represented here (all are **land** plants—only land plants have true leaves!), and the fossils are of many different ages, but the type of plant and the age are not important for our purposes here except to note that the fossil leaves you see here are from both tropical and temperate climates. All of these fossil leaves share some things in common, and these shared features have implications for how fossils of leaves form.

IMPORTANT—understand these two things:

(a) The fossils occur in rocks, but what are now rocks were loose materials at the time that the leaves fell into them and only later became rock—you will learn more about that process in the lectures.

(b) Each fossil is in a piece of rock that was itself part of a larger body of rock, so each specimen used to have rock attached on all parts of it until someone broke it open and discovered the fossil. From the specimens, you cannot tell where in the larger body of rock the fossil used to be!

(2) Ignore the fossils on the rocks for the moment. Do the ***rock types*** in which the different fossils are preserved have any features in common? For example, examine the materials of which those rock types are composed, the colors of the rocks, the texture and feel of the rocks (ignoring any irregularities on the surfaces that are due to breakage of the rock or to preparation to expose the leaf fossil—feel the parts between the irregularities), the sizes of the components making up the rock, the arrangement of the components making up the rock, and many other things—you will probably want to examine the rocks close up and on multiple sides to get the best information about each one. If there are any features in common to all of the rocks, list them here. Note that this question does ***not*** ask you to speculate about either what rock types these are or where or how the rocks formed (3 points)

(3) Now ignore the rock types for the moment, but compare the fossils on all of the specimens. Do the materials of which the ***fossils*** are composed, across ***all*** the specimens, have anything in common? That is, do the materials of which the fossils are composed, and/or their styles of preservation, share any particular features or qualities between specimens? If so, list those commonalities here. (3 points)

STEP 3: Applicability of hypothesis to observations

(4) Do any of the observations you made by examining the actual fossil leaves in questions #2–3 match of the factors/conditions you specified in your hypothesis from question #1? In other words, did any of your observations match/account for things you listed in your initial hypothesis? If so, list them here. (2 points)

(5) Conversely, are there any observations that you made by examining the actual fossil leaves that are ***not*** accounted for in your initial hypothesis? If so, list them here. (2 points)

STEP 4: Revising the hypothesis

(6) Now that you have new, additional data from examining the fossil specimens, you can refine your hypothesis from question #1 to incorporate it to formulate a narrower, more specific and detailed hypothesis. You may end up keeping or discarding some of your original hypothesis, and that's OK. **Phrase your revised hypothesis the same way that you did in question #1.** (3 points)

STEP 5: Applying the hypothesis

Now you will be looking at some specimens of different rock types. Each specimen is simply a piece of a much larger body of rock, but should show the essential features of the type. Examine all the specimens of the 10 rock types by looking at them closely and from different angles, feeling them, etc., and ***read*** **the bits of information about each one—the information on the signs will be critical to answering all the questions from this point on**. Some of the types may be represented by more than one specimen—finding the things they have in common will help you understand the rock type better. (This is by no means an exhaustive sampling of rock types [!], and you will learn more about these rock types in lecture.) In particular, pay close attention to **(a)** **how** and **where** each rock forms, and **(b)** the **compositions** of these samples—what are the components of each one as far as you can tell (you are not expected to know what minerals are present in any of the specimens, but that's not really relevant here anyway). None of these samples has any fossils of leaves in them, but think about each rock type from the perspective of whether or not you think leaf fossils *could* be found in it. Use what you learn from observing the specimens and reading the signs to answer the following questions. Your answers to questions #7–8 should account for ***all*** of the types you see here.

(7) In which of these 10 rock types would you ever expect to find fossil leaves? List those types here ***and***, for each type you list: (a) explain your reasoning as to ***why*** it would be suitable to preserve leaf fossils—what qualities/features of the rock type makes it a good candidate?, ***and*** (b) why would those qualities/features make fossilization of leaves more likely? Your answers should incorporate features of each rock type **as well as** qualities of the environments in which its components formed. (4 points)

(8) In which of these 10 rock types would you ***not*** expect to ever find fossil leaves? List those types here ***and***, for each type you list: (a) explain your reasoning as to ***why*** it would be unsuitable to preserve leaf fossils—what qualities/features of the rock type makes it a poor candidate?, ***and*** (b) why would those qualities/features make fossilization of leaves unlikely? As before, your answers should incorporate features of each rock type **as well as** qualities of the environments in which its components formed. (4 points)

(9) Now go back and look at the fossil specimens again, and re-examine the rocks they are in. Which, if any, of the rock types **that you listed in question #7** have the same ***specific*** features (components, arrangements of components, textures, etc.—ignore color, which is the absolute worst thing to use to identify and characterize rocks!) of the rocks containing the leaf fossils? If any, list those specific features here ***and*** list which rocks types have those features. (4 points)

STEP 6: Revising the hypothesis

(10) Now that you have additional data from examining the rock-type specimens, and comparing them to the rocks that contain the fossils, you can further refine your hypothesis from question #6 by incorporating it to formulate a narrower, more specific and detailed hypothesis. You may end up keeping or discarding some of your original hypothesis, and that's OK. You may or may not specify particular rock types, but *features* of rocks and their formations may be important in your hypothesis! **Phrase your revised hypothesis the same way that you did in question #1.** (3 points)

STEP 7: Testing the hypothesis

At this station, you will conduct some experiments to gauge how correct your hypothesis is. At this station are several bowls of sediments of different grain sizes (coarse to fine) and different degrees of saturation with a liquid, as well as some modern leaves—the leaves are not necessarily from the same kinds of plants you saw in the fossils, but that's OK. Impress the leaves (the sides with the big veins facing down) into the sediments ***firmly*** but ***gently***. Press as much of each leaf in as possible—you may need to hold down parts of the leaf with one hand while pressing with the other. Then, as carefully as possible, remove (by lifting it straight up or carefully peeling it away from where it contacted the sediment) the leaves to examine how they interacted with the different sediments. **When you are finished using each leaf and sediment combination, erase any impressions you made from the sediment and clean the leaf off so that the next students can conduct their own experiments.**

(11) Which, if any, sediment type(s) (gravel, sand, mud) and consistency(s) (dry, wet) was/were able to capture and preserve features of a leaf with the ***most*** similar amount of detail as the actual fossils that you examined in Step 2? (3 points)

(12) For the sediment type(s) you listed in question #11, what characteristics enabled it/them to capture the features of the leaf in the ***most*** detail, ***and*** why would those particular characteristics be conducive to preserving those details? (4 points)

(13) Imagine that the sediments in each of the tubs turned into rock. Which, if any, of the rock types you examined previously (in Step 5) would each of these sediment types (gravel, sand, mud) match? (3 points)

(14) Did the sediment type(s) and consistency(s) you listed in question #11 capture *all* of the features of the leaves you saw in the fossils? If not, which features of the leaves were *not* captured, ***and*** what does that tell you about the fossilization of leaves that was not replicated in your experiments at this station? **HINT:** one (but ***not*** necessarily the only!) thing to think about is the colors of the fossils you saw vs. the "fossils" you made in the sediments—what might that tell you?) (2 points)

(15) Do any of the observations you made from the sediment experiments in questions #11–14 match anything you specified in your hypothesis from question #10? In other words, did any of your observations match/account for things you listed in your most recent hypothesis that would be necessary to preserve a leaf fossil? If so, list them here. (2 points)

STEP 8: Revising the hypothesis

(16) Now that you have additional data from the sediment experiments, you can further refine your hypothesis from question #10 to incorporate it. By now, your hypothesis should have some very specific (***not*** general!) factors/conditions in it to formulate a narrower, more specific and detailed hypothesis. You may end up keeping or discarding some of your original hypothesis, and that's OK. **Phrase your revised hypothesis the same way that you did in question #1.** (3 points)

STEP 9: Broader implications

Now you should have a hypothesis that accounts for many different factors—rock types and the key components in those rocks , water conditions, etc.—that provides a possible explanation for the conditions in which fossil leaves form. Now think about different environments in the real world—you can now use your hypothesis to make inferences about ancient environments! In your considerations, think about things like any transport mechanisms that brought the leaves and the rock-forming materials together (**HINT: go back and re-read the signs with the rock type samples!**), proximity to leaf-bearing plants, etc. Given what you now know about factors/conditions necessary to preserve leaf fossils, and the characteristics of the materials that make up the rocks in which the fossils you saw were preserved, think about ***where*** the conditions would exist necessary to bring together leaves ***and*** the rock materials necessary for leaf fossilization.

(17) In what kind(s) of environment(s) do the conditions necessary to form leaf fossils exist? Note that this question asks ***where***—specify environment types (e.g., "beach," "desert") ***and*** physical places (e.g., "mountain tops," "grasslands"); don't just use vague descriptive terms (e.g., "wet," "has lots of plants"). Then, specify what **qualities** about those environments create the conditions suitable to form fossil leaves. (5 points)

NOTES FOR SCIENTIFIC METHOD

Lab #2
Geologic Hazards

Buildings toppled because of liquefaction during a 1964 earthquake in Niigata, Japan. Photo by T.L. Youd, from the U.S. Geological Survey Photographic Library (ID 453).

The purpose of this exercise is to provide you with an understanding of many different kinds of geologic hazards, emphasizing the prevalence and risks in the St. George–Hurricane area. In addition, this exercise will provide you with some experience in reading maps, particularly ones that outline the risks of various kinds of geologic hazards in the St. George–Hurricane area.

Key Learning Points:

- What a geologic hazard is.
- The root causes of, and conditions necessary for geologic hazards due to:
  - earthquakes,
  - flooding
  - mass wasting,
  - soil types,
  - wind, and
  - groundwater.
- The potentials for these kinds of geologic hazards in the St. George–Hurricane area.
- How to mitigate (reduce the potential for damage of) these hazards.
- How to determine the potential for a geologic hazard anywhere in the U.S.
- Basic map-reading skills.

This exercise is worth 90 points; point values for each question are given at the end of each question.

For all questions in this exercise that involve reading and learning material from the provided maps, your answers* must *be in your own words. Any answers that are copied verbatim from the provided maps will* not *count for credit!

*Name:*____ *Lab Section:*______________________________

A geologic hazard is a geologic event that can endanger human lives and property. Earthquakes are probably the most familiar and well-known geologic hazard; volcanic eruptions are a close second. However, even in areas not prone to either of these, less familiar and less famous geologic hazards can still pose great risks. In monetary terms, these other hazards cost people (and governments) far more money each year than either earthquakes or volcanic eruptions, and many are *not* covered by typical home-owner's insurance policies!

Washington County is susceptible to both earthquakes and volcanic eruptions, but the far more serious, more numerous, and more frequent hazards have little or nothing to do with either one. These include flooding, mass wasting, problematic soils, and even wind and groundwater. Geologists with the Utah Geological Survey (UGS) have been charged with assessing the risks for various hazards around Utah and have produced geologic hazard maps; the ones for the St. George–Hurricane area have been recently redone to reflect up-to-date hazard risks. You will be reading some of these maps in this lab and using them to both learn more about geologic hazards and answer some questions about them. If you plan to live somewhere in Utah (including Washington County) in the future and want to determine what hazards are risks for an area in which you want to live, you can consult these maps on-line for free at http://geology.utah.gov/maps/geohazmap/index.htm. We will not be examining *all* possible hazards in this lab—only some of the more important (and potentially dangerous or damaging) ones. You can find maps for other types of hazards at the link above, and I encourage you to look at them, as well!

EARTHQUAKE HAZARDS

Earthquakes occur all over the world, often without warning. They can have far-reaching effects on humans and on the Earth's surface. As you will learn later in your lectures, the term "earthquake" refers to the vibrations created by movement along a fault or by magma moving underground (sometimes to the surface through a volcano). Earthquakes can even be man-made, induced by explosions or by humans injecting fluids into faults, thereby lubricating them. The vibrations can be violent and cause widespread damage and injury, or they may not even be noticeable. Small, localized earthquakes may not cause noticeable damage; in contrast, large earthquakes famously can cause destruction over broad areas and be felt thousands of miles away.

Earthquakes caused by movement along **interplate** (between tectonic plates) **faults** are the most destructive. The boundaries (margins) of tectonic plates—about which you will also learn later—are active fault zones, and are where most (≈90%) earthquakes occur. In fact, the locations of earthquakes, and the kinds of ruptures they produce, help define the boundaries of tectonic plates. The remaining (≈10%) earthquakes occur on **intraplate** (within plate) **faults**—in the St. George–Hurricane area, several intraplate faults are known, and some have experienced earthquakes since the area was settled in the 1850s (and probably many more since the first Native Americans settled the area thousands of years earlier!).

We tend to think of earthquake damage as the result of the ground shaking, but in many cases, the most damage may be caused by other effects, such as **surface fault ruptures** and **liquefaction**. By understanding these effects, and how they affect human lives and property, we can lessen their impacts, even though we cannot prevent them from happening.

(1) Find and study the Surface Fault Rupture Hazard map, and read the text that accompanies it.

(a) What is surface faulting (rupturing), what causes it, ***and*** how is it a hazard to humans and/or property? (2 points)

(b) What is the ***best*** way to reduce the effects of this hazard, ***and***, in cases where implementing that solution is not possible, what are some other ways to reduce the effects? (2 points)

(c) Examine the map and find the areas at greatest risk of this hazard (HINT: read the map and its legend carefully and completely to find this!). Does the distribution of areas that are at greatest risk have a pattern—that is, do they all occur in the same ***kind(s)*** of place(s) (even if each of those places has its own name), and do those places have any relationship to particular kinds of geologic and/or topographic structures/features (e.g., mountains, valleys, plains, etc.)? If they do not have a pattern, specify some of the major high-risk areas. (4 points).

(d) Find where your home is and describe the potential for this hazard at that location—specifically, if there is a relatively high hazard, what geologic/topographic feature(s), rock formations, etc. at that location create the hazard there? (2 points)

(2) Find and study the Liquefaction Hazard map, and read the text that accompanies it.

(a) What is liquefaction, what factors are involved, ***and*** what causes it? (2 points)

(b) How does liquefaction cause property damage? (2 points)

(c) What is the ***best*** way to reduce the effects of this hazard, ***and***, in cases where implementing that solution is not possible, what are some other ways to reduce the effects? (2 points)

(d) Examine the map and find the areas at greatest risk of this hazard. Does the distribution of areas that are at greatest risk have a pattern—that is, do they all occur in the same ***kind(s)*** of place(s) (even if each of those places has its own name), and do those places have any relationship to particular kinds of geologic and/or topographic structures/features (e.g., mountains, valleys, plains, etc.)? (**HINT:** both the text ***and*** the map will be useful in answering this question!) If so, explain ***why*** this hazard has that relationship. If they do not have a pattern, specify some of the major high-risk areas. (4 points)

(question continues on the next page)

(e) Find where your home is and describe the potential for this hazard at that location—specifically, if there is a relatively high hazard, what geologic/topographic feature(s), rock formations, etc. at that location create the hazard there? (2 points)

SURFACE WATER HAZARD: FLOODING

Floods are among the most common geologic hazards in the U.S.: they occur in every state and cost upward of $6 billion annually. On average, most river systems flood every year or two, although the magnitude of each flood can vary widely. A flood occurs when water in a **stream** leaves the confines of its **channel** and flows outward onto its surrounding **floodplain**—as you will learn later in lecture, rivers create their own floodplains by flooding repeatedly. Three types of floods can be recognized:

- **regional floods**—these rise and ebb gradually and last for weeks or months;
- **flash floods**—these occur suddenly and last only hours; and
- **sheetfloods**—these are broad expanses of moving water produced by storms that spread as thin, continuous, and relatively uniform "films" over large areas for hours.

All of these types are dangerous and capable of inflicting substantial damage to homes, property, and infrastructure, and all can kill. Each year, an average of 140 people are killed by floods in the U.S.

(3) Find and study the Flood Hazard map, and read the text that accompanies it.

(a) How does flooding cause property damage, ***and*** how do humans make the problem worse? (2 points)

(b) What is the ***best*** way to reduce the effects of this hazard, ***and***, in cases where implementing that solution is not possible, what are some other ways to reduce the effects? (2 points)

(question continues on the next page)

(c) Examine the map and find the areas at greatest risk of this hazard (zones AE and A). Does the distribution of areas that are at greatest risk have a pattern—that is, do they all occur in the same ***kind(s)*** of place(s) (even if each of those places has its own name), and do those places have any relationship to particular kinds of geologic and/or topographic structures/features (e.g., mountains, valleys, plains, etc.)? If so, explain ***why*** this hazard has that relationship. If they do not have a pattern, specify some of the major high-risk areas. (4 points)

(d) Find where your home is and describe the potential for this hazard at that location—specifically, if there is a relatively high hazard, what geologic/topographic feature(s), rock formations, etc. at that location create the hazard there? (2 points)

MASS WASTING HAZARDS

Geologists refer to gravity-driven, down-slope movements of earth materials as "**mass wasting**" events. Colloquially, the media usually refers to mass wasting events as "landslides," but the term "**landslide**" is a broad, blanket term for what are actually many different kinds of gravity-driven events, such as earthflows, mudflows, and slumps. You will learn more about mass wasting events later in your lectures, and you will examine some mass wasting events in a later lab.

(4) Find and study the Landslide Hazard map, and read the text that accompanies it.

(a) Read the map's definition of a "landslide." What is the force that governs and controls movement of a landslide? (1 point)

(b) Given your answer to part (a), what role does water play in a landslide? (2 points)

(question continues on the next page)

(c) How do landslides cause disruption and damage to man-made structures? (2 points)

(d) What is the ***best*** way to reduce the effects of this hazard, ***and***, in cases where implementing that solution is not possible, what are some other ways to reduce the effects? (2 points)

(e) What is the ***full*** name of the ***rock unit*** (layer) that is responsible for Susceptible Category B, which is the highest risk for landslides (other than existing, already-moving landslides)? If you are unfamiliar with the abbreviations used on the map, ask your teacher. (1 point)

(f) What substance in this rock unit causes it to be at such high risk for this hazard (what is locally called "blue clay") ***and*** why (and when) is it a problem? (2 points)

(g) Examine the map and find the areas at greatest risk of this hazard. Given your answer to question #4e, does the distribution of areas that are at greatest risk have a pattern—that is, do they all occur in the same ***kind(s)*** of place(s) (even if each of those places has its own name), and do those places have any relationship to particular kinds of geologic and/or topographic structures/features (e.g., mountains, valleys, plains, etc.)? If so, explain ***why*** this hazard has that relationship. If they do not have a pattern, specify some of the major high-risk areas. (4 points)

(question continues on the next page)

(h) Find where your home is and describe the potential for this hazard at that location—specifically, if there is a relatively high hazard, what geologic/topographic feature(s), rock formations, etc. at that location create the hazard there? (2 points)

(5) Find and study the Rockfall Hazard map, and read the text that accompanies it.

(a) What is a rockfall, ***and*** what are ***three*** rock ***types*** (***not*** the names of the units from which the rocks come—however, the names of some of the units tell you what kind of rock they are made of!) are the primary source of risk in the St. George–Hurricane area? (2 points)

(b) What is the ***best*** way to reduce the effects of this hazard, ***and***, in cases where implementing that solution is not possible, what are some other ways to reduce the effects? (2 points)

(c) Examine the map and find the areas at greatest risk of this hazard. Does the distribution of areas that are at greatest risk have a pattern—that is, do they all occur in the same ***kind(s)*** of place(s) (even if each of those places has its own name), and do those places have any relationship to particular kinds of geologic and/or topographic structures/features (e.g., mountains, valleys, plains, etc.)? If so, explain ***why*** this hazard has that relationship. If they do not have a pattern, specify some of the major high-risk areas. (4 points)

(question continues on the next page)

(d) Find where your home is and describe the potential for this hazard at that location—specifically, if there is a relatively high hazard, what geologic/topographic feature(s), rock formations, etc. at that location create the hazard there? (2 points)

PROBLEM SOIL HAZARDS

Problem soils are some of the most widely distributed and costly of geologic hazards. These soils are subject to changes in volume and/or compaction in response to wetting and drying. Although most people do not think of soils as potential hazards—probably because they do not produce "thrilling" events, such as earthquakes do, that cause catastrophic damage on large scales—annually, expansive soils comprise the most expensive of all geologic hazards, costing several billions of dollars.

- **Expansive soils** (and rocks) are unconsolidated (loose) sediments that contain particular clay minerals (such as smectite) that swell when wet—sometimes by an additional 10% of their normal, dry volumes!—and shrink when drying out. After dry rot (which is not a geologic hazard), expansive soils are the most common cause of property damage in the U.S.
- **Collapsible soils** are sediments that lose strength (the ability to support weight) under various conditions. The most common type of collapsible soil, called **hydrocompactive soil**, is common in semi-arid and arid climates of the American Southwest. In such soils, individual sediment grains are stacked atop one another, and not compacted as tightly as they could be. When wetted, the agents that prevent individual grains from slipping soften or dissolve, allowing grains to shift and compact; the entire body of sediment thus loses volume.
- **Gypsiferous soils** contain the evaporite mineral gypsum ($CaSO_4$), which dissolves in water. The introduction of water into a gypsiferous soil (re)dissolves some of the gypsum and carries it away as groundwater. This causes a loss of overall soil volume, similar to what happens with hydrocompactive soils. Occasionally, underground **solution cavities** can develop where massive amounts of gypsum dissolve, and if these cavities near the surface, the ground can collapse into a **sinkhole**. (A similar phenomenon more commonly occurs in areas overlying bedrock of limestone.) Risk of problems from gypsiferous soils is especially strong when large amounts of water are introduced artificially, such as by irrigation for crops, landscaping, and wastewater disposal systems.

(6) Find and study the Expansive Soil and Rock Susceptibility map, and read the text that accompanies it.

(a) How does the map define the term "expansive soil and rock"? (2 points)

(b) How does expansive soil and rock cause damage to man-made structures? (2 points)

(c) What is the ***best*** way to reduce the effects of this hazard, ***and***, in cases where implementing that solution is not possible, what are some other ways to reduce the effects? (2 points)

(d) Examine the map and find the areas at greatest risk of expansive soil and the areas at greatest risk for expansive rock. Does the distribution of areas that are at greatest risk of each of these areas have a pattern—that is, do they all occur in the same ***kind(s)*** of place(s) (even if each of those places has its own name), and do those places have any relationship to particular kinds of geologic and/or topographic structures/features (e.g., mountains, valleys, plains, etc.)? If they do not have a pattern, specify some of the major high-risk areas. (4 points)

(question continues on the next page)

(e) Find where your home is and describe the potential for this hazard at that location—specifically, if there is a relatively high hazard, what geologic/topographic feature(s), rock formations, etc. at that location create the hazard there? (2 points)

(7) Find and study the Gypsiferous Soil and Rock Susceptibility map, and read the text that accompanies it.

(a) How do gypsiferous soils and rocks become an adverse construction condition, ***and*** how do they cause damage to man-made structures? (2 points)

(b) What is the ***best*** way to reduce the effects of this hazard, ***and***, in cases where implementing that solution is not possible, what are some other ways to reduce the effects? 2 points)

(question continues on the next page)

(c) Examine the map and find the areas at greatest risk of gypsiferous soil and the areas at greatest risk of gypsiferous rock. Does the distribution of areas that are at greatest risk of each of these areas have a pattern—that is, do they all occur in the same ***kind(s)*** of place(s) (even if each of those places has its own name), and do those places have any relationship to particular kinds of geologic and/or topographic structures/features (e.g., mountains, valleys, plains, etc.)? If they do not have a pattern, specify some of the major high-risk areas. (4 points)

(a) Find where your home is and describe the potential for this hazard at that location—specifically, if there is a relatively high hazard, what geologic/topographic feature(s), rock formations, etc. at that location create the hazard there? (2 points)

SHALLOW GROUNDWATER HAZARDS

Shallow groundwater hazards occur when sufficiently shallow **water tables** (the tops of the masses of water in the ground) are cyclically or persistently above the level of man-made structures that are underground, resulting in negative impacts to the structures.

(8) Find and study the Shallow Groundwater Susceptibility map, and read the text that accompanies it.

(a) What kinds of problems does shallow groundwater create/cause, ***and*** how do these problems affect construction of subsurface structures? (2 points)

(b) What is the ***best*** way to reduce the effects of this hazard, ***and***, in cases where implementing that solution is not possible, what are some other ways to reduce the effects? (2 points)

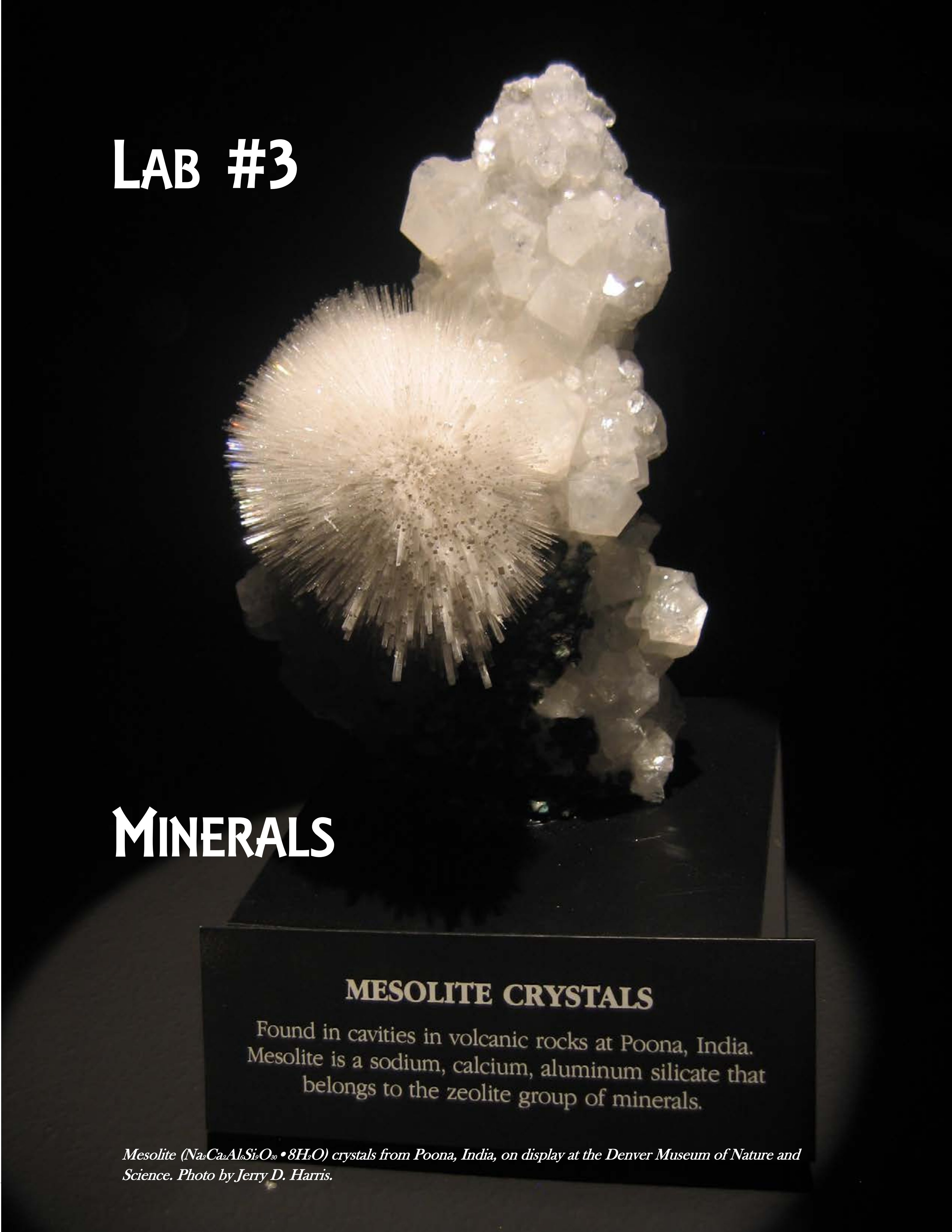
(c) Examine the map and find the areas at greatest risk of naturally wet, poorly drained, and moderately to freely draining soils greatest and that must be considered from a groundwater perspective. Does the distribution of areas that are at greatest risk have a pattern—that is, do they all occur in the same ***kind(s)*** of place(s) (even if each of those places has its own name), and do those places have any relationship to particular kinds of geologic and/or topographic structures/features (e.g., mountains, valleys, plains, etc.)? If they do not have a pattern, specify some of the major high-risk areas. (4 points)

(d) Find where your home is and describe the potential for this hazard at that location—specifically, if there is a relatively high hazard, what geologic/topographic feature(s), rock formations, etc. at that location create the hazard there? (2 points)

NOTES FOR GEOLOGIC HAZARDS

Lab #3

Minerals



Mesolite ($Na_2Ca_2Al_6Si_9O_{30} \cdot 8H_2O$) crystals from Poona, India, on display at the Denver Museum of Nature and Science. Photo by Jerry D. Harris.

The purposes of this exercise are:

- To provide you with first-hand experience with samples of several different minerals. During the course of this lab, you will gain some experience and better understanding of the characteristics that differentiate one mineral from another and the basic ways in which geologists determine these characteristics.
- To give you an appreciation for how minerals are used to create and sustain the technologies that form the base of our modern society.
- To give you an appreciation for many minerals (or elements extracted from minerals) that are used by humans, including you, which is why understanding them, and being able to identify them, is important to geologists.

<u>Key Learning Points:</u>

- Characterizing and identifying mineral samples using color, luster, hardness, cleavage, and streak.
- The basic classification system (silicates and non-silicates, and subgroups of the latter) used for minerals.
- Recognizing that minerals have economic and technological importance in everyday human lives.

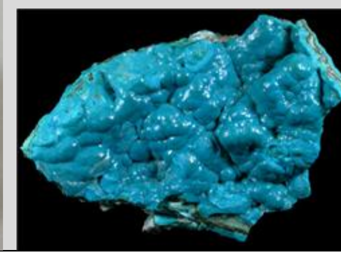
This exercise is worth 120 points; point values for each question are given at the end of each question.

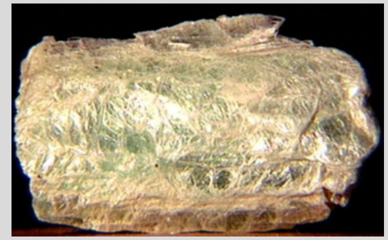
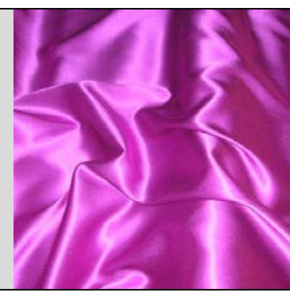
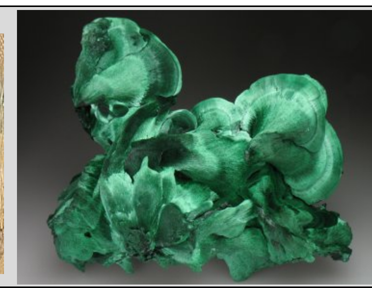
NON-SILICATE MINERAL CLASSIFICATION + EXAMPLES

GROUP	EXAMPLE	FORMULA
Oxides (O, O_2, O_3, O_4)	chromite	$Fe_3Cr_2O_4$
	corundum	Al_2O_3
	hematite	Fe_2O_3
	ilmenite	$FeTiO_3$
	magnetite	Fe_3O_4
	rutile	TiO_2
	uraninite	UO_2
	water ice	H_2O
Hydroxides (OH)	gibbsite	$Al(OH)_3$
	goethite	$FeO(OH)$
	limonite	$FeO(OH) \cdot nH_2O$
Carbonates (CO_3)	aragonite	$CaCO_3$
	azurite	$Cu_3(CO_3)_2(OH)_2$
	calcite	$CaCO_3$
	dolomite	$CaMg(CO_3)_2$
	malachite	$Cu_2CO_3(OH)_2$
	rhodochrosite	$MnCO_3$
	siderite	$FeCO_3$
Phosphates (PO_4)	apatite	$Ca_5(PO_4)_3(F, Cl, OH)$
	monazite	$(Ce,La,Y,Th)PO_4$
	turquoise	$CuAl_6(PO_4)_4(OH)_8 \cdot 5H_2O$
Vanadates (VO_4)	carnotite	$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$
	vanadinite	$Pb_5(VO_4)_3Cl$
Arsenates (AsO_4)	annabergite	$Ni_3(AsO_4)_2 \cdot 8H_2O$
Sulfates (SO_4)	anhydrite	$CaSO_4$
	barite	$BaSO_4$
	celestite	$SrSO_4$
	gypsum	$CaSO_4 \cdot 2H_2O$
Sulfides (S, S_2, S_3)	bornite	Cu_5FeS_4
	chalcopyrite	$CuFeS_2$
	cinnabar	HgS
	galena	PbS
	orpiment	As_2S_3
	pyrite	FeS_2
	sphalerite	ZnS
	stibnite	Sb_2S_3
Halides (F, Cl, Br, I)	fluorite	CaF_2
	halite	$NaCl$
	sylvite	KCl
Native Elements	copper	Cu
	diamond	C
	gold	Au
	graphite	C
	platinum	Pt
	silver	Ag
	sulfur	S, S_8

LUSTER DESCRIPTIONS AND EXAMPLES

NOTE: Some minerals can span more than one luster category (vitreous–resinous, metallic–adamantine, resinous–earthy, etc.).

LUSTER	DESCRIPTION	NON-MINERAL EXAMPLE	MINERAL EXAMPLES
adamantine (brilliant)	▸ brilliant and glaringly reflective, like a cut diamond ▸ transparent/translucent ▸ *not* like a metal (see **metallic**, below) ▸ can be like an extremely reflective version of **resinous** or **vitreous** (see below)		 
dull (earthy)	▸ unremarkable, unreflective (except possibly on cleavage surfaces) ▸ no other luster		 
greasy	▸ dully reflective ▸ as if dipped in clear cooking oil and thus coated in thin sheen of oil or grease		 

metallic	▸ shiny and highly reflective like polished metal ▸ opaque, ***not*** transparent/translucent ▸ not necessarily silvery!		 
pearly	▸ iridescent, many (usually pale) colors, as a pearl		
resinous	▸ plastic- (resin-), amber-, or honey-like ▸ moderately reflective ▸ may or may not be transparent/translucent ▸ if extremely reflective ***and*** transparent/translucent, see **adamantine** (above)		 
silky	▸ fine, fibrous structure ▸ may appear vaguely furry or fuzzy ▸ moderately–dully reflective		 

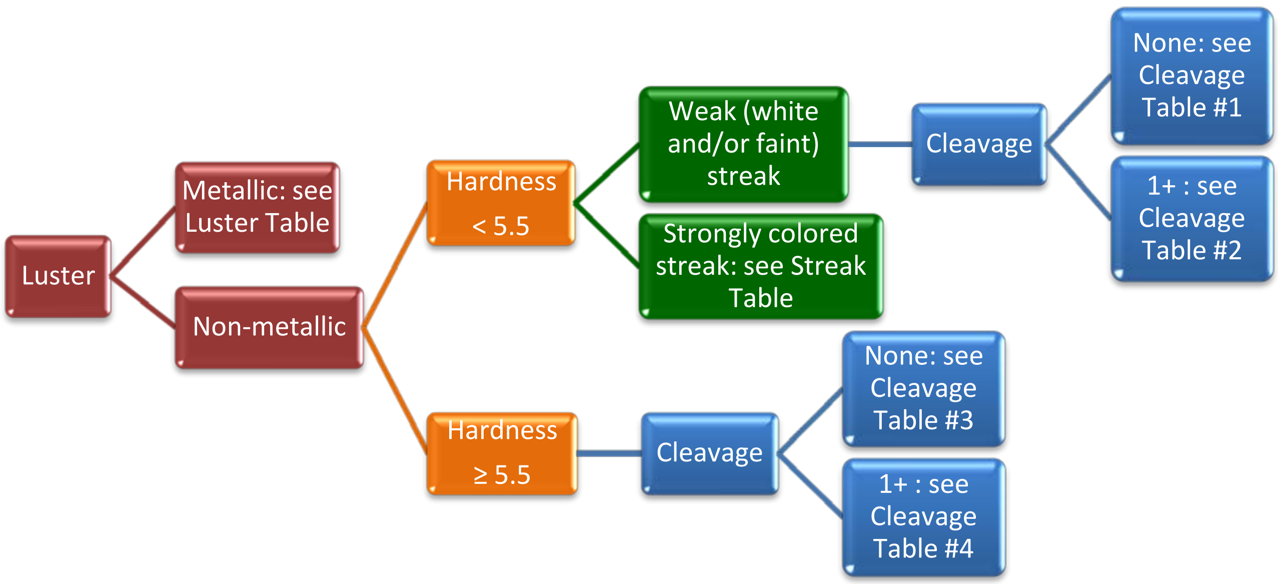
vitreous (glassy) most common luster (70% of minerals)	▸ similar to glass ▸ highly reflective ▸ often transparent/translucent but can be opaque and dark ▸ ***not necessarily*** colorless ▸ if extremely reflective *and* transparent/translucent, see **adamantine** (above)	    
waxy	▸ like candle wax (paraffin) ▸ slightly, dully reflective	  

Photo credits (from left to right per category): adamantine: http://www.professionaljeweler.com/archives/articles/1998/jul98/0798dg.html, http://www.minerals.net/mineral_glossary/adamantine.aspx, and http://www.minfind.com/mineral-10615.html; dull: http://0.tqn.com/d/geology/1/0/w/y/shaleberry.jpg, http://comp.uark.edu/~sboss/vrockbag.htm, and http://en.wikipedia.org/wiki/File:KaolinUSGOV.jpg; greasy: http://pizzaisdelicious.com/wp-content/uploads/2009/02/greasy_01.jpg, http://diamond1872.blogspot.com/, and http://www.minerals.net/mineral_glossary/greasy_luster.aspx; metallic: http://www.calibratedsps.com/screenprint/screen-printing-supplies/transfer-media/transfer-foils/metallic-heat-transfer-foil-12-inch-roll.html, http://organicconnectmag.com/wp/wp-content/uploads/2011/11/pyrite.jpg, and http://jillschneiderman.files.wordpress.com/2010/02/copper1.jpg; pearly: http://www.lincoln.kyschools.us/images/Buttons/pearl.jpg and http://www.cs.cmu.edu/~adg/images/minerals/psilicates/talc.jpg; resinous: http://hyperexperience.com/wp-content/uploads/2008/03/humidifier.jpg, http://o.quizlet.com/i/PeUmQ2YZEb4YoPuvE6towg_m.jpg, and http://upload.wikimedia.org/wikipedia/commons/thumb/2/2e/Sulfur.jpg/210px-Sulfur.jpg; silky: http://www.libertysilk.biz/ProImg/2612200809/royal%20purple%20satin%20silk.jpg, http://nevada-outback-gems.com/mineral_information/Chrysotile_asbestos03.jpg, and http://www.crystalclassics.co.uk/minerals/s_6195.jpg; vitreous: http://recycleforlewisham.files.wordpress.com/2011/02/glass-drinking.jpg, http://img2.etsystatic.com/000/0/5264348/il_570xN.242326374.jpg, http://www.mineralminers.com/html/phantom_quartz_crystal.htm, http://www.thunderhealing.com/rock/orthoclase.jpg, and http://0.tqn.com/d/geology/1/0/y/C/1/tourmaline500.jpg ; waxy: http://bloximages.newyork1.vip.townnews.com/phillyburbs.com/content/tncms/assets/v3/editorial/1/78/178cf2da-3d3c-11e1-b2c8-0019bb30f31a/4f0f0cea096fa.image.jpg, http://www.minfind.com/mfthumbs/390_350_20660973974fbcfbe3748ae.jpg, and http://www.minerals.net/mineral_glossary/waxy_luster.aspx.

(1) Determine the identities of the eight unlabeled, unidentified mineral specimens provided by:

- determining various characteristics of each specimen, and then
- matching those sets of characteristics with an entry on a table of different minerals and their known attributes.

To help guide you through this identification process, here's a simple flowchart to navigate the tables on the pages that follow:



Note that a classification table of **non-silicate minerals** is provided for you on the previous pages—they will be helpful to you for this and many other questions in this lab.

On the tables that you will fill in below, circle the correct number or term for the criteria that have options given; for the other criteria, write in the characteristic. (7 points each; 56 points total)

LUSTER TABLE

Specimen Color	Hardness	Streak	Cleavage	Other	Mineral Name & Formula
bronze-brown	< 5.5	black	1 (rarely visible)	commonly has purple-ish, iridescent tarnish	**bornite** Cu_5FeS_4
black, brownish black	< 5.5	black, greenish black, brownish black, gray	none	luster may be almost non-metallic; weakly magnetic	**chromite** $Fe_3Cr_2O_4$
deep, dark, golden yellow, greenish yellow	< 5.5	black, greenish black, brownish black, gray	none	may occur as coating on other mineral/rocks	**chalcopyrite** $CuFeS_2$
silvery gray	< 5.5	black, greenish or brownish black, gray	3 (at 90°)	very heavy	**galena** PbS
dark brown, black	< 5.5	yellowish brown	none	may occur as rounded masses with radiating fibers	**goethite** (pronounced GER-tite) FeO(OH)
dark gray, blackish	< 5.5	dark gray, blackish	1 (rarely visible)	greasy feel, rubs off easily on paper and fingers	**graphite** C
gray, blackish, faintly reddish or red bands	≥ 5.5	rust red, brownish red	none	may be faintly sparkly	**hematite** Fe_2O_3
dark gray, black	≥ 5.5	black	none	moderately magnetic; may be faintly sparkly	**magnetite** Fe_3O_4
copper, brownish, may have green or brown coating	< 5.5	copper, red	none	malleable (bendable, deformable)	**native copper** Cu
bright, brassy yellow	> 5.5	greenish black, black	none	fairly heavy; crystals may be cubes or dodecahedrons	**pyrite** FeS_2
light yellow, yellowish brown, silvery, black	< 5.5	yellow, brown	6 (almost never visible)	may smell faintly like rotten eggs	**sphalerite** ZnS

STREAK TABLE

Streak	Specimen Color	Hardness	Cleavage	Luster	Other	Mineral Name & Formula
blue	intense, dark blue	< 5.5	none	vitreous	commonly occurs as masses of tiny crystals, often with malachite	**azurite** $Cu_3(CO_3)_2(OH)_2$
dark gray, blackish	dark gray, blackish	< 5.5	1 (but rarely visible)	greasy–pearly, vaguely metallic	greasy feel, gets on paper and fingers	**graphite** C
rust red, brownish red	gray, blackish, faintly reddish	≥ 5.5	none	dull	may be faintly sparkly	**hematite** (rust) Fe_2O_3
strongly creamy white	white, may have brownish tint	< 5.5	none	dull	greasy feel; powdery	**kaolinite** (a clay mineral) $Al_2Si_2O_5(OH)_4$
yellowish brown	yellowish brown, orange-brown, dark brown	< 5.5	none	dull	often occurs as a yellowish- or orange-ish brown, black, or rust-like coating or mass	**limonite** $FeO(OH) \bullet nH_2O$
green	bright green	< 5.5	none	adamantine to vitreous; silky if fibrous; dull if massive	commonly occurs as masses of tiny crystals, often with azurite	**malachite** $Cu_2CO_3(OH)_2$
yellow, brown	light yellow, yellowish brown, silvery, black	< 5.5	6 (almost never visible)	resinous or vitreous; can appear metallic	may smell faintly like rotten eggs	**sphalerite** ZnS
yellow	pale yellow	< 5.5	none	resinous	may smell faintly like rotten eggs	**sulfur** S

CLEAVAGE TABLE 1

Cleavage	Specimen Color	Luster	Other	Mineral Name & Formula
none	light–medium green, brown, yellow	vitreous	six-sided crystals	**apatite** $Ca_5(PO_4)_3(F, Cl,OH)$
3 (indistinct, ≈ 75° and 105°)	buff, gray, white, pinkish	vitreous–pearly	—	**dolomite** $CaMg(CO_3)_2$
3 (only 1 usually visible; others indistinct)	white	vitreous, silky, pearly, waxy	opaque, white–gray, massive = alabaster; fibrous, silky–satiny luster = satin spar gypsum	**gypsum** $CaSO_4 \bullet 2H_2O$
none	white, may have brownish tint	dull	greasy feel; powdery	**kaolinite** (a clay mineral) $Al_2Si_2O_5(OH)_4$
none	multiple greens, gray, black	dull–greasy	slightly greasy feel	**serpentine** $Mg_3Si_2O_5(OH)_4$
1 (difficult to see)	white, gray, apple green	pearly–greasy	greasy feel, softest mineral known	**talc** $Mg_3Si_4O_{10}(OH)_2$

CLEAVAGE TABLE 2

Cleavage	Specimen Color	Luster	Other	Mineral Name & Formula
1 (thin sheets)	dark brownish black but *not* silvery, mirror-like when thick	vitreous; vaguely pearly–silky, metallic (when thick)	cleaves into thin, flexible, elastic sheets that are transparent/translucent, but still faintly brown	**biotite** (a mica) $K(Mg,Fe)_3AlSi_3O_{10}(F,OH)_2$
1 (thin sheets)	clear, silvery-white, mirror-like when thick	vitreous; vaguely pearly–silky, metallic (when thick)	cleaves into thin, flexible, elastic sheets that are transparent/translucent and clear	**muscovite** (a mica) $KAl_2(AlSi_3O_{10})(F,OH)_2$
1	dark green	vitreous–pearly	cleaves into flexible but ***non***-elastic sheets; does not readily split like micas	**chlorite** complex silicate
3 (seems like 1; others indistinct)	white, clear (as selenite)	vitreous, silky, pearly, waxy; dull as alabaster	opaque, white–gray, massive = alabaster; fibrous, silky–satiny luster = satin spar gypsum; clear = selenite	**gypsum** $CaSO_4 \bullet 2H_2O$
2 (at nearly 90°)	dark green	vitreous–dull	crystals tend to look blocky but can appear splintery; greenish-gray streak	**augite** complex silicate
2 (at 124° and 56°)	black, brownish black	vitreous–dull	cleavage faces stepped; appears splintery; pale greenish gray–no streak	**hornblende** (an amphibole) complex silicate
3 (at 90°)	clear, white-ish	vitreous–pearly	tabular or rose-like crystals or massive	**barite** $BaSO_4$
3 (at ≈ 75° and ≈ 105°)	clear, white	vitreous	birefringent (= text/images seen through crystal doubled), dissolves in hydrochloric acid	**calcite** (calcium carbonate) $CaCO_3$
3 (indistinct, at ≈ 75° and ≈ 105°)	buff, gray, white, pinkish	vitreous–pearly	dissolves in hydrochloric acid only when powdered	**dolomite** $CaMg(CO_3)_2$
3 (at 90°)	clear, gray, reddish	vitreous	tastes salty (do ***not*** taste the sample provided!)	**halite** NaCl (table salt)
3 (at ≈ 46° and ≈ 107°)	yellowish brown, black, brown, yellowish- or greenish-gray	vitreous	often forms blocky or tabular crystals; often looks like brown calcite	**siderite** $FeCO_3$
3 (at 90°)	clear, white, orange-ish or pinkish red	vitreous	very bitter taste (do ***not*** taste the sample provided!)	**sylvite** KCl (salt substitute)
4 (at 45° to crystal faces)	purple, green, blue, yellow, clear	vitreous	often occurs as octahedral crystals	**fluorite** CaF_2

CLEAVAGE TABLE 3

Cleavage	Specimen Color	Luster	Other	Mineral Name & Formula
3 (rarely visible)	clear, white, yellowish, reddish, pink, gray, black	vitreous	often forms long, four-sided crystals	**andalusite** Al_2SiO_5
none	brown, pink, blue, gray	adamantine–vitreous	red = ruby; blue = sapphire; second hardest mineral	**corundum** Al_2O_3
2 (only in long crystals)	pistachio green	vitreous–resinous	—	**epidote** complex silicate
none	reddish brown, yellowish tan	vitreous–resinous	12-sided crystals common	**garnet** complex silicate
none	olive green–yellowish green	vitreous–dull	commonly occurs as small masses of tiny grains	**olivine** $(Mg,Fe)_2SiO_4$
none	clear, milky white, pale other colors; may "sparkle" with many pale colors	vitreous–resinous, sometimes pearly	not technically a mineral, but a mineraloid because it lacks a consistent molecular structure	**opal** $SiO_2 \bullet nH_2O$
none	clear, milky white, purple, smoky, yellow, pink	most commonly vitreous; resinous (as rose quartz); dull (as jasper); silky (as tiger eye); waxy (as chalcedony)	clear = crystal quartz; purple = amethyst; yellow = citrine; pink = rose quartz; smoky = smoky quartz; waxy luster = chalcedony; silky luster and orange-brown color = tiger eye; gray with dull luster = flint; red with dull luster = jasper; hardest common mineral	**quartz** SiO_2
none	reddish brown–brownish black	vitreous–resinous, dull	often prismatic and X-shaped crystals	**staurolite** $Fe_2Al_9O_6(SiO_4)_4(O,OH)_2$
none	black, pink, blue, green, brown	vitreous	heavy; slender crystals with triangular cross sections	**tourmaline** complex silicate

CLEAVAGE TABLE 4

Cleavage	Specimen Color	Luster	Other	Mineral Name & Formula
1	bluish green, yellow, white, pink	vitreous–resinous	green = emerald; blue = aquamarine; commonly long, six-sided crystals with flat ends	**beryl** $Be_3Al_2(Si_6O_{18})$
1	light blue–greenish blue	vitreous	blade-like crystals	**kyanite** Al_2SiO_5
1	white, pale green, brown	vitreous–silky	long, slender crystals usually in groups with parallel alignment	**sillimanite** Al_2SiO_5
1	clear, yellow, brown, pink, bluish	vitreous	long crystal prisms with pointed ends	**topaz** $Al_2SiO_4(OH,F)_2$
2 (at nearly 90°)	black, dark green	vitreous–dull	crystals tend to look blocky	**augite** complex silicate
2 (only in long crystals)	light, "pistachio" green	vitreous–resinous	–	**epidote** complex silicate
2 (at 124° and 56°)	black, brownish black	vitreous	cleavage faces stepped; appears splintery	**hornblende** (complex silicate
2 (at nearly 90°)	white, dark gray	vitreous	crystal faces may have parallel striations	**plagioclase** (a kind of feldspar) $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$
2 (at nearly 90°)	usually characteristically salmon red/pink, can be white, gray, greenish	vitreous (though often seems dull or resinous)	crystal faces lack striations of plagioclase	**potassium feldspar** $KAlSi_3O_8$
3 (rarely visible)	clear, white, yellowish, reddish, pink, gray, black	vitreous	often forms long, four-sided crystals	**andalusite** Al_2SiO_5

*Name:*____ *Lab Section:*________________________

SPECIMEN 1	COLOR	
	LUSTER	silky metallic vitreous (glassy) pearly greasy waxy resinous (plastic-like) dull (earthy)
The hardness of the glass plate provided for you = 5.5.	HARDNESS	< 5.5 = 5.5 > 5.5
	NUMBER OF CLEAVAGE PLANES	0 1 2 3 4 6
Test on both the white and black streak plates provided!	STREAK COLOR	
	MINERAL NAME	
	MINERAL CLASSIFI-CATION	silicate oxide hydroxide carbonate phosphate sulfate sulfide halide native element
SPECIMEN 2	COLOR	
	LUSTER	silky metallic vitreous (glassy) pearly greasy waxy resinous (plastic-like) dull (earthy)
	HARDNESS	< 5.5 = 5.5 > 5.5
	NUMBER OF CLEAVAGE PLANES	0 1 2 3 4 6
	STREAK COLOR	
	MINERAL NAME	
	MINERAL CLASSIFI-CATION	silicate oxide hydroxide carbonate phosphate sulfate sulfide halide native element

(question continues on the next page)

SPECIMEN 3	COLOR	
	LUSTER	silky metallic vitreous (glassy) pearly greasy waxy resinous (plastic-like) dull (earthy)
	HARDNESS	< 5.5 = 5.5 > 5.5
	NUMBER OF CLEAVAGE PLANES	0 1 2 3 4 6
	STREAK COLOR	
	MINERAL NAME	
	MINERAL CLASSIFI-CATION	silicate oxide hydroxide carbonate phosphate sulfate sulfide halide native element
SPECIMEN 4	COLOR	
	LUSTER	silky metallic vitreous (glassy) pearly greasy waxy resinous (plastic-like) dull (earthy)
	HARDNESS	< 5.5 = 5.5 > 5.5
	NUMBER OF CLEAVAGE PLANES	0 1 2 3 4 6
	STREAK COLOR	
	MINERAL NAME	
	MINERAL CLASSIFI-CATION	silicate oxide hydroxide carbonate phosphate sulfate sulfide halide native element

(question continues on the next page)

SPECIMEN 5	COLOR	
	LUSTER	silky metallic vitreous (glassy) pearly greasy waxy resinous (plastic-like) dull (earthy)
	HARDNESS	< *5.5* = *5.5* > *5.5*
	NUMBER OF CLEAVAGE PLANES	0 1 2 3 4 6
	STREAK COLOR	
	MINERAL NAME	
	MINERAL CLASSIFI-CATION	silicate oxide hydroxide carbonate phosphate sulfate sulfide halide native element
SPECIMEN 6	COLOR	
	LUSTER	silky metallic vitreous (glassy) pearly greasy waxy resinous (plastic-like) dull (earthy)
	HARDNESS	< *5.5* = *5.5* > *5.5*
	NUMBER OF CLEAVAGE PLANES	0 1 2 3 4 6
	STREAK COLOR	
	MINERAL NAME	
	MINERAL CLASSIFI-CATION	silicate oxide hydroxide carbonate phosphate sulfate sulfide halide native element

(question continues on the next page)

SPECIMEN 7	COLOR	
	LUSTER	silky metallic vitreous (glassy) pearly greasy waxy resinous (plastic-like) dull (earthy)
	HARDNESS	< 5.5 = 5.5 > 5.5
	NUMBER OF CLEAVAGE PLANES	0 1 2 3 4 6
	STREAK COLOR	
	MINERAL NAME	
	MINERAL CLASSIFI-CATION	silicate oxide hydroxide carbonate phosphate sulfate sulfide halide native element
SPECIMEN 8	COLOR	
	LUSTER	silky metallic vitreous (glassy) pearly greasy waxy resinous (plastic-like) dull (earthy)
	HARDNESS	< 5.5 = 5.5 > 5.5
	NUMBER OF CLEAVAGE PLANES	0 1 2 3 4 6
	STREAK COLOR	
	MINERAL NAME	
	MINERAL CLASSIFI-CATION	silicate oxide hydroxide carbonate phosphate sulfate sulfide halide native element

(2) For each of the following four substances, state whether or not it is a mineral. In addition:

- if it has non-mineral occurrences, state where/when it would not be considered a mineral; and
- if it is ***never*** a mineral, state ***why*** it is not. (1 point each, 4 points total).

You should *not* need the Internet to answer the first three of these questions—if you do, go back and make sure you understand the criteria a substance must meet in order to qualify as a mineral!

KERATIN (the stuff your fingernails and hair are made of)

OBSIDIAN (volcanic glass)

WATER ICE

HYDROXYLAPATITE

You may use the Internet or other resources to find answers to questions #3–4.

IMPORTANT NOTE: Keep in mind that many web sites cannot properly do subscript numbers that are required for mineral formulas (for example, it could say H2O or SiO4, but the correct formulas are H_2O and SiO_4). Be sure you report your formulas ***correctly***—don't just copy blindly from the web sites, or you will lose points!

(3) The following three minerals are mined as ores for particular elements—these minerals are ***not*** used directly, but specific ***elements*** extracted from them are. For each mineral, provide:

- the chemical formula,
- the mineral group to which it belongs (use the same classification as in previous questions),
- the predominant element extracted from the mineral and ***at least one*** of the ***modern*** uses of that element ***other than*** any of these unacceptable answer categories:
  - jewelry/gemstone/decoration/mineral specimen
  - money/investment/valuable
  - magic/healing/"New Age" nonsense

IMPORTANT NOTE: Be specific in your answers—for example if a use is "magnets," say what the magnets are used for; if a use is "drugs," say what the drugs treat. (3 points each, 9 points total)

XENOTIME

Chemical Formula:

Mineral Group:

Element & Use(s):

SPODUMENE

Chemical Formula:

Mineral Group:

Element & Use(s):

RHODITE

Chemical Formula:

Mineral Group:

Element & Use(s):

(4) As you have just seen in question #3, many of the elements humans use to manufacture artificial materials cannot be found alone in nature—they only occur in various compound minerals bonded to other elements. When those minerals are mined, they must be processed to extract the element needed. Below is a list of three of these elements and their chemical symbols, along with examples of common (and familiar) places where each is used. For each, provide:

- the name (occurrence) of ***at least one*** mineral that is a source of this element,
- the chemical formula ***for that mineral***, and
- the name of the ***single*** most productive ***country*** in the world where the element (regardless of what mineral(s) it is extracted from) is found and mined. (Keep in mind that countries rich in these particular resources have a huge role in controlling the price of the resource!)

IMPORTANT NOTE: Some of these elements occur as minor parts of other minerals and thus do not usually appear in the chemical formulas for those minerals. (3 points each, 9 points total)

SAMARIUM (Sm)

Element Use(s): *precision-guided weapons; stealth technology; control rods of nuclear reactors; radiation treatments for cancer*

Mineral Occurrence:

Chemical Formula:

Most Productive Country:

GERMANIUM (Ge)

Element Use(s): *blue lasers used in Blu-Ray players; logic chips in cell phones; solar cells in satellites*

Mineral Occurrence:

Chemical Formula:

Most Productive Country:

NEODYMIUM (Nd)

Element Use(s): *phone circuits, speakers, and vibration units in cell phones; powerful magnets used in speakers, headphones, and computer hard drives; electric car batteries*

Mineral Occurrence:

Chemical Formula:

Most Productive Country:

(5) This question concerns mineral resources in Utah. Natural resources are generally divided into metallic and non-metallic resources. You may use the Internet or other sources to find the answers to both parts of this question—if you word your searches properly and cleverly, you will find excellent resources that will enable you to answer the questions quickly and efficiently rather than having to jump around a lot from site to site or try to guess whether or not a particular mineral is metallic or not! If you find yourself looking at lots of sites with complex or ambiguous information, you're probably not looking at the best sites.

(a) Metallic resources are generally far rarer and more valuable than their non-metallic counterparts. Fill in the table below by listing ***five minerals*** (***not*** rock types, and ***not*** elements!) that meet the following criteria:

- they are metallic,
- they are compound minerals (have two or more elements in them), ***not*** native elements (Cu, Au, Ag, Pt, etc.),
- they are ***currently*** mined in Utah, and
- they are mined for ***commercial*** purposes (i.e., in large quantities for processing, ***not*** for pretty mineral specimens).

Then give the chemical formula and classification for each of the five minerals. ***HINT:*** Your search for answers to this question will likely be easier if you search for the alternative term metalliferous resources instead of metallic resources. (3 points each; 15 points total)

Mineral Name	Chemical Formula	Classification

(b) Non-metallic resources include many minerals, materials that contain numerous minerals, and even many non-minerals (such as oil and natural gas). Fill in the table below by listing ***six*** non-metallic ***minerals*** (***not*** rock types, and ***not*** elements!) that meet the following criteria:

- they are non-metallic,
- they are compound minerals (have two or more elements in them), ***not*** native elements (Cu, Au, Ag, Pt, etc.),
- they are ***currently*** mined in Utah, and
- they are mined for ***commercial*** purposes (i.e., in large quantities for processing, ***not*** for pretty mineral specimens).

Then give the chemical formula and classification for each of the six minerals.

Mineral Name	Chemical Formula	Classification

(6) (a) A rare, raspberry-red form of the gemstone mineral beryl has its type locality (the first place it was ever discovered) in Utah. Although it technically goes by the (boring) name "red beryl," and has also been referred to as "red emerald," this beryl has also been given its own unique name, more like those of most other minerals. What was the mineral name of this type of beryl, ***and*** where in Utah is it found? (1 point each; 2 points total)

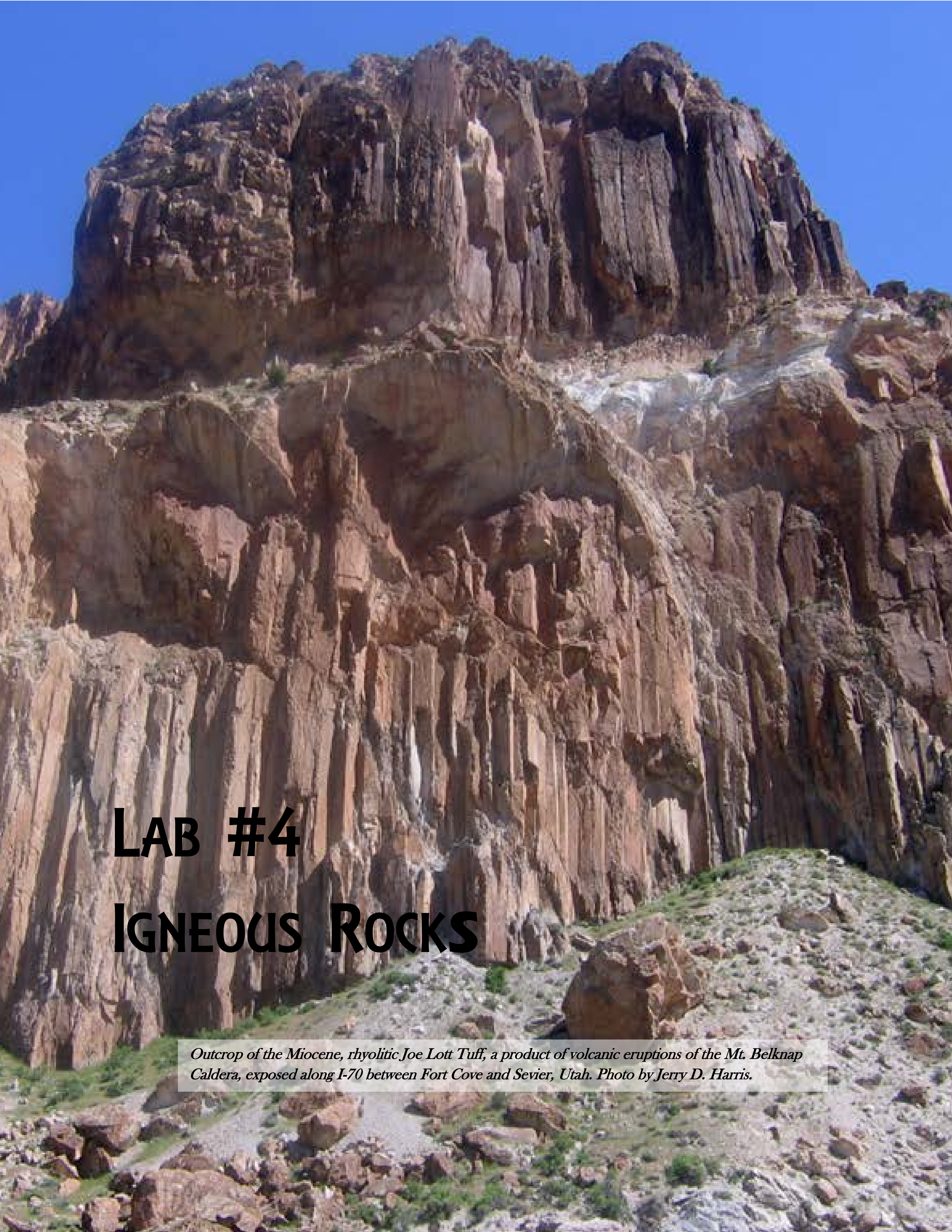
(b) What in this rare form of beryl gives it its red color? (1 point)

(c) Cut, faceted (as opposed to raw, uncut, but still very beautiful!) specimens of this red beryl are extremely expensive because of their rarity. On-line, find an example of a ***cut***, ***faceted, unmounted*** (= not set into a piece of jewelry) specimen of this gemstone that is ≥1.0 carat (ct) in weight ***and*** is from Utah. List its weight, price, and the ***full*** URL of your source here for full credit, but do ***not*** use etsy.com, jtv.com, or gemservice.com, all of which frequently sell fake, artificially enhanced, or lab-grown (i.e., not natural) "stones." Actual, reputable on-line gem shops will probably be the best bets. Have your instructor approve your choice! (1 point)

(d) Based on the specimen you found and its price, determine how valuable red beryl is per gram (1 carat = 200 mg = 0.2 g). ***Show your work*** for full credit. (3 points)

(e) How does this price compare to the current value (per gram) of gold (you can find the current value of gold on-line)? In other words, **gram for gram**, which is worth more: this rare red beryl or gold? (The value of gold is usually given in price per troy ounce; 1 troy ounce = 31.1 g, or 1 g = 0.032 troy ounces). ***Show your work*** for full credit. (3 points)

NOTES FOR MINERALS



Lab #4
Igneous Rocks

Outcrop of the Miocene, rhyolitic Joe Lott Tuff, a product of volcanic eruptions of the Mt. Belknap Caldera, exposed along I-70 between Fort Cove and Sevier, Utah. Photo by Jerry D. Harris.

The purpose of this exercise is to provide you with first-hand experience with the major types of igneous rocks, their characteristics, origin, and classification. During this lab, keep in mind that the small specimens (hand samples) of the different igneous rock types that you will see are merely small pieces removed from much larger bodies of rock—when thinking about the rock types, the characteristics of these larger rock bodies and their formations will be far more important than how the specimens were obtained!

Key Learning Points:

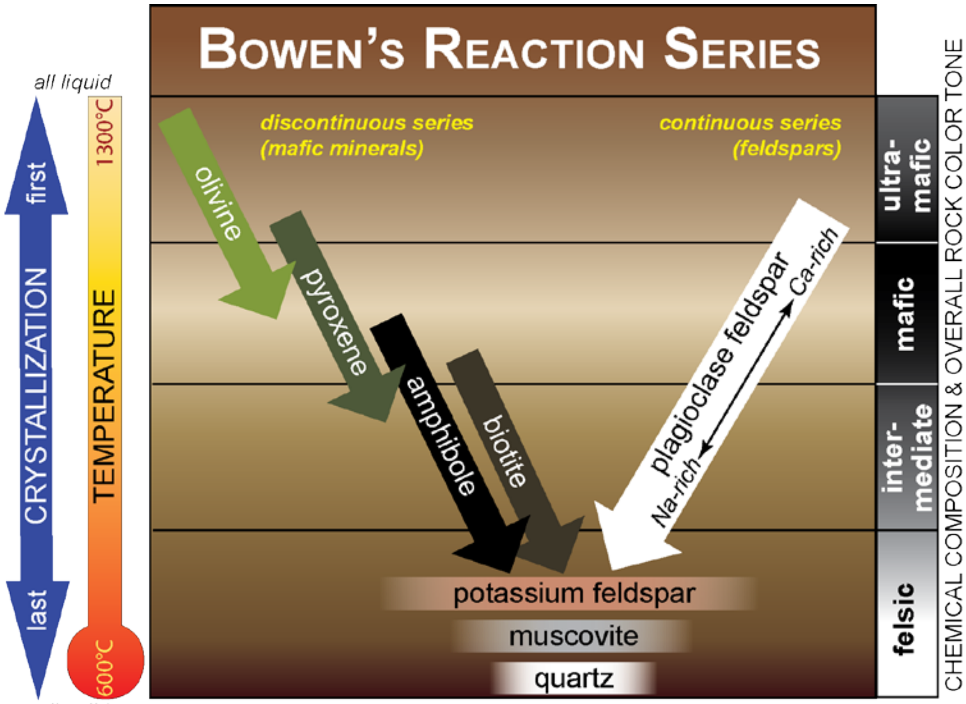
- Igneous rock types, features (crystal size, if applicable), textures (phaneritic, aphanitic, glassy, porphyritic, and pegmatitic), and mineral compositions (felsic, intermediate, mafic, and ultramafic), and the relationships between them.
- Bowen's Reaction Series: how and why it works, and its importance.
- The relationship between crystal size and cooling time.
- Recognizing that igneous rocks are sources for economically valuable natural resources.

This exercise is worth 75 points; point values for each question are given at the end of each question.

Name:____ Lab Section:____________________________

(1) Fill in the boxes on the right side of the Bowen's Reaction Series table below by putting the names of the following six igneous rock types in the appropriate places based on the chemical compositions and crystallization locations of each type (1 point each; 6 points total):

andesite basalt diorite gabbro granite rhyolite



Intrusive (Plutonic)	Extrusive (Volcanic)
peridotite (rare)	*komatiite (rare)*

(NOTE: The color of the arrow or band around each mineral name is approximately the color of that mineral.)

You will need to refer to Bowen's Reaction Series many times throughout this lab!

(2) Examine the eight specimens provided. For each one, characterize it by ***circling one*** of the listed terms for each category. The texture, site of formation, and chemical composition will allow you to pinpoint the rock types. **IMPORTANT NOTE:** You should make *tentative* identifications on each until you have had a chance to see *all* of the different specimens in order to get a better, comparative feel for crystal sizes and color tones. (4 points each specimen, 32 points total)

SPECIMEN 1						
	TEXTURE	phaneritic	aphanitic	glassy		
	SITE OF FORMATION	intrusive	extrusive			
	CHEMICAL COMPOSITION	felsic	intermediate	mafic		
	ROCK TYPE	granite	andesite	rhyolite	basalt	diorite
		gabbro	obsidian/pumice			

SPECIMEN 2	TEXTURE	phaneritic aphanitic glassy
	SITE OF FORMATION	intrusive extrusive
	CHEMICAL COMPOSITION	felsic intermediate mafic
	ROCK TYPE	granite andesite rhyolite basalt diorite gabbro obsidian/pumice
SPECIMEN 3	TEXTURE	phaneritic aphanitic glassy
	SITE OF FORMATION	intrusive extrusive
	CHEMICAL COMPOSITION	felsic intermediate mafic
	ROCK TYPE	granite andesite rhyolite basalt diorite gabbro obsidian/pumice
SPECIMEN 4	TEXTURE	phaneritic aphanitic glassy
	SITE OF FORMATION	intrusive extrusive
	CHEMICAL COMPOSITION	felsic intermediate mafic
	ROCK TYPE	granite andesite rhyolite basalt diorite gabbro obsidian/pumice
SPECIMEN 5	TEXTURE	phaneritic aphanitic glassy
	SITE OF FORMATION	intrusive extrusive
	CHEMICAL COMPOSITION	felsic intermediate mafic
	ROCK TYPE	granite andesite rhyolite basalt diorite gabbro obsidian/pumice

SPECIMEN 6	TEXTURE	phaneritic aphanitic glassy
	SITE OF FORMATION	intrusive extrusive
	CHEMICAL COMPOSITION	felsic intermediate mafic
	ROCK TYPE	granite andesite rhyolite basalt diorite gabbro obsidian/pumice
SPECIMEN 7	TEXTURE	phaneritic aphanitic glassy
	SITE OF FORMATION	intrusive extrusive
	CHEMICAL COMPOSITION	felsic intermediate mafic
	ROCK TYPE	granite andesite rhyolite basalt diorite gabbro obsidian/pumice
SPECIMEN 8	TEXTURE	phaneritic aphanitic glassy
	SITE OF FORMATION	intrusive extrusive
	CHEMICAL COMPOSITION	felsic intermediate mafic
	ROCK TYPE	granite andesite rhyolite basalt diorite gabbro obsidian/pumice

(3) Use Bowen's Reaction Series to answer the following three questions.

(a) The picture at right shows a close-up of a well-known granite found in the vicinity of Pikes Peak near Colorado Springs, Colorado. The reddish mineral in the rock is potassium feldspar. What, then, should ***each*** of the white, gray, and black minerals in the rock be? (3 points)

Photo credit:
http://www.petrifiedwoodmuseum.org/FlorissantPicsWS/PikesPeakGraniteCloseUp560.jpg

(b) **Komatiites** (pronounced koh-MAT-ee-ites) are rare, ultramafic, extrusive (volcanic) igneous rocks—most formed a few billion years ago, and none have formed in the last 90 million years or so. What would you expect to be the primary mineral(s) in a komatiite? (2 points)

(c) **Pegmatites** are intrusive (plutonic) igneous rocks comprised exclusively of extremely large (> 3 cm) crystals (see the specimen provided for an example). They form from the last quantities of liquid in a magma before it completely crystallizes, but grow very large because of the added presence of water in the magma, which enhances crystal growth. What minerals would you expect to find in a typical pegmatite? (3 points)

(4) (a) Examine the pictures of two different ***granites*** below—the one on the left is porphyritic. Assume that both granites are shown at the same scale (same magnification). Note that they both have more or less the same mineralogical compositions—that is, the same minerals are present in both. Given that common mineral composition between the two, why are they otherwise different? Specifically, what was different in the histories of the two parent magma bodies from which each granite formed? (5 points)

Photo credit:
http://thumbs.dreamstime.com/thumblarge_575/1295351425tuY6Wq.jpg

Photo credit:
http://eurasian.com/finland/granite/arctic_white.html

(b) If the black minerals in both specimens is the mineral hornblende (which is one of a group of minerals called **amphiboles**), then, given their light color tone, what mineral are the whitish crystals likely to be? (HINT: Use Bowen's Reaction series and the sizes of the crystals to answer this question correctly.) (3 points)

Photo credit: *http://www.pitt.edu/~cejones/GeoImages/2IgneousRocks/IgneousTextures/4PorphyriticFinez/BasaltRoughOlPheno.jpg*

(5) The picture at right is a close-up of a specimen of a porphyritic basalt. Notice that it contains small (but visible to the naked eye), greenish crystals amid the otherwise typically aphanitic basalt. These are crystals of the mineral **olivine**. Using what you know of Bowen's Reaction Series, find the temperature at which olivine begins to crystallize compared to the other minerals in the basalt (such as **pyroxene** and **amphibole**, which probably makes up much of the rest of this rock)—think specifically what this tells you about the conditions(s) (temperature, depth, etc.) at which the source magma for this basalt must have been. Thinking about this temperature difference ***plus*** the fact that crystal size depends on the amount of time in which the crystal can grow, discuss ***in a few sentences*** how this rock formed—why does it have two vastly different crystal sizes with no others in between, ***and*** what must have been the history of the magma body that produced this rock in order to produce such a porphyry? (5 points)

(6) Kimberlites are a rare type of extrusive (volcanic) igneous rock that are important sources of many minerals resources, but are especially important (and famous) as the primary source for one particular mineral resource. (You may use the Internet to help answer the following questions.)

(a) What is this important, famous mineral? (1 point)

(b) What other (common) minerals are found in kimberlites? (3 points)

(c) Given your answer to part (b), what is the general chemical composition (use Bowen's Reaction Series!) of kimberlites? (2 points)

(d) In your own words, what conditions are required for the rare mineral resource to form in a magma ***and*** at what depth(s) do these conditions occur? (2 points)

(e) Given your answer to part (d), why are kimberlites classified as extrusive (volcanic) igneous rocks? (3 points)

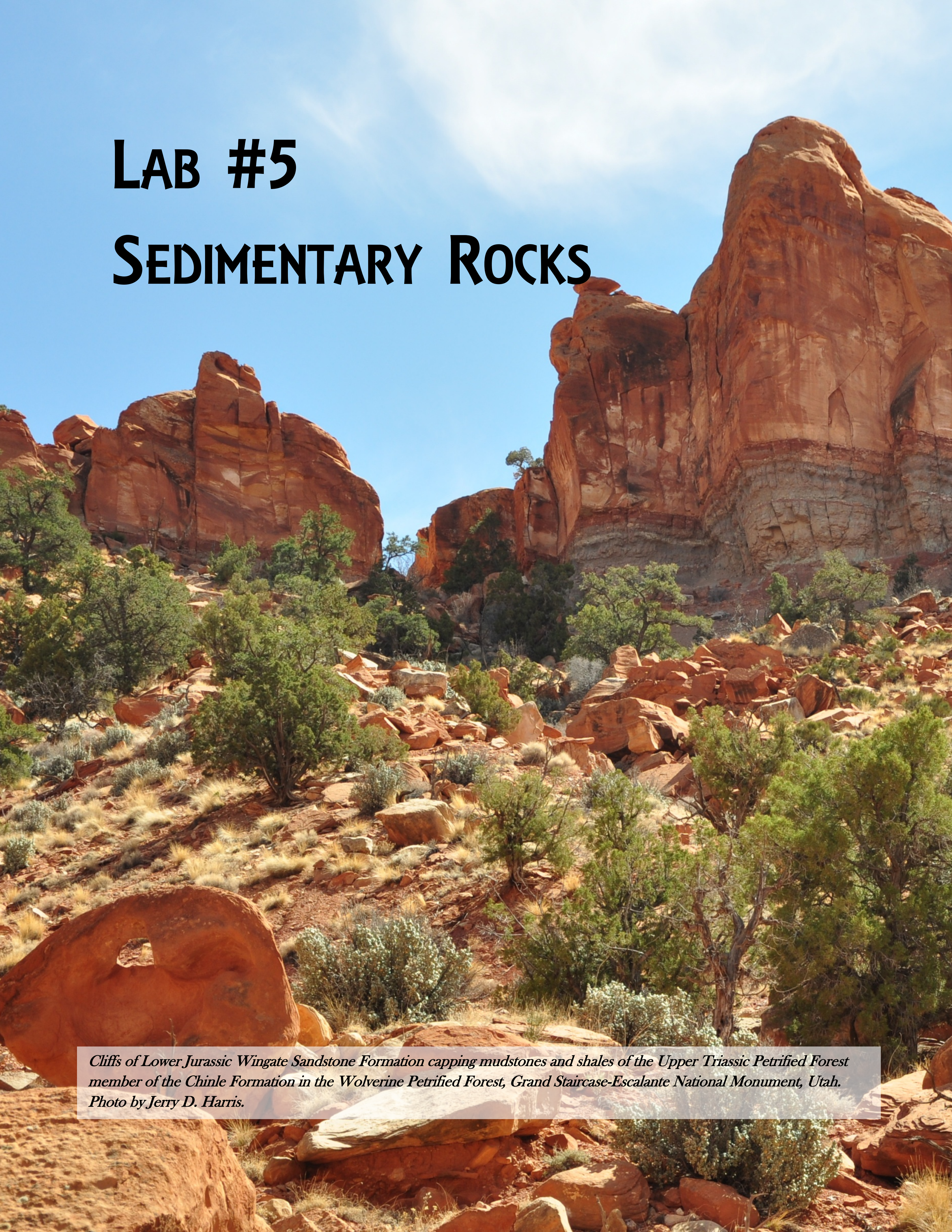
(f) Kimberlites are known all over the world, but in only a few places do they produce useful amounts of the famous mineral. Where in the world is the primary (as well as the largest and richest) source of kimberlites that bear this famous mineral? (3 points)

(question continues on the next page)

(g) A commonly held misconception is that this famous mineral resource from kimberlites forms from coal (which, as you will learn later, forms from the compressed remains of land plants). While humans could create *artificial* examples of this mineral from coal, coal has nothing to do with the *natural* formation of this mineral resource—even if coal were buried so deeply that it melted and became part of a magma, its melted remains *still* wouldn't have anything to do with the formation of the famous mineral from kimberlites. ***Aside*** from the fact that coal forms at the surface, what is the evidence that this is true? (3 points)

NOTES FOR IGNEOUS ROCKS

Lab #5
Sedimentary Rocks



Cliffs of Lower Jurassic Wingate Sandstone Formation capping mudstones and shales of the Upper Triassic Petrified Forest member of the Chinle Formation in the Wolverine Petrified Forest, Grand Staircase-Escalante National Monument, Utah. Photo by Jerry D. Harris.

The purpose of this exercise is to provide you with first-hand experience with the major types of sedimentary rocks and their characteristics, origins, and classification. During this lab, keep in mind that the small specimens (hand samples) of the different sedimentary rock types that you will see are merely small pieces removed from much larger bodies of rock—when thinking about the rock types, the characteristics of these larger rock bodies and their formations will be far more important than how the specimens were obtained!

Key Learning Points:

- Sedimentary rock types, features (clast size grades, where applicable), classification (detrital/clastic, chemical, organic), and the different compositions and formations of each.
- Sedimentary clast behavior under different conditions
- Recognizing that sedimentary rocks are sources for economically valuable natural resources.

This exercise is worth 85 points; point values for each question are given at the end of each question.

*Name:*____ *Lab Section:*__________________________

For the following exercises and questions, examine the specimens available at the stations around the room. You may need to refer to your textbook and/or lecture notes to answer them.

(1) Examine these sedimentary rock specimens and, for each one, characterize it by ***circling one*** of the listed terms for each category. More than one specimen of any particular rock type may be among the samples, and some types may not be present at all. (3 points each, 24 points total)

SPECIMEN 1	CLAST SIZE NAME & GRADE	gravel	sand	mud	not applicable
	ROCK TYPE	breccia conglomerate	limestone sandstone	mudstone shale	evaporite coal
	ROCK CATEGORY	detrital/clastic	chemical	organic	
SPECIMEN 2	CLAST SIZE NAME & GRADE	gravel	sand	mud	not applicable
	ROCK TYPE	breccia conglomerate	limestone sandstone	mudstone shale	evaporite coal
	ROCK CATEGORY	detrital/clastic	chemical	organic	
SPECIMEN 3	CLAST SIZE NAME & GRADE	gravel	sand	mud	not applicable
	ROCK TYPE	breccia conglomerate	limestone sandstone	mudstone shale	evaporite coal
	ROCK CATEGORY	detrital/clastic	chemical	organic	
SPECIMEN 4	CLAST SIZE NAME & GRADE	gravel	sand	mud	not applicable
	ROCK TYPE	breccia conglomerate	limestone sandstone	mudstone shale	evaporite coal
	ROCK CATEGORY	detrital/clastic	chemical	organic	
SPECIMEN 5	CLAST SIZE NAME & GRADE	gravel	sand	mud	not applicable
	ROCK TYPE	breccia conglomerate	limestone sandstone	mudstone shale	evaporite coal
	ROCK CATEGORY	detrital/clastic	chemical	organic	

(question continues on the next page)

SPECIMEN 6	CLAST SIZE CATEGORY	gravel sand mud not applicable
	ROCK TYPE	breccia limestone mudstone evaporite conglomerate sandstone shale coal
	ROCK CATEGORY	detrital/clastic chemical organic
SPECIMEN 7	CLAST SIZE CATEGORY	gravel sand mud not applicable
	ROCK TYPE	breccia limestone mudstone evaporite conglomerate sandstone shale coal
	ROCK CATEGORY	detrital/clastic chemical organic
SPECIMEN 8	CLAST SIZE CATEGORY	gravel sand mud not applicable
	ROCK TYPE	breccia limestone mudstone evaporite conglomerate sandstone shale coal
	ROCK CATEGORY	detrital/clastic chemical organic

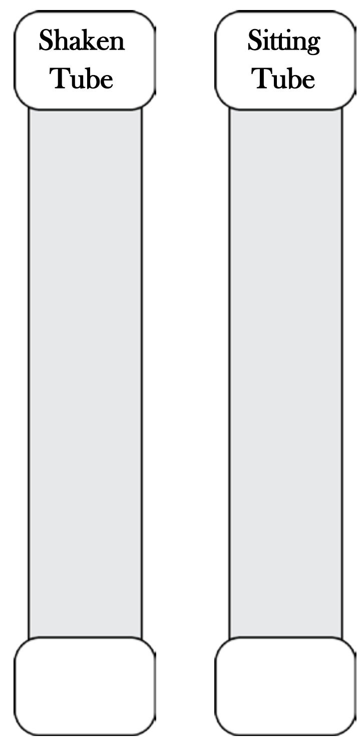
(2) You have just been handed two sedimentary rock specimens that appear identical—same color, same texture, etc. One is a ***detrital (clastic)*** sedimentary rock, and the other is a ***chemical*** sedimentary rock. You ***cannot*** see individual clasts, crystals, or any other components of either specimen with the naked eye. Specify ***two*** ways (tests you could perform, features you would look for, etc.) that you could do/use to tell the difference between them. These do ***not*** have to be perfect features or tests (that is, they don't have to *definitively* tell you which is which), but they should point you ***strongly*** in one or another direction. **Remember**: there are different kinds of chemical sedimentary rocks (e.g., limestone forms differently from rock gypsum), so some tests may work well on one kind but not another—it's still OK to list them here, though, but ***you must mention which kinds of rocks the tests work on!*** (3 points each, 6 points total)

One way to tell the difference:

Another way to tell the difference:

(3) You have just been handed two sedimentary rock specimens that appear identical—same color, same mineral composition, same texture, etc. One of them is an ***igneous*** rock and the other is a ***detrital (clastic) sedimentary*** rock. You ***cannot*** see individual clasts, crystals, or any other components of either specimen with the naked eye. You aren't told anything about where they came from. What ***feature(s)*** might you look for to tell them apart? Recall that the grains (clasts) of sedimentary rocks are made of weathered and eroded crystals and that crystals in igneous rocks can have irregular shapes! (HINT: a microscope might help you see one specific set of features...or absence of those features!) ***NOTE: If ALL you do is state how each rock type forms, you will get this question wrong!*** (5 points)

(4) At this station are two tubes filled with water and sedimentary clasts of different sizes and grades (ignore the colors, compositions, shapes, etc. of the clasts—they are unimportant for the purposes of this question). You will vigorously shake one of the tubes; the other has been sitting undisturbed for a long time—***DO NOT*** touch, bump, or otherwise disturb this tube! Shake the appropriate tube vigorously for several seconds, and then set one of its ends on the table so it stands up vertically. Observe what happens to the different clast sizes in the tube immediately upon setting it down ***and*** for several seconds afterward. Compare what you saw (and continue to see) in this tube with the tube that has been sitting, undisturbed since being shaken several hours earlier—this tube represents what would happen to the shaken tube if it sat for a long time. Once you have examined and compared both tubes, answer the following questions.



(a) In the schematic diagrams of the tubes at right, sketch ***and*** label the positions of the various clast sizes as they appear in each tube. Describe how (in what order) ***and*** when each different clast size (gravel, sand, mud) settled out, beginning with the moment you set the shaken tube on the table. If there are clasts that have not settled, show where they are, too. (4 points)

(question continues on the next page)

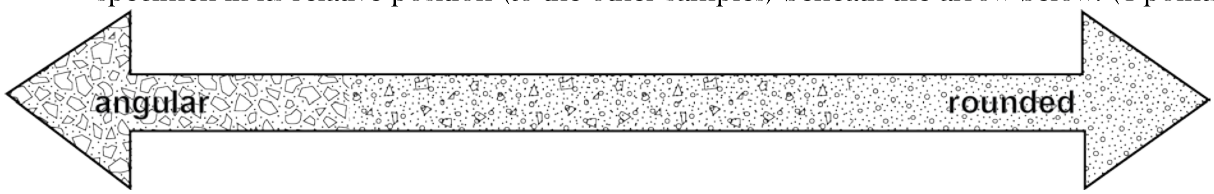
(b) Why do the clasts settle out in this order? If there are clasts that have not settled in the shaken tube, ***why*** have they not settled? Will they ever settle? (3 points)

(c) The picture below is of a portion of a detrital (clastic) sedimentary rock layer. Note how the clasts in it are arranged—this is called **graded bedding**. Based on the conditions necessary to mobilize ***all*** the clasts in the tube you shook, and on the results you observed in ***both*** tubes, what must the conditions have been that were responsible for (1) transporting all these clasts together, and then (2) depositing them in a graded bed that ultimately lithified into this rock, ***and*** where (and when) might those conditions exist in the real world? (3 points)

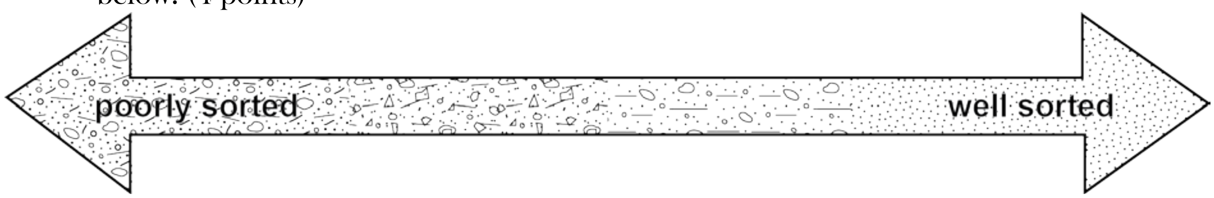
Photo credit:
http://iapetancaptain.files.wordpress.com/2010/04/graded-bedding.jpg

(5) At this station are four samples of a few detrital (clastic) sedimentary rocks, as well as some loose sediment samples (which were taken from single sources—they were not compiled from multiple sources). Use the loupes at this station to examine both the rocks and sediment samples, paying particular attention to the shapes and relative sizes of the clasts comprising each sample.

(a) Rank the samples in order from angular to rounded by placing the letter of the appropriate specimen in its relative position (to the other samples) beneath the arrow below. (4 points)



(b) Rank the samples in order from poorly sorted to well sorted by placing the letter of the appropriate specimen in its relative position (to the other samples) beneath the arrow below. (4 points)



(c) In general, explain how rounding occurs, and explain how sorting occurs. (3 points)

(d) ***<u>Based on what you observed in the specimens at this station</u>***, is there a relationship between sorting and rounding? If so, what is the nature of this relationship ***<u>and</u>*** why are the two phenomena related? (3 points)

(6) At this station are three "fossilized" examples of various kinds of sedimentary ***structures***. For each, do the following: name the type of structure (***not*** the rock type!), sketch the structures **on the specimen**, and state what must have been the environment in which the structures originally formed (in the loose sediment that eventually lithified into the rock you see). Specify environment types (e.g., "deep ocean"); don't just use vague descriptive terms (e.g., "cold"), ***and*** specify what qualities about those environments create the conditions suitable to form each particular kind of sedimentary structure. (3 points each; 9 points total)

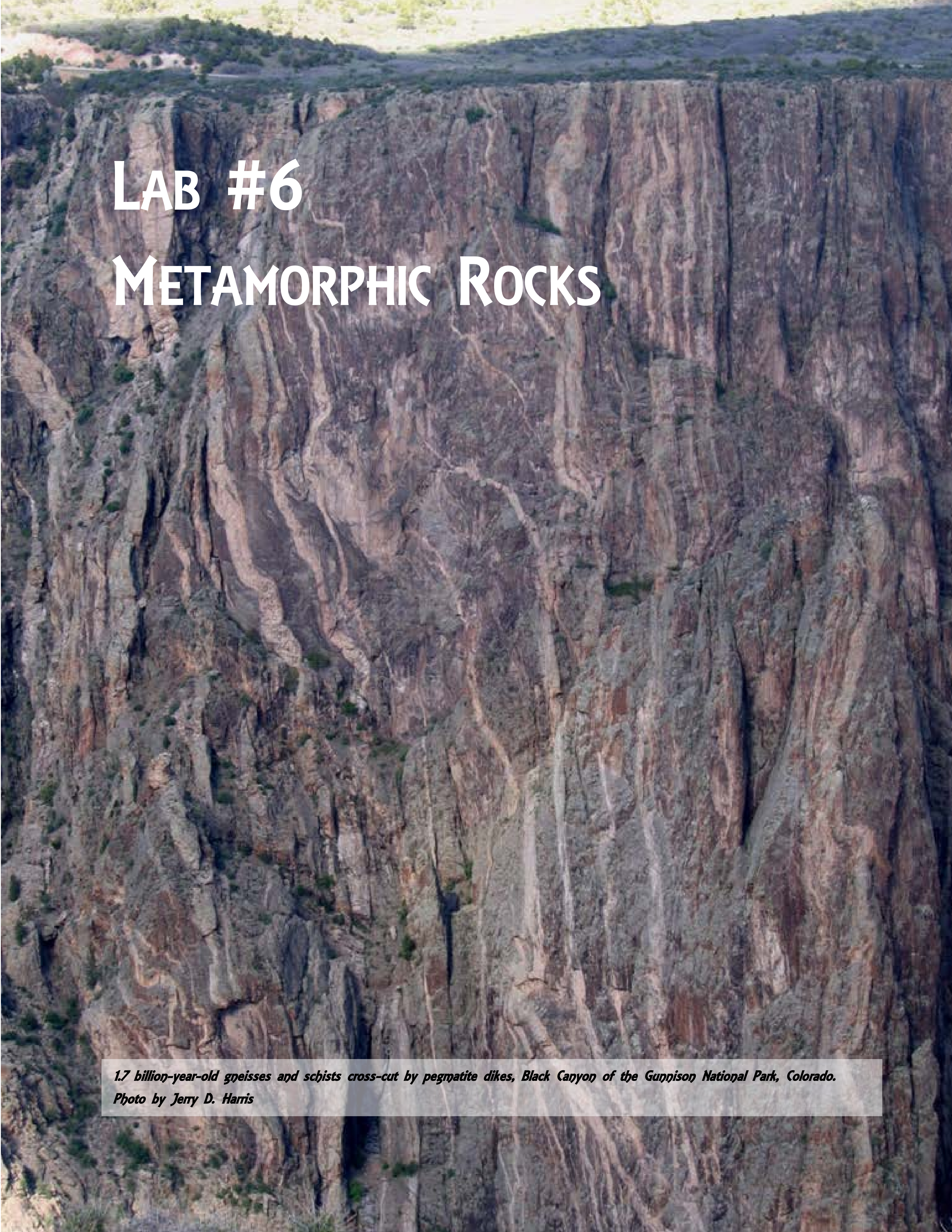
	STRUCTURE NAME	SKETCH OF SPECIMEN	ENVIRONMENT OF FORMATION
SPECIMEN A			
SPECIMEN B			
SPECIMEN C			

(7) Many of the non-metallic mineral resources mined in Utah come from detrital (clastic) and chemical sedimentary rocks. List ***five*** of these sedimentary rock resources and, for each one, the kind of sedimentary rock from which it is extracted, one of the (general) parts of Utah in which it is mined, and at least one ***modern*** use for that particular kind of resource (regardless of where it is mined). (4 points each; 20 points total)

RESOURCE (IF APPLICABLE)	ROCK TYPE RESOURCE IS EXTRACTED FROM	MINED IN WHAT (GENERAL) PART OF UTAH	USE

NOTES FOR SEDIMENTARY ROCKS

Lab #6
Metamorphic Rocks



1.7 billion-year-old gneisses and schists cross-cut by pegmatite dikes, Black Canyon of the Gunnison National Park, Colorado. Photo by Jerry D. Harris

The purpose of this exercise is to provide you with first-hand experience with the major types of metamorphic rocks and their characteristics, origins, and classification. During this lab, keep in mind that the small specimens (hand samples) of the different metamorphic rock types that you will see are merely small pieces removed from much larger bodies of rock—when thinking about the rock types, the characteristics of these larger rock bodies and their formations will be far more important than how the specimens were obtained!

Key Learning Points:

- Metamorphic rock types, features (types of foliation, if present), classification (foliated and non-foliated), and the different heats and pressures that govern the formation of each.
- Recognizing that metamorphic rocks are sources for economically valuable natural resources.

This exercise is worth 70 points; point values for each question are given at the end of each question.

*Name:*____ *Lab Section:*__________________________

For the following exercises and questions, examine the specimens available at the stations around the room. You may need to refer to your textbook and/or lecture notes to answer them.

(1) Characterize each of the specimens by ***circling one*** of the listed terms for each category. (5 points each specimen, 40 points total)

SPECIMEN 1	TEXTURE	nonfoliated foliated: slaty cleavage foliated: schistose foliated: phyllitic foliated: gneissic foliated: other
	AMOUNT OF HEAT	low moderate high
	AMOUNT OF PRESSURE	low moderate high
	ROCK TYPE	slate gneiss marble schist phyllite quartzite: metasandstone —or— metaconglomerate/breccia anthracite
	PARENT ROCK	granite sandstone coal shale basalt conglomerate/breccia limestone no way to tell
SPECIMEN 2	TEXTURE	nonfoliated foliated: slaty cleavage foliated: schistose foliated: phyllitic foliated: gneissic foliated: other
	AMOUNT OF HEAT	low moderate high
	AMOUNT OF PRESSURE	low moderate high
	ROCK TYPE	slate gneiss marble schist phyllite quartzite: metasandstone —or— metaconglomerate/breccia anthracite
	PARENT ROCK	granite sandstone coal shale basalt conglomerate/breccia limestone no way to tell

(question continues on the next page)

SPECIMEN 3	TEXTURE	nonfoliated / foliated: slaty cleavage / foliated: schistose / foliated: phyllitic / foliated: gneissic / foliated: other
	AMOUNT OF HEAT	low / moderate / high
	AMOUNT OF PRESSURE	low / moderate / high
	ROCK TYPE	slate / gneiss / marble / schist / phyllite / quartzite: metasandstone —or— metaconglomerate/breccia / anthracite
	PARENT ROCK	granite / sandstone / coal / shale / basalt / conglomerate/breccia / limestone / no way to tell
SPECIMEN 4	TEXTURE	nonfoliated / foliated: slaty cleavage / foliated: schistose / foliated: phyllitic / foliated: gneissic / foliated: other
	AMOUNT OF HEAT	low / moderate / high
	AMOUNT OF PRESSURE	low / moderate / high
	ROCK TYPE	slate / gneiss / marble / schist / phyllite / quartzite: metasandstone —or— metaconglomerate/breccia / anthracite
	PARENT ROCK	granite / sandstone / coal / shale / basalt / conglomerate/breccia / limestone / no way to tell

(question continues on the next page)

SPECIMEN 5	TEXTURE	nonfoliated foliated: slaty cleavage foliated: schistose foliated: phyllitic foliated: gneissic foliated: other
	AMOUNT OF HEAT	low moderate high
	AMOUNT OF PRESSURE	low moderate high
	ROCK TYPE	slate gneiss marble schist phyllite quartzite: metasandstone —or— metaconglomerate/breccia anthracite
	PARENT ROCK	granite sandstone coal shale basalt conglomerate/breccia limestone no way to tell
SPECIMEN 6	TEXTURE	nonfoliated foliated: slaty cleavage foliated: schistose foliated: phyllitic foliated: gneissic foliated: other
	AMOUNT OF HEAT	low moderate high
	AMOUNT OF PRESSURE	low moderate high
	ROCK TYPE	slate gneiss marble schist phyllite quartzite: metasandstone —or— metaconglomerate/breccia anthracite
	PARENT ROCK	granite sandstone coal shale basalt conglomerate/breccia limestone no way to tell

(question continues on the next page)

SPECIMEN 7	TEXTURE	nonfoliated foliated: slaty cleavage foliated: schistose foliated: phyllitic foliated: gneissic foliated: other
	AMOUNT OF HEAT	low moderate high
	AMOUNT OF PRESSURE	low moderate high
	ROCK TYPE	slate gneiss marble schist phyllite quartzite: metasandstone —or— metaconglomerate/breccia anthracite
	PARENT ROCK	granite sandstone coal shale basalt conglomerate/breccia limestone no way to tell
SPECIMEN 8	TEXTURE	nonfoliated foliated: slaty cleavage foliated: schistose foliated: phyllitic foliated: gneissic foliated: other
	AMOUNT OF HEAT	low moderate high
	AMOUNT OF PRESSURE	low moderate high
	ROCK TYPE	slate gneiss marble schist phyllite quartzite: metasandstone —or— metaconglomerate/breccia anthracite
	PARENT ROCK	granite sandstone coal shale basalt conglomerate/breccia limestone no way to tell

(2) Metamorphism is caused by the applications of heat and pressure to existing rocks. However, the amounts of heat and pressure vary from one *regime* (= one place and set of conditions) to another; where one increases, the other does ***not*** necessarily follow. Foliated metamorphic rocks have foliations because they have had **differential stress** (pressure) applied to them during the metamorphic process—the stress does two things: (a) it flattens existing crystals/grains in the parent rock (in addition to high temperatures enabling ion migration along crystals), and (b) it reorients them perpendicular to the direction of the differential stress. Nonfoliated metamorphic rocks, in contrast, can form in ***two*** different kinds of pressure regimes—what are they? (2 points each; 4 points total)

(3) The most common uses for most metamorphic rock types are decorative, in art (e.g., sculptures, headstones) and construction (e.g., building stones, tiles). However, anthracite is not used in either of these two ways…but it still has an important use. (You may use your lecture textbook, other books, or the Internet to help find the answers to these questions.)

(a) What is the parent rock of anthracite? (1 point)

(b) What are both anthracite and its parent rock used for, ***and***, despite the fact that it's much more expensive, why is anthracite preferable for this use over its parent rock? (4 points)

(c) Where in the U.S. is most anthracite mined? (2 points)

(d) Utah is rich in the parent rock of anthracite. But is anthracite itself mined anywhere in Utah? (2 points)

(4) Serpentinite is a special type of metamorphic rock that commonly forms via hydrothermal metamorphism of mafic igneous rocks, such as basalt. Many serpentinites are rich in greenish minerals*. Some kinds of serpentinite resemble some kinds of marble and are particularly prized as decorative stones. One of the common components of serpentinite is the mineral **chrysotile**, which is a member of a ***group*** of infamous minerals that is known by another (common) name. (You may use various books or the Internet to help find the answers to the following questions.)

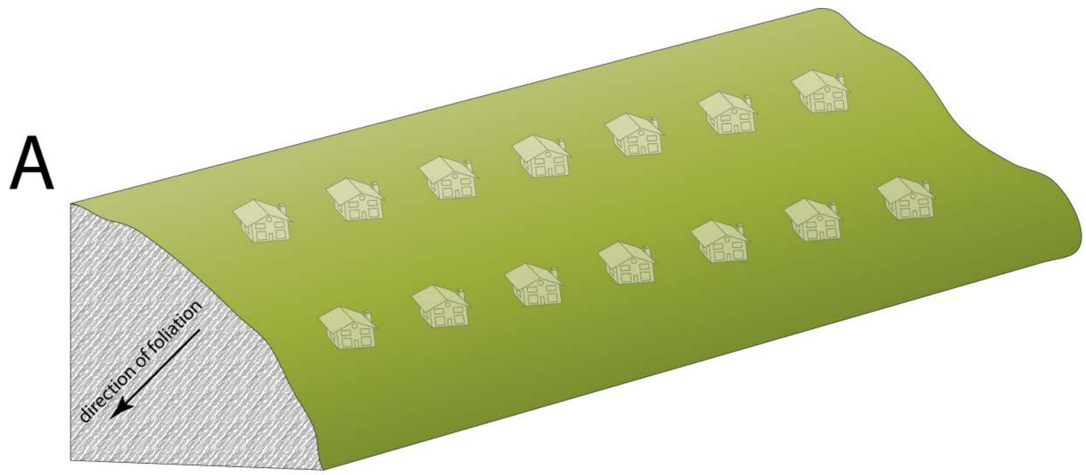
(a) What is this other name? (1 point)

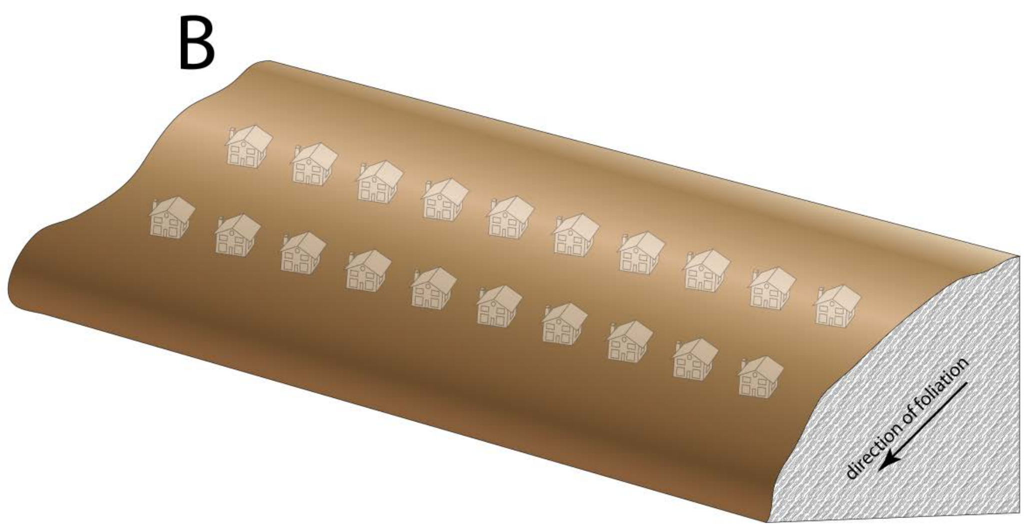
(b) Minerals in this group used to be used heavily in the manufacture of brake pads in vehicles and in various building materials, particularly many kinds of insulation and flame retardants, because they are quite heat resistant. Building renovations that require removing these materials are dangerous and require special precautions and procedures—what can happen to them if removed improperly? (4 points)

(c) The use of these minerals in manufacturing has been banned in the U.S. and many other countries because they have been linked to several, usually fatal, medical conditions. What are some of these conditions, ***and*** what primary part of the body do they affect? (4 points)

**The name "serpentinite" derives from the same Latin root as "serpent," meaning snake, possibly because of the similarity of the color to some snakes, or of the waxy luster of some of the minerals in serpentinite to snake scales*

(5) You, a geologist, have been contracted by a conscientious developer that is considering developing two hillside properties (A and B, below) for a housing development. Your analysis of both localities reveals that the bedrock underlying the hillsides is foliated metamorphic rock, particularly phyllite and schist. You have been able to determine the directions of the foliations of the rocks comprising each hill (see pictures below). Based on this information, combined with what you know about the natures of the textures and structures of phyllite and schist, which of the two hillsides would you tell the developer is better for a housing development ***and*** why is your choice better? (8 points)





NOTES FOR METAMORPHIC ROCKS

Lab #7
Geologic Time: Stratigraphic (Relative) and Radiometric Dating

Pliocene, mafic dike cutting through Permian, marine strata of the Darwin Canyon Formation, near Darwin Falls, Death Valley National Park, California. Photo by Garry Hayes (from http://geotripperimages.com/Volcanism/Plutons%20and%20intrusions.htm)

This lab has two parts:

STRATIGRAPHIC DATING

The purpose of this portion of the exercise is to provide you with some experience with the stratigraphic dating methods that geologists employ to figure out the relative ages of various rock layers (strata) and other bodies. You will be doing this with diagrams, but in reality, many geologists spend large amounts of time in the field mapping where various rock bodies are and their relationships to each other, gathering the necessary information to reconstruct such diagrams. For biostratigraphic dating, geologists can consult published reports of fossil occurrences around the world in order to tie the rocks they are studying to those in far-away places. The use of stratigraphic dating principles over the last two centuries not only enabled the construction of the geologic time scale, but also provided the foundations for our modern understanding of evolutionary processes, which are the foundation of all modern biology (including medicine), and the only body of data about the evolutionary history of all life on Earth. No one place in the world preserves rocks and/or fossils from all time periods in sequence, but vast numbers of places preserve rocks and fossils from different segments of time; deducing their relative positions to one another is therefore critical not only to geology, but to biology, as well.

RADIOMETRIC DATING

The purpose of this part of the exercise is to provide you with first-hand experience with the principles of radiometric dating. Of course, we will not be using any actual radioactive material in class; instead, in the first part of this lab, you will use dice in a simulation. The dice serve as a good model for actual, radiometrically decaying atoms because, in important ways, they behave the same way that unstable atoms do. The dice therefore will be our proxies for actual atoms. In the second part of the lab, you will be answering a few questions about actual radiometrically decaying isotopes.

Key Learning Points:

- Application of stratigraphic dating principles, including the principles of fossil succession, original horizontality, superposition, lateral continuity, cross-cutting relationships, and inclusions, as well as different kinds of unconformities and their recognition and meanings.
- Biostratigraphic correlation and its application to the dating of strata.
- Half lives ($t_{½}$), decay constants (λ), and the relationship between them using the formulas:

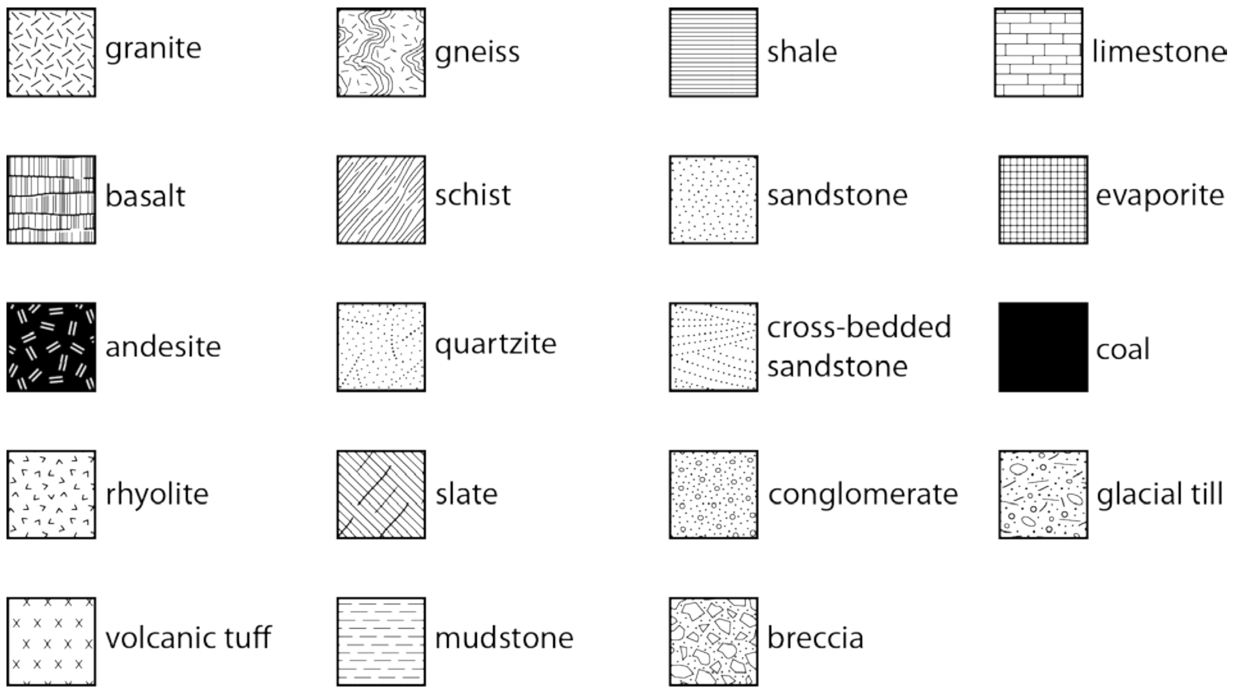
$$t_{½} = {}^{0.693}/_{\lambda} \quad \text{and} \quad \lambda = {}^{0.693}/_{t_{½}}$$

- Creating a graph from collected data.
- Determining a half life from an exponential decay curve by reading a graph.
- Real-world applications of simple algebra.

This exercise is worth 85 points; point values for each question are given at the end of each question.

Stratigraphic Dating

Below (questions #1–2) are schematic geologic cross sections—think of these as gigantic (tens, even hundreds, of kilometers across) slices through the ground in different locations that expose the internal geology of the ground. Each one exposes a number of geologic features, each representing an event: emplacement (e.g., of a magma body, a fault), deposition (e.g., of sediment), creation of a structure (e.g., tilting or folding of strata), erosion, etc. All the sections use the same set of symbols for rock types; a legend for these symbols is given below.

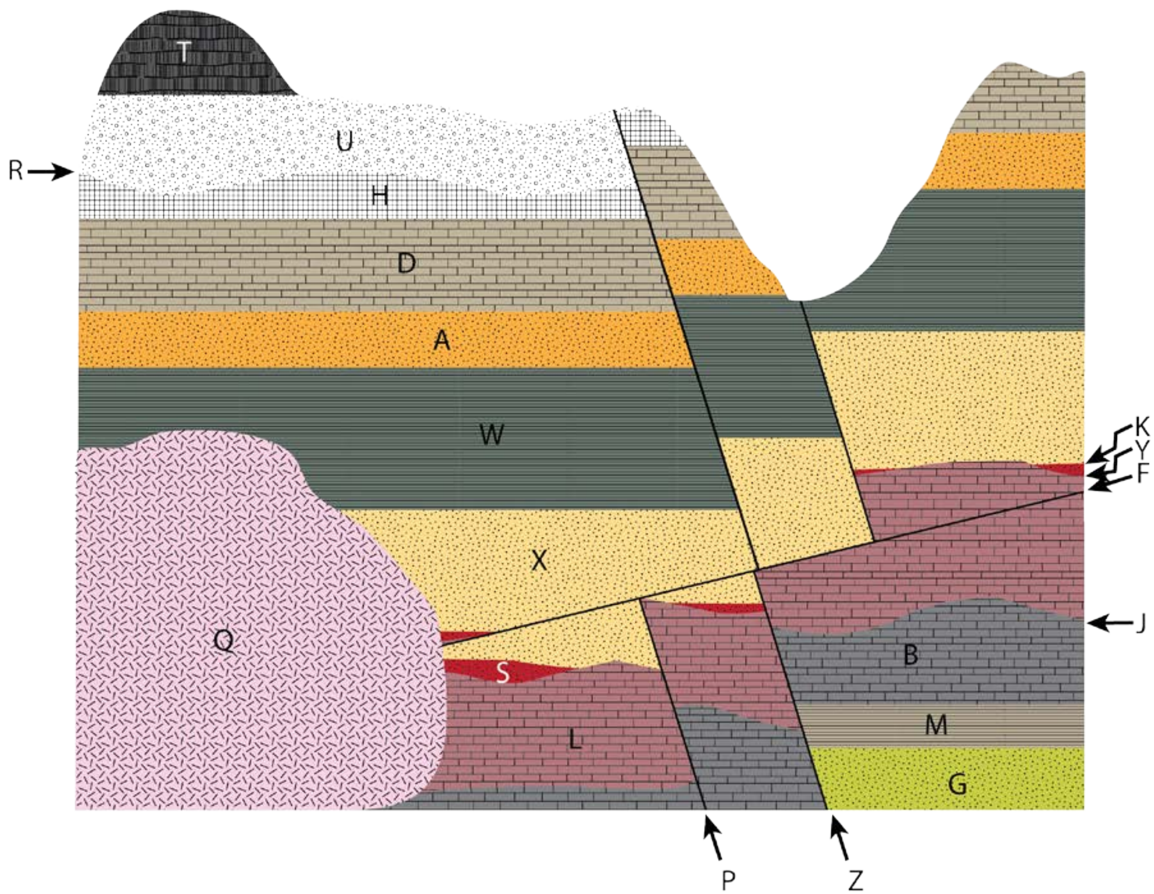


In all cross sections, straight (linear) contacts between rock units are **conformable**, and irregular (wavy) contacts are **unconformable** (erosional).

You should do the exercises in this lab in pencil in case you have to erase and revise as you go.

*Name:*____ *Lab Section:*__________________________

(1) (a) Place the labeled events/features in chronologic order from first/oldest to last/youngest by placing the ***letter*** of the event/feature in the appropriate blank accompanying the cross section. Then answer the questions below the cross section. (10 points)

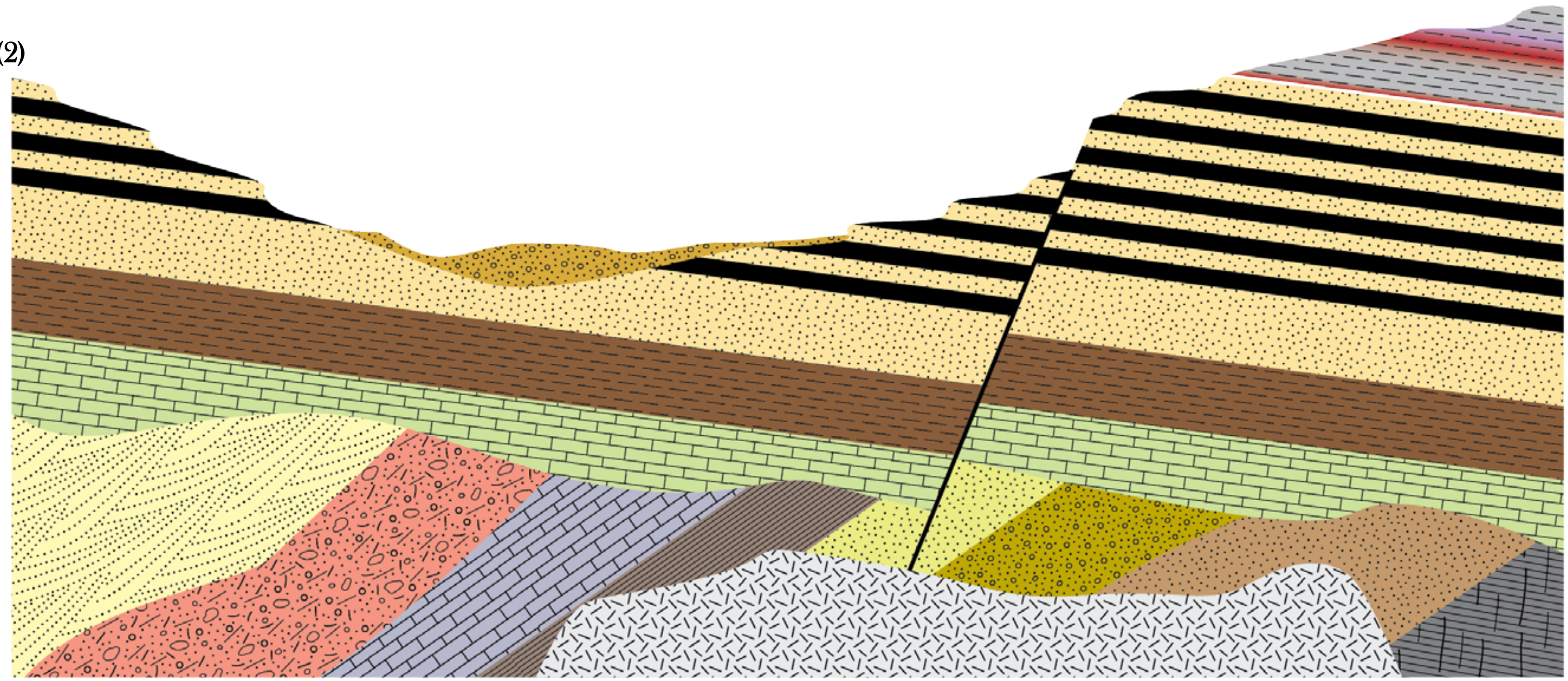


FIRST	**11**
2	**12**
3	**13**
4	**14**
5	**15**
6	**16**
7	**17**
8	**18**
9	**19**
10	**LAST**

(b) What kind of unconformity is J? (1 point)

(c) What kind of unconformable contact does Q have with all the strata that it touches? (1 points)

(2)



The cross section above is similar to the ones you saw in question #1, but here nothing has been labeled—you must identify all the events/features yourself. Do the following:

- Label each feature/event in chronological order (starting with the oldest as #1) on the cross section itself (you can use arrows to link your labels to features if they are too dark to write directly on). Make sure your labels are legible, visible, and unambiguous!
- Treat the alternating sandstone–coal sequence as a single unit (just to make things easier).
- For any unconformities, specify (if possible) what kind each is.
- If the relative ages of any two (or more) events/features cannot be determined, explain why not, and specify what additional data would you need to make such a determination.
- Don't forget geologic-structure-creating events and erosional features! (20 points)

If you need to, put (or continue) your answers on the next page.

(3) The diagram on the following page depicts fossil-bearing stratigraphic sections in three widely separate places around the world. However, some of the strata at each are the same age. The ages of units that can be radiometrically dated (i.e., igneous rocks, including volcanic ashes deposited along with sediments that ultimately became sedimentary rocks) are given on the section. Use the fossil and radiometric data from these sections to answer the following questions.

(a) What is the narrowest age range that can be determined for the coral? (1 point)

(b) What is the narrowest age range that can be determined for the dinosaur track? (1 point)

(c) What is the narrowest age range that can be determined for the crinoid? (1 point)

(d) What is the narrowest age range that can be determined for arthropod B? (1 point)

(e) What is the narrowest age range that can be determined for the fish? (1 point)

(f) What is the narrowest age range that can be determined for echinoderm B? (1 point)

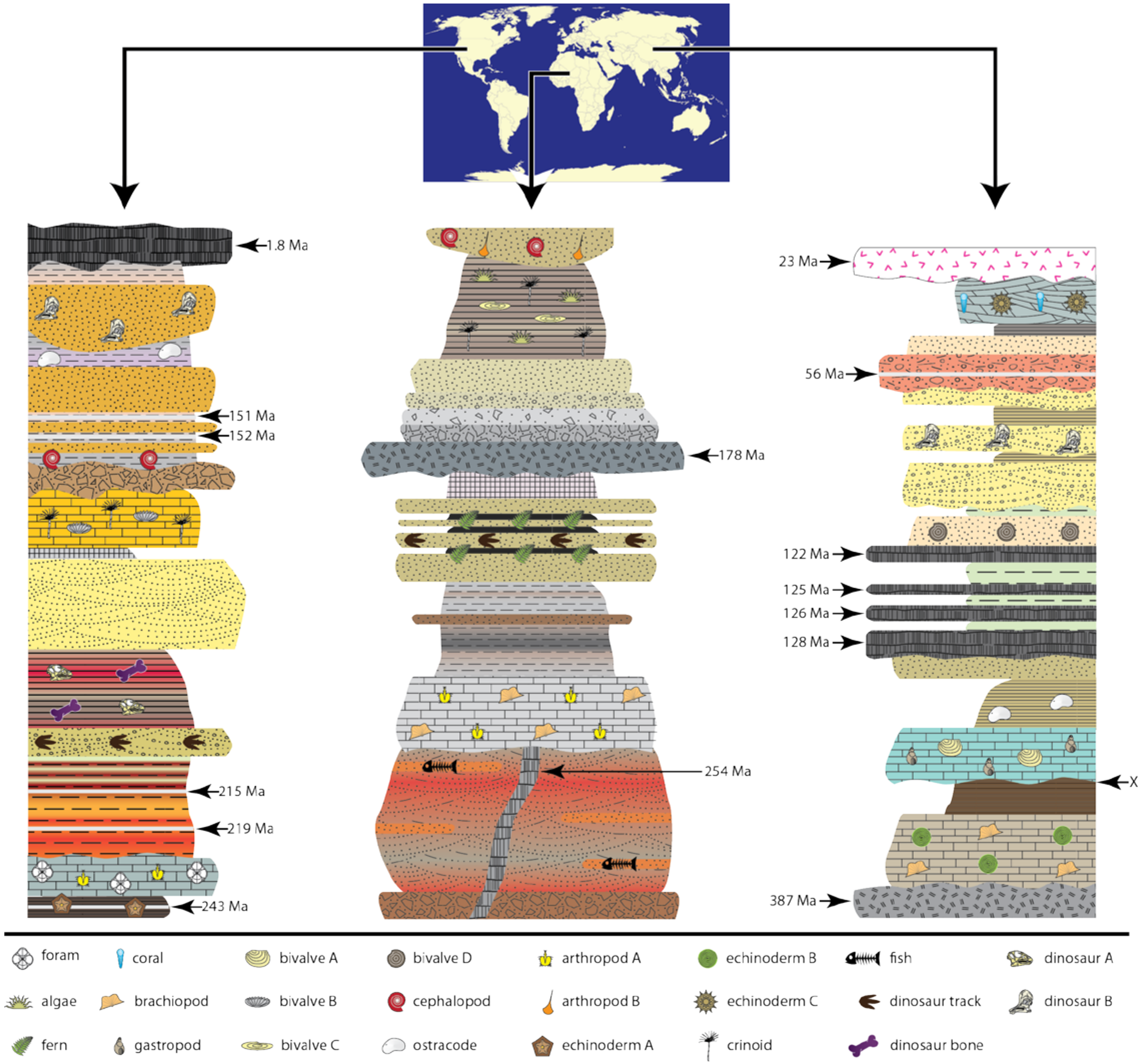
(g) Is bivalve D likely closer in age to dinosaur B or to the ostracode ***and*** what enables such a determination? (**HINT:** examine the strata and their contacts closely!) (2 points)

(h) Are there any fossil organisms in any of these three sections whose age can be determined with a great deal of precision? If so, which one ***and*** how old is it? (2 points)

(question continues on the next page)

(i) Dinosaurs first evolved approximately 230 million years ago and (except for birds) went extinct at the end of the Cretaceous, approximately 65 million years ago. Do the dinosaur fossils found in the areas depicted in the three sections support or refute these established dates, ***and*** how do they do so? (2 points)

(j) Approximately how much time does the unconformity marked **X** represent ***and*** how do you know? (3 points)


1.8 Ma
151 Ma
152 Ma
215 Ma
219 Ma
243 Ma
178 Ma
254 Ma
23 Ma
56 Ma
122 Ma
125 Ma
126 Ma
128 Ma
X
387 Ma
foram
coral
bivalve A
bivalve D
arthropod A
echinoderm B
fish
dinosaur A
algae
brachiopod
bivalve B
cephalopod
arthropod B
echinoderm C
dinosaur track
dinosaur B
fern
gastropod
bivalve C
ostracode
echinoderm A
crinoid
dinosaur bone

Radiometric Dating

For the first part of this exercise, you will work in small groups to collect and analyze data that involve rolling 200 six-sided dice, each with one colored side. Each die in the set represents one atom of an unstable isotope. The dice will serve as a greatly simplified model of how half lives are determined for radioactive, unstable isotopes—they are a good model because in the same way that it is impossible to predict when any actual atom of an unstable isotope in a sample will decay, it is impossible to predict before a roll which face of a die will come up after a roll…but, statistically speaking, some will! On the table on the next page, write down the data obtained during your dice rolls.

Follow these steps your trial:

Step 1: Roll all the dice in the container, and record the number of dice you rolled on the table provided.

Step 2: Any dice that are colored-side up after the roll have "decayed"—remove these from the set and count them; record this number in the table provided.

Step 3: Return all the "un-decayed" dice to the container. (When you have just a few dice left, you can roll them by hand rather than put them in the container before rolling.)

Step 4: Repeat steps 1–3 until all the dice have "decayed."

Step 5: Plot your data on the graph provided. Note carefully where your first data point will land on the graph (**HINT**: it's not at roll #1!).

Step 6: ***DO NOT CONNECT THE DOTS*** on the graph. Instead, draw in (as best as possible) a smooth curve that "fits" the dots for each trial as best as possible (your lab instructor will show you examples of such curves for actual isotopes).

Step 7: Use your graphed data to determine the half life of the dice for the trial. Your teacher will demonstrate how to do this. Note that the technique for doing this works not only for dice, but for all decaying isotopes, as well.

For all questions that require doing math in this exercise, show all your work to receive full credit. Answers that do not show the math will not be given credit, even if the answer is correct!

ROLL # (time)	# DICE ROLLED (count)	# DICE DECAYED
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		

ROLL # (time)	# DICE ROLLED (count)	# DICE DECAYED
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		
36		
37		
38		
39		
40		
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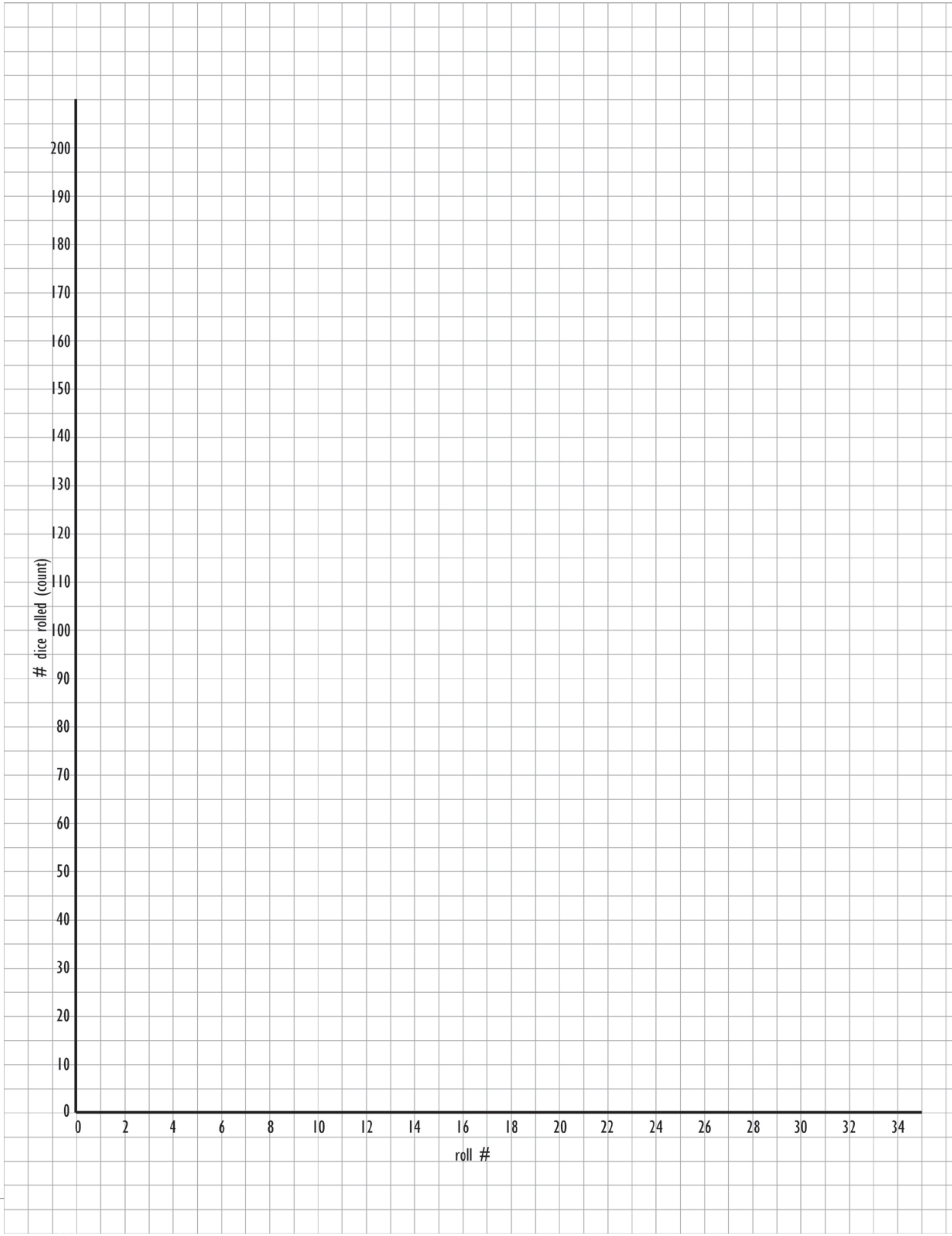
49		
50		

(4) Using the piece of graph paper provided, graph the results of the dice rolled (note that if there were more steps in the trial than allowed by the graph, you only have to graph as much as possible given the space on the graph). As determined ***from your graph***, what is the half-life ($t_{½}$) of the dice for this trial? Get your data from the graph, and show your measurements there, but show your work in calculating the half life here. (12 points)

(5) Given the half-life you determined above, what is the "decay constant" (**λ**) of the dice? (Use the formula for the decay constant **λ** provided above). (3 points)



dice rolled (count)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
roll #

(6) As you are probably aware, dice have a finite probability (the "odds") of getting any one particular face up after a roll, and this probability is a function of how many sides each die has. By having such easily calculated probabilities, dice are not great models for decaying atoms, despite the fact that the dice are otherwise good models (as detailed above). As it turns out, this probability is the "decay constant" (**λ**) of the dice—you can think of the decay constant of any unstable isotope as like the probability that any atom in a sample will decay.

(a) Given that each of your dice has six sides, theoretically, what then ***should*** the "decay constant" of the dice be? (2 points)

(b) Is this theoretical decay constant the same as your experimentally determined one from above (question #5)? (1 point)

(7) Given the theoretical decay constant you got in question #6, what is the theoretical (true) half life (**$t_{½}$**) of a six-sided die? Use the formula for **$t_{½}$** provided in the lecture and above. (2 points)

(8) Let's see how different your *experimental* half life is from the *theoretical* (true) half life—we'll do this as a percentage. To do this, use this formula:

$$\%\ error = \left(\frac{|experimental\ t_{½} - true\ t_{½}|}{experimental\ t_{½}}\right) \times 100$$

...where the vertical lines (|) mean "take the absolute value of" (that is, if the number you get for (experimental **$t_{½}$** – true **$t_{½}$**) is a negative number, drop the negative sign and use the number as if it were positive). (2 points)

(9) So now you have *two* values for the half life of the dice: the experimental value (from question 4) and the theoretical (true) value (from question #7). In all likelihood, they are not the same number, and may not even be very close (as you saw in question #8). ***Without changing the dice***, what one thing could you do in the future to obtain a value for the experimental half-life of the dice that is closer to the true half life value? (3 points)

Use the tables below to answer questions #10–13.

SELECT ISOTOPES USED IN RADIOMETRIC DATING IN GEOLOGY				
Name of Dating Type	**Parent Isotope (P)**	**Daughter Isotope (D)**	**Half-life ($t_{½}$)**	**Materials Dated**
samarium–neodymium dating	samarium-147 (^{147}Sm)	neodymium-143 (^{143}Nd)	106 billion yr	various minerals
rubidium–strontium dating	rubidium-87 (^{87}Rb)	strontium-87 (^{87}Sr)	49 billion yr	hornblende and feldspar
rhenium–osmium dating	rhenium-187 (^{187}Re)	osmium-187 (^{187}Os)	42 billion yr	iron- and sulfur-rich igneous minerals
uranium–lead dating	uranium-238 (^{238}U)	lead-206 (^{206}Pb)	4.5 billion yr	zircon
argon–argon dating	argon-40 (^{40}Ar)	argon-39 (^{39}Ar)	1.3 billion yr	sanidine (a feldspar)
uranium–lead dating	uranium-235 (^{235}U)	lead-207 (^{207}Pb)	704 million yr	zircon
carbon dating	carbon-14 (^{14}C)	nitrogen-14 (^{14}N)	5715 yr	any organic materials

DECAY PARAMETERS (FOR ALL ISOTOPES)			
% P	**% D**	**# Half-lives Elapsed**	**Age**
100.0	0.0	0	0
98.9	1.1	$^1/_{64}$	$t_{½}$ x 0.015
97.9	2.1	$^1/_{32}$	$t_{½}$ x 0.031
95.9	4.2	$^1/_{16}$	$t_{½}$ x 0.062
91.7	8.3	$^1/_{8}$	$t_{½}$ x 0.125
84.1	15.9	¼	$t_{½}$ x 0.250
70.7	29.3	½	$t_{½}$ x 0.500
50.0	50.0	1	$t_{½}$
35.4	64.6	1½	$t_{½}$ x 1.500
25.0	75.0	2	$t_{½}$ x 2.000
12.5	87.5	3	$t_{½}$ x 3.000
6.2	93.8	4	$t_{½}$ x 4.000
3.1	96.9	5	$t_{½}$ x 5.000
1.6	98.4	6	$t_{½}$ x 6.000
0.8	99.2	7	$t_{½}$ x 7.000
0.4	99.6	8	$t_{½}$ x 8.000

(10) A solidified lava flow containing zircon crystals is among strata exposed in an outcrop. Zircon crystals from this lava flow were dated using the ^{235}U–^{207}Pb method, which found a ratio of 71% ^{235}U to 29% ^{207}Pb atoms in the crystals.

(a) How many half-lives have elapsed for this pair of isotopes? (1 point)

(b) What is the age of the lava flow? ***Show your work for full credit.*** (3 points)

(11) The age of the Earth has been determined by dating isotopes, particularly ^{238}U and ^{206}Pb, in meteorites. Although not from Earth, these meteorites and Earth (as well as everything else in the Solar System) all formed at the same time. The oldest meteorites ever found contain nearly equal amounts of both ^{238}U and ^{206}Pb. How old, then, is the Earth? (2 points)

(12) All organisms on Earth take in carbon atoms throughout their lives. Some of these atoms are of ^{14}C. While alive, any atoms of ^{14}C (or any other isotope of carbon) in an organism's body are continually replenished. However, when an organism dies, no new ^{14}C is taken in, and the amount of ^{14}C in its body begins to decrease as it begins to decay to ^{14}N.

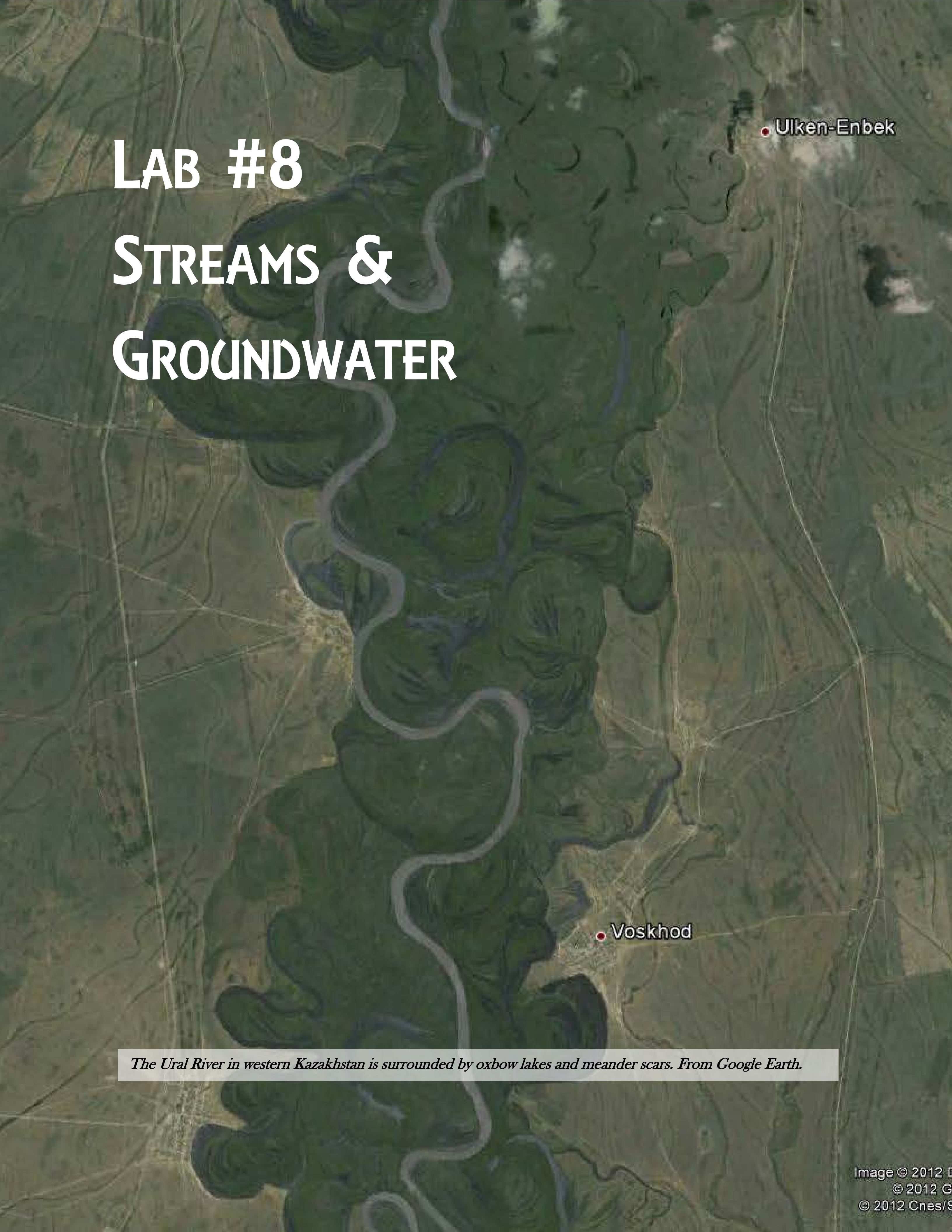
(a) A layer of peat (decaying plant matter that has not yet become coal) contains archeological artifacts of a past human habitation, and you are interested in figuring out how long ago the humans lived in this area. The peat has about 6% of the ^{14}C in modern organisms. How old, then, is the peat bed? ***Show your work for full credit.*** (3 points)

(b) When sampling the peat, you have to avoid including any pieces of an underlying limestone or of young, modern plant roots. Why? (Be specific—overly general answers will ***not*** receive credit!) (3 points)

(13) Zircon ($ZrSiO_4$) crystals form when many magmas and lavas solidify into igneous rock. Often, uranium atoms are incorporated into the crystal structure of the zircon crystals. Walking along a sandy beach somewhere, you note that some of the sand grains are weathered pieces of zircon crystals. If you radiometrically dated any of these grains that have uranium atoms in them, would it tell you the age of the beach on which you are walking? Why or why not? (3 points)

NOTES FOR GEOLOGIC TIME

Lab #8 Streams & Groundwater



The Ural River in western Kazakhstan is surrounded by oxbow lakes and meander scars. From Google Earth.

The purpose of this exercise is to give you some experience recognizing surface features created by streamflow and groundwater. Because (a) both of these are global phenomena, (b) they are uncommon in our vicinity and therefore difficult to see firsthand, and (c) seeing them well requires gaining a lot of altitude, you will instead use Google Earth to examine and explore several such features in various places around the world.

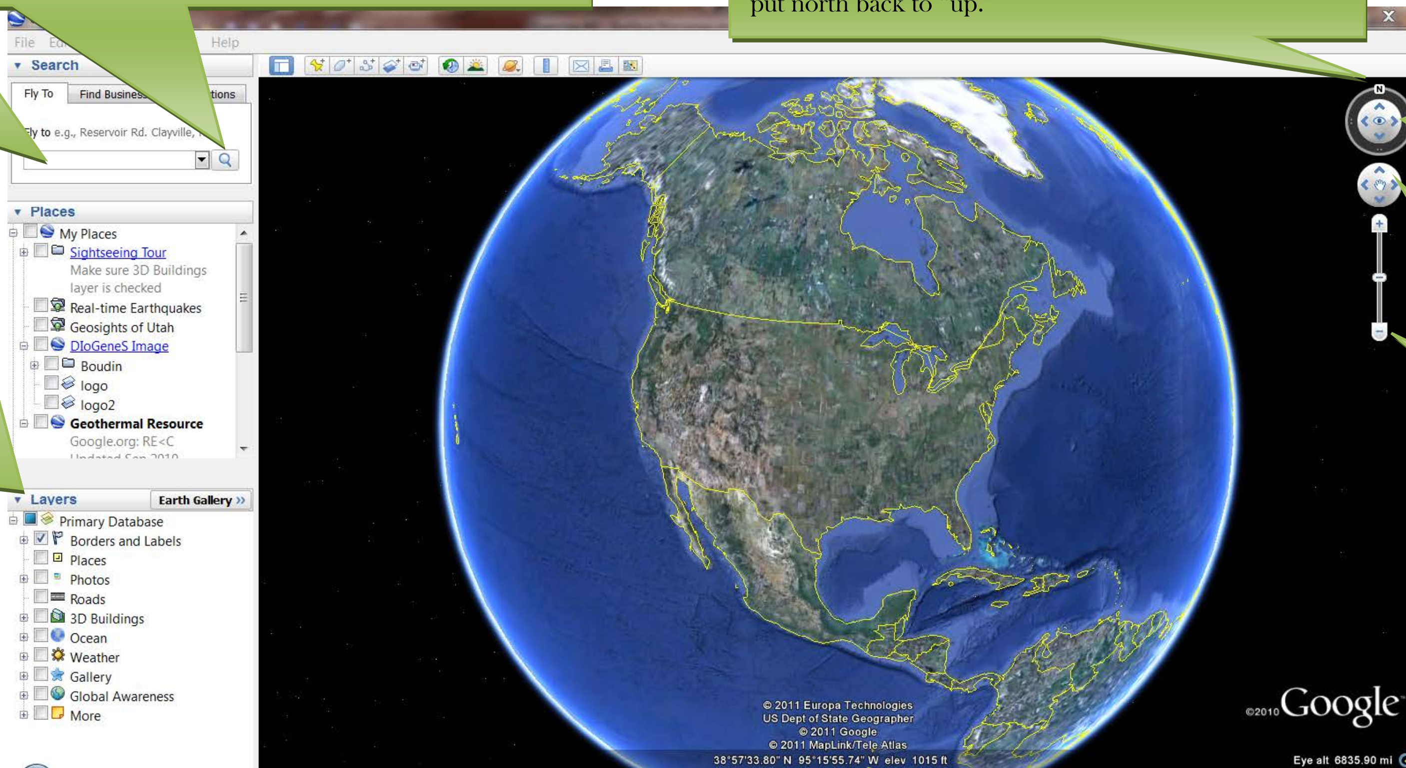
Key Learning Points:

- Recognizing various streamflow- and groundwater-created surface features.
- Using Google Earth as a tool to locate and examine specific places.

This exercise is worth 80 points; point values for each question are given at the end of each question.

For this exercise, you will be using the free, stand-alone (not web-based) program Google Earth to virtually "visit" various geographic locations around the planet in order to see and identify geological structures that were created by the surface processes of streamflow and groundwater. Google Earth uses a collection of satellite photos to depict the entire surface of the planet, much of it in 3D. You will need a computer (either PC or Mac); if Google Earth is not already installed on it, go to http://earth.google.com to download its installer; you will need to run that installer after it has downloaded. You will be doing part of the exercise in Microsoft Word, so your computer must have that installed as well (or another program into which you can paste pictures and label them).

In case you have never used Google Earth before, on the next page is a brief overview of its basic controls (the ones you will need for this exercise) and how to use them. ***Before doing this exercise, you should spend some time practicing with the different controls so that you know how to use them and know what they do—to answer some of the questions on this exercise, you will need to be able to use the controls in complex ways!*** Try, for example, finding your house, or Dixie State College. Fly deep into Grand Canyon and look up at its walls as if you were standing down in the Colorado River in its bottom.



In addition to these controls, here are some other useful things:

- You can zoom into any spot simply by double-clicking on it on the map (whether or not there is a label on it). Note that only in the continental United States is the resolution pretty high at low altitudes; elsewhere in the world will be blurry very close up.
- The cursor, when over the map, turns into a hand; you can click and hold the hand (which turns into a fist) and drag the view in any direction.
- If, when dragging a view, you let go while it's moving, it will "coast" on its own; just click anywhere in the picture to stop it.
- You need to know north, east, south, and west. Knowing what longitude and latitude are will be helpful, too.

IN ADDITION TO THE QUESTIONS IN THIS EXERCISE…

As part of this exercise, you will be copying some pictures from Google Earth into a Microsoft Word document; you will then print out and turn in this document ***in addition*** to the pages on which you answer the questions in this lab exercise. For this Microsoft Word document, do the following:

- Open Microsoft Word at the beginning of this exercise.
- After pasting pictures from Google Earth into Microsoft Word, you may have to shrink the pictures—**you will want to have two or three pictures per page** (to save paper). To do this:
  - Click on the picture in Microsoft Word—a series of white dots (handles) will appear at the corners and in the middle of the edges of the picture.
  - Click ***and hold*** on any of the corner handles, and drag toward the inner part of the picture to make it smaller. Release the handle by lifting your finger off the mouse button to keep it at its appropriate size. Please keep it at a size in which its contents are visible!
  - Once at an appropriate size, you can move the picture around the page.
  - Create labels for your pictures ***below*** the pictures themselves. You can do this by entering a bunch of carriage returns (pressing "Enter" or "Return" several times) until the cursor is below the picture; then type your label. There are other ways of doing this, too, and you are welcome to use them if you know them.
  - Please put a few extra carriage returns between your pictures!
- Save your document often, or else you may end up having to redo them all from scratch!

Name:____ Lab Section:__________________________

(1) (a) Enter the following coordinates[2] in the search box: 40°13'13.03"N, 96°43'44.95"E, and zoom to an eye altitude of about 120 mi. This is a great, very large example of a particular kind of sedimentary structure, which is on the north flank of the Qilian Mountains in Gansu Province, China. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "1a) Qilian." (2 points)

(b) What kind of structure is this? (1 point)

(c) What must the climate (***not*** environment!) in this part of China be like in order for this structure to have formed? (2 points)

(d) What other ***geological structures*** near these coordinates **(not including other examples of the kind of structure seen at the coordinates above**—you will have to **zoom out and move around** to see the larger picture) provide evidence of this year-round climate? If so, what is this evidence? Note that a lack of vegetation is ***not*** a geological structure! (2 points)

(e) From the "Edit" menu, choose "Copy Image" to copy a picture of your view of ***one*** such structure; then paste the copied image into your Microsoft Word document and label it: "1e) Other Evidence." (2 points)

(f) Now enter the following coordinates in the search box: 36°46'37.62"N, 114° 0'23.36"W, and zoom to an eye altitude of about 25,000 ft. You are looking at the small town of Scenic, Nevada, which is just outside of the larger city of Mesquite. Note the green riparian zone around the Virgin River north and west of town, and the green, tree-covered slopes of the Virgin Mountains to the south and east. The town of Scenic, however, sits on a vast, brown plain. Zoom back out to an eye altitude of about 50 mi.: now you can see that this brown plain extends along the entire northern slope of the Virgin Mountains. This brown plain is an example of several, overlapping structures of the type you identified in China above. What is the name of a conjoined series of these structures? (1 point)

(question continues on the next page)

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[2]To type a degree symbol on a Windows PC, hold down the "Alt" key and, on the keypad (**not** the numbers across the top of the keyboard!), type 0176. On a Mac, hold down the "Option" or "Alt" key and type 0.

(g) Knowing what kind of structure the town of Scenic is built on, would this be a good place to build a house? Why or why not? (**HINT:** think about why there are no trees on the brown plain!) (3 points)

(2) (a) In the Search box, type in "Burkes Bridge, Australia" and fly there. Just ***east*** of this town is a portion of the Murray River. Zoom in on a part of the river in this region (down to an eye altitude of about 26,000 ft. is good). From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "2a) Murray River." (2 points)

(b) What kind of river is this ***and*** what features do you see that tells you this? (3 points)

(c) On the picture you pasted in above, label (in Word if possible, or by hand after printing) the following structures (1 point each; 6 points total):

- ***Three*** examples of point bars.
- ***Three*** examples of cut banks.
- ***One*** oxbow lake ***or*** meander scar.
- ***Two*** places where, in the near future, the river is likely to cut off an old channel and form a new oxbow lake or meander scar.

(3) (a) Enter the following coordinates in the search box: 50°3'20.54"S, 72°6'0.31"W. Zoom in on a part of the river in this region (down to an eye altitude of about 32,000 ft. is good). You are looking at a portion of the La Leona River in Santa Cruz Province, Argentina. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "3a) La Leona River." (2 points)

(b) What kind of river is this ***and*** what features do you see that tells you this? (3 points)

(c) Rivers of this type are often associated with what climates (***not*** environments!) that have what ***two*** conditions? (1 point)

(d) What other ***geological structures*** (and the objects that created and occupy them) near these coordinates **(not including other examples of the kind of structure seen at the coordinates above**—you will have to **zoom out and move around** to see the larger picture) provide evidence of this year-round climate? Note that a lack of vegetation is ***not*** a geological structure! (2 points)

(e) From the "Edit" menu, choose "Copy Image" to copy a picture of your view of ***one*** such structure; then paste the copied image into your Microsoft Word document and label it: "3e) Other Evidence." (2 points)

(4) (a) Enter the following coordinates in the search box: 72°52'40.23"N, 126°24'29.42"E and zoom to an eye altitude of about 450 mi. You are on the northern border of Russia and looking at the place where the enormous Lena River empties into the Laptev Sea (which is part of the Arctic Ocean). From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "4a) Lena + Laptev." (2 points)

(b) What kind of sedimentary structure is present here? (1 point)

(question continues on the next page)

(c) What features can you see ***within*** this structure that provides evidence that this is the kind of structure you indicated above? (You may want to zoom in and look around more closely at this area to answer this question.) (2 points)

(d) From the "Edit" menu, choose "Copy Image" to copy a picture of such supporting evidence; then paste the copied image into your Microsoft Word document and label it: "4d) Supporting Evidence." (2 points)

(e) Label on the picture several specific examples of the kinds of features that tell you your answer for question #4c. (2 points)

(5) (a) In the Search box, type in "Winter Haven, Florida," and fly there. Zoom to an eye altitude of about 130 mi. You are in central Florida. Note the huge proliferation of roughly circular lakes in this vicinity. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "5a) Florida." (2 points)

(b) Over the course of your geology lectures, you will have learned about ***two*** possible geological processes that could have created the concentration of rounded depressions such as the ones you see in this area (which may or may not have water in them). What are the two processes ***and*** the names of the pock-marked terrains each one creates? (1 point each; 2 points total)

(c) Move, zoom, and/or pan around this area to get a better look at the larger surface feature structures of the area. Based on what you can (and, perhaps more importantly, what you can***not***) see, you should be able to rule out one of the two possible processes you listed in question #5c. What other features are present—or absent—here that help you rule one out? Note that you must also address the possibility of ***past*** processes existing in the area as well as ***present*** processes! (2 points)

(d) Having ruled one out, which one is more likely? (1 point)

(question continues on the next page)

(e) What kind of rock *must* be at and below the surface in this area? (1 point)

(f) What is the name for this kind of topography? (1 point)

(g) What has happened to this rock in this area to create these structures? Be specific and detailed—your answer should be more than a few words long! (4 points)

(6) (a) In the Search box, type in "Yangshuo, Guilin, China" and fly there. The small city of Yangshuo sits on the Li River in the northeastern part of Guangxi Province, southern China. This town is a hub for international tourism because of the highly unusual mountains in this area. Zoom to an eye altitude of about 40,000 ft. Describe in your own words the general shapes, layout, ***and*** distribution pattern of the mountains in this area that you can see in this view. (3 points)

(b) Pick a spot somewhere amid these mountains just outside of Yangshuo and zoom to a very low eye altitude, about 700 ft. (the picture will become very blurry as you do this, but hold on a minute!). Once at this low altitude, pan up so you have a more or less horizontal view—as if you were standing on the valley floor and looking up at the surrounding mountains. Pivot your view 360° and observe the individual mountains as you do so. Describe in your own words the (in general) shapes of the individual mountains you see in this area. (2 points)

(question continues on the next page)

(c) Stay at this altitude and at this view angle. Move around the area, moving up some of the valleys between peaks. Many of the peaks—called *fengcong* (as conical peaks with connected bases) and *fenglin* (as isolated, often cylindrical peaks)—in this area have bizarre, unusual shapes. Find one such mountain and, from the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "6c) Yangshuo." (2 points)

(d) This region is an extreme example of the phenomenon you saw in Florida in question #5. What type of rock *must* comprise these mountains? (1 point)

(e) As cool as Google Earth is for seeing things like this, it simply cannot do this popular tourist destination any justice compared to real photos. Perform a Google ***image*** search for "Yangshuo Mountains" and find a good photo of what these mountains really look like. Copy and paste that photo into your Microsoft Word document and label it: "6e) Real Yangshuo." (2 points)

(f) How do the shapes of these mountains as seen in the photo compare with how you described them in question 6b? (1 point)

(g) Given that these form in the same way as the features you saw in Florida in question #5 and from the same rock type, why do *fengcong* and *fenglin* look so radically different than what you saw in Florida? Two good sources of information on this are at http://www.speleogenesis.info/directory/karstbase/pdf/seka_pdf9840.pdf (especially see Fig. 19 on p. 10) and http://www.chinaspree.com/china-travel-guide/china-guizhou-guangxi-tours.html (see the second-to-last diagram near the bottom of the page). Note that the word "doline" used on some of these pages is another word for "sinkhole." (3 points)

(7) (a) Enter the following coordinates into the Search box: 54°28'16.68"N, 160°10'6.96"E, and fly there. You are on the Kamchatka Peninsula of remote northeastern Russia, in part of Siberia, very close to the Pacific Ocean. Zoom to an eye altitude of about 32,000 ft.—the view will be rather blurry. You are looking at the valley of the Geisernaya River, an area so remote that it was not systematically explored until the 1970s. This area is renowned for having a specific feature in it that in Russian is called Dolina Geiserov. Open a web browser and search for this name. What is the English name for this area? (1 point)

(b) Why is this area special? (2 points)

(c) Only one other place in the world has more of the features that make Dolina Geiserov special—where is that place? (1 point)

(d) The features that make Dolina Geiserov famous are created by what processes happening beneath the ground in this area? (2 points)

(e) This part of Kamchatka has many other structures created by the same larger processes that create the Dolina Geiserov. In Google Earth, pan up and move around the area to find one such structure that has a name. In the "Layers" menu in the lower left of the Google Earth Window is a "Borders and Labels" menu. Within that is a "Labels" submenu, and in that is a "Geographic Features" option. Check the box next to that, and green "mountain" symbols will appear on many of these structures at this location. Hover the cursor over any one to see the name, and click on it to see more information about the structure. From the "Edit" menu, choose "Copy Image" to copy a picture of your structure; then paste the copied image into your Microsoft Word document and label it: "7d) Kamchatka." (2 points)

(f) What is the name of this structure ***and*** what kind of structure is it? (2 points)

NOTES FOR STREAMS AND GROUNDWATER

Lab #9
Eolian and Glacial Environments and Mass Wasting

Giant sand dunes of the Kumtag Desert (part of the larger Taklamakan Desert) outside the city of Dunhuang in Gansu Province, western China. Dunhuang was a critical stop along the ancient Silk Road trade route. The famous Mogao Grottoes lie in the desert just outside the city. Photo by Jerry D. Harris.

The purpose of this exercise is to give you some experience recognizing surface features created by eolian and glacial processes and by some kinds of mass wasting events. Because (a) all of these are global phenomena, (b) many are uncommon in our vicinity and therefore difficult to see firsthand, and (c) seeing them well requires gaining a lot of altitude, you will instead use Google Earth to examine and explore several such features in various places around the world.

Key Learning Points:

- Recognizing various eolian features, glacial landforms, and mass-wasting-created surface features.
- Using Google Earth as a tool to locate and examine specific places.

This exercise is worth 75 points; point values for each question are given at the end of each question.

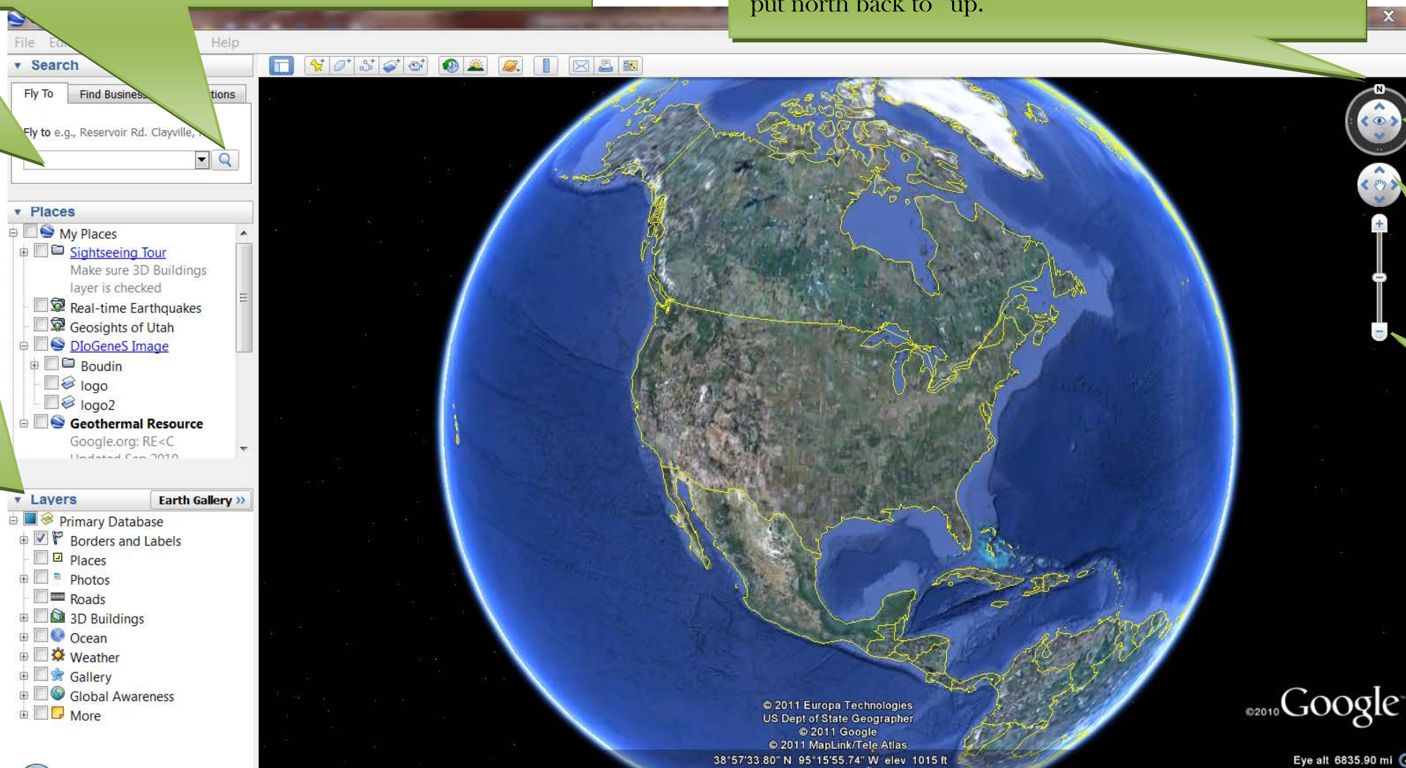
For this exercise, you will be using the free, stand-alone (not web-based) program Google Earth to virtually “visit” various geographic locations around the planet in order to see and identify geological structures that were created by the surface processes of streamflow and groundwater. Google Earth uses a collection of satellite photos to depict the entire surface of the planet, much of it in 3D. You will need a computer (either PC or Mac); if Google Earth is not already installed on it, go to http://earth.google.com to download its installer; you will need to run that installer after it has downloaded. You will be doing part of the exercise in Microsoft Word, so your computer must have that installed as well (or another program into which you can paste pictures and label them).

In case you have never used Google Earth before, on the next page is a brief overview of its basic controls (the ones you will need for this exercise) and how to use them. ***Before doing this exercise, you should spend some time practicing with the different controls so that you know how to use them and know what they do—to answer some of the questions on this exercise, you will need to be able to use the controls in complex ways!*** Try, for example, finding your house, or Dixie State College. Fly deep into Grand Canyon and look up at its walls as if you were standing down in the Colorado River in its bottom.

Fly—after entering text into the Search box, click this magnifying glass to fly to the location you entered.

Compass—you can grab the "N" and rotate it 360º to see things from different angles. Double click on the "N" to put north back to "up."

Search—type (or cut and paste) text, such as coordinates (latitude, longitude) or names of places into this box.



Pan—use the arrows in this circle to pan (tilt) or pivot your view in different ways.

Move—use the arrows in this circle to move north, east, south, or west.

Layers—use the check boxes in this window to turn on various features. For this exercise, the only one you will want checked will be Borders; having any others on will clutter up your view, though some of the Photos are very cool!

Zoom—use this slider bar to zoom in (+) or out (-).

Eye Altitude—this tells you how high you are above the surface you are looking at. (If this isn't showing, make sure "Status Bar" is checked in the "View" menu.

Coordinates—the latitude and longitude of the place you are looking at.

In addition to these controls, here are some other useful things:

- You can zoom into any spot simply by double-clicking on it on the map (whether or not there is a label on it). Note that only in the continental United States is the resolution pretty high at low altitudes; elsewhere in the world will be blurry very close up.
- The cursor, when over the map, turns into a hand; you can click and hold the hand (which turns into a fist) and drag the view in any direction.
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- You need to know north, east, south, and west. Knowing what longitude and latitude are will be helpful, too.

IN ADDITION TO THE QUESTIONS IN THIS EXERCISE…

As part of this exercise, you will be copying some pictures from Google Earth into a Microsoft Word document; you will then print out and turn in this document ***in addition*** to the pages on which you answer the questions in this lab exercise. For this Microsoft Word document, do the following:

- Open Microsoft Word at the beginning of this exercise.
- After pasting pictures from Google Earth into Microsoft Word, you may have to shrink the pictures—**you will want to have two or three pictures per page** (to save paper). To do this:
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    - Once at an appropriate size, you can move the picture around the page.
    - Create labels for your pictures ***below*** the pictures themselves. You can do this by entering a bunch of carriage returns (pressing "Enter" or "Return" several times) until the cursor is below the picture; then type your label. There are other ways of doing this, too, and you are welcome to use them if you know them.
    - Please put a few extra carriage returns between your pictures!
- Save your document often, or else you may end up having to redo it from scratch!

Name:____ Lab Section:_____________________________

(1) (a) In the search box, type "Hellesylt, Norway" and fly there. Zoom to an elevation of about 12 mi. This village sits on the southwestern edge of a long, watery geological structure, which is the subject of this question. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "1a) Hellesylt." (2 points)

(b) There are several lines of evidence that indicate what this structure is. One of these is the latitude of this area. Is the latitude high or low? (1 point)

(c) What, therefore, would you expect the climate in this area to be? (1 point)

(d) Pick a point inside this structure just a little northeast of Hellesylt, slightly past the fork. **Zoom in** to an eye altitude of about 500 ft. so that you are basically sitting deep inside this structure. **Pan around** so that you are **looking northeast** (away from Hellesylt)**, *along*** the long structure. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "1d) Hellesylt Structure." (2 points)

(e) Another indicator of what this structure is its cross-sectional shape. What is this characteristic shape? (1 point)

(f) What is the name of this kind of structure, ***and*** what created it but is no longer present here? (2 points)

(question continues on the next page)

(g) **Zoom way out** from Hellesylt to an eye altitude of about 60 mi. Move directly to the east (the best way is to use the right arrow key on the keyboard). You are now entering Sweden. Once you get out of the mountainous area, you'll pass an area with a few rows of small, fluffy clouds. East of this, notice that there are many, many lakes in this area. Based on the evidence you saw for the structure at Hellesylt, and based on what you know must have created it, what kinds of lakes must these therefore be? (1 point)

(h) From the "Edit" menu, choose "Copy Image" to copy a picture of your view of these lakes; then paste the copied image into your Microsoft Word document and label it: "1h) Finland." (2 points)

(2) (a) Enter the following coordinates[3] in the search box: 53°56'6.81"N, 128°16'54.84"W, and fly there. Zoom to an eye altitude of about 20 mi. You in the Canadian Rocky Mountains in British Columbia; these coordinates lie in a valley bordered on the north by Cobalt Peak (among others). From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "2a) British Columbia." (2 points)

(b) The series of long, parallel features on the south side of the valley are interesting. **Zoom way in** to an eye altitude of about 13,000 ft. and rotate your view so that the valley runs straight up and down in your view and north is off to the left. Now **zoom in even farther**, down to an eye altitude of about 5000 ft. Now you are well within the valley. **Pan up and rotate your view** so you can look at the side valleys on the ***south*** side of the main valley (now on your right). These side valleys are examples of a specific kind of valley. What kinds of valleys are these? (2 points)

(c) From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "2c) Side Valleys." (2 points)

(question continues on the next page)

[3] To type a degree symbol on a Windows PC, hold down the "Alt" key and, on the keypad (**not** the numbers across the top of the keyboard!), type 0176. On a Mac, hold down the "Option" or "Alt" key and type 0.

(d) Now move up one of these side valleys until you reach its head. **Pan you view downward** so it is at an angle to the ground surface (but not vertical), and **zoom out a little bit** to get a better view of the head of the valley. What kinds of features are at the heads of these side valleys? (1 point)

(e) From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "2e) Valley Head." (2 points)

(f) What are the ridges that separate these side valleys from one another? (1 point)

(3) (a) Enter the following coordinates in the search box: 35°52'53.91"N, 76°30'46.22"E and fly there. Zoom to an eye altitude of about 11 mi. You are on a particular mountain in the Karakoram Mountain range (part of the Himalayas) the border between Pakistan and China. **Zoom in alongside (*__not on!!__*) the mountain** to an eye elevation of about 28,000 ft., **and then pan up** so you can look at it from the side in a more horizontal view. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "3a) Karakoram." (2 points)

(b) **Pan and move** around the mountain to view it from several different sides (that is, see many different sides of this mountain). From the "Edit" menu, choose "Copy Image" to copy a picture of an angle you find particularly interesting or appealing (different from your first one); then paste the copied image into your Microsoft Word document and label it: "3b) Mountain." (2 points)

(c) Based on its shape, what kind of mountain is this? (1 point):

(d) What other ***__geological__*** evidence in the vicinity of this mountain is there that supports your interpretation in question #3c? (1 point)

(question continues on the next page)

(e) This particular mountain is special for a good reason. In the "Layers" menu in the lower left of the Google Earth Window is a "Borders and Labels" menu. Within that is a "Labels" submenu, and in that is a "Geographic Features" option. Check the box next to that, and a green "mountain" symbol will appear on the mountain at this location. Hover the cursor over it to see the name of this mountain; you can also click on it to see more information. What is the mountain's name ***and*** why is this mountain special? (2 points)

Turn off (uncheck) the "Geographic Features" and "Labels" function after you have answered this question.

(4) (a) Enter the following coordinates in the search box: 24°21'43.24"S, 15°7'29.12"E and fly there. Zoom to an eye altitude of about 130 mi. You are in Namibia, which is in southwestern Africa. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "4a) Namibia." (2 points)

(b) **Zoom in farther**, down to an eye altitude of 2500 ft. or less, and **pan around** to get a more horizontal view. What features are you seeing in this region? (1 point)

(c) What force created these features? (1 point)

(d) What is the name for the kind of environment dominated by this force? (1 point)

(e) What must the climate be in this area? (1 point)

(question continues on the next page)

(f) From the “Edit” menu, choose “Copy Image” to copy a picture of some of these features in your close-up view; then paste the copied image into your Microsoft Word document and label it: “4f) Namibia Close-up.” (2 points)

(5) (a) Enter the following coordinates in the search box: 50°38'31.48"N, 1°26'20.95"W and fly there. Zoom to a low eye altitude of about 900 ft. You are looking at a portion of the southern coastline of the Isle of Wight, England. From the “Edit” menu, choose “Copy Image” to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: “5a) Isle of Wight.” (2 points)

(b) The cliffs at this location are weathering relatively rapidly, and a particular kind of mass wasting event can be easily seen here—what kind is it? (1 point)

(c) What characteristics do the cliffs here exhibit that tell you what kind of mass wasting event this is? (1 point)

(d) **Zoom in and/or pan around** to get a good view of these features (the 3D is not good at this location), then, from the “Edit” menu, choose “Copy Image” to copy a picture showing these characteristics into your Microsoft Word document and label it “5d) Mass Wasting.” Put in arrows pointing to ***three*** specific examples of this kind of mass wasting in progress (5 points)

(6) (a) Enter the following coordinates in the search box: 38°5'35.70"N, 119°26'44.57"W and fly there. Zoom to an eye altitude of about 21,000 ft. You are in Yosemite National Park, in the Sierra Nevada Mountains of California. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "6a) Yosemite." (2 points)

(b) On the east flank of this mountain is a light-grayish area that marks the site of a particular kind of mass wasting event. **Zoom in close on** this feature to get a better idea of what materials make up the wasted event. What kind of mass wasting event has occurred (and is still occurring!) here? (1 point)

(c) From the "Edit" menu, choose "Copy Image" to copy a picture of your close-up view; then paste the copied image into your Microsoft Word document and label it: "5c) Mass Wasting" (at low altitude, it will be a bit blurry). (2 points)

(d) What characteristics can you see here that tell you what kind of mass wasting event this was? (2 points)

(7) (a) In the search box, type "Nova Friburgo, Brazil" and fly there. Zoom in to an elevation of about 12,000 ft. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "7a) Brazil." (2 points)

(b) At the northern end of this town, where it narrows into a valley, are several brownish scars on the sides of the surrounding hills that were created during several examples of a particular kind of mass wasting event. **Zoom in close on** one or more of these to get a better idea of what materials make up the wasted events. What kind of mass wasting events occurred here? (1 point)

(question continues on the next page)

(c) From the "Edit" menu, choose "Copy Image" to copy a picture of your close-up view; then paste the copied image into your Microsoft Word document and label it: "7c) Mass Wasting" (at low altitude, it will be a bit blurry). (2 points)

(d) What characteristics can you see here that tell you what kind of mass wasting event this was? (2 points)

(8) (a) Enter the following coordinates in the search box: 51°24'16.89"N, 1°58'9.96"W and fly there. Zoom to an eye altitude of about 1900 ft. You are near the picturesque hamlet of Calstone Wellington in Wiltshire, England. Notice that the hillsides in this area all have a rippled appearance. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "8a) Wiltshire." (2 points)

(b) Note that you are fairly far north here—is the latitude of this area high or low? (1 point)

(c) What, then, would you expect the average annual temperature to be in this area? (1 point)

(d) Given this, zoom in and pan around, looking more closely at the "rippled" areas (it may help to zoom in to near ground level and look up at them as if you were standing below the hills). Do the orientations of the ripples share anything in common—that is, do they all point in a common general direction ***with respect to the surrounding elevations and features***? If so, what is this common orientation? (2 points)

(question continues on the next page)

(e) This rippling is actually an example of a type of slow mass wasting event involving the soil at the surfaces of the hills in this area. What is the name of this kind of mass wasting ***event*** (***not*** the name of the process)? (1 point)

(f) What causes this kind of mass wasting event? (1 point)

(9) (a) Examine the funky rocks in the photographs below:

Photo credits *(clockwise from upper left):* *http://farm1.static.flickr.com/211/452042967_10fa70673a.jpg, http://images.publicradio.org/content/2009/01/29/20090129_antarctica_2_040_33.jpg, http://3.bp.blogspot.com/_1CweQZAAl2o/TPjAAgRV0dI/AAAAAAAABUk/_q6YqQfh5aU/s1600/P1020118.JPG, and http://lh6.ggpht.com/-rUQLX4zZPdc/T9CHDItJzxI/AAAAAAAAYhY/4rtlR3fE4Wk/McMurdo-dry-valleys-9%25255B6%25255D.jpg.*

All of these photographs were taken in the vicinity of the following coordinates: 77°28′0″S, 162°31′0″E. Enter these coordinates into the "Search" box and fly there. Zoom to an eye altitude of about 130 mi. You are on the floor of the Dry Valleys area of McMurdo, Antarctica, one of the few non-glaciated places on the entire continent. From the "Edit" menu, choose "Copy Image" to copy a picture of your view; then paste the copied image into your Microsoft Word document and label it: "9a) Antarctica." (Sadly, the resolution of the satellite photos in this area is not good enough to allow you to zoom in and see rocks like these in the area.) (2 points)

(b) Although the valley you are in was doubtlessly glaciated at points in the past, these rocks were not shaped by glaciers. What force was responsible for sculpting these rocks? (1 point)

(c) What is the name of the process that produced the shapes of these rocks? (1 point)

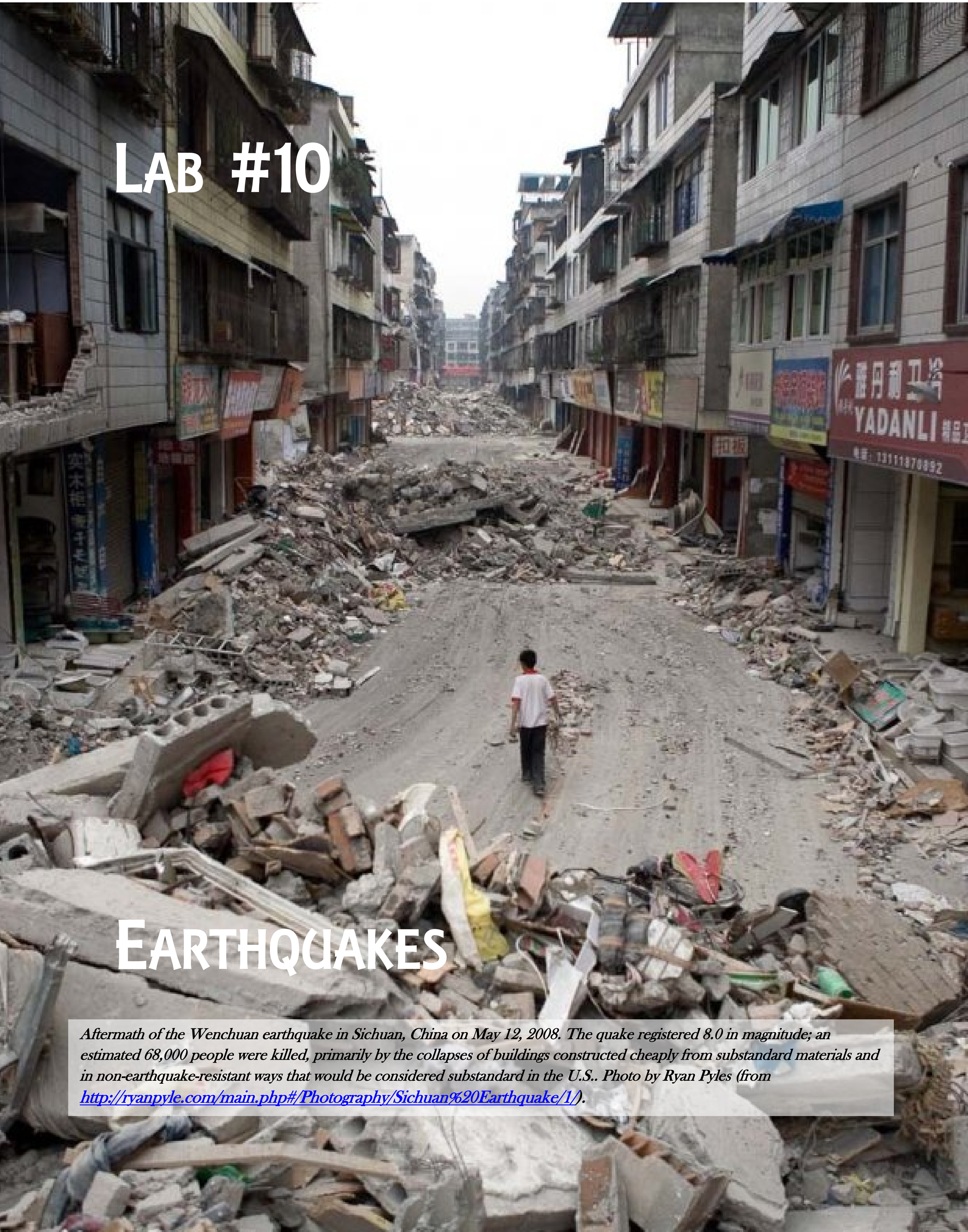
(d) What is evidence ***on the rocks themselves*** that the rocks were not shaped by glaciers? (2 points)

(e) What kind of environment must this region of Antarctica have, in addition to glaciated? (1 point)

NOTES FOR EOLIAN AND GLACIAL ENVIRONMENTS AND MASS WASTING

Lab #10

Earthquakes



Aftermath of the Wenchuan earthquake in Sichuan, China on May 12, 2008. The quake registered 8.0 in magnitude; an estimated 68,000 people were killed, primarily by the collapses of buildings constructed cheaply from substandard materials and in non-earthquake-resistant ways that would be considered substandard in the U.S.. Photo by Ryan Pyles (from http://ryanpyle.com/main.php#/Photography/Sichuan%20Earthquake/1/).

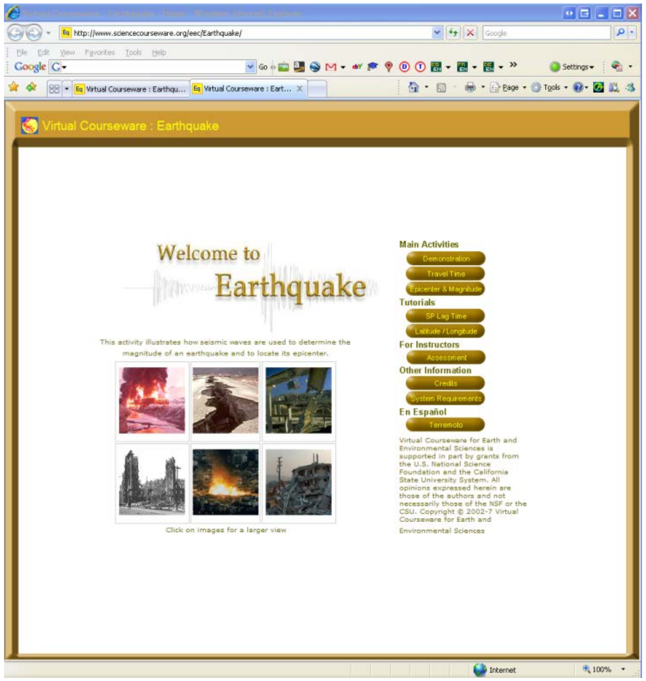
The purpose of this exercise is to provide you with experience in determining information about an earthquake after it has happened. You will be using computer simulations of earthquakes and seismic waves to, in essence, behave as a geophysicist that has to determine basic information about the quake.

Key Learning Points:

- Understanding seismic-wave travel times and S–P lag times.
- Determining the position of the epicenter of an earthquake using multiple seismographs.
- Determining the magnitude of an earthquake.

This exercise is worth 70 points; point values for each question are given at the end of each question.

For this exercise, you will need a computer that is hooked up to a printer (color is great, but not necessary). You will be doing a web-based exercise, so you will need a web browser program. For some reason, Google Chrome does not seem to like this exercise, so please use either Internet Explorer or (preferably) Firefox. If your browser uses a pop-up blocker, ***please either turn it off before you begin or be sure that the URL below is listed as an exception to blocking pop-ups***—the exercise site uses pop-ups. I highly recommend having ***no*** other windows open on your computer as you do this—pop-up windows can be easily lost in a pile!



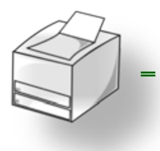
The activities you will do are accessed at http://www.sciencecourseware.org/eec/Earthquake. Its introductory screen is shown at left. At this site, you will do ***three*** things (in this order):

• Do an exercise to determine the travel time of an earthquake to various seismographs;

• Do an exercise to determine the position of the epicenter of an earthquake and its magnitude; and

• Take a short (10 question) quiz on these topics.

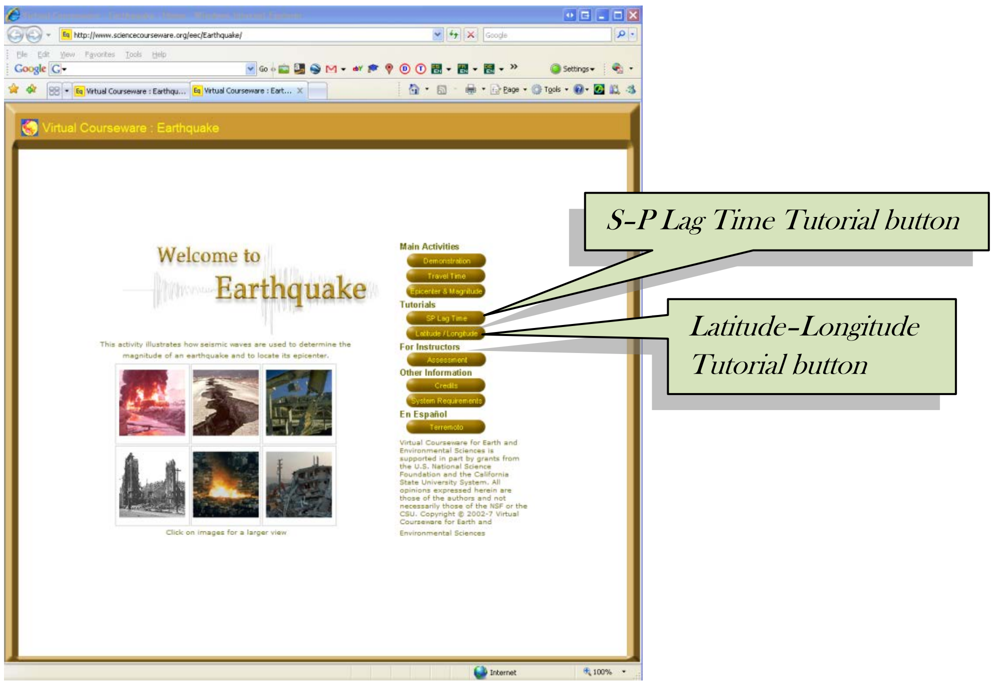
All work for this exercise will be done ***on-line***, and you will need to print and hand in your work and results in order to get credit for this exercise. ***DO NOT*** **hand in the pages from this book**; they are ***only*** to help guide you through how to do the online exercises. Below, you will be instructed on how and what to print out and hand in to get credit for this exercise. Watch for the big printer icon—that will be your cue that something needs to be printed.

 **= TIME TO PRINT SOMETHING!**

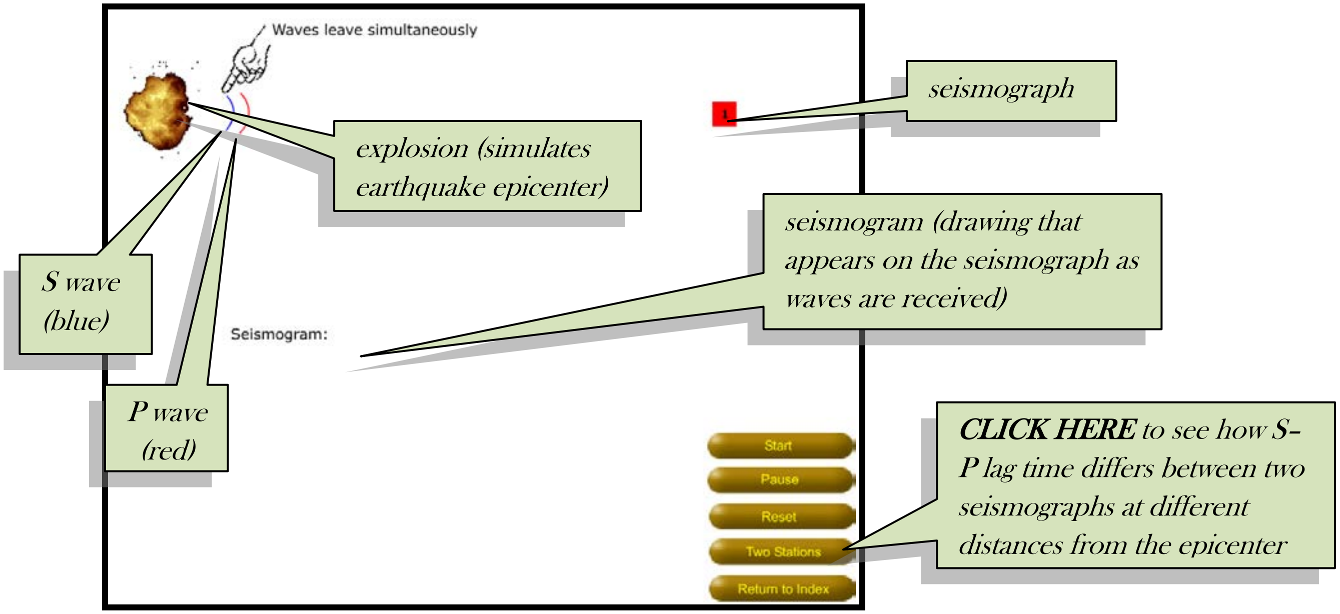
NOTE: Because this exercise uses Java, you may see some unexpected things on the screen. Most prominently, when you hover the cursor over a button (or field of buttons), you may see the region outlined, and a little box will pop up that says something like "Click to activate and use this control." Do just that—click ***once*** anywhere in the outlined field, and then the buttons will work as you would expect.

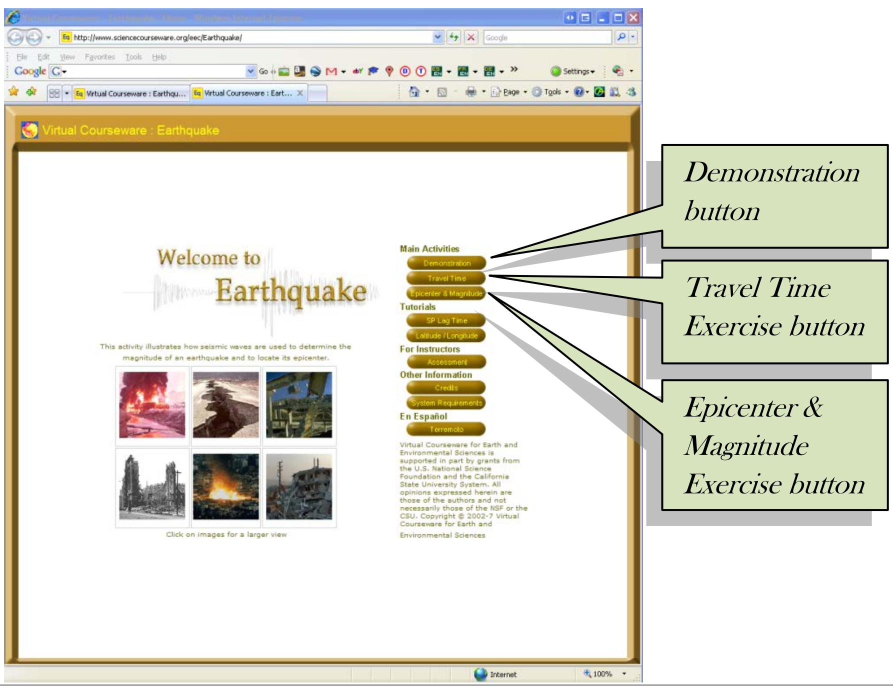
EARTHQUAKE TRAVEL TIME EXERCISE

The purpose of this exercise is to use the lag time between the arrivals of P waves and S waves at a seismograph in order to figure out where the epicenter of an earthquake was—remember that P waves travel 1.7 times as fast as S waves, so at any seismograph, P waves will be received first and S waves second; the difference between when these waves are received is called the **S–P lag time.** To review this concept, it will be well worth your while to do the "S–P lag Time" Tutorial available at the site—it will only take you a few minutes.



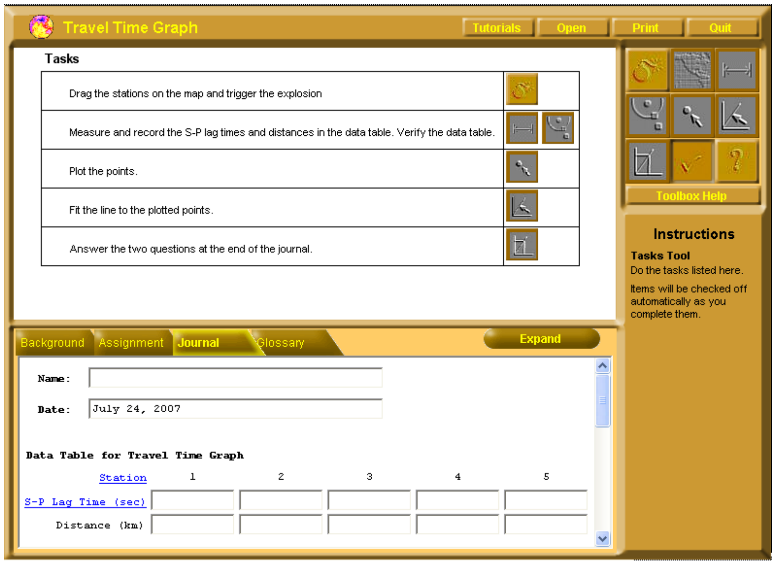
Here's what the tutorial will look like (once you click the "Start" button):





Run through the site's Demonstration of this exercise before you begin—it will walk you through how the site works. You can access this Demonstration by clicking on the "Demonstration" button on the introductory screen. When you are ready to do the exercise, click on the "Travel Time" button.

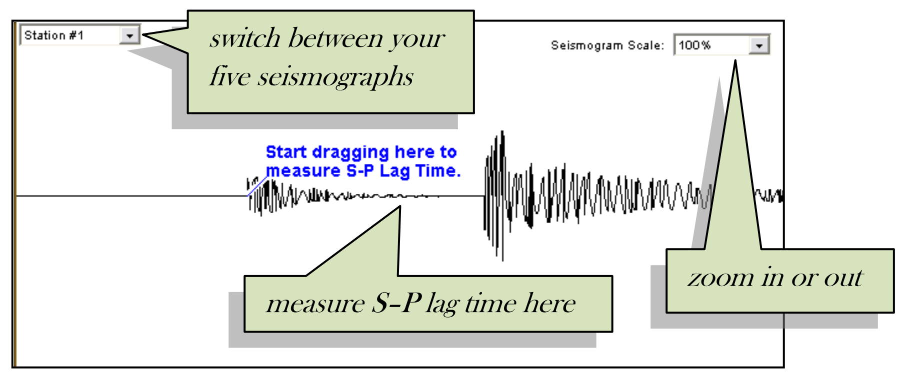
Once you click on the "Time Travel" button, a pop-up window will appear (if it does not, make sure your pop-up blocker is turned off!). Click on the "Start" button in this window to begin the exercise, and this is what you will see:



STEP 1: Put your name in the Name field (you will have to click in the blank box to put the cursor there).

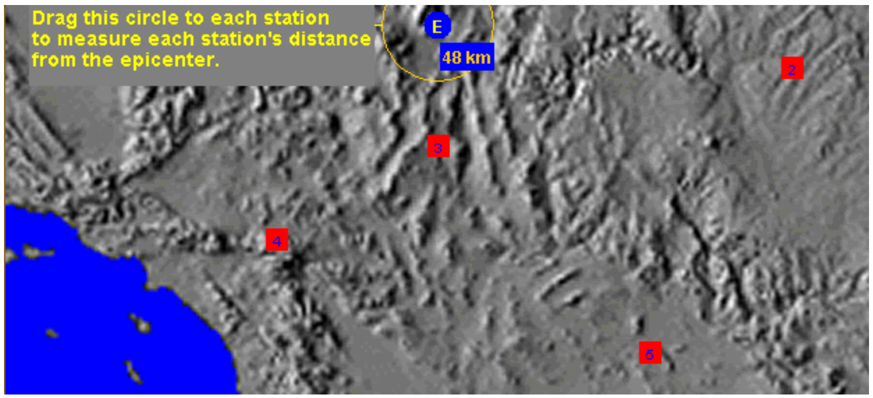
STEP 2: Note the "Tasks" box that dominates the top of the window; the bottom part of the window, where you will record your data, is the Journal area. Items highlighted in gold are things you have to do, and you'll do them in the order presented. Hovering the cursor over a gold-highlighted button tells you what the button does. Click on the gold highlighted button to perform that task. (Note the matching icons in the upper right—you can go back to any part of the activity by clicking on the appropriate button.) Also note the empty data fields for "S–P Lag Time" and "Distance" at the bottom—you will fill these in as you go through the exercise. Click on the "Move Stations" button.

STEP 3: An aerial photo appears at the top of the window. The numbered, red boxes in the lower left—these are your seismographs. The blue circle with the "E" at the top is where the earthquake epicenter will be. Use the mouse to drag your **five** seismographs (red squares) to different positions on the photo—they should all be in very different, widely separated positions from each other **and** different distances from the epicenter; don't cluster any of them near each other. Once they are in the positions you want, click on the "Trigger Explosion" button in the upper right to create the earthquake. Once the quake is over, you will return to the Tasks list.



STEP 4: Now you have to measure and record the S–P lag times and distances to fill in the data fields at the bottom. Click first on the "S–P button. You will see the seismogram recorded at your first seismograph station (the number in upper left). If the squiggles you see are either really small or really big, change the zoom (scale) using the pull-down menu in the upper right. Use the mouse to drag from the indicated point (at the reception of the first P wave) to the reception point of the first S wave. This will highlight the distance between the two in red; the time (in seconds) is given at the lower right corner of the red box that appears as you do this. Enter this time in the datum field at the bottom of the window. **Repeat this for the other four seismograms.**

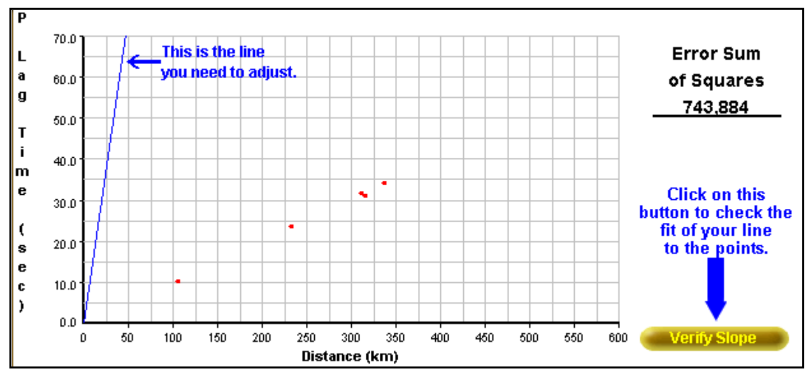
STEP 5: Click on the "Distance" button in the cluster of buttons in the upper right. This returns you to the aerial photo and layout of your seismographs. For each seismograph, use the mouse to drag the orange circle so that part of the circle goes through the middle of each of your numbered stations. As you do this, the distance from your station to the epicenter ("E") appears next to your cursor—this is the radius of the circle you are drawing. Record this datum in the appropriate fields at the bottom of the window for each of the five seismographs.



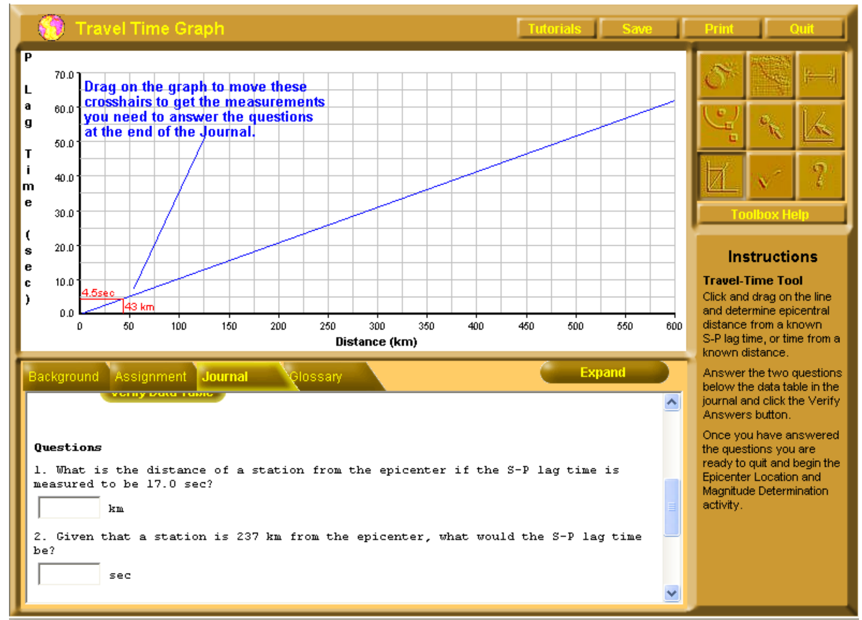
STEP 6: Notice that the Journal field has a scroll bar. Once you have filled out all the fields, scroll down a little bit to reveal a "Verify Data Table" button. Click this to see if your data are accurate. If they are, click "OK" in the box that pops up to tell you so and return to the Tasks list; if not, go back and adjust your data as needed and repeat this step.

STEP 7: Now you will create a graph of your data. Click on the "Point Plotter" button. The top of the window turns into a graph. At the right of the graph is a table of your data; each seismograph is represented by a red dot. Use the mouse to drag each dot to its appropriate place on the graph. When you place the last dot, a button will appear asking you to verify if your placement is accurate. Click this; if your points are correct, click "OK" to return to the Tasks list and go to Step 8. If not, readjust your dots as needed and re-verify.

STEP 8: Now you have to fit a line to a graph of your S–P lag times. Click on the "Fit Line" button. In the graph part of the window that appears, drag the blue line so it makes the best possible fit to all the dots. When you are done, click on the "Verify Slope" button. This may tell you to adjust your line to a better fit; when your fit is acceptable, click "OK" in the pop-up window that appears and return to the Tasks list.



STEP 9: There are two questions to answer below your data fields in the Journal area; scroll down to them. Then click on the "Travel-Time" button to reveal another graph that you will need to answer the two questions. On the graph, you can use the mouse to drag the red lines up and down the blue line to get the answers you need. (The questions and answers will be different for everyone!) After you have entered your answers in the blank boxes, scroll down to and click on the "Verify Answers" button. If your answers are good, click "OK" in the pop-up window that appears.



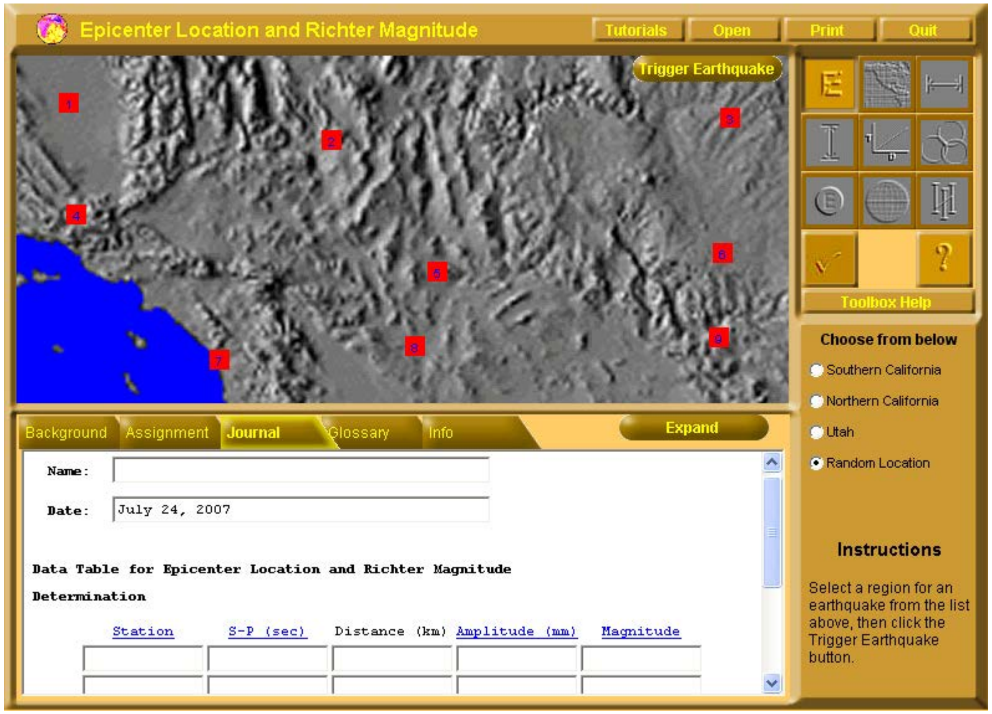
STEP 10: Now you will need to print your answers as part of what you will hand in for this exercise. Click the "Print" button in the upper right of the window. A pop-up will ask you what you want to print. **You will need to hand in print-outs of your Map *and* your Journal (the data fields).** Note that it will tell you to **print the map in "Landscape" format**, so in the Printer dialog box that appears, ***be sure to tell your printer to do this*** (how to do this depends on the printer; if there's no option in the main dialog box, click on the "Properties" button in it; it's probably in there).

STEP 11: Click "Quit" in the upper right to close this window and return to the main window. Don't worry about saving the data unless you want to (as a backup or to print somewhere else).

EPICENTER & MAGNITUDE EXERCISE

In this exercise, you will determine the position of an earthquake's epicenter and the magnitude of the quake on the Richter scale (which has not actually been used as a means of measuring earthquake magnitudes since the 1970s…but it's the process that's important because the scale that *is* used now uses a similar process). Part of this exercise will involve reading latitude and longitude from a map; if you are not familiar with how to do this, do the short "Latitude/Longitude" Tutorial available via a button on the main screen; you might also benefit from visiting http://geography.about.com/cs/latitudelongitude/a/latlong.htm or http://www.phy6.org/stargaze/Slatlong.htm—you'll probably want to open this in a new window or tab so you don't lose all your work!). When you are ready to begin the exercise, click on the "Epicenter & Magnitude" button in the main screen. An introductory screen will appear; in it, click "Start Activity."

STEP 1: As before, a pop-up window will appear in which you will do the exercise; its layout is similar to the one for the S–P lag time part of the exercise. Put your name in the Name field near the bottom.



STEP 2: Click on the "Choose an earthquake" button. In the resultant screen, notice that in the "Instructions" box in the lower right you can choose from one of three locations: southern California, northern California, and Utah; you can also choose a random location. Any of these will do. The aerial photo you get will appear in the top of the window, along with several numbered (red boxes) seismographs.

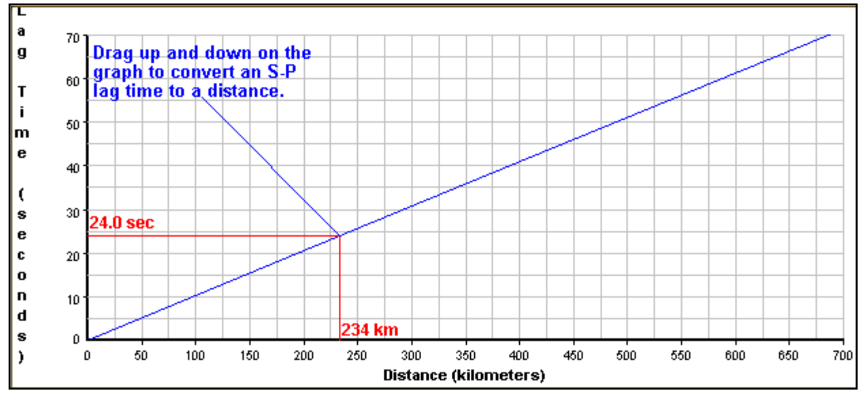
STEP 3: Click the "Trigger Earthquake" button at the top. Once the quake is over, the window will return to its Tasks list.

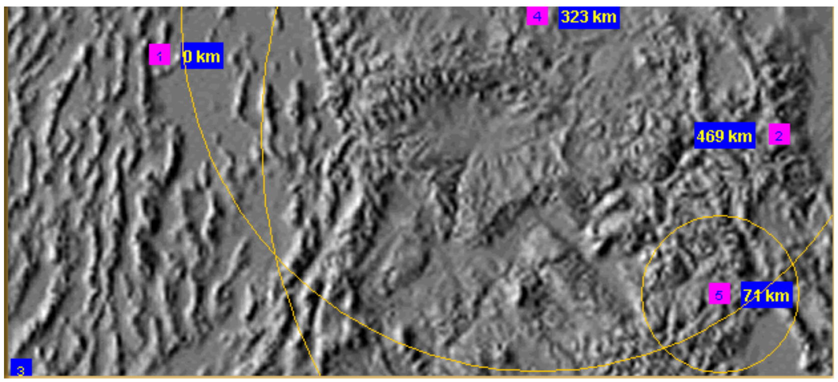
STEP 4: Click the first of the two "Measure S–P lag times and Amplitudes" buttons (the one with the horizontal bar in it). The screen that appears is similar to the one you saw in Step 4 of the last part of the exercise, and it works the same way. The only difference is that now, in your data fields at the bottom, there's only room for data from three seismographs, so you can pick whichever ones you want from the pull-down menu in the upper left. (The zoom menu may also be helpful here, too.) Be sure to record the station number along with your data!

STEP 5: When you are done with Step 4, click on the vertical bar button (below the "E" button) in the button collection in the upper right. The seismogram window will change somewhat; here you will measure the amplitude of your seismogram. The amplitude is the height of the waves recorded on the seismogram. Use the mouse to drag the red measuring bar up or down to the highest point (the strongest wave)—it measures from the midline to that peak in millimeters. Record this datum for each of the ***same*** three seismographs you used in Step 4. **NOTE:** for some seismograms, even the lowest zoom value won't allow you to see the peaks; if this happens, the exercise will tell you so and ask you to pick a different station. If you have to do this, you will also have to go back and change the S–P lag time number to match the new station (click on the horizontal bar button in the upper right to do this).

STEP 6: Now you will need to find the distances of each of your three seismographs to the quake epicenter. Click on the "Travel-Time" button (the one with the L-shaped graph) in the upper right. This will make a graph appear in the top of the window. It works the same way the one in Step 9 of the previous part of the exercise did: drag the red measuring bars up and down the blue line to get the distances (in km) that correspond to your S–P lag times. Record these data for your three seismographs.

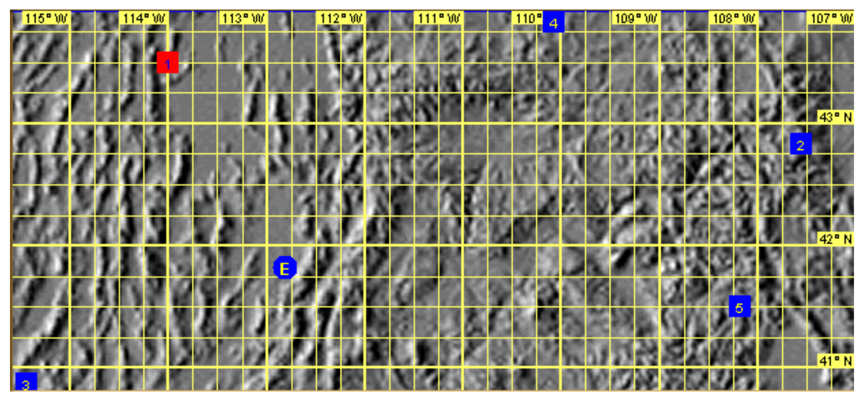
STEP 7: Now you will make a map of the **epicentral circles** for each of your stations. An epicentral circle is a circle drawn around a seismograph (which is at the center) and whose radius equals the distance to the epicenter of the quake. Click on the "Epicentral Circle" button in the upper right (the one with three overlapping circles on it). This returns you to your aerial photo, and tells you to drag the orange circles out to the distances you recorded in the previous step. **Be sure that you do this for the *same* three stations for which you got your data!** (Ignore the other stations.) When you are done, all three circles should overlap at one common point—this point is the epicenter of the earthquake.



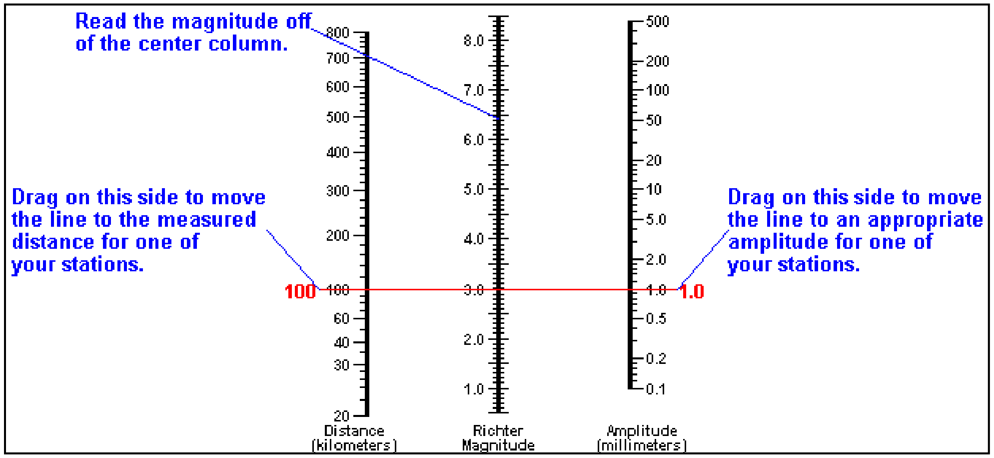


STEP 8: Now you need to figure out the position of the epicenter. Click on the "Locate Epicenter" button (the one with the small "E" in a circle) in the upper right. You will still have your aerial photo and epicentral circles up, but now there is an "E" in a blue circle that you must drag to the epicenter.

STEP 9: To figure out the position of the epicenter, click on the "Latitude/Longitude" button (the globe in the bottom center of the button field in the upper right). Again, you still have your aerial photo, but now it is overlain by latitude and longitude lines. Using this, estimate the position of your epicenter and record this datum in the appropriate blanks in the bottom of the window (you may have to scroll down to see these fields) in degrees (°)* and minutes (′). Note that the divisions used in this map are in quarters of a degree; recall that a degree can be divided into 60 minutes. **Don't forget to note N, S, E, or W!**



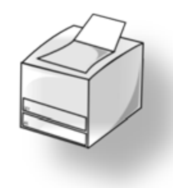
*To type a degree symbol on a Windows PC, hold down the "Alt" key and, on the keypad (<u>not</u> the numbers across the top of the keyboard!), type 0176. On a Mac, hold down the "Option" or "Alt" key and type 0.



STEP 10: Lastly, it is time to figure out the magnitude of your earthquake on the Richter scale (which, recall, is no longer used—however, the procedure for determining the magnitude is the same in the moment magnitude scale!). To do this, you will use a chart called a **nomogram** that uses your distance and amplitude data to determine the magnitude of the quake. Click on the "Magnitude" button in the upper right (the one with three offset vertical bars). The nomogram you see at left will appear. Drag the red lines **on both sides** to the appropriate positions for the data from **each** of your three seismographs. Note that as you do this, numbers in red at the ends of each line change to show you the exact value on the graph that the line is sitting on. Once the distance and amplitude lines are in position, you can see where the red line crosses the Richter Magnitude graph in the middle. Record the magnitude for each one in the appropriate field.

STEP 11: Click on the "Verify Answers" button in the bottom of the Journal area to see if you have correctly obtained all the data. If you have not, make the appropriate changes in the appropriate fields (use the buttons in the upper right to get to individual screens).

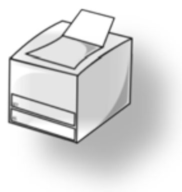
STEP 12: If your data are all good, you will need to print out your data as part of what you will hand in. **Click the "Print" button in the upper right; as before, print the Map *and* the Journal.**

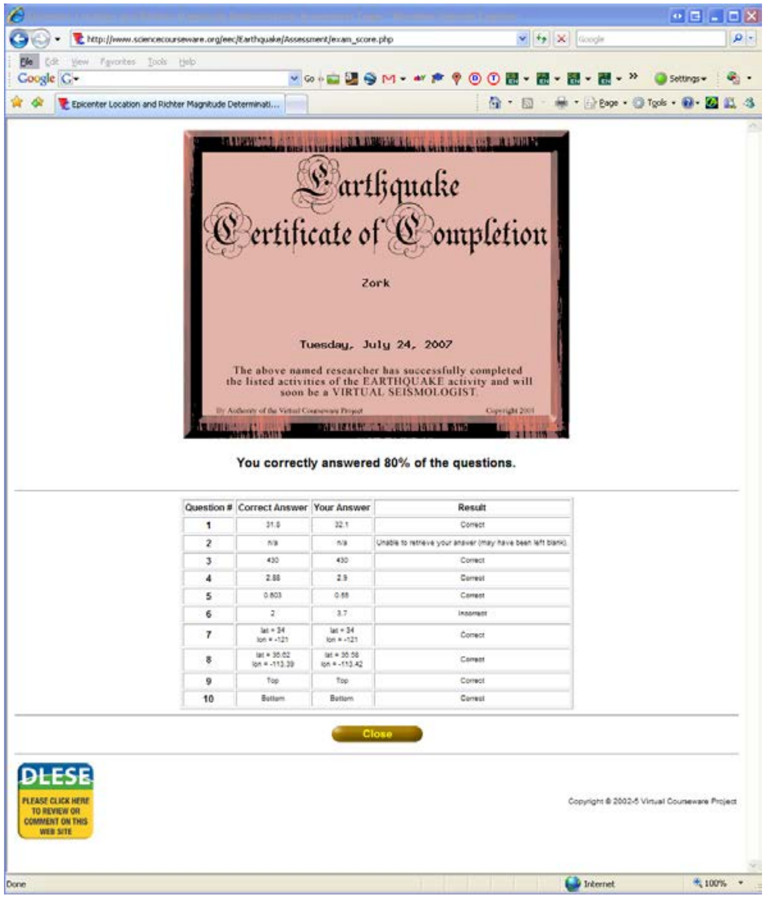


When you are done, click "Quit" in the upper right. When you do this, a new browser window should open and tell you that you have successfully completed the activity. To move on to the quiz, click in this window where it says "Click HERE to continue."

QUIZ

After clicking as above, the new window will change and ask you to enter your name, Institution, Location, and Class Code. The Code you will need to enter is **1021386**. The quiz has 10 questions on five screens; all of them ask questions that entail making the same kinds of measurements and reading the same kinds of graphs you already did for the above exercises. (Question #6 is tricky—read it carefully!) Note that you *can* leave an answer blank, but I don't recommend it—**these questions, and your score on the quiz, *will* count toward your grade on the exercise**. When you are done, a screen will appear that tells you your score on the quiz. This page also has a big pink "Certificate of Completion" at the top with your name in it. ***You must print this page*** (choose "Print..." from the File menu) and hand it in with the other sheets above as part of your exercise.





Thus, you will be handing in five (5) things:

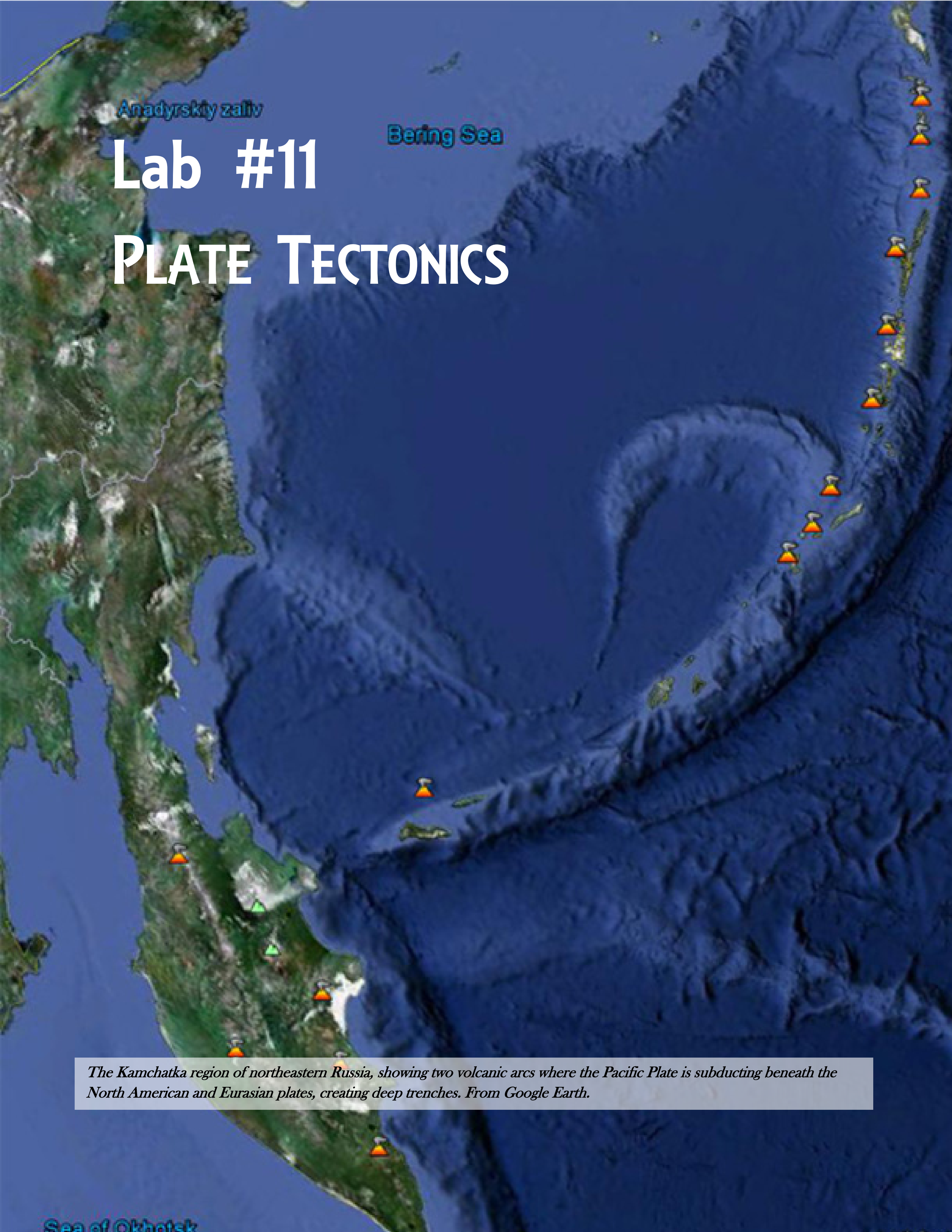
- ***the Map and Journal from the Travel Time exercise;***
- ***the Map and Journal from the Epicenter & Magnitude exercise; and***
- ***the certificate page from the quiz.***

Make sure that your name is on at least the first page!

Staple these things together ***in this order*** and hand it in on the due date. You ***will not*** be handing in the pages from this lab manual!

NOTES FOR EARTHQUAKES

Lab #11
Plate Tectonics



The Kamchatka region of northeastern Russia, showing two volcanic arcs where the Pacific Plate is subducting beneath the North American and Eurasian plates, creating deep trenches. From Google Earth.

The purpose of this exercise is to provide you with some experience dealing with various aspects of plate tectonics. Tectonic plates are immense, and most tectonic activity occurs in inaccessible places (such as deep underground). In addition, tectonic movements take place over long time scales that cannot be observed in short human time spans (let alone the span of a single Introduction to Geology lab!). Therefore, this lab uses (a) computer animations to examine plate motions over time, and (b) accepted, scientific web sites that document the results of plate movement to connect long-term tectonics and the characteristic features of those movements that can be observed on a human time scale.

Key Learning Points:

- Phanerozoic paleogeography and the changing configurations of plates over time, including predicting future plate positions and the effects of their movements.
- The rates at which tectonic plates move, using the equation:

$$\text{rate} = \frac{\text{distance}}{\text{time}}$$

- Recognizing different kinds of plate boundaries based on events that occur at those boundaries.

This exercise is worth 80 points; point values for each question are given at the end of each question.

Name:____ Lab Section:_________________________

For questions #1–6 of this exercise, you will use one of the computers in the classroom to play a Flash animation (.swf format) titled "PlateMoTime" (short for "plate motions through time"). This animation shows the motions of the Earth's major plates over the last 600 million years (remember, though, that there was plate tectonic activity well before this, too!). When you have the animation open, note that there are two buttons at the bottom of the screen: "Continuous Play" and "Explanation Pauses." Both run the animation more or less the same way; the "Explanation Pauses" version stops periodically to give you more time to read the snippets of text that pop up on the animation, requiring you to manually restart the animation each time it pauses. You can run the animation either way for the purposes of this exercise, but you may like the "Explanation Pauses" version better just so you can assimilate information better. Click whichever of the two buttons you want. After you do this, a control bar will appear beneath the buttons, and whichever button you selected will change to read "Main Screen."

On the control bar, click the "Play" button (▶). While the animation is playing, this button turns into a "Pause" button (||). There is also a little hourglass-shaped controller that progresses from left to right in the control bar; any time you want, you can click and hold to grab this and drag it left to go backward in time or right to go forward in time. Note that the animation progresses in different intervals—sometimes it jumps forward 40 million years between scenes; other times, only 20 or 30 million years; basically, it is designed to show you the significant, major events in tectonic history (during the last 600 million years, of course!). Also note that you can hover your cursor over the "Legend" button in the upper left of the animation to see what the different colors mean. Be ***very*** careful to note that the light blue, shallow seas that cover some parts of the continents ***do not*** necessarily mark boundaries between plates—two plates can be joined into one plate but have their former boundary covered by such a shallow sea! This information will be critical to your answering some of the questions below.

You will also want to find an atlas or globe to help you with this exercise, especially if you don't yet know which continents are which! Maps and a globe are available in the lab, and there are many on-line ones available, too.

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(1) Advance the animation to 300 million years ago. This is when the various, separate continents—which have been separate since the single supercontinent of Rodinia split apart several hundred million years earlier—assembled into the single supercontinent Pangea. Let the animation play from this point—as time goes on, Pangea breaks up into two separate landmasses: a northern one called **Laurasia**, made of today's North America, Europe, and Asia, and a southern landmass called **Gondwana**, made up of today's South America, Africa, Australia, India, and Antarctica. Let the animation progress from the 300 million year point. When did Pangea begin to split into these two smaller landmasses? (4 points)

(2) Today's landmass of Eurasia is now a single continent made up of several smaller landmasses that came together at different points in time. (2 points each; 6 points total)

(a) When did the main mass of Eurasia ("Siberia" + "Northwestern Europe") come together (a collision that created the Ural Mountains)?

(question continues on the next page)

(b) When did today's southeast Asia (China and surrounding areas) add to the landmass?

(c) When did India, the newest addition to Eurasia, get added on?

(3) In the animation, watch North America from around the beginning of the animation. Note that for a long time, the distinctive peninsula of Florida isn't there—it was actually a part of other plate(s) and didn't get attached to North America until later. To what other modern continental landmass(es) was Florida once attached, ***and*** when did it become part of North America? Be careful here to note that when it became attached is ***not*** necessarily the time when you first see it! (3 points)

(4) (a) When did India become an "island continent" (not connected to anything else)? (1 point)

(b) What is the landmass to which India was last connected? (**HINT:** this land mass isn't a continent and isn't labeled in the animation, and you may have to run the animation to the present and use a map or atlas to identify it.) (1 point)

(c) For how long was India isolated as an "island continent"? (1 point)

(5) As continents collide and separate, old oceans close and new ones open. Study the animation to observe how the ***modern-day*** Atlantic Ocean formed.

(a) Did the entire ocean form at the same time? (1 point)

(b) If not, in what order did its parts form? (2 points)

(question continues on the next page)

(c) When did each part begin to form? (4 points)

(d) The motions of which plates formed *each* part of the ocean? (4 points)

(e) What kind(s) of tectonic movement did these plates undergo during the formation of the Atlantic Ocean? (2 points)

(6) In the following exercise, you are going to determine how fast the Atlantic Ocean is spreading using past movements of South America and Africa—in short, the rate at which the sea floor is spreading. To do this, you will need to use the mathematical formula:

$$\boldsymbol{distance = rate \times time}$$

You will want to calculate the rate by measuring a distance and, using the animation, determining the time. Thus, you can rearrange the formula above to:

$$\boldsymbol{rate = \frac{distance}{time}}$$

First, you need to find a distance. To do this, using a map, atlas, or globe, find two points—one in South America, and one in Africa—***that used to be more or less a single point when these two continents were last connected*** (that is, two points that used to be approximately zero distance apart when the two continents were united). Probably the easiest things to find will be cities on those points, but you are welcome to use any other points for which you can find exact location coordinates (latitude and longitude, UTM, etc.).

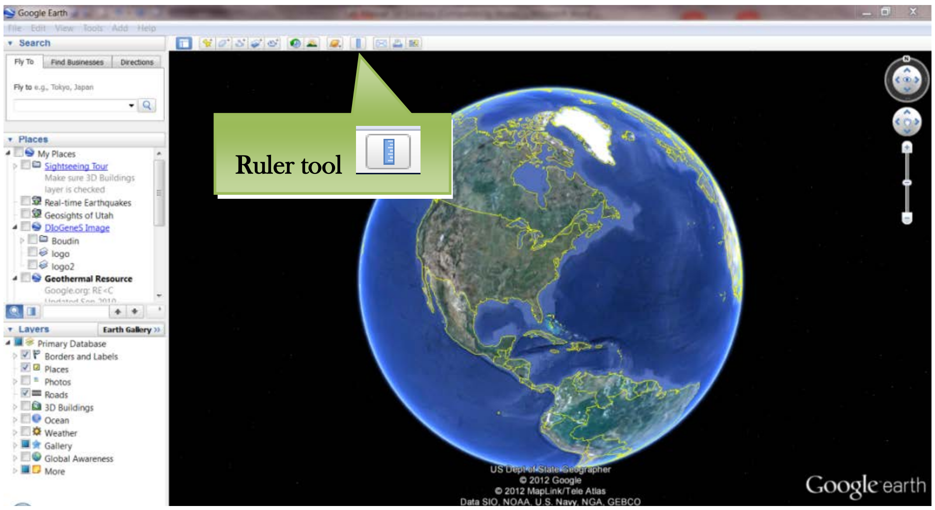
(a) Where/what are your two points? ***Include the names of the modern-day countries in which your points occur.*** (2 points)

South America:

Africa:

(question continues on the next page)

Now you need to figure out how far apart your two points are today **in kilometers** (km). You can do this either by measuring on your map, atlas, or globe (and doing some simple math using the scale provided on the globe or map to convert from the units on your ruler to units in the real world). Alternatively, you can use a tool, such as the Ruler in Google Earth. To do this, launch Google Earth; if you do not see the Ruler tool or the toolbar at the top of the Google Earth window, make sure that "Toolbar" is checked in the "View" menu.



When you click on the Ruler tool button, a small Ruler window will open—in it, make sure that the "Line" tab is open and the "Mouse Navigation" box is ***not*** checked. With this tool, you can *either* (a) click on the starting point of where you want to measure, then move and click on the end point of your measurement line, or (b) click ***and hold*** on your starting point, and then drag a line to your end point, and release the mouse button. The distance between your two points will show up in the Ruler window (be sure to set the units to km!). To turn off the Ruler tool and use the mouse to move to a new position on the globe or type in the Search box, check the "Mouse Navigation" button. (You won't, however, be able to double-click at any point to zoom in—you'll have to use the zoom bar in the upper right for that.) Be sure to uncheck the box again to finish taking the measurement or to start a new one!

(b) What is the distance between your two points? (2 points)

Now that you have a distance, you need to find a value for time. Use the animation to figure out how long ago your two points separated from each other—because the animation jumps in fairly large intervals (20–40 million years), you will probably have to use the last time shown in the animation, which in reality may be a few million years too old, but that's OK.

(c) When was the last time they were connected **in millions of years ago** (Ma)? (2 points)

(question continues on the next page)

(d) Now you are ready to make your calculation, using the formula above. Notice that if you simply take your numbers that you obtained above and plug them into the equation, you will get an answer whose units are in km/millions of years. Because that is rather difficult to comprehend, **convert your answer to cm/year**. (Remember that there are 100,000 cm in a km and that there are 1,000,000 years in a million years.) How fast has the Atlantic Ocean been spreading? ***Show your work for full credit.*** (1 point)

(7) (a) Earthquakes occur wherever there is tectonic movement, both within plates and, most famously, at the boundaries between plates. Go to http://earthquake.usgs.gov/earthquakes, and find a recent earthquake that had a magnitude of at least 5.0. In what region was this earthquake, and what was its magnitude? (1 point each; 2 points total)

(b) Find the location of this earthquake on a map (HINT: look at the web page you are on carefully—you may spot a quick way to do this!). Compare its location to a map of plates and plate boundaries (below). Did the quake occur as a result of activity at a boundary between two plates? If so, what kind of plate boundary is it? (2 points)

(8) (a) As you will have learned in lecture, most of the world's volcanic activity is also associated with plate tectonics boundaries. Go to http://www.volcano.si.edu/reports/usgs and find an example of recent volcanic activity (except Hawaii—don't use Kilauea or any of the other Hawaiian volcanoes). Where is this volcano and what is the date of its most recent reported activity? (1 point each; 2 points total)

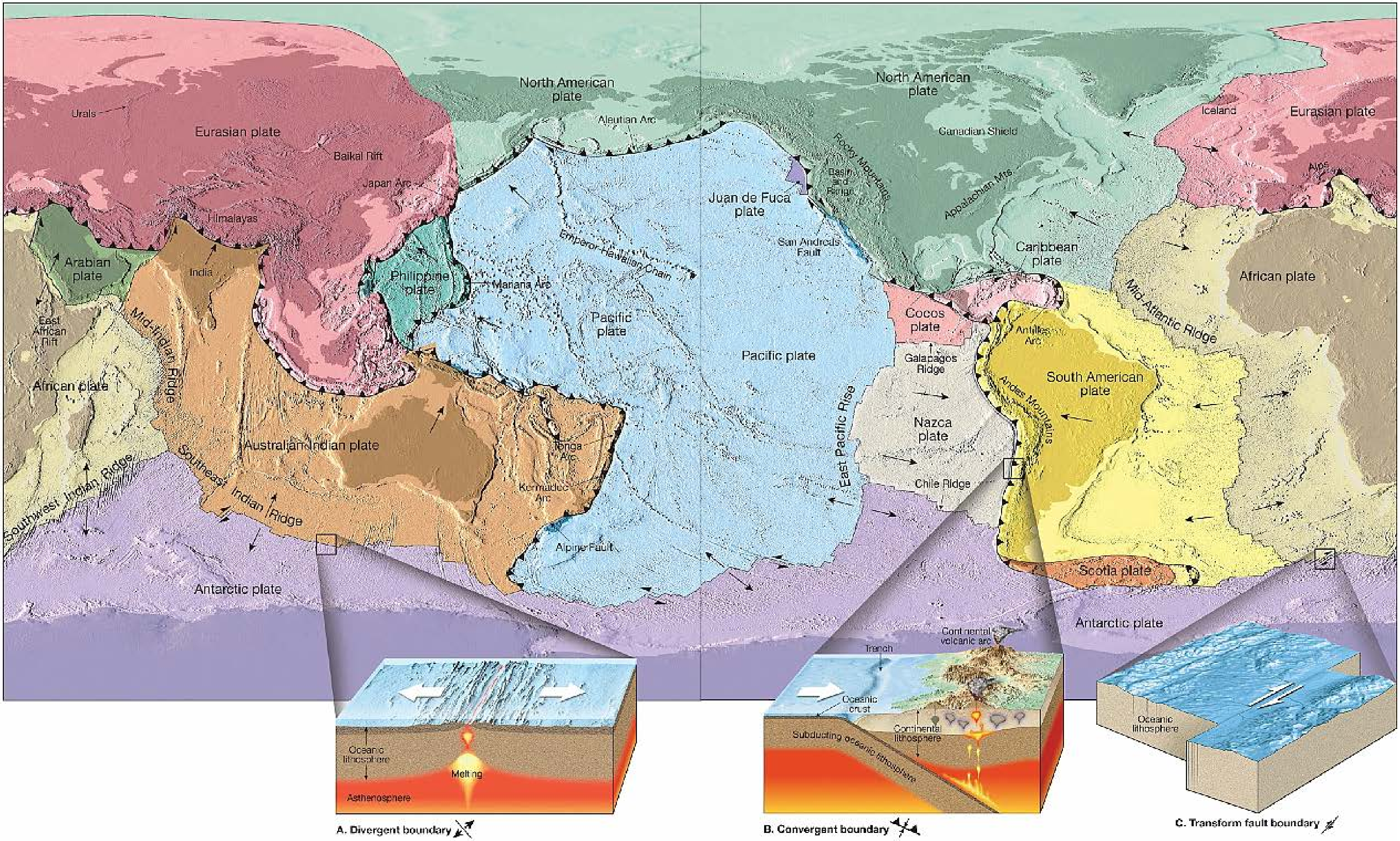
(question continues on the next page)

(b) Find the location of this volcano on a map. Compare its location to the map of plates and plate boundaries. Was the volcano the result of activity at a plate boundary or above a hot spot? If it was a plate boundary, what kind of boundary is it? (1 point each; 2 points total)

(9) (a) Look again at the map of the plates, and focus on where the different kinds of boundaries are (watch the symbols associated with each type). Now compare this map to a regular map of the world. What major water body is in the process of closing? **HINT:** it's not an ocean, though it is connected to an ocean and contains ocean water! (1 point)

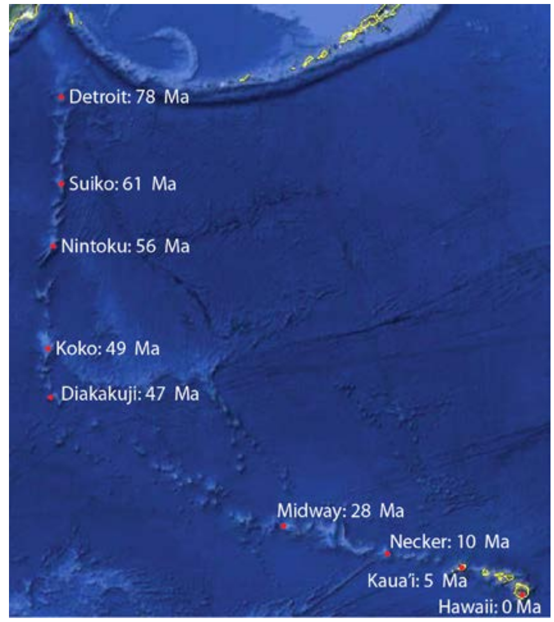
(b) ***Why*** is this body of water closing—the motions of which to plates are causing the closure and what kind of tectonic movement is involved? (3 points)

(c) What kind of geologic structure(s) (***not*** landmasses!) will eventually be in place of this water body? (2 points)



Picture credit: *Lutgens, F.K. and Tarbuck, E.J. 2005.* Essentials of Geology, Ninth Edition. *Boston: Prentice Hall.*

(10) At right is a Google Earth picture showing the Hawaiian–Emperor chain, which comprises both islands (above sea level) and seamounts (below sea level, many or all of which used to be islands but have weathered so extensively that they no longer peek above the waves). All of these were created by the hot spot that is presently located under Hawaii—all of the other islands and seamounts in the chain are extinct volcanoes. Each was created when it was above the hot spot, but became detached from it as movement of the Pacific Plate carried it away from the position of the hot spot beneath the lithosphere. Some of these islands and seamounts are labeled, and the ages of the basalts making up those points are provided in millions of years (Ma = mega-annum).



Launch Google Earth and find the Hawaiian–Emperor chain. Note that the seamounts are not labeled (though some of the islands are), so use the picture above to locate the labeled points. Use the Ruler tool (see instructions with question #6b, above) to measure the distances ***in km*** between the labeled points.

POINTS	DISTANCE (km)	AGE DIFFERENCE	RATE OF MOTION (cm/yr)
Detroit to Suiko			
Suiko to Nintoku			
Nintoku to Koko			
Koko to Diakakuji			
Diakakuji to Midway			
Midway to Necker			
Necker to Kaua'i			
Kaua'i to Hawaii			
		MEAN PACIFIC PLATE RATE OF MOTION =	

(a) Record your distances ***in km*** in the table above. (1 point each; 8 points total)

(b) Calculate the age difference between each of the two points and record those in the table. (1 point each; 8 points total)

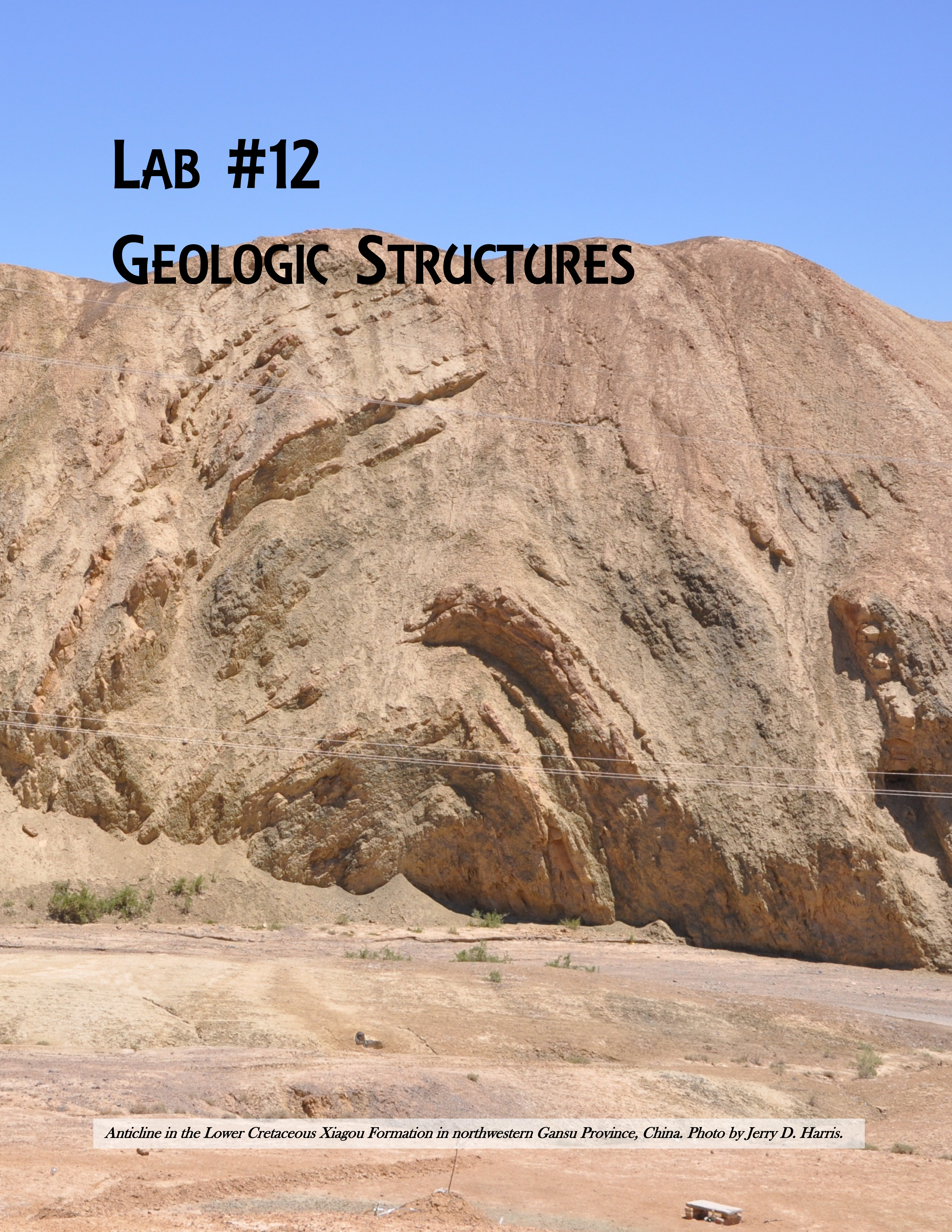
(question continues on the next page)

(c) Using the formula above (the same one you used for question #6), calculate the rate of motion ***in cm/yr*** of the Pacific Plate between the times the Hawaiian hot spot created **each** of the two points and record them in the table. ***Show your work below for at least two of your calculations below for full credit on all of your rates.*** (12 points)

(d) Average all of your individual rate times together to determine the mean rate at which the Pacific Plate has been moving for the last ≈80 million years and record this at the bottom of the table. (2 points)

NOTES FOR PLATE TECTONICS

Lab #12
Geologic Structures



Anticline in the Lower Cretaceous Xiagou Formation in northwestern Gansu Province, China. Photo by Jerry D. Harris.

The purpose of this exercise is to provide you with some experience understanding, recognizing, and interpreting various geologic structures (different kinds of folds and faults) and the application of this ability.

Key Learning Points:

- Understanding how different applications of stress to rocks result in different kinds of geologic structures.
- Recognizing different kinds of geologic structures and how they form.
- Reconstructing different kinds of geologic structures based on a limited data set.
- Understanding how the ability to recognize geologic structures has economic importance.

This exercise is worth 90 points; point values for each question are given at the end of each question.

Name:____ Lab Section:__________________________

(1) Use the Silly Putty™ at your table to answer the following questions.

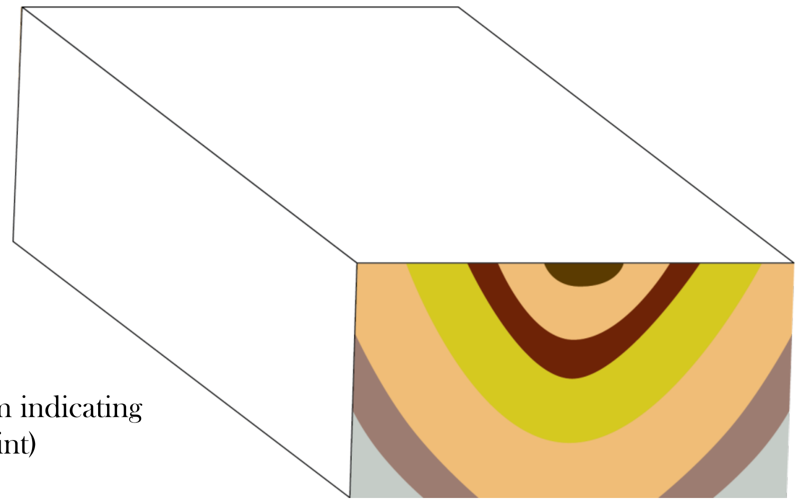
(a) Roll the putty into a solid cigar shape. You will use the putty here to examine **ductile** behavior of a solid substance, meaning how it changes shape when a stress (force) is applied. Hold either end of the roll and **S L O W L Y** pull them apart. Describe below what happens to the ***shape*** of the putty roll as you do this, mentioning what happens as your start pulling, continue pulling, and what the end result is. (Ignore the effects of gravity in your description.) (3 points)

(b) Roll the putty again as you did in question #1a above. You will use the putty here to examine **brittle** behavior of a solid substance, meaning how it breaks when a stress (force) is applied. Again, hold each end of the roll. This time, pull the ends apart **very fast**—as fast and hard as you can. Describe below what happens as you do this and what the end result is. (3 points)

The different speeds at which you pulled on the putty in questions #1a and 1b above equate to applying the same **stress** (force)—in this case, tension—to the putty over different time spans (long and short). Despite the fact that us humans tend to think of rocks as immutably hard, solid things (which they usually are on day-to-day human scales), rocks behave very much like the putty when stressed (with a little variation depending on rock type, minerals present, and how the stress is applied). When rock behaves ductily, it can be **strained**, meaning it changes its shape in some way when stress is applied. Keep these differences in mind when doing the following exercises. From your "experiment" with the putty above, what associations do you see between the time spans over which the stress is applied and the kinds of strain that result? (2 points)

The diagrams in the next questions below are cross sections through the ground—think of them as rectangular chunks of the ground, several miles long, that have been removed from the Earth's surface. In other words, what used to be the ground surface on top has been removed (and planed flat), and everything that used to connect on all sides have also been removed (and planed vertically flat). The flat top surfaces of each diagram is the surface on which you would be walking; you would not be able to see the front or side surfaces from that perspective.

(2) (a) What kind of fold is depicted in the diagram at right? (1 point)

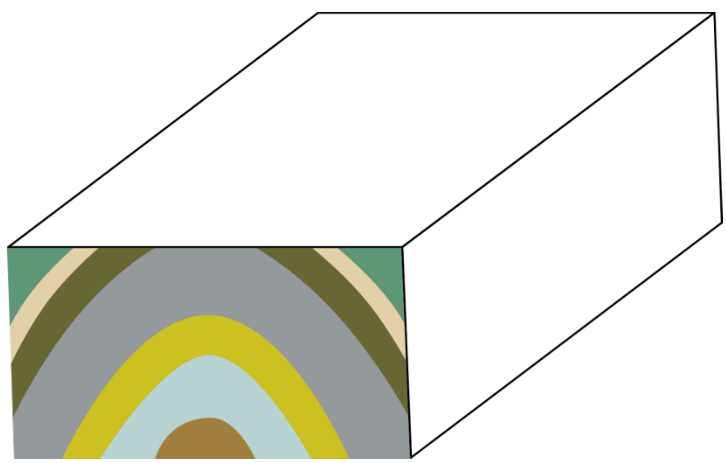


(b) On the blank top and side of the cross section, draw in the strata as they would appear on those surfaces based on the structure you can see on the front surface. (7 points)

(c) Draw a **dashed** line on the diagram indicating the position of the fold axis. (1 point)

(d) If you were to stand on the dark brown layer in the center of the diagram, would the strata on either side of you get younger or older the farther away you would get? (1 point)

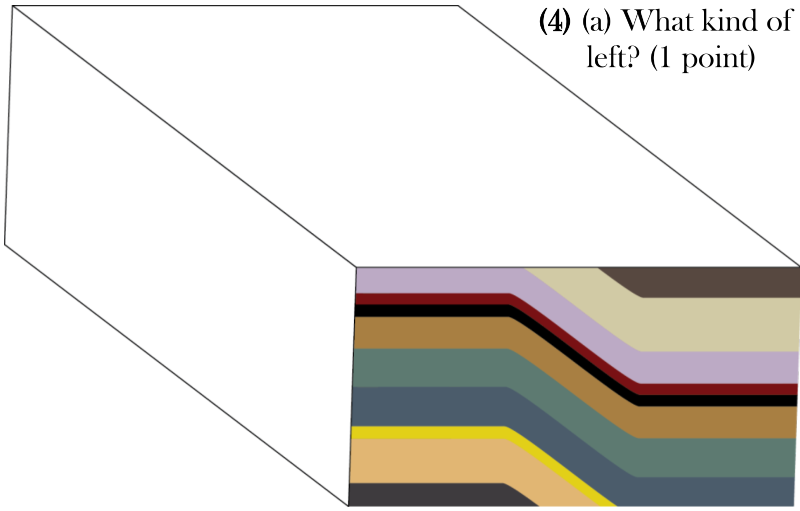
(3) (a) What kind of fold is depicted in the diagram at right? (1 point)



(b) On the blank top and side of the cross section, draw in the strata as they would appear on those surfaces based on the structure you can see on the front surface. (7 points)

(c) Draw a **dashed** line on the diagram indicating the position of the fold axis. (1 point)

(d) If you were to stand on the gray layer in the center of the diagram, would the strata on either side of you get younger or older the farther away you would get? (1 point)

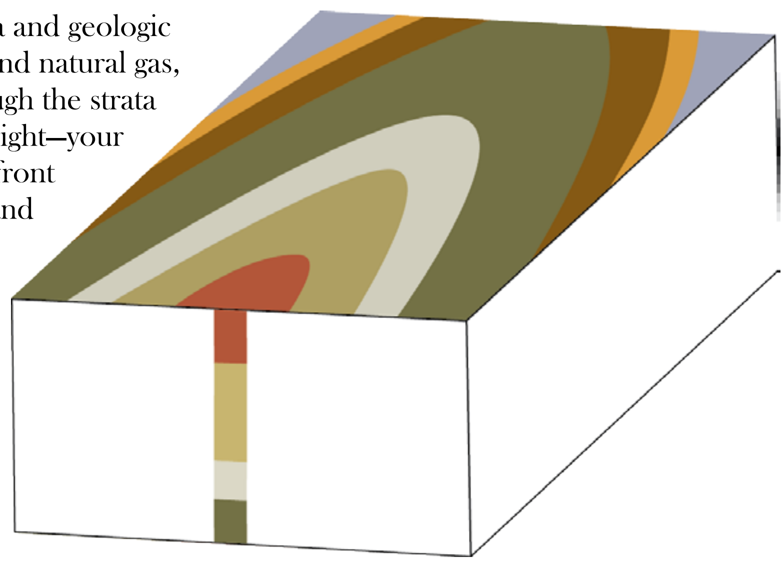


(4) (a) What kind of fold is depicted in the diagram at left? (1 point)

(b) On the blank top and side of the cross section, draw in the strata as they would appear on those surfaces based on the structure you can see on the front surface. (7 points)

(c) If you were to stand on the beige layer in the center of the diagram, would the strata on either side of you get younger or older the farther away you would get? (1 point)

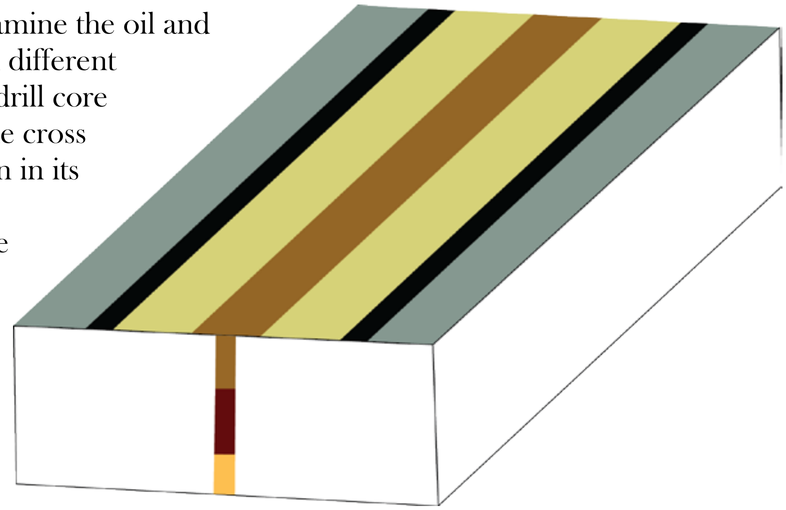
(5) (a) To assess the possibility that the strata and geologic structures in a given area might contain oil and natural gas, you have just taken a vertical drill core through the strata in the area depicted on the cross section at right—your core is shown in its original position on the front surface of the diagram. On the blank front and sides of the cross section, draw in the strata as they would appear on those surfaces based on the top surface and your drill core. (7 points)



(b) What kind of fold is this? (2 points)

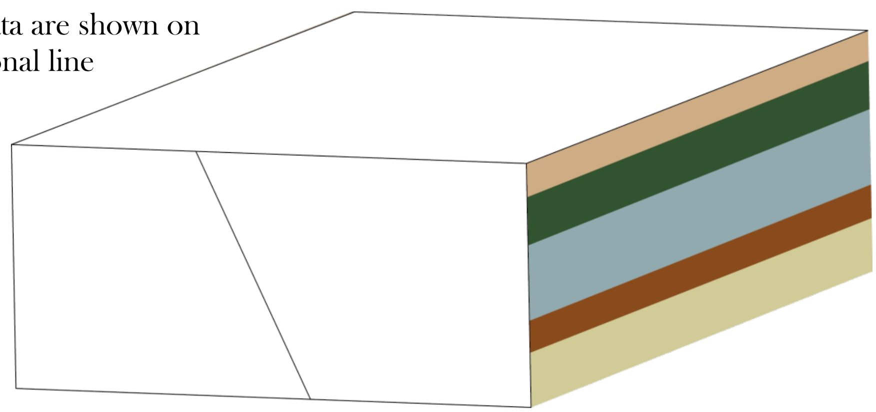
(c) Draw an arrow (***not*** just a line!) along the plunge of this fold that indicates the direction and approximate dip (angle) of the plunge of this fold. (2 points)

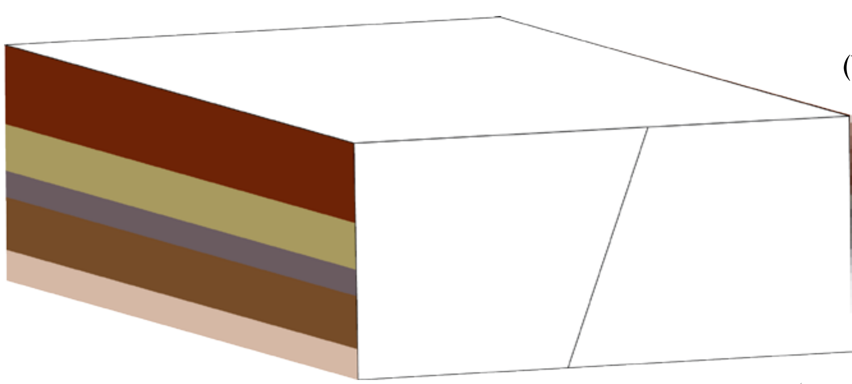
(6) (a) Now you have been reassigned to examine the oil and natural gas resources in a different area with different geological structures. As before, you take a drill core through the strata in the area depicted on the cross section at right, and your core is again shown in its original position on the front surface of the diagram. On the blank front and sides of the cross section, draw in the strata as they would appear on those surfaces based on the top surface and your drill core. (7 points)



(b) What kind of fold is this? (1 point)

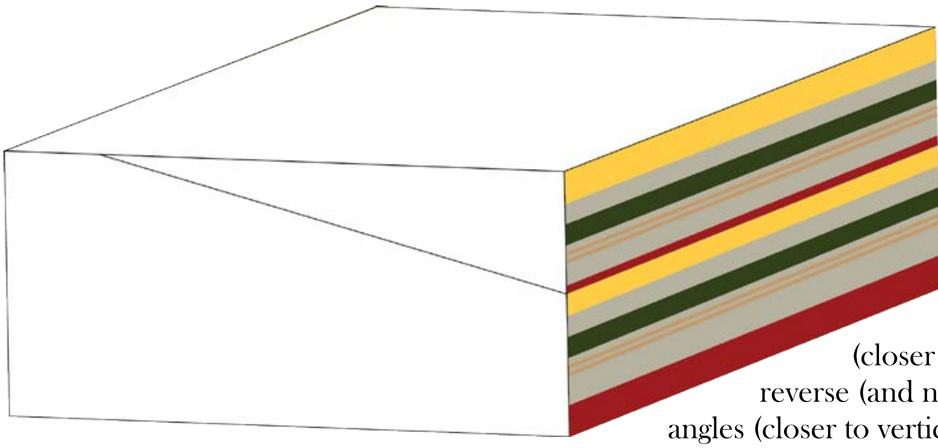
(7) (a) On the diagram at right, strata are shown on one face. A **normal** fault (the diagonal line on the front face) cuts through this block. Draw on both the front face ***and*** the top surface what the strata would look like with this normal fault in place. (5 points)





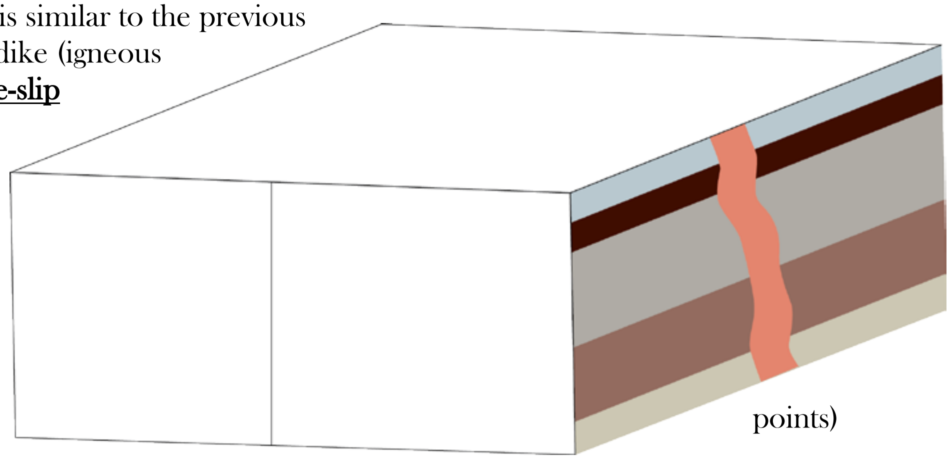
(b) The diagram at left is similar to the one in question #6a, but now has a **reverse** fault running through it. Draw on both the front face ***and*** the top surface what the strata would look like with this reverse fault in place. (5 points)

(question continues on the next page)



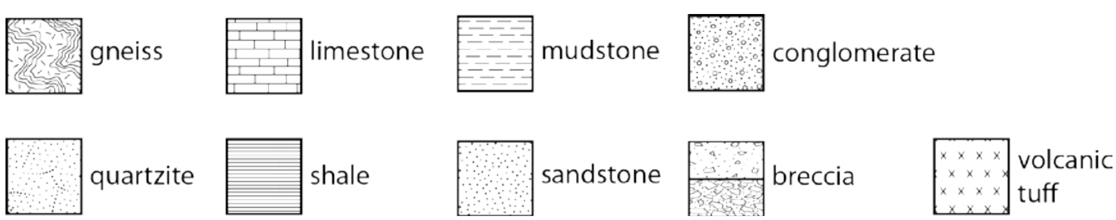
(c) The diagram at left is similar to the previous one, but instead of a typical reverse fault, it has a variation called a **thrust** fault running through it. Thrust faults happen at very low angles (closer to horizontal), whereas reverse (and normal) faults are at high angles (closer to vertical). Draw on both the front face ***and*** the top surface what the strata would look like with this strike-slip fault in place (note carefully what the strata shown are telling you!). (5 points)

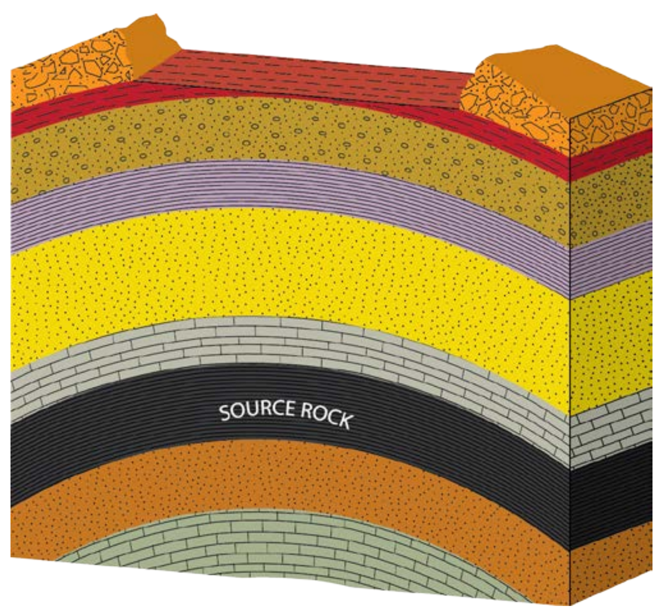
(d) The diagram at right is similar to the previous ones, but has both a dike (igneous intrusion) and a **strike-slip (transform)** fault running through it. Draw on both the front face ***and*** the top surface what the strata and dike would look like with this strike-slip fault in place. (5 points)



Understanding geological structures—especially ones that are not entirely visible at the surface of the Earth—are extremely important in locating oil and natural gas reserves. Without understanding where structures are underground, drilling for oil and natural gas would be a completely random process of guesswork…and drilling is extremely expensive! Fortunately, various kinds of geologic structures can be beneficial because they can serve as **traps** for the oil and natural gas. Oil (a liquid) and natural gas are both produced from the alteration of the remains of marine plankton, primarily algae. Both are much less dense than groundwater, so under the pressure (weight) of overlying rock, they are squeezed from their **source rocks** and rise through strata that are **permeable** (meaning that they allow the passage of gases and fluids). To be permeable, any stratum through which the oil and natural gas rise must be (1) highly **porous**, meaning that it has lots of interconnected spaces between individual sediment grains (typical of coarser-grained sedimentary rocks, such as sandstones and conglomerates), and/or (2) heavily **fractured**, creating a series of narrow but interconnected passages. The oil and natural gas rise until they hit a **cap rock** layer that is **impermeable**. A stratum will be impermeable if it has pore spaces that are very small and not well connected to one another (typical of finer-grained sedimentary rocks, such as mudstone and shale) and/or is not heavily fractured. Some kinds of geologic structures can trap rising oil and natural gas in much shallower places underground than the source rock itself. Identifying the positions of such traps is highly desirable because drilling to shallow depths is much less expensive than drilling very deeply into the source rock, and the less a company spends to drill, the more cheaply they can sell the oil and natural gas (making it attractive to buy by consumers) and still make a profit!

The diagrams below shows the details of underground geologic structures that can serve as oil and natural gas traps; the legend provided below shows the rock types involved in both. Use this to answer the following questions.

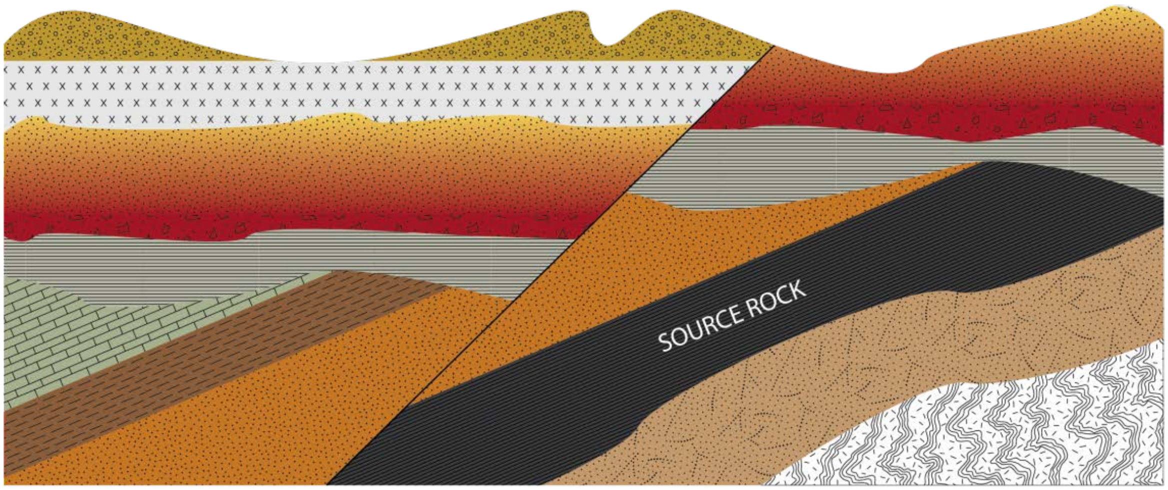




(8) (a) The diagram below shows the details of an underground fold. The black shale, which is several thousands of meters underground, is a producer of oil and natural gas. Assume that the overlying limestone is fractured. On the diagram, indicate where the trap is by drawing in the pool that will form as the oil and natural gas collect under the cap rock. (4 points)

(b) Which layer is acting as the cap rock for this trap ***and*** why is it a cap rock? (2 points)

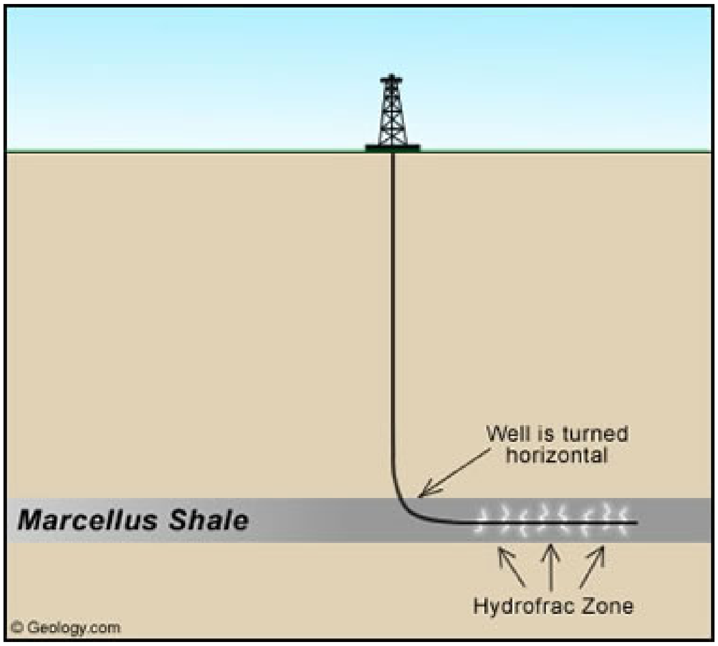
(9) (a) The diagram below shows the details of an underground fault. The black shale, which is several thousands of meters underground on both sides of the fault, is, as in question #8, a producer of oil and natural gas. On the diagram, indicate where the traps are by drawing in the pools that will form as the oil and natural gas collect under the cap rock. (3 points)



(b) What kind of fault is this? (1 point)

(c) The fault in the diagram above has created one advantageous spot for recovering oil and natural gas cheaply and easily. Indicate on the diagram where this area is ***and*** describe here why this spot is advantageous (accounting, in your answer, for the fault and other geologic structures in the area depicted in the diagram). (3 points)

(d) Other than the advantageous spot you noted in part (c) above, oil and natural gas could be obtained from elsewhere in the area depicted—after all, the source rock is producing oil and natural gas along the entirety of its preserved length!—although it would be more expensive to get it because it's deep underground. To get the oil and natural gas most easily, you could **frack** (artificially fracture) part of any impermeable cap rock layers to create a series of fractures that would allow the oil and natural gas to permeate a cap rock layer, or even the source rock layer itself. Fracking works by drilling down to the layer that needs to be fractured, drilling a long way into it horizontally, then pumping fluids and gases into the horizontal tunnel at high pressures to create the fractures (see diagram at left, which depicts fracking a shale horizon in New England called the Marcellus Shale, which is a huge reservoir of otherwise locked-up natural gas). If you had a limited amount of funds and could only frack any ***cap rock*** layers in ***one*** small area in the diagram above, where would that area be? Mark that spot on the diagram above with a star ***and*** explain why this location would be the best. (3 points)



Picture credit: *http://geology.com/articles/hydraulic-fracturing/marcellus-gas-well.jpg*

NOTES FOR GEOLOGIC STRUCTURES