Contents

GENERAL INFORMATION

INTRODUCTION

Read through the lab material before you go to lab. Because lecture and lab topics cannot coincide exactly, the labs will be easier to understand if you read the appropriate material in your lab manual and textbook before lab, especially if it has not been discussed in lecture yet. Bring your lab manual and textbook to each lab session. You may need to refer to diagrams and tables in your text. The schedule of topics is listed on page iii.

GRADING INFORMATION

Each lab session will be evaluated by a quiz or an exercise. Each quiz or exercise is worth 10% of your lab grade. You will not receive a separate grade for the lab. The total lab grade will account for 20% of the final grade in GEOL 101. Remember, as it says in the lecture syllabus, if you miss more than three lab sessions, you cannot pass the course. Therefore, attendance and participation in the lab are required.

MAKING UP A LAB

Ordinarily, if you miss a lab, the only way to make it up is by attending another lab session. For the First Summer Session, this will not be possible, as there is only one section of lab. Please consult with your Instructor, and try not to miss any labs. For the Second Summer Session, there are two lab sections, so you will have a limited opportunity to make up missed labs, but again, it's best not to do so.

ACKNOWLEDGMENTS

This lab manual has been developed specifically for the Introductory Geology course at California State University, San Bernardino. We have unique geological resources available to this campus because of its location, and are highlighting some of those resources in our lab exercises. Several people have devoted considerable work to do this effectively. These include: Barbara Bailey, Hasaan Boroon, Joan Fryxell, Karen Hobart, Sally McGill, Ross McIntosh, Jim Mehegan, Erik Melchiorre, Harry Quinn, Tim Ross, and Jeni Williams. Individual sources are acknowledged where images are used.

SCHEDULE OF LAB SESSIONS

	Monday	Tuesday	Wednesday	Thursday	Friday
September	20	21	22	23	24 Lab 1 -- Reading Topographic Maps 0900-1150AM
	27 Lab 1 -- Reading Topographic Maps 0100-0350PM 0600-0850PM	28 Lab 1 -- Reading Topographic Maps 0900-1150AM 0100-0350PM 0600-0850PM	29 Lab 1 -- Reading Topographic Maps 0900-1150AM 0100-0350PM 0600-0850PM	30	
October					1 Lab 2 -- Plate Tectonics 0900-1150AM
	4 Lab 2 -- Plate Tectonics Walking Field Trip to San Andreas Fault 0100-0350PM 0600-0850PM ***	5 Lab 2 -- Plate Tectonics 0900-1150AM 0100-0350PM 0600-0850PM ***	6 Lab 2 -- Plate Tectonics 0900-1150AM 0100-0350PM 0600-0850PM ***	7	8 Lab 3 -- Earthquakes 0900-1150AM
	11 Lab 3 -- Earthquakes 0100-0350PM 0600-0850PM	12 Lab 3 -- Earthquakes 0900-1150AM 0100-0350PM 0600-0850PM	13 Lab 3 -- Earthquakes 0900-1150AM 0100-0350PM 0600-0850PM	14	15 Lab 4 -- Rock-Forming Minerals and Quiz 0900-1150AM
	18 Lab 4 -- Rock-Forming Minerals and Quiz 0100-0350PM 0600-0850PM	19 Lab 4 -- Rock-Forming Minerals and Quiz 0900-1150AM 0100-0350PM 0600-0850PM	20 Lab 4 -- Rock-Forming Minerals and Quiz 0900-1150AM 0100-0350PM 0600-0850PM	21	22 Lab 5 -- Igneous Rocks and Quiz 0900-1150AM
	25 Lab 5 -- Igneous Rocks and Quiz 0100-0350PM 0600-0850PM	26 Lab 5 -- Igneous Rocks and Quiz 0900-1150AM 0100-0350PM 0600-0850PM	27 Lab 5 -- Igneous Rocks and Quiz 0900-1150AM 0100-0350PM 0600-0850PM	28	29 Lab 6 -- Mass Wasting and Erosion 0900-1150AM
November	1 Lab 6 -- Mass Wasting and Erosion 0100-0350PM 0600-0850PM	2 Lab 6 -- Mass Wasting and Erosion 0900-1150AM 0100-0350PM 0600-0850PM	3 Lab 6 -- Mass Wasting and Erosion 0900-1150AM 0100-0350PM 0600-0850PM	4	5 Lab 7 -- Sedimentary Rocks and Quiz 0900-1150AM
	8 Lab 7 -- Sedimentary Rocks and Quiz 0100-0350PM 0600-0850PM	9 Lab 7 -- Sedimentary Rocks and Quiz 0900-1150AM 0100-0350PM 0600-0850PM	10 Lab 7 -- Sedimentary Rocks and Quiz 0900-1150AM 0100-0350PM 0600-0850PM	11	12 Lab 8 -- Groundwater 0900-1150AM
	15 Lab 8 -- Groundwater 0100-0350PM 0600-0850PM	16 Lab 8 -- Groundwater 0900-1150AM 0100-0350PM 0600-0850PM	17 Lab 8 -- Groundwater 0900-1150AM 0100-0350PM 0600-0850PM	18	19 Lab 9 -- Metamorphic Rocks 0900-1150AM
	22 Lab 9 -- Metamorphic Rocks 0100-0350PM 0600-0850PM	23 Lab 9 -- Metamorphic Rocks 0900-1150AM 0100-0350PM 0600-0850PM	24 Lab 9 -- Metamorphic Rocks 0900-1150AM 0100-0350PM 0600-0850PM	27 Thanksgiving Holiday	28 Thanksgiving Holiday
December	1 Lab 10 -- Relative Dating 0100-0350PM 0600-0850PM	2 Lab 10 -- Relative Dating 0900-1150AM 0100-0350PM 0600-0850PM	3 Lab 10 -- Relative Dating 0900-1150AM 0100-0350PM 0600-0850PM	4	5 Lab 10 -- Relative Dating 0900-1150AM

*** these labs will need to attend one of the other lab sessions, or a specially scheduled time, to do the hiking portion of Lab 2.

CONVERSION FACTORS, ETC.

numbers: *prefix:* *quantity:* *fraction:* *decimal:*

prefix	quantity	fraction	decimal
milli-	one thousandth	1/1000	0.001
centi-	one hundredth	1/100	0.01
deci-	one tenth	1/10	0.1
kilo-	one thousand		1000.0
mega-	one million		1,000,000.0
giga-	one billion		1,000,000,000.0

length: *Metric relations:* *abbreviations:*

10 millimeters = 1 centimeter.............. 10 mm = 1 cm
1000 millimeters = 1 meter ....1000 mm = 1 m
100 centimeters = 1 meter ....100 cm = 1 m
1000 meters = 1 kilometer..................1000 m = 1 km

Metric - English conversions:

1 yard = 0.9144 meter .... 1 yd = 0.9144 m
1 inch = 2.54 centimeter ....1 in = 2.54 cm
1 kilometer = 0.62 mile............................1 km = 0.62 mi

English relations:

12 inches = 1 foot......................................12 in = 1 ft
3 feet = 1 yard... 3 ft = 1 yd
5280 feet = 1 mile ....5280 ft = 1 mi

latitude and longitude: degrees, minutes, seconds:

1 degree = 60 minutes......... 1° = 60'
1 minute = 60 seconds .... 1' = 60"

temperature: 0° C = 32° F (water freezes)
100° C = 212° F (water boils)

from Celsius to Fahrenheit: 9/5 °C + 32 = °F
from Fahrenheit to Celsius: 5/9 (°F - 32) = °C

logarithms: Common logarithms are the exponents to which the base number 10 is raised. Used as a shorthand notation in many applications; also the numbers used in Richter Magnitude.

log	base with exponent	number
0	10^0	1
1	10^1	10
2	10^2	100
3	10^3	1,000

log	base with exponent	number
4	10^4	10,000
5	10^5	100,000
6	10^6	1,000,000
7	10^7	10,000,000

. . . and so forth. As a memory aid, note that the number of zeros in each number equal the corresponding logarithm.

LAB 1. READING TOPOGRAPHIC MAPS

MATERIALS:

You bring: pen and pencil, scratch paper, textbook if possible, calculator (optional).
Supplied: work sheet, San Bernardino North topographic map, ruler.

WHERE SHOULD I MEET YOU?

Several grid systems exist to allow us to identify specific positions on the surface of the Earth. The longest standing one is that of latitude and longitude. More recently, the Universal Transverse Mercator (UTM) system has been developed.

Latitude and Longitude

A grid system has long been used to identify particular places on the surface of the Earth. This system was first used at least 300 years B.C. Ptolemy used them on his world atlas in the 2nd century A.D. The lines of this grid follow these rules:

1. Lines of **latitud**e (called **parallels**) run east - west around the earth. The Equator is the line of zero latitude. These lines are numbered 0° (at the Equator) to 90° at the poles. The Equator divides the world into the Northern and Southern Hemispheres.

2. Lines of **longitude** (called **meridians**) run north - south from pole to pole. The meridian that runs through Greenwich, England, has been designated the **prime meridian**, and is 0°. From there westward, longitude lines are numbered up to 180° West (forming the Western Hemisphere), and from Greenwich eastward, longitude lines are numbered up to 180° East (forming the Eastern Hemisphere). The 180° meridian is (more or less) the International Date Line.

3. Any point on the Earth's surface can be identified as the intersection of a line of latitude and a line of longitude. It is necessary to specify which hemisphere of latitude and which hemisphere of longitude in which a particular spot lies. For example, California is in the Northern Hemisphere (latitude), and Western Hemisphere (longitude).

4. Latitude and Longitude are expressed in degrees, minutes, and seconds.

   1 degree (1°) = 60 minutes (60')
   1' = 60 seconds (60")

For example, Pfau Library at CSUSB is at approximately:

34° 10' 56" North Latitude, and
117° 18' 59" West Longitude.

Map Series

In the U.S., three series of maps have been generally published. The most detailed is the 7.5' series, which covers 7.5' of latitude and 7.5' of longitude. These are published at a scale of 1:24,000. Next is the 15' series, which covers 15' of latitude, and 15' of longitude, and was published at a scale of 1:62,500. These are no longer being printed, although you will find copies in libraries, and may find copies still for sale in some places. Last is the 1° x 2° series, which covers 1° of latitude, and 2° of longitude, and is published at a scale of 1:250,000. The lines of latitude and longitude that bound each map are labeled off the ends of each line. For example, 34° 07' 30" North Latitude forms the southern boundary to the San Bernardino North 7.5' Quadrangle, and it is so labeled at the east and west ends of itself.

Each map is named for some geographic feature that occurs in that quadrangle, as well as the scale of the map (for example, San Bernardino North 7.5' Quadrangle). The adjacent quadrangles are named along the edges of each map. For example, the Silverwood Lake 7.5' Quadrangle is the next one to the north of the San Bernardino North 7.5' Quadrangle, and the Fontana 7.5' Quadrangle is the map to the southwest.

Exercise 1. Latitude and Longitude

1. Where is the name of the quadrangle printed on this map?
2. Does this map belong to the 7.5' series or to the 15' series?
3. Which 7.5' quadrangle is located east of this one?
4. Which 7.5' quadrangle is located northwest of this one?
5. What is the latitude along the top of the map?
6. What is the latitude along the bottom of the map?
7. How many degrees, minutes, and seconds of latitude are covered by this map?
8. What is the longitude at the left edge of the map?
9. What is the longitude at the right edge of the map?
10. How many degrees, minutes, and seconds of longitude are covered by this map?
11. What is the latitude and longitude of the center of the map? Give degrees, minutes, and seconds for each one.

Universal Transverse Mercator (UTM)

More recently, the National Imagery and Mapping Agency of the U.S. government adopted a special grid for military use. This grid turned out to be easier to use in some ways than the latitude and longitude system, and is becoming popular outside of military applications.

The UTM grid divides the world into sixty north-south zones, numbered 1-60, with each zone covering 6° of longitude. Zone 1 begins at the 180° W meridian of longitude, zone 2 begins at 174° W, zone 3 begins at 168° W, and so forth proceeding eastwards.

Specific values are given in meters east of the zone meridian (set to the west of the zone), with grid lines marked every 1,000 m on a map. These values are refered to as **eastings.** Each zone is broken into segments that are identified by letters. However, these are optional for actual location determinations. They are convenient, and can speed things up.

The latitudinal component of the UTM system is given in meters north (or south) of the equator, with every 1,000 m marked by a grid line on a map. These values are referred to as **northings**.

UTM coordinates are given with the zone first, followed by the easting, then the northing. To determine the coordinates for any location on a map, look around the margins of the map to identify the eastings and northings. Older maps will have them marked with small tick marks around the margin, and newer maps will have the grid of every 1,000 m marked across the entire map. Figure 1 shows some of the UTM markings for the San Bernardino North quadrangle. As you can see, the numbers vary in size, which is designed to help guide your eye and highlight relevant grid numbers. Often, the trailing zeros are omitted, to keep things from getting cluttered up. In addition, each side of the map will identify the measure-

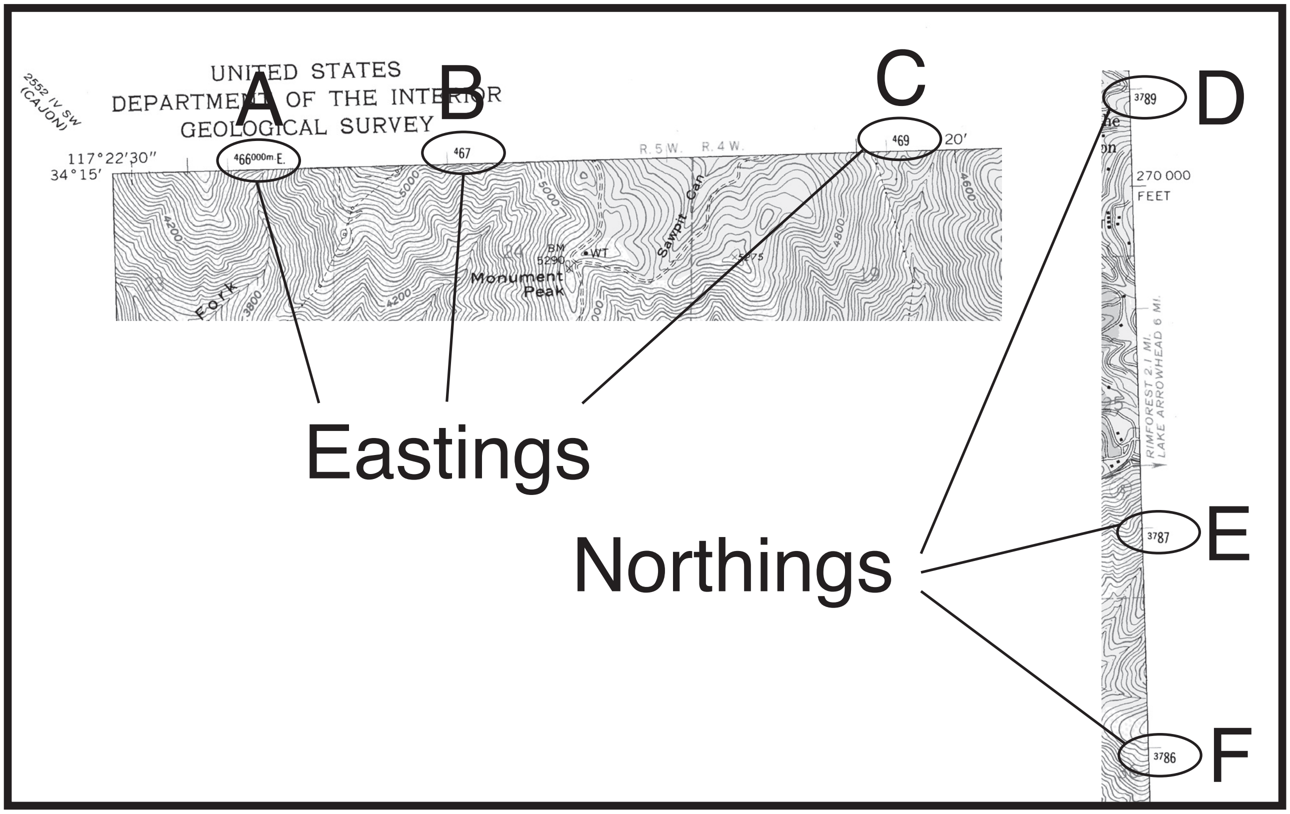

Figure 1. Universal Transverse Mercator Grid. These are parts of the San Bernardino North quadrangle, with the UTM markings highlighted. Note that not all the 1,000 m tick marks are labeled -- some are omitted to prevent cluttering up the margin of the map.

Note also that the final three zeros are only printed once per side of the map -- also omitted to prevent cluttering up the map. You are just supposed to remember they're there. A-C are eastings, and D-F are northings, as indicated on the figure. Compare these with your actual San Bernardino North maps to confirm that the numbers indicate:

A. 466,000 meters E.
B. 467,000 meters E.
C. 469,000 meters E.
D. 3,789,000 meters N.
E. 3,787,000 meters N.
F. 3,786,000 meters N.

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ment as an easting (E) or a northing (N).

Because the UTM system is set up with grid markings 1,000 m (1 km) apart, specific coordinates can be determined directly by measuring distance from the grid markings, and expressed in meters. This is a much simpler notation system than the hexadecimal latitude - longitude system, and with a little practice, often becomes preferred by people who work with spatial data.

One last note: on Figure 1, you can see that the edges of the map are shown slightly angled relative to the page. When the UTM coordinate system was established, it was

Exercise 2. UTM Grid

12. What is the easternmost easting gridline on the San Bernardino North quadrangle?
13. What is the southernmost northing gridline on the same map?
14. What are the UTM coordinates for Monument Peak?
15. What are the UTM coordinates for the top of Badger Hill (labeled 1854' on the map)?

decided to align maps in digital format with the UTM grid, as it is more accurate that the long-ago-surveyed latitude and longitude lines on which the maps were based. You will often see this slight discordance also on maps that have the gridlines marked on them.

Topographic Quadrangles:

In the United States, the U.S. Geological Survey publishes topographic maps in the form of **quadrangles**. As the name implies (*quad* = four, *angle* = angle), these maps have four corners, and hence four sides. Each side is a line of **longitude** (east and west sides) or a line of **latitude** (north and south sides). The area of the map is subdivided by the **Public Land Survey System**, which divides the land into **Townships**, **Ranges**, and **Sections**.

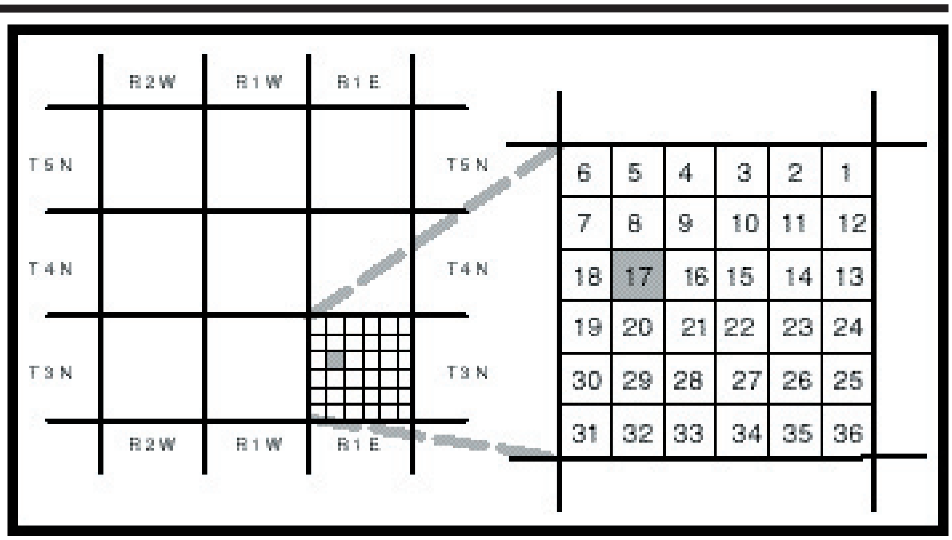
Public Land Survey System:

Township lines run east - west, and **Range** lines run north - south. Each state has a baseline latitude for townships and a baseline longitude for ranges. Townships are numbered relative to their baseline. For example, T1N and T2N are the first and second townships north of the baseline. Similarly, ranges are labeled R3W or R2E, for the third range west of the baseline, or the second range east of the baseline, respectively. Range lines and township lines are six miles apart, so one range-and-township block comprises 36 square miles. Each of these square miles is named a **Section**. Sections are numbered starting with the northeast corner as 1, proceeding west to 6, etc. as shown on the next page. Sections can be subdivided into quarters, such as the NW quarter, the SW quarter, etc., and further subdivided into quarters again and again as needed. This is useful for locating real estate, among other things.

True North vs. Magnetic North:

Lines of longitude converge at true geographic north (the rotational axis of the planet). Unfortunately, the magnetic north pole does not coincide exactly with this point, but lies in northern Canada. Thus, to use a compass (which responds to magnetic north) accurately, you must know by how much, and in what direction, magnetic north deviates from true north. Each quadrangle gives this information along the bottom of the map, just to the left of center. The star indicates true north, and "MN" indicates magnetic north. The number of degrees between them is labeled. For example, on the San Bernardino North Quadrangle, magnetic north is 15° east of true north.

Figure 2. Public Land Survey System. The grid on the left shows the Range colums and the Township rows. The grid on the right shows the sections within a single Range-and-Township block. The highlighted square is Section 17, T3N, R1E.



Most compasses can be adjusted to account for this difference, which is called the **magnetic declination.**

Scale:

A map is a relatively small piece of paper representing a large area of the Earth's surface. To do this accurately, a definite scale must be used. Scale states what distance on the map represents a given distance on the ground. For example, the scale of 1:24,000 states that one inch on the map represents 24,000 inches (= 2,000 ft.) on the ground. Any unit can be used (centimeters, feet, thumbnail widths, etc.) as long as the same unit is used for both the map and the ground. For your convenience, scale bars are also given at the bottom center of the map, showing miles, feet, and kilometers.

Please note that the scale bars are centered on zero, with one unit extending each direction. For example, the mile bar has one mile to the right of the zero, and a second mile, divided into tenths, on the left of zero. Thus, the whole bar is two miles long.

Contour Lines:

As mentioned above, a topographic map represents the shape of the ground surface. The map itself is a flat sheet of paper. so the change in elevation (the relief) of the ground surface cannot be shown directly. To show the third dimension, **contour lines** are used. These are printed in brown on most maps. A contour line connects all points of a certain elevation above sea level. To make reading these lines easier, every fifth line is thicker, and from place to place, each is labeled with its elevation. These thicker lines are called **index contours**. For example, the contour line that goes through the Biology Bldg. on campus is 1520'. A specific interval is chosen to separate one contour line from the next one. This contour interval is given next to the scale at the bottom center of the map. For 7 1/2' maps, it is often 40 feet.

Contour lines follow several definite rules:

1. Contour lines never cross.
2. Contour lines never split.
3. Contour lines are very close together where the land is very steep, and are quite widely spaced where the land is nearly flat.
4. Concentric series of closed contour lines represents a hill.
5. Concentric series of closed contour lines with hachure marks on the downhill side represents a closed depression.
6. Contour lines form a V-shaped pattern when they cross a stream. These Vs point upstream.

Examples of these rules in practice are shown in Figure 3-5 on the next pages.

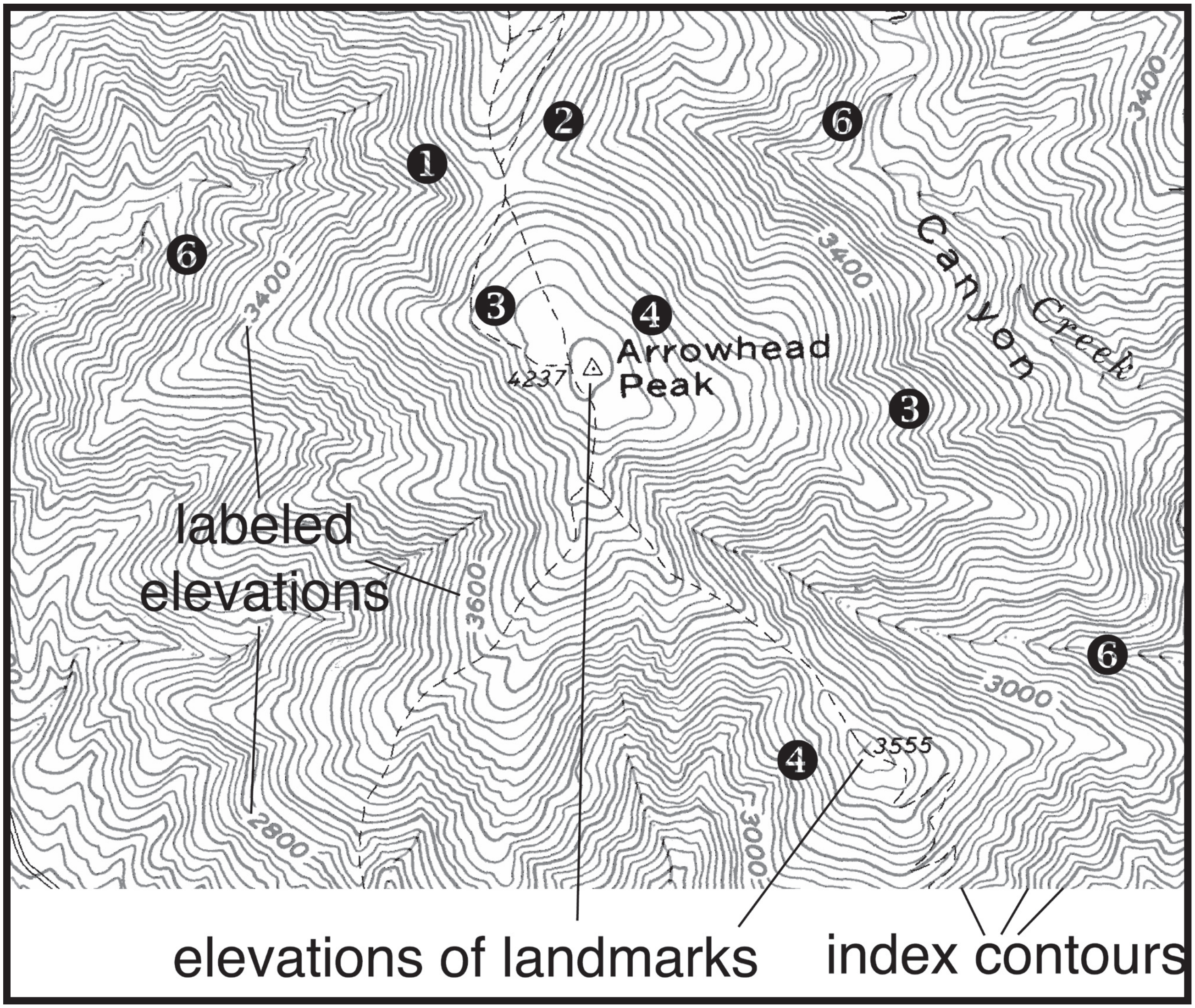


Figure 3. This piece of topographic map from the San Bernardino North Quadrangle illustrates the basic rules that contour lines follow:

1. They never cross.
2. They never split.

3A. They are close together where topography is steep.

3B. They are far apart where topography is gentle.

4. When they form a concentric pattern, that indicates a hill.
5. When they form a concentric pattern with hachure marks indicate a closed depression (fig. on next page). This is an impact crater .
6. They form a "V" that points upstream.

Figure 4. Meteor Crater, Arizona. This is an impact crater from a meteorite that struck about 50,000 years ago. The crater is over 1 km in diameter, and nearly 200 m deep. On the topographic map, note how the concentric contour lines have hatch marks on the inside of each line, indicating a closed depression. Photo courtesy of the U.S. Geological Survey. The Map is a portion of the Meteor Crater, Arizona Quadrangle.

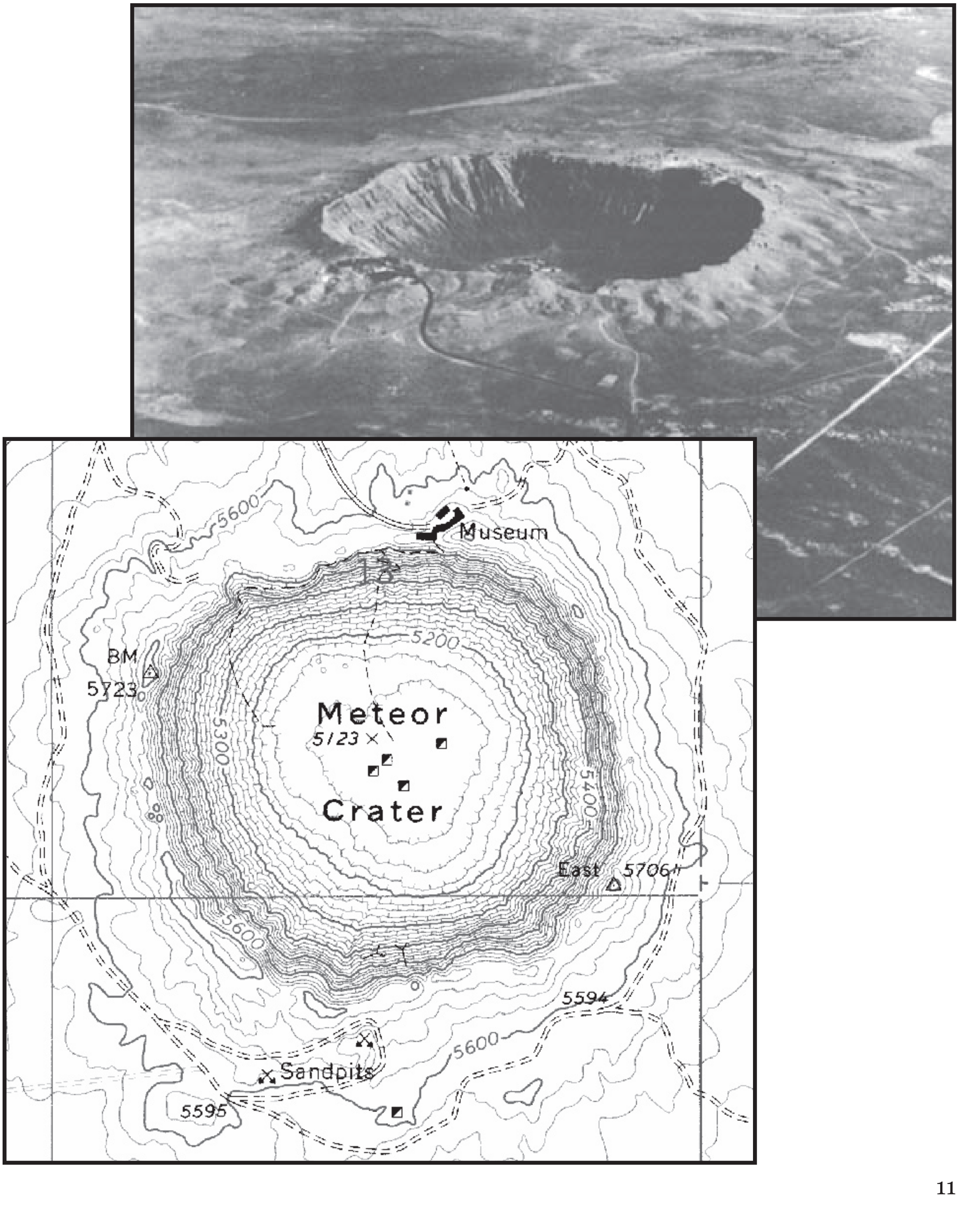


Figure 5. To further illustrate the nature of contour lines, a landscape is shown in perspective view (upper figure) and as represented by a topographic map (lower figure). Note spacing of contour lines in comparison to steepness of the slope. Images modified from those available courtesy of the U.S. Geological Survey.

Exercise 3. Topographic Quadrangles

16. Who publishes these maps?
17. What does the black color indicate for features on this map?
18. What does the gray (or pink) shading indicate for features on this map (e.g., Muscoy)?
19. What does the blue color indicate (e.g., Lake Gregory)?
20. What is the scale of this map?
21. What does that ratio mean?
22. What is the distance (in kilometers, to the nearest tenth) from the north edge of the map to the south edge of the map?
23. What is the contour interval of this map?
24. How much elevation difference is there between index contours?
25. What is the elevation at 117°17'30" W. Long. and 34°12'30" N. Lat.?
26. Describe the general topography in Muscoy (steep or gentle).
27. How did you determine this?
28. What is the elevation of the Biology Building on campus?
29. Small buildings are shown by small squares. What is the elevation of the western-most building in Badger Canyon?
30. Would you gain or lose elevation walking from the Biology Building to that building in Badger Canyon?
31. How much elevation would you gain or lose?
32. How far apart are these two buildings? Give your answer in miles, to the nearest tenth.

Preparation for Lab 2: Earthquakes and Plate Margins.

To practice using latitude and longitude in plotting position, and to think a little bit about one of the aspects of plate tectonics, plot the locations of the earthquakes in the chart on the next page.

A. Using the copy of the tectonic map of the world in the handout, color in the different boundaries the following colors:
   - Divergent - red
   - Convergent - blue
   - Transform - green

B. Plot the locations of earthquakes listed on the table, that occurred between June 11 and June 20, 1991. Note the plate boundary type (or none) for each earthquake in the column on the right.

C. Think about:

What plate boundary type has the deepest earthquakes?

Do all earthquakes occur on plate boundaries?

D. Remember to bring the map to lab next week -- you will need to provide answers to these questions at that time.

Table 1. Dates and locations of earthquakes, to be plotted on the global map handout.

Latitude	Longitude	Depth (km)	Plate Boundary Type*
June 11			
17N	121E	124	
8N	103W	10	
84N	108E	28	
18S	179W	630	
5S	103E	33	
June 12			
2S	79W	95	
15N	96E	10	
59N	163E	33	
43N	143E	111	
June 13			
42N	7W	10	
60N	152W	67	
16S	70W	227	
20S	176W	210	
June 14			
39N	24E	10	
48N	154E	33	
52N	178E	33	
20S	176W	221	

* convergent, divergent, transform, or not a boundary

Latitude	Longitude	Depth (km)	Plate Boundary Type*
June 15			
45N	7E	11	
28N	130E	33	
15N	120E	10	
39N	17E	6	
June 16			
21S	179W	500	
38N	22E	10	
June 17			
23S	70W	203	
62N	150W	33	
43N	75W	5	
20S	178W	515	
June 18			
51N	115W	5	
38N	26W	10	
82N	119E	33	
June 19			
13N	90W	33	
34N	118W	5	
46N	122W	12	
June 20			
20S	178W	435	
55N	161W	33	
11N	62W	110	
40N	9W	10	

LAB 2. PLATE TECTONICS AND SAN ANDREAS FAULT

MATERIALS:

You bring: Lab Manual, pen and pencil, scratch paper, calculator (optional), comfortable clothes, good walking shoes, hat and sunscreen, water.

Supplied: work sheet, San Bernardino North map, red, green, and blue pencils, ruler.

SPECIAL NOTE:

We will meet at the **usual lab time** and in the **lab room**, unless your instructor tells you otherwise. After we finish working on the maps, we will walk to the San Andreas fault. The trip is a walk uphill on dirt roads about half a mile to the main trace of the San Andreas fault, which is the plate boundary between the Pacific Plate and the North American Plate. Wear comfortable clothes that are appropriate for the weather that day, and good walking shoes. Leather soles and/or heels are not suitable. Bring your topographic maps. We will be out for the rest of the lab period, so bring water, and a snack if you'd like.

PLATE TECTONICS

The crust of the Earth can be **oceanic crust**, which is thin and dense, or it can be **continental crust**, which is thick and relatively low in density. This is important to how the plates behave relative to one another due to the characteristics of each type of crust:

oceanic crust: composed mainly of basalt, averages 5-8 km thick, and has a density of about 3.2.

continental crust: composed mainly of granite, averages 40 km thick, and has a density of about 2.7.

The crust of the Earth consists of about half a dozen large slabs, or plates, and several small plates. These plates float on the underlying mantle, and move with respect to each other. Three directions of motion between two plates are possible. They can move towards each other, in which case the boundary along which they run into each other is called a **convergent margin**. They can move away from each other, in which case the boundary between them is called a **divergent margin**. The third possibility is that they can slip side to side past each other, in which case the boundary between them is called a **transform margin**. Each type of boundary generates a characteristic set of geologic features, which are outlined below.

Exercise 1. Earthquake Locations.

1. What plate boundary type has the deepest earthquakes?
2. Do all earthquakes occur on plate boundaries?

Convergent Margins:

Subduction zones

Along a convergent margin, two plates move towards each other. This is obviously going to create a problem with where to put the edges of the plates. Generally, the denser plate goes down into the mantle (subducts), where it is eventually absorbed. If one plate is of continental crust and the other is oceanic crust, the oceanic plate subducts, as it is the denser plate. If both plates are of oceanic crust, the older plate subducts, because as a plate gets older, it cools and contracts, becoming denser. If both plates are of continental crust, neither can subduct, as continental crust is of too low density to subduct. In this case, a collision zone forms, creating very large mountain ranges, such as the Alps and the Himalayas.

Trenches

Where the two plates meet, the subducting plate bends as it begins to go down. This creates a very deep trough on the sea floor, called a trench. All the deepest parts of the oceans occur in such trenches, such as the Marianas trench, the Peru-Chile trench, the Japan trench, etc.

As with any basin or trough, trenches tend to accumulate sediment. Trenches accumulate more than most because they are right next to the overriding plate, which has a substantial mountain belt along its leading edge. These mountains are eroding, which provides a major source of sediment. This accumulation of sediment in the trench gets disrupted by the bulldozer action of the overriding plate against the subducting plate. As a result, the chaotic mix is called **melange**, for its stirred aspect.

Earthquakes

As you might suspect, two plates grinding and scraping together as they converge generate a lot of earthquakes. Convergent margins can generate larger earthquakes than any other plate tectonic setting. This is true for two reasons: 1) rocks are stronger in compression than tension, and 2) the plates are thickened along the margin. Both factors contribute to larger earthquakes because the stronger the rock is, the more energy it takes to break it. The energy that goes into it is released when it breaks, generating the earthquake. So, as more energy goes in, the larger the resulting earthquake.

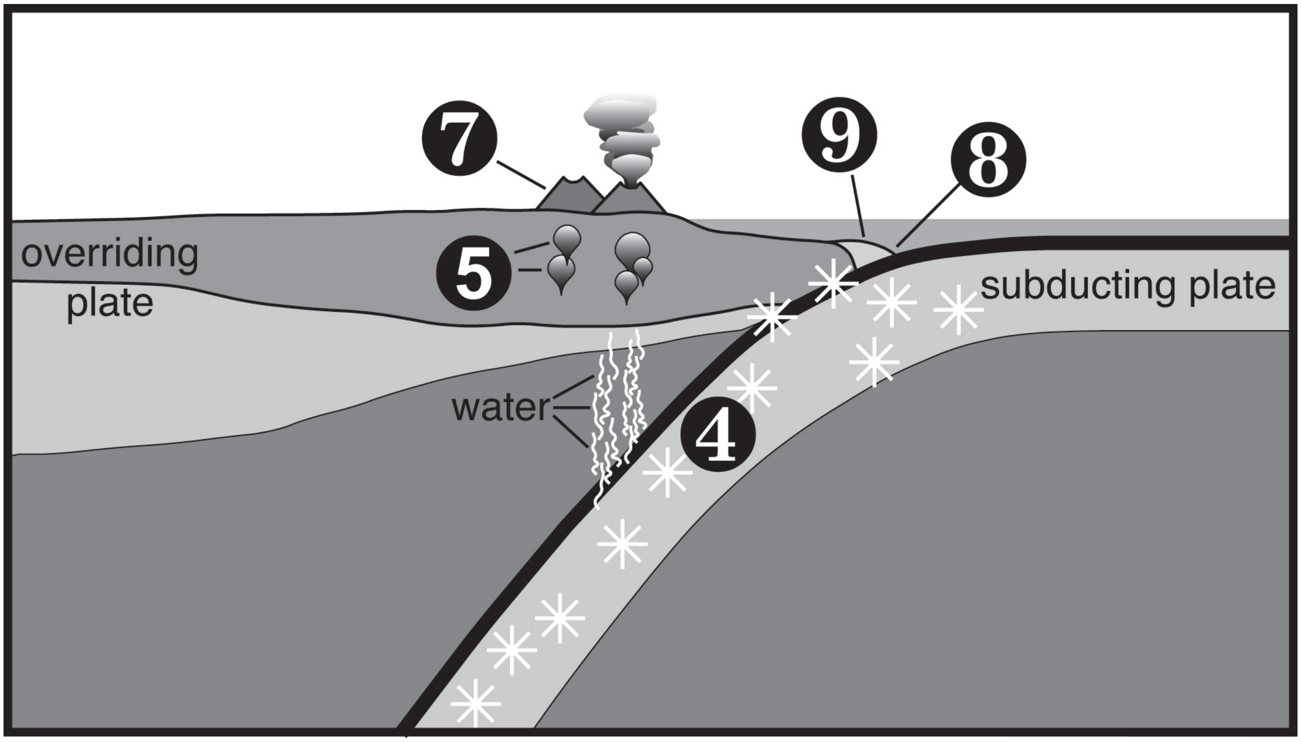
Earthquakes occur in rocks that are relatively cold, therefore brittle. The subducting slab is quite cold, having sat around as the sea floor for a couple hundred million years, and rocks conduct heat poorly, so they heat up slowly. Thus, the subducted plate stays cold enough to generate earthquakes until it is quite deep in the mantle. These earthquakes have been recorded as deep as 700 km. Hugo Benioff noticed that earthquake sources get deeper under the overriding plate proceeding away from the trench. He realized that this inclined array of earthquake sources indicate the position of the portion of the plate that has already been subducted. Thus, that pattern of earthquakes is known as a **Benioff zone.**

Mountain belts

The overriding plate buckles and crumples along its leading edge, forming large mountain belts of folded and faulted rocks. The Andes and the Canadian Rockies are examples of this type of mountain belt. Built on top of these already substantial mountains are a series of volcanoes, discussed next.

Volcanic activity

As the subducting plate goes down, it carries with it small amounts of water from the sea floor. This water acts exactly like antifreeze on the rocks it encounters in the subduction zone. It lowers the melting point of those rocks, partly melting them, which generates bodies of molten rock (**magma**). This magma is less dense than the surrounding solid rock, so it rises buoyantly through the crust (a slow, complicated process). Some of it rises as far as the surface, where it can erupt (molten rock on the surface is called **lava**). It cools and crystallizes, forming volcanoes made of a rock called **andesite** (the name given to this composition of rock). The magma that does not make it to the surface eventually cools and crystallizes as well, but does so very slowly, so the resulting rock looks quite different than the quickly cooled andesite. Because it looks so different, it gets its own name (**diorite**). More on that in the Igneous Rocks Lab.



Exercise 1. Convergent Margins.

3. What is the relative motion between these two plates?
4. What is the composition of the subducting plate?
5. Why is it subducting?
6. A. What events mark the position of the plate after it has been subducted? These are represented by the white asterisks on the figure.
   B. What range of sizes can these be?
   C. How deep can these occur?
   D. What is the name of this array?
7. What material is produced by the water that the subducted plate introduced to the bottom of the overriding plate?
8. What is the composition of that material?
9. What feature does that material form on the overriding plate?
10. What is the topographic feature along the actual boundary of the two plates?
11. What is the material that fills in this topographic feature?

Magma with an andesitic composition produces fairly violent eruptions. Some recent examples include Mt. St. Helens in the U.S. (1980), Mt. Pinatubo in the Philippines (1992), and Montserrat in the Caribbean (1996).

Divergent Margins:

Spreading pattern

Two plates moving away from each other form a divergent margin where they part. As their trailing edges move, a gap forms in their wake. Magma formed in the underlying mantle wells up, cools, and crystallizes into rock, attaching itself to these trailing plate edges. In this way, new crust is formed. This new crust forms a stripe on the edge of each plate parallel to the spreading center. Because it attaches itself to both edges, new crust forms symmetrically on either side of the spreading center. These stripes of crust are brand new next to the spreading center, and are progressively older proceeding away from it. These stripes of rock do not look different from each other, but are identified by their magnetic signatures and by their ages.

Volcanic activity

The magma that forms in the mantle and erupts to form new crust at divergent margins is **basaltic** in composition. Right near the spreading center the newly formed crust is still fairly hot, as is the underlying mantle, so the crust is only 1-2 km thick. As the plate moves away from the spreading center, it continues to cool, which allows additional material to solidify against the underside of the crust, thickening it to 5-8 km thick. Because this crust is made of basalt, which is dense, and it is relatively thin, it floats low on the mantle. Thus, crust produced at spreading centers forms vast areas of low-lying crust. Water flows downhill to fill in low places, so this crust is almost always covered by water, and sea water at that. Because of that, this kind of crust is called oceanic crust.

Basalt forms a lava that is relatively thin and runny (has a low **viscosity**). It tends to form flows, so it forms very broad, gently sloping volcanoes, called **shield volcanoes** where it erupts on dry land. When it erupts underwater, the water quenches the lava quickly, so it takes on bulbous forms called **pillow basalts**, as pictured in your text. Because basalt has a low viscosity, it is not generally very explosive when it erupts.

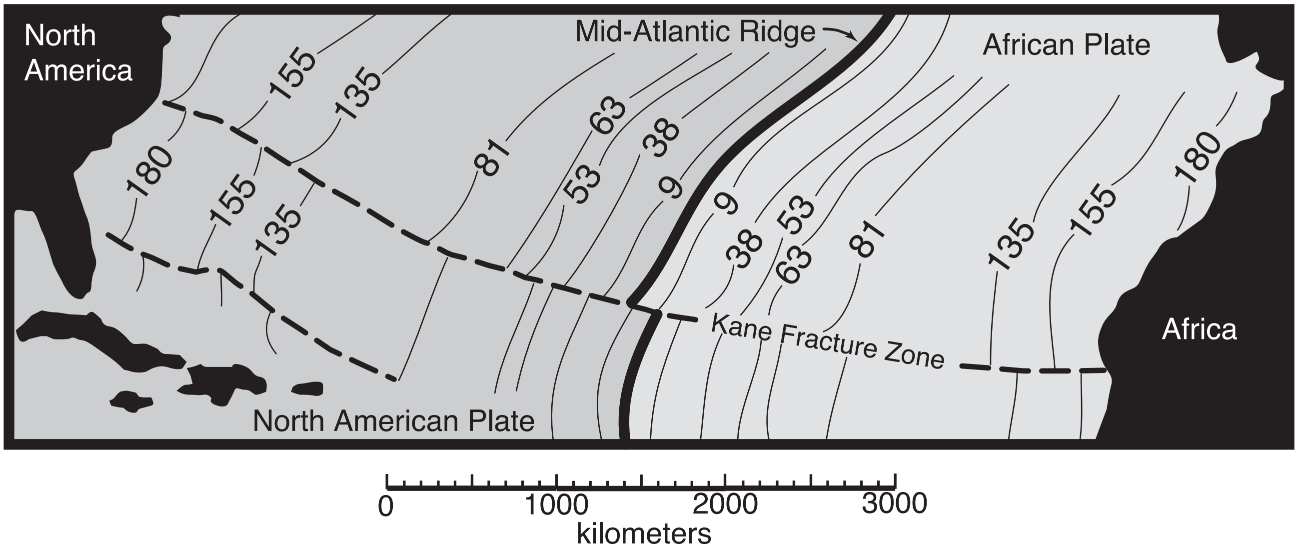
Earthquakes

Earthquakes along divergent margins tend to be small to moderate in magnitude. The newly formed crust is still fairly thin, so not much crust exists to break when faults form. Also, the crust is pulling apart, and rocks are weaker in tension than in compression. Both factors contribute to making the crust easy to break. Not much energy goes in, so not much energy comes out when a fault moves, so earthquakes are not very large. A magnitude 5 event is a big one for a divergent margin.

Transform Margins:

Direction of Motion

Two plates that meet along a transform margin slide side-to-side past each other. California is divided along most of its length by a **transform plate margin** — the San Andreas fault. East of this fault lies the North American plate, and west of the fault lies the Pacific plate. This includes CSUSB, most of the developed portions of southern California, and the California coast north to the bay area. The Pacific plate is moving north relative to the North American plate about 2.5 cm/yr, or about an inch per year,on average. This average must be determined over a long period of time, because the fault “sticks” and will not move at all for up to a 200 or 300 years, then it will break (generating an earthquake), and move sev-



Exercise 3. Divergent Margins

The map above is of a portion of the North Atlantic sea floor. The numbered lines indicate the age of the ocean floor in millions of years (Ma). The heavy lines indicate plate boundaries.

Answer the following questions, expressing spreading rate in two ways:

A. in kilometers per millions of years (km/Ma)

B. and in millimeters per year (mm/yr).

For example, between 81 and 135 Ma, 1000 km of new crust was produced, so the spreading rate was 1000 km/54 Ma = 18.5 km/Ma.

To convert to mm/yr, multiply the km by the number of mm in a km, and restate Ma in yr. Remember that there are unit conversions on page 4 of this lab manual.

12. What type of plate margin is the Mid-Atlantic Ridge?
13. Part of the Kane Fracture Zone lies between segments of the Mid-Atlantic Ridge. What type of plate margin is the that portion of the Kane Fracture Zone?
14. What was the spreading rate of the Mid-Atlantic Ridge between 63 Ma and 53 Ma?
15. What was the spreading rate of the Mid-Atlantic Ridge between 135 and 155 Ma?
16. What was the spreading rate of the Mid-Atlantic Ridge for the past 180 Ma?
17. Has the spreading rate changed through time?
18. When did North America and Africa begin to diverge?
19. What magnitude earthquakes are likely to mark the position of the Mid-Atlantic Ridge?

eral meters all at once.

This boundary is one of the longer transform margins in the world, and it is unusual in that it occurs on continental crust. Most transform margins occur between segments of divergent margins, and thus are found in oceanic crust. They are useful features to geologists because they are parallel to the motion of the two plates they separate.

Earthquakes

As with any plate boundary, the motion between the two plates generates earthquakes. Crust along a transform margin is under more compression than is crust at a divergent margin, so earthquakes can be bigger than those at a divergent margin. However, the rocks are not under as much compression as those at a convergent margin, nor is the crust so thick as it is there, so we are not at risk for the exceedingly large earthquakes possible along a convergent margin. Transform margins are in the middle, generating moderate to strong earthquakes depending on what kind of crust they occur in. Here in California, where the boundary cuts through continental crust, it may generate earthquakes up to the magnitude 8 range.

Offset features

Because transform margins neither create nor destroy crust, they do not tend to build extensive mountain ranges. Their most distinctive characteristic is the offset they produce in rock formations and in surface features. These include:

bedrock mismatch - If a transform margin cuts across a rock formation, it will cut it in two as it moves, and offset each piece relative to its counterpart. Matching back such offset units is one way to determine the movement history of a transform system.

offset streams - Because the fault only moves occasionally, stream channels can get established across the fault. When the fault moves, it separates the upstream portion of the channel from its downstream extension. Stream water often flows down its channel, then turns and follows the fault until it encounters its downstream continuation, and flows on down. This angular jog in the stream channel can form an obvious pattern on the landscape, especially if several streams all jog the same directions.

sag ponds - Faults in general tend to produce lines of springs because groundwater percolates easily through the fractured rock of a fault. If a spring comes up in a low spot, it pools and forms a pond. Lost Lake north of Devore is a sag pond.

shutter ridges - If a fault moves a portion of a ridge over across a drainage, that ridge will form a dam across the drainage. The ridge “shuts off” the drainage, so it is called a shutter ridge.

linear valleys - Valleys formed by erosion of intact bedrock tend to wander back and forth and branch, forming a pattern resembling tree branches. Faults tend to be planar features, so the edges of them form straight lines. Faults are also easy to erode because the rock in the fault zone is fractured. Thus, valleys that are quite straight are probably controlled by the presence of a fault. For example, the San Andreas fault runs right up the middle of Lone Pine Canyon near Wrightwood.

offset manmade features - Probably the most memorable images of the power of an active fault are produced by offsets of manmade features. Roads that are torn in two, fencelines, pipelines or lines of telephone poles that no longer are one straight line, or houses that are pulled apart, speak to us much more effectively than the same offset of some natural feature.

SAN ANDREAS FAULT FIELD TRIP

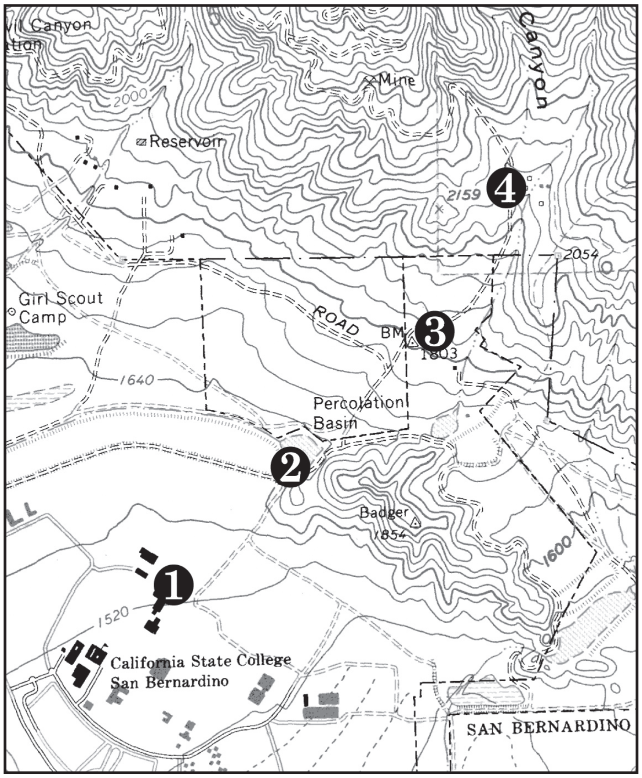


Figure 3. Map of stops for the fault hike.

A Few Facts and Figures:

- The North American plate moves an average of about 47 mm/yr relative to the Pacific plate.
- The San Andreas fault takes up about 25 mm/yr of this motion.
- The observed bedrock offset across the San Andreas fault is about 250 km.
- The Landers earthquake (M7.4) produced maximum offsets of about 5 m.
- The last time that this part of the San Andreas fault may have broken was in 1812.

In-Lab Questions:

20. How long would it take to accumulate enough motion for a Landers-size earthquake?
21. If this section of the San Andreas fault breaks similarly to the rupture of the Landers earthquake, how many earthquqakes of this size have occurred in the past?
22. How many years ago did this segment of the San Andreas fault break the last time?
23. When might we expect the next rupture to occur?

Stop 1: North side of Biology Building.

***View of San Andreas Fault*.**

From here, look north to the base of the mountains. You can see a sharp break in the topography, from the gentle incline of the alluvial apron nearer to us, to the more rugged, irregular slopes of the mountains themselves further away. The line marking that change is the main strand of the San Andreas fault.

Line of Trees.

Along that line marking the change in topography you can see a line of trees and shrubs. If it has not rained for a long time, you can also see that vegetation along this line is also much greener than vegetation either above on the mountain slopes or below closer to campus. The trees and generally greener vegetation is supported by a line of springs that come up along the fault. Faults are often marked by springs because the rock in the fault zone is ground up, making it easy for water to percolate through, and because movement across the fault can juxtapose rocks of very different permeabilities, forming a seal on one or both sides. Such seals force water to the surface, forming springs.

Stop 1 Questions:

24. What is the elevation at this stop?
25. What Plate Tectonic feature does the San Andreas fault form?
26. Find the line of trees to the north. Why are they growing there?
27. What is the elevation of that line of trees?

Stop 2: North end of Badger Hill.

Pelona Schist.

Pick up a piece of this rock and look at it closely. You can see that it is well layered, and is composed primarily of small flakes of micas. Such a rock is called schist (you will see more of this in the Metamorphic Rocks lab). It is a metamorphic rock that was produced by subjecting the sedimentary rock shale to higher temperatures and pressures, which caused the original clay in the rock to recrystallize into micas. Why is the presence of this rock near the San Andreas fault interesting? First, one of the ways to detect the presence of a fault is that it has moved different kinds of rocks next to each other (i.e., the rocks don't match across the fault). In this area, this unit, the Pelona Schist occurs only on the southwest side of the fault. To find it on the northeast side of the fault, we would have to go about 300 km to the south to the Orocopia Mountains. How is this information useful in figuring out the history of the San Andreas fault?

Joints.

Joints, or cracks in the rock, form by wedging the rock apart through freezing and thawing of water in the cracks and through the growth of plant roots. Such crack formation is part of **weathering**, the group of processes that break rocks down and start the process of soil formation. As you can see, the rocks exposed in this roadcut are thoroughly jointed. Joints generally occur in sets, each of which has a more or less uniform orientation. Here, one set is parallel to the layering of the rock, and the other sets are perpendicular to the layering.

Talus piles.

After joints have formed in the rock, the rock is actually composed of many separate chunks. Further wedging apart of these chunks can push them out to the point that they overbalance, and fall down the exposed face. This gravity-driving movement is called **mass wasting**. The pile of loose rocks that accumulates by this process is called a talus pile. Often these are cone shaped, so they are also called **talus cones.**

Percolation basins.

In many places around southern California, earthen dikes are built to catch water that runs out of canyons. The purpose of the basins formed by these dikes is to allow that water to percolate into the ground, and to protect developed areas from flooding. Allowing this water to seep into the ground helps recharge the groundwater, replacing some of what we extract through wells.

Stop 2 Questions:

28. What is the elevation at this stop?
29. What is the elevation at the top of Badger Hill?
30. What type of rock forms Badger Hill?
31. List two geologic processes that are operating on these rocks.
32. List two features produced by these processes.
33. What is the man-made feature that is just west of where we are standing? What is its purpose?

Stop 3: Main fault scarp.

Now we are standing on the main strand of the San Andreas fault, which forms the plate boundary between the North American plate to the northeast and the Pacific plate to the southwest. Not very exciting at first glance, is it? However, the features right around us tell us much about the significance of the spot on which we are standing.

Fault scarp.

We walked up a steady incline from the last stop at Badger Hill until we got to the last bit up this hill, when it got much steeper. As we look back down, we can also see there is another, smaller steep section we walked up. These are both fault scarps, probably produced during the last time this segment of the fault ruptured. The San Andreas fault is a strike-slip fault, meaning that rocks on the two sides of the fault move horizontally past each other. How then can vertical scarps such as these form? One way is for the fault simply to cut through a hill, and move one side of it over, next to a valley. Another way is for the two sides of the fault to buckle slightly as they move, to accomodate local stresses in the rocks along the fault. Which do you think happened here?

Hummocky topography.

As you look around, you can see that the ground here is a jumble of small hills and valleys, with no well-integrated system of higher ground to the northeast. This is typical of fault zones. Normally, through time, runoff from rainfall produces a drainage pattern across the ground. When a fault breaks and the two sides move, this pattern is disrupted. When this happens repeatedly, the drainage pattern becomes completely chaotic, as you see here.

Brecciated rocks.

Look at the ground around us, and you may be able to see that the bedrock is completely smashed in this area. If we are at the end of a dry spell, this may be covered by a layer of dust churned up by the dirt bikes that frequent these roads (if so, trust us, it's there). This brecciated rock forms a zone about 100 m wide here, suggesting a long history of movement along this fault to have ground up so much solid rock.

Fault history.

As mentioned above, the San Andreas fault is a strike-slip fault, which means that the blocks on either side of the fault move horizontally past each other. If you stand on one side of the fault and look across to the other side, that side can move one of two directions. If it moves to the left, the fault is called a left-lateral fault. If it moves to the right, it is called a right-lateral fault. This is a convenient way to classify these faults, because it does not matter which side of the fault you stand on to determine this. As the two blocks continue to move, will San Bernardino get closer to or farther from Victorville? What would happen to us if the fault ruptured while we are standing on it? What would happen to campus? What would happen to Interstate 15 in Cajon Pass?

Stop 3 Questions:

34. What is the elevation at this stop?
35. If the fault moved right now, which direction would the opposite side move with respect to you (left, right, up, or down)?
36. Assuming this segment of the fault breaks similarly to the fault that produced the Landers earthquake, how far would we expect it to move?
37. Why do we think that a large magnitude earthquake will occur along this section of the San Andreas fault?

Stop 4: North strand of fault.

In this part of the San Bernardino Mountains, the San Andreas fault has broken into two strands: the main fault and this north strand. While this strand probably has not moved as far as the main fault, it does have the advantage for us in that the fault surface is actually exposed along a road cut. Here, actually we see two faults. The first one placed alluvial fan gravels against brecciated (fractured) granite, and the second one placed soil against the granite.

Sag ponds and shutter ridges.

Note how the soil is quite thick and dark, and how it forms a depression behind the granite. Before the half we are standing on was cut away, this probably formed a small basin, which was likely filled with water. The rich dark soil formed at the bottom of this pond. Such ponds are called **sag ponds**, and are characteristic features of faults like the San Andreas, which move side to side and can block drainages by moving a ridge over against a stream bed. Such ridges are called **shutter ridges**. Here, the granite probably formed the shutter ridge that formed the pond.

Springs.

As with the main strand of the fault, this north strand is marked by a line of springs. The palm trees and other large trees just upstream from this stop are supported by spring water, which is always available. They were planted as part of the landscaping for the old nudist camp that used to exist at this site (the building foundations are still there), but they survive nicely on their own because they have a reliable water source. If you follow this strand of the fault to the east into Waterman Canyon, you will find Arrowhead Springs, a rather better-known part of this spring system.

Stop 4 Questions:

38. What is the elevation at this stop?
39. What is the elevation of the Biology Building on campus?
40. How far have you climbed from there to here?
41. Does this explain why you are out of breath?
42. Why does this portion of Badger Creek flow year-round?
43. What are the rock types on each side of the fault at this stop?
44. Which is steeper, Waterman Canyon or Badger Canyon?
45. How did you determine that?
46. Which direction does the stream in the bottom of Badger Canyon flow (north, south, east, or west)?

LAB 3. EARTHQUAKES

MATERIALS:

You bring: Lab Manual, textbook, pen and pencil, scratch paper, calculator (optional).
Supplied: work sheet, ruler, protractor.

EARTHQUAKE WAVES

An earthquake is the shaking of the ground that results from a sudden rupture and movement along a fault. Stress builds up across the fault until it exceeds the strength of the rock, which then breaks. Each side of the fault rebounds as the stress is released, generating seismic waves. These waves fall into three catagories:

Primary waves (P waves) — These waves travel the fastest, so they are the first to arrive at a seismic station, giving them their name. They are compression/expansion waves, and can travel through solids and liquids.

Secondary waves (S waves) — These waves travel slower than the P waves, so they are the second series of waves to reach a seismic station. They are shear waves, and can travel through solids only.

Surface waves — These waves travel still slower, and are confined to the surface of the Earth's crust. They produce a vertical and/or lateral rolling motion, like waves on water.

RECORDING AN EARTHQUAKE

A seismograph is an instrument that records small movements of the Earth produced by earthquakes. Older seismographs use inertia to measure movement of the Earth. A simple inertial seismograph may be constructed using a heavy object that is hung from a stable foundation that is attached to the Earth. This allows the Earth to move without moving the weight. If a pen is attached to the weight and paper is attached to the foundation, then movement of the Earth will produce a line on the paper showing how much the Earth moved (the amplitude of the seismic waves) in one direction. By attaching the paper to a rotating drum, we can record the movement of the Earth through time. Modern seismographs are produced by more sophisticated instruments which turn the movement into an electric signal which is recorded on a computer and/or sent to a printer. The modern variety accomplishes the same end as our unsophisticated inertial seismograph, but allows a variety of ways to store the records.

DETERMINING DISTANCE TO AN EARTHQUAKE

The actual speed a seismic wave travels depends on the density and rigidity of the rock through which it travels. However, the **difference** between the speed of P waves and S waves remains proportional regardless of the exact speed at which they are traveling. When we feel an earthquake, we do not know when or where those waves originated, but we do know how fast they travel, and we do know when we felt them. We can use this information to figure out the other questions, as illustrated in the next couple of questions for you.

Exercise 1. Distance to Epicenter.

Given that waves traveling through solid rock are a little hard to visualize, here is an analogous situation, where two vehicles behave in the same way as primary and secondary waves do.

Following an earthquake, two seismologists inspect the surface rupture of the fault that generated the earthquake. When they are finished collecting data, they get in their cars at the same time, and return to campus. One drives 60 mph; the other drives 35 mph. One arrives back at campus at 3:00 pm, and the other arrives at 4:45 pm.

You know that

D = rt, where
D = distance,
r = rate of travel, and
t = time of travel.

The distance traveled for both vehicles is the same, as is the starting time for both vehicles.

1. How far did they drive?
2. On Figure 1, what is the difference (in seconds) in S wave and P wave arrival times? Using Figure 2, how far away was that earthquake (in kilometers)?

LOCATING AN EARTHQUAKE

A single seismic station records the arrival of the P waves, S waves, and surface waves, as shown in Figure 1. From this information you can determine the **distance** from that seismic station to the epicenter of the earthquake, but this information by itself will not tell you in which **direction** it is. Thus, using the information from one seismic station, the epicenter of the earthquake could be anywhere on a circle centered on the seismic station whose radius is the distance determined by the time interval between the arrival of the P waves and the S waves, as shown in Figure 3A. To figure out **where** on that circle the epicenter is located, data from two additional seismic stations are needed. Repeat the calculation to determine the distance to the epicenter for each of these stations, and draw circles with those distances as the radii around each seismic station, as shown in Figure 3B. These three circles will coincide at the epicenter of the earthquake.

Questions:

3. Using Figure 2, determine the distances from the epicenter of stations with S-P arrival time differences of:

 5 seconds
 8 seconds
 12 seconds
 17 seconds

4. Find and label the epicenter on the map on the worksheet for an earthquake that records the following data:

Station	Distance to epicenter
A	700 km
B	650 km
C	400 km

5. Under what special circumstance would it be possible to determine the exact epicenter of an earthquake using only two seismic stations?

SIZE OF AN EARTHQUAKE

Richter Magnitude

In 1935, Charles F. Richter defined the magnitude of an earthquake to be determined by taking the logarithm of the largest amplitude wave for an earthquake, as

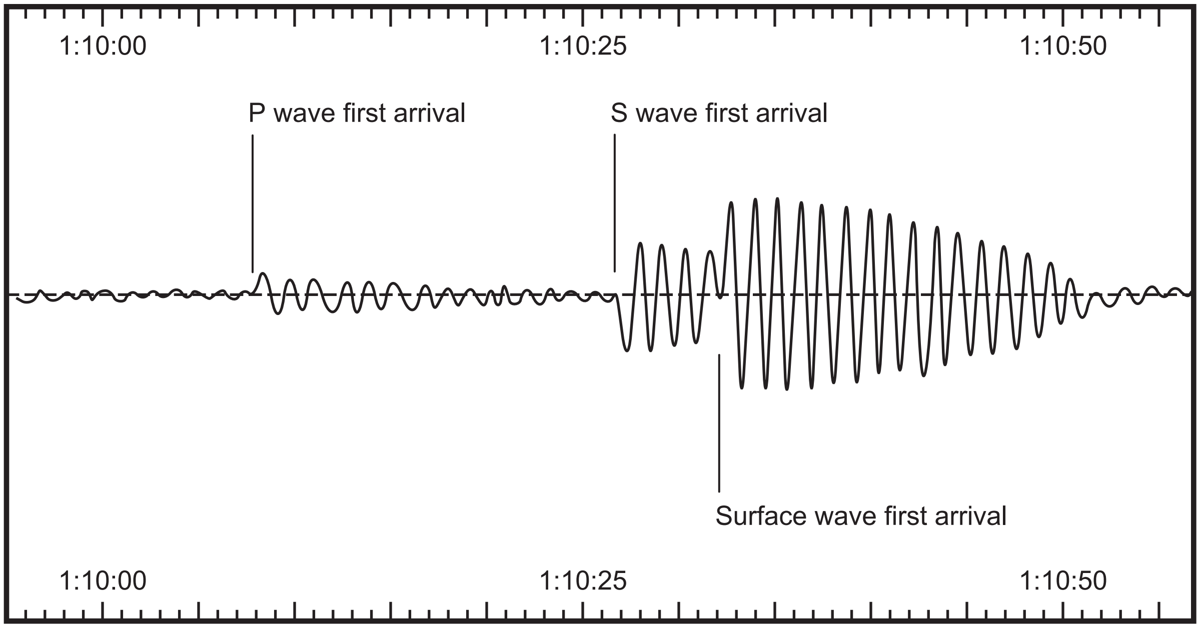


Figure 1. Sample seismogram, showing P waves, S waves, and surface waves. The time line along the top and bottom of the chart is hours:minutes:seconds, with each tick mark being one second. To determine the time of first arrival of a wave, use the beginning of that wave, as marked for each wave. For example, the first arrival of the surface wave occurred at 1:10:32.

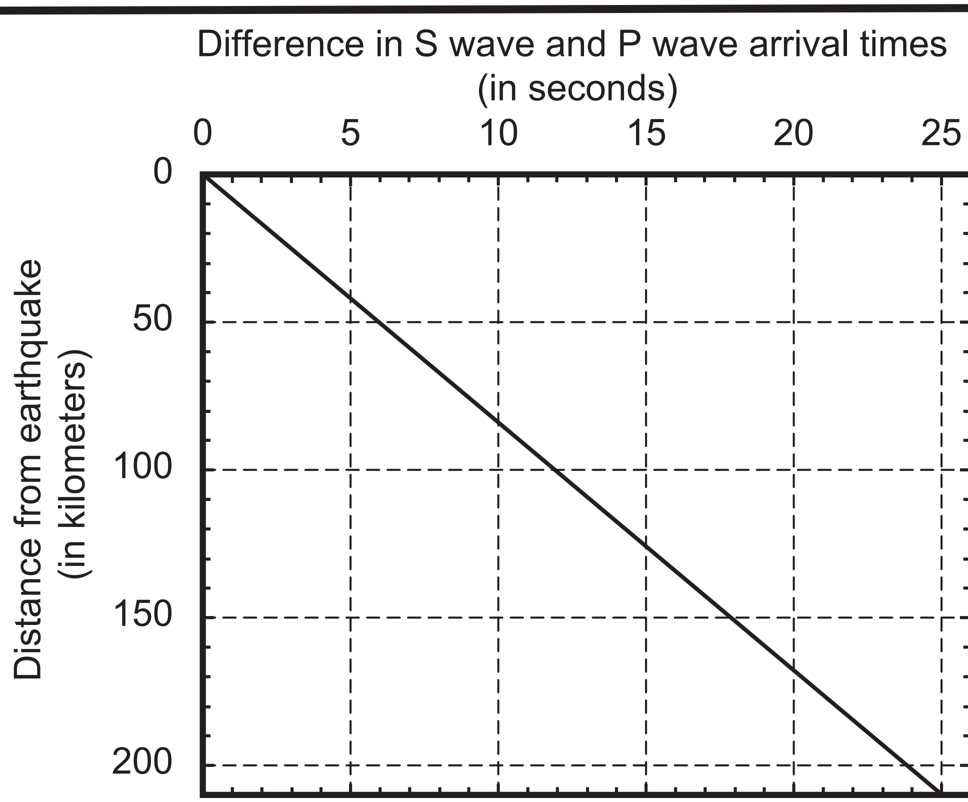


Figure 2. Graph of S wave - P wave arrival time difference relative to distance to earthquake. For example, the epicenter of an earthquake with an S-P arrival time difference of 10 seconds is 85 km away.

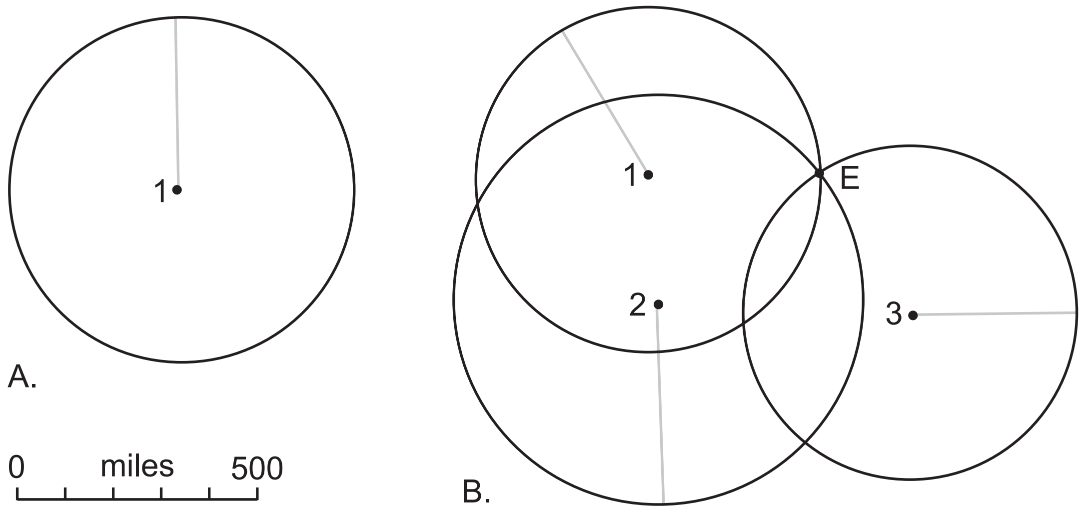


Figure 3. Illustration of general technique used to locate the epicenter of an earthquake. Numbered points are seismograph stations; E = epicenter. A. Earthquake could have occurred anywhere on the circle around the seismograph. B. Earthquake could only have occurred where all three circles intersect.

recorded on a seismogram, measured 100 km from the epicenter. He defined a magnitude 0 (M0) earthquake to produce a movement of 1/1000 of a millimeter at 100 km from the epicenter:

$1/1000 \text{ mm} \times 10^0 =$
$1/1000 \text{ mm} \times 1 =$
$1/1000 \text{ mm}$

He chose this as the minimum, because it was the smallest amplitude that could be measured at that time.

Because seismic wave amplitudes range over a very large extent, listing the actual numbers is cumbersome, so the logarithm is used. Therefore, each succeeding magnitude earthquake produces 10 times the wave amplitude of the preceding magnitude. For example, an M1 quake produces waves 10 times the amplitude of an M0 quake ($1/1000 \text{ mm} \times 10^1 = 1/1000 \text{ mm} \times 10 = 1/100 \text{ mm}$), and an M2 quake produces waves 10 times the amplitude of an M1 (100 times an M0) and so on.

Questions:

6. What is the Richter defined amplitude of a M5 earthquake that is measured at 100 km from the epicenter?
7. How much more energy is released by an M6 quake than an M5 quake? an M7 vs. M5? an M8 vs. M5?
8. How many M5 earthquakes would it take to equal the energy release of an M6? an M7? an M8?
9. If there were no humans on earth and an M10 earthquake occured, what would the Mercalli Intensity of that earthquake be? Why?

Energy Release

Because the stored elastic energy released by the earthquake is directly related to the amplitude of the waves that are produced, the amount of energy released by an earthquake increases as the magnitude increases. The energy increases, however, as a factor of about 30, not as a factor of 10 as does the amplitude. So the energy released by an M2 quake is 30 times that released by an M1 quake and an M3 quake releases 30 times the energy of an M2 quake (or 30 x 30 = 900 times an M1 quake) and so on.

Intensity of Ground Shaking

Ground shaking caused by an earthquake is generally most intense near the epicenter and diminishes as distance from the epicenter increases. The scale most commonly used in the United States to quantify ground shaking is the Modified Mercalli Intensity Scale. It was originally developed by the Italian seismologist G. Mercalli in 1902, and has been modified by H.O. Wood and F. Neumann (Table 1). This scale is defined by human observation and destruction of human structures. As you can see in the table in this lab manual, the Modified Mercalli Intensity Scale is a subjective measure of the severity of the shaking caused by an earthquake. The severity of shaking (the amplitude and duration), and therefore damage caused, will vary not only with the magnitude of the earthquake and distance from the epicenter, but also with the type of rock or sediment is present. For example, the Marina District of San Francisco was more severely damaged than areas closer to the epicenter of the Loma Prieta earthquake (1989). The Marina District was built on swampy land that had been back-filled with dirt and gravel, whereas areas closer to the epicenter were built on bedrock. In addition to the severity of the shaking, the damage caused to human made structures is dependent on the types of materials used and the method of construction.

Table 1. Modified Mercalli Intensity Scale

I.	Not felt
II.	Felt by a few people at rest.
III.	Noticeable indoors, especially in upper floors of buildings, but not generally recognized as earthquake.
IV.	Recognized by many. Rattling and creaking of buildings and contents.
V.	Felt by nearly all. Some dishes and windows broken. Unstable objects fall.
VI.	Felt by all. Some heavy objects moved. Damage slight.
VII.	Damage little to considerable in buildings of good to poor construction, respectively. Noticed by automobile drivers.
VIII.	Damage small to specially designed buildings, may collapse poorly built buildings. Auto drivers disturbed. Chimneys may fall.
IX.	Damage considerable to specially designed structures. Ground cracking and broken underground pipes prevalent.
X.	Some well built buildings destroyed. Landslides, water sloshing ground cracking considerable.
XI.	Few buildings standing. Bridges, underground pipes, rails bent or destroyed.
XII.	Damage total. Waves seen on ground surface. Objects thrown into the air.

DETERMINING THE RICHTER MAGNITUDE

One method of determining the magnitude of an earthquake is by the use of a nomogram which graphically relates the distance from the earthquake and the amplitude of the waves to the Richter Magnitude (Figure 4). To use this method, first determine the interval of time between the arrival of the S and P waves at that station (S arrival time - P arrival time). Second, measure the amplitude of the largest wave from the baseline to the peak or trough. Next, plot both of these points along their appropriate axes and draw a straight line between the two points. The Richter Magnitude is read at the point where the line crosses the Richter Magnitude axis.

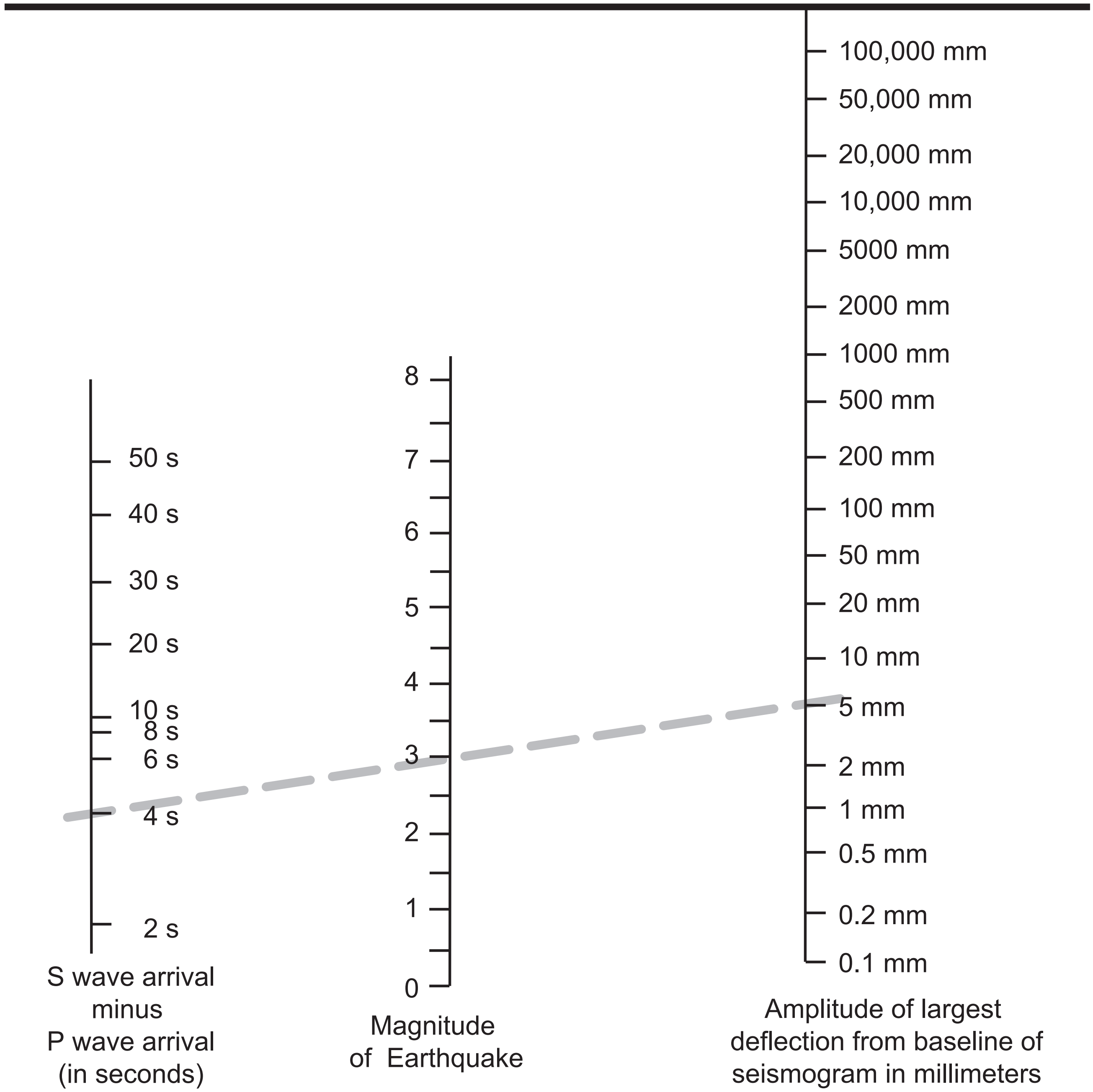


Figure 4. Nomogram for determining the magnitude of an earthquake. For example, if a seismometer registers the delay in arrival of the S wave (S wave - P wave) to be 4 seconds and the amplitude of the wave recorded is 5 millimeters, then the magnitude is 3.0.

Question:

10. Determine the magnitudes of the following earthquakes.

	S-P arrival difference	maximum amplitude
1.	10 seconds	0.2 mm
2.	8 seconds	50 mm
3.	20 seconds	20 mm

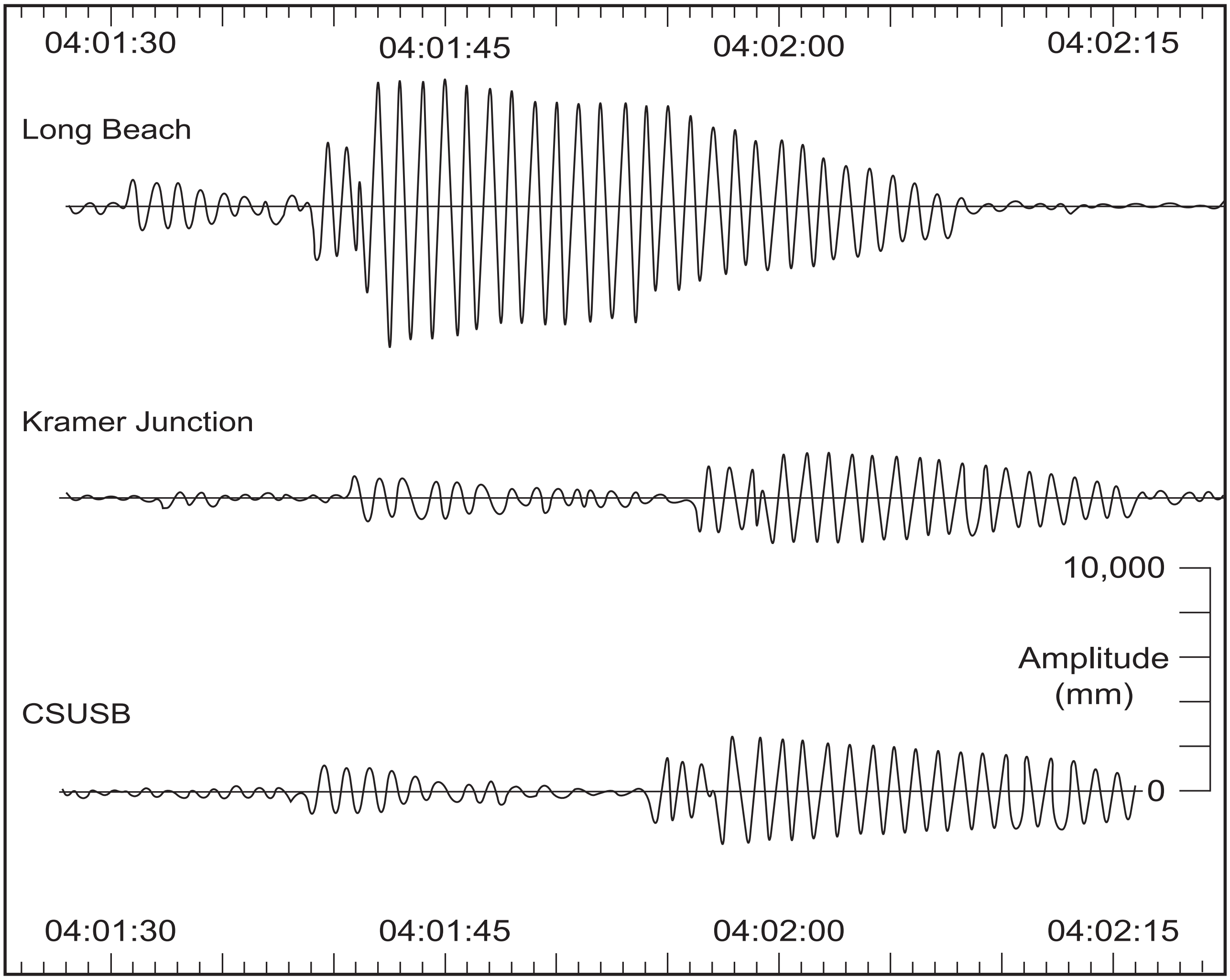


Figure 5. Seismograms recording the same earthquake at three locations. As in Figure 1, time is given in hours:minutes:seconds. Note the amplitude scale given next to the CSUSB seismogram.

Questions:

11. Use the seismograms in Figure 5, the techniques described earlier (and reviewed below), and the map in your work sheet to determine the epicenter of the earthquake.

    Step 1: Use a ruler to mark off the first arrivals of the P waves and S waves on the time scale for each seismograph location. Pick off these times to the nearest half-second and enter them into the appropriate boxes in columns 1 and 2 on the handout. Subtract the P wave arrival time from the S wave arrival time to find the difference, and enter this into column 3 on the handout.

    Step 2: Use the S-P time difference in column 3 to find the distance from the epicenter on Figure 2 for each station and enter that number in column 4.

    Step 3: Draw a circle on the map whose radius is the distance from the epicenter for each station. Where the three circles cross is the epicenter.

Step 4: Label the epicenter on the map, determine and label its map coordinates (latitude and longitude, to the nearest minute).

12. What is the latitude of the epicenter?
13. What is the longitude of the epicenter?
14. What is the name of this location?
15. What was the magnitude of this earthquake? Use the amplitude scale in Figure 5 and the nomogram in Figure 4 to determine this.
16. What was the date of this earthquake? Check Table 2.

Table 2. Major Earthquakes that occurred in California from 1857 to 1994

year	date	location	fault name	type of fault*	max. slip in meters	magnitude	MMI	deaths
1857	Jan. 9	Fort Tejon	San Andreas	rl-ss	(10)	≈8	X-XI	several
1906	April 18	San Francisco	San Andreas	rl-ss	6.4	≈8.25		650
1933	Mar. 10	Long Beach	Newpt./Ingle.		rl-ss	6.2	IX	210
1940	May 18	Imperial Valley	Imperial	rl-ss	5.9	7.1	X	8
1952	July 21	Kern County	White Wolf	ll/thr	1.2	7.7		
1968	April 9	Borrego Mtn	San Jacinto	rl-ss	0.4	6.8		
1971	Feb. 9	San Fernando	Sierra Madre	ll/thr	2.1	6.5	XI	65
1979		Imperial Valley	Imperial	rl-ss	0.8	6.7	IX	
1986	July 8	Palm Springs	Banning	rl-ss		6.0		
1987	Oct. 1	Whittier	blind thrust	thrust	5.9	5.9	VIII	8
1989	Oct. 17	Loma Prieta	San Andreas	rl-ss	2h/1.2v	6.9	VIII-IX	65
1992	June 28	Landers	5 faults	rl-ss	6.7	7.4		1
1992	June 28	Big Bear	new fault	ll-ss	---	??		none
1994	Jan. 17	Northridge	blind thrust	thrust	---	??		72

* rl = right lateral   ll = left lateral   ss = strike-slip   thr = thrust.

LAB 4. ROCK-FORMING MINERALS

MATERIALS:

You bring: Lab Manual, text book (recommended for mineral pictures), pen and pencil, scratch paper.

Supplied: quiz sheets, tray of mineral specimens, hand lens, tools for determining hardness (in your table drawers).

MINERAL PROPERTIES: DEFINITIONS AND TERMS

Mineral:

A mineral is a naturally occurring, inorganic solid with a definite chemical composition and a definite crystal structure. The composition and structure give minerals a characteristic set of physical properties, which we use to identify each type of mineral. These are:

Cleavage:

The tendency of a mineral to break along planes of weak bonds in the crystal structure. Some minerals have one direction of cleavage; some have two, three, four or six. Other minerals do not exhibit cleavage.

Fracture:

A fracture is a break that does not follow the crystal structure of a mineral. Instead, it is a random break with respect to the crystal structure. The most distinctive type of fracture is **conchoidal fracture**, which forms the curved, shell-like breaks such as those seen in glass.

Hardness:

The resistance of a mineral to being scratched. Ten index minerals form the **Mohs Hardness Scale**, with 1 being the softest, and 10 being the hardest.

Density:

The ratio of the mass of a mineral to the mass of the same volume of water. For example, if a block of a mineral one centimeter on a side weighed three grams, and a block the same size filled with water weighed one gram, the ratio would be 3:1, so the mineral would have a density of 3.

Luster:

The way a mineral reflects light. The terms used to describe luster are descriptive, and therefore fairly self-explanatory. The most commonly used terms are:

<u>vitreous:</u> the surface more or less resembles glass.

<u>metallic:</u> the mineral looks like it is made of metal.

<u>dull:</u> the surface has a "matte finish", with no shine.

<u>pearly:</u> the mineral's surface resembles a pearl.

<u>silky:</u> some fibrous minerals have a sheen that resembles silk.

Table 1. Mohs Hardness Scale. * indicates the material can scratch minerals with that hardness.

hardness	index mineral	fingernail (2.5)	penny (3.5)	glass (5.5)	steel file (6.5)	quartz (7)
1	talc	*	*	*	*	*
2	gypsum	*	*	*	*	*
3	calcite		*	*	*	*
4	fluorite			*	*	*
5	apatite			*	*	*
6	orthoclase				*	*
7	quartz					
8	topaz					
9	corundum					
10	diamond					

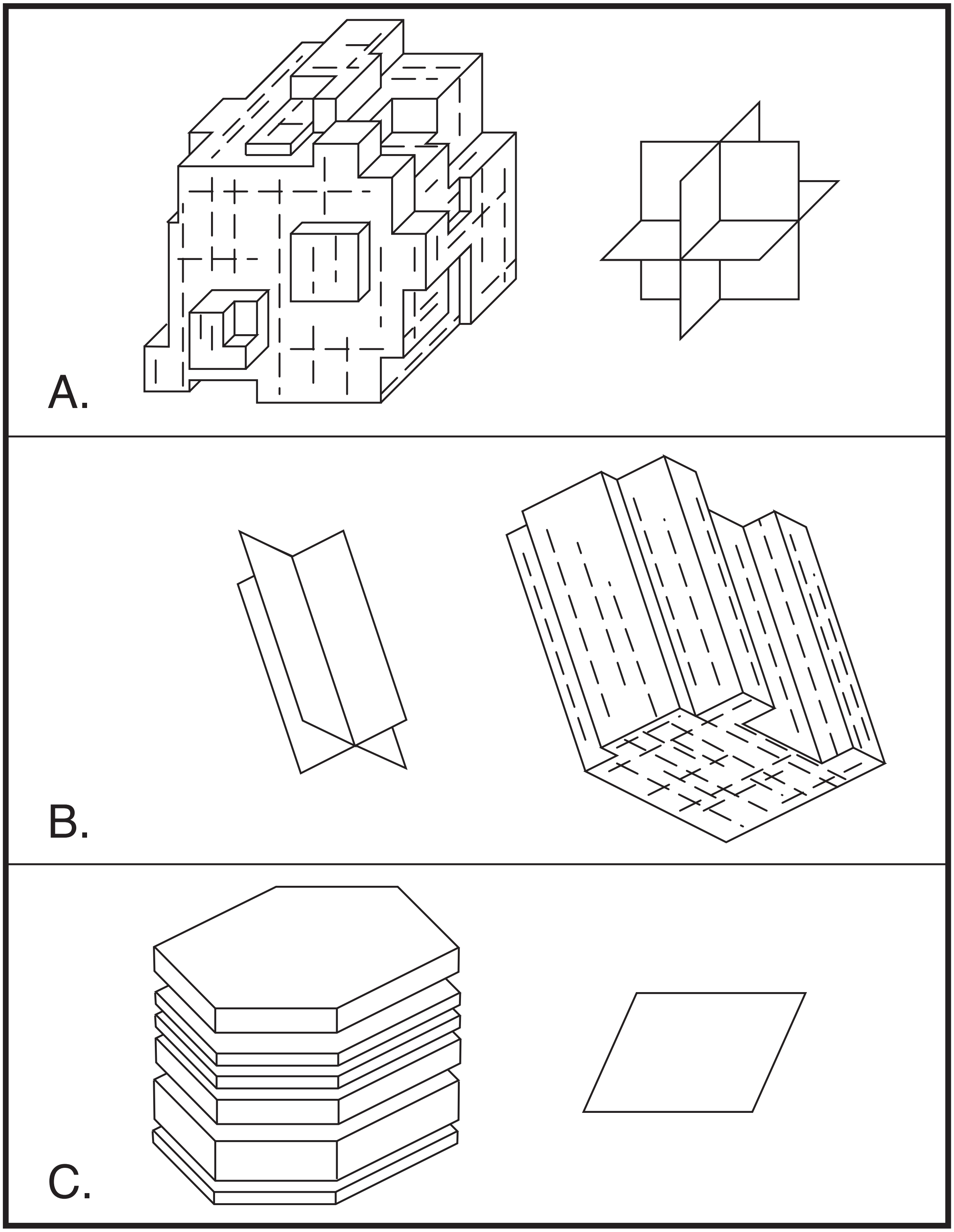


Figure 1. Examples of mineral cleaavage. A. Three directions of cleavage, with 90° between cleavages. This is also known as cubic cleavage. B. Two directions of cleavage, with 60° and 120° between cleavages. C. One direction of cleavage. The mineral splits into sheets. Note that in all cases, it is the number of ***directions***, not the number of ***surfaces*** present, that need to be described.

Streak:

The color a mineral leaves when scratched across an unglazed porcelain plate. This color is more consistent than the color of the mineral, and may be quite different than the color of the mineral itself.

Color:

Mostly self-evident. It should be noted here that even though the color is the most obvious thing about a mineral, and is the first thing you notice, it may be unreliable. In particular, minerals that are inherently colorless (such as quartz or calcite) may take on any color due to the presence of impurities. Minerals that are strongly colored (such as biotite) do not vary much in color.

MINERAL GROUPS

Groups of minerals are separated according to their crystal structure, so they have similar properties such as cleavage and hardness. The major groups that you will see in the rock forming minerals are:

Amphiboles:

This group has a double (amphi) chain (bole) structure, giving them two cleavages at about 60° and 120°. They are also generally rich in iron and magnesium, giving them a dark green to black color. The common amphibole you will see is ***hornblende***.

Feldspars:

These minerals have a framework structure, and all have two cleavages at about 90°. These are very common minerals; most igneous rocks contain one or two members of this group. You will see ***orthoclase feldspar*** and two of the ***plagioclase feldspars, albite*** and ***anorthite***.

Micas:

These minerals have a sheet structure, giving them one <u>perfect</u> cleavage. They cleave so well in this direction that you almost always see them in sheets. This group includes ***biotite*** and ***muscovite***.

Pyroxenes:

These minerals have a single chain structure, giving them two cleavages at about 90°. The common member of this group that you will see is ***augite***.

Quartz:

This is actually a single mineral, but it is both important and common, so we list it here. It has a framework structure. It has a hardness of 7 and no cleavage. It fractures conchoidally, and may occur in any color.

In the key to minerals and mineral property chart on the next pages, you will find the major rock forming minerals as well as some of the major ore minerals. Your instructor will tell you which minerals you will be responsible for knowing.

KEY TO MINERALS

1A. mineral shows cleavage
- 2A. one obvious cleavage direction
  - 3A. hardness 1 or 2
    - 4A. hardness 2, mineral clear to white, luster vitreous .... gypsum
    - 4B. hardness 1, mineral white, luster pearly .... talc
  - 3B. hardness of 2 to 3, cleavage sheets extremely thin
    - 5A. mineral is dark colored
      - 6A. mineral is dark bluish green .... chlorite
      - 6B. mineral is dark olive green, dark brown, or black .... biotite
    - 5B. mineral is colorless, pale green or tan .... muscovite
- 2B. more than one cleavage direction
  - 7A. two cleavage directions
    - 8A. angle between cleavages near or at 90°
      - 9A. mineral is white or green
        - 10A. all cleavage faces lack striations, mineral white or green..... orthoclase
        - 10B. some cleavage faces striated, mineral is white ....albite
      - 9B. mineral is salmon pink, grey, dark green, or black
        - 11A. all cleavage faces lack striations
          - 12A. mineral is salmon pink...orthoclase
          - 12B. mineral is dark green or black ....augite
        - 11B. some cleavage faces striated, mineral is dark.........................anorthite
    - 8B. angles between cleavages about 60° and 120°, mineral is dark ..... hornblende
  - 7B. more than two cleavage directions
    - 13A. three cleavage directions
      - 14A. angle between cleavages 90°
        - 15A. luster metallic, mineral is grey .... galena
        - 15B. luster vitreous, mineral is ***colorless**** ....halite
      - 14B. angles between cleavages about 70° and 110°, mineral is ***colorless**** .... calcite
    - 13B. more than three cleavage directions
      - 16A. four cleavage directions, mineral is ***colorless**** to purple.............fluorite
      - 16B. six cleavage directions, mineral is brown ....sphalerite

****colorless minerals may take on other colors if impurities are present***

1B. mineral does not show cleavage

17A. luster vitreous

18A. hardness less than 5.5

19A. hardness 5, color variable...apatite

19B. hardness 2.5, mineral is ***colorless****, salty taste ....halite

18B. hardness greater than 5.5

20A. occurs in sugary granular masses, color green .... olivine

20B. does not occur in granular masses

21A. color is red-brown, has uneven fracture...garnet

21B. ***colorless**** to any color, has conchoidal fracture.............................quartz

17B. some other luster

22A. luster metallic

23A. streak grey, mineral grey

24A. hardness of 1 .... graphite

24B. hardness of 5.5 to 6.5, may be magnetic ....magnetite

23B. streak is another color

25A. streak greenish black, mineral brassy yellow....................................pyrite

25B. streak red-brown, mineral grey ....hematite

22B. luster not metallic

26A. luster silky, hardness 2 .... gypsum

26B. luster dull

27A. streak dark grey, mineral grey to red, may be magnetic.............magnetite

27B. streak is some other color

28A. streak is strongly colored

29A. streak is red-brown, mineral grey to red............................hematite

29B. streak is yellowish-brown,mineral yellow, red, or brown.. limonite

28B. streak is colorless or white

30A. hardness of 7, mineral ***colorless****.......................................quartz

30B. hardness of 1-2, mineral white..kaolinite

****colorless minerals may take on other colors if impurities are present***

Table 2. Properties of common and economically important minerals.

Mineral Name Composition	Cleavage	Hardness	Density	Luster	Streak	Color*	Comments
albite $NaAlSi_3O_8$	2 at 90°	6	2.6	vitreous	-----	white	some cleavage surfaces have striations; member of the plagioclase feldspar group
anorthite $CaAl_2Si_2O_8$	2 at 90°	6	2.7	vitreous	-----	grey to black	some cleavage surfaces have striations; member of the plagioclase feldspar group
apatite $Ca_5(PO_4)_3(F,OH,Cl)$	1 poor	3.2		vitreous to resinous	-----	green, blue, brown, or white	mineral that forms teeth
augite $FeMgSi_2O_6$	2 at 90°	5-6	3.2	vitreous	-----	dark green to black	a member of the pyroxene group
biotite $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	1	2.5-3	2.8-3.2	vitreous	-----	dark green	a member of the mica group brown, or black
calcite $CaCO_3$	3 at 75°	3	2.7	vitreous	-----	***colorless****	fizzes in acid; clear specimens have double refraction
chlorite $(Mg,Fe)_{12}(Si,Al)_8O_{20}(OH)_{16}$	1	2-2.5	2.6-3.3	vitreous	-----	dark bluish green	a member of the mica group
fluorite CaF_2	4 at 60°	4	3.2	vitreous	-----	***colorless**** to deep purple	source of fluorine

Table 2, continued:

Mineral Composition	Cleavage	Hardness	Density	Luster	Streak	Color*	Comments
galena PbS	3 at 90°	2.5	7.6	metallic	grey to black	grey	major ore of lead
garnet $Mg_3Fe_2Si_3O_{12}$	none	6.5-7.5	3.5-4.3	vitreous	—-	red, brown, yellow, green, or black	gemstone; abrasive
graphite C	1	1-2	2.2	metallic	grey	grey	used for pencil "leads"
gypsum $CaSO_4 2H_2O$	1 excellent, 2 poor	2	2.3	vitreous to silky	—-	***colorless****	drywall and plaster of paris
halite NaCl	3 at 90°	2.5	2.2	vitreous	—-	***colorless****	tastes salty (it <u>is</u> table salt)
hematite Fe_2O_3	none	5-6	5	metallic to dull	red-brown	red-brown, grey, or black	major ore of iron
hornblende $Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	2 at 60°	5-6	2.9-3.8	vitreous	—-	dark green to black	member of amphibole group
kaolinite $Al_2Si_2O_5(OH)_4$	1	2	2.6	dull	—-	white	a member of the clay mineral group crystals are microscopic
limonite several Fe oxides	none	seems 1, 5-5.5	3.5-4.0	dull	yellow-brown	yellow, brown, or black	this is rust

Table 2, continued:

Mineral Composition	Cleavage	Hardness	Density	Luster	Streak	Color*	Comments
magnetite Fe_3O_4	none	5.5-6.5	5	metallic to dull	grey	grey	<u>may</u> be magnetic
muscovite $KAl_3Si_3O_{10}(OH)_2$	1	2-2.5	2.7	vitreous	—-	pale tan to green	a member of the mica group
olivine $(Mg,Fe)_2SiO_4$	none	6.5-7	3.2-4.3	vitreous	—-	pale green	occurs in sugary granular masses
orthoclase $KAlSi_3O_8$	2 at 90°	6	2.6	vitreous	—-	salmon, bright green, grey, or white	a member of the feldspar group
pyrite FeS_2	none	6-6.5	5.2	metallic	greenish black	brass yellow	fool's gold
quartz SiO_2	none	7	2.6	vitreous to dull	—-	a variety of colors	ITS EVERYWHERE! occurs in many different forms
sphalerite ZnS	6 (!)	3.5-4	4	bright vitreous	white to yellowish	dark yellow-brown	major ore of zinc
talc $Mg_3Si_4O_{10}(OH)_2$	1	1	2.7-2.8	pearly	—-	white, grey,	member of the mica group

* ***WATCH OUT!*** minerals listed as "colorless" may take on any color if they contain impurities.

LAB 5. IGNEOUS ROCKS

MATERIALS:

You bring: Lab Manual, pen and pencil, scratch paper, text (recommended for rock pictures).

Supplied: quiz sheets, tray of rock specimens, hand lens, tools for determining hardness (in your table drawers).

INTRODUCTION

Igneous rocks are those that crystallize from **magma** (underground molten rock) or **lava** (molten rock at the surface). Igneous rocks can be distinguished from other rock types because they are formed of interlocking crystals that have grown in place. Sedimentary rocks, such as sandstone, do not have interlocking crystals. Instead, they are composed of abraded and rounded crystals that are physically packed together.

TEXTURES

Plutonic Rocks

Magma that cools and crystallizes slowly beneath the Earth's surface are called **intrusive** igneous rocks or **plutonic** rocks. Because intrusive rocks cool and crystallize very slowly, the crystals have time to grow to large sizes, so they are all large enough to see without the aid of a microscope.

phaneritic texture:
Crystals are all large enough to see without the aid of a microscope. All plutonic rocks have a phaneritic texture.

equigranular texture:
All the crystals are about the same size.

porphyritic texture:
If the magma at first cools extremely slowly, the first crystals to form grow quite large. Sometimes the partly crystallized magma then cools somewhat faster, so the rest of the crystals are smaller. This resulting texture of some very large crystals surrounded by smaller ones is called a **porphyritic** texture.

Volcanic Rocks

When magma erupts onto the Earth's surface where it cools rapidly the resulting rocks are called **extrusive** igneous rocks or **volcanic** rocks. Extrusive igneous rocks cool so rapidly that in part or all of the rock no crystals are visible. Volcanic rocks may have several different textures:

glassy texture:
The magma cooled so rapidly that no crystals even had time to form. The rock is a random jumble of atoms with no crystalline structure. A volcanic rock that has a glassy texture is called **obsidian**. Obsidian usually exhibits **conchoidal fracture**.

aphanitic texture:
The magma cooled quickly, but a little bit more slowly than for a glassy texture. The rock has crystals, but they are too small to see without a microscope. Rocks with an aphanitic texture are named on the basis of their composition, which is determined by the rock's color. For example: aphanitic rhyolite (light colored), aphanitic andesite (intermediate shades) or aphanitic basalt (dark grey to black).

porphyritic texture:
This term describes a rock in which there are some large crystals in a much finer grained

ground mass. *This texture can form in either volcanic or plutonic rocks*. In volcanic rocks, it forms when the magma begins to crystallize slowly underground (forming the large crystals), and then is erupted onto the Earth's surface where the remaining liquid cools very rapidly to form much finer-grained crystals. The large crystals in a rock with porphyritic texture are called **phenocrysts**. Porphyritic rocks are also named on the basis of their composition. For example, porphyritic rhyolite, etc.

vesicular texture:

This term describes volcanic rocks that have holes in them. The holes are called **vesicles** and are remnants of gas bubbles in the magma. Rocks that have a moderate amount of vesicles are named according to their composition, such as vesicular basalt. Rocks that are extremely vesicular are called **pumice** if they are rhyolitic (light colored), or **scoria** if they are basaltic (dark colored).

pyroclastic texture:

This term describes rocks that form from the accumulation of volcanic ash, crystals, pumice and rock fragments that were explosively ejected from a volcano. Rocks that have a pyroclastic texture are called tuff. If the volcanic ash is very hot when it falls to the ground, particles may become fused together to form a rock called welded tuff.

CLASSIFICATION OF IGNEOUS ROCKS

Igneous rocks are classified based first on their texture, and second on the minerals present within them. The **texture** of an igneous rock tells you whether it is plutonic or volcanic. Plutonic rocks have a phaneritic texture and may be equigranular or porphyritic; volcanic rocks may have a glassy, aphanitic, porphyritic, vesicular or pyroclastic texture, or a combination of those. Once the rock has been classified as plutonic or volcanic, it is further classified based on its **composition** (that is, on the minerals present within the rock). The descriptions below give the plutonic name first, then the volcanic name. For example, granite is the plutonic name and rhyolite is the volcanic name.

Plutonic Name:	**Volcanic Name:**
Granite	**Rhyolite**

composition: always contains abundant quartz, orthoclase and plagioclase (albite), and may contain some combination of muscovite, biotite, hornblende, and/or augite. A special kind of granite is pegmatite, which has the same composition as granite but contains very large crystals, usually 1 cm or more in diameter.

Plutonic Name:	**Volcanic Name:**
Diorite	**Andesite**

composition: always contains plagioclase and hornblende, and it may also contain pyroxene or biotite. The plagioclase in diorite is usually more enriched in sodium than in calcium (that is, its composition is closer to albite than to anorthite), so it is generally light colored. It generally lacks quartz, although small amounts are occasionally present.

Plutonic Name:	**Volcanic Name:**
Gabbro	**Basalt**

composition: always contains plagioclase (anorthite) and augite, and may sometimes contain hornblende and olivine.

Plutonic Name:	**Volcanic Name:**
Peridotite	**(no equivalent)**

composition: is composed of mostly of olivine, and may contain small amounts of augite, anorthite, and/or garnet.

These descriptions only list which minerals are present in a given rock type. Consult the chart on the next page for the relative abundances of each mineral in each rock type. For example, according to the description above, both gabbro and peridotite may contain plagioclase, pyroxene and olivine. This chart provides additional information which will help distinguish these two rock types; gabbro is dominated by plagioclase and pyroxene with a lesser amount of olivine, whereas peridotite has only a small amount of plagioclase and large amounts of olivine and pyroxene.

Looking at that chart you can also see that granite is composed of 2-20% mafic (magnesium and iron bearing, usually dark colored) minerals. Diorite is composed of 20-30% mafic minerals. Gabbro is composed of about 30-70% mafic minerals. Peridotite has more than 80% (and commonly about 95%) mafic minerals.

Some hints for identifying minerals in igneous rocks:

- Quartz has no cleavage, whereas both orthoclase and plagioclase feldspars have cleavage. Therefore if a light colored crystal (other than muscovite) has smooth, shiny surfaces it is probably a feldspar, not quartz.
- Pink feldspar grains are usually orthoclase, but white feldspar grains may be either orthoclase or plagioclase.
- Plagioclase may be distinguished from white orthoclase by the fact that some cleavage faces of plagioclase have striations.
- Biotite and muscovite appear as small flakes or packets of flakes. They are almost metallic and are fairly soft.
- Pyroxene (e.g. augite) has two cleavage directions oriented at 90° to each other, whereas amphibole (e.g. hornblende) has two cleavages oriented at 120° to each other.
- Sometimes amphiboles form long, needle-like crystals whereas pyroxenes form more stubby crystals.
- Both pyroxenes and amphiboles are dark, often rather dull, and blocky, while biotite is dark, quite vitreous, and flaky.

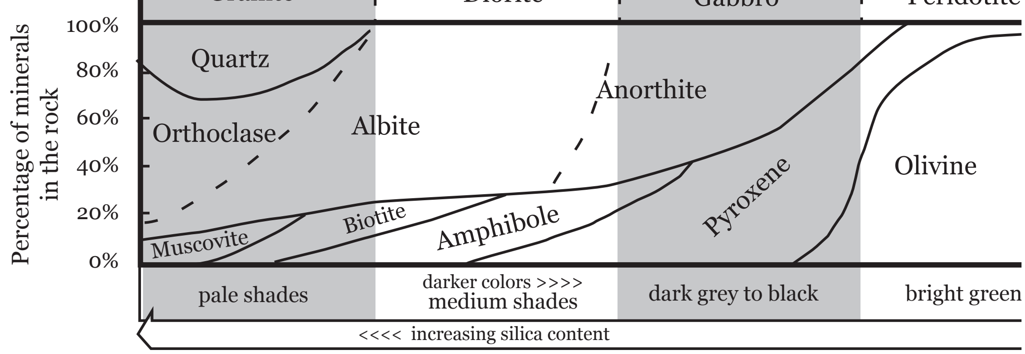
Igneous Rocks Texture Key

1A. rock contains bubble holes .... vesicular[V]
1B. rock does not contain such holes
  2A. crystals are visible in the rock
    3A. all crystals in the rock are of visible size
      4A. all crystals are about the same size .... phaneritic and equigranular[P]
      4B. some crystals are much larger than the rest .... phaneritic and porphyritic[P]
    3B. only some crystals are of visible size .... porphyritic with an aphanitic matrix[V]
  2B. no crystals are visible
    5A. rock has a uniform, matte appearance .... aphanitic[V]
    5B. rock has some other appearance
      6A. rock appears to be made of various fragments
        7A. rock is light in weight, and appears chalky............................... pyroclastic[V]
        7B. rock is substantial, shows layering,
          and may appear glassy ....pyroclastic (welded)[V]
      6B. rock is uniformly glassy in appearance..glassy[V]

[v] The rocks with these textures are volcanic. Determine to the best of your ability the composition (the minerals that make up the rock), and assign the appropriate compositional name to the rock.
[p] The rocks with these textures are plutonic. Determine the composition (the minerals that make up the rock), and assign the appropriate name to the rock.

Igneous Rock Identification Chart
First, identify the texture(s) from the key above. This will determine which row of names apply to the rock. Then, identify the minerals you can see in the rock, and use those to determine which compositional column the rock belongs in.

Pyroclastic	Tuff	*Tuff (rare)*	Cinders	*None*
Vesicular	Pumice	*Pumice (rare)*	Scoria	*None*
Glassy	Obsidian	*Obsidian (rare)*	*Rare*	*None*
Aphanitic (partly or all)	Rhyolite	Andesite	Basalt	*None*
Phaneritic	Granite	Diorite	Gabbro	Peridotite



LAB 6. MASS WASTING AND EROSION

MATERIALS:

You bring: Lab manual, pen and pencil, scratch paper, calculator (optional).
Supplied: work sheet, plastic flume, large stream table, small stream table, sediments.

INTRODUCTION

Many of the landforms we see have been sculpted by weathering, mass wasting, and erosion. These are natural parts of the rock cycle. Rocks are worn away by weathering, mass wasting, and the erosive action of streams, glaciers, waves, wind, and groundwater. Sedimentary processes of transportation and deposition can be seen all over the Earth's surface.

WEATHERING

When rocks are exposed to the elements at the surface of the Earth, they become quite unstable and will break down. There are two types of weathering:

Mechanical Weathering

This process breaks larger rocks into smaller rocks. Factors involved in mechanical weathering include burrowing animals, plant root growth, human activity, daily fluctuations in temperature, and frost wedging. Frost wedging works by moisture working its way into cracks and crevices of exposed rock. When this water freezes, its expansion into ice wedges the cracks apart. Abrasion is also an important mechanism for mechanical weathering. Harder minerals and minerals lacking cleavages tend to be more resistant to mechanical weathering, as it is more difficult to break them into smaller pieces. As mechanical weathering proceeds, it increases the amount of the rock's surface area exposed to chemical processes.

Chemical Weathering

This is the chemical breakdown of rocks. Air, water, and plant decay in the soil combine to form a common weak acid, carbonic acid (H_2CO_3), that reacts chemically with rocks to break them down. Carbonic acid acts on exposed rock surfaces to break down silicate minerals such as feldspars and micas into clay minerals and dissolves calcite from carbonate rocks. Some minerals are more resistant to weathering than others. To determine which is which, look at Bowen's Reaction series (discussed in your text under Igneous Rocks). The lower the temperature of formation of a mineral, the more resistant it is to chemical weathering, because it is closer to chemical equilibrium at Earth surface conditions.

Questions:

1: Do mechanical weathering and chemical weathering operate independently of each other? Explain.

2: Which igneous mineral is the most stable, both mechanically and chemically? Explain.

MASS WASTING

Mass wasting is the movement of soil and loose rock material downslope due to the pull of gravity. It most often occurs when the slope of the land can no longer hold the material at that angle. While water is not the mode of transportation for mass wasting, it plays an important role by acting as a lubricant and by increasing the weight of the material. Mass wasting processes operate at a wide range of rates, from imperceptibly slow to hazardously fast. The different types discussed below are listed in approximate order of speed, starting with the slowest one.

Types of mass wasting

soil creep

This is grain-by-grain movement of loose material on a slope. As soil expands due to freezing or getting wet, it expands outward from the slope surface. As it shrinks due to thawing or drying out, it settles directly downward due to the pull of gravity. Each outward-downward cycle produces very small movement of the particles downhill, but with this cycle repeated up to hundreds of times each year, this slowly works soil downslope, and is significant over time. It often moves at rates of millimeters per year.

slump

This slope movement is characterized by downward and outward movement of a portion of a hillside. The part that moves usually slips on a curved surface within the soil. It often resembles a shovel-shaped scoop of material. It generally moves at rates of centimeters per hour.

mud or debris flow

It is a mass of unconsolidated soil and clay (mud flow) or with coarser particles mixed in (debris flow), saturated with water, and moving as a slurry. Many of these resemble a milkshake or pouring wet cement as they move. They typically move a few kilometers per hour.

rockslide

A large mass of bedrock detaches from the rock below, often along joints or bedding planes, and slides downhill. These bodies often move more or less as a unit, can be extremely large (whole mountainsides) and often move at rates of kilometers per hour.

rock or debris fall

This type of slope movement consists mainly of blocks of bedrock (rock fall) or of unconsolidated rock and sediment (debris fall). It will freefall from a cliff or steep slope. As with any falling object, it moves under the acceleration of gravity (9.8 meters per second per second), so watch out below!

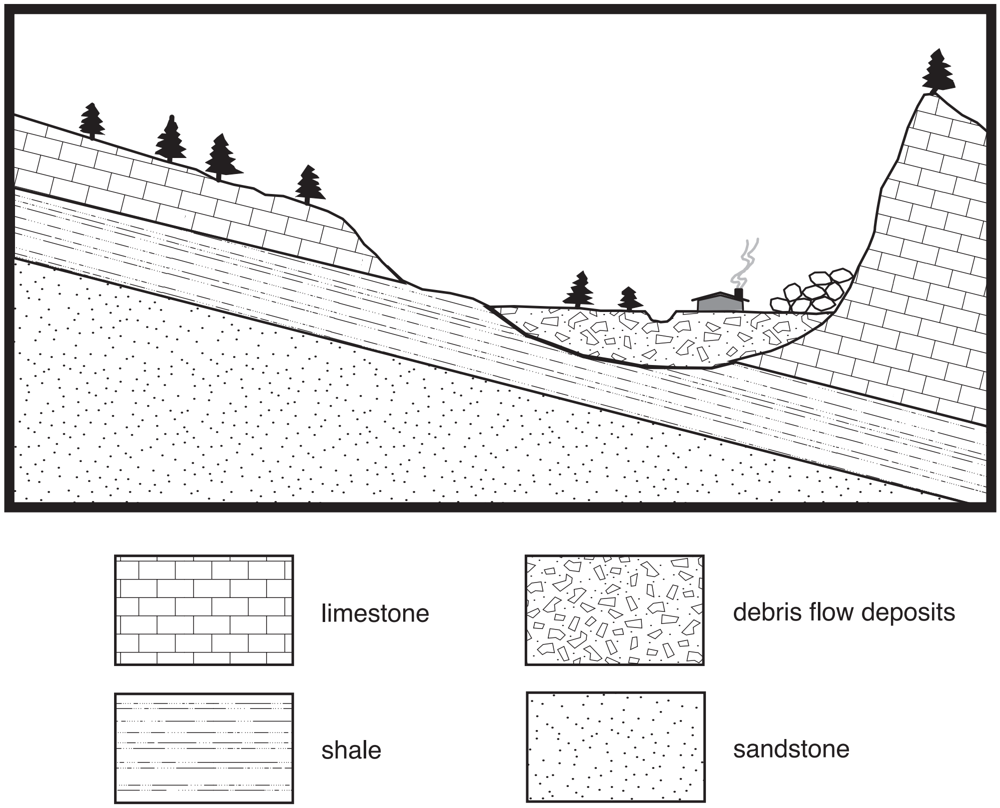
debris or rock avalanche

This type of movement is similar to snow avalanches, where large masses of material break loose and travel swiftly downhill mixed with and cushioned by air. This air cushion allows them to travel quite fast, up to hundreds of kilometers per hour. Such mass movements can be triggered by earthquakes.

EROSION

Erosion is the transport of loose sediment by a transporting agent such as running water, wind, or glacial ice. Although the cliché that says "it never rains in Southern California" is often used by those who do not live here, we can see evidence that the features of our surrounding landscape have been sculpted by water processes. All one has to do is look at the local hills and mountains to see canyons in various stages of development from very narrow, steep valleys, indicating youthful streams, to broad flood plains indicating older stream activity.

When rocks are weathered by mechanical or chemical processes, the residual material rarely stays in place but instead moves downslope. That is because the Earth's surface is rarely completely and totally flat. Water is most often the mechanism to move rock material downward to base level, which is the level below which a stream cannot erode. Base level is most often sea level, although locally it can be a high mountain lake



or a desert basin below sea level. Agents of erosion literally carry material or push it along.

Running water and sediment deposition

The main erosional agent on this planet is running water, which includes streams confined to channels and sheet erosion (thin layers of water that run over large areas). Running water carries a load of rock material made up of varying sizes of sediments and dissolved material. It can move sediment as **bed load**, **suspended load**, or **dissolved load**. Its **competence** and **capacity** depend upon the velocity of the water. The faster the water is moving, the larger the particles that may be moved and the more total material can be moved.

bed load

The largest particles a stream can move. These are rolled along the stream bed.

Questions:

3: Explain the difference between weathering and erosion.

4: See the figure of the cabin above. Your good friend has the opportunity to purchase this riverside land in a beautiful canyon at a good price with a log cabin on the site. Knowing some geology, list all the geologic hazards can you identify. Would you advise her to buy this cabin or not?

suspended load

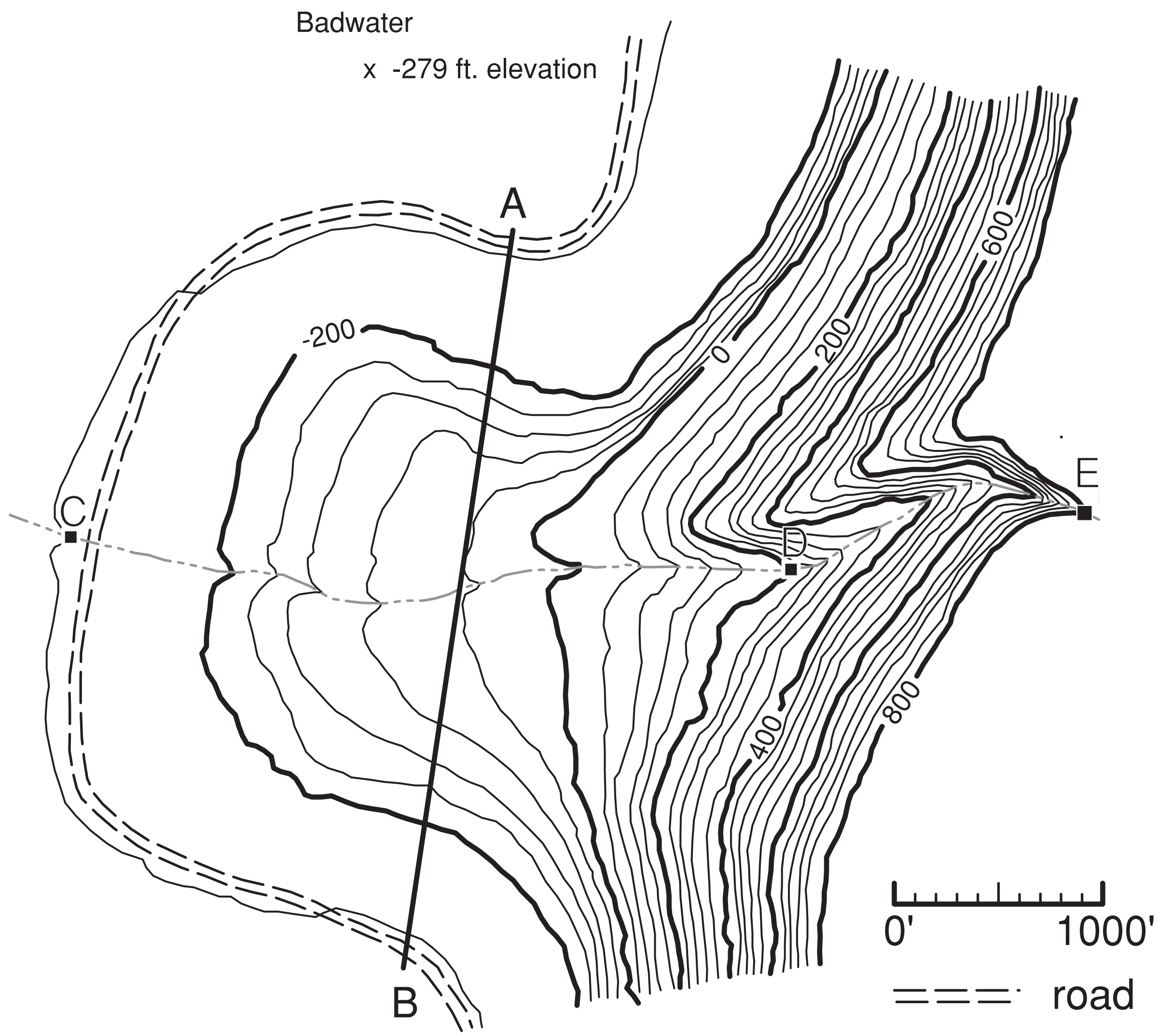
These particles are carried suspended in the water as the stream moves. It is the suspended load that makes many streams and rivers look muddy.

dissolved load

The material that is dissolved in the water. This commonly includes salts and carbonates.

Exercise 1. Badwater Map

Sediment deposition occurs when the velocity of water or wind can no longer carry the rock material and it is left behind. Features formed by the accumulation of sediment include: alluvial fans, deltas, glacial moraines, and flood plains. The topographic map of the Badwater area in Death Valley reproduced below illustrates an alluvial fan. Look at the shape of the contour lines on the alluvial fan south of Badwater. The contour lines form a concentric, semi-circular pattern. This shape is characteristic of alluvial fans. The fan on this map was formed as the stream carried sediments from the Black Mountains into Death Valley. The location of the active channel of the stream has shifted back and forth across the fan so that debris has been deposited on different parts of the fan at different times. Note the double line representing a road that skirts the lower edge of the fan.



Exercise 1, continued.

9. What is the contour interval of this map?

10. Make a topographic profile along the line marked AB.

•First, place the edge of a piece of paper along the line with A on the right and B on the left. Mark the positions of A and B on your paper. On your paper, place a small mark everywhere a contour line intersects the AB line (where it hits your paper). Next to these marks, record the elevation value for the line.

•Now, place your paper along the AB line drawn below the map. Carefully place a dot vertically above each mark and at the correct elevation (use the scale on the sides).

•Next, draw in the profile (side view) of the alluvial fan by artistically connecting the points together into a line. Remember that the land surface is continuous, even when there isn't a contour line as a guide.

11. Calculate the stream slope for three lengths of the stream coming down the alluvial fan. First measure the distances in feet and record them. Then determine the elevation change by looking at the contour lines. Next, calculate the slope of the stream for each segment. Use the table on your handout to record and calculate. If the erosive potential of a stream is proportional to its gradient, which of the two segments of this stream (C-D or D-E) should have the greatest erosive power?

competence

The largest particle a stream can move.

capacity

The total mass of sediment, including bed load, suspended load, and dissolved load that a stream can move.

Questions:

5: Over a long period of time, sheet erosion can contribute to a significant amount of erosion. It has been estimated that running water removes an average of 1 meter of sediment every 30,000 years from the entire land surface of North America. Calculate the annual rate of erosion. Show your work. Is this a trivial amount of erosion? Explain.

6: What is the difference between the competence and the capacity of a stream?

Valley Evolution

Stream valleys change over time depending upon rock type, amount of water, and gradient, or steepness. A young valley will have steep V-shaped walls and a steep gradient. A mature valley is wide with most of its area made up of the floodplain. The stream will wind or loop over the floodplain. Sometimes the meanders will get cut off and form oxbow lakes. An old-age valley has a very low gradient and is very wide with many meanders and oxbow lakes.

Gradient

The gradient of a stream is defined as the drop in elevation along its course and is expressed in meters per kilometer or in feet per mile. The gradients of feet/mile or meters/kilometer cannot be compared to one another directly because they are in different units. However, these gradients can be expressed as feet/foot or meters/meter and then reduced to a slope. As slopes, they can be compared directly to one another, because slope is a ratio and carries no units.

Slope

Slope can be calculated by dividing the drop in elevation by the horizontal distance over which that the drop takes place (remember that slope = rise/run, or the vertical change divided by the horizontal change). For example, if a stream dropped 100 feet in elevation over a distance of 2 miles, the **gradient** is 50 ft/mile, and the **slope** is 100 ft/10,560 ft = 1/1056 = 0.00095.

Note: 5280 ft = 1 mile, and 1000 meters = 1 km.

Questions:

7: What is the slope of a stream whose gradient is 264 ft/mile? Show your work.

8: What is the gradient of a stream that drops 10 m over a distance of 500 m? Show your work.

Exercise 2. Sediment Behavior.

Use the stream table to collect data and answer the following questions:

Part 1: Stream velocity vs. gradient and discharge.

A. Set up the plastic flume with the stand such that the lower end of the flume is in the sink. The stand heights are set to produce slopes of 5°, 10° and 15°.

B. Adjust the output of the water pump to about 5 cc/second (slow). Measure the discharge by running the water into the graduated cylinder for 5 seconds and measuring the accumulated volume of water (you may need to adjust the flow and measure again) and allow the water to run down the 5° slope.

C. Measure the velocity of the stream by dropping a small piece of paper in and timing its trip down the marked section of the flume. Record this velocity into the table on your handout. Repeat for slopes of 10° and 15°.

D. Repeat the above experiment for 10 cc/second and 15 cc/second. Plot your results on the graph on your handout.

12: How is the slope of the flume related to stream velocity?

13: How is the discharge of the stream related to its velocity?

Part 2: Angle of repose.

A. Using the small stream table, pour some dry sand out to form a cone. Stop periodically to observe the shape and angle of the sides of the cone.

B. Using the “rainmaker” carefully sprinkle water onto this cone until it becomes saturated.

14: What is the slope angle of the sides of the dry cone?

15: What happens when the sand becomes saturated?

16: What is the slope angle for the saturated cone?

Part 3: Alluvial fans and deltas.

A. Build a flat area with a very steep slope with the sand in the large stream table. Turn on the water very slowly and allow it to run down the steep slope. Turn the water off after about thirty seconds.

17: Describe the feature that has formed at the bottom of the slope. What is this feature called?

18: Are there any other features that have formed along the steep slope away from the water channel? What are these features called?

B. Turn the water back on and watch the feature build for about two minutes.

19: What has happened to the feature at the bottom of the slope through time?

C. Turn the water on medium to high (for about three minutes) and observe sedimentation where the flowing water encounters still water.

20: What feature are you watching form? How does this feature differ from the previous one?

LAB 7. SEDIMENTARY ROCKS

MATERIALS:

You bring: Lab Manual, pen and pencil, scratch paper, text (recommended for rock pictures).

Supplied: quiz sheets, tray of rock specimens, hand lens, tools for determining hardness (in your table drawers).

INTRODUCTION

A sedimentary rock is a rock formed by the consolidation of sediment. There are two main types of sedimentary rocks: **clastic**, and **chemical** (including **biochemical**) sedimentary rocks.

Clastic sedimentary rocks are composed of fragments of older rocks that have been deposited and consolidated. Sandstone is an example a clastic sedimentary rock.

Chemical sedimentary rocks form when minerals precipitate from ions dissolved in water (an aqueous solution). Halite and gypsum are examples of minerals that precipitate from aqueous solutions to form chemical sedimentary rocks.

Biochemical sedimentary rocks are composed of accumulations of organic debris. Coal and some limestones are examples of biological sedimentary rocks.

CLASTIC SEDIMENTARY ROCKS

Formation of clastic sedimentary rocks:

The formation of clastic sedimentary rocks begins with weathering of others rocks exposed at the Earth's surface. **Weathering** is the in-place, chemical and physical break-down of rocks at the Earth's surface. Weathering breaks down the rock into smaller particles, called sediment, and may also change the minerals present in the sediment. For example, rain water (which is generally slightly acidic) reacts with feldspar to produce clay minerals. Once the bedrock has been broken down into smaller particles it may be eroded. **Erosion** is the removal of rock fragments and smaller grains from the bedrock by wind, water, ice or gravity. The sediment eroded may be **transported** long distances or it may be **deposited** relatively near the bedrock from which it was eroded. Sediment may be transported by wind, by streams and rivers, by waves and currents in lakes and oceans, by glaciers, or by rockfalls, landslides and mudflows. Large amounts of sediment are deposited in the oceans, but sediment may also be deposited on the continents in lakes, rivers, alluvial fans, and sand dunes. After sediment has been deposited it may be buried by younger sediment. The pressure of overlying material causes **compaction** of the sediment. Fluids passing through the buried sediment may precipitate minerals in the pore spaces between grains, leading to **cementation** of the sediment. Sediment that has been consolidated through compaction and/or cementation is sedimentary rock. Several minerals can be found as cements, but the most common cements are **calcite**, **quartz**, and **hematite**.

Properties of clastic sedimentary rocks:

Grain Size:

One of the most obvious properties of clastic sedimentary rocks is their grain size.

Grains are classified by their diameter according to the following scale:

boulders	greater than 25.6 cm
cobbles	6.4 to 25.6 cm
pebbles	2 mm to 6.4 cm
sand	1/16 mm to 2 mm
silt	1/256 mm to 1/16 mm
clay	less than 1/256 mm

The grain size of a sedimentary rock is significant because it reflects the strength of the process by which the sediment was transported. For example, boulders can not be transported in a slowly flowing river. They can only be transported by rivers in flood stage, by mud flows, by landslides or by some other high-energy process. Silt and clay are usually not deposited in swiftly flowing rivers because the turbulence in the river keeps them suspended in the water and prevents them from settling to the bottom of the river. Silt and clay are usually deposited in very low energy environments, where the water is still, such as in a lake or in the deeper parts of the ocean.

Sorting:

Another important property of clastic sedimentary rocks is the degree of **sorting** of different grains sizes. If most or all of the grains in a sediment or sedimentary rock have the same size, we say that the sediment is **well sorted**. If the sediment or sedimentary rock contains a broad range of grain sizes it is **poorly sorted**. The degree of sorting in a sedimentary rock reflects whether or not the transport process was able to sort the sediment according to its grain size. Sediments that are continually reworked by waves or wind (e.g. beach sediments or sand dunes) are usually **well sorted,** because the reworking process has selectively concentrated grains of the same size. Sediments that are deposited rapidly with little or no reworking (e.g. in a rockslide or mudflow) are usually **poorly sorted.**

Grain Shape:

The shape of the grains in sedimentary rocks is also significant. Grains that have sharp or rough edges and corners are **angular** and have probably not been transported very far nor have they been significantly reworked. Grains that have smooth surfaces are **rounded** and have either been transported long distances or have been reworked so that their rough edges have been ground down by bumping into other grains as they moved along.

Minerals:

Another property of clastic sedimentary rocks that is important to describe is the **mineralogy** of the grains. Because quartz is resistant to both chemical and physical weathering, it is the most common mineral in clastic sedimentary rocks. Feldspar may be present but is usually less abundant than quartz because feldspar may be chemically altered to form clay minerals. Another common constituent of clastic sedimentary rocks is fragments of older rocks of any rock type.

Classification of clastic sedimentary rocks:

Sedimentary rocks are classified based primarily on their grain size. Within each grain size range, rocks may be further subdivided based on their mineralogical composition. Some common clastic sedimentary rocks are listed below.

conglomerate:
A clastic sedimentary rock composed of **rounded** pebbles, cobbles and/or boulders.

breccia:
A clastic sedimentary rock composed of **angular** pebbles, cobbles and/or boulders.

sandstone:
A clastic sedimentary rock composed of

sand-sized particles. This includes:

quartz sandstone: a sandstone in which 95% or more of the grains are quartz.

arkose: a sandstone in which quartz and feldspar are the most common grains. Other minerals or rock fragments may also be present.

graywacke: a sandstone that contains a large amount of silt or clay-sized matrix. The sand grains may include quartz, feldspar, dark minerals, and rock fragments.

siltstone:
A rock composed of silt-sized particles. It commonly has a massive, structureless appearance.

shale:
A rock that is composed of clay-sized particles and that has a finely laminated structure that allows it to be easily split along planes.

Depositional environments of clastic sedimentary rocks:

conglomerate:
The large grain size in conglomerates indicates that they are deposited in a high energy environment, because is takes a strong current to move pebbles, cobbles and boulders. The roundness of the particles in the rock indicates that the sediment was transported a fair distance or was significantly reworked to remove the sharp edges and corners. Conglomerates may be deposited in the upstream portions of rivers, on alluvial fans, on beaches and by glaciers.

breccia:
The large grain size in breccia indicates that it was deposited in a high energy environment, but the angularity of the particles indicates a very short transport distance and little or no reworking. Breccias may be deposited by rockslides and rockfalls.

sandstone:
The medium grain size indicates a medium-energy environment of deposition. Sandstones may be deposited in a wide variety of environments. Sandstones that are well sorted are commonly deposited on beaches, in windblown sand dunes, and on continental shelves. In these environments, constant reworking by waves, winds and currents is effective at sorting the sediment according grain size. Sandstones that are moderately or poorly sorted are commonly deposited in rivers, on deltas and on alluvial fans. Sandstones that are very poorly sorted (such as graywacke) are commonly deposited by debris flows or underwater slumps of sediment.

siltstone and shale:
These rock types are deposited in low energy environments. Silt and clay can only settle to the bottom of a body of water and be deposited when there is little or no current. They are commonly deposited in lakes, in the deeper parts of oceans, and on the floodplains surrounding river channels.

CHEMICAL AND BIOCHEMICAL SEDIMENTARY ROCKS

chert:
Chert is a sedimentary rock composed of microscopic crystals of quartz or amorphous silica. It may form from the accumulation of organisms with shells or skeletons composed of silica, or it may precipitate chemically. Chert that forms from organic silica is an organic (or biological) sedimentary rock, whereas chert that forms by chemical precipitation is a chemical sedimentary rock. Chert is usually deposited in deep ocean basins. Chert may be recognized by its noncrystalline appearance. (The crystals are

much too small to be seen). Chert is harder than a steel file and exhibits conchoidal fracture. Because it is composed of quartz, it does not react with acid. Chert varies in color from white to dark gray or other colors.

limestone:

Limestone is a sedimentary rock composed primarily of calcite. It can be easily identified because it reacts with acid. Limestone is usually deposited in warm, shallow seas. It may form in several different ways. Many organisms use the calcium (Ca) and carbonate (CO_3^{2-}) dissolved in sea or lake water to construct their shells. When these organisms with shells composed of calcium carbonate (calcite) die, their shells may accumulate to produce the rock limestone. Limestone that forms in this way is an organic sedimentary rock. If the shells are transported and broken by waves or currents they behave as clastic sediment and may form a bioclastic limestone. Bioclastic limestones are both organic and clastic sedimentary rocks. A bioclastic limestone composed primarily of coarse shell fragments is called **coquina**. A bioclastic limestone composed of the calcite shells and skeletons of microorganisms is called **chalk.** Chalk is very fine-grained, soft, and is usually white or light gray in color. It can be scratched with your fingernail. Because it is composed of calcite, it reacts with acid.

Calcite may also precipitate chemically from sea water or from lake water to create limestone that is a chemical sedimentary rock. Limestones that precipitate chemically may have a texture in which individual crystals are visible. Or, they may have an **oolitic texture**. A limestone with oolitic texture is composed of many spherical grains of calcite. These spherical grains are called **ooids**. They are commonly a few millimeters in diameter and have a concentrically layered internal structure. Ooids form as small grains are rolled along the floor of a shallow sea. Algae that grow on the surfaces of these grains precipitate calcite in layers around the grains, forming the concentrically layered internal structure of the ooids. A limestone composed of ooids is an **oolitic limestone**.

dolomite:

Dolomite is a rock composed of the mineral dolomite. The mineral dolomite is similar to calcite ($CaCO_3$), but dolomite also contains magnesium. The chemical formula for the mineral dolomite is $(CaMg)CO_3$. In some cases dolomite may form by chemical precipitation, but in most cases it forms when the calcite in limestones is altered to dolomite by magnesium-rich water passing through the limestone. Dolomite can be distinguished from limestone in that limestone reacts with acid, whereas a fresh sample of dolomite does not. A fine powder of the rock dolomite, however, does react with hydrochloric acid.

evaporite minerals:

gypsum: Some rock are composed entirely or nearly entirely of the mineral gypsum. Gypsum is an **evaporite mineral**, which means that it forms by chemical precipitation as a body of water evaporates. Most bodies of water contain dissolved ions that were originally derived from the chemical weathering of rocks. As a body of water evaporates, the ions are left behind. When the body of water becomes saturated, minerals may precipitate. Gypsum is one such mineral. Gypsum forms in lakes or inland seas in arid regions where evaporation exceeds the influx of water in to the lake or sea. Recall that gypsum has a hardness of 2. Thus, you can scratch gypsum with your fingernail. However, you can also scratch chalk with your fingernail. In order to distinguish chalk from gypsum, use the acid test. Chalk will react (fizz) with acid because it is composed of calcite. Gypsum will not react with acid.

halite: Halite (also known as rock salt) is another example of an **evaporite mineral**. It forms by chemical precipitation when a body of water evaporates. Like gypsum, it forms in lakes or inland seas in arid regions. Halite has a hardness of 2.5. Thus, you usually can not scratch it with your fingernail, but you can scratch it with a penny. Halite also has three directions of cleavage oriented at 90° to each other, so it tends to break into cubes. It also has a cubic crystal form, so it tends to grow in cubes. Halite does not react with acid.

coal:

Coal is an organic sedimentary rock. It forms by the accumulation and compaction of plant debris. The plant debris that forms coal commonly accumulates in swamps, where there is so much organic material that there is not sufficient oxygen for all of it to decay. Therefore some of the organic material is preserved and becomes coal after it becomes rock (lithified). As plant debris is buried, it is subjected to increasing temperature and pressure. It goes through several stages of coalification which increase the-carbon content of the coal and decrease the moisture in the coal. Each stage is given its own name:

Peat consists of unconsolidated plant remains. It is brown, crumbly, and resembles the sphagnum moss available for gardening.

Lignite is a type of coal produced when peat is buried at shallow depths. Lignite is soft and brownish-black. When buried more deeply, lignite converts to:

Bituminous coal. Bituminous coal is black, and is harder and shinier than lignite. At still greater depths bituminous coal converts to:

Anthracite coal, which is a metamorphic rock. Anthracite coal is harder, denser and shinier than bituminous coal. You will see anthracite coal in the Metamorphic Rocks lab.

SEDIMENTARY STRUCTURES

Sedimentary structures form in or on a sediments before they are lithified. Some of the most common sedimentary structures are described below:

ripples:

When sand is transported by a moving fluid (such as water or air) it commonly forms ripples. If you have ever looked closely at the bed of a sandy stream or at the shallow bottom of a lake or the ocean near the beach, you have probably seen ripples. These ripples are sometimes preserved in sedimentary rocks. They may be seen when an old bedding plane becomes exposed.

cross-bedding:

If you cut a cross-section through a sedimentary rock with ripples in it you will see cross-bedding. Most ripples migrate in a downstream direction. As they migrate, sand grains are eroded from the upstream side of each ripple and are deposited on the downstream side of each ripple. This results in many thin beds that are parallel to the downstream side of each ripple. The beds thus dip (slope downward) in the downstream direction. When cross-bedding is preserved in sedimentary rocks, it may be used to determine which way the current was flowing when the sediment was deposited.

mudcracks:

Mudcracks form when silt- and clay-sized sediment that was wet dries out. As the clay minerals dry out they shrink, creating cracks in the sediment. A sedimentary rock with mudcracks preserved in it indicates that the sediment was deposited in an environment that was alternately wet and dry, such as a tidal mud flat, or a playa.

raindrop impressions:
Occasionally the impressions formed by rain drops impacting a muddy surface are preserved in the rock record. If raindrop impressions are preserved in a sedimentary rock this indicates that the sediment was exposed to the air after it was deposited (because rain doesn't fall underwater!).

SEDIMENTARY ROCKS IDENTIFICATION TIPS

You may find it helpful to use the following criteria to identify and name each of the rock specimens.

1. Is the rock clastic or non-clastic?

   A. If clastic:

      1. What is the dominant grain size in the rock?

      2. Describe the sorting of the grains in the rock.

      3. What is the dominant grain shape (if visible)?

      4. What is the name of this rock type?

      5. In what environment(s) might this rock have been deposited?

   B. If non-clastic:

      1. What is the hardness of the specimen?

      2. Does the specimen react with dilute HCl?

      3. Does the rock have fossils, crystals, or spherical grains?

      4. What is the name of this rock type?

      5. In what environment(s) might this rock have been deposited?

2. Sedimentary Structures: Look for the following sedimentary structures, read the descriptions in your lab manual , and answer the following questions.

   1. Ripples: What is the dominant grain size? What is the grain shape? Describe the sorting. Explain how the ripples form.

   2. Crossbedding: Sketch the specimen and indicate which direction the wind or water was flowing.

   3. Mudcracks: What is the dominant grain size? What is the grain shape? Describe the sorting. Explain how mudcracks form.

   4. Raindrop impressions: What does this indicate about the environment where the sediment was deposited?

Table 1. Clastic Sedimenary Rocks

Particle Size	Distinctive Features	Depositional Origin	Rock Name
pebble, cobble, and/or boulder (> 2 mm)	rounded grains in a finer matrix	high energy environments, rivers, ocean shorelines, alluvial fans	***Conglomerate***
pebble, cobble, and/or boulder (> 2 mm)	angular grains in a finer matrix	product of mass wasting processes, such as rockslide, mud and debris flows, rockfall, etc.	***Breccia***
sand (1/16 to 2 mm)	contains all quartz grains, often rounded grains, well sorted	sand dunes, beaches	***Quartz Sandstone***
sand (1/16 to 2 mm)	more angular grains of quartz, feldspars, biotite, and/or hornblende, fairly well sorted	river sand bars	***Arkose***
mainly sand with a finer matrix	gray to greenish, usually angular grains in a silt or clay matrix	underwater mud flows, deltas	***Greywacke***
silt (1/256 to 1/16 mm)	fine grained, can't see grains with naked eye, often massive (not layered)	low energy environments, outer parts of deltas, floodplains	***Siltstone***
clay (< 1/256 mm)	very fine grained, can't see individual grains, usually layered	very low energy environments: deep lake or ocean floors	***Shale***

Table 2. Chemical and Biogenic Sedimentary Rocks

Main Minerals	Distinctive Features	Depositional Environmnet	Rock Name
calcite	hartness of 3, fizzes readily with HCl	shallow oceans	***Limestone***
calcite	as above, with obvious fossils of clams, snales, etc.	shallow oceans	***Fossiliferous Limestone***
calcite	as top, except nothing but shell fossils, may look like granola	shallow oceans	***Coquina***
calcite	as top, except obvious spherical grains (ooids)	shallow oceans, inlet/outlet to tidal lagoons	***Oolitic Limestone***
calcite	as top, fine grianed, soft (can write with it), will fizz in HCl, but porous nature may mask this	shallow oceans	***Chalk***
dolomite	looks like limesotne, but only the powder fizzes with HCl	shallow oceans	***Dolomite***
halite	no reaction to HCl, tastes salte (rince HCl off before tasting!)	sites of high evaporation, desert "dry" lakes, and ocean margins	***Halite***
gypsum	no reaction to HCl, hardness of 2	sites of high evaporation, desert "dry" lakes, and ocean margins	***Gypsum***
quartz	hardness of 7, conchoidal fracture, may be any color	very deep oceans, hydrothermal systems, direct precipitation near volcanoes	***Chert***
organic material (no minerals)	dark brown to black, low density, may have plant fossils	plant ramins accumulated in swamps or bogs	***Coal***

LAB 8. GROUNDWATER

MATERIALS:

You bring: Lab Manual, textbook, pen and pencil, scratch paper, calculator (optional).
Supplied: work sheets, sediment columns, plastic trays, eyedroppers, beakers, food coloring, test "well" solutions.

INTRODUCTION

Groundwater has is origin in rainwater that has percolated into the soil and underlying rock units. Two properties of soil and rock that determine how this groundwater moves and accumulates are:

porosity: The amount of space between grains in a rock, or the amount of space present as holes. For example, gravel is highly porous, as is vesicular basalt, but a welded tuff or a granite has no porosity.

permeability: This is a measurement of how well connected the pore spaces are. If a rock is permeable, groundwater can percolate through it readily. For example, gravel is highly permeable, but vesicular basalt is impermeable because the pore spaces are not connected to each other.

Questions:

1: What two factors determine whether a rock unit will be an aquifer or an aquaclude?

2: We see many examples of liquids percolating through permeable solids in our daily life. What are three that you have seen recently?

GROUNDWATER FLOW

Groundwater is water that percolates through cracks and pore spaces in soil, unconsolidated sediment, and bedrock. This water starts out as rain, and works its way into the ground. Sediments or rocks that allow easy movement of water are called **aquifers**, and those that do not allow water movement are called **aquitards** or **aquacludes.**

Exercise One: Groundwater Movement

In the front of the lab, your instructor has six columns, filled with coarse- medium- and fine-grained material, some of which are well-sorted and some poorly sorted. When water is poured on them, the water will percolate through them at different speeds.

3: Which do you predict will be fastest and slowest in water moving through them, and in what order will the others be? How many seconds or minutes do you predict for water to reach the bottom of the column through each material?

4: What are the observed times? Record these on your work sheet.

5: Based on these results, which is the most permeable? Which is the least permeable?

CONCENTRATION OF DISSOLVED MATERIAL

Solutions can be described either by weight percent or by volume percent of dissolved material in water. For example, 10 grams of solution that is 10% by weight is made by dissolving 1 gram of solid in

9 grams of water. This gives 10 grams total weight, 1 of which is the solid material. To produce a 10% concentration by volume, one could take 10 milliliters of chocolate, and combine it with 90 milliliters of milk, to make a 10% solution of chocolate milk.

Question:

6: How much salt and how much water would you need to produce 50 grams of salt water that is a 20% solution by weight?

Exercise Two: Repeated Dilution of a Solution

In this exercise, we will look at the effect concentration has on the appearance of a solution. We will start with a solution that is 10% by weight of powdered food coloring in water.

A. Place a plastic tray on a piece of white paper so you can easily see the color of the solution. Fill a beaker with water. Put some extra water in a small beaker for rinsing your eyedropper.

B. Your instructor will place 6 drops of the 10% solution of food coloring in cup 1.

C. Using your eyedropper, place 9 drops of water in nine of the large cups.

D. Remove some food coloring from cup 1 with the eyedropper, put one drop into cup 2, then but the rest of the food coloring back in the first cup. Rinse the eyedropper, and mix cup 2 thoroughly.

E. Using your dropper, put one drop of solution from cup 2 into cup 3. Mix thoroughly. Rinse the dropper.

F. Repeat this procedure for cups 4 through 10.

G. Record the colors of the solutions in the data table on the work sheet. Determine the concentrations of the various cups and record them in the data table.

Questions:

7: What is the number of the cup in which the solution first appeared colorless?

8: What is the concentration of the solution in this cup?

9: Do you think there is any food coloring present in this cup even through it is colorless? Explain.

10: What experiment can you do with the solutions to see what might be present if the water was removed?

Exercise 3. Groundwater Flow Model

This exercise demonstrates and allows interpretation of how water flows through the ground, using a model of a groundwater system. All wells are numbered from left to right.

Part 1. Permeability

A. Withdraw water from well #1.

11. Does this water withdraw easily?
12. How does the withdrawal of this water affect the water level in the other wells?

B. Now withdraw water from well #4.

13. Does this water withdraw easily?
14. How does the withdrawal of this water affect the water level in the

other wells?

15. How do these wells differ? Which well allows faster withdrawal? Which well affects the wells around it more?

C. Withdraw water from well #2.

16. How easily does the water withdraw?

17. Which other wells are affected? Which wells not affected? Why do you suppose this is so?

18. What role does the black layer play?

Changes in materials affect the permeability of the material.

19. From your observations above, list three materials in this tank and their relative permeabilities (lower, medium, higher).

D. Withdrawal of water from wells affects the level of water in nearby wells.

20. Using your observations above, explain what happens.

21. What do you think might happen to a nearby shallow well (#4) if a deep well (#3) was pumped very fast?

Part 2. Unconfined and Confined Aquifers:

There are both confined and unconfined aquifers in this demonstrator. A confined aquifer is sealed from overlying aquifers by an impermeable layer. Wells that penetrate a confined aquifer will react differently under discharge and recharge pumping than wells in the unconfined aquifer. See what happens to the water levels for wells 5, 6, 7, and 8 when you extract water from wells 2 and 4.

A. Extract water from well #4 such that one of the wells (5, 6, 7, 8) draws down 1 inch (2.5 cm):

22. Circle the well(s) that draw down the most and place an "X" over the wells that are not affected.

B. Allow the water levels to recover.

23. Does the water level recover back to the original level?

C. Slowly pump water into well #4.

24. Circle the well(s) in which water level rises the most and place an "X" over the wells that are not affected.

D. Extract water from well #2 such that one of the wells (5, 6, 7, 8) draws down 1 inch (2.5 cm):

25. Circle the well(s) that draw down the most and place an "X" over the wells that are not affected.

26. Is it easier or harder to produce an effect on the level of the wells with well #2 or well #4?

E. Allow the water levels to recover.

27. Does the water level recover back to the original level?

28. Is the recovery faster or slower than with well #4? Why?

F. Slowly pump water into well #2.

29. Circle the well(s) in which water level rises the most and place an "X" over the wells that are not affected.

G. Also observe well #9 while pumping into well #2.

30. What do you see? Why is this happening?

Part 3. Water Flow:

Your instructor will now demonstrate

how water moves through the ground by placing blue dye in each of the wells. Observe the starting water level in each of the wells from left to right.

31. What differences do you see in water level?

Variability of water level --

Your instructor will tip the filled quart jar (with rubber stopper attached) into the left reservoir and open the drain on the lower right side of this demonstrator to allow discharge while keeping the water level constant on the left side of the demonstrator.

A. Observe the water level in each of the wells from left to right.

32. What differences do you see in water level?

33. What boundary is marked by the water level as shown by the wells?

34. What is the zone of material called that is below this level?

35. What is the zone of material called that is above this level?

36. Why is it not flat?

Red dye will be placed into the buried tank on the left side of the demonstrator.

B. Observe what happens for a couple of minutes. Record your observations, noting the position of the dye and the time it is put into the tank: Note when the dye reaches the following wells:

37. Time dye was placed in tank.

38. Time dye arrived at well #4.

39. Time dye arrived at well #7.

40. Time dye arrived at well #10.

41. Time dye pours out into the reservoir.

42. Does the dye move farther vertically or horizontally?

Now your instructor will pump water from well #7.

C. As the water is extracted, observe what happens to the water levels of all of the different wells. Also observe the movement of dye from the wells as the water is extracted.

43. What happens to the water levels?

44. How does the water move toward the well (dye motion shows water motion)?

Your instructor will remove the well extension from the well in the river.

D. What happens when the top of the well is below the level of the surrounding wells (#8 and #10)?

45. What is this type of free-flowing well called?

Exercise 4. Groundwater in Muscoy.

Your cousin has just graduated from CSUSB, lands a job in Fontana and moves to an older house in Muscoy to save up a down payment for his dream home in Highland. While giving you the grand tour, your cousin turns on the hose to top off the koi pond in the back yard and you smell a strange chemical odor. Looking at the goldfish, you notice that some of them don't swim very well, and there are no small fish. Your cousin says he was hoping to breed koi for some additional income, but he is disappointed, as they are not reproducing. After a nice tour, you decide to go for a jog. While out on your jog, you are thirsty, so you stop in at a gas station for a drink of water. You notice that same chemical smell as you get a sip of water. When you get back to your cousin's house, you draw a nice cool glass of water from the kitchen sink and (getting a bit suspicious) first sniff it. It smells OK, so you drink up. Your cousin informs you that the house is on municipal water, but the hose to the pond is from the old water well. Because you have learned how water moves through the ground in your Geology 101 course at CSUSB, you suspect that there might be some contamination in the ground water supply. You decide on figuring out where the contamination is coming from and how big the problem is now. With a little research with local and county agencies, you learn that your cousin's water contains the chemical "perchloroethylene," also called PERC or PCE (a known carcinogen).

You do some research on PERC, and find that it is a colorless liquid used as a dry-cleaning solvent and as a degreasing agent for computer manufacture and cleaning brakes. You find information on its short term effects on animals, including nervous system damage that produces headaches, dizziness, fatigue, and lack of coordination. Contact with PERC in liquid or vapor form can irritate eyes, nose, throat, and skin. Long term effects include liver and kidney damage, memory loss, reproductive disorders, irregular heartbeat, and cancer. You also find that the federally established MCL (maximum contaminant level—maximum legal level of substance) is 5 ppb. This information comes with the disclaimer that the "safe" level of concentration is yet to be established, but studies suggest that it is probably much lower than the MCL.

This concerns you greatly, partly because you like your cousin and want him to stay healthy, and partly because you are concerned for the welfare of the koi, who appear to be suffering ill effects from exposure to this contaminant. So, you decide to see what you can do to determine the source of the contamination. You contact the water district that monitors this area, and they say they have enough money in their budget to test twelve water samples from their wells. However, due to cutbacks, they do not have enough staff to assign someone to determine a testing pattern or to analyze the results. You work out a deal with them where they will analyze the samples you choose, and you will examine the data produced. Their lab is set up to run samples in pairs, so to learn as much as possible, you decide to choose two wells, have them analyzed, then use those results to decide which two to do next.

Your lab worksheet contains a map that has the wells located for the Muscoy area. You know from your research what the elevation of groundwater is at each well and can use this information to determine which way the groundwater flows. In talking with the water district folks, you see that you need to identify the source(s) of the contamination, and to determine how far the PERC has migrated in the groundwater, to help them develop a plan to remediate this hazard to public health.

Your task is to first determine which way the groundwater is flowing. Then choose a pair of wells, see what their test results are, then choose another pair, examine those results, and so on until you have used up your allotment with the water district. Your report to them will include the shape of the contaminated plume of groundwater, showing them which wells are affected, and identify if possible the source(s) of the PERC, so steps can be taken to stop any more from seeping into the groundwater.

46. IN PENCIL, draw the 1300, 1200, and 1100 foot groundwater elevation conturs on your map. The local groundwater flows in which general direction?
47. Draw the shape of the plume of contaminated groundwater on your map.
48. What is your best judgement as to the source of the contamination?

LAB 9. METAMORPHIC ROCKS

MATERIALS:

You bring: Lab Manual, pen and pencil, scratch paper, text (recommended for rock pictures).

Supplied: quiz sheets, tray of rock specimens, hand lens, tools for determining hardness (in your table drawers).

INTRODUCTION

Metamorphic rocks form when pre-existing rocks (either igneous, sedimentary or even other metamorphic rocks) are subjected to increased temperature and pressure. This increase is generally brought about by burial of rock deeper and deeper in the crust, either by depositing more sediment on top of it, or by folding and thrust-faulting rock over the top. The temperature alone may be increased by heat released from a pluton. Also, pressure may be increased without much heating in a subduction zone. During metamorphism rocks may undergo mineralogical, textural and/or compositional changes.

MINERALOGICAL CHANGES

Each mineral is stable within a specific range of temperatures and pressures. As a rock is subjected to increasing temperatures and pressures, some of the minerals in the rock may become unstable and may react with each other to form new minerals. Temperature is generally given in terms of °C (at 0°C, water freezes, and at 100°C, it boils), and pressure is generally given in terms of kilobars (1 atmosphere [15 lbs./sq.in.] ≈ 1 bar; 1 kilobar = 1000 bars). The general trend as a rock progressively metamorphoses is for more compact crystal structures to be favored, as the pressure increases.

TEXTURAL CHANGES

As a rock undergoes metamorphism the minerals in the rock may **recrystallize** to form larger crystals of the same minerals. This recrystallization occurs in the solid state (*the rock DOES NOT MELT*). For example, if a fossiliferous limestone undergoes metamorphism, the calcite in the fossils and in the matrix will recrystallize into large, interlocking crystals of calcite. The fossiliferous texture of the limestone will be destroyed in the process. The resulting rock is called marble.

Another type of textural change may occur if the rock undergoes **deformation** during metamorphism. Deformation occurs when the stresses in the Earth are stronger in one direction than in another direction. This causes the rock to change shape (to be deformed). Deformation of rocks may occur at subduction zones, at continental collisions and elsewhere along plate boundaries. When a rock undergoes deformation, the platy minerals in the rock (such as the micas) tend to align themselves perpendicular to the direction of compression. This creates layering in the rock that is called **foliation**. **Foliation** is the layering resulting from the parallelism of platy and flattened minerals in a metamorphic rock.

COMPOSITIONAL CHANGES

In some cases the overall chemical composition of a rock may change during metamorphism. This can only happen if new atoms are added to the rock or are taken away by fluids migrating through the rock during metamorphism. The general trend is for the minerals to expel water and carbon dioxide from their crystal structures as they recrystallize, but for the rock to otherwise retain the chemical composition it had prior to metamorphism.

METAMORPHIC GRADE

The term metamorphic grade refers to the intensity of metamorphism to which a rock was subjected. Rocks that were subjected to relatively low temperatures (less than 300-400°C) and pressures (less than 3-4 kilobars) have experienced **low grade metamorphism**. Low grade metamorphism occurs at shallow depths in the crust (less than 10 km deep). Rocks that have been subjected to temperatures of 600-800°C and to pressures of 12-15 kilobars have undergone **high grade metamorphism**. High grade metamorphism occurs at depths of 40-55 km in the Earth. Rocks that have been subjected to intermediate temperatures and pressures have undergone **medium grade metamorphism.**

SOME COMMON METAMORPHIC ROCKS

Rocks formed when shale is metamorphosed:

Shale is a very common type of sedimentary rock. Consequently, metamorphic rocks derived from shale are also very common. As shale is subjected to higher and higher grades of metamorphism, different metamorphic rocks form.

Slate:

Slate forms when shale undergoes low grade metamorphism. The clay minerals in shale break down and re-form into microscopic crystals of micas, commonly biotite, muscovite, and chlorite. This gives the rock a dull surface. Although these crystals are much too fine grained to be seen, they are aligned along planes perpendicular to the direction of maximum compression. The rock breaks easily along these smooth planes. This property of slate is called **slaty cleavage.**

Phyllite:

Phyllite is a low-grade metamorphic rock formed of mica crystals that are too small to see easily. Phyllite forms when rock that was originally shale is subjected to low-grade metamorphism. In phyllite, the mica crystals are larger than in slate (although still too small to see easily) and they give the rock a sheen, whereas slate has a dull surface. Phyllite sometimes has wavy, wrinkled surfaces.

Schist:

Schist is a medium-grade metamorphic rock made primarily of micas. It forms from rock that was originally shale. Schist is characterized by mica crystals that are larger than those in phyllite, and are easily visible. This gives schist a glittery appearance. The mica crystals in schist are aligned in planes and give the rock a layered texture, called schistosity.

Gneiss:

Gneiss is a high-grade metamorphic rock. It forms from rock that was originally shale. High-grade metamorphic conditions are above the range of stability for most micas, so they have broken down and recombined to form feldspar and other minerals. Gneiss is a layered rock, with layers of light-colored minerals alternating with layers of dark-colored minerals.

other rock types:

Quartzite:

Quartzite is produced when sandstone undergoes low to high grade metamorphism. The quartz grains in the sandstone recrystallize to form interlocking crystals of quartz. When quartzite breaks the fracture usually

Table 1. Common Metamorphic Rocks

Texture	Grain Size	Major Minerals	Comments	Rock Name
foliated	individual mineral grains not visible	micas -- muscovite, biotite, and/or chlorite	dull appearance	***Slate***
foliated	individual mineral grains not visible	micas -- muscovite, biotite, and/or chlorite	satiny or waxy appearance	***Phyllite***
foliated	can see individual grains	micas -- muscovite, biotite, and/or chlorite	often a glittery appearance	***Schist***
foliated	medium to coarse	some mix of feldspars, quartz, micas, hornblende	minerals separated into light and dark layers	***Gneiss***
random crystals	medium to coarse, crystals visible	calcite	hardness of 3, fizzes with HCl	***Marble***
random crystals	fine to medium, crystals visible	quartz	hardness of 7, doesn't fizz with HCl	***Quartzite***
foliated, lineated, or random crystals	medium to coarse, crystals visible	hornblende	generally black, may have needle-shaped crystals	***Amphibolite***
not usually foliated	coarse grained	variety of clast types	stretched appearance to clasts	***Stretched-pebble Conglomerate***
no foliation	fine grained	organic material (no minerals)	black, low density, bright luster	***Anthracite Coal***
no foliation	medium grained	graphite	writes on paper	***Graphite, or Graphite Schist***
no foliation	fine to very fine	variety of green minerals	waxy appearance, massive	***Serpentinite***

cuts through individual crystals of quartz. In contrast, when sandstone breaks, the fracture goes in between individual grains of quartz, rather than breaking through them. Quartzite may or may not be layered. If it is layered, those layers may be preserved sedimentary bedding planes or true metamorphic layering (foliation).

Stretched pebble conglomerate:

This rock type may form when conglomerate is subjected to low to medium grade metamorphism. The pebbles from the original sedimentary rock are still visible but have been flattened by the high pressure to which the rock was subjected.

Rocks formed by metamorphism of *limestone:*

Marble forms when limestone is metamorphosed, generally under medium grade conditions. Marble is composed of interlocking calcite crystals. Marble may or may not be layered. If it is layered, those layers may be preserved sedimentary bedding planes or true metamorphic layering (foliation).

Amphibolite:

Amphibolite forms when basalt is subjected to medium to high grade metamorphism. It is composed primarily of hornblende. It may or may not have metamorphic layering (foliation).

Gneiss:

Gneiss may form by the metamorphism of granite or schist. (See above).

Rocks formed by metamorphism of organic material:

Coal:

As plant debris is subjected to increasing temperature and pressure it goes through several stages of coalification which increase the carbon content of the coal and decrease the moisture in the coal. **Peat** consists of unconsolidated plant remains. **Lignite** is a type of coal produced when peat is subjected to low temperatures and pressures. At higher temperatures and pressures lignite converts to **bituminous coal** and then to **anthracite coal**. Anthracite coal is harder and denser than bituminous coal and has a semi-metallic luster. Coal consists primarily of the element carbon in an amorphous form (no crystal structure). Anthracite coal is a medium grade metamorphic rock.

Graphite:

Graphite forms when organic debris (carbon) is metamorphosed at high grade. Graphite consists of pure carbon that has crystallized

METAMORPHIC ROCKS IDENTIFICATION TIPS

You may find it helpful to use the following format, along with the table above, to identify each of the unknown rock specimens.

1. Is the specimen foliated or non-foliated?
2. List the minerals that you can see with a hand lens as well as with your unaided eye.
3. What was the protolith (original, pre-metamorphosed rock)?
4. What is the metamorphic grade?
5. Name the specimen.

LAB 10. DATING GEOLOGIC EVENTS

MATERIALS:

You bring: Lab Manual, textbook, calculator, pen and pencil.
Supplied: work sheets.

INTRODUCTION

Geologists figure out the geologic history of an area by using relative dating principles to determine the order in which geologic events occurred, and by using radiometric dating techniques to determine the time of formation of certain minerals found in some rocks. Together, these techniques allow us to understand some, if not most, of the geologic history of regions of the earth.

RELATIVE DATING

Many geological events are described by the relative order in which they occur. Several basic geologic principles are used to determine the geological history of an area. These principles are:

Principle of Original Horizontality:

Sedimentary strata are horizontal, or nearly so, when deposited.

Principle of Superposition:

In any section of undisturbed sedimentary strata, the oldest layer is at the bottom, and each successive layer is progressively younger upwards.

Principle of Cross-cutting Relationships:

A rock body, or a geological feature, that cuts across another rock body or geological feature is the younger of the two.

Principle of Faunal Succession:

Major groups of organisms (e.g., trilobites, dinosaurs, mammals) start out small, simple, and plain. As geologic time progresses, these groups diversify, become larger, more specialized, and often more ornate.

RADIOMETRIC DATING

Most elements occur with different isotopes (atoms with more or fewer neutrons than protons). Some of these isotopes are unstable (i.e., radioactive), and decay to other elements over time. The rate of decay is unique to each isotope, and can range from instants to billions of years. Decay can occur in a few ways (see your text for details), but the identity of the isotope always changes from one element to another as decay occurs. The starting element is called the parent isotope, and the new element produced by radioactive decay is called the daughter product. The decay rate is described in terms of half-lives, that is, the amount of time over which half of the starting amount of parent isotope decays to the daughter product.

If the amounts of parent isotope and daughter product present in a mineral are known, the half life is known, and if neither element has entered or left the mineral (the mineral is a closed system), the amount of time that has elapsed since the mineral formed can be determined. The amounts of parent and daughter can be measured, generally by high-precision mass spectrometer analysis. The half life of the parent isotope has been determined by numerous experiments and comparisons with other isotopic systems. Within limits, minerals often behave as closed systems, but attention must be paid to the history of the rock unit and the area overall to determine whether the mineral being analyzed has changed chemically. Assuming these factors check out, the rest is a fairly simple calculation. Figure 1 shows a general half-life graph, from which you can calculate ages of minerals.

DIRECTIONS

Figure 2 is the explanation of the patterns used to depict rock types, and the symbols used to show geologic features, as shown on the example cross sections and in your worksheets. The following four pages are some example cross sections illustrating how relative dating principles are implemented in figuring out the geologic history of an area. Look them over and familiarize yourself with how these principles are expressed.

The last page is a simplified Geologic Time Scale, for you to determine time constraints of some rock units, as described in the captions of the example cross sections.

Your worksheets consist of cross sections for you to determine the geologic histories for. You will need to use the relative dating principles, calculate ages of key minerals using the radiometric decay graph, and your knowledge of the Geologic Time Scale. Keep in mind that some sequences will be clear, and some may have some ambiguities. Such uncertainties exist in most geologic settings, and it is important to be aware where these are, so be sure to note any uncertainties as you list the order of events.

Note: it is helpful to label events in pencil, as revisions generally become necessary as you work.

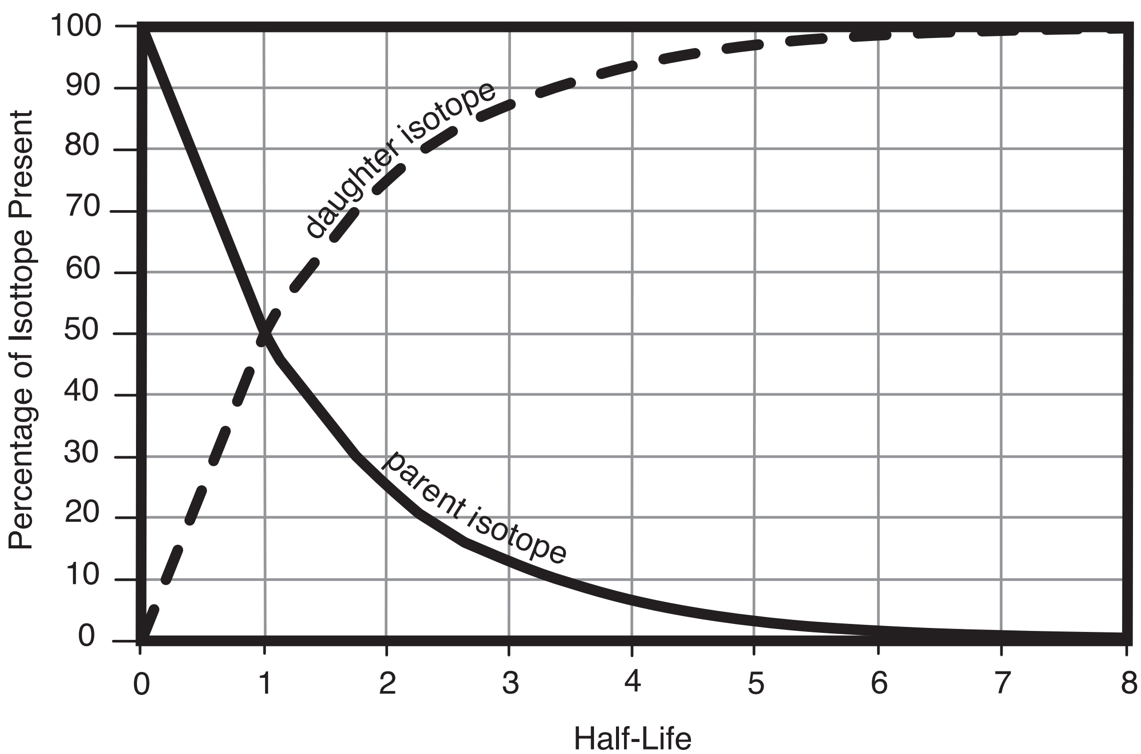
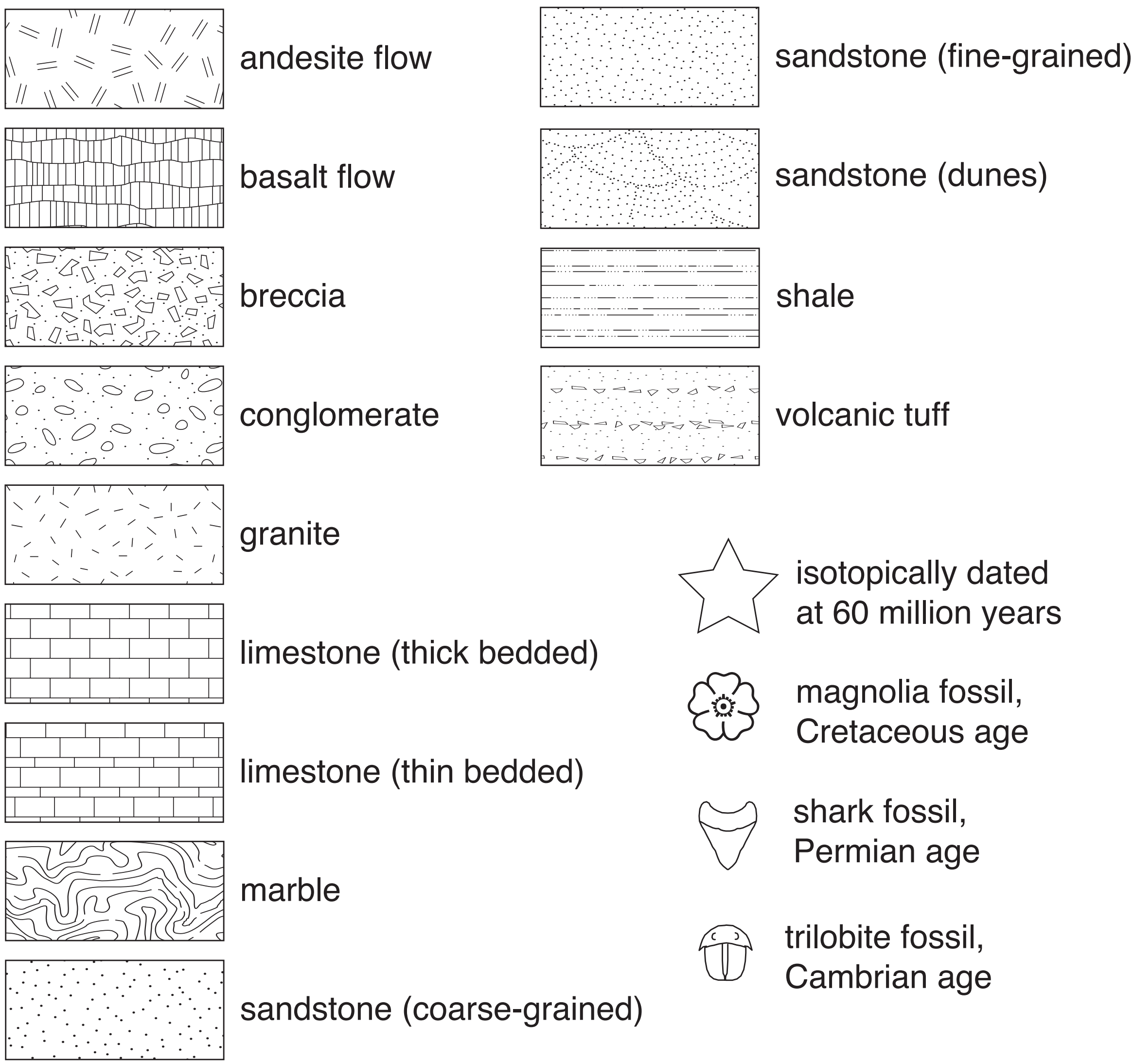
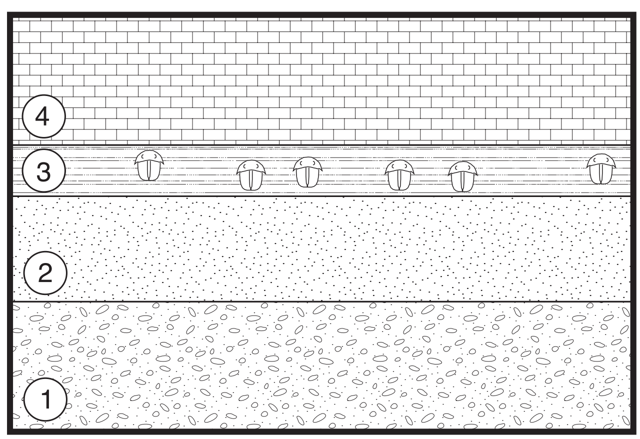


Figure 1. Radiometric decay graph.
Use this with your worksheets to determine required isotopic dates.

Figure 2. Explanation of patterns and symbols used in example cross sections, and on your worksheets.



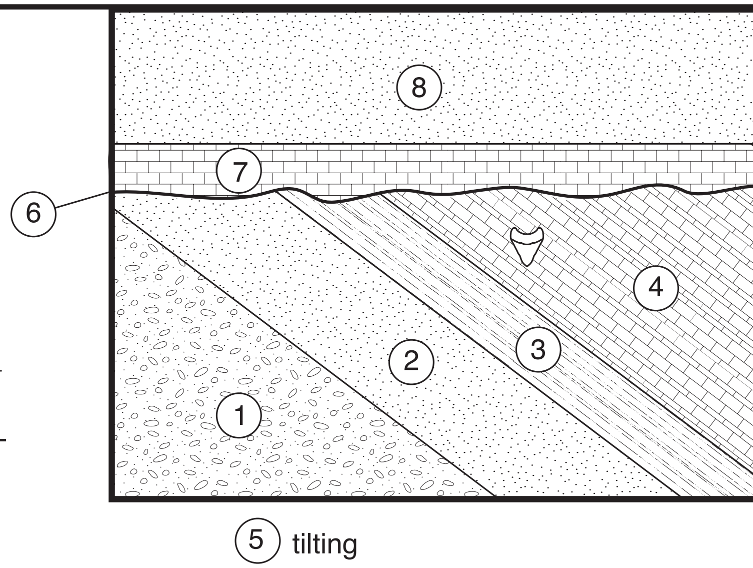
Example Cross-section 1.



Undeformed sedimentary rocks: Layer 1 (conglomerate) was deposited first, layer 2 (sandstone) was deposited second, layer 3 (shale) was deposited third, and layer 4 (limestone) was deposited last. This is an example of the Principle of Superposition, and of Original Horizontality.

The shale contains trilobite fossils that are Cambrian in age. The overlying limestone could be any age younger than Cambrian, or could be of a younger Cambrian age than the fossils. The sandstone and conglomerate, similarly, could be Archean or Proterozoic in age, or could possibly be early Cambrian.

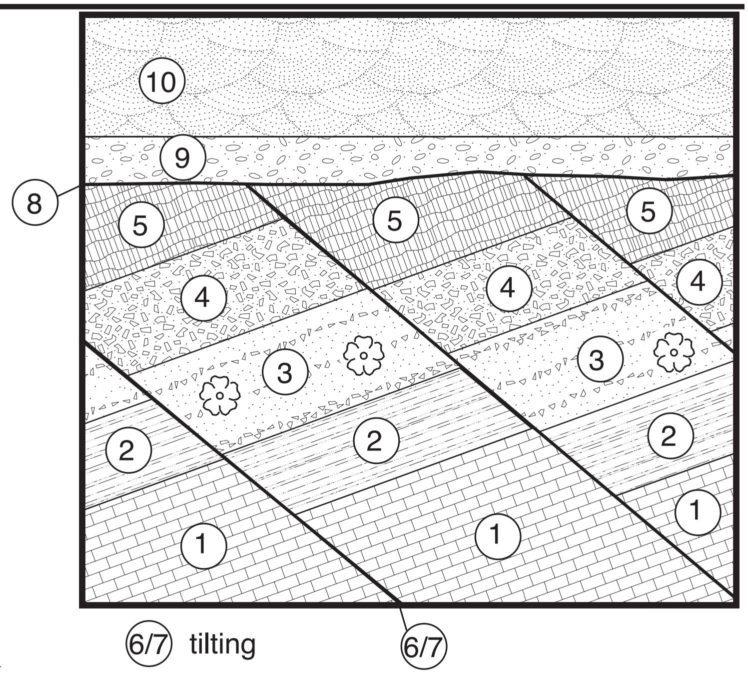
Example Cross Section 2.



Sedimentation, tilting, erosion, and more sedimentation: Layers 1, 2, 3, and 4 were deposited in that order. Later, they were tilted (event 5), then partly eroded away, beveling off the layers, forming an unconformity (event 6). After that, younger sediments (layers 7 and 8) were deposited on the erosional surface. This is an example of the Principle of Superposition (sedimentation), Original Horizontality (sedimentation, then tilting), and Cross-cutting Relationships (erosional surface cross-cuts the tilted layers).

The older limestone contains fossil shark teeth known to be Permian in age. Therefore, layers 1, 2, and 3 must be older than Permian. If the sequence of deposition was continuous, they are all probably all Paleozoic in age, although without additional information, and older age cannot be ruled out. Layers 7 and 8 must be younger than Permian in age. They could be Mesozoic or Cenozoic in age, but without additional information, we cannot tell where in that timespan they might be.

Example Cross Section 3.



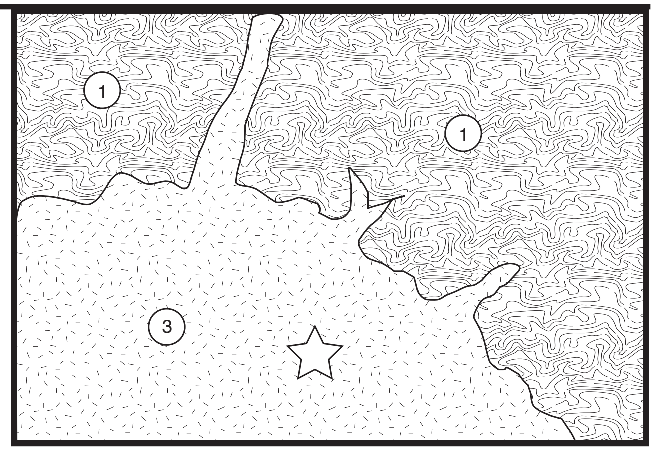
Sedimentation, faulting, erosion, and more sedimentation: Layers 1, 2, 3, 4, and 5 were deposited, in that order. Later, they were faulted into blocks (event 6/7), which tilted as they moved (event 6/7). The upper edges of the blocks were eroded down (event 8). Younger sediments (layers 9 and 10) were then deposited over the top of the fault blocks. This is an example of the Principle of Superposition (sedimentation), Original Horizontality (pre-faulting orientation of sedimentary rocks), and Cross-cutting Relationships (faults cutting rock layers, erosional surface cutting both rock layers and the faults, and younger sedimentary rocks overlapping older units).

Layer 3 is a volcanic tuff that contains fossils of an early form of Magnolia wood, one of the first flowering plants. Therefore, this layer is mid-Cretaceous in age, and all subsequent layers and events must be younger than that. Layers 1 and 2 could be any age older than mid-Cretaceous. As with the previous cross-section, if the deposition of layers 1-5 was continuous, layers 1 and 2 are probably not much older than early Cretaceous in age.

Example Cross Section 4.

Sedimentation, metamorphism, and intrusion: Limestone was deposited (event 1). Later, it was metamorphosed (event 2) into marble. Then, granite intruded the marble (event 3).

The granite has been isotopically dated at 60 million years old (in the Paleocene Epoch of the Tertiary Period), so the limestone must have been deposited, and the metamorphism must have occurred prior to that, probably in Paleozoic or Mesozoic time, although an earlier age cannot be ruled out.



(2) metamorphism

GEOLOGIC TIME SCALE *

Eon	Era	Period	Epoch	Time, in millions of years	
				0	YOU ARE HERE
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01	
			Pleistocene	1.8	*Ice Ages*
		Tertiary	Pliocene	5.3	
			Miocene	23.8	
			Oligocene	33.7	
			Eocene	54.8	
			Paleocene	65.0	EXTINCTION OF DINOSAURS
	Mesozoic	Cretaceous		144	*first flowering plants*
		Jurassic		206	*first birds*
		Triassic		248	*first dinosaurs; first mammals* LARGEST EXTINCTION EVENT
	Paleozoic	Permian		290	*first reptiles*
		Pennsylvanian		323	*first cone-bearing plants*
		Mississippian		354	*first amphibians*
		Devonian		417	*first fishes, insects, land plants*
		Silurian		443	
		Ordovician		490	
		Cambrian		540	*first fossils of animals with shells*
Proterozoic				2500	*fossils of algae and bacteria*
Archean				4000	*oldest known terrestrial rocks*
				4600	*formation of planet*

* taken from the full version, available at: http://www.geosociety.org/pubs/timescl.htm